United States Coast Guard
Pier Improvements Analysis

Coast Guard Station Scituate, Massachusetts

US Army Corps
of Engineers
New England Division

SCITUATE HARBOR
U.S. COAST GUARD PIER IMPROVEMENTS ANALYSIS

JUNE 1990

PREPARED BY:

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NEW ENGLAND DIVISION
COASTAL DEVELOPMENT BRANCH

SCITUATE HARBOR
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EXECUTIVE SUMMARY

The U. S. Coast Guard has requested assistance from the Corps of Engineers in conducting a study of the wave climate and sediment transport relating to impacts of pier replacement at the Coast Guard Station located in Scituate, Massachusetts.

Scituate Harbor is a tidal estuary located at the extreme northwestern end of Cape Cod Bay, approximately thirteen (13) miles southeast of Boston and about thirty-three (33) miles northwest of the Cape Cod Canal. The structure in question consists of an open pile timber pier located on the south side of the harbor, just west of First Cliff.

The scope of work involved in the pier replacement includes: demolition of the existing timber piers, launchway, floating piers, and utilities, and the construction of a new timber pile supported pier with attached wave attenuator; a new concrete floating pier with steel pipe guide piles and aluminum gangway, and the associated utilities.

Wood slatting on the north side of the pier would act as the wave attenuator and offer protection to a floating pier to be constructed on the south, or leeward side of the fixed pier. The new pier will also have a denser configuration of timber pile supports.

The Corps' study addresses concerns that the pier modifications will increase shoreline erosion during storms by diverting wave action laterally towards the shoreline. The data includes existing wave and water circulation patterns, the direction and volume of sediment transport, and how any changes may affect coastal resources on abutting properties and in the general vicinity of the pier. In addition, a local landowner is concerned that any increase in the erosion will undermine his adjacent property and the existing road that is used as access to the boathouse and adjacent properties. The Coast Guard has determined that it is necessary to investigate these concerns because of the possible threat to the roadway and the importance of continuing the cooperative relationship with the surrounding community.

The following is a summary of our findings:

- A wave refraction analysis shows it is unlikely that variations in wave characteristics between the with project and without project conditions will be substantial even though the proposed pile spacing is closer than the current pile spacing. It is also unlikely that the proposed pier will have any adverse impacts on present erosion patterns.

- Changes in wave reflection caused by pier modifications will be negligible.

- Current velocities will not be greatly affected by pier modifications. Since there are no significant changes in wave direction between the existing and future conditions there will also be no significant effect on the wave-induced current direction associated with pier construction.

- Neither the direction of sediment transport nor the longshore current velocity will be substantially altered by pier modifications.

- Any variations in wave-induced currents and sediment transport are due to changing the orientation of the middle section of the pier, lengthening the pier, providing closer spaced timber piles, and adding the wave attenuator screen.

- The construction of the proposed pier with its closer (than the existing configuration) spaced timber piles may reduce the amount of sediment transport to the leeward (south) side of the pier. Sediment transport along the shoreline northeast of the pier will not change substantially.

- Changes in the longshore transport rate are insignificant further away from the pier along the shoreline in either direction.

The findings of this study are highly dependent on the wave climate which exists in the immediate area of the pier. Since wave characteristics are not greatly affected by the pier modifications, it is unlikely that there will be any significant changes in the other coastal processes either. Our analysis assumed an impermeable wall, which conservatively reflects the conditions that the wave attenuator screen will create. The transfer of wave energy to the leeward side of the pier could be reduced from present conditions.

Based on the findings of this study, it can be concluded that construction of the proposed pier could result in a slight change in wave conditions that will alter both sediment transport at the shoreline southwest of the pier and wave-induced currents at the wave attenuator screen. However, these changes are considered negligible. The proposed modifications to the present configuration of the pier will not result in any substantial increase of erosion of the shoreline.

SCITUATE HARBOR
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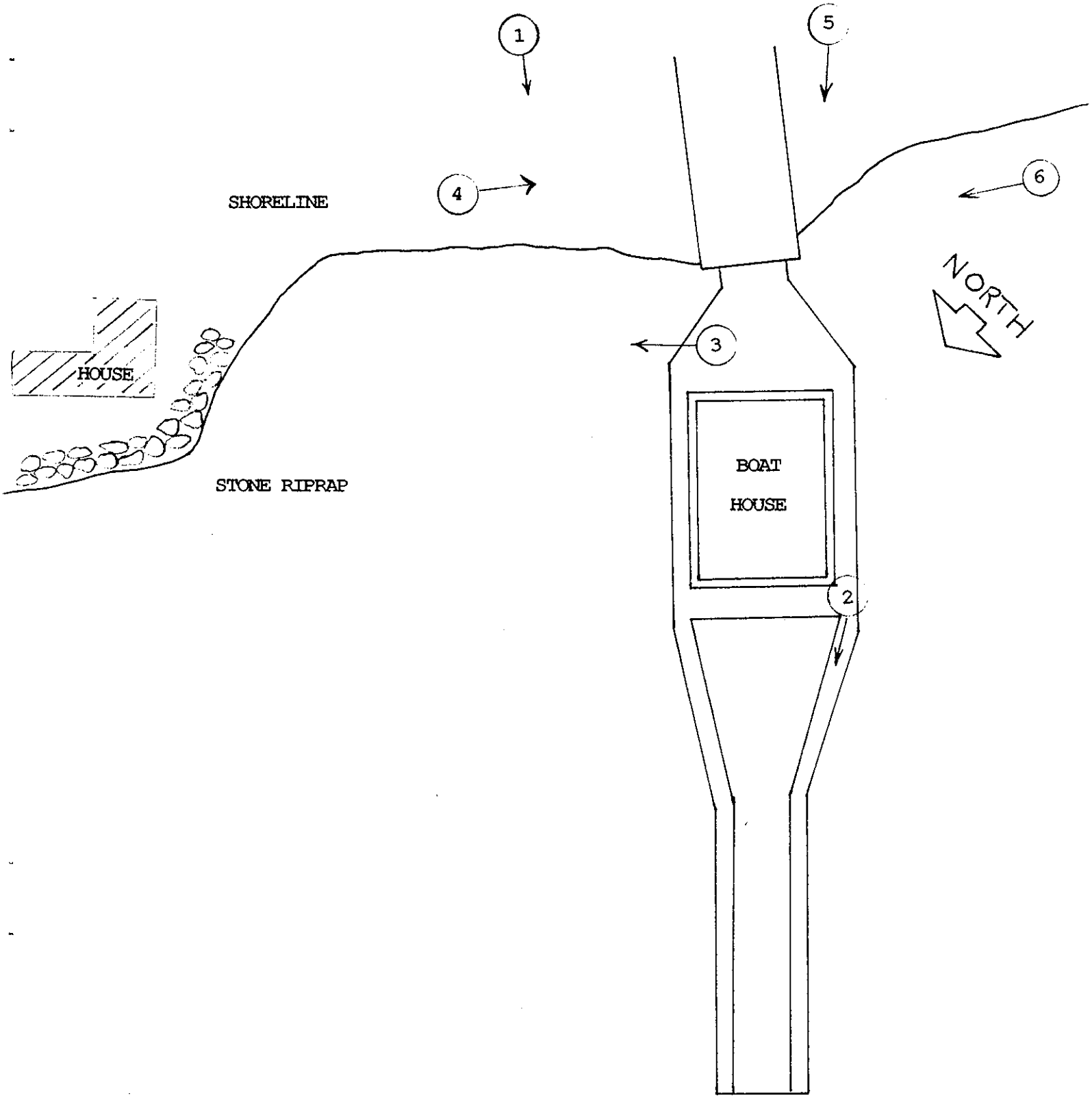


PHOTO LOCATION MAP

NOT TO SCALE

SCITUATE HARBOR
COAST GUARD PIER IMPROVEMENTS ANALYSIS

1. INTRODUCTION

The U. S. Coast Guard has requested assistance in conducting a study of the impacts of pier replacement on the wave climate and sediment transport in the vicinity of the pier. The scope of work involved in the pier replacement includes:

1) demolition of the existing timber piers, launchway, floating piers, and utilities,
2) construction of a new timber pile pier with attached wave attenuator,
3) construction of a new concrete floating pier with steel pipe guide piles and aluminum gangway,
and 4) providing the associated utilities.

Wood slatting on the north side of the pier would act as a wave attenuator and offer protection to a floating pier to be constructed on the south, or leeward side of the fixed pier. The new pier will also have a denser configuration of timber pile supports.

The Corps study focuses specifically on the following items:

Determination of Wave Climate.
Wave-Induced Currents.
Direction of Sediment Transport.
Volume of Sediment Transport.
Recommendations.

2. NATURAL SETTING

LOCATION

The Coast Guard Station is located at Scituate, Massachusetts. Scituate Harbor is a tidal estuary located at the extreme northwestern end of Cape Cod Bay, approximately thirteen (13) miles southeast of Boston and about thirty-three (33) miles northwest of the Cape Cod Canal. The open pile timber pier is located on the south side of the harbor, just west of First Cliff. See Location Map.

SITE DESCRIPTION

The existing timber boathouse and pier was constructed in 1936. Jetties are present on the north and south sides of the inlet to the harbor. The north jetty is approximately 1,020 feet long and the south jetty is 450 feet long. The north jetty was extended to its present length in 1959. The property northeast of the pier is privately owned and the shoreline is protected by large rocks placed there to protect against wave attack. See Photos 1-6.

The shoreline in the vicinity of the pier is composed of gravel, shells, and sand along the surface of the beach. The ramp leading from the road to the boathouse acts as a groin blocking sediment movement south along the shoreline. There is a height differential of approximately 4-5'

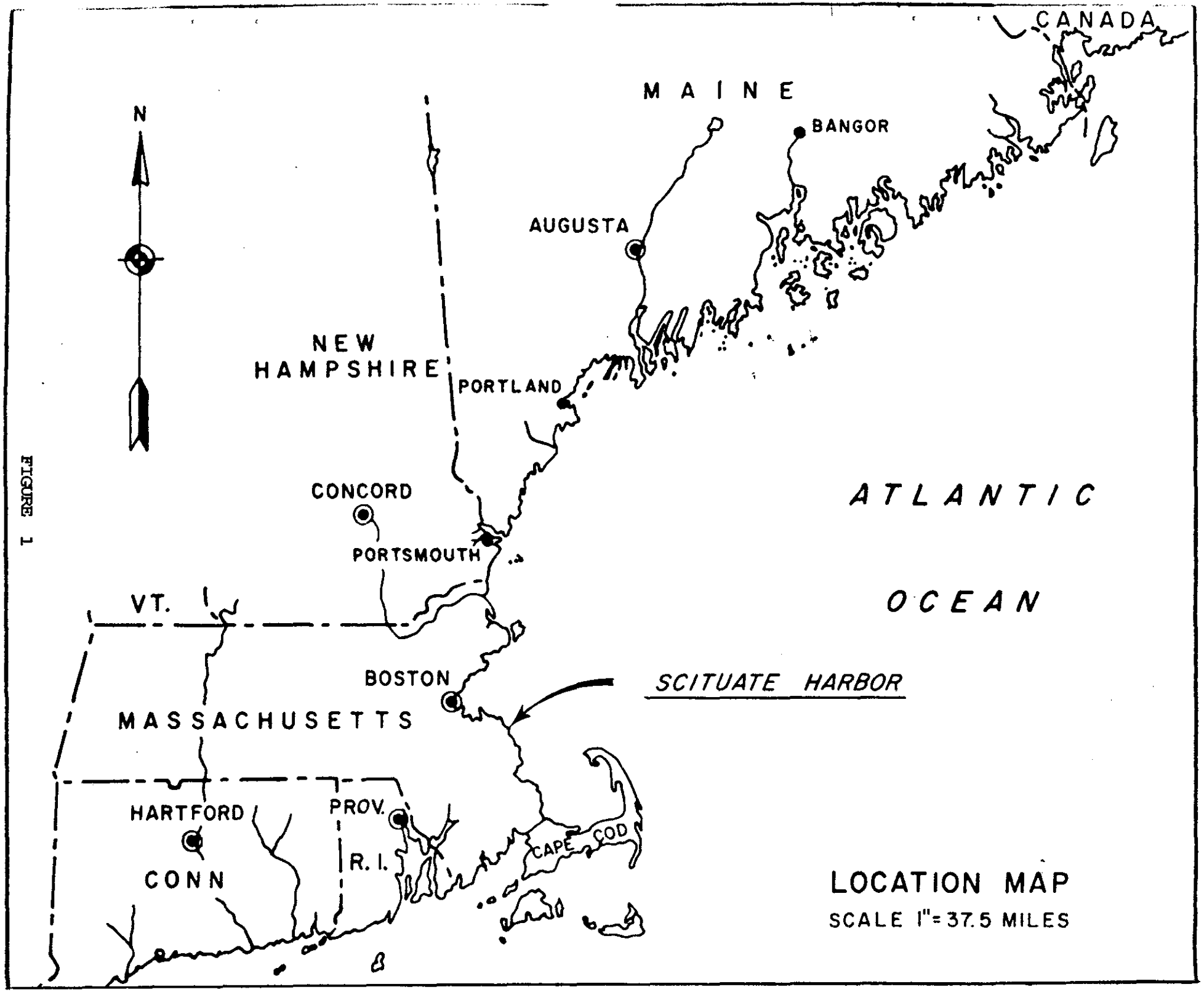
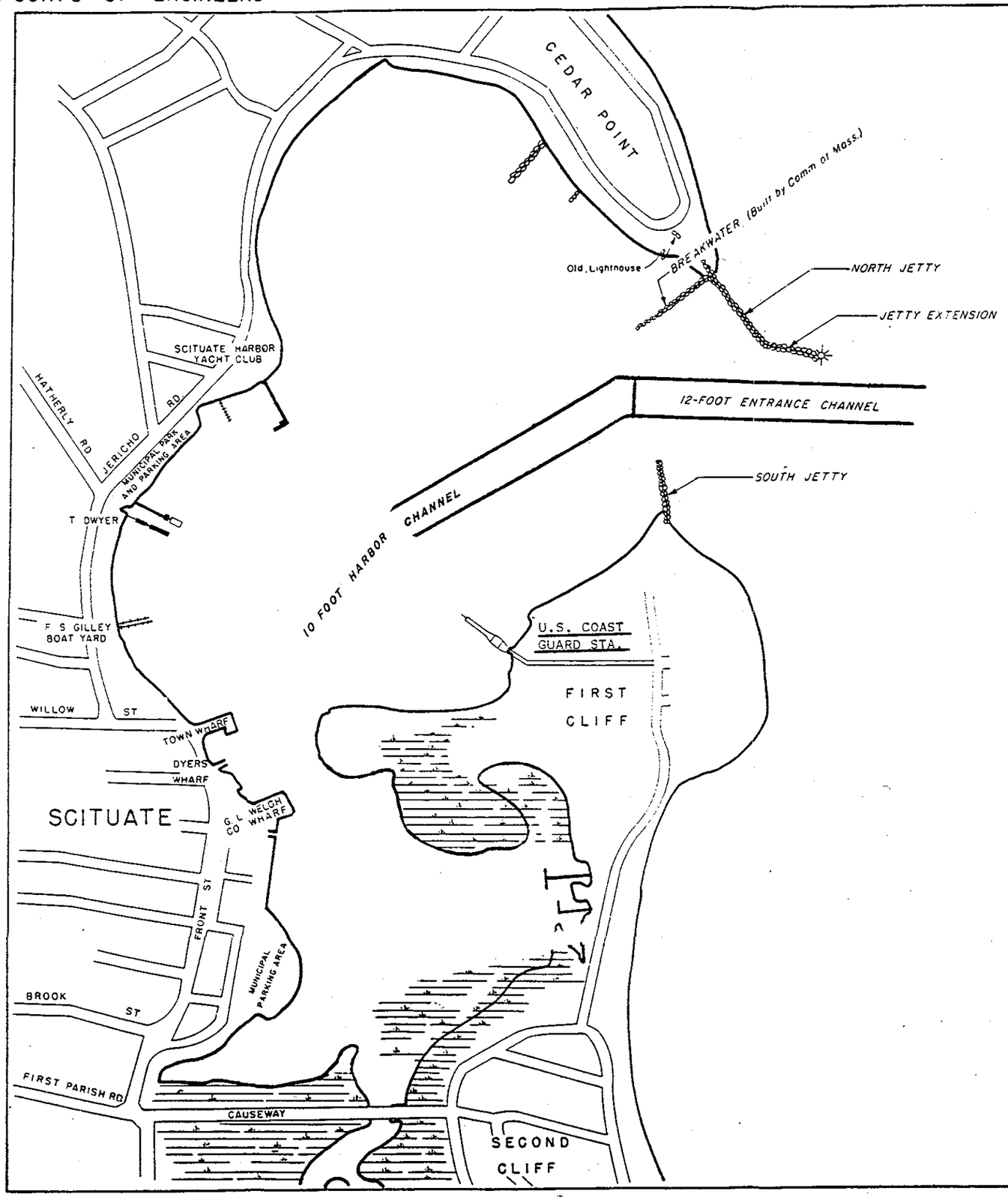
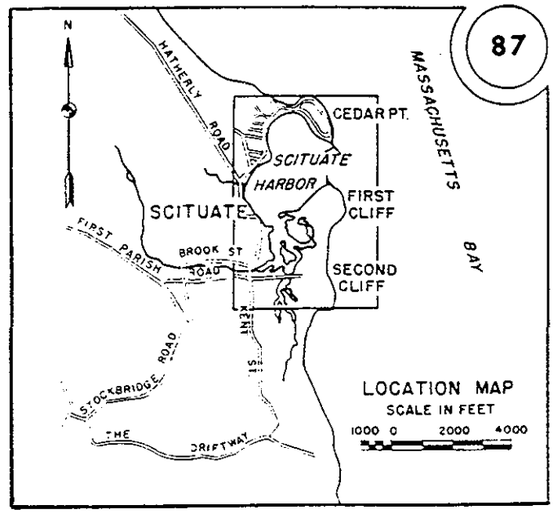

CANADA
MAINE
BANGOR
AUGUSTA
N
NEW HAMPSHIRE
PORTLAND
CONCORD
PORTSMOUTH
ATLANTIC
OCEAN
VT.
BOSTON
SCITUATE HARBOR
MASSACHUSETTS
HARTFORD
PROV.
CONN
R. I.
CAPE COD
LOCATION MAP
SCALE 1"=37.5 MILES

FIGURE 1





SCITUATE HARBOR, MASS.

30 SEPTEMBER 1986

IN 1 SHEET SCALE IN FEET

200 0 200 400 600 800 1000 1200

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

FIGURE 2

between the northeast and southwest sides of the ramp leading to the boathouse. See Photos 4 an 5. Note the buildup of material on the northeast side compared with the southwest side.

3. PROBLEM IDENTIFICATION

There are concerns that the pier modifications identified in the "Introduction" will increase shoreline erosion during storms by diverting wave action laterally towards the shoreline. The data requested by the Coast Guard in order to determine this includes existing wave and water circulation patterns, the direction and volume of sediment transport, and how any changes may affect coastal resources on abutting properties and in the general vicinity of the pier.

An owner of the property adjacent to the boathouse, Mr. Eugene MacDonald, is concerned that any increase in the erosion will undermine his adjacent property and the existing road that is used as access to the boathouse and adjacent properties. Mr. MacDonald has informed the Corps that accelerated erosion of his shoreline followed the extension of the north jetty at the harbor entrance in 1959. The Coast Guard has determined that it is necessary to investigate these concerns because of the possible threat to the roadway and the importance of continuing the cooperative relationship with the surrounding community.

4. WAVE CLIMATE

The Corps of Engineers Coastal Engineering Research Center (CERC) has developed Sea State Engineering Analysis System (SEAS) which is a data base containing the sea conditions along the U. S. coast at 3 hour intervals for the years 1956-1975. The data was hindcast using actual meteorological conditions for the time period. Atmospheric pressure differences were used to generate wind speeds at a 19.5 meter elevation. A numerical model utilized these wind speeds to simulate wave generation. Available data includes significant wave height, peak spectral period, and wave direction.

Three phases were conducted for the SEAS study. Phase I is the numerical hindcast of deepwater wave data. Phase II is the derivation of wave data which is subjected to refraction, diffraction and shoaling effects. Phase III is the transformation of the Phase II data into shallow water. Each phase used in the SEAS study brought the waves closer to the shoreline.

Phase II data was used to generate the specific wave conditions found at the entrance to Scituate Harbor. It used deepwater wave conditions and refined it to better reflect the sheltering effects of the continental shelf geometry.

Phase III wave data was not used because of conditions which are "site-specific" and which limit the usefulness of the data derived in this particular phase.

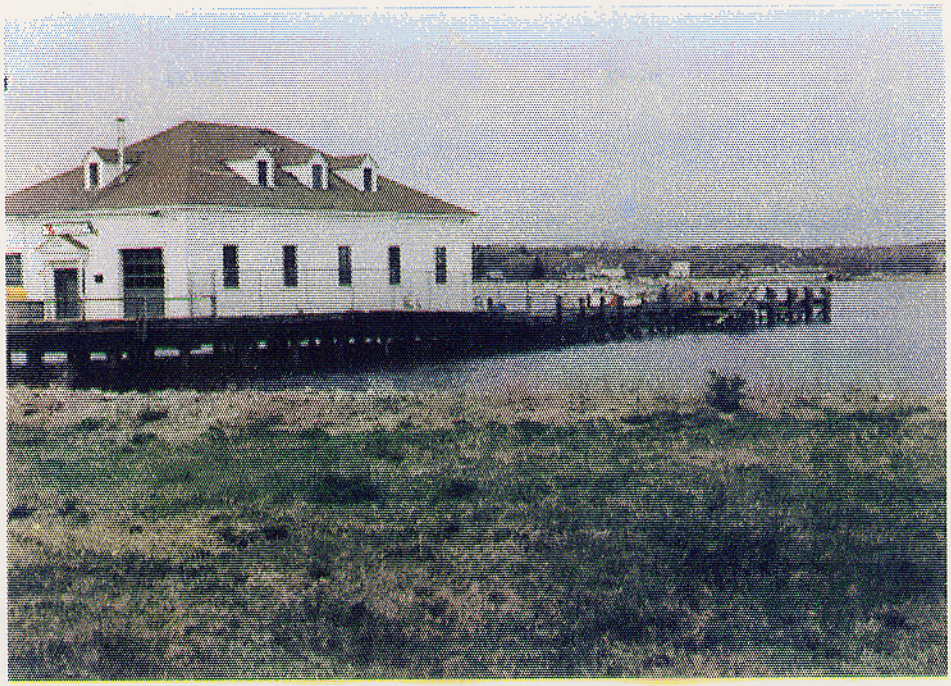


PHOTO 1 - COAST GUARD STATION - BOATHOUSE AND PIER, APRIL 1990

PHOTO 2 - EXISTING PIER CONFIGURATION, MARCH 1989

PHOTO 3 - RIPRAP AND SHORELINE NORTHEAST OF BOATHOUSE, MARCH 1989

PHOTO 4 - NORTH SIDE OF BOAT RAMP, MARCH 1989
NOTE ACCUMULATION OF MATERIAL

PHOTO 5 - SOUTH SIDE OF BOAT RAMP, APRIL 1990
NOTE LACK OF ACCUMULATION OF MATERIAL
(SEE PHOTO 4)

PHOTO 6 - SOUTH ELEVATION OF PIER AND BOATHOUSE, APRIL 1990

TABLE 1

SEAS SYSTEM REPORT

PERCENT OCCURENCE (X1000) OF HEIGHT AND PERIOD BY DIRECTION

22.5 DEGREES ABOUT 90.0 DEGREES AZIMUTH

STATION: A2013 42.54N/ 70.23W

NO. CASES: 3579
% OF TOTAL: 6.1

HEIGHT IN METERS	PEAK PERIOD (IN SECONDS) 0.0-2.9	3.0-4.9	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.	19.0-LONGER	TOTAL
0.0-0.9	484	1262	376	1307	20	308	.	.	.	.	3757
1.0-1.9	.	99	544	424	82	361	.	.	.	.	1510
2.0-2.9	.	.	123	277	23	68	.	.	.	.	491
3.0-3.9	.	.	25	231	15	5	.	.	.	.	276
4.0-4.9	.	.	.	34	23	.	.	.	.	.	57
5.0-5.9	.	.	.	.	20	1	.	.	.	.	21
6.0-6.9	.	.	.	.	3	.	.	.	.	.	3
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	484	1361	1068	2273	186	743	0	0	0	0	

MEAN HS(M) = 1.1 LARGEST HS(M) = 6.3 MEAN TP(SEC) = 6.2

MEAN HS(FT.) = 3.6 LARGEST HS(FT.) = 20.7

The Phase II SEAS station located closest to Scituate Harbor is A2013. This is located at 70.23 degrees west longitude and 42.54 degrees north latitude. This is approximately 33 nautical mile in a northeast direction from Scituate Harbor.

For each direction, SEAS calculates the percent of the waves coming from that direction, average significant wave height, maximum significant wave height and average peak spectral period over the twenty year period. The SEAS data used to generate wave heights at the harbor entrance was derived from Table 1.

Mean Significant Wave Height: 3.6 ft. ; Mean Period: 6.2 seconds

Largest (Storm) Wave Height: 20.7 ft. ; Peak Period: 11.0 seconds

This data is for waves which come directly from the east. Although slightly larger waves are experienced coming from the northeast, the east direction was chosen because the entrance to the harbor opens to the east and this will give the "worst case" condition for further wave analysis as described below.

A wave refraction analysis associated with this study was applied to two locations. The first area examined was immediately outside the harbor entrance. The second area was inside the harbor and included the pier and adjacent shoreline. Both were accomplished using the Regional Coastal Processes Linear Wave Propogation model (RCPWAVE) which is a computer program which solves Berkhoff's mild slope equation using an iterative finite difference scheme. It calculates refraction and diffraction effects assuming linear waves. The program does not include energy dissipation except in the surf zone where it is introduced when the waves break. RCPWAVE was developed by the U. S. Army Corps of Engineers Coastal Engineering Research Center (CERC), and is described in CERC Technical Report 86-4.

RCPWAVE requires bathymetry data, deep water wave height, wave period and wave direction as input. The bathymetry data for the refraction analysis outside the harbor was obtained from nautical chart number 244 (U.S. Coast and Geodetic Survey, 1968) and placed in a grid for further analysis. The wave height, period, and direction was obtained from the SEAS data (Table 1), and consisted of wave characteristics for both the average day wave and storm waves. This was then used in the refraction analysis outside the harbor. The output consisted of wave heights and direction of approach at the entrance to the harbor.

The wave characteristics generated from the first analysis were then used to perform the wave refraction analysis for inside the harbor. The bathymetry data for the refraction analysis inside the harbor was obtained from a condition survey of the harbor from May 1983 and was placed in a grid format. Due to the physical setup of the harbor, and the results of the refraction analysis outside the harbor entrance, only waves entering the harbor at a particular angle were studied. This angle was

approximately 80 degrees from the shore normal and is indicative of waves directly approaching the pier from the harbor entrance. See Figure 3.

Waves which propagate into the harbor at a greater angle tend to diverge, or spread out as they approach the pier. Waves coming into the harbor at less of an angle to the shore normal than 80 degrees are highly unlikely. The wave data which would cause the most adverse effects at the shoreline and pier were used to obtain a "worst case" condition. See Figures 3 through 6. This was accomplished for the average day and storm wave conditions for both the existing pier configuration and the proposed (future) pier configuration. The wave characteristics used to generate the conditions specifically in the area of the pier were:

Average Day: Height = 3.0 ft. ; Period = 5.8 seconds

Storm : Height = 8.0 ft. ; Period = 9.5 seconds

It was assumed that the worst condition for interrupting sediment transport and wave-induced currents, and causing modified erosion patterns of the adjacent shoreline, would be generated if the timber pile pier acted as a solid vertical wall. This condition was used in the refraction analysis for both the "existing" and "future" scenarios. It should be noted that the proposed closer timber pile spacing and presence of a wave attenuator screen at the modified pier will cause it to <u>not</u> act as an impermeable vertical wall. Since our analysis assumes an impermeable vertical wall, the magnitude of any adverse impacts obtained from further analysis will most likely be greater than what can actually be expected.

Figures 3 through 6 plot the angle the waves make with the shoreline in each cell of the grid. The wave crest is perpendicular to the line of the wave angle and wave propagation is toward the shoreline. This is not a ray trace; it shows wave angle but not areas of energy concentration. However, even though data for energy concentration is not available, it is reasonable to infer that the patterns of wave convergence are indicative of areas of energy concentration. Because of the extreme variability of the bottom bathymetry, the results are not definitive. Very irregular bottom bathymetry and/or very oblique wave incidence may cause the RCPWAVE program to produce questionable results. Both of these conditions existed while performing the refraction analysis for the inner harbor. Although these conditions may produce erroneous results in certain localized areas of the grid they are valuable tools when used on a comparative basis, such as between the existing and future conditions. The results of the RCPWAVE refraction analysis are summarized below:

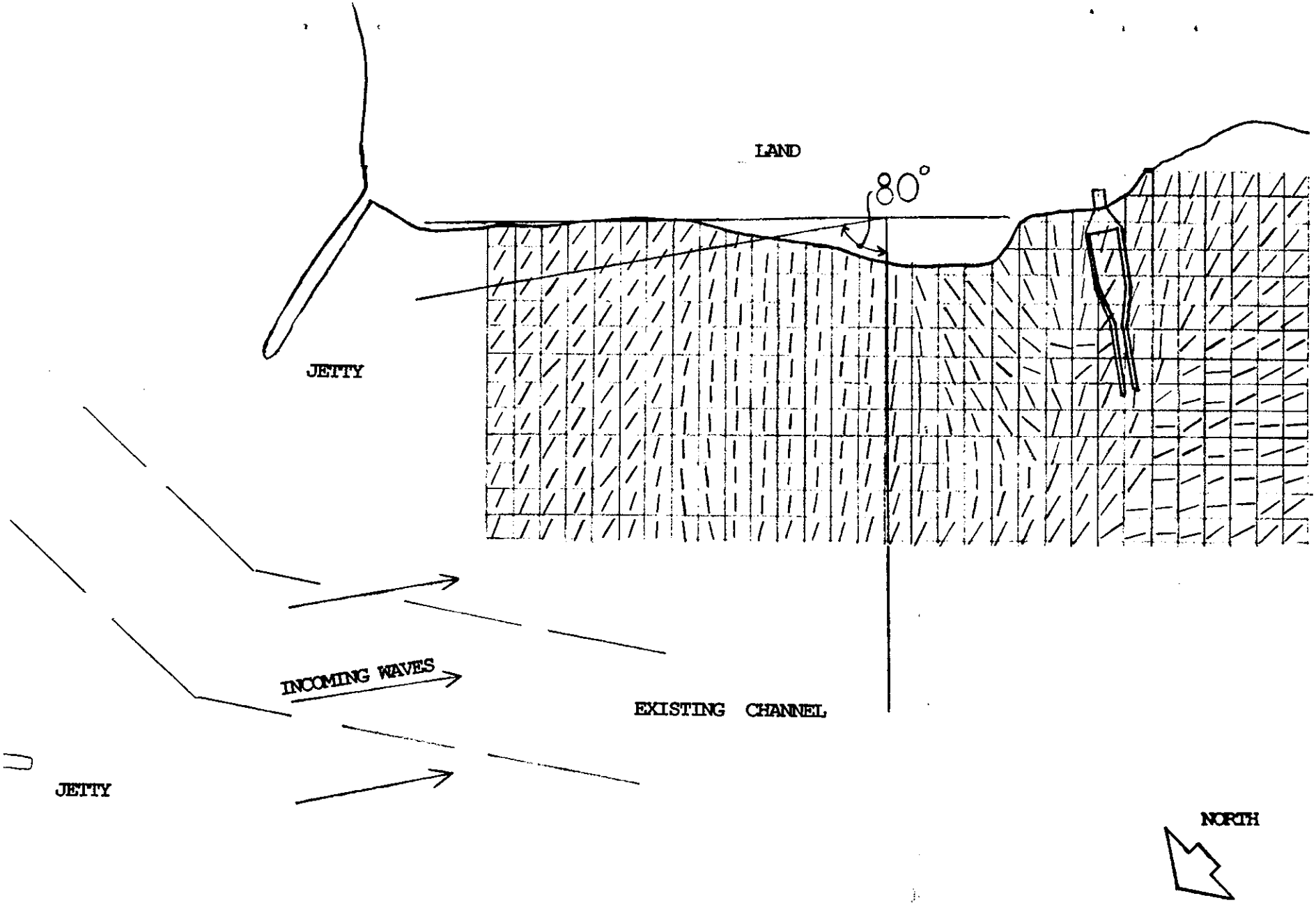
Along the shoreline:

1) Wave characteristics (wave heights, wave angles, or breaking wave conditions) along the shoreline in the vicinity of the pier show no large variations or significant changes due to pier modifications. However, there are small changes in certain areas, such as a slight increase in wave heights, especially at the shore northeast of the pier. This effect may be due to the assumption that the pier acts as an impermeable vertical wall.

Adjacent to pier extension:

2) Wave characteristics directly adjacent to the proposed pier extension do exhibit some change in both height and direction, but this is highly localized and the effects of this do not interfere with the general wave patterns exhibited in the area or at the shoreline.

Any variations in wave characteristics between the existing and future conditions may be an exaggerated representation of the actual situation (open pile construction) versus the assumed condition (solid vertical wall) of the pier. It is unlikely that these variations will be substantial even though the proposed pile spacing is closer than the current pile spacing. It is also unlikely that the proposed pier will have any adverse impact on present erosion patterns.



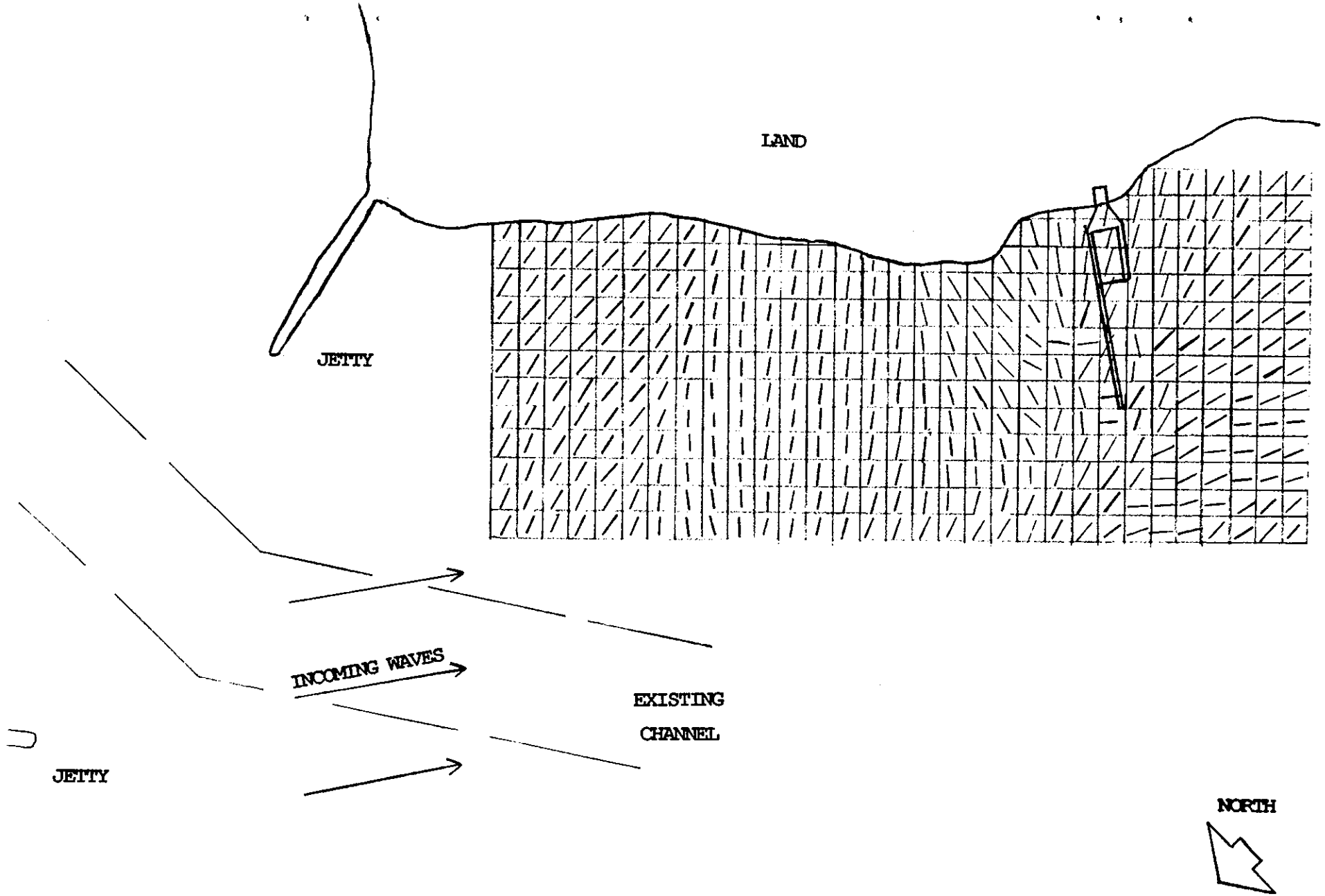
WAVE REFRACTION ANALYSIS - SCITUATE HARBOR

AVERAGE DAY WAVE CONDITION

EXISTING PIER CONFIGURATION

SCALE: 1"=200'

FIGURE 3



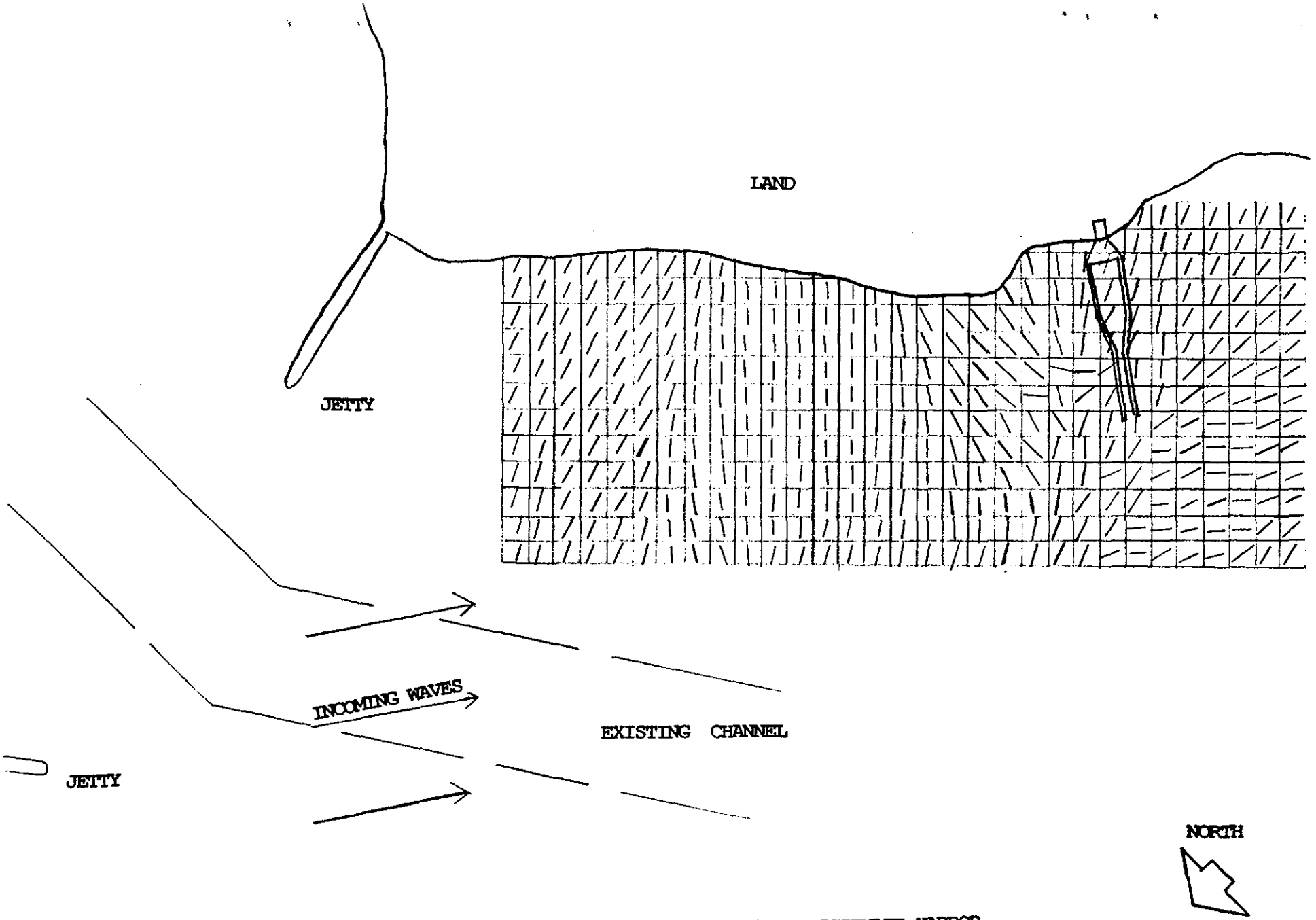
WAVE REFRACTION ANALYSIS - SCITUATE HARBOR

AVERAGE DAY WAVE CONDITION

FUTURE PIER CONFIGURATION

SCALE: 1"=200'

FIGURE 4



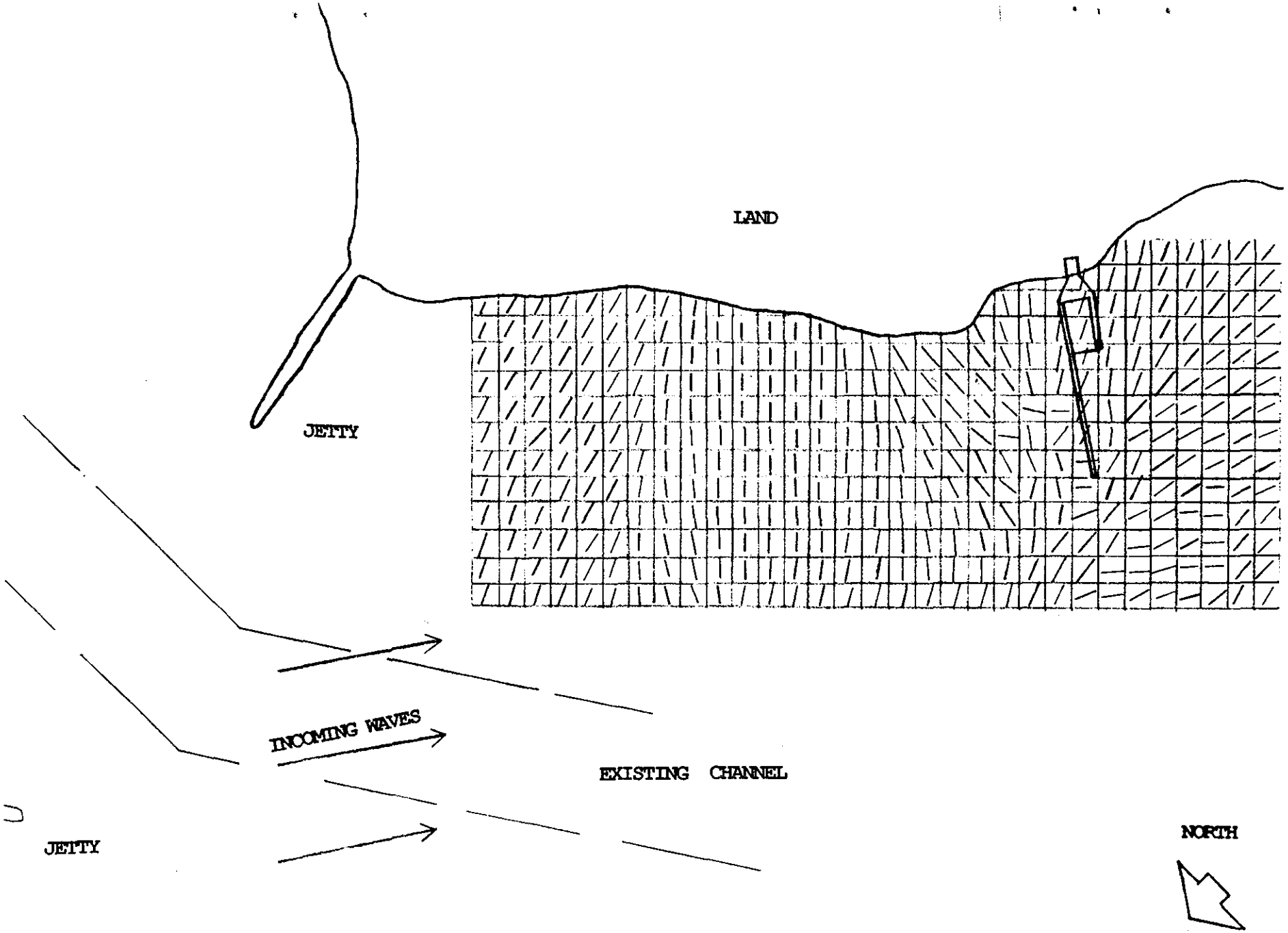
WAVE REFRACTION ANALYSIS - SCITUATE HARBOR

STORM WAVE CONDITION

EXISTING PIER CONFIGURATION

SCALE: 1"=200'

FIGURE 5



WAVE REFRACTION ANALYSIS - SCITUATE HARBOR

STORM WAVE CONDITION

FUTURE PIER CONFIGURATION

FIGURE 6

SCALE: 1"=200'

5. WAVE REFLECTION

Wave reflection is often an important consideration in the design of coastal structures associated with harbor development. The reflection of wave energy and absence of sufficient energy dissipation within a harbor complex can result in a buildup of energy in a localized area. This wave energy buildup has been known to result in an increase of erosion to an adjacent shoreline. This situation was investigated for both the "Average Day" and "Storm" wave conditions for the existing and future scenarios.

The pier was assumed to act as an impermeable vertical wall. Wave reflection analysis was accomplished using the Automated Coastal Engineering System (ACES) developed by the Corps' Waterways Experiment Station. It estimates wave height modification due to combined diffraction and reflection near structures such as piers. Certain assumptions inherent in this approach include linear, monochromatic (same length and period), unidirectional waves, and constant water depth. The structure is assumed to be straight with vertical walls which are treated as fully reflecting. Wave height modifications due to combined diffraction and reflection near the pier were obtained for both the existing and future conditions. Table 2 gives a summary of the results from this analysis based on average day wave conditions. These results are best used on a comparative basis between the existing and future conditions.

The new pier extension with the wave attenuator screen will most likely not add any significant wave buildup to the area. From the RCPWAVE wave refraction analysis, the incident wave impinging on the pier in this area will not reflect towards the shoreline. See Figures 7 through 10. Also, the analysis of reflected wave heights shows only a lower change in wave heights in this area. Figures 7 through 10 show Stations where comparisons of wave heights were made between the existing and future conditions. See Table 2, Station 1.

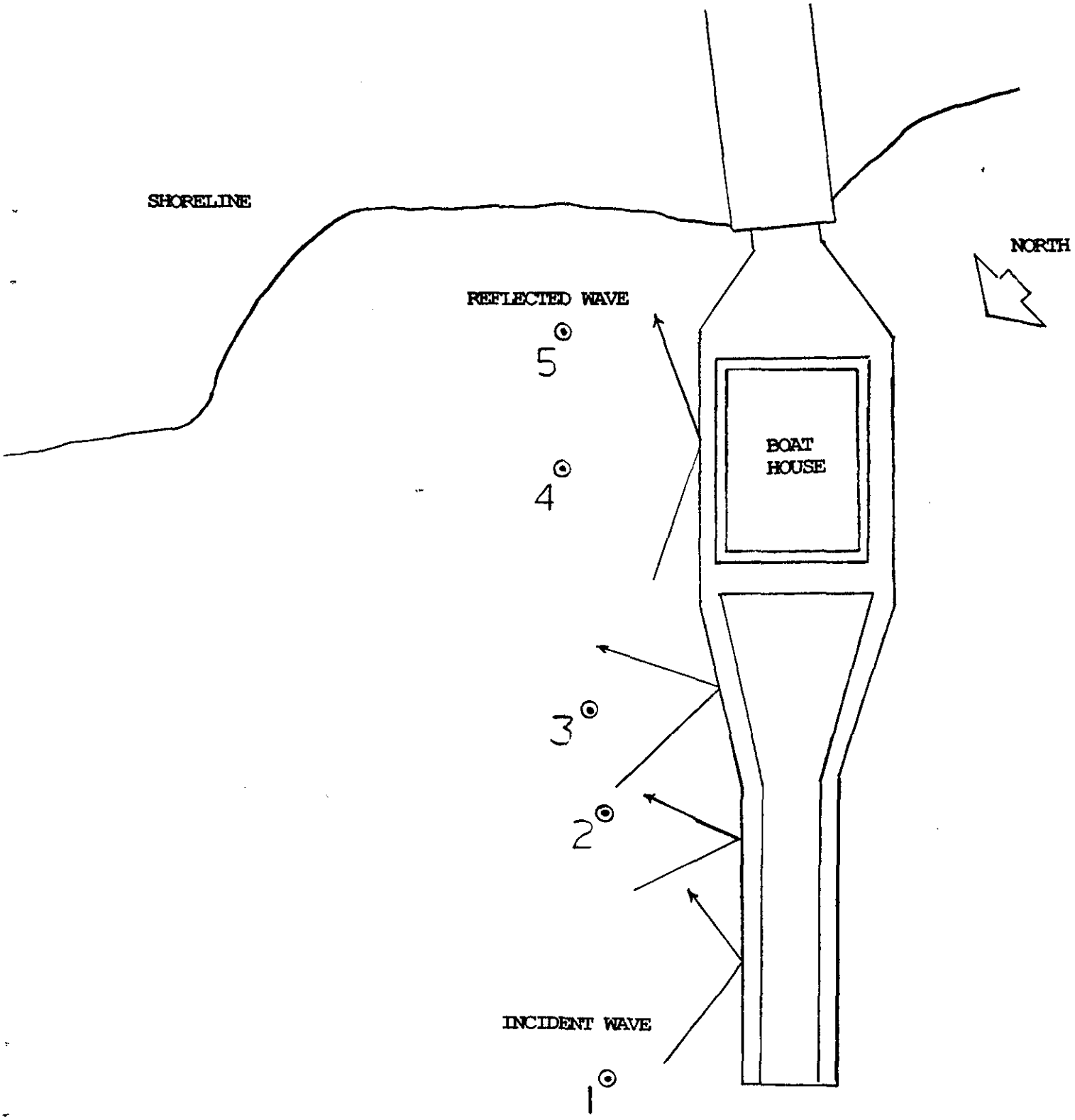
There will also not be any significant change in the reflected wave angle associated with the rest of the pier length, except at the portion of pier which will be straightened out during pier modification. This segment of pier accounts for approximately 30% of the total pier length. By comparing the existing and future conditions at this part of the pier, the reflected waves will be directed more towards the shoreline in the future condition. The future reflected wave heights in the area of pier straightening (Stations 2 & 3) are less than those exhibited in the existing condition, except for Station 2 in the storm wave condition. The changes in wave heights at Stations 4 and 5 are slight and should not have any significant adverse effects on the shoreline.

Conclusion

The magnitude of any changes of reflected waves due to pier modifications will actually be less than those computed because the pier will not reflect all wave energy, only a small fraction of it. Therefore, changes in wave reflection caused by pier modifications will be negligible.

TABLE 2
WAVE REFLECTION

	STATION	REFLECTED WAVE HEIGHT (FT.) EXISTING	REFLECTED WAVE HEIGHT (FT.) FUTURE
AVERAGE	1	0.89	0.36
	2	4.22	0.81
	3	3.47	2.52
	4	0.47	0.39
	5	0.47	0.39
STORM	1	1.17	0.60
	2	0.54	2.56
	3	1.93	0.92
	4	0.16	0.22
	5	0.16	0.22



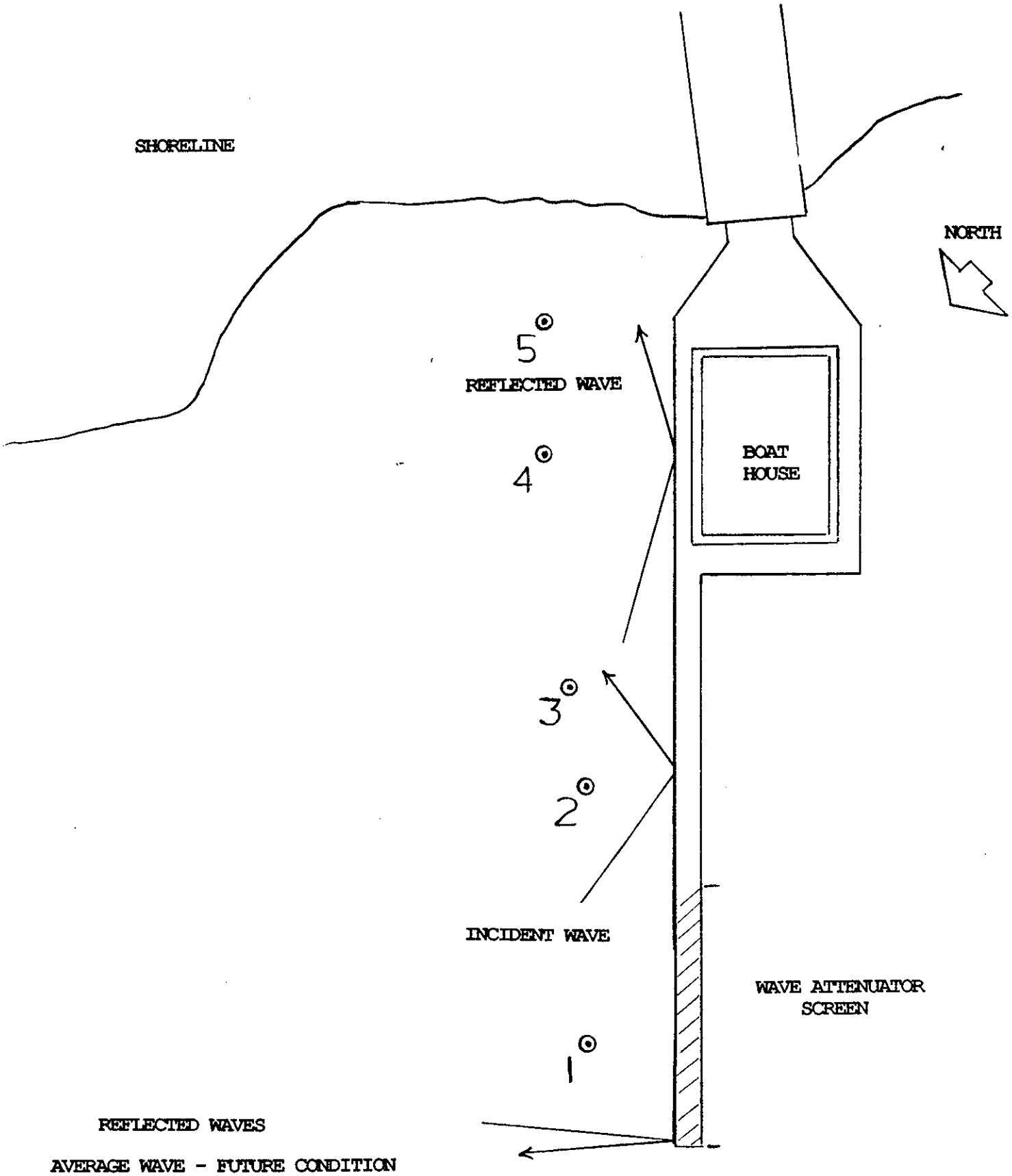
REFLECTED WAVES

AVERAGE WAVE - EXISTING CONDITION

STATION ⊙

SCALE: 1"=40′

FIGURE 7



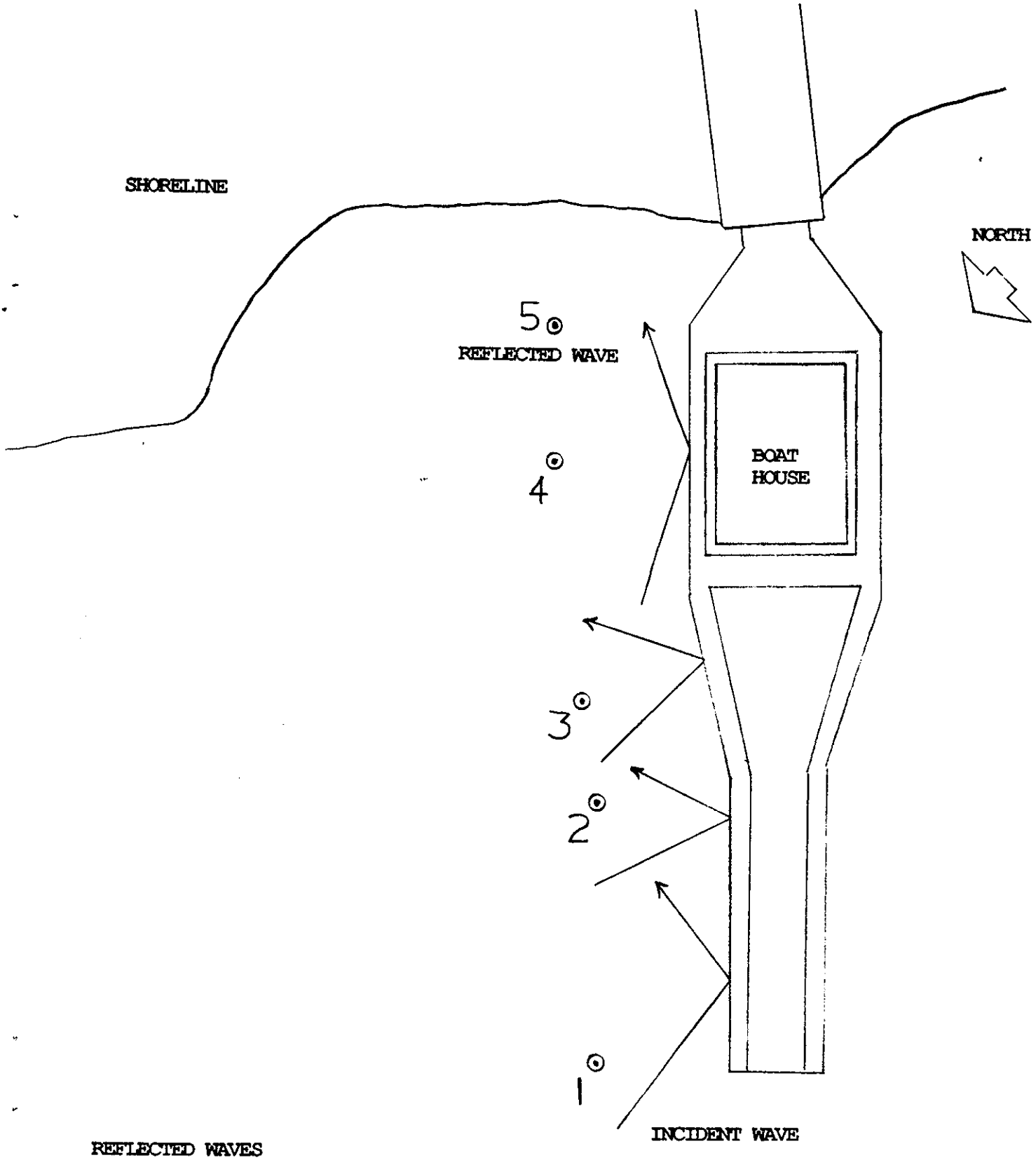
REFLECTED WAVES

AVERAGE WAVE - FUTURE CONDITION

STATION ⊙

SCALE: 1"=40'

FIGURE 8



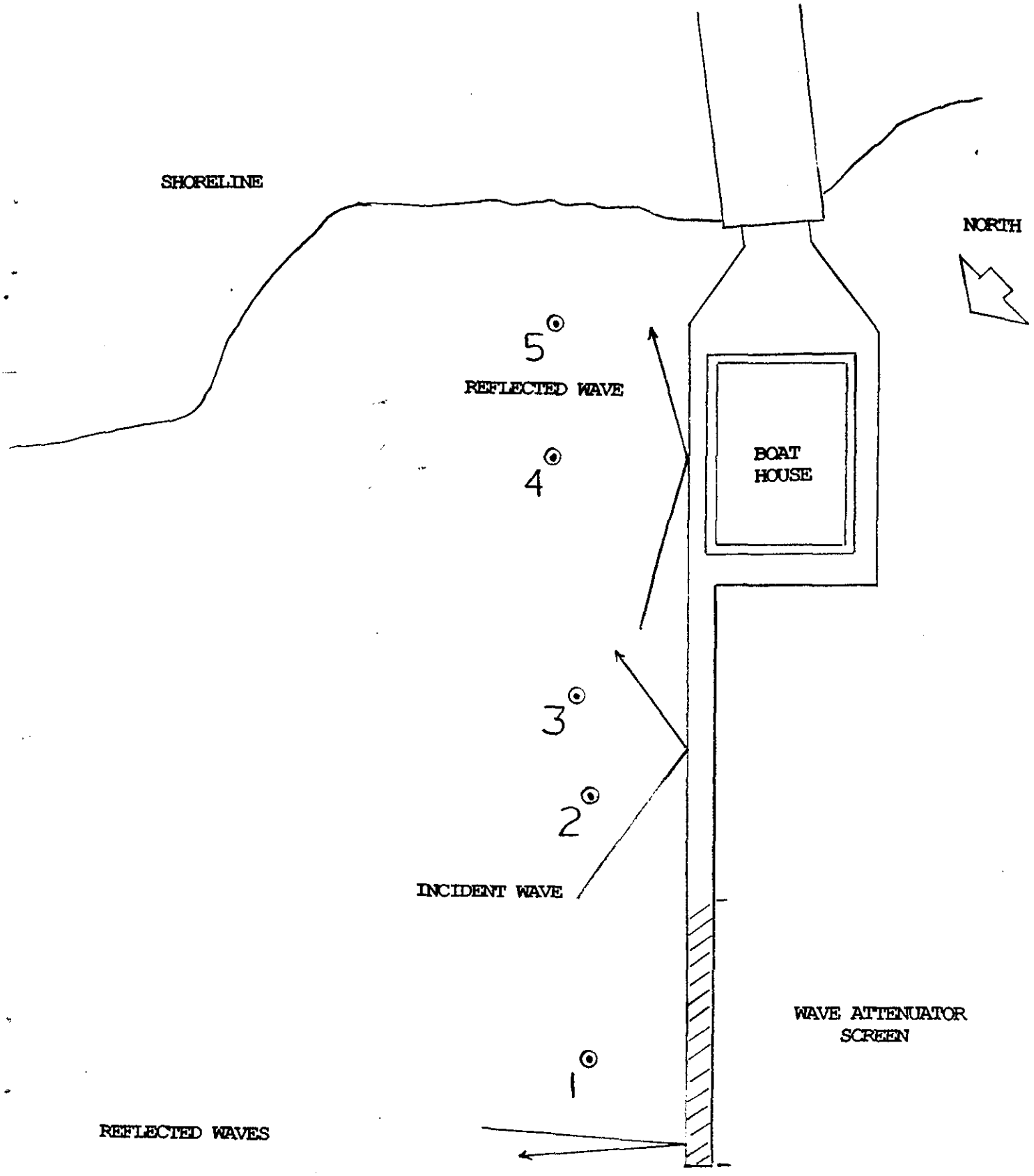
REFLECTED WAVES

STORM WAVE - EXISTING CONDITION

STATION ⊙

SCALE: 1"=40'

FIGURE 9



STORM WAVE - FUTURE CONDITION

STATION ⊙

SCALE: 1"=40′

FIGURE 10

6. WAVE-INDUCED CURRENTS

This section discusses the effects of pier modification on the wave-induced currents surrounding the pier. In relatively shallow water, wave-induced water particle motion is nearly straight along the bottom, and it is this wave-induced water particle motion that causes the sediment at the bottom to move, or be transported. Using methods developed in the Shore Protection Manual (Vol. 1, 1984) by the Coastal Engineering Research Center, the horizontal length (2A) of the path moved by a water particle as a wave passes in shallow water and the maximum horizontal water velocity (U max) of the water particles are given in Tables 3 through 6. These results should be used only on a comparative basis.

Velocity

Comparing U max in Tables 3 through 6 between the existing and future pier configurations shows that there are localized areas where the current velocity will change due to pier modifications. These changes are most noticeable in the area of the proposed wave attenuator screen. There is a definite decrease in current velocity which occurs due to pier modifications in cells (32,9), (33,8) and (33,9) during the average day wave conditions. These cells are defined on Figures 11 and 12. Since the current velocity is less, there may be deposition of sediment material in front of the screen in this area. However, during relatively infrequent storm periods, the current velocity in cells (33,8) and (33,9) are higher than in the existing condition. (See Figure 12) This implies that there will not be deposition of material during storms. Figures 11 and 12 show changes in U max, the velocity of the wave-induced currents, between the existing and future conditions for both average day and storm waves. The prediction of sediment deposition or scour is based on the wave-induced current velocities and is only an indication of possible effects on sediment movement in the area of the wave attenuator screen.

Direction

The direction of these currents in the vicinity of the pier will also change based on the wave directions derived from the refraction analysis for the existing and future scenarios. The direction of the wave-induced current may be inferred from the direction of the wave crest in each cell of the RCPWAVE grid. A graphic representation of the wave-induced current direction for storm driven waves is shown in Figures 13 and 14 for the area around the pier. The arrows are indicative of wave-induced current direction only, and have no significance as to the velocity of the currents. This is a generalized representation of the currents based on the wave directions generated through the refraction analysis.

The most significant change in wave-induced current direction occurs where the pier will be extended. This is also in the area of the proposed wave attenuator screen. However, these changes will be highly localized. The analysis shows that there is little change in the direction of wave-induced currents along the adjacent shoreline in either direction or further offshore in deeper water.

Based on these results, it may be assumed that existing wave-induced water particle motions along the shoreline will <u>not</u> be significantly affected by the proposed pier modifications.

Summary and Conclusions

Although wave-induced current velocities do exhibit some changes, especially in the area of the proposed wave attenuator screen, this does not necessarily mean that there will be any substantial change in erosion at the shoreline. The model study has assumed that the entire pier, including the area with the wave attenuator screen, is an impermeable wall which extends below Mean Low Water to the bottom. Since the proposed wave attenuator screen is approximately 20% porous and will not extend to the bottom or be impermeable, the magnitude of changes in wave-induced current velocities exhibited in Tables 3 through 6 will most likely not be significant.

Wave-induced current velocities predict the water particle motions which may then be used to predict movement of sediment along the bottom. Since sediment characteristics have not been identified at the site, wave-induced current velocities are only an indication of possible sediment movement in the area. Therefore, changes in current velocities exhibited in Tables 3 through 6 are considered a conservative estimate of present and future conditions.

There will also be no significant negative effects on the wave-induced current direction associated with pier construction.

The results obtained by this analysis are limited by the capabilities of the wave refraction analysis which defines the wave climate of the area.

TABLE 3

SCITUATE HARBOR WAVE-INDUCED CURRENT ANALYSIS

AVERAGE WAVE - EXISTING CONDITION

CELL(X,Y)	2A (FT.)	U max (FT./SEC.)	CELL(X,Y)	2A (FT.)	U max (FT./SEC.)
(28,5)	2.095	1.135	(34,1)	2.095	1.135
			(34,2)	2.095	1.135
(29,4)	2.095	1.135	(34,3)	2.095	1.135
(29,5)	2.619	1.419	(34,4)	2.619	1.419
			(34,5)	2.095	1.135
(30,3)	1.571	0.851	(34,6)	2.780	1.506
(30,4)	2.095	1.135	(34,7)	0.741	0.401
(30,5)	3.143	1.702	(34,8)	17.810	9.647
			(34,9)	1.571	0.851
(31,3)	1.571	0.851	(34,10)	1.571	0.851
(31,4)	1.571	0.851	(34,11)	1.397	0.757
(31,5)	1.571	0.851	(34,12)	1.048	0.567
(31,6)	0.000	0.000			
(31,7)	0.000	0.000	(35,1)	2.095	1.135
(31,8)	0.000	0.000	(35,2)	2.095	1.135
(31,9)	0.000	0.000	(35,3)	2.095	1.135
(31,10)	0.828	0.449	(35,4)	2.095	1.135
(31,11)	1.397	0.757	(35,5)	2.095	1.135
(31,12)	1.921	1.040	(35,6)	3.334	1.806
			(35,7)	0.469	0.254
(32,3)	1.571	0.851	(35,8)	0.000	0.000
(32,4)	2.095	1.135	(35,9)	0.000	0.000
(32,5)	4.190	2.270	(35,10)	0.000	0.000
(32,6)	0.000	0.000	(35,11)	0.000	0.000
(32,7)	0.000	0.000	(35,12)	0.000	0.000
(32,8)	0.000	0.000			
(32,9)	1.111	0.602			
(32,10)	1.325	0.718			
(32,11)	1.491	0.807			
(32,12)	1.921	1.040			
(33,6)	7.857	4.256			
(33,7)	22.000	11.916			
(33,8)	23.572	12.768			
(33,9)	7.037	3.812			
(33,10)	1.491	0.807			
(33,11)	1.571	0.851			
(33,12)	1.397	0.757			

NOTE: 2A: HORIZONTAL DISTANCE WATER PARTICLE TRAVELS AS WAVE PASSES.

U max: MAXIMUM HORIZONTAL WATER VELOCITY

TABLE 4

SCITUATE HARBOR WAVE-INDUCED CURRENT ANALYSIS

AVERAGE WAVE - FUTURE CONDITION

CELL(X,Y)	2A (FT.)	U max (FT./SEC.)	CELL(X,Y)	2A (FT.)	U max (FT./SEC.)
(28,5)	2.095	1.135	(34,1)	2.095	1.135
			(34,2)	2.095	1.135
(29,4)	2.619	1.419	(34,3)	2.095	1.135
(29,5)	2.619	1.419	(34,4)	2.095	1.135
			(34,5)	2.095	1.135
(30,3)	2.095	1.135	(34,6)	4.705	2.548
(30,4)	2.619	1.419	(34,7)	4.815	2.608
(30,5)	3.143	1.702	(34,8)	12.048	6.526
			(34,9)	7.508	4.067
(31,3)	2.095	1.135	(34,10)	5.762	3.121
(31,4)	2.095	1.135	(34,11)	1.397	0.757
(31,5)	4.190	2.270	(34,12)	1.048	0.567
(31,6)	0.000	0.000			
(31,7)	0.000	0.000	(35,1)	2.095	1.135
(31,8)	0.000	0.000	(35,2)	2.095	1.135
(31,9)	0.926	0.502	(35,3)	2.095	1.135
(31,10)	0.994	0.538	(35,4)	2.095	1.135
(31,11)	1.397	0.757	(35,5)	2.095	1.135
(31,12)	1.921	1.040	(35,6)	4.815	2.608
			(35,7)	0.000	0.000
(32,3)	2.095	1.135	(35,8)	0.000	0.000
(32,4)	2.095	1.135	(35,9)	0.000	0.000
(32,5)	2.095	1.135	(35,10)	0.000	0.000
(32,6)	19.381	10.498	(35,11)	0.000	0.000
(32,7)	0.000	0.000	(35,12)	0.000	0.000
(32,8)	0.000	0.000			
(32,9)	0.556	0.301			
(32,10)	0.497	0.269			
(32,11)	1.491	0.807			
(32,12)	1.921	1.040			
(33,6)	2.095	1.135			
(33,7)	22.000	11.916			
(33,8)	18.857	10.214			
(33,9)	0.000	0.000			
(33,10)	2.816	1.525			
(33,11)	1.571	0.851			
(33,12)	1.397	0.757			

NOTE: 2A: HORIZONTAL DISTANCE WATER PARTICLE TRAVELS AS WAVE PASSES.

U max: MAXIMUM HORIZONTAL WATER VELOCITY

TABLE 5

SCITUATE HARBOR WAVE-INDUCED CURRENT ANALYSIS

STORM WAVE - EXISTING CONDITION

CELL(X,Y)	2A (FT.)	U max (FT./SEC.)	CELL(X,Y)	2A (FT.)	U max (FT./SEC/)
(28,5)	3.432	1.135	(34,1)	3.432	1.135
			(34,2)	3.432	1.135
(29,4)	3.432	1.135	(34,3)	3.432	1.135
(29,5)	3.432	1.135	(34,4)	4.290	1.419
			(34,5)	3.432	1.135
(30,3)	3.432	1.135	(34,6)	4.553	1.506
(30,4)	3.432	1.135	(34,7)	1.213	0.401
(30,5)	10.296	3.405	(34,8)	27.455	9.079
			(34,9)	5.720	1.892
(31,3)	3.432	1.135	(34,10)	6.578	2.175
(31,4)	3.432	1.135	(34,11)	6.578	2.175
(31,5)	6.006	1.986	(34,12)	4.004	1.324
(31,6)	0.000	0.000			
(31,7)	0.000	0.000	(35,1)	3.432	1.135
(31,8)	0.000	0.000	(35,2)	3.432	1.135
(31,9)	0.000	0.000	(35,3)	3.432	1.135
(31,10)	2.984	0.987	(35,4)	3.432	1.135
(31,11)	5.720	1.892	(35,5)	3.432	1.135
(31,12)	7.436	2.459	(35,6)	6.067	2.006
			(35,7)	0.000	0.000
(32,3)	2.574	0.851	(35,8)	0.000	0.000
(32,4)	3.432	1.135	(35,9)	0.000	0.000
(32,5)	3.432	1.135	(35,10)	0.000	0.000
(32,6)	6.864	2.270	(35,11)	0.000	0.000
(32,7)	0.000	0.000	(35,12)	0.000	0.000
(32,8)	0.000	0.000			
(32,9)	3.337	1.103			
(32,10)	4.612	1.525			
(32,11)	5.155	1.705			
(32,12)	8.580	2.837			
(33,6)	36.893	12.200			
(33,7)	36.893	12.200			
(33,8)	31.745	10.498			
(33,9)	4.247	1.404			
(33,10)	3.798	1.256			
(33,11)	7.722	2.554			
(33,12)	5.148	1.702			

NOTE: 2A: HORIZONTAL DISTANCE WATER PARTICLE TRAVELS AS WAVE PASSES.

U max: MAXIMUM HORIZONTAL WATER VELOCITY

TABLE 6

SCITUATE HARBOR WAVE-INDUCED CURRENT ANALYSIS

STORM WAVE - FUTURE CONDITION

CELL(X,Y)	2A (FT.)	U max (FT./SEC.)	CELL(X,Y)	2A (FT.)	U max (FT./SEC.)
(28,5)	3.432	1.135	(34,1)	3.432	1.135
			(34,2)	3.432	1.135
(29,4)	3.432	1.135	(34,3)	3.432	1.135
(29,5)	3.432	1.135	(34,4)	3.432	1.135
			(34,5)	3.432	1.135
(30,3)	3.432	1.135	(34,6)	8.056	2.664
(30,4)	3.432	1.135	(34,7)	6.977	2.307
(30,5)	10.296	3.405	(34,8)	18.017	5.958
			(34,9)	12.298	4.067
(31,3)	2.574	0.851	(34,10)	14.299	4.729
(31,4)	3.432	1.135	(34,11)	6.578	2.175
(31,5)	3.432	1.135	(34,12)	4.004	1.324
(31,6)	8.580	2.837			
(31,7)	0.000	0.000	(35,1)	3.432	1.135
(31,8)	0.000	0.000	(35,2)	3.432	1.135
(31,9)	0.000	0.000	(35,3)	3.432	1.135
(31,10)	2.171	0.718	(35,4)	3.432	1.135
(31,11)	5.720	1.892	(35,5)	3.432	1.135
(31,12)	7.436	2.459	(35,6)	7.887	2.608
			(35,7)	0.000	0.000
(32,3)	3.432	1.135	(35,8)	0.000	0.000
(32,4)	3.432	1.135	(35,9)	0.000	0.000
(32,5)	3.432	1.135	(35,10)	0.000	0.000
(32,6)	3.432	1.135	(35,11)	0.000	0.000
(32,7)	11.527	3.812	(35,12)	0.000	0.000
(32,8)	0.000	0.000			
(32,9)	0.000	0.000			
(32,10)	0.000	0.000			
(32,11)	5.155	1.705			
(32,12)	8.580	2.837			
(33,6)	7.722	2.554			
(33,7)	3.432	1.135			
(33,8)	33.461	11.065			
(33,9)	7.583	2.508			
(33,10)	9.496	3.140			
(33,11)	7.722	2.554			
(33,12)	5.148	1.702			

NOTE: 2A: HORIZONTAL DISTANCE WATER PARTICLE TRAVELS AS WAVE PASSES.

U max: MAXIMUM HORIZONTAL WATER VELOCITY

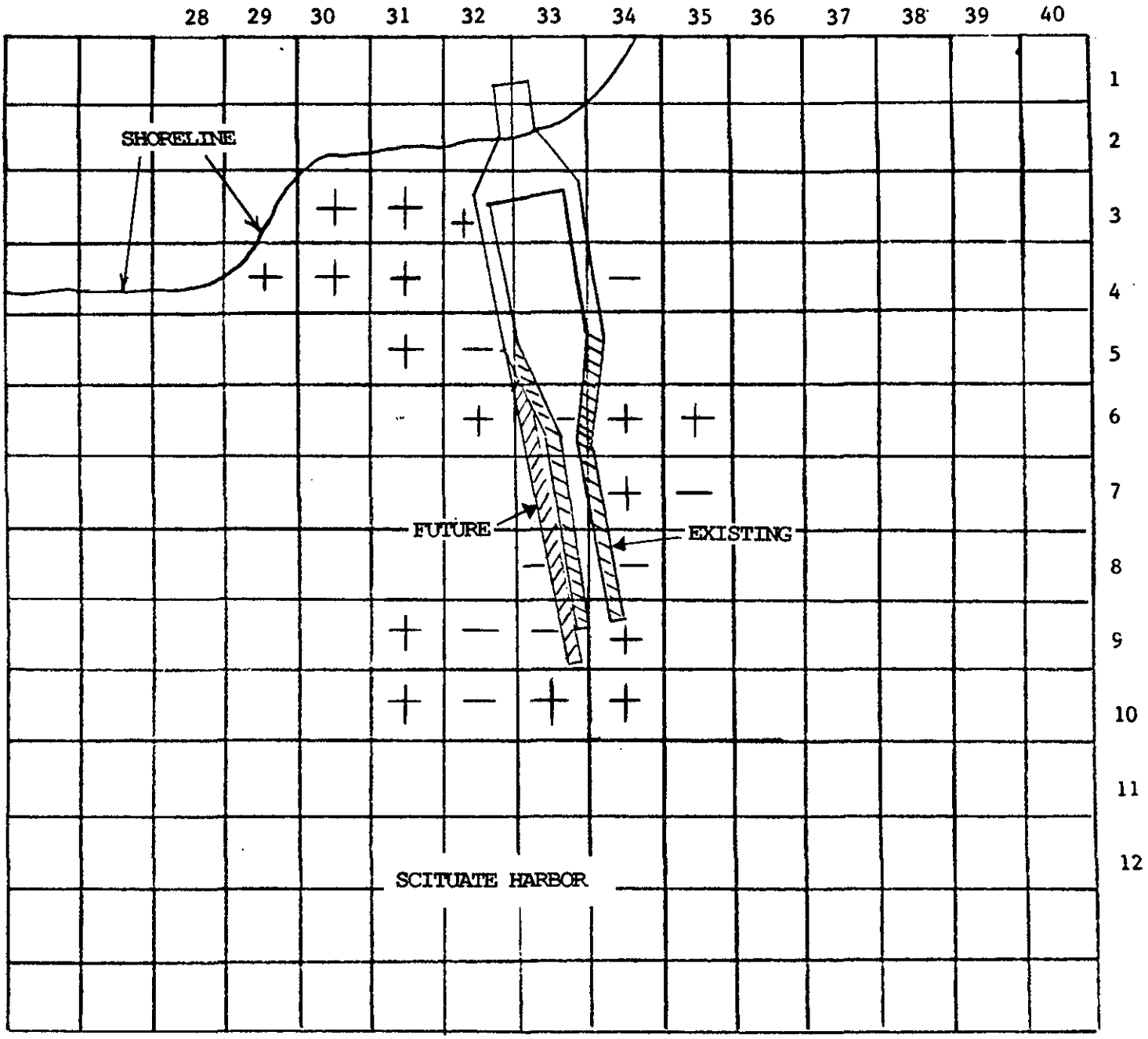


FIGURE 11

CURRENT VELOCITY CHANGES
AVERAGE DAY WAVE CONDITIONS

Note: "+" refers to an increase in current velocity between the existing and future conditions.

"-" refers to a decrease in current velocity between the existing and future conditions.

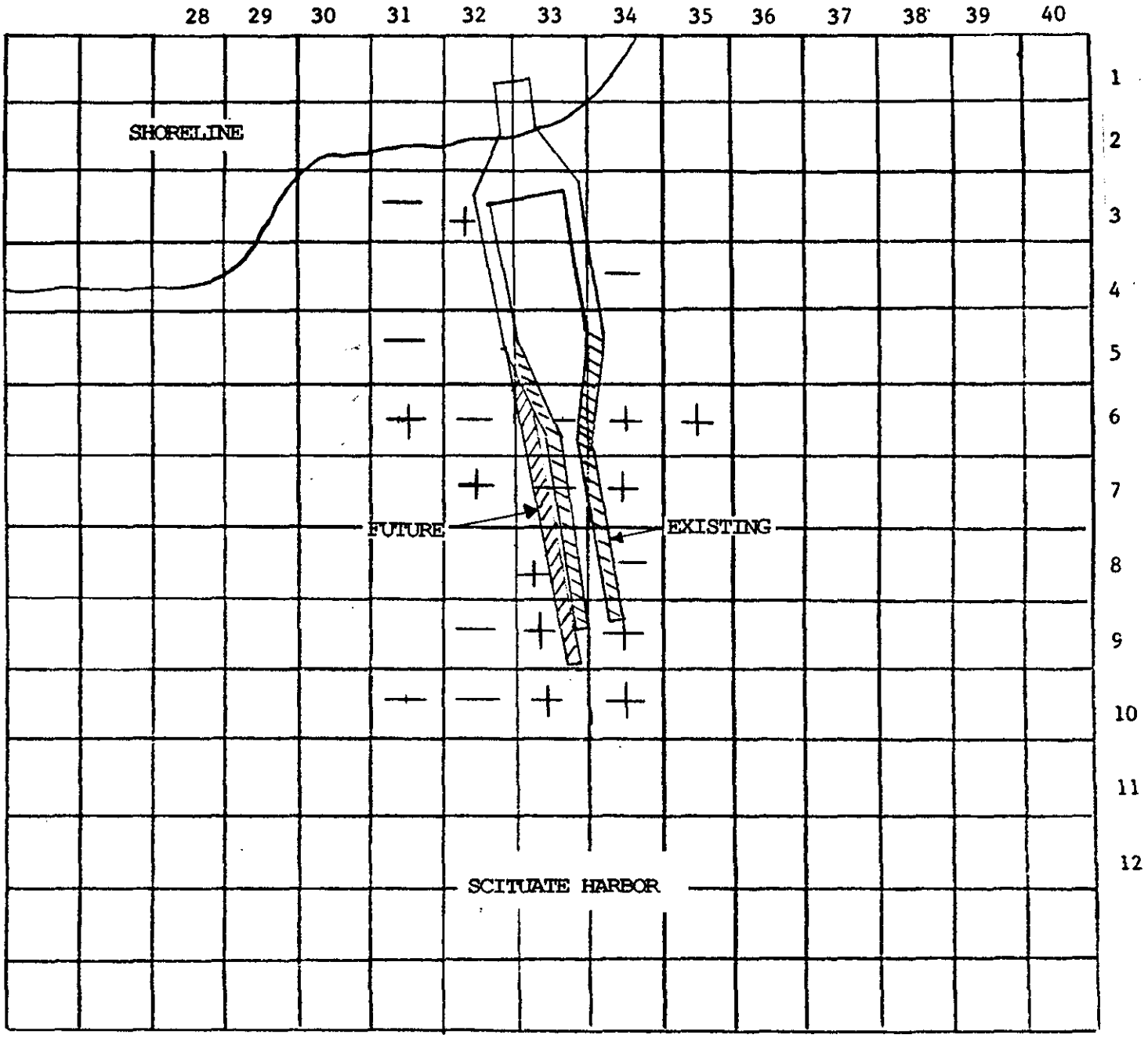


FIGURE 12

CURRENT VELOCITY CHANGES
STORM WAVE CONDITIONS

Note: "+" refers to an increase in current velocity between the existing and future conditions.

"-" refers to a decrease in current velocity between the existing and future conditions.

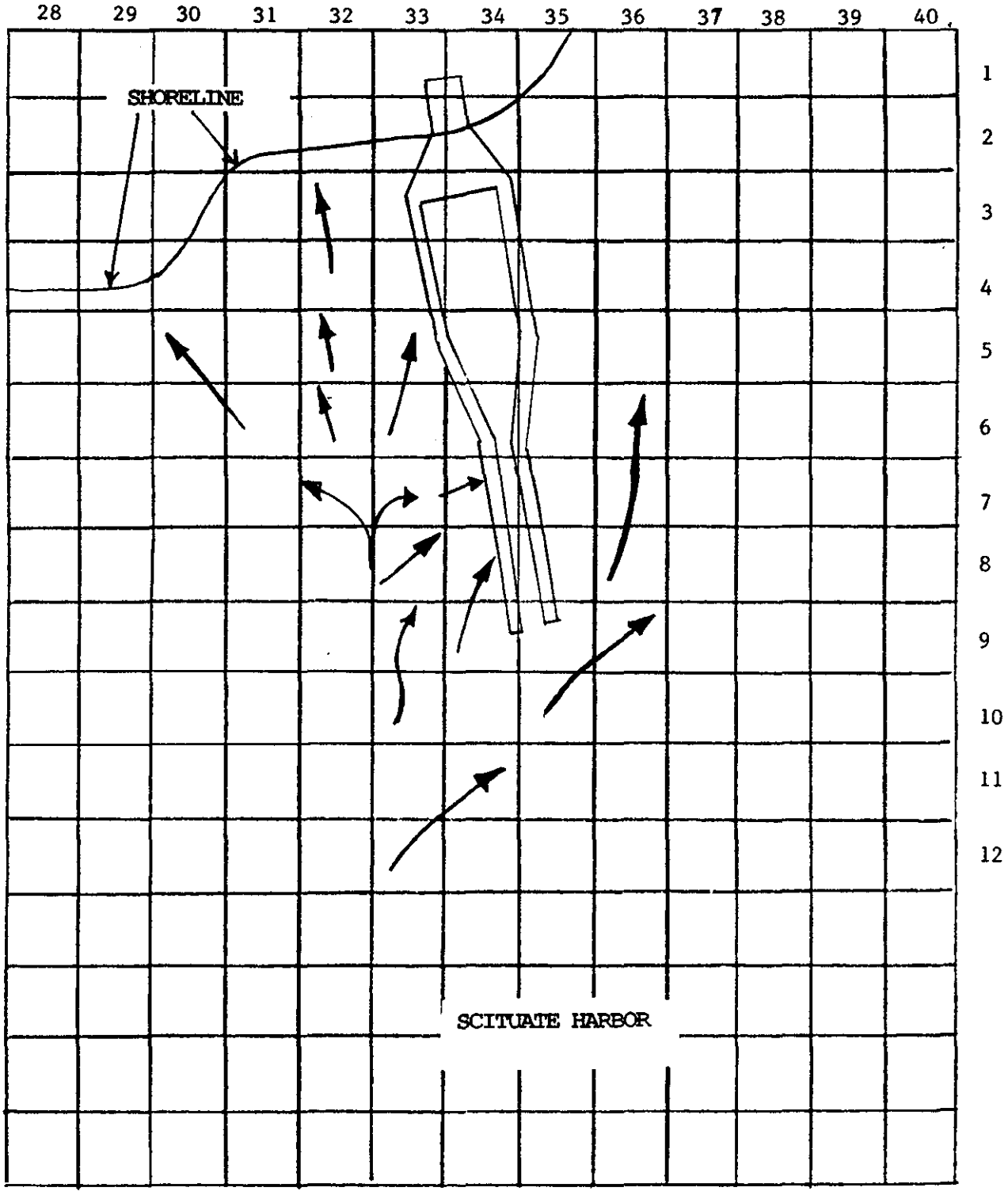


FIGURE 13

GENERALIZED WAVE INDUCED CURRENT PATTERNS
EXISTING CONDITION

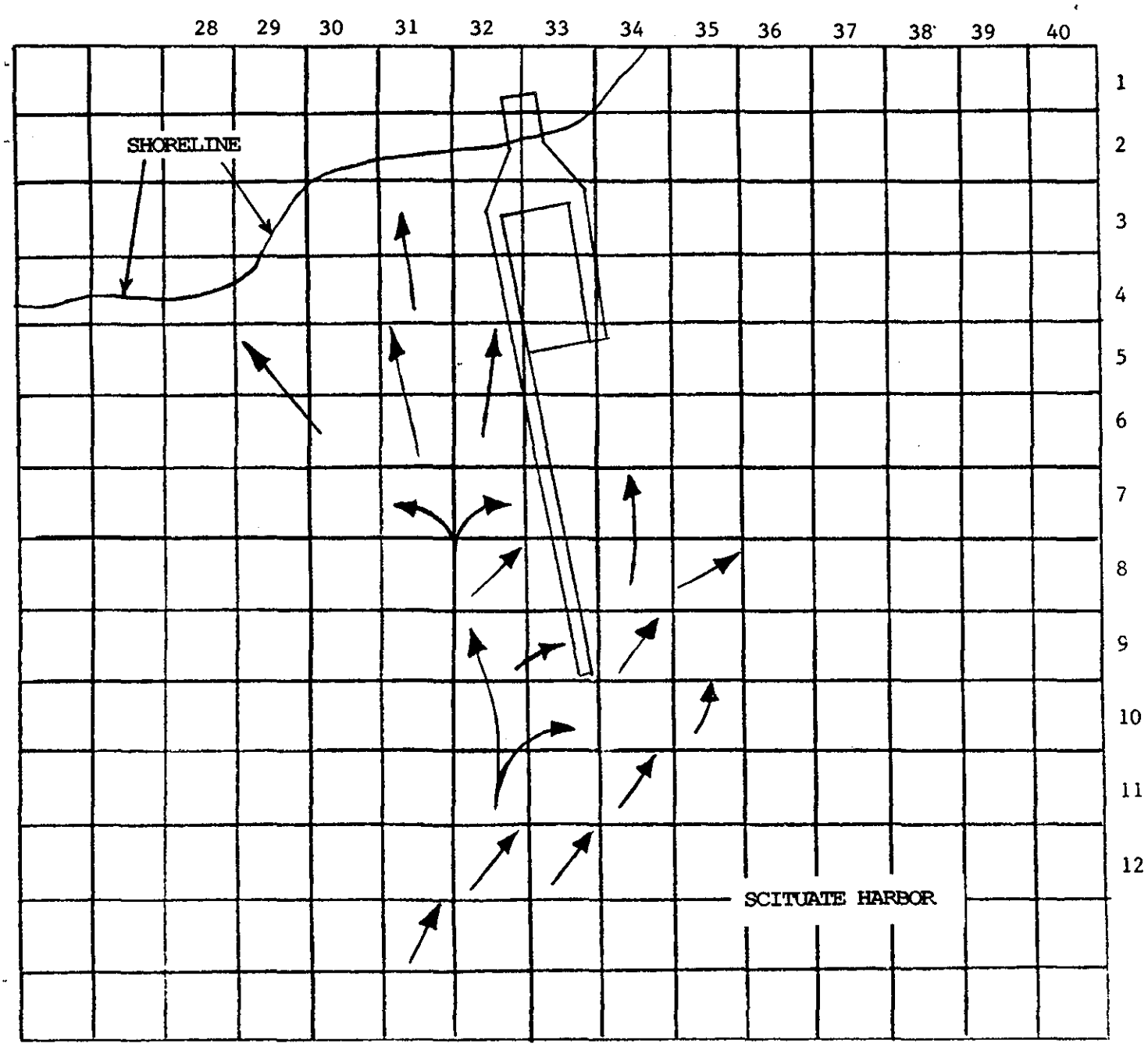


FIGURE 14

GENERALIZED WAVE INDUCED CURRENT PATTERNS
FUTURE CONDITION

7. SEDIMENT TRANSPORT (DIRECTION & VELOCITY)

This section discusses the effects of pier modifications on the direction and velocity of sediment transport in the vicinity of the pier. Waves arriving at the shore are the primary cause of sediment transport in the littoral zone. Most longshore currents are generated by the longshore component of motion in waves that obliquely approach the shoreline. Longshore currents flow parallel to the shoreline between the zone of breaking waves and the shoreline.

Direction

The angle between the crest of the breaking wave and the shoreline determines the direction of the longshore component of water motion in the surf zone and, usually, the longshore transport direction. The general direction of sediment transport has been determined by examining the direction of wave propagation provided by the RCPWAVE analysis. By examining the wave refraction diagrams (Figures 3 through 6), the direction of the sediment transport northeast of the pier is toward the harbor entrance and south of the pier it is away from the harbor entrance.

Through comparisons of the existing and future wave conditions, it has been determined that the direction of sediment transport will not be substantially altered by pier modifications. However, the direction of sediment transport south of the pier along the shoreline does show a tendency for the sediment to propagate more onshore than alongshore due to pier modifications. This is a result of the proposed pier timber piles being placed closer together resulting in a decrease of wave energy on the leeward (south) side of the pier.

Velocity

The variation in longshore current velocity at the shoreline, and the uncertainties in variables such as surf zone hydrography and tidal current velocity variations, make prediction of longshore current velocity uncertain. However, one possible way of predicting longshore currents is by using the radiation stress theory developed by Longuet-Higgins. This method is outlined in the Shore Protection Manual (Vol. 1, 1984).

Longshore current velocities are most sensitive to changes in the wave breaker angle and, to a lesser degree, to changes in the breaking wave height. Tables 7 and 8 give longshore current velocities along the shoreline at certain cells of the grid used for the refraction analysis.

Longshore current velocities in the cells along the shoreline south of the pier are slightly less in the future condition than in the existing condition. This has resulted in less of a longshore transport component and more of an onshore-offshore movement of sediment. Since the breaker angle does not change significantly in most of the cells, the longshore currents will not be substantially altered due to pier modification.

Summary and Conclusions

Neither the direction of sediment transport nor the longshore current velocity will be substantially altered by pier modifications.

TABLE 7
SCITUATE HARBOR LONGSHORE CURRENT VELOCITY ANALYSIS
AVERAGE WAVE

CELL(X,Y)	LONGSHORE CURRENT VELOCITY (FT/SEC) EXISTING CONDITION	LONGSHORE CURRENT VELOCITY (FT/SEC) FUTURE CONDITION
(28,5)	15.987	15.987
(29,4)	14.431	16.134
(29,5)	17.379	17.379
(30,3)	1.418	1.221
(30,4)	1.935	2.164
(30,5)	2.760	2.760
(31,3)	0.584	0.674
(31,4)	0.665	0.768
(31,5)	0.904	1.476
(32,3)	0.502	0.484
(32,4)	0.674	0.674
(32,5)	1.217	0.861
(34,1)	1.715	1.221
(34,2)	1.715	1.221
(34,3)	1.791	1.221
(35,1)	1.638	1.393
(35,2)	1.638	1.393
(35,3)	1.558	1.393

TABLE 8
SCITUATE HARBOR LONGSHORE CURRENT VELOCITY ANALYSIS
STORM WAVE

CELL(X,Y)	LONGSHORE CURRENT VELOCITY (FT/SEC) EXISTING CONDITION	LONGSHORE CURRENT VELOCITY (FT/SEC) FUTURE CONDITION
(28,5)	16.185	16.185
(29,4)	14.431	14.431
(29,5)	15.711	15.711
(30,3)	1.638	1.638
(30,4)	1.864	1.864
(30,5)	3.904	3.904
(31,3)	0.579	0.502
(31,4)	0.768	0.768
(31,5)	1.381	0.953
(32,3)	0.502	0.484
(32,4)	0.674	0.579
(32,5)	0.861	0.861
(34,1)	1.715	1.221
(34,2)	1.715	1.221
(34,3)	1.791	1.308
(35,1)	1.638	1.308
(35,2)	1.638	1.308
(35,3)	1.558	1.308

8. LONGSHORE TRANSPORT RATE

Littoral transport is the movement of sediment material by waves and currents. This section discusses the littoral transport rate along the shoreline surrounding the pier and compares the rates between the existing and future conditions. Longshore transport has an average net direction parallel to the shoreline. It is the longshore transport rate which is of primary concern in this analysis.

Longshore transport at this site was predicted by using breaking wave conditions to compute a longshore component of wave energy flux entering the surf zone. There are a number of assumptions associated with the approximation of the energy flux, including that there are straight bottom contours parallel to the shoreline. The area immediately adjacent to the pier consists of very complex bathymetry which may not yield accurate quantitative results of longshore transport rates.

Tables 9 and 10 show estimates of potential longshore transport rates (Q) for the cells along the shoreline. These rates of transport were calculated using the Automated Coastal Engineering System (ACES) developed by the Corps of Engineers Waterways Experiment Station. The method used is based on the empirical relationship between the longshore component of wave energy flux entering the surf zone and the immersed weight of sand. According to the ACES technical reference, "...Judgement is required in using the empirical relationship between longshore transport rate and the energy flux factor. The accuracy of Q found using the energy flux factor can be estimated to be plus or minus 50 percent." The values of Q in Tables 9 & 10 can most productively be used on a comparative rather than absolute basis.

The construction of the proposed pier with its closer (than the existing configuration) spaced timber piles may reduce the amount of sediment transport to the leeward (south) side of the pier. Sediment transport along the shoreline northeast of the pier will not change substantially.

The wave characteristics (wave height and angle) do not show any significant changes along the shoreline either northeast of Cell (28,5) or southwest of Cell (36,1). The cells are designated on Figures 13 and 14. Therefore, there is virtually no change in the longshore transport rate in the areas further away from the pier along the shoreline in either direction.

Previous discussion has mentioned the assumption of the pier acting as an impermeable vertical wall, thereby forming a barrier to the longshore transport of sand. Since the proposed pier will not act in this manner, changes in the longshore transport rate will actually be less than those found in Tables 9 and 10.

TABLE 9

LONGSHORE TRANSPORT RATE

AVERAGE DAY WAVE CONDITIONS

CELL(X,Y)	Q (EXISTING) (cu.yds./yr)	Q (FUTURE) (cu.yds./yr)
(28,5)	23,817	23,817
(29,4)	21,499	37,556
(29,5)	40,454	40,454
(30,3)	6,972	14,312
(30,4)	16,914	29,548
(30,5)	54,283	54,283
(31,3)	2,869	5,890
(31,4)	3,269	6,711
(31,5)	4,443	51,597
(32,3)	2,466	4,228
(32,4)	5,890	5,890
(32,5)	42,563	7,524
(34,1)	14,991	10,674
(34,2)	14,991	10,674
(34,3)	15,651	10,674
(35,1)	15,651	12,174
(35,2)	15,651	12,174
(35,3)	13,616	12,174

TABLE 10

LONGSHORE TRANSPORT RATE

STORM WAVE CONDITIONS

CELL (X,Y)	Q (EXISTING) (cu.yds./yr)	Q (FUTURE) (cu.yds./yr)
(28,5)	24,112	24,112
(29,4)	21,499	21,499
(29,5)	23,405	23,405
(30,3)	14,312	14,312
(30,4)	16,292	16,292
(30,5)	307,069	307,069
(31,3)	5,062	2,466
(31,4)	6,711	6,711
(31,5)	36,953	8,328
(32,3)	2,466	4,228
(32,4)	5,890	5,062
(32,5)	7,524	7,524
(34,1)	14,991	10,674
(34,2)	14,991	10,674
(34,3)	15,651	11,431
(35,1)	14,312	11,431
(35,2)	14,312	11,431
(35,3)	13,616	11,431

9. SUMMARY & FINDINGS

WAVE CLIMATE

Accurate identification of wave characteristics depends upon the method of analysis. RCPWAVE gives generalized indications using linear wave theory and assumes non-complex bathymetry. However, the complex bathymetry in the area of the pier may produce results which do not accurately reflect actual conditions. For this reason, the results are best used on a comparative basis. Since these results are used throughout the remainder of the analysis (wave-induced currents, wave reflection, sediment transport, etc.) they should be used only as a tool to judge the effects of pier modification.

The results of the RCPWAVE refraction analysis are summarized below:

Along the shoreline:

1) Wave characteristics (wave heights, wave angles, or breaking wave conditions) along the shoreline in the vicinity of the pier show no large variations or significant changes due to pier modifications. However, there are small changes in certain areas, such as a slight increase in wave heights, especially at the shore northeast of the pier.

Adjacent to pier extension:

2) Wave characteristics directly adjacent to the proposed pier extension do exhibit some change in both height and direction, but this is highly localized and the effects of this do not interfere with the general wave patterns exhibited in the area or at the shoreline.

Any variations in wave characteristics between the existing and future conditions may be an exaggerated representation of the actual situation (open pile construction) versus the assumed condition (solid vertical wall) of the pier. It is unlikely that these variations will be substantial even though the proposed pile spacing is closer than the current pile spacing. It is also unlikely that the proposed pier will have any adverse impacts on present erosion patterns.

WAVE REFLECTION

The magnitude of any changes of reflected waves due to pier modifications will actually be less than those computed because the pier will not reflect all wave energy, only a small fraction of it. Therefore, changes in wave reflection caused by pier modifications will be negligible.

WAVE-INDUCED CURRENTS

Wave-induced current velocities do change in the area adjacent to the shoreline northeast of the pier due primarily to increased wave heights at the shoreline in the future condition. Changes are also evident where the pier is expected to be extended. These increases in current velocity are due to slight increases in wave heights at the corresponding cells and does not necessarily mean that there will be any substantial change in present erosion patterns at the shoreline. Since our analysis assumed an ideal condition that the pier is an impermeable vertical wall, current velocities will not be greatly affected by pier modifications.

Since there are no significant changes in wave direction between the existing and future conditions there will also be no significant effect on the wave-induced current direction associated with pier construction.

SEDIMENT TRANSPORT (DIRECTION & VELOCITY)

Neither the direction of sediment transport nor the longshore current velocity will be substantially altered by pier modifications. However, our analysis shows that the direction of sediment transport south of the pier along the shoreline has a tendency to propagate more onshore than alongshore due to pier modifications. This is a result of the proposed timber piles and wave attenuator screen being modeled as impermeable, which results in a decrease of wave energy on the leeward (south) side of the pier.

The variations in wave-induced currents and sediment transport are due primarily to changing the orientation of the middle section of the pier, lengthening the pier, and adding the wave attenuator screen. Since our analysis assumed the pier acts as a vertical wall impermeable to all wave energy, any adverse conditions leeward (south) of the pier are certainly an exaggeration of the actual conditions.

LONGSHORE TRANSPORT RATE

The construction of the proposed pier with its closer (than the existing configuration) spaced timber piles may reduce the amount of sediment transport to the leeward (south) side of the pier. Sediment transport along the shoreline northeast of the pier will not change substantially. Changes in the longshore transport rate are insignificant further away from the pier along the shoreline in either direction. Previous discussion has mentioned the assumption of the pier acting as an impermeable vertical wall, thereby forming a barrier to the longshore transport of sand. Since the proposed pier will not act completely in this manner, changes in the longshore transport rate will actually be less than those found in Tables 9 and 10.

10. CONCLUSIONS

The findings of this study are highly dependent on the wave climate which exists in the immediate area of the pier. Wave characteristics ultimately determine factors such as sediment transport and wave-induced currents associated with this area. Wave characteristics are not greatly affected by the pier modifications and it is unlikely that there will be any significant changes in other coastal processes. Corps analysis modeled the existing and future pier configurations as impermeable structures due to limitations of the computer model RCPWAVE, and to provide a "worst case" scenario to conservatively reflect the wave characteristics and coastal processes of the area. Although it was shown that wave reflection is not a significant factor at the wave attenuator screen, the transfer of wave energy to the leeward side of the pier could be greatly reduced from present conditions.

Based on the findings of this study, it can be concluded that construction of the proposed pier could result in a slight change in wave conditions that will alter both sediment transport and wave-induced currents. However, it is felt that these changes are negligible and that the proposed modifications to the present configuration of the pier will not result in any substantial increase of erosion of the shoreline.

11. RECOMMENDATIONS

Based on the results of the Corps analysis and computer model RCPWAVE, there are no recommendations.

12. ACKNOWLEDGMENTS

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APPENDIX 1

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APPENDIX 2

GLOSSARY

Bathymetry - The measurement of depths in oceans, lakes, harbors, etc.

Beach Erosion - The carrying away of beach materials by wave action, tidal currents, littoral currents, or wind.

Hydrography - A configuration of an underwater surface including its relief, bottom materials, coastal structures, etc.

Jetty - A structure extending into a body of water, and designed to prevent shoaling of a channel by littoral materials, and to direct and confine the stream or tidal flow. Jetties are built at the mouth of a tidal inlet or river to help deepen and stabilize a channel.

Leeward - The direction toward which waves are traveling.

Littoral Current - Any current in the littoral zone caused primarily by wave action.

Littoral Drift - The sedimentary material moved moved in the littoral zone under the influence of waves and currents.

Littoral Transport - The movement of littoral drift in the littoral zone by waves and currents. Includes movement parallel (longshore transport) and perpendicular (onshore-offshore) to the shore.

Littoral Transport Rate - Rate of transport of sedimentary material parallel to or perpendicular to the shore in the littoral zone. Commonly used as synonymous with Longshore Transport Rate.

Littoral Zone - An indefinite zone extending seaward from the shoreline to just beyond the breaker zone.

Longshore - Parallel to and near the shoreline.

Longshore Current - The littoral current in the breaker zone moving essentially parallel to the shore, usually generated by waves breaking at an angle to the shoreline.

Longshore Transport Rate - Rate of transport of sedimentary material parallel to the shore. Commonly used as synonymous with Littoral Transport Rate.

Monochromatic Waves - A series of waves generated in a laboratory; each wave has the same length and period.

Pier - A structure, usually of open construction, extending out into the water from the shore, to serve as a landing place, rather than to afford coastal protection.

Shoaling - The deposition of littoral material which may endanger surface navigation.

Shoreline - The intersection of a specified plane of water with the shore or beach.

Significant Wave - A statistical term relating to the one-third highest waves of a given wave group and defined by the average of their heights and periods.

Significant Wave Height - In wave record analysis, the average height of the highest one-third of a selected number of waves, this number being determined by dividing the time of record by the significant period.

Significant Wave Period - In wave record analysis, this is determined as the average period of the most frequently recurring of the larger well-defined waves in the record under study.

Surf Zone - The area between the outermost breaker and the limit of wave uprush.

Tidal Current - The alternating horizontal movement of water associated with the rise and fall of the tide.

Wave Attenuation - A lessening of the amplitude of a wave with distance from the origin.

Wave Diffraction - The phenomenon of which energy is transmitted laterally along a wave crest.

Wave Energy Flux - The rate at which energy is transmitted in the direction of wave propagation across a vertical plane perpendicular to the direction of wave advance and extending down the entire depth.

Wave Height - The vertical distance between a crest and the preceding trough.

Wave Period - The time for a wave crest to traverse a distance equal to one wave length.

Wave, Reflected - That part of an incident wave that is returned seaward when a wave impinges on a barrier or other reflecting surface such as a vertical wall.

Wave Refraction - The process by which the direction of a wave moving in shallow water at an angle to the contours is changed.