NEW HAVEN HARBOR
CONNECTICUT
NAVIGATION IMPROVEMENT PROJECT

INTEGRATED FEASIBILITY REPORT AND ENVIRONMENTAL IMPACT STATEMENT

APPENDIX D
ENGINEERING AND DESIGN AND SITE GEOLOGY

New Haven Harbor, CT,

Navigation Improvement Study

Appendix D

Engineering and Design and Site Geology

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Existing Conditions

a. Existing Bathymetry:

For the purposes of this study, the existing conditions of New Haven Harbor is represented from the May 2014 USACE post-dredge hydrographic survey (NHH924_v.xyz). The May 2014 USACE survey does not cover the entire extent of the proposed turning basin. For the small portion of the turning basin, the 2013 Spec Survey was referenced (NHH921_v.xyz). The southern limits of the Entrance Channel are represented by the NCEI mix of multibeam, singlebeam, and sidescan data collected in the year 2000 (H11011.xyz). The NCEI file was converted from Lat/Long decimal degrees to NAD 83 CT State Plane feet. The elevation results were converted from meters to feet (H11101_CTStatePlane_FT.txt).

b. Existing Utilities:

The Cross-Sound Cable Company, LLC (Company) installed a 24 mile long, high voltage, direct current and fiber optic cable system within the seabed of Long Island Sound and New Haven Harbor. The horizontal and vertical location of the cable was provided by Mr. J. Leighfield from the Company after conducting the 2005 cable migration survey OSI Report #13ES036 dated 26 June 2013 (CSCListing_depths-rev3_toACOE2005-06-27.xls). The Company has conducted a cable migration survey every two years since the cable was installed in 2002. Based on the results of the cable migration study, the Company is confident that the cable has not migrated since installation.

The cable generally runs along the centerline of the Federal Navigation Channel within the harbor and was installed at or below -48 feet MLLW along its length except for the reach known as “Area 6/7”. This area is located between buoy R “10” and R “8” north of the harbor breakwaters.

In this location, “Area 6/7”, approximately 700 feet of cable length was installed at or below -41.5 feet MLLW. This “Area 6/7” corresponds to existing stationing 79+00 to 86+00.

The Cross Sound Cable (CSC) alignment exits the existing navigation channel at station 37+00 where the cable is a sweeping arch to the east. The CSC then crosses back across the harbor channel alignment approximately 8,400 feet to the south, beyond the existing channel limits, and beyond the proposed channel extension, at the -46 foot MLLW contour. Along this reach, the cable is installed only four feet below existing grade.

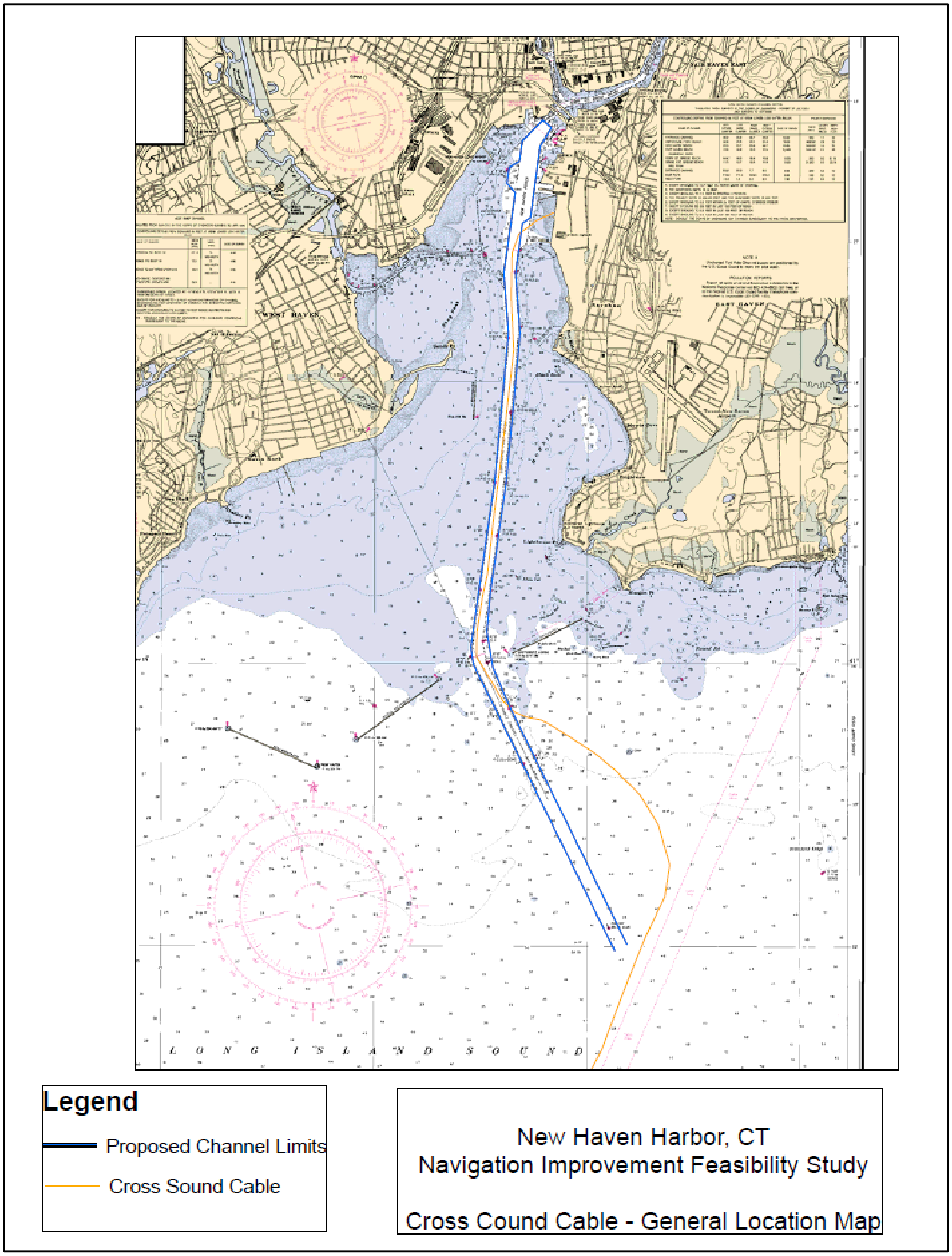


Figure 1 - Location of Cross Sound Cable

c. Existing Site Geology:

Previous explorations were conducted by USACE during the 1970s and 1980s. These results were presented in the 1986 FS report and the 1988 PED report. The boring locations shown on the site plans in section 3.7 and 3.8 of the Geology Attachment are approximate. The boring locations shown on the plans are from two sampling events. The 1988 boring locations were scaled off the figure shown in the

1988 PED Report. The 1988 borings are located sporadically throughout the entire navigation channel, however the majority of borings are located within the vicinity of the bend between the two breakwaters. The 2002 boring locations are from the Cross Sound Cable Project Area 6/7 Geotechnical Investigation Report prepared by Cross Sound Cable Company in October 2002. Area 6/7 is located just north of the bend. The boring locations included in the report were converted from NAD 83 LI Lambert State Plane feet to NAD 83 CT State Plane feet. Borings are depicted on Appendix D Figures 4, 5, 11, 12 and 13, as green dots.

Native materials that will likely be encountered during dredging include organic silts, silty sands with gravel, glacial till, and bedrock. The sediments represent deltaic and glaciolacustrine sediments deposited into Glacial Lake Connecticut, the precursor to Long Island Sound. During investigations in the 1970s and 1980s, soils collected from the inner portions of New Haven Harbor consisted of Holocene, black to gray, organic silt and clay (OH-OL) overlying reddish-brown silty medium-fine sand (SP-SM) and soils collected from the outer portions of New Haven Harbor consisted of black to gray organic silt and gray organic silt (OL-OH), underlain by gray, medium-fine sand, silty-fine sand, and reddish brown silty fine sand (SW-SM), underlain by Till, underlain by bedrock.

Bedrock encountered during borings was described as very hard, unweathered, highly to moderately fractured, gray, coarse to medium grained, gneiss. Rock Quality Designation (RQD) generally ranged from 50% to 90% (fair to good quality) and laboratory results for Unconfined Compressive Strength (UCS) ranged from 12,087 to 20,447 psi (Class B – High Strength intact rock). A 1974 seismic investigation identified bedrock with high seismic velocity, extending north from the 50-ft contour to the channel bend near the breakwater, thence roughly 4,000 feet further north into the harbor. A 1987 seismic investigation confirmed the presence of bedrock near the bend, but the extent of bedrock in the inner harbor was not documented due to the presence of gaseous organic sediments which limit seismic energy penetration.

An approximate bedrock surface was created from the contours shown in section 3.7 of the geology attachment from the 1988 PED report. Additionally, the 2002 borings were analyzed against the contours and were found to be consistent, and therefore not explicitly used in developing the rock surface in the 3D model. In the area of 6/7, the 1989 contours span a 40ft and 45ft contour and the 2002 borings show 42 ft within this area. This is consistent with the contours as the boring location is between the 40 and 45 ft contour. For the basis of preliminary quantities, the bedrock surface was used to estimate quantity of rock removal expected within the bend area. The quantities in rock include an additional two feet of required dredging, as well as a two foot overdepth allowance, per EM 1110-2-1613. Refer to section 3, Quantities, for further explanation regarding quantity calculation methodology.

Refer to Geology Attachment at the end of this document for more information.

II. Channel Design

The design engineer adapted the guidelines outlined in EM 1110-2-1613 dated 31 May 2006 for improving the New Haven Harbor deep-draft navigation project. The design goal is to provide safe, efficient, environmentally sound and cost-effective waterway for ships and other vessels. The guidance presented in EM 2220-2-1613 is based on average navigation condition and situations. During the design process, the design engineer has adapted these guidelines to the local, site-specific conditions of the project.

The key components of a designed channel are its depth, width and alignment which are dictated by the vessels expected to utilize the channel as well as physical conditions of the area. The New Haven Harbor Deep Draft channel design is categorized by four navigation reaches:

1. Entrance Channel
2. Channel Bend
3. Inner Channel
4. Turning Basin

a. Design Vessel:

The design width of the channel will be determined to accommodate the design ship representative of the project. Refer to Economics Appendix for design vessel information. For the purpose of the proposed channel design the vessel dimensions have a beam of 106 feet, length of 700 feet, and a maximum draft of 45 feet. (Note: The selected channel draft will be determined based on the economic evaluation of incremental depths deeper than the currently authorized channel depth of 35 ft MLLW depth.)

b. Alignment:

To minimize the improvement dredging quantity, the alignment of the improved channel generally follows the course of the existing authorized channel. However, the proposed channel alignment aims to improve navigability concerns identified by Mr. Charles Jonas, pilot for New Haven Harbor.

i. Entrance Channel

For the purpose of this study, the alignment of the entrance channel is and will remain controlled by the fixed green range lights located in West Haven (Light List Numbers 24020 (front) and 24025 (rear) at heights 34 and 68 feet above Mean High Water, respectively). The Entrance Channel is naturally deeper to the east, therefore widening the channel to the east may reduce dredge quantity when compared to widening the channel equally to the east and west. Widening the channel to the east would result in the need to move the existing West Haven land based range to the east as well. Preliminary coordination with the U.S. Coast Guard to discuss the process and ability of moving the range took place during the development of the TSP to determine if this is something that should be considered further in PED.

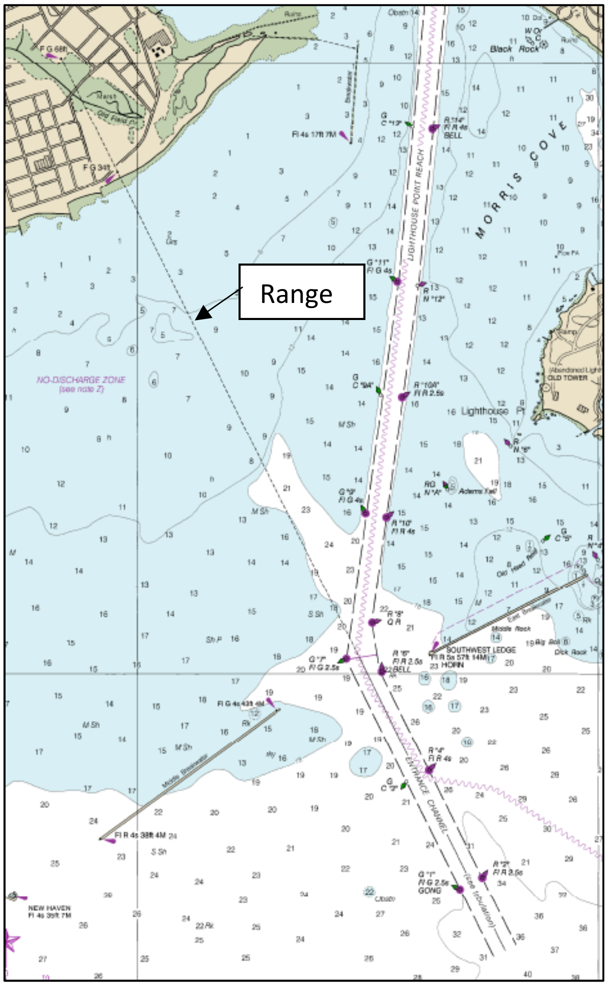


Figure 2 - New Haven Federal Navigation Entrance Channel

ii. Interior Channel

The existing alignment of the interior channel has small bends at existing stations 140+00, 201+00, and 231+00. According to New Haven Harbor pilot, Mr. Jonas, these small bends do not impede navigation. Typically, channel alignments are designed to be straight and limit any unnecessary bends. However, if the existing New Haven Harbor alignment was straightened, the new alignment would cross areas shoaled as much as -3.0 feet MLLW. For the purposes of this study, the proposed inner channel alignment mirrors the existing inner channel alignment to minimize required volume of dredge material to be removed for improvement.

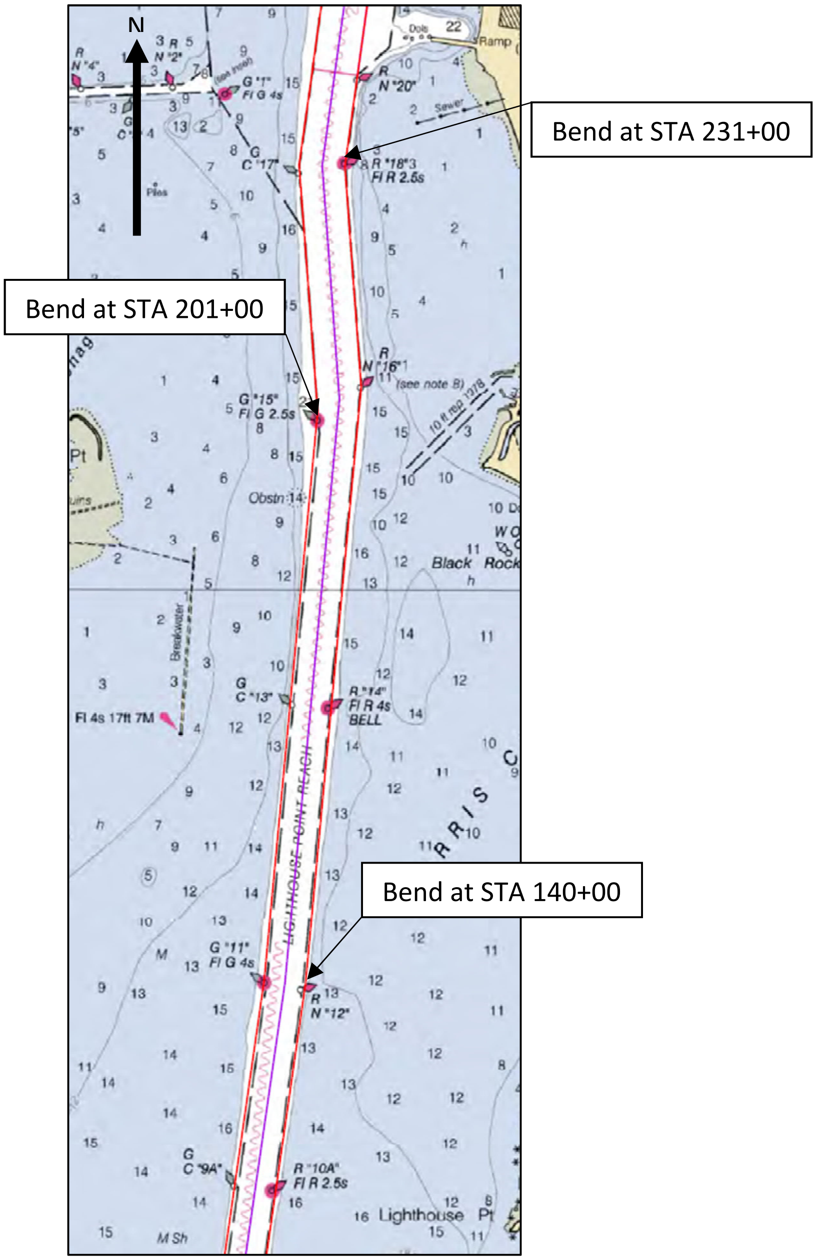


Figure 3 - New Haven Federal Navigation Channel Bends

iii. <u>Bend</u>

According to the New Haven Harbor pilots (Mr. Charles Jonas, personal communication), navigating the bend between the two jetties is challenging. The alignment of the bend is constricted by the two existing jetties, and the 35 degree angle is bound by the entrance and inner channel alignments. The proposed bend alignment will replicate the existing bend. However, improvements will be made in width, length and depth.

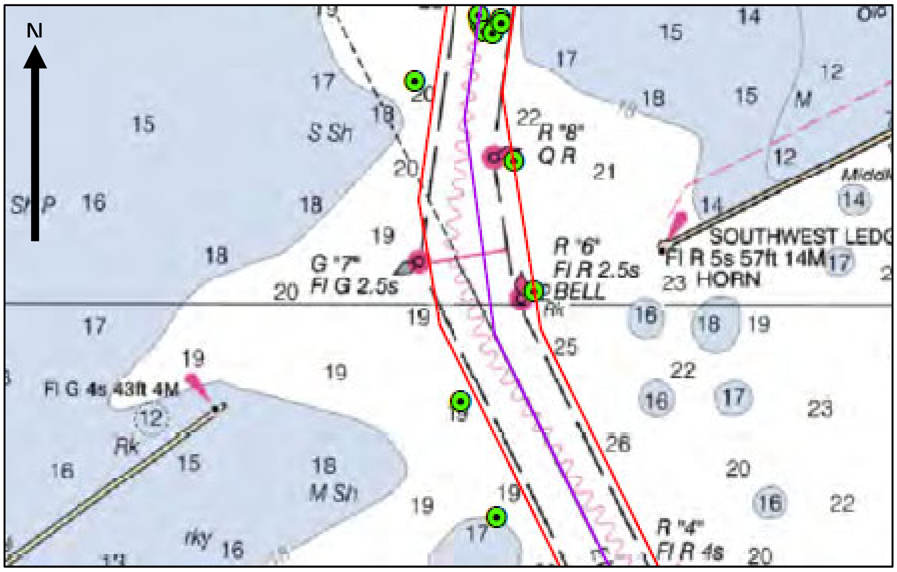


Figure 4 - Proposed New Haven Federal Navigation Channel Bend Widening

iv. Turning Basin

The existing authorized project at New Haven Harbor includes a maneuvering area east of the channel along the developed industrial waterfront, and a turning basin located within and west of the channel below its head. The existing turning basin shown on the existing plans was never formally authorized, having been adopted as an O&M modification, and has since been maintained by the U.S. Army Corps of Engineers. It is recommended that an improved turning basin be formally authorized as part of this project. The majority of the existing maneuvering area located east of the channel is also recommended for improvement to accommodate the needs of the terminals. However, the southern portion of the maneuvering area will not be deepened and will remain at the currently authorized 35 feet, as the only active terminal in this area—PSE&G to the south—currently only accepts barges. The proposed maneuvering area will be improved to facilitate safe movement of larger vessels in the busy upper channel reaches. Improving the maneuvering area is important, so that all terminals have access to the main channel, and terminal owners will maintain the same responsibility in maintaining their berths to at least the newly improved channel depths.

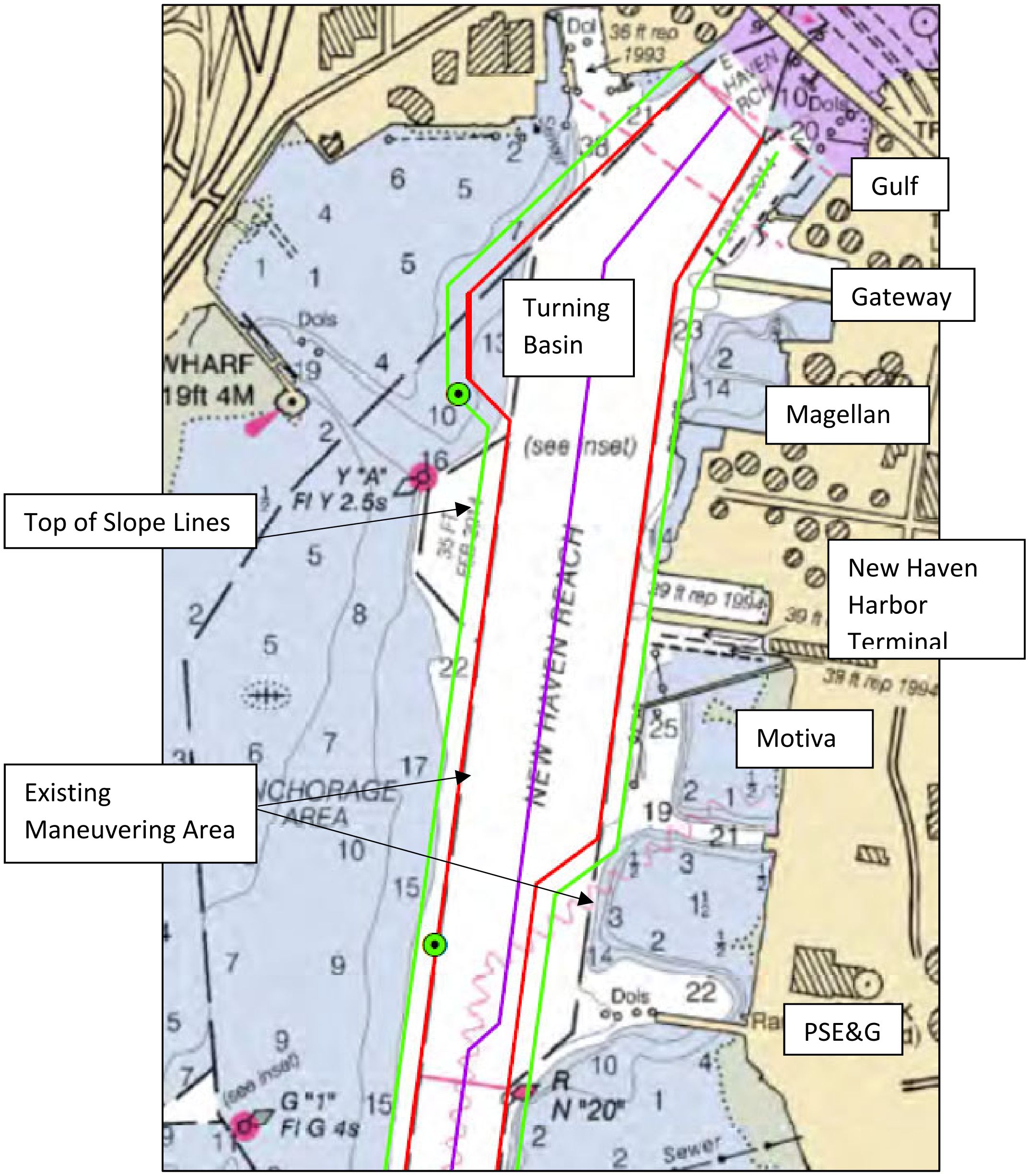


Figure 5 - Proposed New Haven Federal Navigation Turning Basin Changes

c. Channel Width:

This proposed channel width will vary with each navigation component as necessary to ensure the design vessel can make a safe transit under the environmental and operational conditions of each reach. The channel width required depends on the following factors (EM 1110-2-1613 – 31 May 2006):

1. Design ship beam, length and draft
2. Local piloted ship control
3. Channel cross section and alignment

4. River and tidal currents
5. Navigation traffic pattern (one or two-way)
6. Vessel traffic intensity and congestion
7. Wind and wave effects
8. Visibility
9. Quality and spacing of navigation aids
10. Composition of channel bed and banks
11. Variability of channel and currents
12. Speed of design ship

Figure 8.1 and Table 8.2 from EM 1110-2-1613 are key figures when designing channel width. The figures will be referenced as they apply to each reach of the New Haven Harbor improvement project below.

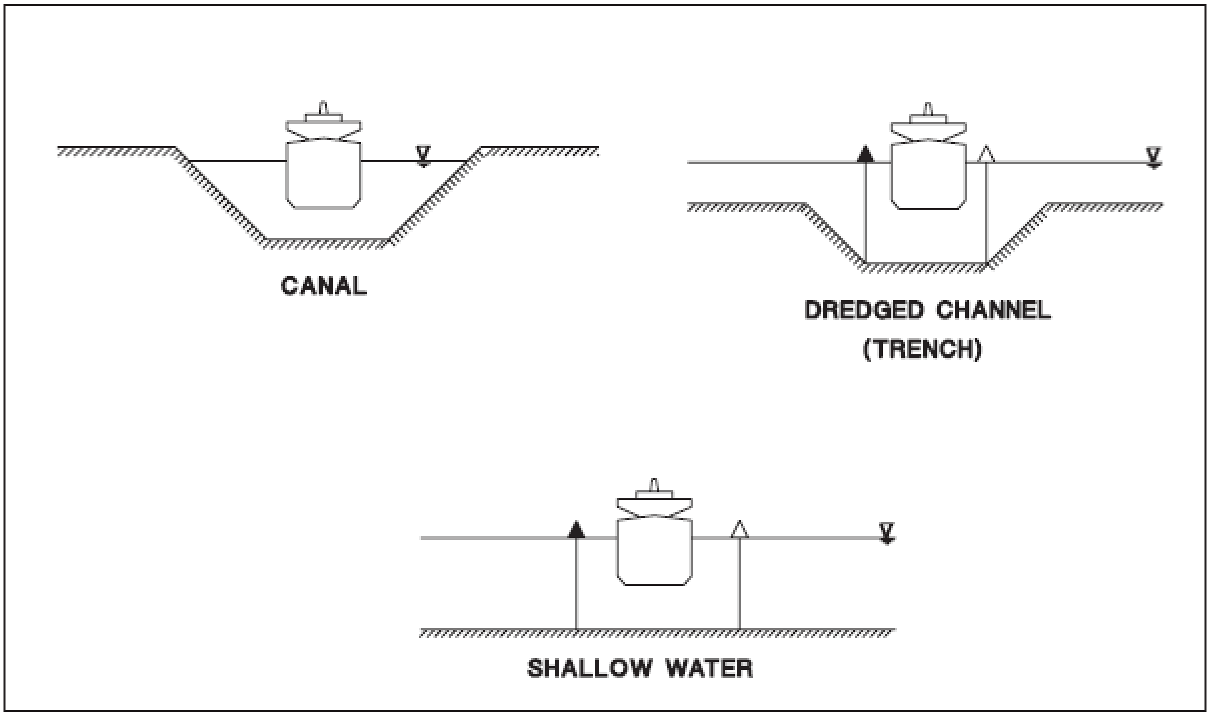
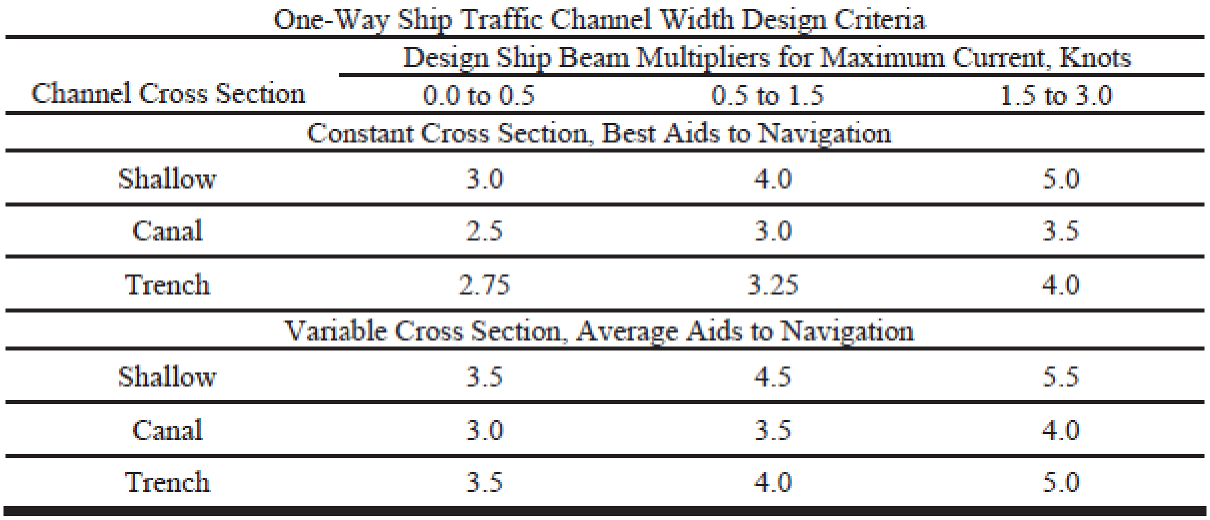


Figure 6 - Figure 8.1 Channel Cross Section (EM 1110-2-1613)



One-Way Ship Traffic Channel Width Design Criteria

Channel Cross Section	Design Ship Beam Multipliers for Maximum Current, Knots		
	0.0 to 0.5	0.5 to 1.5	1.5 to 3.0
Constant Cross Section, Best Aids to Navigation			
Shallow	3.0	4.0	5.0
Canal	2.5	3.0	3.5
Trench	2.75	3.25	4.0
Variable Cross Section, Average Aids to Navigation			
Shallow	3.5	4.5	5.5
Canal	3.0	3.5	4.0
Trench	3.5	4.0	5.0

Figure 7 - Table 8.2 One-Way Ship Traffic Channel Width Design Criteria (EM 1110-2-1613)

Table 8-4 and Figure 8-3 from EM 1110-2-1613 are key figures regarding design channel turn configurations. The figures will be referenced as they apply to the design of the channel bend improvements, described below.

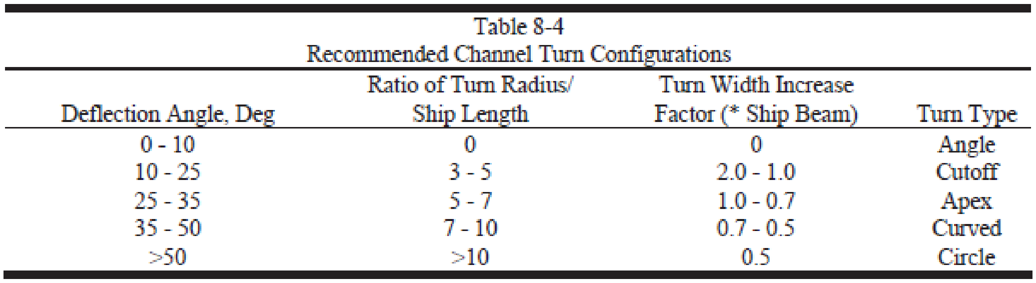


Table 8-4
Recommended Channel Turn Configurations

Deflection Angle, Deg	Ratio of Turn Radius/ Ship Length	Turn Width Increase Factor (* Ship Beam)	Turn Type
0 - 10	0	0	Angle
10 - 25	3 - 5	2.0 - 1.0	Cutoff
25 - 35	5 - 7	1.0 - 0.7	Apex
35 - 50	7 - 10	0.7 - 0.5	Curved
>50	>10	0.5	Circle

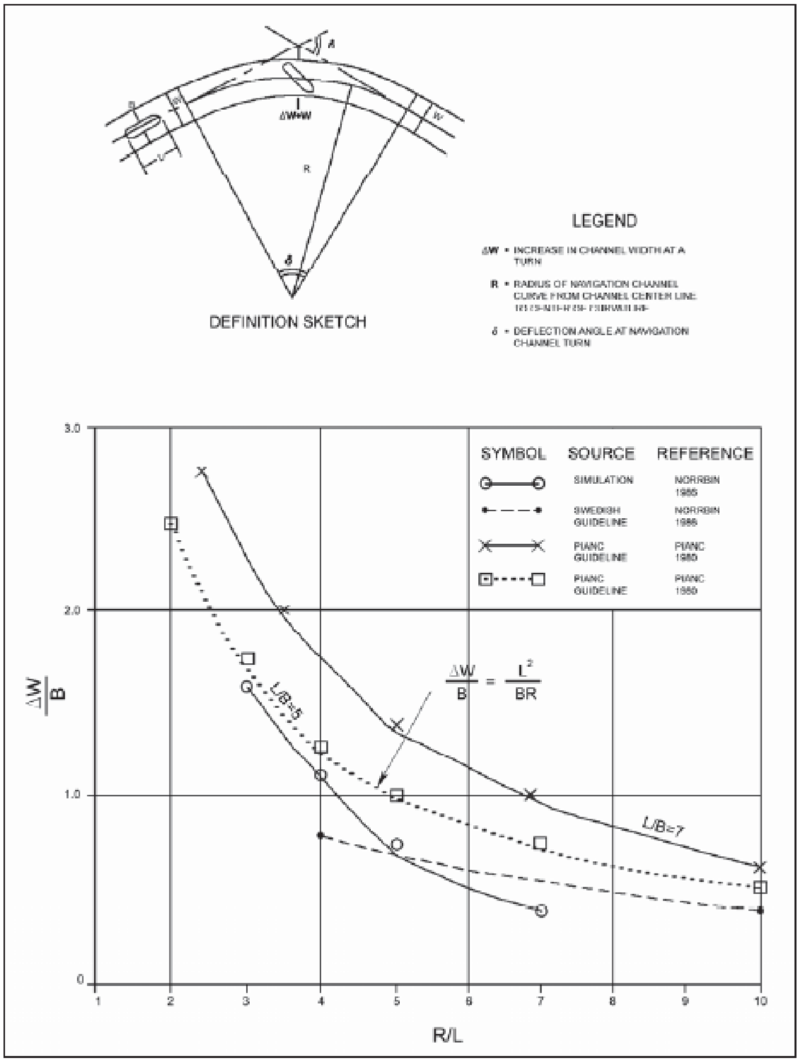
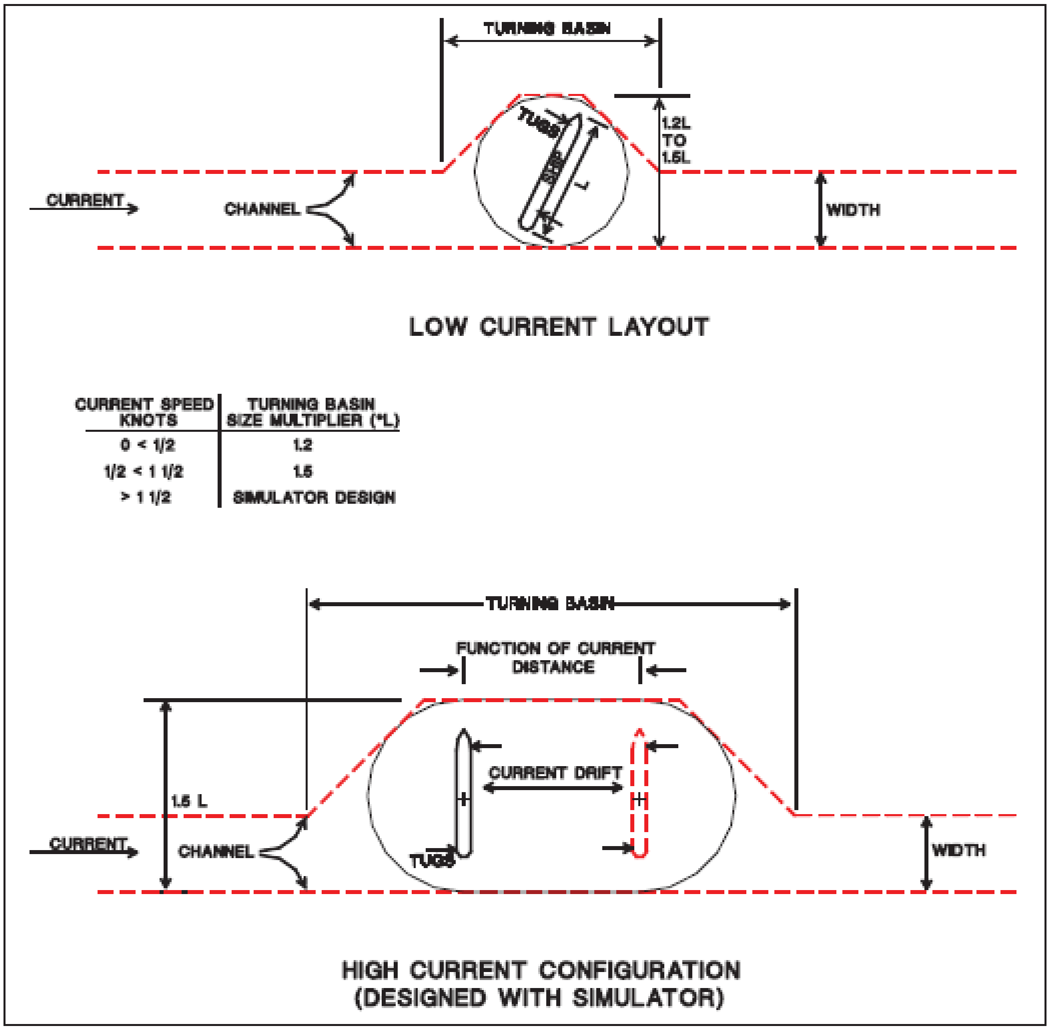


Figure 8-3. Channel width increase in turns

Figure 8 - Figure 8-3 Channel Width Increase in Turns (EM 1110-2-1613)



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

Figure 9 - Figure 9-1 Turning Basin Alternative Designs (EM 1110-2-1613)

i. Interior Channel:

The interior channel provides harbor access from the entrance channel to the port area. The traffic pattern in the interior channel is currently one-way, and one-way traffic is anticipated in the future.

The channel cross section of the inner channel is defined in Figure 8.1 as “Trench.” Trench is defined as a dredged channel, with submerged banks on each side, usually provided with range markers and channel edge buoys or beacons.

The aids to navigation are considered excellent in the interior channel. Lights are located on every other buoy. For design, the maximum current within the interior channel is conservatively estimated at 2.0 knots. Refer to the Coastal Engineering section for more current and tide information. Tug assistance is also required in order to navigate the inner harbor channel. For the purposes of the TSP, the design assumed one tug assist within the interior channel. However, during the 7 November 2017 coordination meeting, the New Haven Harbor Gateway Terminal, including their tug operator, indicated that two tugs are typically utilized within the interior channel. Updates to the design and quantities were incorporated in Section V. to reflect the pilot’s input during the Optimization Phase of the project.

Given the width design criteria outlined above in Table 8.2, the inner harbor channel width is calculated with the following assumptions:

One-Way Ship Traffic
Channel Cross Section: Trench
Maximum Current, Knots: 1.5 to 3.0
Constant Cross Section Best Aids to Navigation
BEAM MULTIPLIER: 4.0
Beam: 106 feet x 4.0 = 424 feet
Add One Tug: 424 feet + 48 feet = 472 feet
INNER CHANNEL WIDTH: 500 FEET

ii. Entrance Channel:

The maneuverability of ships in a given navigation situation is influenced by environmental forces and resulting movements caused by the speed and direction of river and tidal currents, wind, waves and channel banks. Given these influences, the maneuverability of the entrance channel will vary greatly from the inner channel. Width allowances in excess of the interior channel width to account for wave effects on horizontal ship motion is difficult to estimate.

For the purposes of developing the TSP, Table 8.2 was referenced to calculate the entrance channel width. Navigation in the entrance channel is adversely affected by strong and variable tidal currents, rough seas and swell, breaking waves and wind. New Haven entrance channel is known to have frequent fog which will cause visibility problems. In order to take poor visibility into account, Aids to Navigation were determined as average. The maximum current is estimate as 2.0 knots (Refer to Coastal Engineering Appendix for more information).

The channel cross section of the entrance channel is defined in Figure 8.1 as "Trench." Trench is defined as a dredged channel, with submerged banks on each side, usually provided with range markers and channel edge buoys or beacons. For the purposes of the TSP, the design assumed one tug assist at the exterior channel. However, during the 7 November 2017 coordination meeting the New Haven Harbor Gateway Terminal, including their tug operator, indicated that tugs are not utilized within the exterior channel. Instead, the tugs meet incoming vessels after the channel bend at the breakwaters in the vicinity of buoys G "9" and R "10." Updates to the design and quantities were incorporated to reflect the pilot's input during the Optimization Phase of the project, as shown in Section 5, Ship Simulation Refinements.

Since the improvement proposed involves deepening the channel, the entrance channel length was extended approximately 2,200 feet to reach the new proposed channel depth.

Given the width design criteria outlined above in Table 8.2, the entrance channel width is calculated with the following assumptions:

One-Way Ship Traffic
Channel Cross Section: Trench
Maximum Current, Knots: 1.5 to 3.0
Constant Cross Section Average Aids to Navigation
BEAM MULTIPLIER: 5.0

Beam: 106 feet x 5.0 = 530 feet
Add One Tug: 530 feet + 48 feet = 578 feet
ENTRANCE CHANNEL WIDTH: 600 FEET

iii. Channel Bend at Breakwaters:

Channels with bends are more difficult to navigate compared with straight reaches because of reduction in site distance, reduced effectiveness of aids to navigation, changing channel cross-sectional area, and greater effects from varying current and bank suction forces. The width of the ship path is dependent on the following (EM 1110-2-1613 – 31 May 2006):

1. Ship yaw angle while turning
2. Length and beam of the ship
3. Ship rudder angle
4. Possible use or nonuse of kick turning by the pilot
5. Location and spacing of aids to navigation in the turn.
6. Local current and other environmental conditions.

The existing channel bend at New Haven is 35 degrees and passed between the middle and eastern breakwaters. The channel cross section of the bend is asymmetric. This means that the channel cross section has different bank conditions on each side of the channel centerline. The banks are very steep and strong bank forces effects are experienced. Passing ships tend to drift away from channel centerline toward the steep bank. The bank conditions are even stronger when the larger draft ships are forced to enter New Haven Harbor on a rising tide, as they are when using tidal assistance to ensure adequate depth under keel. In this case, the ships are forced to navigate through the bend under high current conditions.

The swept path of a turning ship is dependent mainly on the channel turn radius and the ship length. Figure 8-3 from EM 1110-2-1613 presents a definition sketch of the relevant variables and a plot of channel width increase curves. The deflection angle of the channel turn may also be a factor resulting from the piloting and ship control difficulty while maneuvering a ship around a channel turn. The effects of bank suction at the channel bend have been noted by the pilots and are also very important to the design of the turn. However, the recommended turn design does not include bank effects, but the design of the turn was optimized based on the ship simulation in February 2018 (refer to section 5, Ship Simulation Refinements). Table 8-4 summarizes the recommendations on the channel turn configurations including channel width increases in the turn. The table includes recommended turn-to-ship length ratios as a function of turn deflection angles.

Given the width design criteria outlined above in Table 8.4, the bend width is calculated with the following assumptions:

Deflection Angle = 35 degrees → For a deflection angle 25-35 degrees
Ratio of Turn Radius/Ship Length = 4900 ft/700ft = 7 → For a Turn Width Increase Factor of 0.7
Turn Width Increase Factor* Beam = 0.7 * 106 feet =74.2;
Width + 74.2 = 600 +74.2 = 674.2 → Round up to 700’
BEND WIDTH: 700 FEET

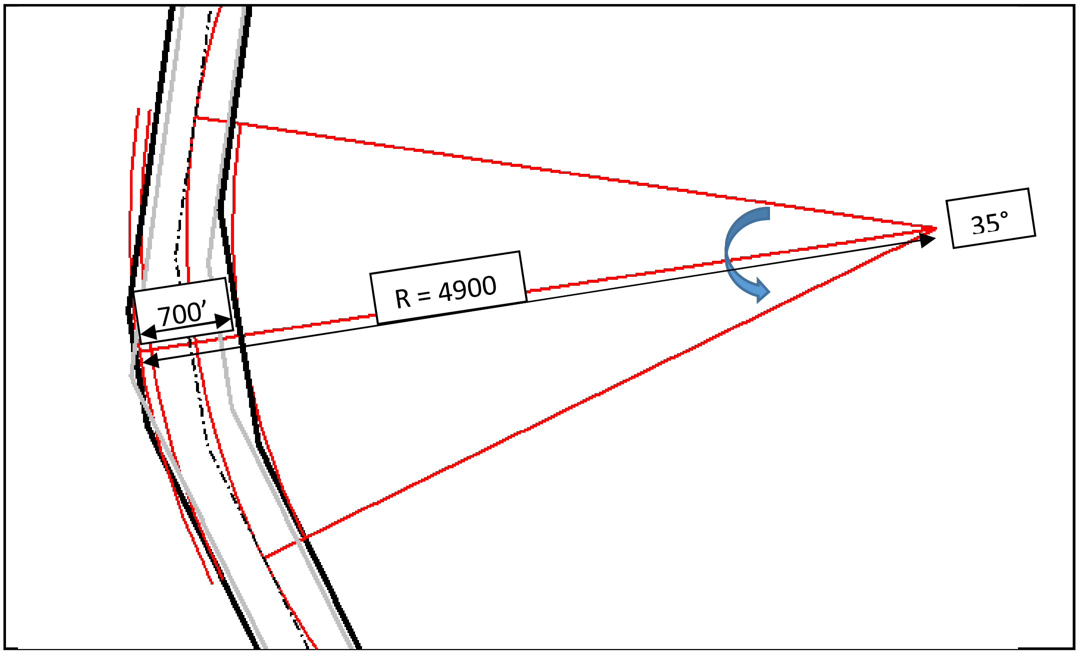


Figure 10 - Proposed New Haven Federal Navigation Channel Bend Design

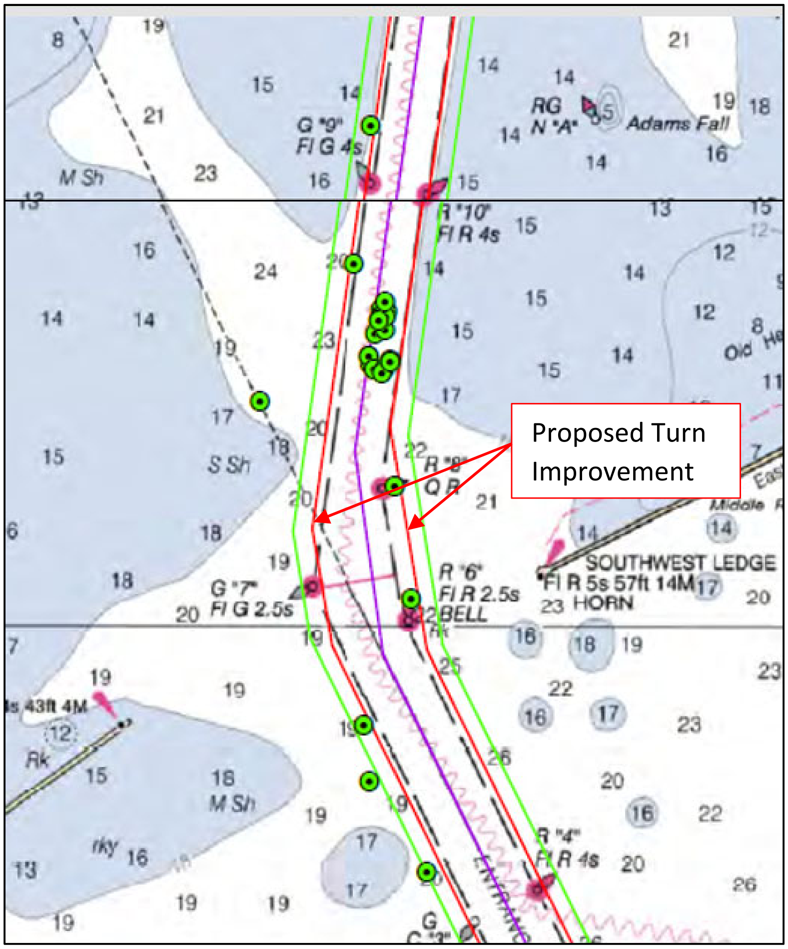
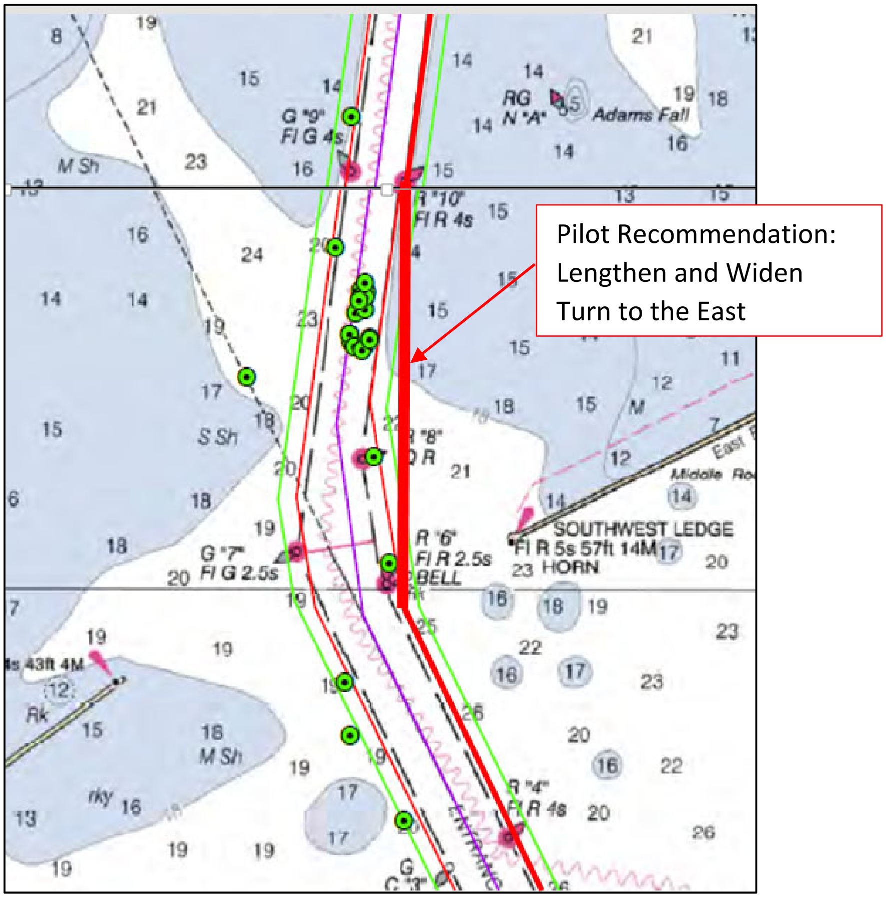


Figure 11 - Proposed New Haven Federal Navigation Channel Bend Improvement

A ship simulation reconnaissance trip was conducted at New Haven Harbor by ERDC and New England District on 7 November 2017. This meeting was attended by representative of the Connecticut Pilots, Gateway Terminal representatives including their tug operator, and the New Haven and State of Connecticut Port Authorities. During the meeting, the New England District described the alignment and width of the proposed improved turn (figure above). The Pilots recommended additional improvements to the turn be considered. The pilots used previous navigational records to show the strong bank forces in effect at the turn. In order to provide additional maneuverability within the turn, the pilots recommend lengthening the proposed turn on the east side from the R "6" buoy to the R "10" buoy as shown below. The ERDC ship simulation will test and verify the pilot's channel bend improvement recommendation. The design and quantities were updated based upon the results of the ship simulation during the Optimization Phase of the project, refer to Section 5, Ship Simulation Refinements.



Pilot Recommendation: Lengthen and Widen Turn to the East

Figure 12 - New Haven Federal Navigation Channel Bend - Pilot Recommendation

iv. <u>Turning Basin:</u>

According to EM 1110-2-1613, 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. If currents are 1.5 knots or more, the turning diameter should be at least 1.5 times the length of the design ship. 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 times the ship length. The ends will make angles of 45 degrees or less with the adjacent edge of the channel. Modification of the shape are acceptable to permit better sediment flushing characteristics to accommodate local operation considerations.

Given the width design criteria outlined above in Table 9.1, the Turning Basin diameter is calculated with the following assumptions:

Low Current Layout: 1.5 Knots
Turning Basin Size Multiplier: 1.5
Length of Ship 700 feet x 1.5 = 1050 feet → round up to 1100 feet
TURNING BASIN DIAMETER: 1100 FEET

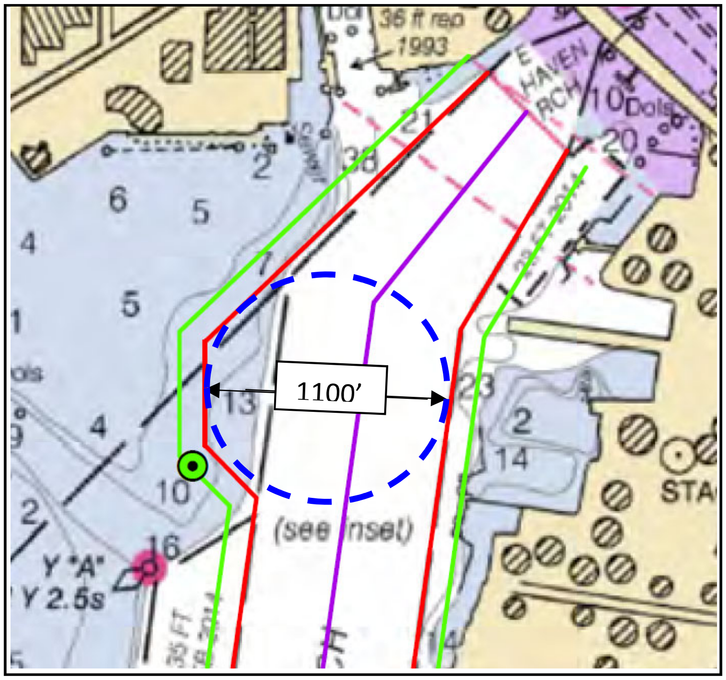


Figure 13 - Proposed New Haven Federal Navigation Turning Basin Design

d. Channel Depth:

Channel depth "should be adequate to safely accommodate ships with the deepest drafts expected to use the waterway" according to EM 1110-2-1613. This statement not only addressed the physical characteristics of the design vessels but the economic projects of usage. See the economics appendix for discussion of the current and future vessels. The physical concerns are the draft of the vessel and how it operates when underway. Vessels will ride deeper in the water when underway than when at berth. The term for this is "squat" and conditions affecting the amount of squat can be water depths or channel cross-section. Ships also are impacted by the wave conditions and tend to roll, pitch, or heave. For instance, a long vessel can pitch forward or back and increase the depth required at the bow or stern by a foot or more in addition to the swell or squat additives. The EM provides technical guidance related to the design depth and this is considered by including under-keel clearance* in the economics calculations. The alternatives analysis uses an economic approach of examining the costs of various channel depths compared to the economic benefits. The existing authorized channel depth is 35 feet. Channel alternatives examined began at 37 feet MLLW design depth and went to a 42 feet MLLW design depth. Provision of 2 feet of overdepth is standard practice in estimating dredging quantities for mechanical dredging operations. In calculating the quantities for the alternatives, 2 feet of allowable overdepth (OD) was included in the dredging quantities for each alternative, except in areas where hard bottom (bedrock) was anticpated to be encountered. In those locations there is an additional 2 feet of required dredging along with a 2 foot overdepth allowance, per EM 1110-2-1613. For example, if the authorized depth of the channel was -40 MLLW, then the required depth in hard bottom locations would be -42 MLLW, and the overdepth allowance would be -44 MLLW.

*The New Haven Harbor pilots require at least 2 feet of under-keel clearance for harbor transit, and an additional 2 feet to account for squat and other vessel motion under normal conditions. Ship owners and underwriters may require additional clearance for certain vessels and cargos.

e. Cable Cover Requirements:

The required cable depth of -48 MLLW was prescribed per the NED Engineering Regulation, "Setting Pipeline and Cable Cover Requirements in Navigable Waters and Navigation Channels." The policy states that bottom cover associated with the initial installation of pipelines and cables under navigable waters and navigation channels shall be 48 inches in soil. These minimum bottoms cover requirements for pipelines and cables shall be measured from the maximum depth of dredging to the top of utility. In this case, the assumed maximum depth of dredging took into consideration future deepening of the channel to -40 MLLW, along with two feet of allowable over depth, and two feet of advanced maintenance. Therefore, maximum depth of dredging would be -44 MLLW, which would set the required depth of the cable at -48 MLLW.

III. Quantities

a. Total Dredge Quantities:

Using the hydrographic surveys from 2000 and 2014, the 1988 PED Report bedrock contours, and a proposed channel alignment with the widths identified above, quantities of material to be removed were developed using 3D models in Microstation’s InRoads. The 1988 bedrock contours were created with both geophysical data and borings and rock is anticipated to be limited to the ares of the channel in the vicinity of the bend. The 3D model is an evaluation tool used in Bentley InRoads to compute cut and fill volumes. Cut and fill volumes obtained with this tool are calculated between two triangulated surfaces, or Digital Terrain Models (DTMs), by projecting the triangles from an existing surface onto a design surface and then computing the volume of each of the resultant prismoids. The volume calculated using the Triangle Volume method is the exact mathematical volume between the two selected surfaces. The accuracy of the results of the 3D model is limited only by the accuracy of the DTMs that are used. The volume calculation methodology utilized all available data and side slopes were assumed to be 3H:1V for channel design and volume calculations.

Table 1 - New Haven Federal Navigation Channel - Improvement Quantities

37-FT PROJECT	**Dredging Quantities (CY)**			**Dredging Areas (SF)**
	Cut	2-FT OD	Total	
Maintenance Dredging (EL 35):				35' Contour
Entrance Channel	0	4,000	4,000	0
Bend (Maintenance STA 45+00 to 85+00)***	200	4,300	4,500	Side Slopes (avg 2ft cut)
Interior Channel	1,500	48,600	50,100	Side Slopes (avg 2ft cut)
Maneuvering Area (within Improved footprint)	1,300	49,800	51,100	Side Slopes (avg 2ft cut)
Turning Basin (Located in Different location than Improved Turning Area)				
Total Maintenance Dredging	3,000	106,700	109,700	
Improvement Dredging (EL 37):				37' Contour*
Entrance Channel**	82,300	97,700	180,000	844,000
Bend (Ordinary Material)	10,900	236,700	247,600	619,400
Bend (Rock) (Required Cut to El 39)	4,400	2,200	6,600	39,600
Interior Channel	619,600	548,800	1,168,400	4,613,700
Maneuvering Area	4,100	272,800	276,900	3,415,300
Turning Basin (Located in 15' Anchorage)	209,500	23,400	232,900	228,100
Total Improvement Dredging	930,800	1,181,600	2,112,400	9,760,100
Total All Dredging	**933,800**	**1,288,300**	**2,222,100**	Improvement Areas include Maintenance Areas

*Rock "Dredge Area" measured from 39' Contour, per EM 1110-2-1613 for required rock dredging

**Used H11101 Survey for Entrance Channel Extension Quantities

*** Approx. 100 CY of Rock within Maintenance Bend Limits at EL -37. This quantity was subtracted from Maintenance Quantity

38-FT PROJECT	**Dredging Quantities (CY)**			**Dredging Areas (SF)**
	Cut	2-FT OD	Total	
Maintenance Dredging (EL 35):				35' Contour
Entrance Channel	0	4,000	4,000	0
Bend (Maintenance STA 45+00 to 85+00)***	200	4,300	4,500	Side Slopes (avg 2ft cut)
Interior Channel	1,500	48,600	50,100	Side Slopes (avg 2ft cut)
Maneuvering Area (within Improved footprint)	1,300	49,800	51,100	Side Slopes (avg 2ft cut)
Turning Basin (Located in Different location than Improved Turning Area)				
Total Maintenance Dredging	3,000	106,700	109,700	
Improvement Dredging (EL 38):				38' Contour*
Entrance Channel**	123,000	137,500	260,500	1,509,500
Bend (Ordinary Material)	198,000	101,500	299,500	667,500
Bend (Rock) (Required Cut to El 40)	6,600	9,500	16,100	52,400
Interior Channel	856,500	668,600	1,525,100	4,798,600
Maneuvering Area	129,500	301,600	431,100	3,451,500
Turning Basin (Located in 15' Anchorage)	221,100	23,600	244,700	228,100
Total Improvement Dredging	1,534,700	1,242,300	2,777,000	10,707,600
Total All Dredging	**1,537,700**	**1,349,000**	**2,886,700**	Improvement Areas include Maintenance Areas

*Rock "Dredge Area" measured from 40' Contour, per EM 1110-2-1613 for required rock dredging

**Used H11101 Survey for Entrance Channel Extension Quantities

*** Approx. 100 CY of Rock within Maintenance Bend Limits at EL -37. This quantity was subtracted from Maintenance Quantity

39-FT PROJECT	**Dredging Quantities (CY)**			**Dredging Areas (SF)**
	Cut	2-FT OD	Total	
Maintenance Dredging (EL 35):				35' Contour
Entrance Channel	0	4,000	4,000	0
Bend (Maintenance STA 45+00 to 85+00)***	200	4,300	4,500	Side Slopes (avg 2ft cut)
Interior Channel	1,500	48,600	50,100	Side Slopes (avg 2ft cut)
Maneuvering Area (within Improved footprint)	1,300	49,800	51,100	Side Slopes (avg 2ft cut)
Turning Basin (Located in Different location than Improved Turning Area)				
Total Maintenance Dredging	3,000	106,700	109,700	
Improvement Dredging (EL 39):				39' Contour*
Entrance Channel**	186,100	171,700	357,800	1,777,600
Bend (Ordinary Material)	247,700	132,000	379,700	1,183,700
Bend (Rock) (Required Cut to El 41)	10,600	12,900	23,500	110,800
Interior Channel	1,168,400	738,600	1,907,000	6,640,500
Maneuvering Area	276,900	312,800	589,700	3,451,500
Turning Basin (Located in 15' Anchorage)	232,900	23,700	256,600	228,100
Total Improvement Dredging	2,122,600	1,391,700	3,514,300	13,392,200
Total All Dredging	**2,125,600**	**1,498,400**	**3,624,000**	Improvement Areas include Maintenance Areas

*Rock "Dredge Area" measured from 41' Contour, per EM 1110-2-1613 for required rock dredging

**Used H11101 Survey for Entrance Channel Extension Quantities

*** Approx. 100 CY of Rock within Maintenance Bend Limits at EL -37. This quantity was subtracted from Maintenance Quantity

40-FT PROJECT	**Dredging Quantities (CY)**			**Dredging Areas (SF)**
	Cut	2-FT OD	Total	
Maintenance Dredging (EL 35):				35' Contour
Entrance Channel	0	4,000	4,000	0
Bend (Maintenance STA 45+00 to 85+00)***	200	4,300	4,500	Side Slopes (avg 2ft cut)
Interior Channel	1,500	48,600	50,100	Side Slopes (avg 2ft cut)
Maneuvering Area (within Improved footprint)	1,300	49,800	51,100	Side Slopes (avg 2ft cut)
Turning Basin (Located in Different location than Improved Turning Area)				
Total Maintenance Dredging	3,000	106,700	109,700	
Improvement Dredging (EL 40):				40' Contour*
Entrance Channel**	278,800	182,700	461,500	2,682,700
Bend (Ordinary Material)	309,100	146,800	455,900	1,485,500
Bend (Rock) (Required Cut to El 42)	16,100	16,600	32,700	147,300
Interior Channel	1,525,100	774,200	2,299,300	7,691,600
Maneuvering Area	431,100	319,500	750,600	3,451,500
Turning Basin (Located in 15' Anchorage)	244,700	23,900	268,600	228,100
Total Improvement Dredging	2,804,900	1,463,700	4,268,600	15,686,700
Total All Dredging	**2,807,900**	**1,570,400**	**4,378,300**	Improvement Areas include Maintenance Areas

*Rock "Dredge Area" measured from 42' Contour, per EM 1110-2-1613 for required rock dredging

**Used H11101 Survey for Entrance Channel Extension Quantities

*** Approx. 100 CY of Rock within Maintenance Bend Limits at EL -37. This quantity was subtracted from Maintenance Quantity

b. Sand Quantities:

Results from the most recent 2017 survey, and previous subsurface investigations conducted in 1977, 1988, and 2002 were analyzed to estimate the quantity of sand within the proposed dredge prism. Refer to the Geology Attachment at the end of this document for more information on the results of the subsurface investigations.

The borings were interpreted and classified with the ASTM D2487 soil classification system. Soils classified as SW, SP, SM and SC were compiled and treated as ‘sand’ for the purposes of the quantity estimate. The top and bottom elevation of the sand horizon was tabulated at each boring location. The sand horizon elevation between boring locations was qualitatively estimated. Utilizing the existing boring information and utilizing best estimates between borings, the general sand horizon was estimated for each dredge reach. The shellfish creation area will be used to place material that is predominantly sand (>65-70%) and the area does not require narrowly graded sand.

As a general estimate, the team assumed that all quantity dredged from the entrance channel is sandy. This assumption is supported by the USGS sidescan sonar data presented in the Geology Attachment and the deltaic glacial environment. Within the bend area, a portion of the dredge area is considered sand. The interior channel, maneuvering area and turning basin does not have sand. Utilizing these generalizations, assume that 12% of the total dredge quantity will be sand.

Total Sand Quantity for Proposed Depths:

Table 2 - New Haven Federal Navigation Channel - Improvement Sand Quantities

Proposed Project	Total Quantity (CY)	Sand Quantity (CY)
37-FT Project	2,222,100	266,700
38-Ft Project	2,889,700	346,800
39-Ft Project	3,624,000	434,900
40-Ft Project	4,378,300	525,400

IV. Disposal Areas

a. Central Long Island Sound Disposal Site Historic Mound Restoration

The main disposal site recommended for the New Haven Deep Draft Improvement Project is the Central Long Island Sound (CLIS) Disposal Site. New Haven maintenance dredge material has been placed at CLIS Disposal Site from 1964 to the most recent maintenance dredging in 2014, and is located approximately 10.5 miles from the New Haven Turning Basin.

There are additional benefits of utilizing the improvement dredging material at CLIS Disposal Site. The improvement dredge material can be used to restore historic mounds within the disposal site. Refer to the environmental appendix for more information.

b. Morris Cove Borrow Pit

An October 2003 DAMOS (Disposal Area Monitoring System) report examined a potential disposal area for material dredged in New Haven Harbor. A small, man-made bottom depression, or borrow pit, located in Morris Cove in New Haven was created several decades ago when sand and gravel were mined for use as fill for the construction of Interstate Highway 95 through New Haven. The sediments were excavated along a north-northwest to south-southeast axis, resulting in a submerged pit approximately 650 feet wide and 2450 feet in length. Currently, water depths in the vicinity range from approximately 10 feet on the harbor substrate to 30 feet within the borrow pit. A large area of the pit has depths that are approximately 11 to 20 feet deeper than the surrounding harbor bottom, suggesting that the pit could contain a substantial amount of additional dredged material.

During January and May 2000, an estimated total of 18,500 cy of sediment dredged from the U.S. Coast Guard Base in East Haven, Connecticut, was placed in the borrow pit. The rationale for the placement of dredged sediments within the Morris Cove borrow pit was to begin the process of re-establishing flat, uniform bottom topography and promoting improved water quality within Morris Cove. The USCG surveyed Morris Cove prior to and following the disposal. Pre-placement survey was collected in 1998 and the post-placement survey was collected in 2000. The combination of these surveys were used as the existing bathymetric conditions at Morris Cove (EXIST-SURF-1988-2000-MORRIS-COVE-MERGED.dtm).

The Morris Cove borrow pit has reportedly become a sink for organic detritus in New Haven Harbor. While the predominance of sandy substrate in the vicinity of the borrow pit is indicative of the influence of wave and tidal current energy acting on the bottom sediments, the borrow pit constitutes a distinct depression that may enhance deposition of fine-grained material. The pit's distinct margins tend to limit the flow within the pit and the volume of water exchanged.

The capacity of the Morris Cove borrow pit for the potential deposition of dredged material in the future remains quite large. Approximately 623,000 CY of silty dredged material is recommended to be strategically placed within the pit to fill it to a depth of -11.5 feet MLLW (MORRIS-COVE-SURFACE-AT-EL-11_5), roughly even with the surrounding ambient bottom.

New England District discussed potential dredge material disposal locations with David Carey of the Connecticut Department of Agriculture on December 20, 2017. Mr. Carey agrees that filling Morris Cove with suitable silty material is a beneficial re-use of dredge material, however he further suggests that the final finished surface should be a sandy material. In order to encourage shellfish production, Mr. Carey recommends capping Morris Cove with sandy material after the silty dredge material has been placed. The practicality of capping Morris Cove with sandy material will be further evaluated during the Optimization Phase of the project.

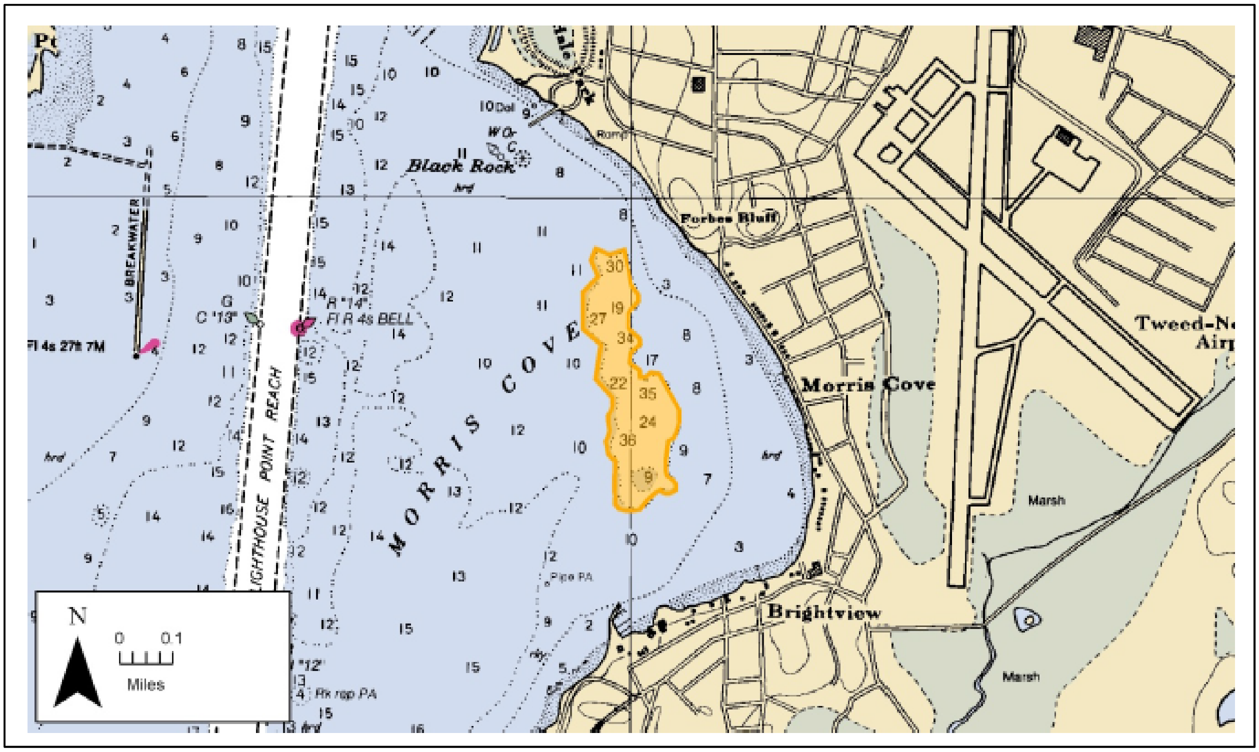


Figure 14 - Morris Cove Borrow Pit Disposal Area

c. East Breakwater Oyster Bed

New England District Staff and Mr. David Carey of the Connecticut Department of Agriculture, Bureau of Aquaculture identified the area behind the east breakwater as a potential new oyster bed area. The area behind the breakwater ranges from elevation -13 feet MLLW to -25 feet MLLW. The existing conditions behind the east jetty are represented by the results of the 2017 USACE sidescan survey effort. The final surface used to represent the existing conditions behind the east jetty is E_BW_ShellFishArea.dtm.

Mr. Carey recommended the placement area identified in the figure below. According to Mr. Carey, the final elevation of the oyster bed is not as important as the substrate of the oyster bed. The existing substrate within this area is silty, and in order for oyster bed establishment, the substrate must be a sandy material. The disposal recommendation for the New Haven Deep Draft improvement project is to place a minimum of 2-ft of sandy dredge material within the proposed placement area to encourage oyster bed development. Mr. Carey identified two areas; the South Area which is 4,076,000 SF, and the North area which is 1,794,000 SF. Utilizing a recommended 2-ft depth of sandy material placed on top of the native silty material, the East Breakwater Oyster bed has a capacity of beneficially re-using 434,800 CY of sandy dredge material. Depending upon the recommended project depth and total dredge quantity, the East Breakwater Oyster Bed will account for the placement of most, if not all, of the sandy dredge material for the New Haven deep draft improvement project.

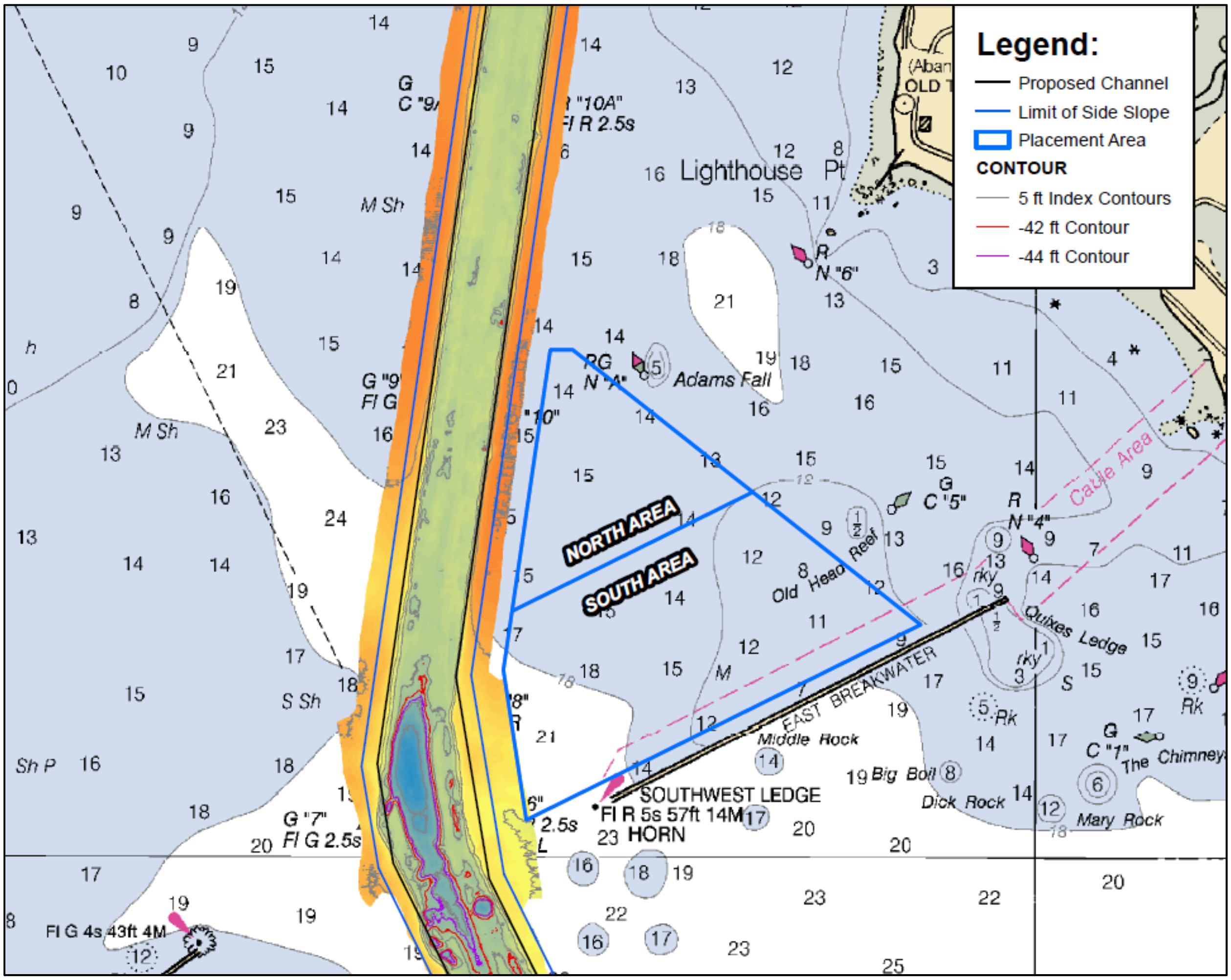


Figure 15 - East Breakwater Oyster Bed Disposal Area

d. West Breakwaters Rock Disposal

The proposed plan recommends that the rock removed from the improvement dredging project be placed at the land-side toe of the existing west breakwater. The rock will be beneficially re-used to bolster the existing breakwater structure. All of the removed rock will be placed on the western side of the west breakwater as shown in the figure below. There is one existing shellfish lease in that area.

The existing conditions behind the west and middle jetties are approximated using the NCEI mix of multibeam, singlebeam, and sidescan data collected in the year 2000 (H11011_OuterChannel) merged with 2015 USACE LiDAR of the West and Middle Jetties (EX_WestMidJetties_MLLW). The final surface used to represent the existing conditions behind the west jetty is EX_H11011_2015Lidar_MergedMLLW.dtm.

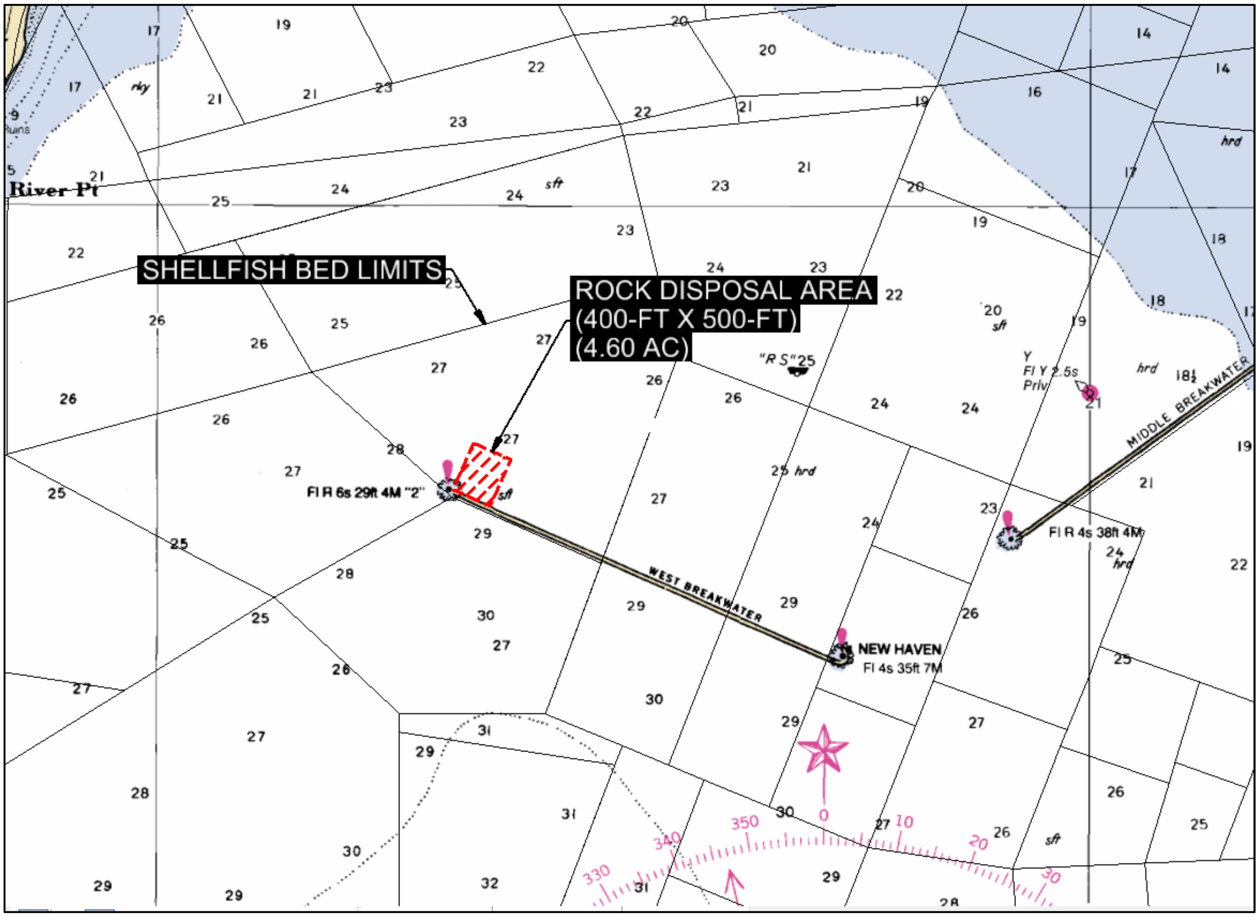


Figure 16 - West Breakwater Rock Disposal Area

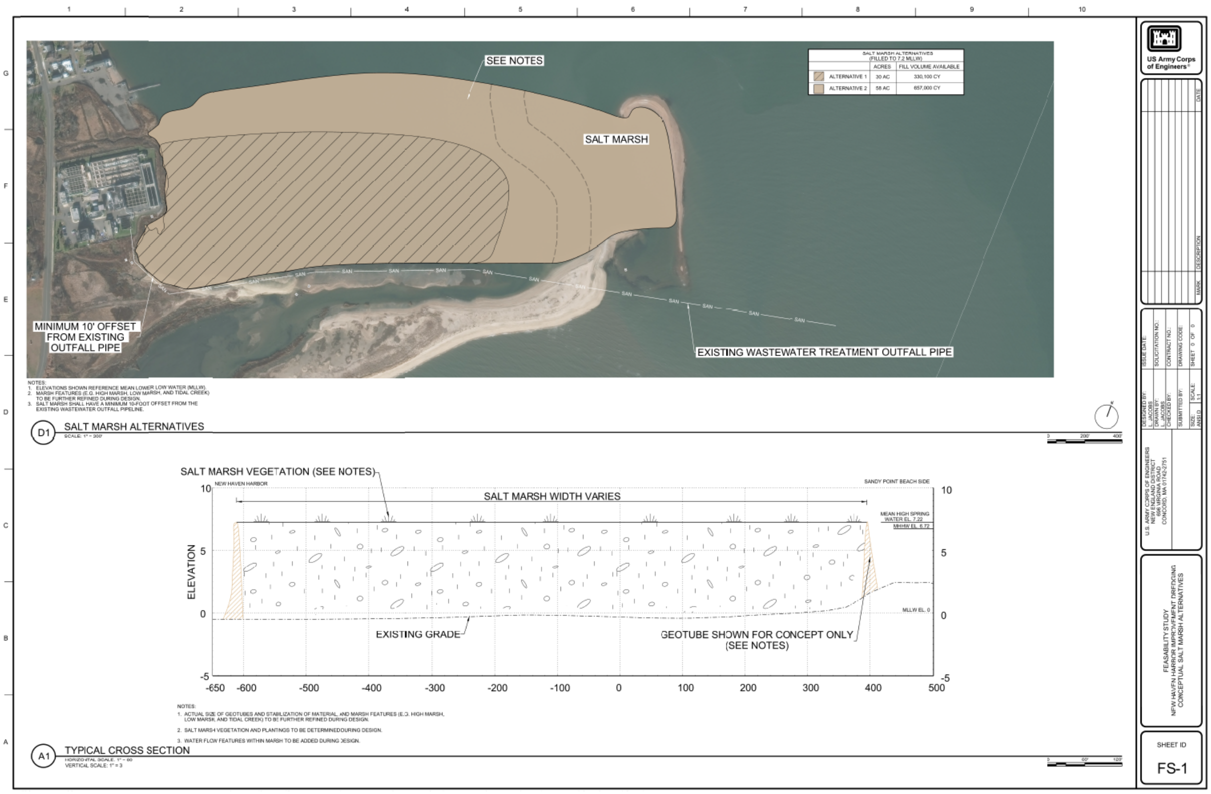
e. Sandy Point Marsh Creation

CTDEEP proposed Sandy Point Marsh as a potential disposal alternative. The concept of this disposal alternative is to beneficially reuse dredged sediment for the purpose of creating new tidal wetland (salt marsh) area and shoreline erosion mitigation at Sandy Point. The Sandy Point project site is located along the western shore of the inner New Haven Harbor, just north and in the lee of a spit of land known as Sandy Point, in the vicinity of the West Haven Water Pollution Control Facility at 1 First Avenue, West Haven. The spit that extends along the southern boundary is currently undeveloped and is identified as a bird sanctuary.

A stone dike constructed by the USACE in the 1880s extends east from the end of the spit with an outer leg parallel to the entrance channel. The dike was constructed as a control feature to assist in keeping the channel from shoaling. An outfall pipe from the wastewater treatment plant extends through this area and discharges in deeper water offshore. Maintaining both the bird sanctuary and the outfall pipe will be important considerations during the design phase of this project.

The concept for Sandy Point Restoration area is to establish a structural perimeter boundary, fill the area with suitable silty dredged material through either mechanical or hydraulic means, and plant wetland vegetation. The goal of the proposed disposal area would be to place the sediment to an elevation where intertidal wetland plant species would thrive.

Figure 17 - Sandy Point Marsh Creation Location



SALT MARSH ALTERNATIVES (FILLED TO 7.2 MLLW)		
	ACRES	FILL VOLUME AVAILABLE
▨ ALTERNATIVE 1	30 AC	330,100 CY
ALTERNATIVE 2	58 AC	657,000 CY

NOTES:
1. ELEVATIONS SHOWN REFERENCE MEAN LOWER LOW WATER (MLLW).
2. MARSH FEATURES (E.G. HIGH MARSH, LOW MARSH, AND TIDAL CREEK) TO BE FURTHER REFINED DURING DESIGN.
3. SALT MARSH SHALL HAVE A MINIMUM 10-FOOT OFFSET FROM THE EXISTING WASTEWATER OUTFALL PIPELINE.

NOTES:
1. ACTUAL SIZE OF GEOTUBES AND STABILIZATION OF MATERIAL, AND MARSH FEATURES (E.G. HIGH MARSH, LOW MARSH, AND TIDAL CREEK) TO BE FURTHER REFINED DURING DESIGN.
2. SALT MARSH VEGETATION AND PLANTINGS TO BE DETERMINEDDURING DESIGN.
3. WATER FLOW FEATURES WITHIN MARSH TO BE ADDED DURING DESIGN.

Figure 18 –Sandy Point Marsh Creation Footprint Alternatives

Two alternatives were analyzed. The first wetland creation alternative consisted of a 58 acre site, approximately 7,210 linear feet perimeter, and capable of holding 657,00 cubic yards of dredged material. The second wetland creation alternative consisted of a 30 acre site, approximately 5,110 linear feet perimeter, and capable of holding 330,100 cubic yards of dredged material. The 58 acre site is the preferred alternative because it maximizes the beneficial use of dredged material that would otherwise go to Central Long Island Sound Disposal Site and provides an additional 28 acres of salt marsh habitat over the smaller plan. The target elevation for the surface of the wetland is approximately 7.22 feet MLLW, which requires the elevation to be raised by a range of 2.5 feet to 7 feet within the proposed wetland creation area. This would enable the cell to receive a total of approximately 657,000 cubic yards of dredged sediment. This project would restore salt marsh to that section of shoreline.

V. Ship Simulation Refinements

A feasibility level ship simulator study was performed for the proposed channel improvements outlined in Section I for New Haven Harbor at the USACE Engineer Research and Development Center (ERDC), Coastal Hydraulics Laboratory (CHL) 13-16 February 2018. Representatives from ERDC, the Connecticut Pilots (Capt. David Charlie Jonas and Capt. DJ Toby), and the New England District participated for the duration of the simulation which tested the navigability of the proposed improvements using a limited set of design ships and tidal and wave forcing across the range of proposed project depths from 37 to 42 feet. Feedback from the pilots on the proposed design resulted in confirmation of the design widths of the entrance and inner channels as well as the configuration of the maneuvering area. Iterative testing of the channel bend and turning basin designs resulted in the modifications described below.

a. Channel Bend at Breakwaters

The proposed bend widening was performed for the 37, 38, 40, and 42 foot project depths. While the widened condition allowed the pilots to make the turn at the breakwater entrance, the turn still required the pilots to use all their rudder, leaving no additional rudder control to respond to unexpected changes in environmental conditions (wind, waves, current, etc.) and little room for error. For this reason, the proposed bend design was widened by shifting the locations of the R "6" and R "8" buoys east 100 feet. This resulted in an increase in bend width from the proposed 700 ft width to 800 ft, and allowed the pilots to make the turn without bank effects. The proposed bend widening resulted in a significant increase of rock material.

b. Turning Basin

The proposed turning basin was tested using the longest of the simulator study's three design ships, a 750 ft LOA tanker, with the assistance of two tugs coming off the Magellan T-Dock. The pilots indicated that the longest ships typically berth at the Magellan T-Dock at the center of the harbor. While the pilots were able to maneuver within the proposed turning basin at the head of the harbor, it was determined that the existing turning basin, with a small enlargement, would be better suited given its more central location. The proposed enlargement would lengthen the turning basin 200 feet by shifting it existing northeastern and northwestern corners approximately 200 feet toward the head of the harbor to points 1 and 2 as depicted in the figure below.

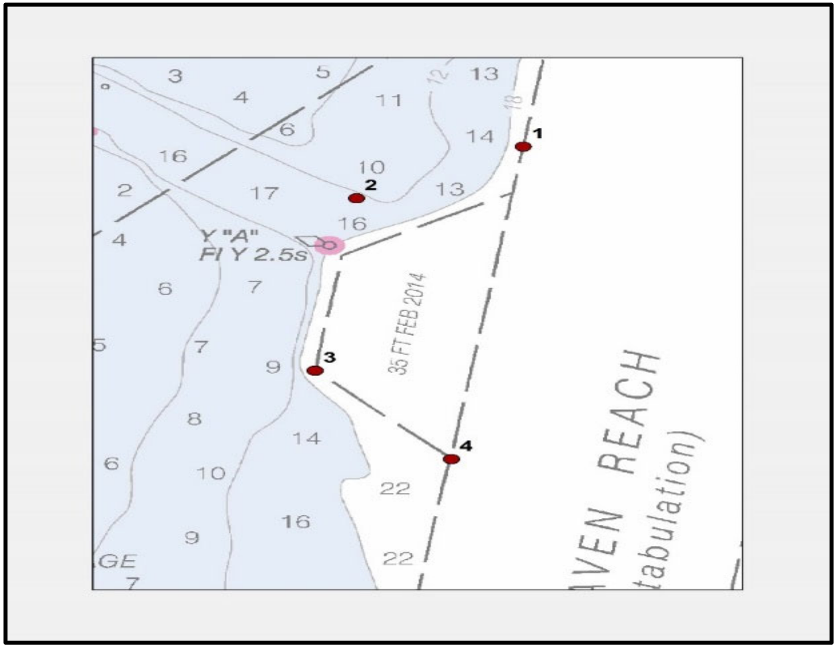


Figure 19 - Ship Simulation Effort – Proposed Adjustments to Turning Basin

c. Quantity Adjustments

Table 3 - Ship Simulation Effort – Channel Adjustment Quantities

40-FT PROJECT	**Dredging Quantities (CY)**			**Dredging Areas (SF)**
	Cut	2-FT OD	Total	
Maintenance Dredging (EL 35):				35' Contour
Entrance Channel	0	4,000	4,000	0
Entrance Channel Extension	0	0	0	
Bend (Maintenance STA 45+00 to 85+00)***	200	4,300	4,500	Side Slopes (avg 2ft cut)
Interior Channel	1,500	53,900	55,400	Side Slopes (avg 2ft cut)
Maneuvering Area (within Improved footprint)	2,400	41,700	44,100	Side Slopes (avg 2ft cut)
Turning Basin	1,300	9,100	10,400	
Total Maintenance Dredging	5,400	113,000	118,400	
Improvement Dredging (EL 40):				40' Contour*
Entrance Channel**	263,600	200,900	464,500	2,181,200
Entrance Channel Extension	14,700	39,100	53,800	752,756
Bend (Ordinary Material)	475,300	161,300	636,600	1,841,612
Bend (Rock) (Required Cut to El 42)	24,900	18,600	43,500	257,000
Interior Channel	1,537,400	776,000	2,313,400	8,138,400
Maneuvering Area	377,700	274,600	652,300	3,402,200
Turning Basin	117,900	40,200	158,100	412,300
Total Improvement Dredging	2,811,500	1,510,700	4,322,200	16,985,468
Total All Dredging	**2,816,900**	**1,623,700**	**4,440,600**	Improvement Areas include Maintenance Areas

*Rock "Dredge Area" measured from 42' Contour, per EM 1110-2-1613 for required rock dredging

**Used H11101 Survey for Entrance Channel Extension Quantities

*** Approx. 100 CY of Rock within Maintenance Bend Limits at EL -37. This quantity was subtracted from Maintenance Quantity

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Figure 3: Contour Map of the Bedrock Surface, New Haven-Woodmont Quadrangles, Connecticut, U.S. Geological Survey, Miscellaneous Field Studies Map MF-557A, 1:24,000, F.P. Haeni and J.E. Sanders, 1974 (MLW)

Figure 4: Quaternary Geologic Map of Connecticut and Long Island Sound Basin, U.S. Geological Survey, Scientific Investigation Map 2784, 1:125,000, J.R. Stone et al., 2005.

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Figure 7a and 7b: Boring Locations, Soil and Bedrock Profiles, USACE NAE, PED Report, 1988.

Figure 8: Area 6/7 Boring Locations and Top of Rock Contours, New Haven Harbor, Connecticut, Cross Sound Cable Project, ESS, 2002.

1.0 Regional Bedrock Geology and Structure

The bedrock surface underlying the New Haven area reflects mature drainage and dissection, with deep pre-glacial valleys developed in the rock, subsequently modified by glacial processes, with sediments deposited below or adjacent to the glacial ice sheet, further modifying the original topography.

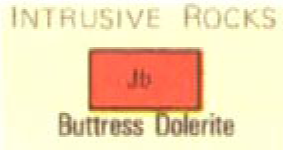
Bedrock underlying the New Haven area is composed of two very different rock types, put in proximity to each other due to a fault, the Eastern Border Fault, which strikes East-Northeast to West-Southwest, and dips to the north (Figure 1). The younger rock is on the downthrown side to the north. The older rock is to the south.

The Eastern Border Fault forms the eastern and southern boundary of the Mesozoic Hartford Basin. Mesozoic sedimentary rock is located to the north and west of the Eastern Border Fault and older Precambrian metamorphic rock is located to the south and east of the Eastern Border Fault. The sense of displacement on the fault is down on the north/west side of the normal fault. The fault dips to the north and is shown by the dashed red line in Figure 1. The New Haven Harbor Federal Channel is located both north, and south, of the Eastern Border Fault. The Eastern Border Fault crosses New Haven Harbor at the approximate latitude of Morris Cove (Figure 1).

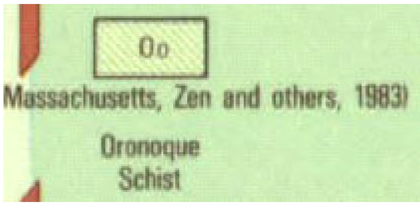
In general, New Haven Harbor is underlain by bedrock consisting of undivided schists and gneisses consisting of metasedimentary and meta-igneous rocks of Proterozoic to Devonian age.

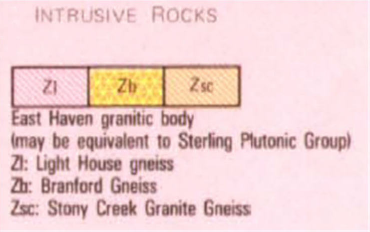
Most of New Haven Harbor is surrounded to the north, northwest, and northeast by New Haven Arkose (Tnh) consisting of red, poorly sorted sandstone and conglomerate. (Figure 1).

The Buttress Dolerite (Jb) is located east of New Haven Harbor. It consists of gabbro, traprock, and basalt. (Figure 1).



The Oronoque Schist (Oo) is located southwest of New Haven Harbor. It consists of granofels and gray/silver schist. (Figure 1)





The Light House Gneiss (Z1) is located south and southeast of New Haven Harbor. It consists of pink granitic gneiss. (Figure 1) and represents rock on the southeast side of the Eastern Border Fault.

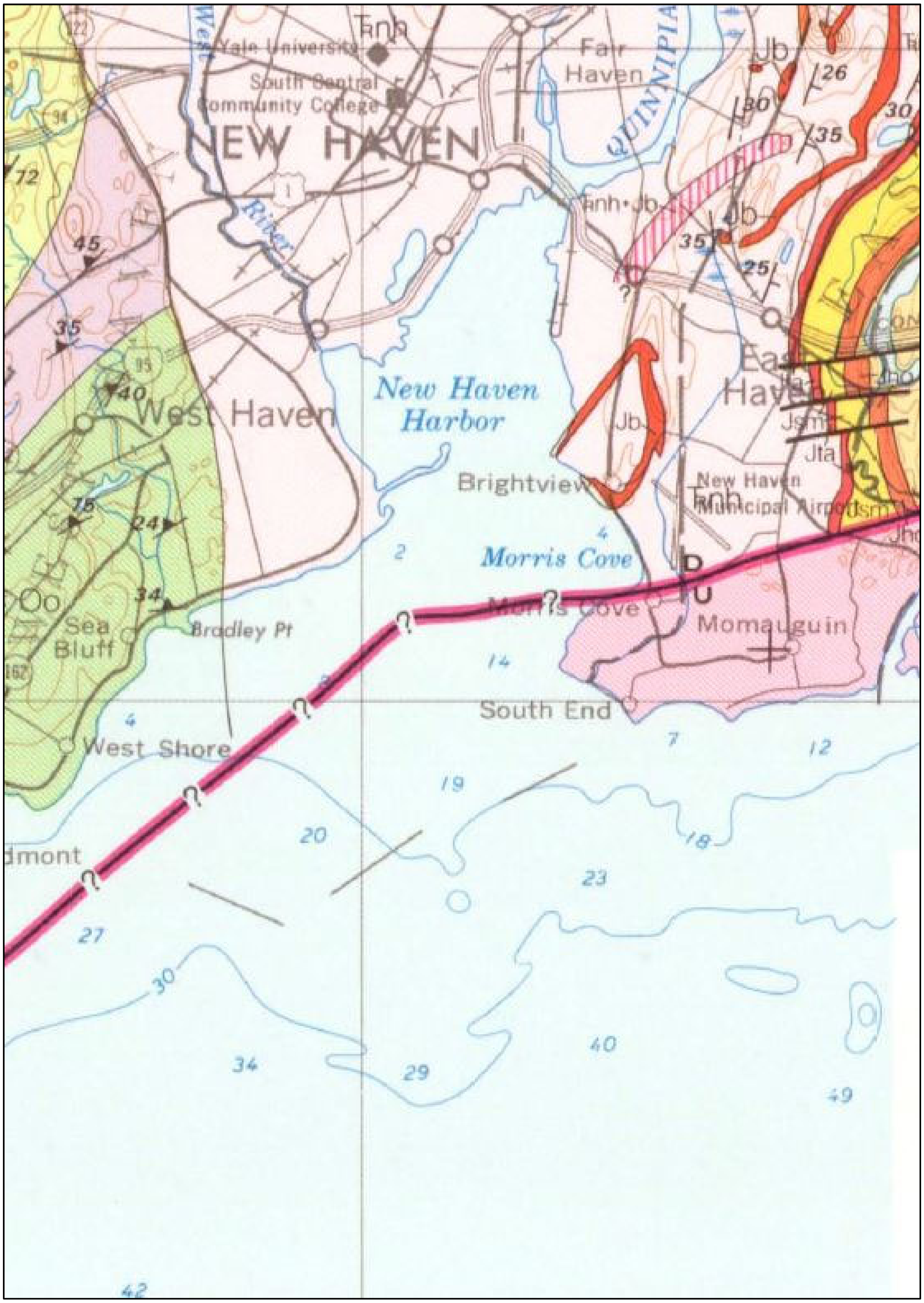


Figure 1: Bedrock Geological Map of Connecticut, Connecticut Geological and Natural History Survey and U.S. Geological Survey, 1:125,000, J. Rodgers, 1985.

The bedrock topography beneath New Haven Harbor consists of the large West Haven Bedrock Valley formed by the coalescence of three smaller V-shaped bedrock valleys associated with the West River, Quinnipiac River, and Farm River. The head of the large bedrock valley is at the approximate latitude of Morris Cove. The large valley strikes southwesterly parallel to the western edge of New Haven Harbor and parallel to the inferred orientation of the Eastern Border Fault (Figure 2 and Figure 3).

The fault zone, marking a sharp contrast between the sedimentary rock types to the north and the harder metamorphic rocks to the south, may have exerted structural control over river drainage development, resulting in the preferential erosion and deepening of the pre-glacial bedrock valley along the fault line. The presence of the harder, more resistant rock south of the fault also may help explain the point that juts out at South End, as well as the indentation at Morris Cove to the north, where glacial deposits fill the deep bedrock valley.

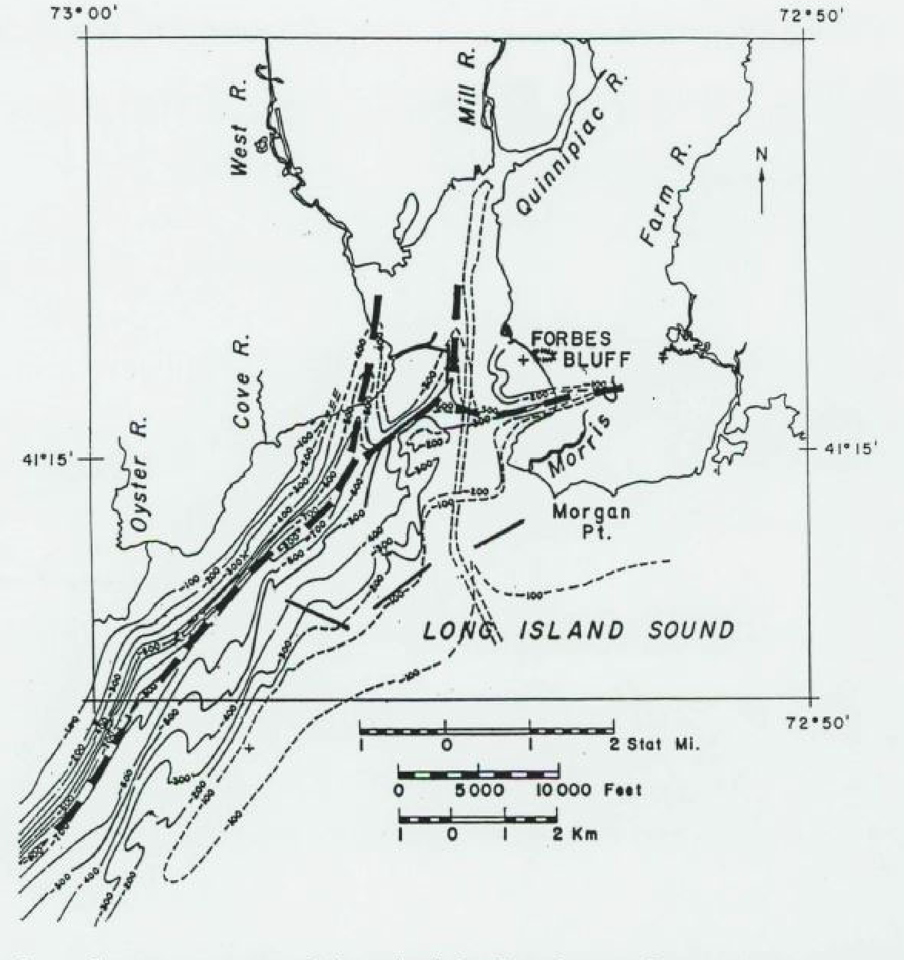


Figure 3. Contour map of buried bedrock surface, New Haven harbor and vicinity, CT. Contour interval, 100 ft. Based on data from continuous seismic-reflection profiles. Datum, mean high water.

Figure 2: Buried, Anomalously Deep V-Shaped Valley in Bedrock Surface, New Haven Harbor, Connecticut, Department of Geology, Hofstra University, J.E. Sanders, 1965.

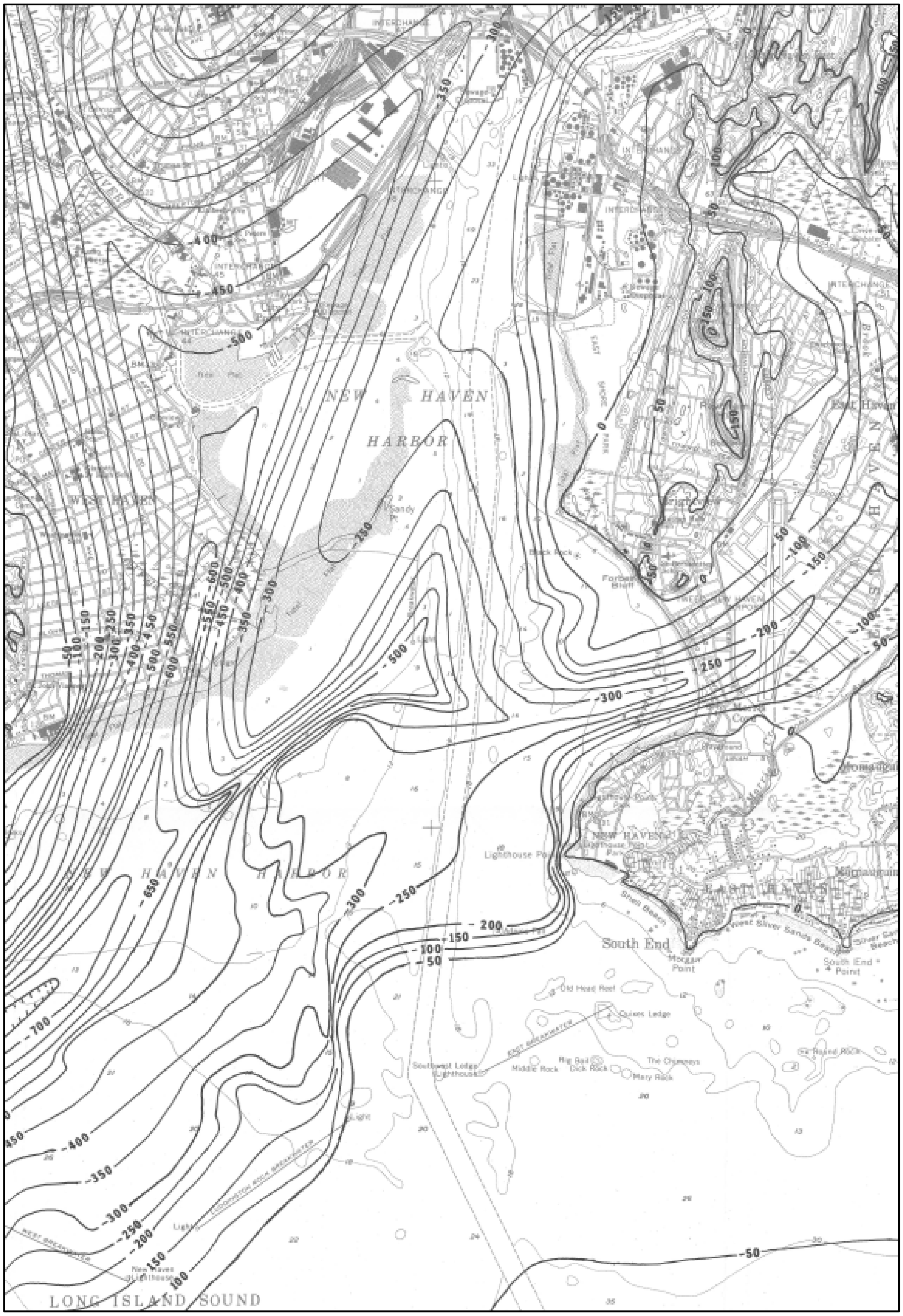


Figure 3: Contour Map of the Bedrock Surface, New Haven-Woodmont Quadrangles, Connecticut, U.S. Geological Survey, Miscellaneous Field Studies Map MF-557A, 1:24,000, F.P. Haeni and J.E. Sanders, 1974 (MLW)

2.0 Regional Surficial Geology

Glaciation resulted in a variety of material types deposited in varying depositional environments, such as: till deposited at the base of the ice; ablation till deposited by material melting out of glacial ice (supraglacial); and material deposited by meltwater, including glaciofluvial outwash deposited by flowing water, lacustrine silts and clays deposited in lakes formed by glacial ice and/or sediment dammed drainages; and deltas where drainages enter larger quiet water bodies and drop their sediment load. Glacial Lake Connecticut was formed by a glacial moraine dam and was the precursor to the current Long Island Sound. Deltaic and glaciolacustrine sediments from the meltwater of receeding glaciers were deposited in Glacial Lake Connecticut.

The surficial geology of the New Haven Uplands has been mapped by J.R. Stone et al (2005) and J.R. Stone et al (1992) and both are presented here as Figures 4 and 5. These maps are in general agreement and are complementary. The 2005 map is a Quaternary Geologic Map of Connecticut and Long Island Sound and the 1992 map is a Surficial Materials Map of Connecticut.

2.1 Surficial Geology of New Haven Uplands

Thin till (t) is located to the east/southeast and west/southwest of New Haven Harbor (Figure 4). Thin till (t) consists of areas where till is generally less than 10-15 ft. thick and includes areas of bedrock outcrop where till is absent. Thin till is predominantly an upper till that is loose to moderately compact, generally sandy, and commonly stony. Two till facies are present in some places; a looser, coarser-grained ablation facies, melted out from supraglacial position; and a more compact finer-grained lodgment facies deposited subglacially. In general, both facies of upper till were derived from the red Mesozoic sedimentary rocks of the central lowland of Connecticut and are finer-grained, more compact, less stony, and have fewer surface boulders than upper till derived from crystalline rocks of the eastern and western highlands (Figure 5).

t Thin till deposits

t Thin till

Coastal Beach/Dune Deposits (b) are located to the east and west of New Haven Harbor (Figure 4). Beach Deposits (b) consisting of sand and gravel deposited along the shoreline by waves and currents and by wind action are located to the east and west of New Haven Harbor. The texture of beach deposits varies over short distances and is generally controlled by the texture of nearby glacial materials exposed to wave action. Beach deposits are generally well sorted and rarely more than a few feet thick. Many sand beaches along the Connecticut coast have been "restored"; these have not been distinguished from natural beaches on this map. However, extensive beaches that consist totally of "made-land" are mapped as artificial fill (Figure 5).

af Artificial fill
b Coastal beach and dune deposits

b Beach deposits

af Artificial fill

Holocene Tidal Marsh Deposits (sm) are located to the east and west of New Haven Harbor (Figure 4). These deposits consist of peat and muck interbedded with sand and silt, deposited in environments of low wave energy along the coast and in river estuaries. Marsh deposits are dominantly peat and muck, generally a few feet to 35 ft. thick. They are shown on the map only where greater than about 25 acres in area. In the major estuaries marsh deposits may overlie estuarine deposits which are sand and silt with minor organic material as much as 40-90 ft. thick. These deposits are generally underlain by the glacial material shown adjacent on the map; either till or sand and gravel. Where they are known or inferred to be underlain by sand or fines, they are shown on the map by various line patterns (Figure 5).

sm Tidal-marsh deposits

sm Salt-marsh and tidal-marsh deposits

2.2 Surficial Geology of New Haven Inner Harbor

Glaciofluvial deposits are present in the uplands to the north, northwest, and east of the harbor and are mapped as the New Haven Deposits and East Haven Deposits (Lcnh and lcenh). These deposits are associated with a sediment dammed lake (Figure 4).

lcnh New Haven deposits

lcenh East Haven deposits

These deposits were previously mapped as Sand Overlying Fines (S/f) (Figure 5). Sand is of variable thickness, commonly in inclined foreset beds and overlying thinly bedded fines of variable thickness. The sand represents glaciofluvial deltaic deposits overlying glaciolacustrine lake-bottom sediment. S/f is a subset of Stacked Coarse Deposits Overlying Fine Deposits (Figure 5).

s/f Sand overlying fines

Uncorrelated Meltwater Terrace Deposits of Distal Meltwater Streams (fd) are mapped in the uplands north of New Haven Harbor in the area of the Quinnipiac River (Figure 4).

fd Uncorrelated meltwater terrace deposits

These deposits were previously mapped as Sand and Gravel, Overlying Sand, Overlying Fines (Sg/s/f) in the uplands north of New Haven Harbor in the area of the Quinnipiac River. Sand and gravel is generally less than 20 ft. thick, horizontally bedded, and overlies thicker inclined beds of sand which in turn overlie thinly bedded fines of variable thickness. These are deltaic deposits overlying lake-bottom sediment. Sg/s/f is a subset of Stacked Coarse Deposits Overlying Fine Deposits (Figure 5).

sg/s/f Sand and gravel overlying sand overlying fines

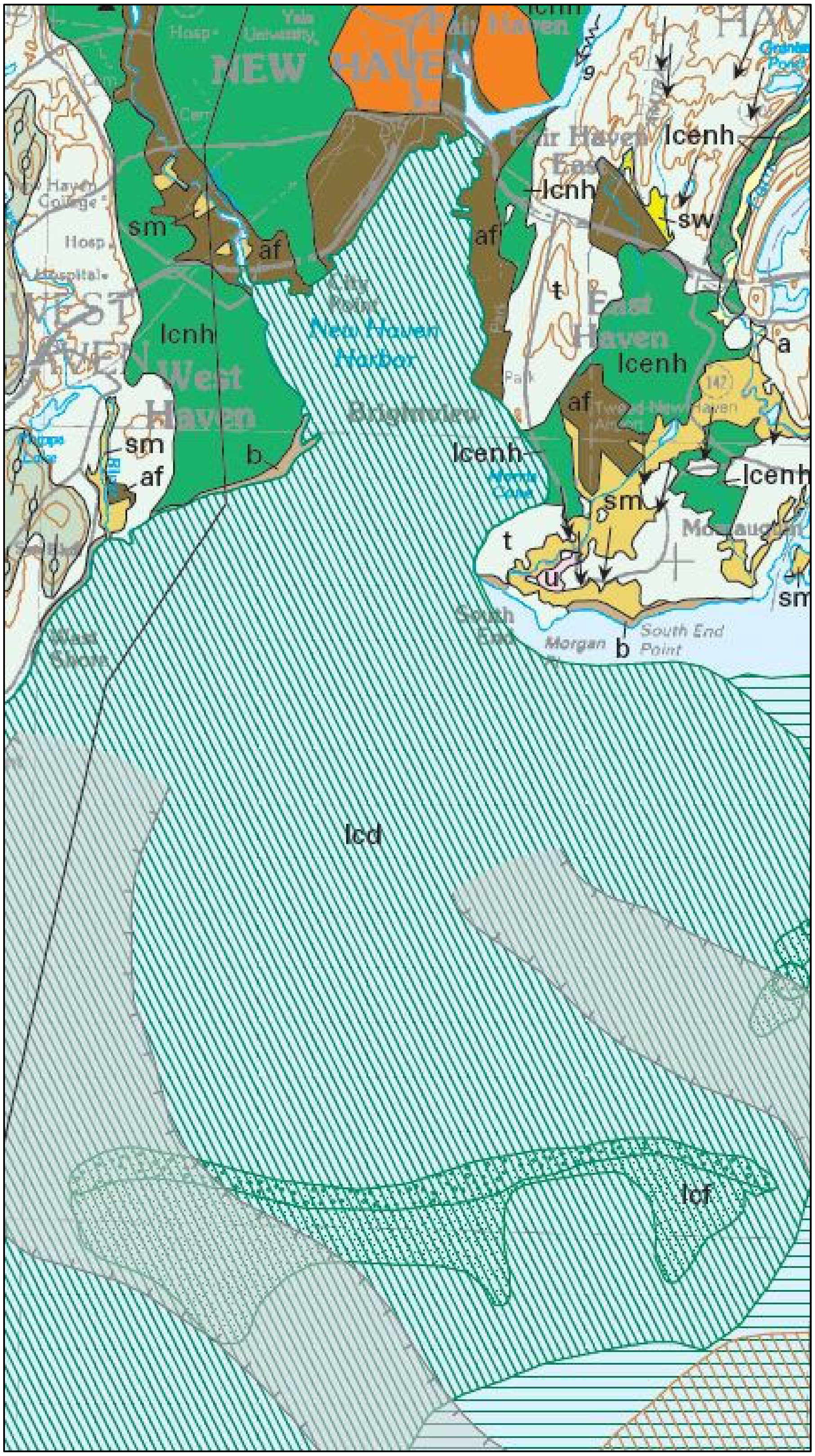


Figure 4: Quaternary Geologic Map of Connecticut and Long Island Sound Basin, U.S. Geological Survey, Scientific Investigation Map 2784, 1:125,000, J.R. Stone et al., 2005.

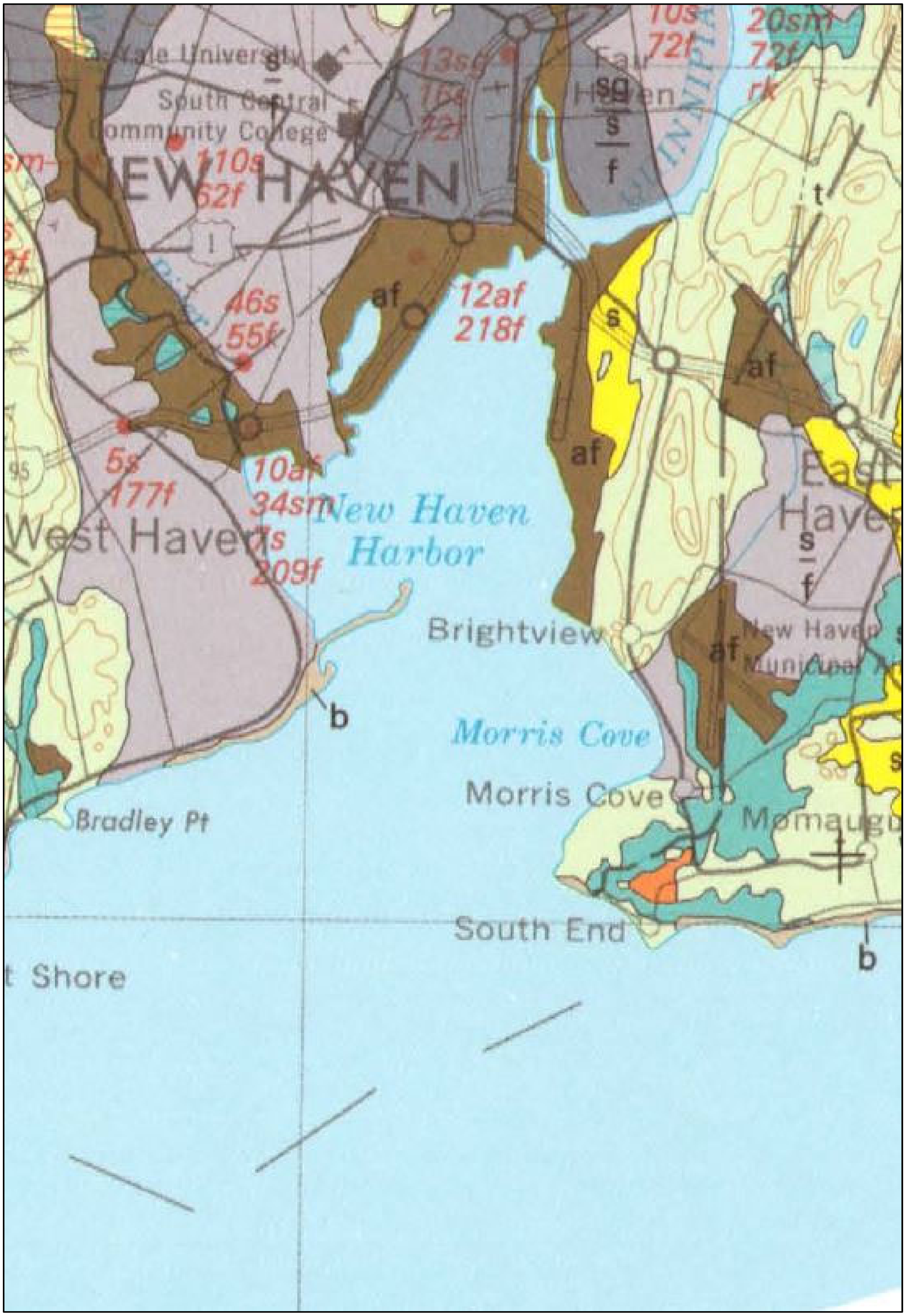


Figure 5: Surficial Materials Map of Connecticut, U.S. Geological Survey, 1:225,000, J.R. Stone et al, 1992.

2.3 Surficial Geology of New Haven Outer Harbor

Glacial Lake Connecticut, the precursor to Long Island Sound, extended across what is now Long Island Sound, as the outlet was dammed by a recessional morraine. Deltas formed where rivers entered the lake (proximal), dropping their coarser sediment load, while silts and clays accumulated in the distal, quiet-water lacustrine environment.

The surficial geology consists of Offshore Submerged Deposits of Glacial Lake Connecticut, including Deltaic Deposits consisting of foreset and bottomset beds overlying lake-bottom sediments (Lcd). The Deltaic Deposits are due to deposition from the Quinnipiac River, the Mill River, and the West River into Glacial Lake Connecticut (Figure 4).

▨ lcd Deltaic deposits

2.4 Surficial Geology of Long Island Sound

The Offshore Submerged Deposits of Glacial Lake Connecticut (Late Wisonsian) generally include the following deposits (from oldest/deepest to recent): Lake bottom deposits (lclb); Deltaic deposits (lcd); Coarse-grained proximal facies (lcf) and Fine-grained distal facies (lcf). The lake-bottom deposits are fine-grained, deposited in the deep quiet waters of Glacial Lake Connecticut, and are blanketed by deltaic sediments, deposited at the mouth of the river, with coarser material to the north (closer to the mouth), and finer material to the south (distal to the outlet). Depositional features are described below, in order from oldest to most recent.

Offshore Submerged Deposits of Glacial Lake Connecticut (Late Wisconsinan) include Deltaic Deposits (Lcd) depicted by diagonal green lines (Figure 4). These deposits are inferred from seismic-reflection data to be delta-foreset and bottomset facies of emergent deltaic deposits of coastal Connecticut. Deposits are up to 30 m (131 ft.) thick and are a dominant component of lake sediment in much of the northern nearshore area. Deposits locally overlie bedrock, undifferentiated drift, end moraine deposits, or lacustrine-fan deposits. Generally, however, they overlie and intertongue distally with varved clay lake-bottom facies (lclb). Internally, delta facies exhibits seaward-dipping, oblique-tangential reflectors. These progradational clinoform configurations occur most commonly on north-south-trending profiles. On east-west profiles, reflectors within delta facies are typically parallel to subparallel, horizontally stratified infill configurations with lows in basal bounding surfaces.

▤ lclb Lake-bottom deposits
▨ lcd Deltaic deposits

Coarse-grained, proximal facies are depicted by large green dots and Fine-grained, distal facies are depicted by small green dots. (Figure 4). Ice-marginal lacustrine fan deposits are present in the lower part of the glaciolacustrine section. These deposits overlie bedrock, Cretaceous strata, and, or, undifferentiated drift and are commonly in the same stratigraphic positon as moraine deposits. Fans occur locally throughout the basin, but are numerous and more extensive in wide central Long Island Sound.

Each lacustrine-fan sequence consists of two facies that have different seismic characteristics. Ice-proximal facies always occur in the northern part of the deposit, and distal facies always occur in the southern part. On the map, each facies is distinguished by its own pattern, but both with the Lcf label. Proximal facies are commonly an asymmetric, positive relief form with steeper southern slopes and gentler northern slopes. These deposits are inferred from seismic-reflection data to consist of coarse-grained sand and gravel in south-dipping beds and probably contain boulders (at least on the surface) and ablation till in most proximal parts. Deposits are typically either seismically amorphous or display chaotic internal reflectors. However, multiple seismic-reflection profiles run in different directions across single fans reveal that internal reflectors, which have chaotic configuration on some crossings, appear as steeply dipping clinoforms on other crossings. The seismic data provide evidence that proximal facies contain coarse-grained stratified sediment as well as nonstratified ablation material. The surface of distal facies slopes gently southward from higher-standing proximal facies. These deposits are inferred from seismic-reflection data to consist of finer grained lacustrine beds similar to overlying lake clays but were deposited by turbidity underflow processes. The finer grained lacustrine beds are characterized by finely laminated, subparallel to parallel internal reflectors that fill underlying topographic lows.

Lacustrine fans were built beneath waters of Glacial Lake Connecticut by meltwater streams that issued from the grounding line of the ice sheet. On several seismic-reflection profiles, evidence of systematic northward retreat of ice is provided by shingled sequences of up to 10 ice-marginal fan deposits. In these sequences, proximal facies of one fan are overlain by distal facies of the next younger fan to the north

lcf	Coarse-grained, proximal facies
lcf	Fine-grained, distal facies

Offshore Submerged Deposits of Glacial Lake Connecticut (Late Wisconsinan) include Lake-Bottom deposits (Lclb) depicted by horizontal green stripes. (Figure 4). These deposits are inferred from seismic-reflection data to be varved silt and clay commonly 80m (262 ft.) thick and locally greater than 150 m (492 ft.) thick in deep valleys. These deposits dominate the glacial section in the southern half of the basin and variously overlie bedrock and, or, Cretaceous beds, undifferentiated drift, end-moraine deposits, and lacustrine-fan deposits. The unit is characterized by finely laminated, parallel internal reflectors that distinctively drape underlying topography. Several vibracores penetrated varved clay lake-bottom facies. One core (LISAT 6) contained 6.5 m (21 ft.) of typical glaciolacustrine varved sediment in silt-clay couplets, which range from 0.7 to 7.1 cm (0.5 to 3 in) thick with a mean thickness of 2.2 cm (1 in) and (if interpreted as annual) represent 280 years of lacustrine deposition in the interval sampled. Seismic-reflection data collected at the core location reveal that another 30 m (98 ft.) of lake-bottom clay facies is present in the section beneath the cored interval, and that local tidal scour has removed about 20m (66 ft.) of lake-bottom clay that formerly existed above the cored interval. In many places, reflectors within lake-bottom clay facies can be traced northward into deltaic facies.

Early Postglacial Deposits (Early Holocene, Late Wisconsinan) include Submerged marine deltaic deposits – Deltaic facies (md) and Delta-distal facies (mdd) depicted by orange diagonal stripes. Deltaic facies contain internal reflectors that consist of long, southwest-dipping, oblique-tangential clinoforms interpreted as sandy delta-foreset facies and packages of chaotic reflectors interpreted as coarser grained beds (locally delta-topset facies). Delta-foreset facies generally occur in prograded-fill configuration overlying a wave-cut unconformity, and are present -60 m (-197 ft.) and -42 m (-138 ft.) below sea level. Delta-topset facies occur as high as -30 m (-198 ft.) in altitude. The interpreted delta topset-foreset contact lies at about -42 m (-138 ft.). Deltaic beds occupy the eastern half of the deposit. The eastern area has undergone intensive modern tidal scour and only remnants of delta deposits remain. Delta-distal facies contain thin, parallel-laminated internal reflectors interpreted as delta-distal, fine grained facies. The deposits overlie a wave-cut unconformity in an onlap-fill configuration to as high as about -40m (-131 ft.). Relict shoreline features (beaches, bars, or spits) that lie at -42m (-138 ft.) in the southwest and -36 m (-118 ft.) in the northwest are associated with outer edges of delta-distal facies. Continuous reflectors can be traced across delta-distal facies, indicating that these levels were isochronous. The difference in altitude of the paleoshoreline between north and south is attributed to glacio-isostatic tilting. The top of delta-distal facies is cut by a minor unconformity with up to 4 m (13 ft.) of relief. Vibracores penetrating the unconformity indicate delta-distal facies to be finely laminated, very fine sand.

md	Submerged marine deltaic deposits—Deltaic facies
mdd	Submerged marine deltaic deposits—Delta-distal facies

Early Postglacial Deposits (Early Holocene) include Submerged fluvial-estuarine, and channel-fill deposits depicted in gray (Ch). (Figure 4). Fluvial sediments are overlain by estuarine sediments (inferred from seismic-reflection data) up to 20 m (66 ft.) thick in channel-fill configuration overlying steep-sided, channel-shaped unconformities that truncate glacial-lake deposits. The lower part of the channel-fill sequence is complex and includes hummocky, lenticular, and short oblique clinoform reflectors suggesting a cut-and-fill origin. These deposits are interpreted from diatoms in vibracores (Szak, 1987) to be terrestrially derived fluvial sediment deposited when streams drained across a subaerially exposed lakebed. Map patterns of these channels show a paleodrainage system related to terrestrial valleys. Tributary channels draining southward from Connecticut and northward from Long Island join an east-draining trunk valley that has thalweg altitudes in the -40-m (-131-ft) range in the west and slopes to about -60m (-197 ft.) in the east where it exited the Long Island Sound basin at The Race. Fluvial facies are commonly overlain in the upper section of channel-fill by a parallel-laminated to seismically opaque unit interpreted to be fine-grained, estuarine sediment deposited as the rising postglacial sea entered the basin through the -60m (-197-ft) notch at The Race and spread to the west via a paleochannel system. Estuarine sediment extends outside the channel system in many places but is not mapped.

ch	Submerged fluvial-estuarine, channel-fill deposits

2.5 Regional Grain Size Analyses

The USGS has estimated regional grain size in the outer portions of New Haven Harbor and Long Island Sound based upon the results of sidescan sonar studies. The distribution of sediments has been mapped as depicted in Figure 6. The USGS mapping documents the presence of sandy material occurring on the seafloor in the areas of the existing channel entrance and the proposed extension of the channel entrance.

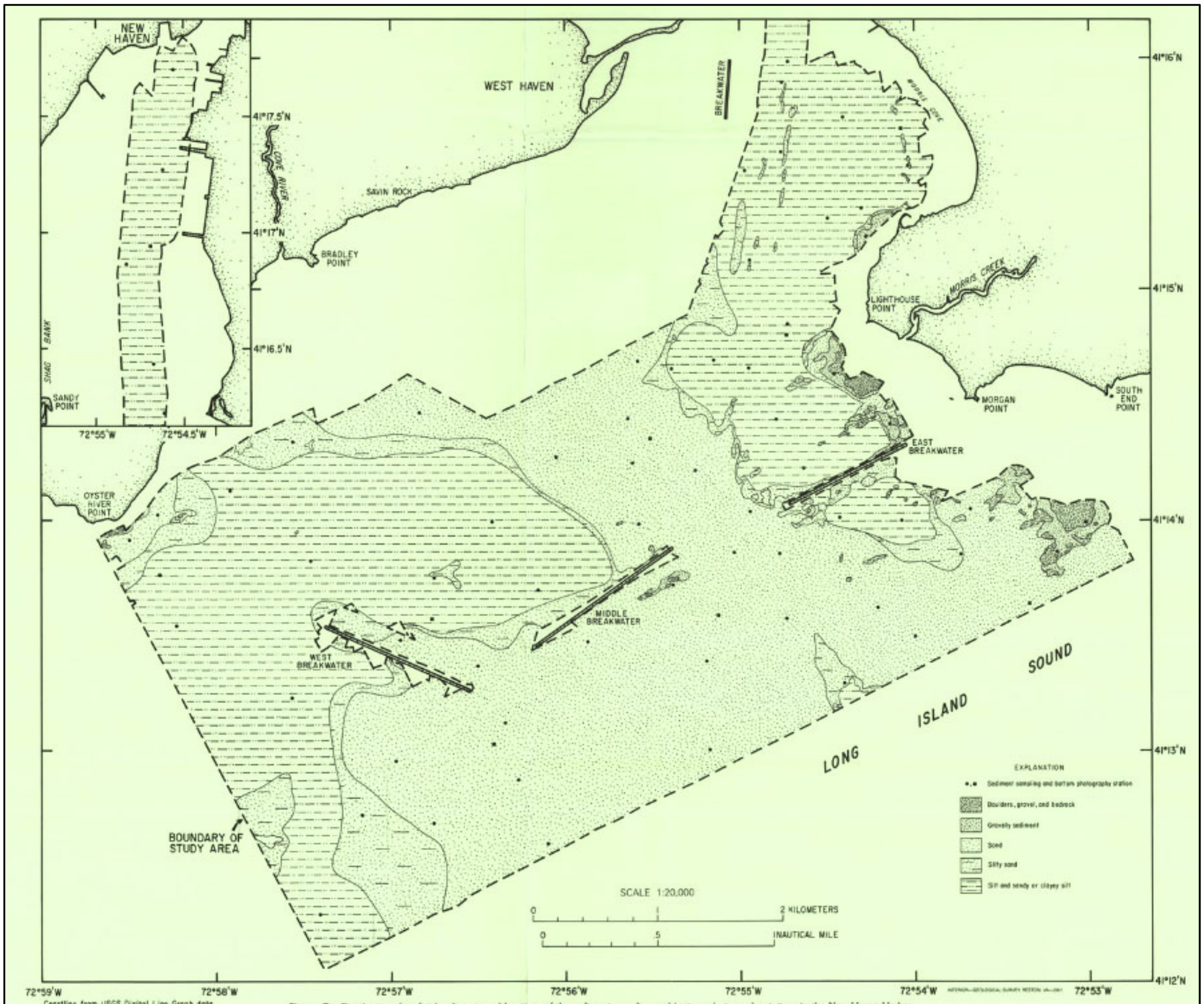


Figure 7.—Distribution of surficial sediments and locations of the sediment sampling and bottom photography stations in the New Haven Harbor study area (squares, March 1996; circles, March 1998). Interpretation of the sediment distribution is based on data from these stations, on tonal changes in backscatter on the sidescan sonar image (fig. 4), and on correlation of the textural and backscatter data with the bathymetry (fig. 2).

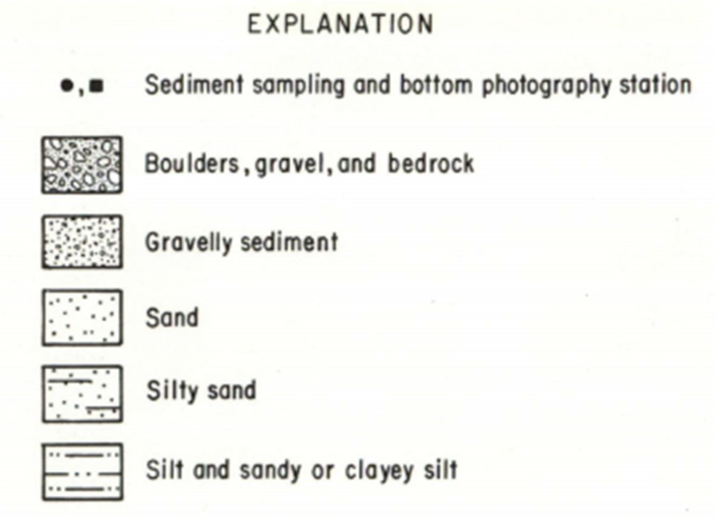


Figure 6.

Figure 6: Sidescan Sonar Images, Surficial Geologic Interpretations, and Bathymetry of the Long Island Sound Sea Floor in New Haven Harbor and New Haven Dumping Ground, Connecticut, U.S. Geological Survey, Geologic Investigations Series Map I-2736, L.J. Poppe et al., 2001.

2.6 Previous Site Specific Surficial Stratigraphy

The site specific stratigraphy of New Haven Harbor has been previously investigated by the USACE with boring programs in the 1970s and 1980s. These results were presented in the 1986 FS report and the 1988 PED report.

Hard copies of 1970s laboratory testing and boring logs were not located for this report. 1980s laboratory gradation testing was reported to be "On-file at NED office", but could not be located for this report.

Soils collected from the inner portions of New Haven Harbor consisted of Holocene, black to gray, organic silt and clay (OH-OL) overlying reddish-brown silty medium-fine sand (SP-SM). Soils collected from the outer portions of New Haven Harbor consisted of black to gray organic silt and gray organic silt (OL-OH), underlain by gray, medium-fine sand, silty-fine sand, and reddish brown silty fine sand (SW-SM), underlain by Till, underlain by bedrock.

Native materials that will likely be encountered during dredging include organic silts, silty sands with gravel, glacial till, and bedrock. The organic silt and clay represents Holocene deposition, while the underlying sand, and silty sands with gravel, represent deltaic and glaciolacustrine sediments deposited into Glacial Lake Connecticut, the precursor to Long Island Sound.

3.0 Previous Investigations

3.1 1974 Haley & Aldrich (H&A) Borings for Bolt, Beranck, and Newman, Inc. (BBN)

Three borings were conducted in bedrock. Boring Y-3A was located in the channel at approximate station 250+. Boring Y-4 was located outside of the channel at approximate station 270. Boring G-1 was located outside of the channel at approximate station 235.

Borings were conducted near the breakwater in area of Station 235+00 to 275+00. Six Borings were conducted.

In general, borings had very poor recovery (<50%). The main drilling problems were a result of the use of a floating spud barge held in place with anchors. Wave and tide interference, particularly near the outer breakwaters, resulted in poor recovery and poor characterization of bedrock. Bedrock was described as very hard, unweathered, highly to moderately fractured, gray, coarse to medium grained, ortho-gneiss.

3.2 1974 BBN Seismic Investigation

Bedrock was identified in the Federal Channel from the 50-ft contour north to the channel bend near the breakwater, thence roughly 4,000 feet further north into the harbor.

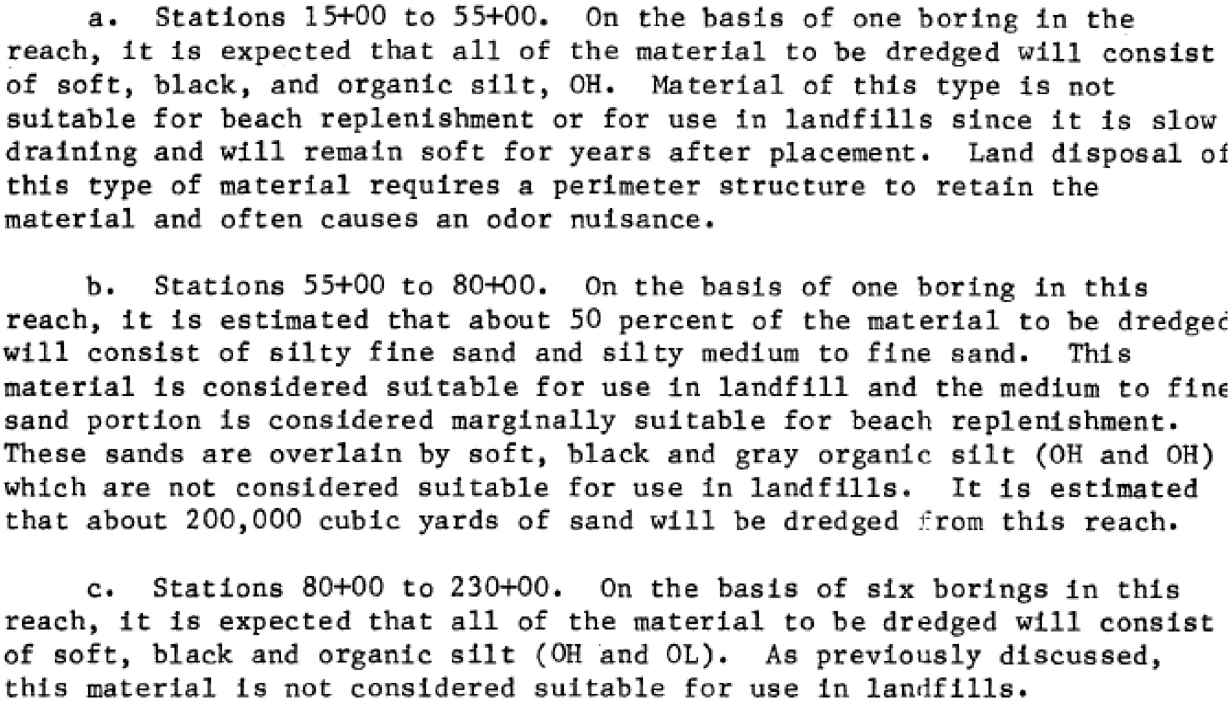
3.3 1977 UASCE-NED Study

The 1977 USACE-NED study concluded that approximately 1.2 million cubic yards of dredged material would be suitable for landfill applications and that no materials were suitable for beach nourishment.

These conclusions were based upon 10 drive samples collected at 2,500 ft. intervals along the length of the channel. No rock coring was conducted. Copies of boring logs for FD-1 through FD-10 were reported to be on file at NED. Copies of test data and laboratory grain size analyses were also reported to be on file at NED. However, hard copies of boring logs and laboratory gradations could not be located for this report.

3.4 1974 and 1977 Borings Summarized in 1981 FS Report

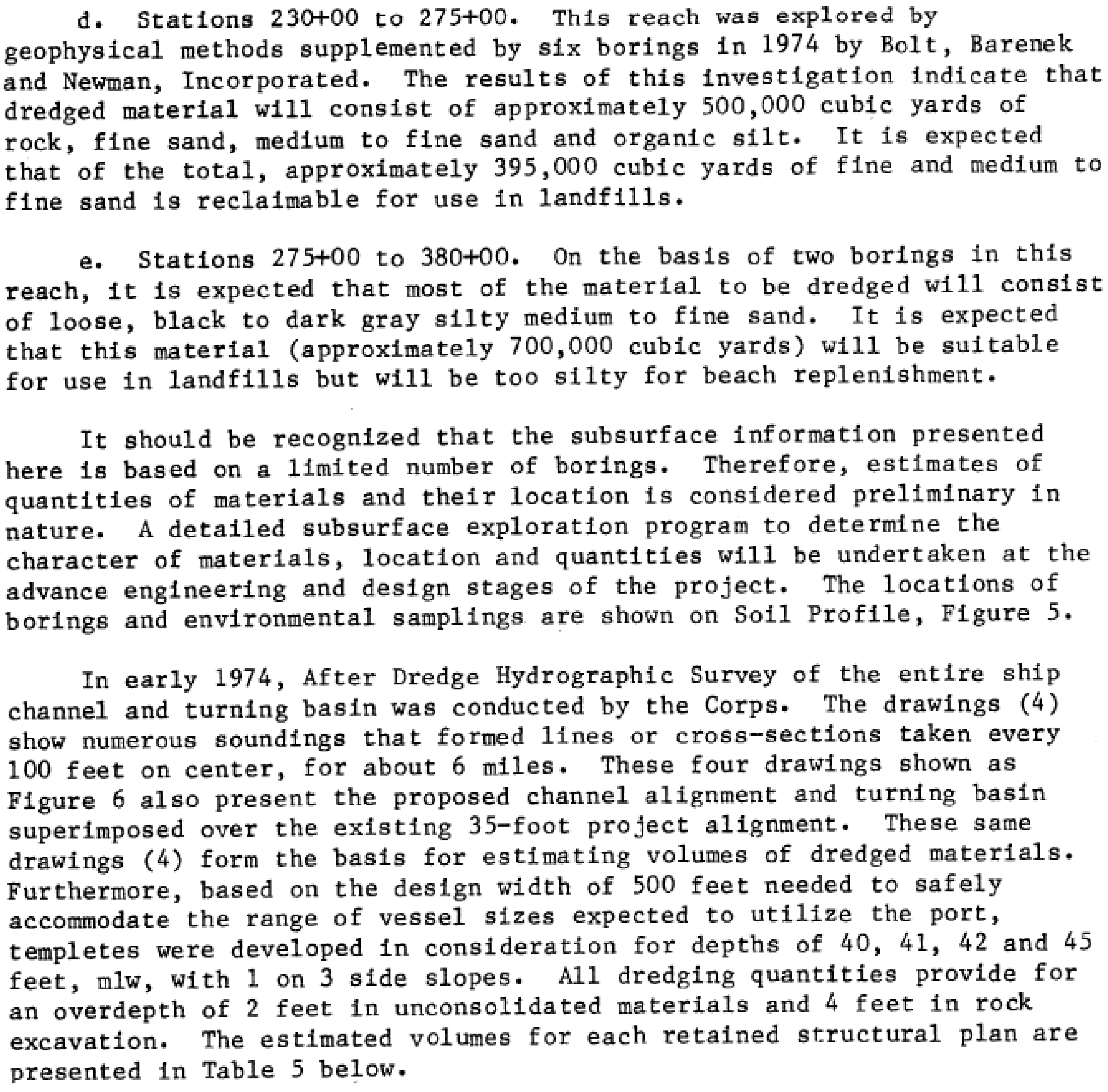
In the 1981 FS Report the anticipated types of materials to be encountered during dredging were summarized in the following excerpts:



a. Stations 15+00 to 55+00. On the basis of one boring in the reach, it is expected that all of the material to be dredged will consist of soft, black, and organic silt, OH. Material of this type is not suitable for beach replenishment or for use in landfills since it is slow draining and will remain soft for years after placement. Land disposal of this type of material requires a perimeter structure to retain the material and often causes an odor nuisance.

b. Stations 55+00 to 80+00. On the basis of one boring in this reach, it is estimated that about 50 percent of the material to be dredged will consist of silty fine sand and silty medium to fine sand. This material is considered suitable for use in landfill and the medium to fine sand portion is considered marginally suitable for beach replenishment. These sands are overlain by soft, black and gray organic silt (OH and OH) which are not considered suitable for use in landfills. It is estimated that about 200,000 cubic yards of sand will be dredged from this reach.

c. Stations 80+00 to 230+00. On the basis of six borings in this reach, it is expected that all of the material to be dredged will consist of soft, black and organic silt (OH and OL). As previously discussed, this material is not considered suitable for use in landfills.



d. Stations 230+00 to 275+00. This reach was explored by geophysical methods supplemented by six borings in 1974 by Bolt, Barenek and Newman, Incorporated. The results of this investigation indicate that dredged material will consist of approximately 500,000 cubic yards of rock, fine sand, medium to fine sand and organic silt. It is expected that of the total, approximately 395,000 cubic yards of fine and medium to fine sand is reclaimable for use in landfills.

e. Stations 275+00 to 380+00. On the basis of two borings in this reach, it is expected that most of the material to be dredged will consist of loose, black to dark gray silty medium to fine sand. It is expected that this material (approximately 700,000 cubic yards) will be suitable for use in landfills but will be too silty for beach replenishment.

It should be recognized that the subsurface information presented here is based on a limited number of borings. Therefore, estimates of quantities of materials and their location is considered preliminary in nature. A detailed subsurface exploration program to determine the character of materials, location and quantities will be undertaken at the advance engineering and design stages of the project. The locations of borings and environmental samplings are shown on Soil Profile, Figure 5.

In early 1974, After Dredge Hydrographic Survey of the entire ship channel and turning basin was conducted by the Corps. The drawings (4) show numerous soundings that formed lines or cross-sections taken every 100 feet on center, for about 6 miles. These four drawings shown as Figure 6 also present the proposed channel alignment and turning basin superimposed over the existing 35-foot project alignment. These same drawings (4) form the basis for estimating volumes of dredged materials. Furthermore, based on the design width of 500 feet needed to safely accommodate the range of vessel sizes expected to utilize the port, templetes were developed in consideration for depths of 40, 41, 42 and 45 feet, mlw, with 1 on 3 side slopes. All dredging quantities provide for an overdepth of 2 feet in unconsolidated materials and 4 feet in rock excavation. The estimated volumes for each retained structural plan are presented in Table 5 below.

3.5 1987 Atlantic Testing Laboratories (ATL) Borings

Only two of the 11 proposed borings were completed. One boring was located within the channel. No bedrock sampling or laboratory analyses were conducted. The main drilling problems were a result of the use of a floating spud barge held in place with anchors. Wave and tide interference, particularly near the outer breakwaters, prevented coring of bedrock.

Boring FD-87-2 was located in the channel at approximate station 240+00. FD-87-2 encountered the following sediments with increasing depth: 1) Soft organics 2) Gray, medium to fine sand, with a trace of silt, organics, and shells (SW) 3) Gray, coarse, medium, and fine sand with a trace of gravel, a trace of silt, a trace of organics, and a trace of shells (SW) and 4) Brown, coarse, medium, and fine sand, with little gravel, and a trace of silt (SW).

Boring FD-87-1 encountered the following sediments with increasing depth: 1) Soft organics and 2) Gray, medium to fine sand, with a trace of silt, a trace of organics, a trace of shells, and a trace of fine gravel (SW). No laboratory gradations were provide in the 1987 ATL report.

3.6 1987 Weston Geophysical Corporation Seismic Reflection and Refraction for ATL

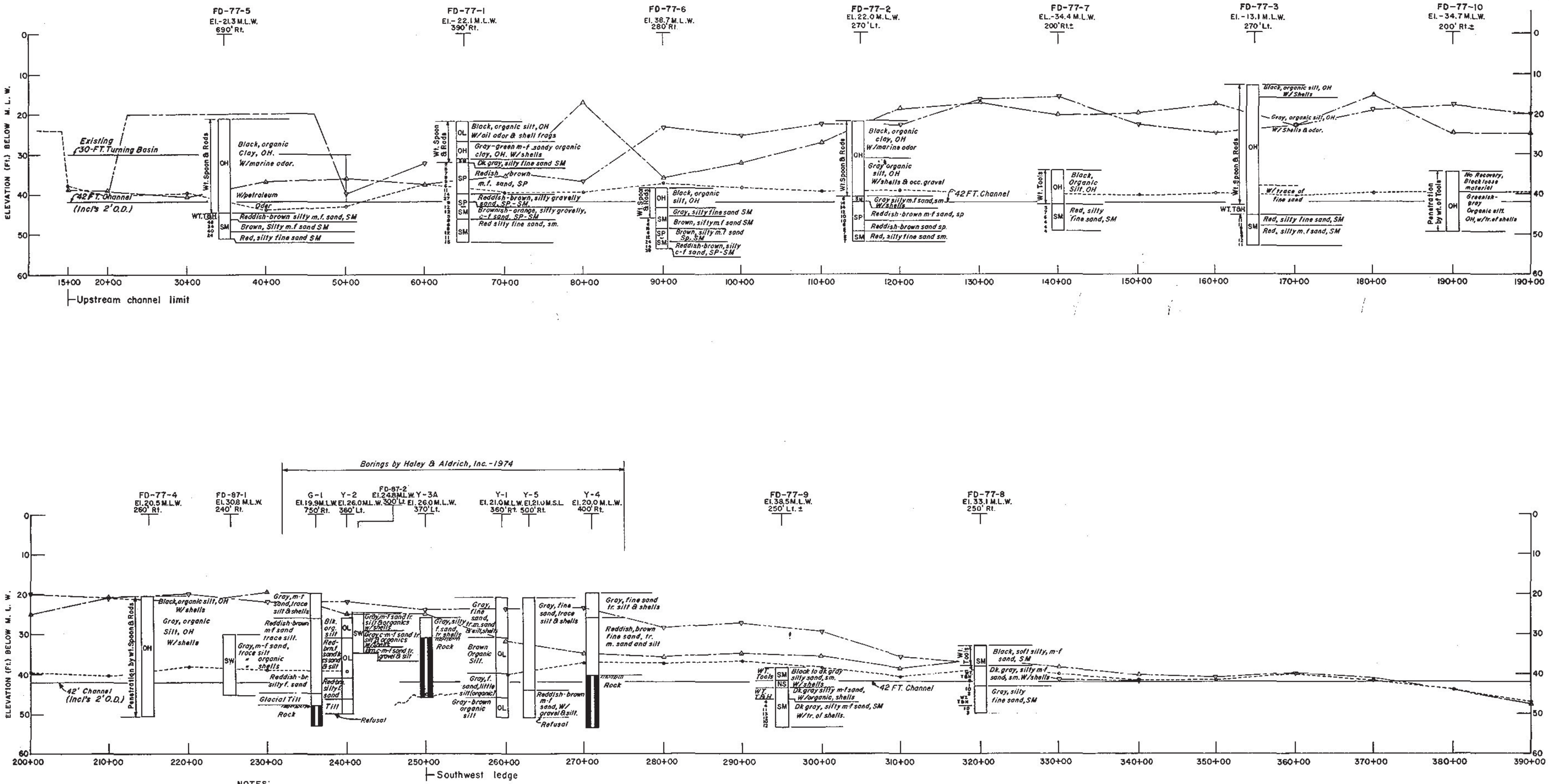
Gaseous organic sediments are located in the inner harbor, extending from stations 15+00 to 220+00. Therefore, there was limited, to no, energy penetration for reflection or refraction seismic studies in the inner harbor. However, gaseous sediments are not located near the channel bend in the area of shallow bedrock, so seismic studies work well in the bend and outer channel areas.

The seismic investigation used both a boomer seismic source and a sparker energy source for the seismic reflection survey. The channel located north of approximate Station 230 was not imaged due to gas charged sediments which are located north of Station 224+00.

For the refraction survey, air gun seismic sources were used along three lines. The lines were located on the east side, on the west side, and in the center of the channel. The eastern line extended to Station 310+00. The center line extended to Station 250+00 and the western line extended to Station 380+00 and in turning basin. The average seismic velocity of the bedrock was high, approximately 16,000 feet per second.

3.7 1988 PED Report

In the 1988 PED report, shallow bedrock was identified in three areas. The areas are: Station 230 -240 (FD-87-2 (240+)); Station 245-255 (Y-3A (250+)); and Station 273-274 (No borings). Rock was recovered, however, no rock mechanics testing was conducted. Therefore the engineering characteristics of the bedrock are unknown. Figure 7A is a soil profile from the 1988 PED report and Figure 7B is a bedrock profile from the 1988 PED report.



NOTES:

1. Soil classification conforms to Unified Soil Classification System.
2. Numbers to left of boring indicate number of blows per foot to drive a 2 inch solid spoon sampler using a 350 Lb. hammer with 18-inch free fall.

LEGEND:

•---------• Approximate Profile @ Channel ℄

△---·---△ " " " Left Side of Channel.

▽---·---▽ " " " Right Side of Channel.

FD-87-4 Boring #4 (1987)

SCALES: HORIZ: 1" = 500 FT.
VERT: 1" = 10 FT.

GRAPHIC SCALES

1" = 10' 0 10' 20'

1" = 500' 0 1,250' 2,500'

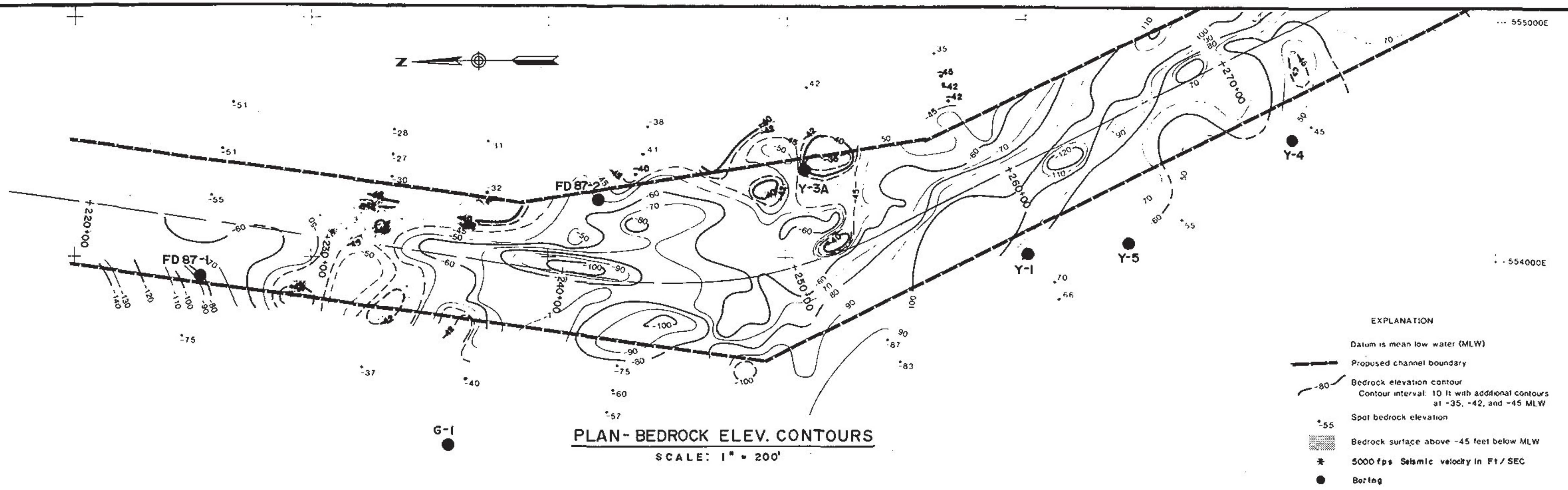
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

NEW HAVEN HARBOR, CONNECTICUT

FIGURE 7A

SOIL PROFILE

AUGUST 1988



EXPLANATION

Datum is mean low water (MLW)

Proposed channel boundary

Bedrock elevation contour
Contour interval: 10 ft with additional contours at -35, -42, and -45 MLW

•-55 Spot bedrock elevation

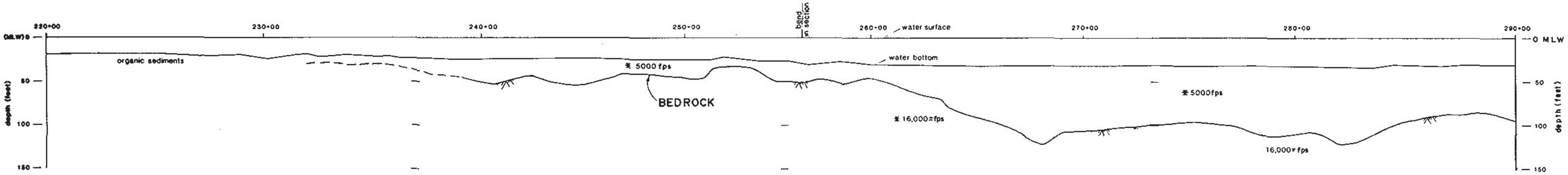
▨ Bedrock surface above -45 feet below MLW

* 5000 fps Seismic velocity in Ft / SEC

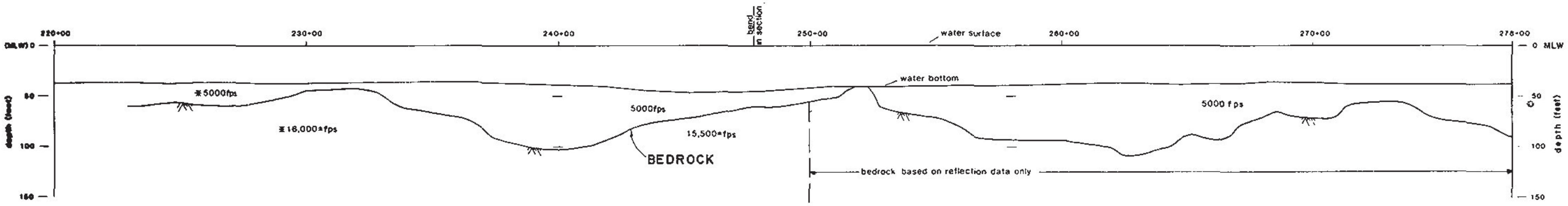
● Boring

PLAN- BEDROCK ELEV. CONTOURS
SCALE: 1" = 200'

East Edge of Channel

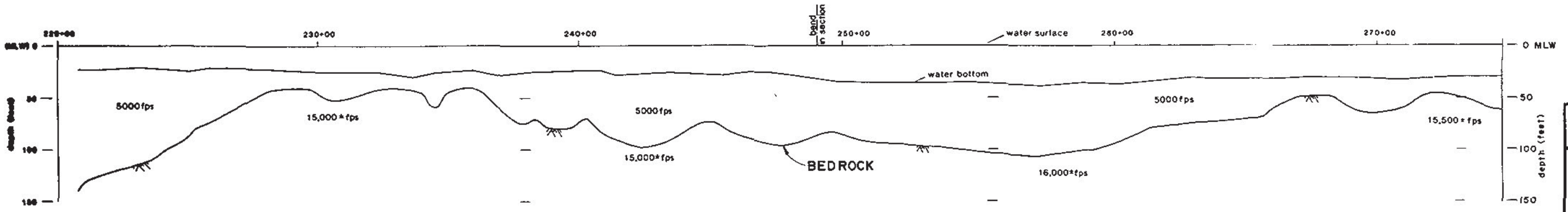


Center Line of Channel



NOTES:
1. STATIONING ALONG EAST AND WEST EDGE LINES PROJECTED FROM CENTER LINE OF CHANNEL.
2. DATUM IS MEAN LOW WATER
3. RESULTS ARE FROM A SEISMIC SURVEY DONE IN AUGUST 1987.

West Edge of Channel



GRAPHIC SCALES
1" = 50' 0 50 100
1" = 200' 0 500 1000
SCALE IN FEET

BEDROCK PROFILES
SCALE: 1" = 200' HORIZ.
1" = 50' VERT.

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

NEW HAVEN HARBOR, CONNECTICUT
BEDROCK PROFILES
FROM
SEISMIC SURVEY

FIGURE 7B

AUGUST 1988

3.8 2002 ESS, Inc. (October 22, 2002)

Cross Sound Cable Project: Area 6/7 Geotechnical Investigation, New Haven Harbor, New Haven, Connecticut: Environmental Science Services, Inc. and Ocean Surveys, Inc. for Cross-Sound Cable Company, LLC

ESS conducted 128 jet probes to map the extent and elevation of bedrock in Area 6/7. Area 6/7 is located upstream of the channel bend near the breakwaters. Sediment ranged from three to 15 feet thick. Sediments consisted of an upper layer of soft aqueous organic silt and clay sediment; a middle layer of dense fine to medium reddish-brown sand and gravel; and a lower layer of coarse sand and gravel till with some cobbles directly above bedrock.

ESS conducted 16 rock core borings in Area 6/7. Seven select rock core samples were laboratory tested for unconfined compressive strength (UCS), tensile strength, and unit weight. The bedrock consisted of light gray, medium to coarse grained, granodioritic gneiss with variable gneissic foliation.

The bedrock has been previously mapped as the Light House Gneiss. The Light House Gneiss is described as a pink or gray to red, medium grained, generally well foliated granitic gneiss of Proterozoic age (Figure 1).

The bedrock is generally hard and fresh to very slightly weathered. The Rock Quality Designation (RQD) generally ranged from 50% to 90% (fair to good quality). The total range of RQDs was 0% to 100%. The lowest RQDs were due to the presence of near vertical fractures. Fracture spacing was close to very close.

From the report's description of low RQD due to the presence of vertical fractures, it is unclear if the RQD method was correctly applied. For vertical fractures one should measure the length of the core centerline and not discount the entire length. It is also unclear if mechanical breaks were differentiated from natural breaks. If all breaks are assumed to be natural, this would result in a lower RQD which would result in underestimating the effort needed to remove the rock during dredging. Low RQDs might also be attributable to mechanical breaks from the use of a spud barge drilling platform rather than a jack-up barge or liftboat.

Laboratory results for UCS ranged from 12,087 psi to 20,447 psi. This range of UCS falls within Class B – High Strength intact rock. This range of UCS is most likely beyond the limits of cutter head dredgability and may also be beyond the productivity limits of backhoe dredgability.

Laboratory results for average splitting tensile strength ranged from 2,607psi to 4,062 psi with a bulk density of approximately 164 lbs. per cubic foot.

Based upon the laboratory results discussed above and RQDs greater than 50%, it is likely that rock will be removed via confined underwater blasting rather than by mechanical means.

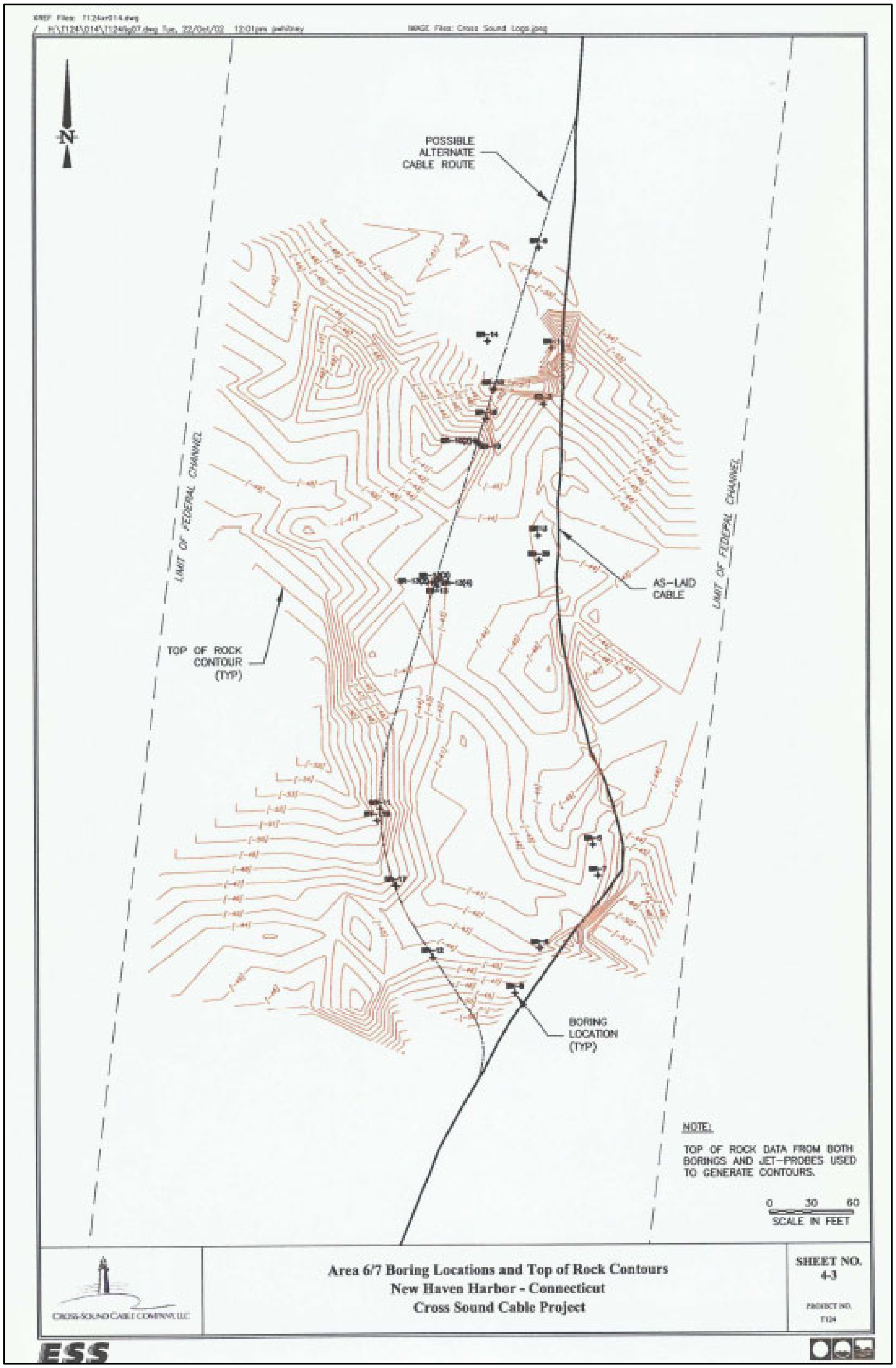


Figure 8: Area 6/7 Boring Locations and Top of Rock Contours, New Haven Harbor, Connecticut, Cross Sound Cable Project, ESS, 2002.

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