# Major Port Improvement Alternatives for the Texas Coast

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Ocean Engineering Program

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# ABSTRACT

With the advent in recent years of very large commercial craft (VLCC) and ultra large commercial craft (ULCC), United States has fallen behind many other maritime countries in providing suitable docking facilities. The shortfall in port facilities capable of handling the deep-draft vessels, coupled with rapidly growing volume of imports and exports of bulk commodities, has resulted in a critical need for improved port facilities in this country.

Ship channel design criteria are discussed in terms of minimum width and depth requirements for various size vessels.

Improved channel designs are presented for the ports of Port Arthur, Galveston, Freeport and Corpus Christi.

# PREFACE

The study described in this report was conducted as part of the research program of the Ocean Engineering Program at Texas A&M University.

The manuscript was edited by Dr. Gisela Mahoney and typed for publication by Joyce McCabe.

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# MAJOR PORT IMPROVEMENT ALTERNATIVES FOR THE TEXAS COAST

## I. ECONOMIC CONSIDERATIONS

### Future Utilization of Texas Ports

With the advent in recent years of very large commercial craft (VLCC) and ultra large commercial craft (ULCC), United States has fallen behind many other maritime countries in providing suitable docking facilities and efficient handling equipment. Where, just a few years ago, the United States could boast that its ports were capable of accommodating the largest ships in service, today other nations have moved considerably ahead in both port construction and shipbuilding. Hence, the United States now finds itself as a second-rate nation in terms of port facilities for ships greater than 65,000 deadweight tons (DWT), fully loaded. (2)*

The shortfall in port facilities capable of handling these deep-draft vessels, coupled with a rapidly growing volume of imports and exports of bulk commodities, has resulted in a critical need for improved port facilities in this country. (2) The onshore deepwater port, which has been almost exclusively pursued by European ports, is the solution to the problem. (4) It offers flexibility as to the types of commodities that it can handle, as well as maximum availability since its utilization is reduced only by low visibility conditions which make navigation hazardous. The availability of an onshore deepwater port is not influenced by winds and waves to any significant degree. (2)

Other reasons for seriously considering onshore deepwater facilities

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* Numbers in parentheses after a sentence or paragraph refer to the Bibliography on pages 42-43.

are many and include: (1) projected growth in oil importation and refining levels, coupled with the problems inherent in the building of pipelines, give rise to expectations that there will be sizeable increases in the seaborne movement of petroleum products between processing and consuming regions, such as from the Gulf Coast to the eastern seaboard; (2) growing depletion of domestic reserves of various critical materials, such as iron ore, greatly increases the probability of massive imports of these commodities in future years; and (3) changes in American foreign trade policies will cause greater emphasis to be placed on the worldwide marketing of coal and agricultural products. Since the economy of transportation tends to favor the use of VLCC's for bulk movements such as these, it appears that deepwater facilities for dry bulk commodities and petroleum products will become highly desirable. (1,2,4)

## Trends in Tanker and Cargo Ship Design

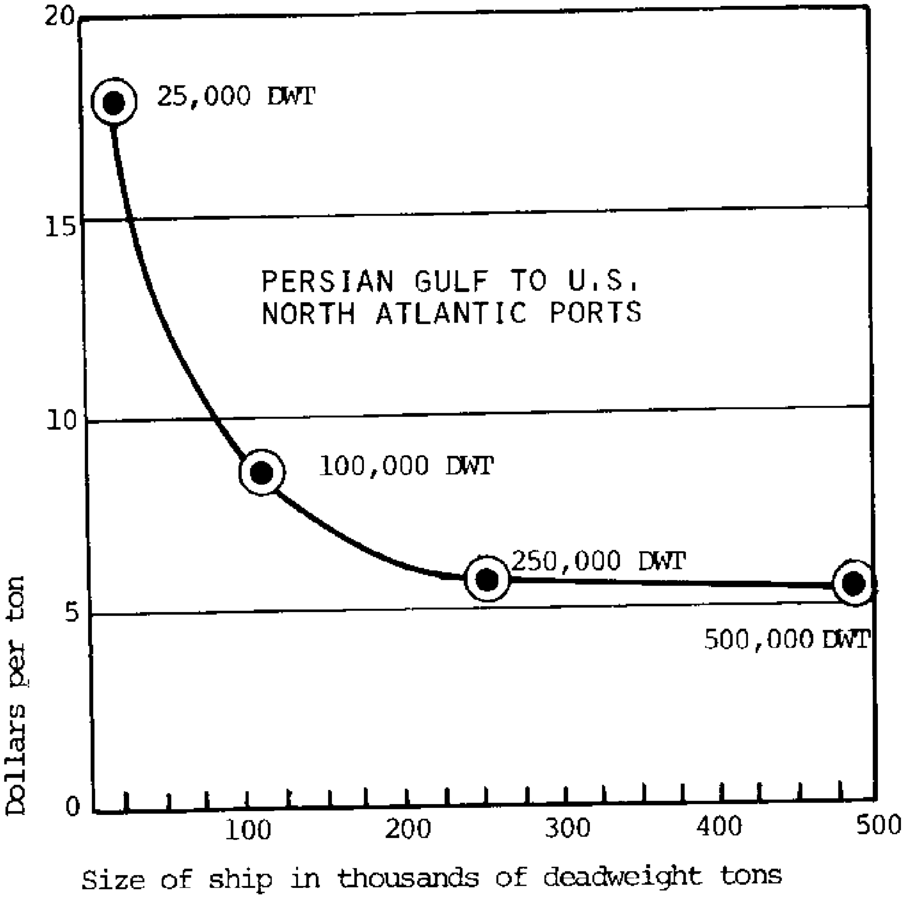
One of the most fundamental questions with respect to deepwater port facilities is that of savings in transportation costs that can be realized through the use of VLCC's. Given that the average size of vessels currently in use on the Gulf of Mexico is 30,000 to 50,000 deadweight tons, important cost savings can be realized by making the Texas coast accessible to VLCC's.(1,2,4)

As shown in Figure I-1, cost savings are significant through a range of vessel sizes extending to 250,000 to 265,000 deadweight tons. However, as the size increases over 265,000 deadweight tons, the savings is practically negligible. The savings realized by using a 500,000 DWT vessel instead of a 250,000 DWT vessel is only a small fraction of a dollar per ton. Consequently, this difference appears to be of minor significance to industry and ultimately to the consumer. This leveling of savings in transportation costs seems to indicate a practical limit to port facilities improvement.(4,14)

Increases in the size of dry bulk carriers have been less dramatic as compared to crude carriers, although large combination bulk carriers are being developed in the 200,000 to 300,000 DWT range. In addition, some container ships are being built that will exceed a 40-foot draft. According to shipping experts, an ore-handling port that can accommodate vessels with a draft of 68 feet is in a very good competitive position, because it is not anticipated that many ore carriers will be constructed that exceed this figure.(4)

Indications are that future use of VLCC's over 250,000-265,000 DWT will be far more limited than first anticipated because of the relatively small number of vessels presently operating or those on order that will

EXHIBIT II
COSTS VS. TANKER SIZE



SOURCE: U.S. Maritime Administration

FIGURE I-1. Cost vs. Tanker Size.(14)

eventually be built worldwide, and their relatively minor potential to achieve savings in transportation costs. This trend will be reinforced by increases in construction costs and insurance costs for VLCC's, as well as an increase in various safety-related restrictions which are being applied to them while at sea and in channels.(4)

## Design Vessels

In order to arrive at possible improvements to various port facilities on the Texas coast, several design vessels have been selected, so that the required channel geometry for each vessel may be investigated, and then applied to each port as deemed applicable. The design vessels with their respective dimensions are given in the table below.

Table I-1. Design Vessels and Their Dimensions.

| Design Vessel | Length(L) | Beam(B) | Draft(D) |
|---|---|---|---|
| 100,000 DWT | 850 ft | 130 ft | 50 ft |
| 150,000 DWT | 900 ft | 150 ft | 56 ft |
| 250,000-<br>265,000 DWT | 1100 ft | 175 ft | 67 ft |

## II. SHIP MANEUVERABILITY IN RESTRICTED WATERWAYS

Vessel behavior in channels and maneuvering areas will be influenced by bottom and bank suction, interference of passing ships, waves, winds, and currents:

Vessel Behavior = f (bottom suction, bank suction, interference of passing ships, waves, winds, and currents)

A vessel in motion experiences a lowering of the water level around it which increases the required channel depth, measured from mean low water (MLW), by an amount which is a function of the vessel's characteristics and speed, the relation of ship's beam and draft to the width and depth of the channel, and the vessel's location with respect to the centerline of the channel. An interaction of the vessel and channel boundary takes place which tends to push the bow away from the near bank, and pull the stern towards the near bank. The control of the ship in a restricted channel at low speeds is very difficult, particularly while passing another ship due to the interference of the flow of water about the other ship and to waves and pressure differences on the sides of each vessel. Shallow and narrow channels do not allow sufficient time or space to make the necessary evaluation and judgment for a quick adjustment and compensation of rudder to avoid a mishap. Furthermore, in shallow confined waters, power to propel the ship increases considerably over that required for the same speed in deep open water and the rudder response is much slower.(5,6)

As a vessel moves through deep water, the water level at the bow and stern sinks and the vessel with it. Lowering of the water surface at the bow is greater than at the stern until the ship's speed-length ratio, $V:\sqrt{L}$, reaches a value of one. When this ratio is greater than one, the water level at the stern continues to sink while the water at the bow begins to rise. The lowering continues with the increase of vessel speed and the decrease of water depth. At practical speeds of VLCC's, it is the forward part of the ship that sinks. (5,7)

For channels and maneuvering areas with small underkeel clearance, flow under a vessel is restricted which changes the side forces and moments acting on a ship. There is a considerable increase of water resistance over that in deep water. The lesser underkeel clearance causes an increase of water velocity, with a subsequent decrease of water pressure and increased sinkage, trim, and resistance, which is termed the shallow water effect.(3,5)

A greater depth of water is required for good control of a VLCC than the absolute minimum arrived at from the geometry of the ship, its loading, the density of water, wave and wind action, and bottom suction which affect a vessel. This is because the normal maneuvering characteristics of a vessel are modified by an inadequate depth of water, causing difficulties in the process of executing a maneuver. Therefore, from the point of view of controllability, adequate overdepth is a prerequisite for good performance, rudder effectiveness, and minimum power consumption.(5,6,16)

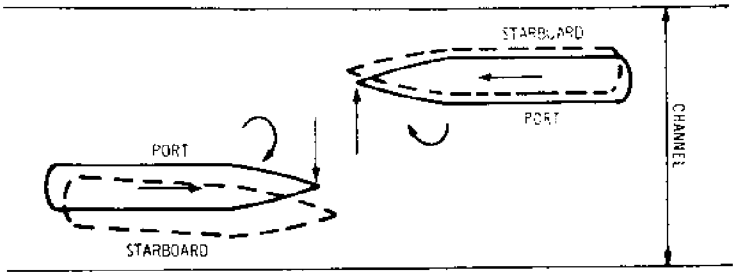
Because of the contraction between the banks of a channel and the bow of a ship, the speed of water flow increases, causing a current in the constricted area. Waves created by the passage of ships in this constricted area are attenuated or absorbed. When the ship runs too close to the bank, the propeller draws water from between the ship and the bank, causing the stern to drift into the bank. Lateral asymmetric hydrodynamic forces are therefore produced and a yawing moment develops, directing the bow of the ship away from the near bank and the stern towards the near bank. It is difficult to keep a vessel on course, even when in the center of a narrow channel. As the ship takes an off-center position and approaches the bank, a yawing moment develops due to bank suction, which requires an increase of rudder angle to keep the ship in equilibrium and on course. The rudder angle required to counteract the yawing moment while maintaining the ship's course, could be the practical measure of the amount of bank suction.(5)

Lateral forces are much lower for the ship located further away from banks and in the deeper area of the channel where navigation conditions are more favorable. In addition, sinkage is greater when a vessel is near the bank rather than at the centerline of the channel. Thus, by deepening and widening the channel, a larger percent of the total width is available for safe navigation.(5)

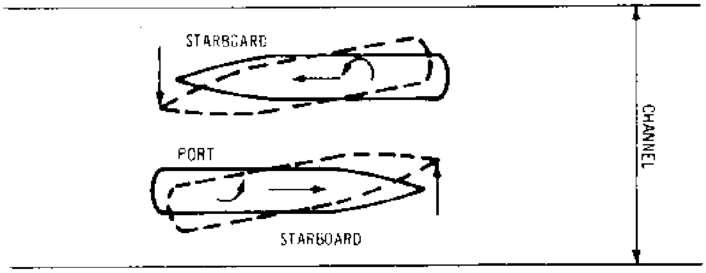
The effect of location of a vessel in a channel within a wide waterway should not be as pronounced as in restricted waterways, except that maintaining course may be more difficult, especially in inclement weather. This may be due to a lack of exact delineation of channel boundaries in open waters as opposed to canals where the shore is clearly visible, and due to the shifting of buoys.(5,18)

Control of a ship is very difficult while passing because of the interference with the flow of water about the other vessel and the difference in pressures on the sides of each ship. Passing problems are particularly pronounced in restricted channels where two-way traffic offers a design problem due to decreased controllability of vessels during meeting situations, their interaction, and effects of bottom and bank suction. When two vessels meet in a channel, the symmetrical pressure distribution around them before meeting becomes disturbed on both sides of each vessel. The asymmetry of this pressure is responsible for the tendency of diverting the vessels from the paths which they followed before meeting. The situation can be described in three phases: (1) when the bows come abreast of one another, they tend to spread apart because of the pressure build-up between them. The bank suction, opposing this tendency, will provide a degree of safety during this phase; (2) when the bow of one vessel approaches the stern of the other, low water at the stern draws the bow towards the stern of the opposing vessel, which coincides with the action of bank suction, thereby reinforcing the yaw of the bows towards low water to the port of each vessel; and (3) when the sterns of vessels approach one another, the sterns yaw to port. If the vessels are close, their sterns have a tendency to join in a depression of water created by the passage of the vessels. In this phase, the bank suction will decrease this dangerous tendency. After the sterns have passed one another, interactions between the vessels and banks cause the vessels to sheer away from their paths towards the far bank if they are too close to the bank. Large wave interference in the restricted channel considerably increases the yawing moments after the passing maneuver is executed.(5,6)

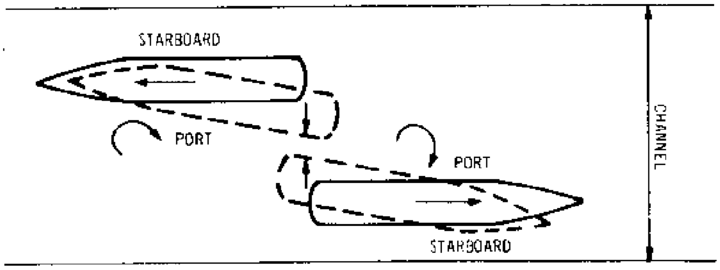
The effect of passing vessels in channels within wide waterways will not be as dangerous as in restricted waterways. The effects of bank suction will be decreased in proportion to the depth of water beyond the limits of the dredged prism. Interference with the flow about each vessel and disturbance of pressures around vessels, particularly on their starboard side, will be less than in a canal. Additionally, in open-type channels, wave interference will not have as great an effect in producing yawing moments as in restricted-type channels. The velocity of reverse flow in the case of an open-type channel will be much lower than for a restricted channel.(5,18)



1. Bows Abreast: Bows yaw away, but bank suction will oppose this tendency. (sheer to starboard)



2. Bows Approach Sterns: Bows yaw toward low water and the bank suction will tend to reinforce this movement. (sheer to port)



3. Sterns Opposite Each Other: Sterns yaw toward low water at sterns but bank suction will oppose this tendency.

FIGURE II-1. Meeting of Two Ships in Channel.(6)

In entrance channels, a vessel may be exposed to winds, large waves, and currents. These elements will tend to alter the intended movements of vessels underway. The motions induced by these elements, such as rolling, pitching, yawing, and heaving, may influence the required water depth and width of a channel. An adverse combination of elements can present an extremely serious danger to a vessel attempting to negotiate an entrance, or even prevent it from reaching sheltered waters. If the entrance channel is too narrow or too shallow for the wind, wave, and current conditions, the ship may have to wait until it becomes safe to enter.(5,17)

In open-type channels, the path of a vessel in transit will often be wider than in restricted-type channels because of the action of winds, waves, and currents. Thus open-type channels require an increase in width as the vessel may proceed in a yawed condition in order to maintain course. Also, floating buoys delineating the channel may be displaced over their anchor locations in the direction of the wind, waves, and current. This displacement of channel buoys will be more pronounced in areas of larger tidal variations.(5,17,18)

The rolling, pitching, and heaving of a vessel in an entrance channel must also be considered. These induced motions will require a substantial depth allowance in order to provide safe navigation. The pitching of a vessel is the most important motion to consider in this case because it has the greatest potential to restrict safe navigation of a channel.(5,18)

An advantage of a restricted channel, over an open channel, is the absence of cross-channel currents since the current is generally parallel to the banks in a restricted channel or canal. In restricted channels, wind has the greatest effect on the vessel's course and path width, while wave effects are secondary.(5)

# III. CHANNEL GEOMETRY

Navigation facilities must be designed for good control and safe maneuvering of ships. The width, depth, and alignment of channels, and dimensions of maneuvering areas must be adequate for safe navigation but not excessive.(5)

A ship owner's objective is to carry his cargo at the least possible cost per ton-mile, unload, and proceed to the next port.(18) Consequently, the continuous drive for economy and advancements in shipbuilding techniques have created larger vessels.(5)

A ship forfeits open-water maneuverability when it enters a channel. The navigator must be completely aware of the restrictions imposed on his vessel. Maneuverability is affected by the configuration of the waterway, the alignment and dimensions of the channel, the depth under the keel, tidal fluctuations, currents, waves, meteorological conditions, steerage, and interference from other traffic. These problems have always been present but are now magnified by the trend toward larger ships.(18)

Because the requirement of cost, size, and course-keeping ability of the vessel conflict with its maneuverability in waterways, the handler of a larger vessel has to deal with inadequate existing channels and maneuvering areas. In view of the increase in vessel sizes, projects for improving channels and maneuvering areas, straightening of curves, and deepening as well as increasing the widths of the various sections of channels, are being requested by navigation interests.(5)

## Width

General practice dictates that the width of a channel be measured at the bottom of the slope or at the design depth which is the required depth for safe navigation. Design width is determined from the beam and steering characteristics of the design vessel ; the depth of water under the keel of the vessel ; the speed of the vessel relative to the channel bottom; the traffic density; the characteristics of other vessels encountered in the channel ; whether the channel is of the restricted- or open-type ; currents; and wave action and winds that will cause the vessel to yaw:

Design Width = f(vessel size, vessel steering characteristics, vessel speed, traffic density, water depth, channel-type, currents, waves, and winds).(17,18)

The first step is the determination of the width of the maneuvering lane. This is defined as that portion of the channel within which the ship may maneuver, without encroaching on the safe bank clearance or without approaching another ship so closely that dangerous interference between ships will occur. When consideration is given to the disaster and economic loss that occur when vessels collide or the damage suffered when they go aground, it is likely that a lane width of 180 percent of the beam of the vessel should be employed for reaches where there are no yawing forces. In cases where the vessel is known to have poor controllability, the lane width might be increased to 200 percent of the ship's beam. Where strong yawing forces are present, such as in bar channels at port entrances, the maneuvering lane should be increased by 100 to 200 feet in width depending on the characteristics of the design vessel.(18)

In cases where the channel is required to handle two-way traffic involving large vessels, a ship clearance lane must be provided between the two maneuvering lanes. It is taken to be the distance between the inner boundaries of the maneuvering lanes, as each ship could be in this position during the passing operation. Model tests have shown that interaction between the passing vessels created no appreciable hazard when the distance between them was equal to the beam of the larger ship.(18)

The distance between the ship and the near bank of the channel is a function of the equilibrium rudder angle, the width and depth of the channel, and the speed of the vessel. A wider clearance is required for a five degree equilibrium rudder angle than for a ten degree equilibrium rudder angle, where equilibrium rudder angle is defined as the angle that causes the course of the ship (not the longitudinal centerline of the ship) to be parallel with the channel bank. A wider lane is required for a given rudder angle at a higher speed than at a lower speed. In addition, increased channel depth permits use of a narrower bank clearance lane for a given rudder angle, channel width, and ship's speed.(18)

However, there are other factors that require consideration. These include the existence of strong currents, currents at an angle to the channel, winds and waves, and whether the depths within the channel close to the bank are somewhat less than those closer to the channel centerline due to shoaling. When these conditions exist the width of the bank clearance lane should not be less than 150 percent of the beam of the design vessel.(18)

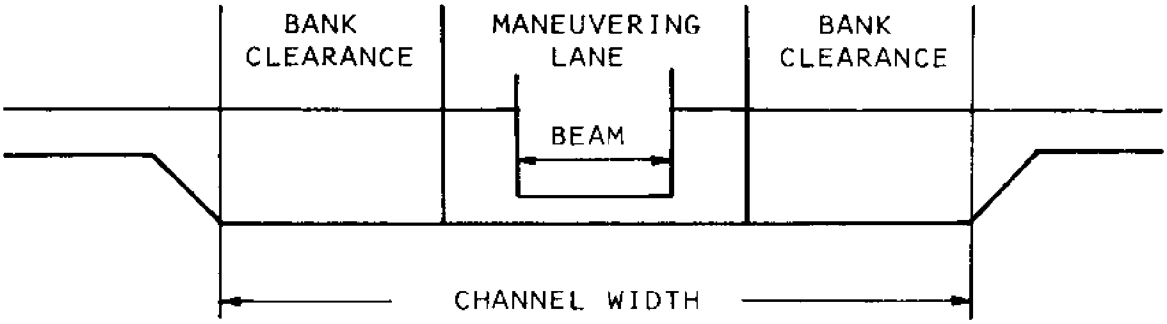


FIGURE III-1. Channel Width for One-Way Traffic.

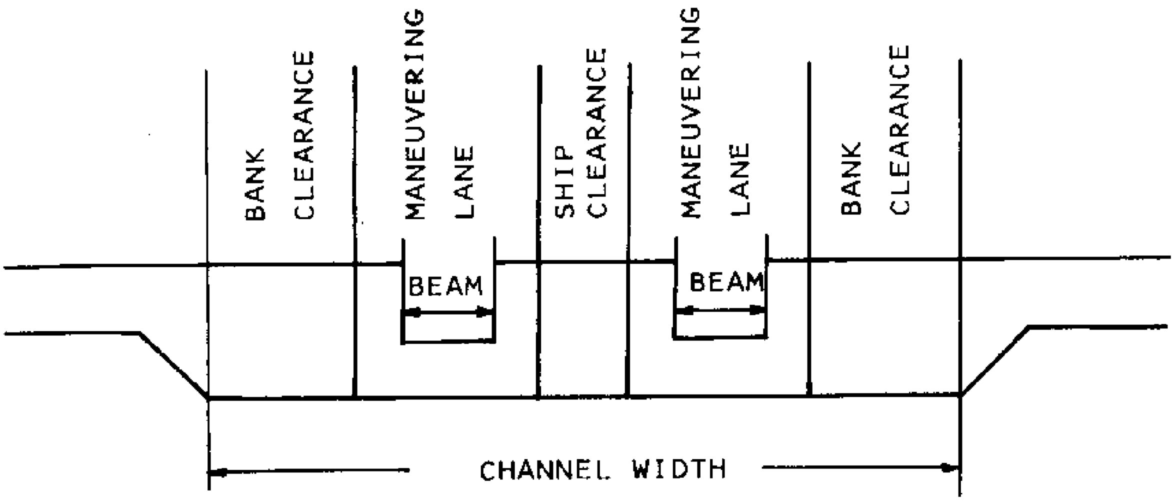


FIGURE III-2. Channel Width for Two-Way Traffic.

Each of the following tables gives the calculated dimensions of the maneuvering lane or lanes, the bank clearance lanes, and the ship clearance lane, as well as the total widths required for one-way and two-way traffic of each of the design vessels. The first table is applicable to inner channels where strong yawing forces due to atmospheric conditions are not present, whereas the second table is applicable to outer channels where these yawing forces are present. It should be noted that these numbers are considered to represent the minimum values which will provide safe navigation.

Table III-1. Channel Width For Safe Navigation.

| Design Vessel | Maneuvering Lane (A) = 2.0 × Beam | Bank Clearance (B) = 1.5 × Beam | Ship Clearance (C) = 1.0 × Beam | One-Way Traffic Width (A + 2B) | Two-Way Traffic Width (2A + 2B + C) |
|---|---|---|---|---|---|
| 100,000 DWT<br>L - 850 ft<br>B - 130 ft<br>D - 50 ft | 260 ft | 195 ft | 130 ft | 650 ft | 1040 ft |
| 150,000 DWT<br>L - 900 ft<br>B - 150 ft<br>D - 56 ft | 300 ft | 225 ft | 150 ft | 750 ft | 1200 ft |
| 250,000-<br>265,000 DWT<br>L - 1100 ft<br>B - 175 ft<br>D - 67 ft | 350 ft | 263 ft | 175 ft | 876 ft | 1401 ft |

NOTE: These values are applicable to ship channels where strong yawing forces are not present.(The Inner Channel)

Table III-2. Channel Width for Safe Navigation.

| Design Vessel | Maneuvering Lane (A) = 2.0 × Beam + L sin 10° | Bank Clearance (B) = 1.5 × Beam | Ship Clearance (C) = 1.0 × Beam | One-Way Traffic Width (A + 2B) | Two-Way Traffic Width (2A + 2B + C) |
|---|---|---|---|---|---|
| 100,000 DWT<br>L - 850 ft<br>B - 130 ft<br>D - 50 ft | 408 ft | 195 ft | 130 ft | 798 ft | 1336 ft |
| 150,000 DWT<br>L - 900 ft<br>B - 150 ft<br>D - 56 ft | 456 ft | 225 ft | 150 ft | 906 ft | 1512 ft |
| 250,000 - 265,000 DWT<br>L - 1100 ft<br>B - 175 ft<br>D - 67 ft | 541 ft | 263 ft | 175 ft | 1067 ft | 1783 ft |

NOTE: These values are applicable to ship channels where strong yawing forces are present, such as in the approach channel to a port entrance. (The Outer Channel)

## Depth

Channel depths substantially greater than the loaded static drafts of the vessels using the waterway are required in order to insure safe and economic navigation. The channel design must take into consideration not only the requirements of present-day vessels that will use the waterway but also the trend in vessel size.(18) Generally, the depth of waterways and maneuvering areas will be determined by the vessel's loaded draft; trim or list due to loading; ship motions due to waves, such as pitch, roll, and heave; character of the bottom, soft or hard; wind influence of water level and tidal variations; and sinkage of the vessel due to squat or bottom suction:

Design Depth = f(vessel's loaded draft, vessel squat, waves, winds, tidal variations, and character of the bottom).(6,16)

Loaded draft usually refers to the draft amidships of a vessel at rest when loaded to the summer load line. Also, common practice on the Gulf coast of the United States is to establish depths at mean low water (MLW).(18)

In passing from seawater to fresh water, a vessel's displacement must increase due to the difference in the densities of the two fluids. A vessel will sink two to three percent of its draft, depending upon hull design. A vessel with a 67-foot draft in seawater will have a 69-foot draft in fresh water, with intermediate drafts in brackish waters.(16,18)

A ship in motion will apparently sink or squat an amount depending on the speed of the vessel through the water, the distance between the keel and the bottom, the trim of the vessel, the cross-sectional area of the channel, whether the channel is of the open- or restricted type, whether the vessel is passing or overtaking another vessel, the location of the vessel relative to the centerline of the channel, and the characteristics of the ship. In channels where squat occurs, additional depth must be provided for safe navigation.(18)

Figure III-3, a plot of dimensionless squat (d) as a function of the Froude number (F) for a range of values of s, the ratio of ship cross-sectional area (A) to channel cross-sectional area (wh), clearly shows that the dimensionless squat parameter (d) increases at moderate rates as the Froude number increases until some critical value of F is attained. When the critical value of F is reached, the curve becomes asymptotic and the squat increases with great rapidity. Apparently it is not possible for the speed of the vessel to exceed a certain value, depending on the depth and the relation between the cross-sectional area of the vessel and that of the waterway, regardless of the propulsion effort exerted (note that when two vessels are meeting in a channel, the squat experienced by each vessel is computed based on a deduction from the channel cross-sectional area of the cross-sectional area of the other vessel).(18)

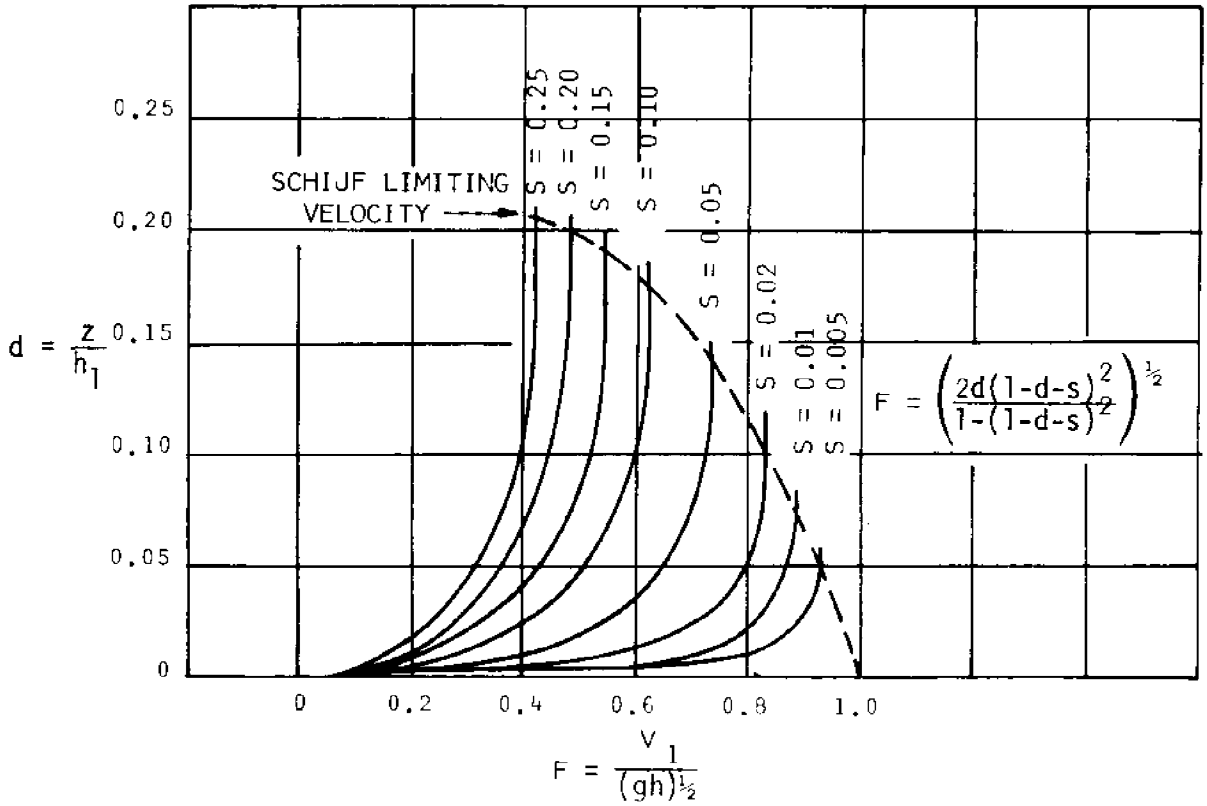


Fig. III-3. Dimensionless squat as a Function of the Froude Number.

$F$ = Froude number

$V_1$ = speed of the ship relative to the water

$g$ = acceleration of gravity

$h_1$ = undisturbed mean depth of water

$d$ = dimensionless squat parameter

$z$ = squat

$s$ = ratio of ship cross-sectional area A to channel cross-sectional area wh

$w$ = width of the waterway

Pitch, roll, and heave occur under the influence of waves.(18) A pitch angle of one degree would increase the draft of a 1000-foot vessel by about 9 feet. A five-degree roll of a ship, having a beam of 150 feet, would increase the draft of that ship by 7 feet. These occurrences are certainly not unusual in entrance channels, and therefore must be considered carefully when determining channel depth for safe navigation.

The conditions that produce sinkage also produce violent flow patterns in channels which affect ship steering and maneuverability, and produce bed-load movements which result in displacement of material. A vessel may displace one to two feet of material which would obstruct the passage of the next vessel. A clearance of at least three feet under the keel of a vessel in motion is necessary to avoid damage to ship propellers from sunken timbers and debris, reduce displacement of bottom material, and prevent fouling of pumps and condensers by bottom material. In channels where the bottom is hard, additional clearance will be necessary to insure safe navigation.(18)

The following tables delineate the results of the calculations made to determine the required channel depths for safe navigation of each of the design vessels. The tables consider the needs of one-way traffic in an inner channel, two-way traffic in an inner channel, and one-way and two-way traffic in an outer channel. Again, it should be noted that these numbers are considered to represent the minimum values which will provide safe navigation.

Table III-3. Channel Depth for Safe Navigation.
(one-way traffic/inner channel)

| Design Vessel | 100,000 DWT | 150,000 DWT | 250,000 - 265,000 DWT |
|---|---|---|---|
| Loaded Draft | 50 ft | 56 ft | 67 ft |
| Squat for a Speed of 8 Knots | 2 ft | 2 ft | 2 ft |
| Minimum Depth Under Keel | 3 ft | 3 ft | 3 ft |
| Total Depth | 55 ft | 61 ft | 72 ft |

Table III-4. Channel Depth for Safe Navigation.
(two-way traffic/inner channel)

| Design Vessel | 100,000 DWT | 150,000 DWT | 250,000 - 265,000 DWT |
|---|---|---|---|
| Loaded Draft | 50 ft | 56 ft | 67 ft |
| Squat for a Speed of 8 Knots | 1 ft | 1 ft | 1 ft |
| Minimum Depth Under Keel | 3 ft | 3 ft | 3 ft |
| Total Depth | 54 ft | 60 ft | 71 ft |

Table III-5. Channel Depth for Safe Navigation. (one-way and two-way traffic/outer channel)

| Design Vessel | 100,000 DWT | 150,000 DWT | 250,000 - 265,000 DWT |
|---|---|---|---|
| Loaded Draft | 50 ft | 56 ft | 67 ft |
| Effect of Pitch and Roll (L/2 sin 1°) | 8 ft | 8 ft | 10 ft |
| Minimum Depth Under Keel | 3 ft | 3 ft | 3 ft |
| Total Depth | 61 ft | 67 ft | 80 ft |

## Turning Basins

The location of a turning basin is very important and its design must provide the proper configuration, the proper dimensions, and easy access. In addition, a turning basin should be protected from waves, strong currents, and winds, while being free of pipelines, cables, and obstructions.(5)

A turning basin's size is a function of the length and maneuverability of the ships using it, and the time permitted for the execution of turning maneuvers. As the time allowance is shortened, the diameter of the turning basin must increase. The optimum size of a turning basin would be a basin which contains a circular area whose diameter is four times the length of the largest vessel expected to use the turning basin. The intermediate size of a turning basin, with more difficult turning, would be one incorporating an area whose diameter is approximately twice the length of the design vessel. The turning maneuver in this basin will take longer but may be accomplished by the judicious application of ship's power and skillful steering or tug assistance. The minimum size of a turning basin would be one whose diameter is 20 percent longer than the length of the largest ship to be turned. In such a basin, the vessel must be handled around a fixed point at the perimeter of the turning circle, such as a dolphin.(5)

The following table gives the diameters of the smallest practical turning basin and an intermediate-sized turning basin for each of the three design vessels:

Table III-6. Turning Basin Diameter.

| Design Vessel | Smallest Practical Turning Basin Diameter | Intermediate-sized Turning Basin Diameter |
|---|---|---|
| 100,000 DWT<br>L - 850 ft<br>B - 130 ft<br>D - 50 ft | 1020 ft | 1700 ft |
| 150,000 DWT<br>L - 900 ft<br>B - 150 ft<br>D - 56 ft | 1080 ft | 1800 ft |
| 250,000 -<br>265,000 DWT<br>L - 1100 ft<br>B - 175 ft<br>D - 67 ft | 1320 ft | 2200 ft |

## Bends

Turns in channels should only be employed where absolutely necessary. This is because any change of the channel's direction causes changes in flow as compared to the straight section and makes navigation more difficult. The path of a ship in a bend is wider than in straight sections of the channel and its width tends to increase with an increase in curvature of the bend. Because the direction of the ship constantly changes, moment, side and hydrodynamic forces develop, making it far more difficult to steer in bends than in straight runs. Turning of vessels in bends has to be made at the proper time to prevent contact with the banks, particularly when proceeding against a current. In addition, course-keeping is made more difficult due to the absence of navigation ranges while passing through a bend.(5)

A change from one direction of the channel into another can be accomplished, especially for highly maneuverable ships, without the introduction of a curve at the intersection of straight runs. A widening by flattening the interior of the channel may be all that is required. Its use in an open-type channel is justified. However, in restricted channels, such a change in cross-sectional area may cause undesirable disturbances in the flow pattern, resulting in a change of hydrodynamic forces acting on a ship.(5)

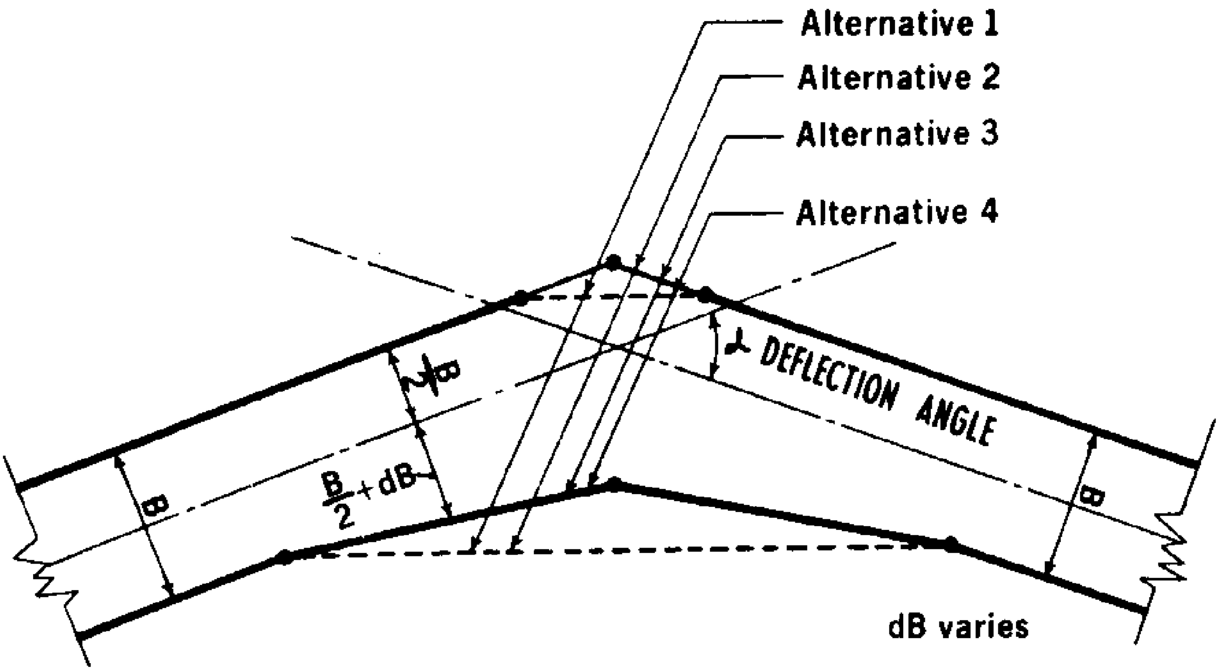


FIGURE III-4. Straight Line Turn (5)

A vessel, making any turn, proceeds along a curve with a linear velocity constantly changing direction, which in effect is a tangent to the curve. If the change of direction is appreciable or if the maneuvering characteristics of vessels frequently using the channel are poor, the introduction of curve in the channel is warranted. For calm water, the minimum radius or maximum central angle will depend on the characteristics of the least maneuverable vessel using the channel, its size and rudder effectiveness, depth of water, and width of the channel.(5)

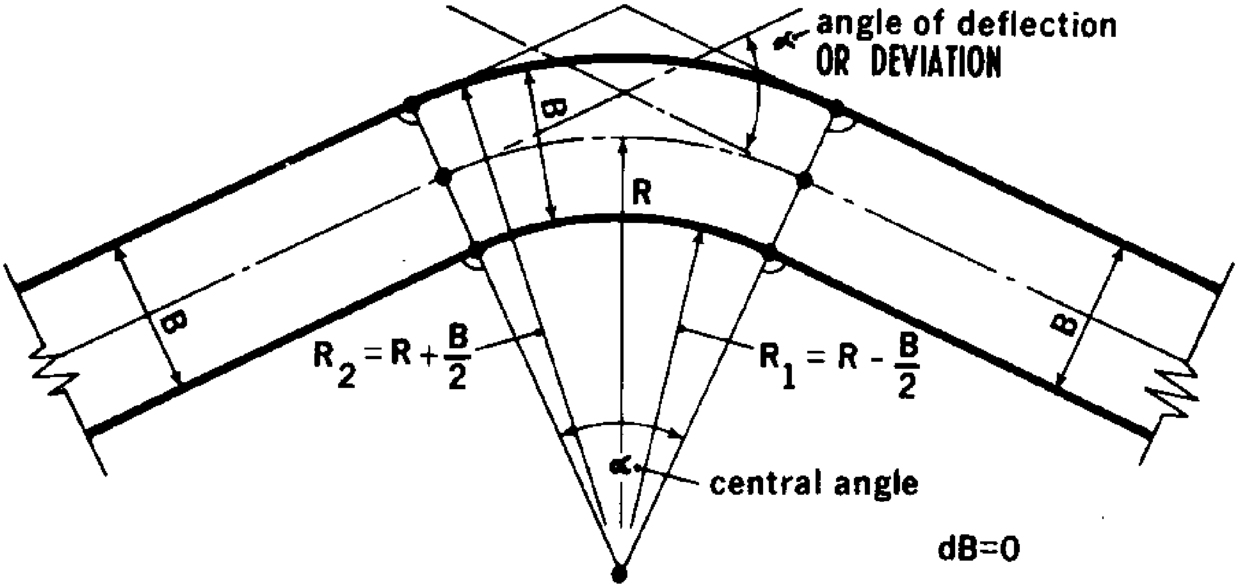


FIGURE III-5. Constant Width Turn in Channel. (5)

A vessel, during maneuvering in bends, will deviate from its course appreciably more than in straight runs. Therefore, channel bends are usually widened to provide more space for maneuvering. The increase of channel width in bends is considered as a function of a number of variables such as deflection angle, radius of curvature, environmental conditions, and the length, beam, and controllability of the design vessel. The entire amount of widening may be applied to the inside curve of the channel bend, or it can be split equally or unequally on both sides of the channel to produce symmetrically or unsymmetrically widened bends. However, there is a deficiency in investigative work to provide a sound basis for determination of the width's increase in channel bends.(5,6)

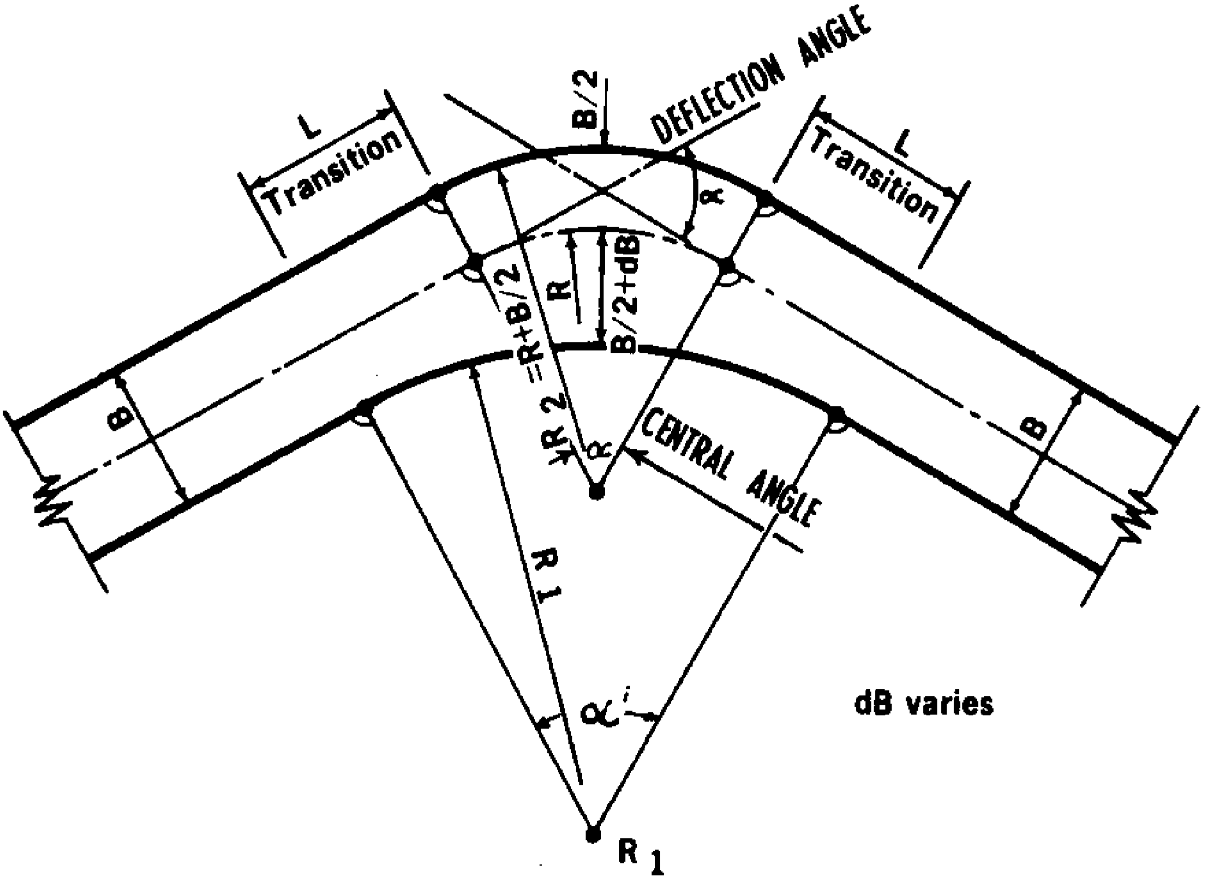


FIGURE III-6. Unsymmetrically widened Turn with Curved Transitions.(5)

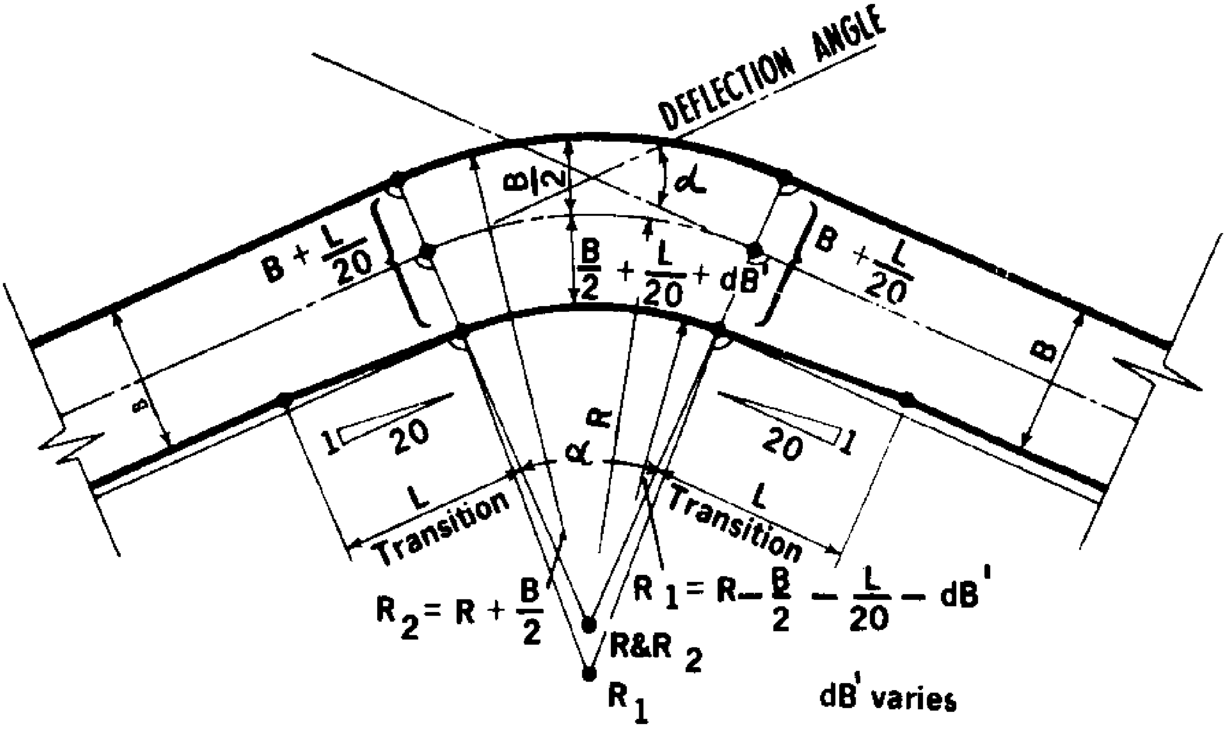


FIGURE III-7. Unsymmetrically widened Turn with Straight Transition Sections.(5)

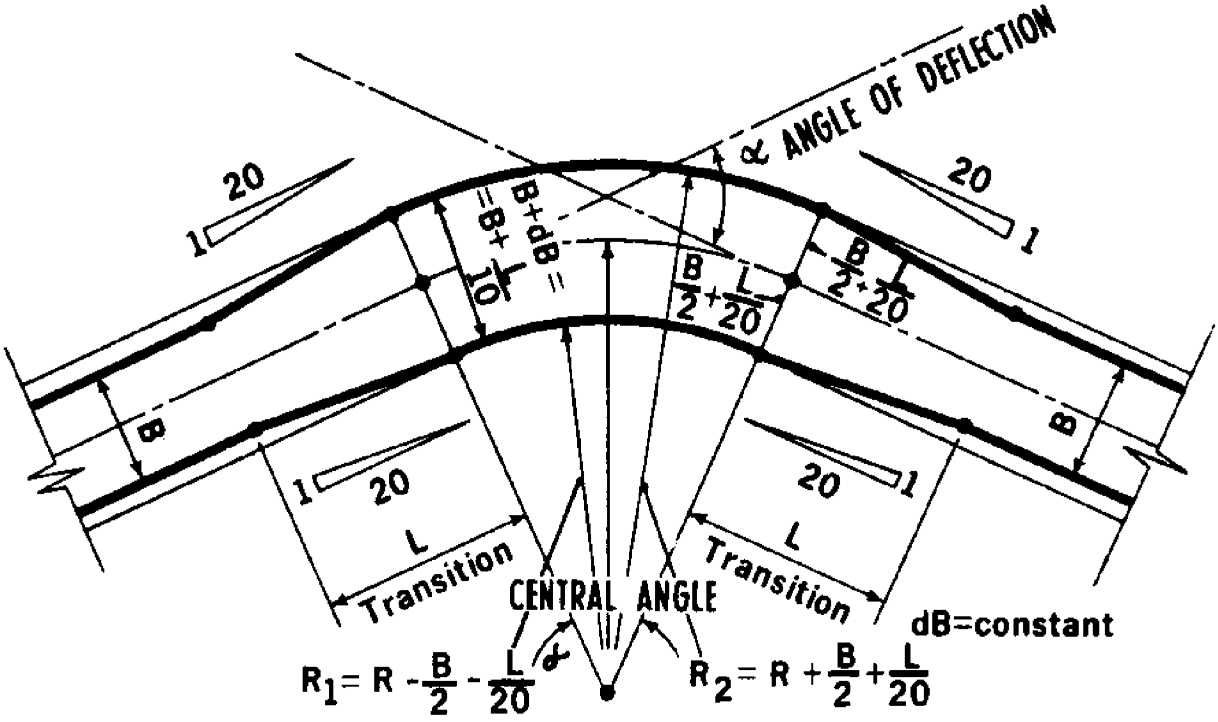


FIGURE III-8. Parallel-widened Turn in Channel.(5)

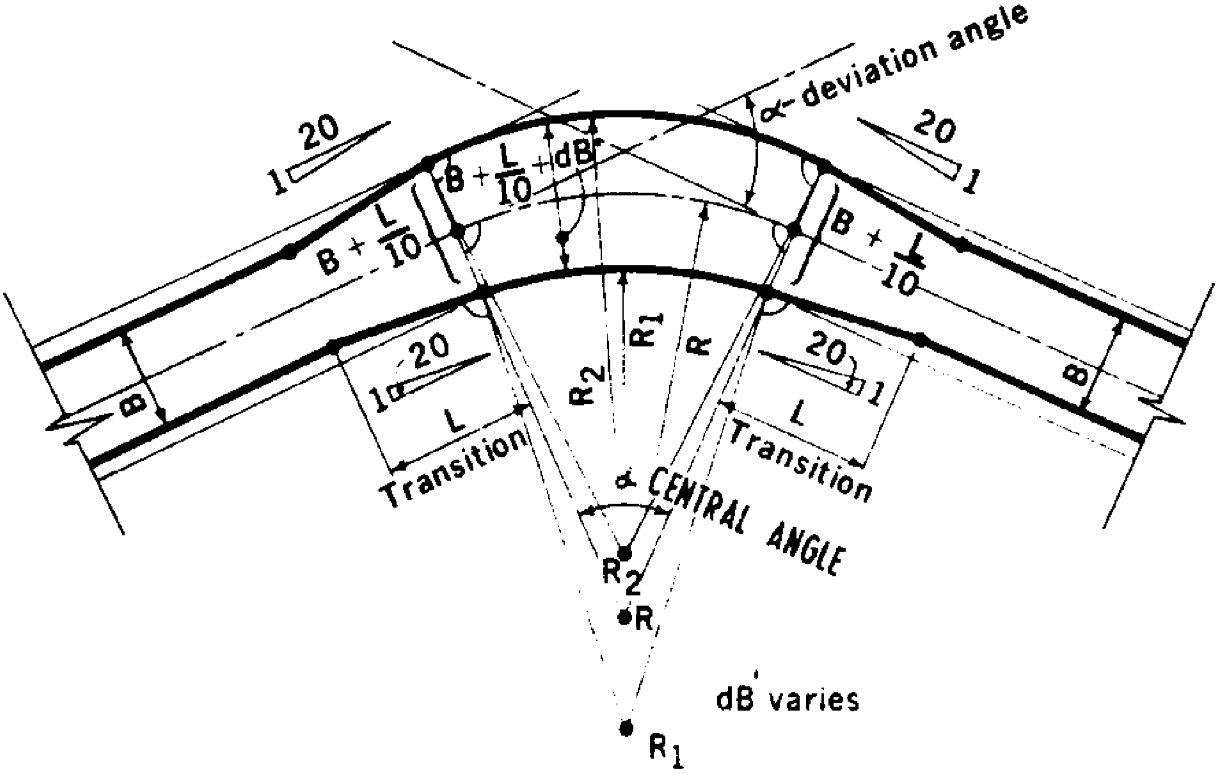


FIGURE III-9. Symmetrically widened Turn with Straight Transitions.(5)

Widening of curves creates transition areas from the width in straight runs to the increased width in curves. The transition causes changes of the flow with resulting asymmetric hydrodynamic forces exerted on a ship as it enters the turn. Because of disturbances in flow caused by the transition, easement curves should be considered which should be as gradual as possible to provide a smoother change from the straight channel cross-section to the widened cross-section of the bend. If a straight-line transition is used, the maximum rate of widening should be about one in twenty.(5)

# IV. CHANNEL DESIGN

In this chapter, improved channel designs are presented for the ports of Port Arthur, Galveston, Freeport, and Corpus Christi. For each port, a design vessel was selected and the required channel geometries, as calculated in Chapter III, were applied. However, it should be noted that the selection of the design vessel for each port was somewhat arbitrary. Owing to the fact that this report is primarily concerned with the physical dimensions of channels, exhaustive economic studies were not undertaken to determine the most desirable design vessel for each port.

## Port Arthur

The Port Arthur ship channel, which is 12.5 miles in length, extends from the Taylor Bayou turning basin to Texas Point. Due to its length, a deepening of the channel to 55 feet can probably be considered an upper limit for any future improvement of the Port Arthur ship channel. A channel, with a depth of 55 feet and a width of 650 feet, is capable of accommodating vessels up to 100,000 DWT.

In this case, the length of the approach channel from the Gulf of Mexico to Texas Point would be 38 miles, which is required to reach a natural depth of 61 feet on the continental shelf. A depth of 61 feet and a width of 798 feet is believed to be necessary for the approach channel because of the increased magnitude of forces present over the continental shelf which induce larger yawing and pitching motions of a vessel.

In conclusion, it must be pointed out that the over-all length of the project (50 miles) makes any larger undertaking very unlikely, particularly in the near future.

## Galveston

In laying out the VLCC terminal and its associated channels, a design vessel of 250,000 to 265,000 DWT was considered. The Bolivar Roads Channel/ Turning Basin is 2200 feet in width with a depth of 72 feet. The inner channel, which includes the inner bar channel and the outer bar channel, extends to the end of the jetties with a width of 876 feet and a depth of 72 feet. The outer channel or entrance channel is composed of two legs, having a total length of 52 miles, a width of 1067 feet, and a depth of 80 feet.

While the VLCC terminal is envisioned to handle only petroleum products, the Galveston channel and its associated facilities will provide for the loading and unloading of large dry bulk carriers. In this regard, the Galveston channel is designed to accommodate a 150,000 DWT vessel, with a depth of 61 feet and a continued width of 1125 feet.

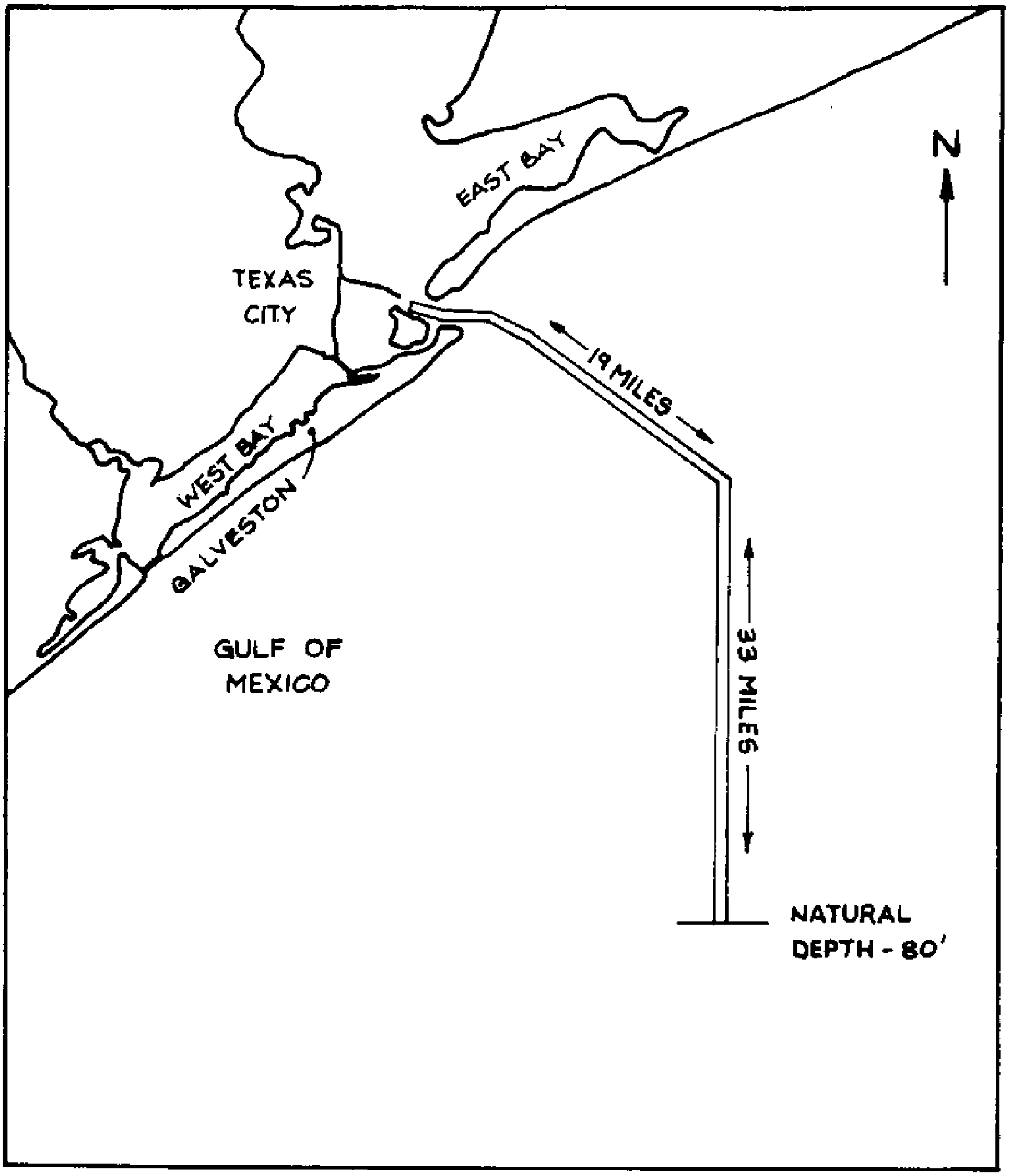


FIGURE IV-1. GALVESTON DEEP-DRAFT CHANNEL

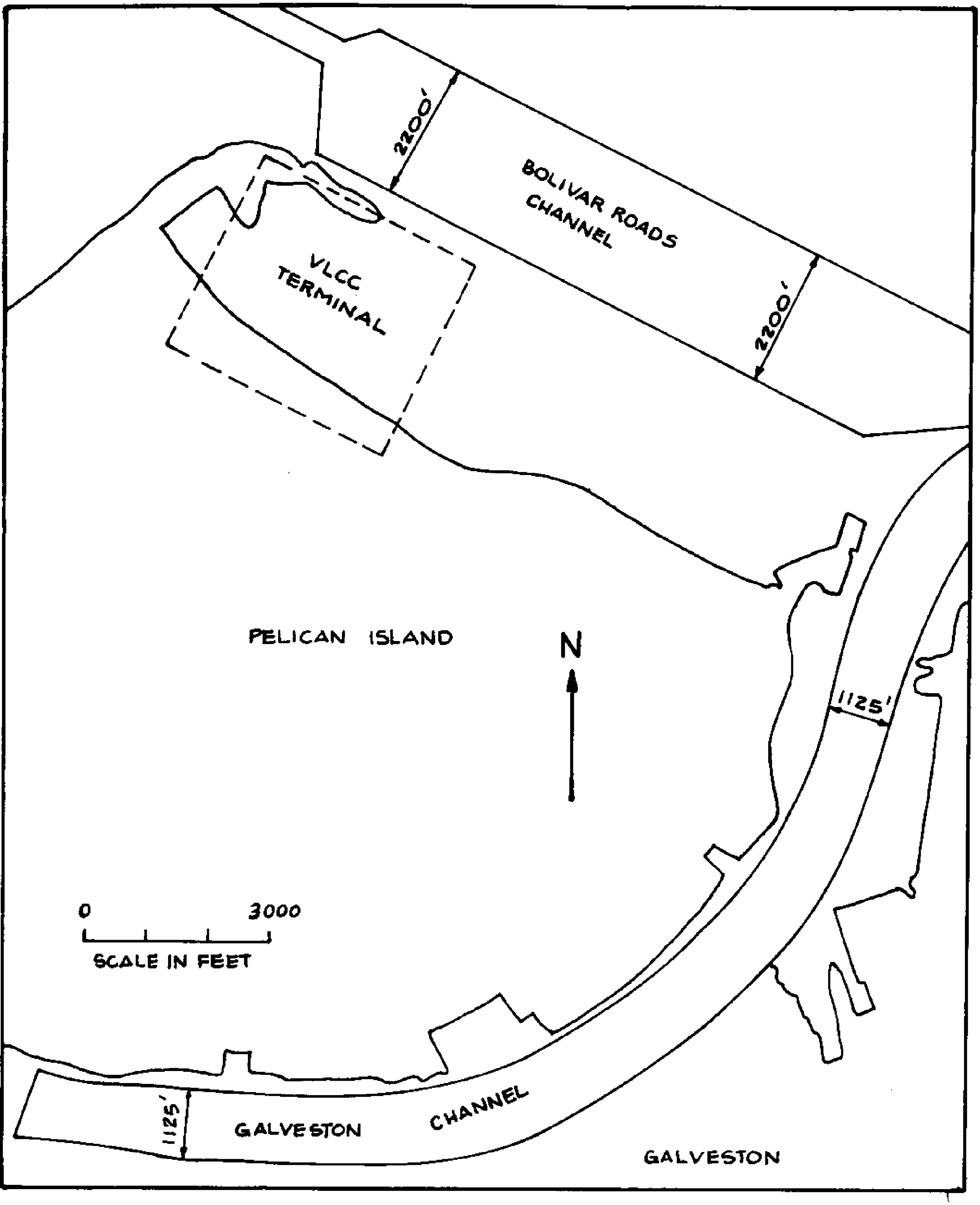


FIGURE IV-2. Bolivar Roads and Galveston Channels.

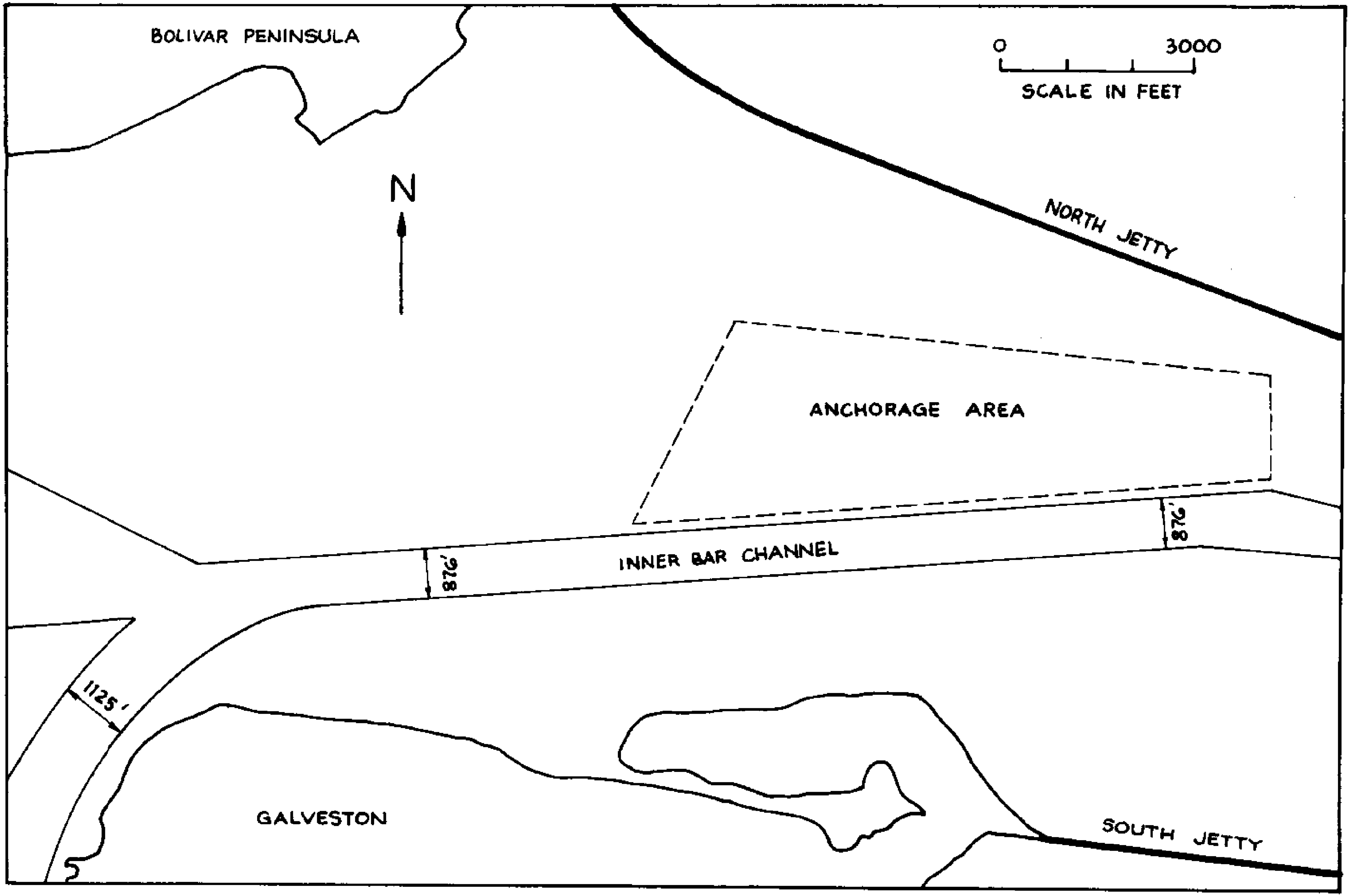


FIGURE IV-3. Galveston Inner Bar Channel

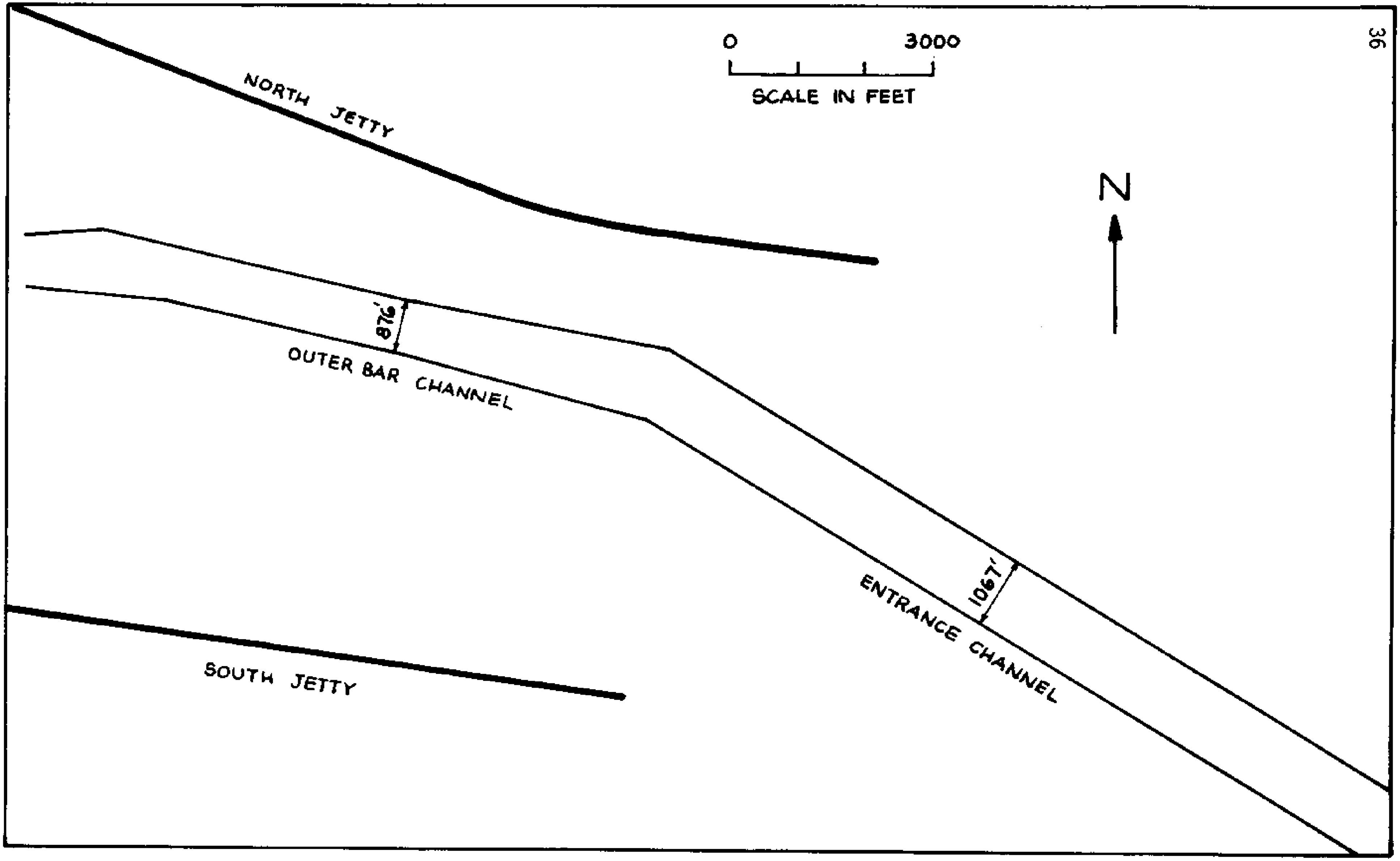


FIGURE IV-4. Galveston Bay Entrance Channel

### Freeport

A design vessel of 150,000 DWT was chosen for Freeport Harbor. From earlier calculations, the inner channel, which is approximately 2.5 miles long, has a depth of 61 feet and a width of 750 feet. The diameter of the turning basins is 1200 feet which is slightly more than the smallest practical turning basin diameter of 1080 feet. At this point, it should be noted that VLCC's will require tug assistance in the inner channel, particularly with the number of bends to be encountered in this relatively short channel.

The entrance channel or outer channel extends 11.4 miles off the continental shelf, and has a depth of 67 feet and a width of 906 feet outside of the jetties.

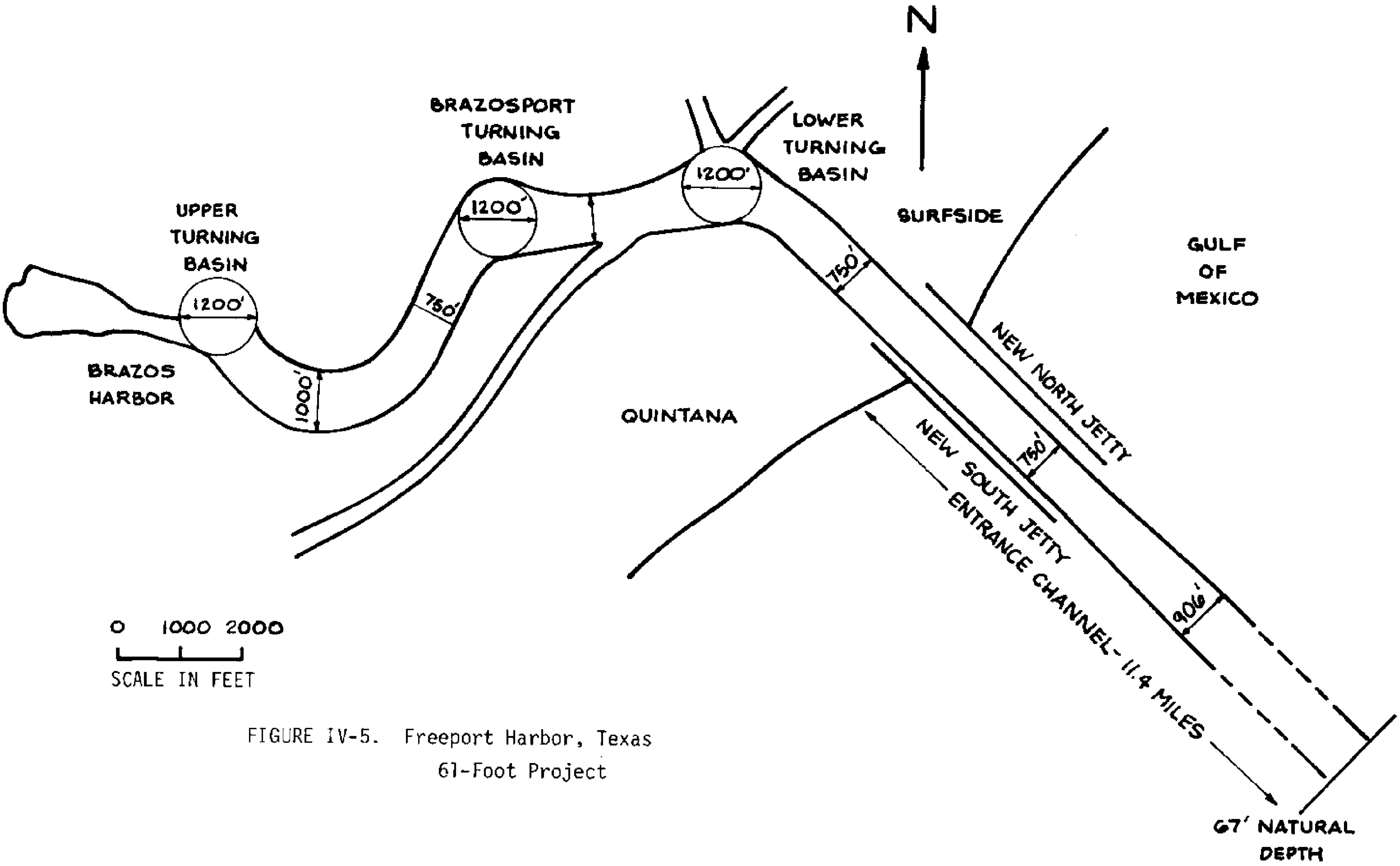


FIGURE IV-5. Freeport Harbor, Texas
61-Foot Project

## Corpus Christi

As in the case of the VLCC terminal at Galveston, the Harbor Island deep-draft port was designed using a vessel of 250,000 to 265,000 DWT. The mooring basin is 1200 feet in width, the turning basin is 2200 feet in diameter, and the inner channel is 876 feet in width, while each has a depth of 72 feet. Extending 10.4 miles on the continental shelf, the outer channel or approach channel measures 1067 feet in width and 80 feet in depth.

To provide an efficient dry bulk handling facility in the Corpus Christi area, the channel from Port Aransas to Port Ingleside must be deepened to 61 feet and widened to 750 feet, in order to accommodate vessels up to 150,000 DWT at Port Ingleside. In addition, the turning basin at Port Ingleside requires widening to approximately 2000 feet at its widest point.

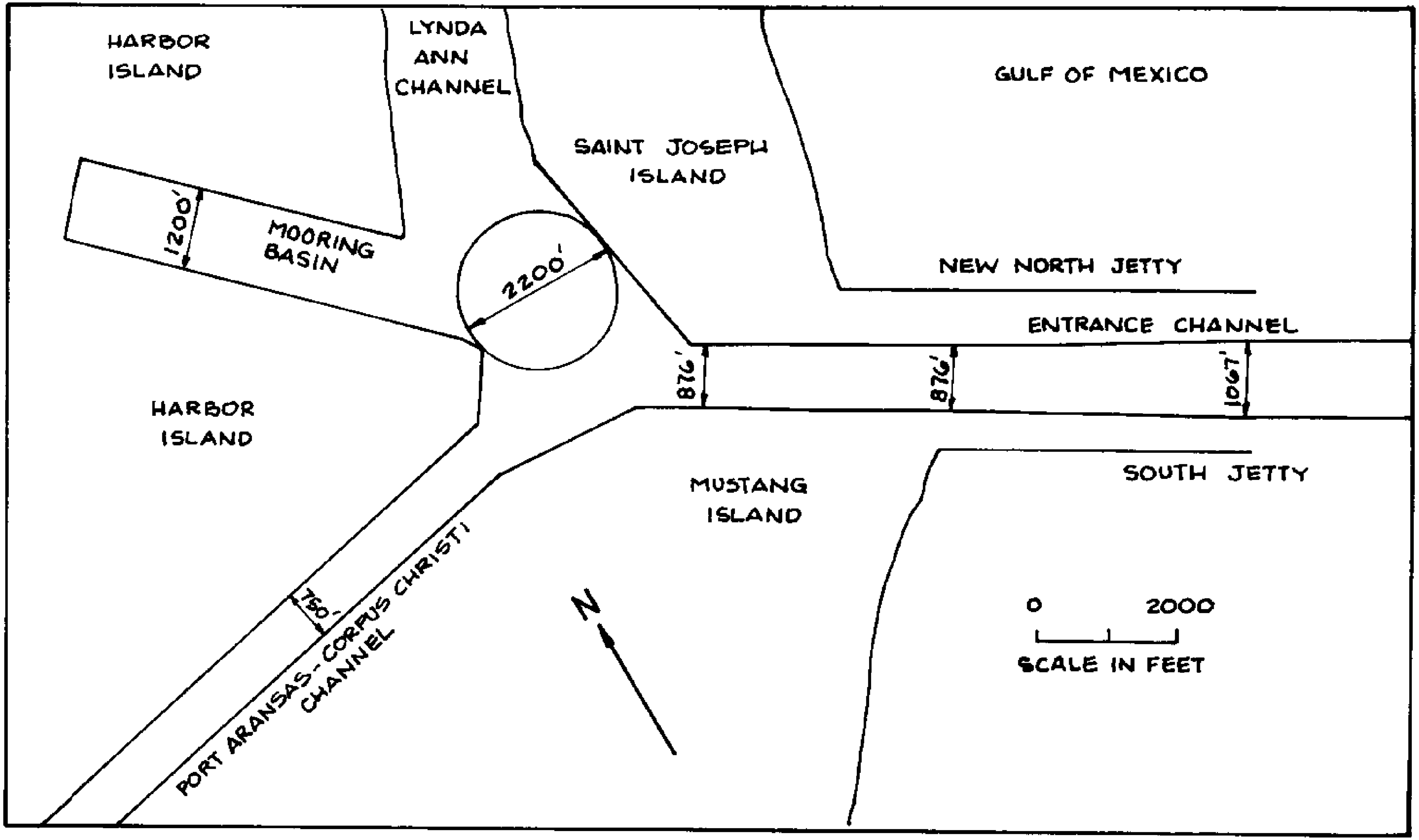


FIGURE IV-6. Harbor Island Deep-Draft Port

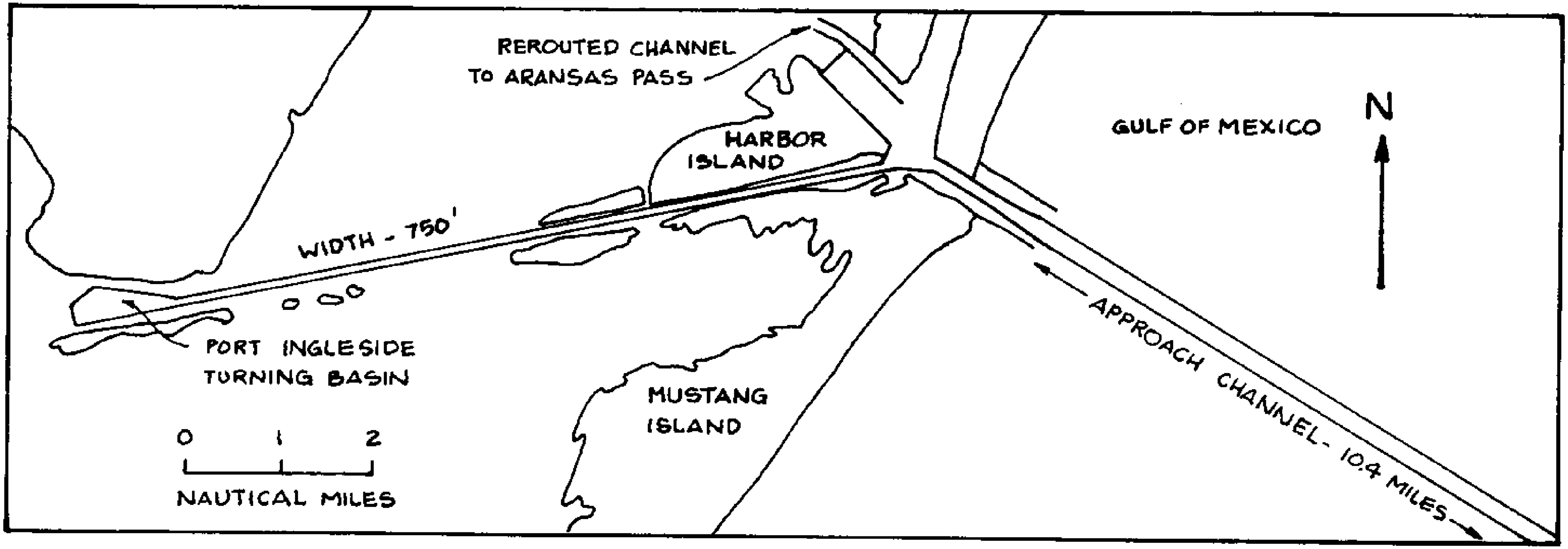


FIGURE IV-7. Corpus Christi Deep-Draft Channel

## V. CONCLUSIONS AND RECOMMENDATIONS

The lack of port facilities capable of handling VLCC's and ULCC's, coupled with a rapidly growing volume of imports and exports of bulk commodities, and projected growth in oil importation and refining levels, make it imperative that port facilities be further improved along the Texas coast. The onshore deepwater port has the advantage of being able to accommodate the larger carriers of bulk commodities as well as large tankers which transport petroleum products. The port improvements for the Texas coast are deemed to be necessary to provide modern and efficient port facilities to shippers, and insure continued economic well-being for the regions served by these ports.

As discussed in Chapter III, the following channel design criteria are necessary to provide for the safe navigation of VLCC's and ULCC's:

1. Channel Width

   Maneuvering Lane(A) = 2.0 × Beam + L sin 10° where L sin 10° applies for channels with strong yawing forces

   Bank Clearance Lane(B) = 1.5 × Beam

   Ship Clearance Lane(C) = 1.0 × Beam

   One-Way Traffic Width = A + 2B

   Two-Way Traffic Width = 2A + 2B + C

2. Channel Depth

   Channel Depth in Inner Channel = f (loaded draft, squat, and minimum keel clearance)

   Channel Depth in Outer Channel = f (loaded draft, effect of pitch and roll, and minimum keel clearance) where effect of roll and pitch = L/2 sin 1°.

In closing, it should be pointed out that a portion of the design work contained in this paper was checked using a mathematical model developed by

Mr. Edward T. Gates of the U.S. Army Corps of Engineers and a graduate student at Texas A&M University. It is recommended that this mathematical model be utilized extensively in any future work dealing with channel design.

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