CHAPTER 9

Integral Project Features

9-1. Navigation Features. The following is a list of navigation features normally considered as a part of the overall improvement project:

a. Turning basins.

b. Anchorage areas.

c. Jetties and breakwaters.

d. Dikes and other channel training or control structures.

e. Salinity barriers.

f. Diversion works.

g. Aids to navigation.

h. Ice barriers.

i. Maneuvering areas.

j. Ship locks.

k. Channel wideners at turns or bends (local width increases).

These individual features when pertinent are usually integral to and necessary for the day-to-day operation of the port and allow the design ship to sail through the proposed channel improvement project in a safe and efficient manner.

9-2. Turning Basins.

a. *Ship Turning.* In normal operations, turning basins are used by the pilots in conjunction with two or more tugs to bring the ship about. Full advantage is also taken of the prevailing currents and wind conditions to help maneuver the ship. The pilot strategy may be different on flood or ebb tide current and may change with wind direction. If the ship is equipped with thrusters (bow or stern, sometimes both), then these will be used to the fullest. The ship engine and rudder are usually manipulated, which will provide additional control. Care is usually taken to keep the ship stern away from shoals, rocks, banks, and docks to minimize possible damage to propellers and rudders. Pilot strategy may change, however, depending on the location of the ship bridge on the ship. When the bridge is located at or near the stern of the ship, turning will be accomplished using the stern with another visible reference to control and monitor ship position.

b. *Location.* Navigation channel project improvements will provide for a turning basin to enable the ships to be turned about to reverse ship direction and allow an outbound sailing transit. The basin is usually located at the head of navigation near the upstream end of the channel project, upstream of a group of terminals and docks on a long channel, or at the entrance to a side channel with berthing facilities. The turning basin will be designed to provide sufficient area to allow the design ship to turn around using ship bow and stern thrusters (if available) and with local port tug assistance. Preference in turning basin location should be given to a site with the lowest current effects, since this has a major impact on the turning ship and therefore the size of the turning basin. Figure 9-1 gives recommended shape and size of turning basins in low and high current situations.

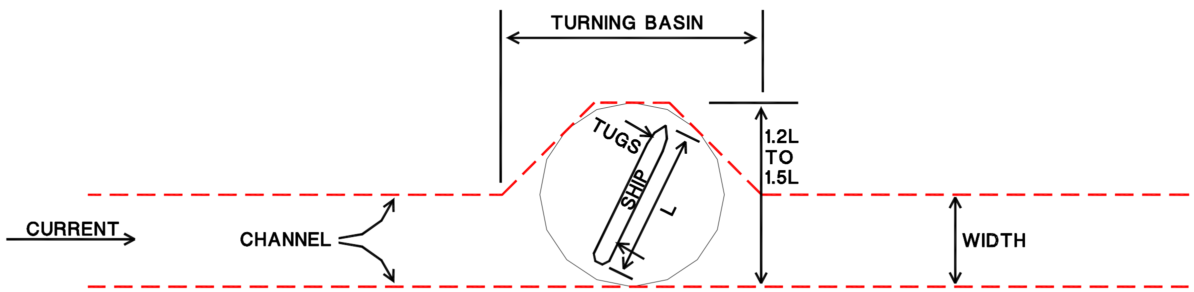
c. *Size.*

(1) The size of the turning basin should provide a minimum turning diameter of at least 1.2 times the length of the design ship where prevailing currents are 0.5 knot or less. Recent ERDC/WES simulator studies have shown that turning basins should provide minimum turning diameters of 1.5 times the length of the design setup where tidal currents are less than 1.5 knots. The turning basin should be elongated along the prevailing current direction when currents are greater than 1.5 knots and designed according to tests conducted on a ship simulator (Figure 9-1). Turning operations with tankers in ballast condition or other ships with high sail areas and design wind speeds of greater than 25 knots will require a special design study using a ship simulator.

(2) Where traffic conditions permit, the turning basin should use the navigation channel as part of the basin area. The shape of the basin is usually trapezoidal or elongated trapezoidal with the long side coincident with the prevailing current direction and the channel edge. The short side will be at least equal to the design multiple (1.2 or 1.5, depending on the current) times the ship length. The ends will make angles of 45 deg or less with the adjacent edge of the channel, depending on local shoaling tendencies. Modifications of this shape are acceptable to permit better sediment flushing characteristics or accommodate local operational considerations.

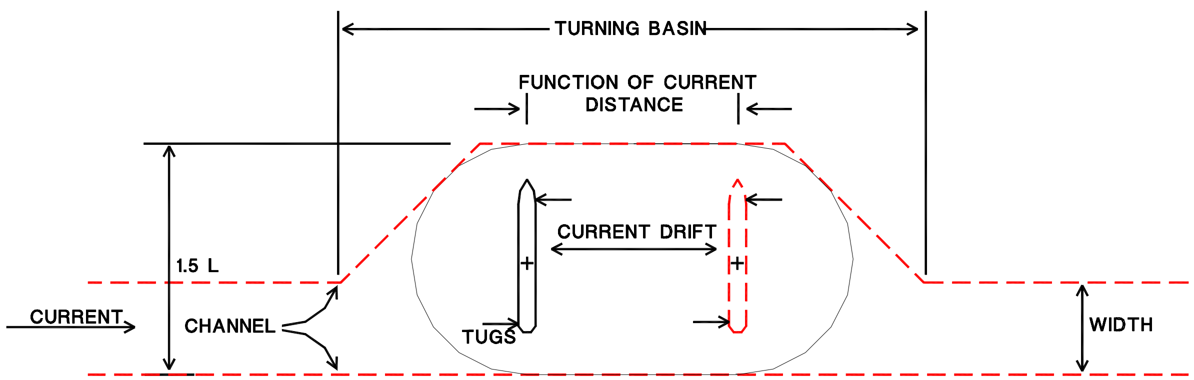
d. *Depth.* Normally, the depth of a turning basin should be equal to the channel depth leading or adjacent to the basin proper. This is done to prevent any possibility of confusion by the channel project users that could cause grounding accidents. The normal dredging tolerance and advance maintenance allowance are included in the depth of the turning basin. In some operational circumstances where design ships will always turn in ballast, the turning basin could be designed to a smaller ballasted ship draft, which could provide substantial cost savings.

e. *Shoaling.* A turning basin will tend to increase shoaling rates above normal channel rates because of the increase of the channel cross-sectional area, which modifies current patterns. Increased shoaling in the basin could cause modifications in shoaling patterns farther downstream or upstream.



LOW CURRENT LAYOUT

CURRENT SPEED KNOTS	TURNING BASIN SIZE MULTIPLIER (*L)
0 < 1/2	1.2
1/2 < 1 1/2	1.5
> 1 1/2	SIMULATOR DESIGN



HIGH CURRENT CONFIGURATION
(DESIGNED WITH SIMULATOR)

Figure 9-1. Turning basin alternative designs

9-3. <u>Anchorages.</u> Anchorages are provided near the entrance to some ports for vessels awaiting berthing space, undergoing repairs, receiving supplies and crews, awaiting inspection, and lightering off cargo. In cases with long navigation channels to get to the port area and heavy traffic, additional anchorages may also be provided along the channel. As shown in Figure 9-2, design of the required anchorage area depends on the method of ship mooring, the size and number of the ships in the anchorage, and the environmental forces (wind, currents, and waves) acting on the anchored ships. Normally, anchorage areas provide space to allow for free-swinging bow anchoring, since some ships are not equipped with stern anchors. Free-swinging moorings require a circular area having a radius equal to the length of the ship plus the length of the anchor chain (scope of the anchor). The U.S. Navy (1981) has calculated a set of tables giving these required dimensions from which the following approximation can be developed for average 15-m (50-ft-) depth conditions and design ship lengths from 213 to 305 m (700 to 1,000 ft):

$$D/L = 3.0 \tag{9-1}$$

where

D = diameter of anchor swing in feet

L = ship length in feet

This formula assumes that the length of the anchor chain swing circle is six times the depth and that 2.7 m (90 ft) of anchor drag occurs. Large free-swinging anchorages can be expensive to construct and maintain, since sedimentation frequently becomes a problem. Consideration should be given by the designer for the use of fixed mooring dolphins, which can substantially reduce the dredging area costs. Figure 9-2 presents two design anchorage configurations for two ships with free-swinging and fixed mooring situations.

9-4. Jetties and Breakwaters.

a. *Layout.* Entrance channel jetties are usually designed to maintain a stable channel location and depth, control sediment from littoral drift, and reduce wave action in the entrance navigation channel. Some entrances at coasts with high wave action may also include breakwaters in addition to or separate from the entrance channel jetties. The entrance channel alignment should be oriented to reduce channel waves and control sediment movement, keeping in mind the ship maneuvering and control required through waves and crosscurrents. In most cases, two jetties, one on each side, will be needed to keep littoral drift from entering the channel. Jetties are normally aligned parallel with the channel alignment. However, curved jetties may act like a river training system and will help establish a stable deep channel on the outside of the bend. Converging alignments (arrowhead type) often produce unsatisfactory layout solutions because of greater length, no improvement in wave action, and entrance channel meandering. Some general entrance channel layout guidelines follow:

(1) Natural entrance channels in noncohesive (sandy) material are usually unstable.

(2) Parallel aligned twin jetties are preferred.

(3) Curved alignment should be considered if there is significant tidal flow or river discharge.

(4) Straight jetty alignments require closer spacing than a curved alignment to maintain channel depths.

(5) Unequal jetty lengths can cause asymmetric current patterns, making navigation difficult.

Further discussion on entrance channel layout and alternative structures is available in EM 1110-2-2904 and the Coastal Engineering Manual (CEM), Part V, Chapter 5.

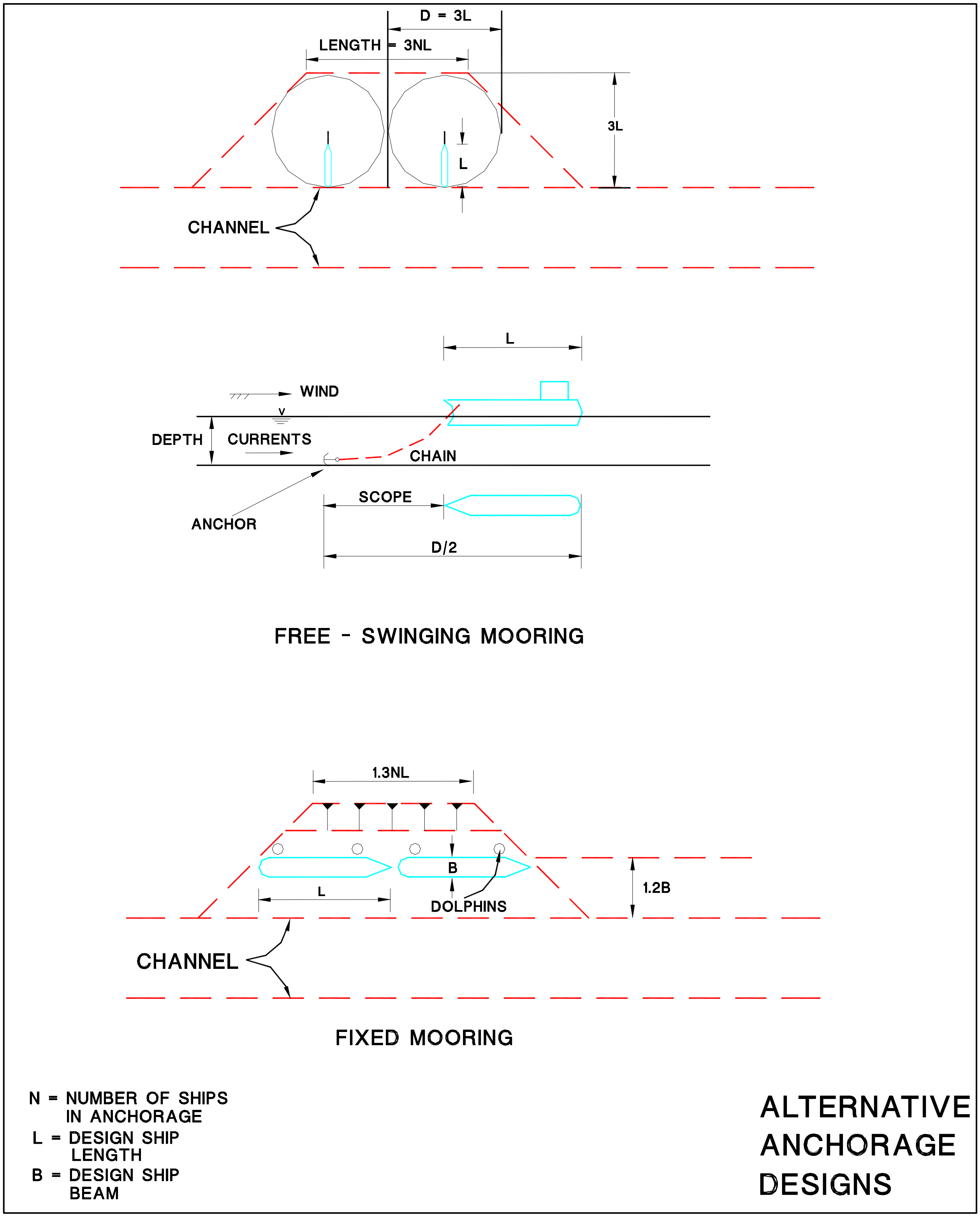


Figure 9-2. Alternative anchorage designs

b. *Spacing.* Determination of the width of the entrance channel should consider navigation difficulties that are frequently encountered in entrance channels from wave action, wind, crosscurrents, and poor visibility. The distance between the toes of the jetties is designed to provide space beyond the channel edges for jetty stability. Consideration of the penetration of wave energy into the harbor should be balanced with the necessary entrance channel width required for safe ship passage. As is the case for proper channel width design, the quality and spacing of the aids to navigation are important considerations also. Harbor entrance channels normally require larger widths than the interior channels as a result of more adverse navigation conditions. Entrance widths in the vicinity of the proposed project improvement should be compared and used in the initial design phase. In most cases, entrance widths equal to the ship length have been found to be satisfactory. Since the ship length-to-beam ratio for most commercial ships is about 1:7, a width of 7*B* may be used for preliminary project design. Spacing in tidal entrances may be governed by tidal flow considerations.

c. *Orientation.* One design criterium to be considered in the layout of jetties and breakwaters is adequate navigation depths in the area to be protected from waves, especially the entrance channel and the harbor interior. To minimize adverse ship motions and wave-generated crosscurrents, the entrance channel should be oriented in the direction of the more severe waves. Bar channels and entrances protected by jetties and breakwaters will require special studies of ship navigation, tidal currents, waves, littoral transport, and shoaling tendencies to determine the optimal design of channel width, cross section, alignment, orientation, and ship response to wave action. Waves aligned with the entrance channel will be reduced in height as they travel between jetties (Melo and Guza 1991a, 1991b). This reduction can be estimated by treating the jetty entrance as a breakwater gap. The inter-jetty propagation distance corresponds to the normal interior distance from the gap, and wave height change can be estimated from standard wave diffraction diagrams. As a general rule, jetties should be long enough to extend beyond the littoral zone so that sedimentation and breaking waves do not impact entrance channel navigation. Additional design details on channel and jetty alignment can be obtained from EM 1110-2-1607. Design procedures on jetty length and type are covered in EM 1110-2-2904. Consideration of hydraulic physical, ship simulator, and mathematical model tests is highly recommended for jetty and breakwater layout to optimize the design.

9-5. Ship Locks and Salinity Barriers.

a. *Ship Locks.* Salinity barriers may be required to control and mitigate the effect of salinity intrusion. A navigation lock is often used as an effective barrier against ocean salinity propagating into freshwater portions of estuaries and canals. General guidelines for salinity barrier design are presented in EM 1110-2-1607. The navigation conditions for ship locks require careful design, especially the lock approach conditions, which should provide adequate distance without waves, turns, and crosscurrents. An additional concern is the density-driven salt water admitted into the lock chamber and thence the upper pool during the lockage of vessels for navigation. Several devices and strategies have been developed to deal with this phenomenon, such as submerged gates on the lock floor, pneumatic barriers, and special design of lock filling and emptying systems. EM 1110-2-1611 and EM 1110-2-1604 discuss navigation and lock design considerations, respectively.

b. *Submerged Barriers.* Barriers can be located in the deeper portions of the navigation channel to reduce salinity intrusion by stopping the deeper, denser saline water's movement upstream. Permanent sills have been considered for installation in the San Francisco Bay to reduce possible saltwater migration into the San Joaquin Delta. A temporary, erodible sill was investigated and implemented in the Lower Mississippi River during the 1988 drought to help protect the freshwater supply for New Orleans (Johnson, Boyd, and Keulegan 1987). The effectiveness of submerged sills and salinity barriers should be investigated and designed with the help of appropriate physical and mathematical models.

9-6. Diversion Works. Diversion works are constructed to separate navigation channels from upland streams and to divert upstream flows. The purpose of the diversion might be to prevent sediment in the stream from shoaling the navigation channel, to limit salinity intrusion into the natural stream channel, or to return upstream flows back to estuarine areas for environmental purposes. Diversion works consist of a dam to close off normal discharges and a canal to convey diverted waters to a neighboring stream, bay, or sea. The environmental and navigational consequences of proposed flow diversion schemes will require intensive study as a result of potentially major changes in water quality and degradation of navigation conditions from crosscurrents and current increases.

9-7. Bridge Clearance.

a. *General.* The clear horizontal and vertical spacing available for navigation at overhead bridges should be sufficient to permit the safe transit of the design ship expected to use the navigation channel under normal operational conditions. The 1972 Waterways Safety Act placed responsibility for establishing bridge clearances with the U.S. Coast Guard. Therefore, initial project design planning of navigation projects involving new or existing bridge crossings should be coordinated with the local Coast Guard District Office, and final design will require Coast Guard approval. The following general guidance applies also to hurricane barriers, power line towers, or other structures that may be a potential obstruction to navigation in a waterway.

b. *Horizontal Clearance.* In general, it is desirable that the horizontal clearance between bridge piers, including bridge fenders, should be equal to or greater than the local channel width. The design should provide for location of bridge piers to cause ship grounding rather than collision with piers or obstructions, which could cause loss of life. Some projects with older bridges built when ships were much smaller than today may have very difficult navigation conditions, sometimes with very small ship clearances. The project planner/designer should study the possibility of upgrading such bridges or other structures to reduce possible navigation hazards. In some cases, smaller distances between bridge piers than desirable may be necessary, depending on local conditions. Each design should consider the following factors:

(1) Navigation traffic density and pattern (one- or two-way).

(2) Alignment and speed of water current.

(3) Risk of collision.

(4) Potential damage from collision, loss of life, hazardous cargo spillage, bridge and ship damage, and interruption to waterway and bridge traffic.

(5) Cost of bridge pier fendering to protect bridge and vessels.

(6) Possible addition of islands around bridge piers.

(7) Navigation span alignment and clearance of other waterway bridges.

c. *Vertical Clearance.* Ship superstructure including radar and radio masts may well be a limiting factor in ship navigation under railroad and highway bridges or other overhead obstructions above waterways and channels. The vertical clearance under bridges is the vertical height between the water level during normal ship transits and the lowest member of the bridge structure over the channel width. In tidal waterways, the water level specified is the mean higher high spring tide elevation. In rivers, some small percent occurrence of water level has been used to specify the water level. A study of the variation of water surface about the higher elevations should be undertaken for important waterway projects to establish vertical clearance (also called air draft).

d. *Bridge Approaches.* The navigation approach to overhead bridges should preferably be straight and normal or nearly normal to the bridge alignment. Crosscurrent alignment and magnitude have a significant effect on navigation conditions and may require an increase in channel width as well as possible channel or bridge realignment. The length of the straight reach of the approach channel on each side of the bridge should be five times the design ship length.

9-8. Training Dikes and Revetments.

a. *Dikes.* In rivers and waterways with high sediment transport subject to shoaling, training structures are frequently required to help maintain deep-draft navigable channel depths during low-water season. Several different types of training dikes have been developed to control navigation channel alignments and maintain adequate channel depths, including spur dikes, vane dikes, longitudinal dikes, and L-head dikes. Training structures are usually designed to constrict the flow at low-water seasons to increase water currents and the natural scouring tendency in the navigation channel. Longitudinal dikes extending along the waterway are often used to help guide or direct currents to reduce shoaling and improve navigation conditions. Dikes are usually constructed of timber pile clusters, stone, or piling with stone fill. Refer to EM 1110-2-1611, *Layout and Design of Shallow-Draft Waterways*, Chapter 7, Section V, for a more thorough discussion of this topic.

b. *Revetments.*

(1) Bank erosion caused by currents or wave wash from navigation is frequently a problem in natural streams and waterways with erodible banks. Protection from bank erosion by revetments should be considered, if required, during project design. Rock riprap and articulated concrete mattress have both been used as revetments to control bank erosion.

(2) The clearance between training structures and navigation channels must be adequate to assure safe navigation. Pilots and captains in charge of ships transiting along channels have a strong aversion to dikes and rock riprap and will keep their ships well away from such structures. It is desirable to locate dikes and revetments to avoid possible damage to ships striking these structures. Careful design and location are especially important in channel curves or turns where ships

are required to maneuver. Design procedures for river and waterway training structures are detailed in EM 1110-2-1611. The principles for the design of bank revetments are explained in EM 1110-2-1601. The location, layout, and orientation of dikes and revetments and the flow, deposition and scour, and impacts on the waterway can be determined best by use of a physical or numerical hydraulic model.

9-9. Hurricane Barriers. Storm and hurricane surges have historically caused major floods and damage in Europe, and the United States' structural barriers located near and across the entrance to rivers, bays, and coastal regions have been proposed, designed, and in some cases built in a number of developed areas. The details of surge analysis are treated in EM 1110-2-1412, which should be consulted for barrier design. The following discussion presents important navigational impacts that should be considered in barrier planning and design.

a. Hurricane and storm surge barriers are normally located as close to the ocean as possible to increase the area of protection inside the river or bay. In most cases, a navigation lock or gap will be required as a part of the barrier. The approaches to the navigation gap or lock should allow for a straight sailing course for a distance equal to five times the design ship length. It is desirable that the design reduces or prevents crosscurrents and wave action in the gap approach to maintain safe navigation. The width and depth of the navigation gap should be designed to allow adequate clearance by normal size ships with due regard for safety of ship transits inside the barrier. To reduce upstream surge transmission, the gap width and depth should be kept as small as possible; thus, there is a need in planning and design to optimize and balance project benefits from flooding reduction with the requirements of navigation.

b. Because current velocities though the navigation gap will be greater than the normal or preproject currents in the waterway, the design should consider whether the user ships can navigate safely through the hurricane barrier. A satisfactory design of the navigation gap and adjacent control gates usually will require the development and use of the appropriate numerical and physical models as well as a ship simulator study. From these studies, an optimum arrangement and barrier location can be developed that will provide for adequate surge protection and safe ship navigation conditions. Model studies can also provide assistance during project construction to reduce any adverse navigation conditions.

9-10. Sediment Traps. Sediment traps or deposition basins are areas in the waterway that are excavated in or near the navigation channel to reduce shoaling in the project navigation channel and manage the sedimentation processes so that the project maintenance dredging is conducted in the most cost-effective manner. Sediment traps have been provided in navigation projects in both estuarine and littoral environments. The effects on navigation from the sediment trap should be considered in the design and trap location for the range of conditions and proposed dredging operations at the sediment trap. For example, the location of a sediment trap on the outside edge of a turn may eliminate the bank cushion effect normally used by pilots to assist in turning the ship. The investigation procedures of sediment traps using physical and numerical models are outlined in EM 1110-2-1607 for estuarine areas. The design procedures to be used in the littoral zone are covered in the *Shore Protection Manual* (1984).