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INTRODUCTION

The mining of submerged sands from the Lower Bay of New York Harbor is presently confined to dredged navigation channels but substantial amounts of sand had been recovered from both the East Bank and the West Bank shoals (Bokuniewicz, 1988). In New Jersey waters, a pending proposal would supply sand to the regional markets by deepening the outer stretch of the Ambrose Channel to -70 feet except where a gas pipeline crosses the channel. In addition, the State of New York is considering licensing mining on the East Bank shoal and elsewhere in New York waters.

The hydrodynamic changes that would accompany such mining operations, and the implications of these changes on sediment transport, have been the subject of studies by Kingsman et al. (1979), Wong and Wilson (1979), Vieira and Bokuniewicz (1990) and Bokuniewicz (1991). It is the purpose of this report to further consider two particular issues, namely:

1. the adjustment of the channel floor over the pipeline crossing that might occur in response to deepening the channel on either side, and
2. the potential for changes in shoreline erosion or accretion along the Staten Island beaches.

Substrate adjustment in the Ambrose Channel

The Ambrose Channel must be maintained at a depth of at least 45 feet. Recent dredging has provided a channel 53 feet deep over most of the outer stretch of the channel in New Jersey waters (R. Rosamilia, McCormack Aggregates, 1991, personal communication). A buried gas pipeline crosses the channel at a depth of 67 feet so that it is presently covered by a layer of sand 14 feet thick. If the channel on either side of the pipeline is deepened to 70 feet, the mound of sand remaining over the pipeline would adjust to the new conditions. The finer sizes of sand would be winnowed from the area leaving a coarser, stationary lag deposit at a slightly lower elevation. The lag deposit armors the channel floor against further sediment transport. Detailed predictions of this adjustment would be difficult and subject to large uncertainties because of (a) the non-linearity of the process of sediment transport (e.g., Sternberg, 1972) under time-varying tidal flows, (b) the complicated interaction of waves and currents on the movement of

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sediment (e.g., Pattiaratchi and Collins, 1984), and (c) the mutual influence of mixed grain sizes on the channel floor (Ludwick, 1989). An estimate of the anticipated response of the channel floor might be made, however, using empirical methods developed by hydraulic engineers with the assumption that most of the adjustment will be due to the exposure of the sediment to repeated maximum tidal velocities.

A sample of the bottom sediment was taken by McCormack Aggregates in 1990. It was dried and sieved at the Center. The results were:

Sieve grain size (mm)	Weight (gms)	% finer than
9.50	115.42	93.05
4.75	311.20	74.31
2.38	183.50	63.26
0.85	585.10	28.02
0.60	218.96	14.84
0.25	185.18	3.69
PAN	61.20	0
Total =	1660.56	

The grain size distribution is shown in Figure 1. The median grain size is 1.8 mm and the geometric, graphic standard deviation (σ) is 3.3 mm. Little and Mayer (1976) concluded that the standard deviation on the grain size distribution must be greater than 1.5 mm for armoring to occur. The sediment over the pipeline in Ambrose Channel meets this condition. Knoroz (1971, as reported by Sutherland, 1987) suggested as an alternative condition that D_{95}/D_5 be greater than five where D_a is the size fraction for which "a" % is finer. D_{95}/D_5 is thirty-five for the sample from Ambrose Channel. By both of these criteria, therefore, the channel floor will become armored in response to alterations in the flow conditions.

Measurements made by the U.S. Coast and Geodetic survey in 1958-59 show the vertically averaged maximum tidal current in the channel to be about 82.5 cm/sec (Doyle and Wilson, 1978). By continuity, the vertically averaged maximum tidal velocity over the channel floor at -53 feet would be 70 cm/sec. The shear velocity, which measures the stress exerted by the flow on the channel floor, may be estimated by the universal velocity defect law (Komar, 1976, equations 20 and 21). The shear velocity, U_x, is approximately 0.0547 times the flow velocity measured one meter above the bottom (Sternberg, 1972). If the boundary layer thickness in Ambrose Channel is assumed to be 7 m, then the shear velocity at times of maximum tidal current would be 2.77 cm/sec. The critical shear velocities needed to move sediment of various grain sizes are shown in Figure 2. For sand with a grain size of 1.8 mm, the median grain size of the sample from Ambrose Channel, the critical shear velocity, U_{xc}, is 1.76 cm/sec. This value is needed to forecast bed armoring.

Empirical relationships have been determined for predicting the composition of the non-eroding armor (Shen and Lu, 1983). The model of the armoring process takes into account the protection of small grains in the hydraulic "shadow" of larger grains, the turbulence level and a temporary increase in the mobility of larger grains due to the progressive removal of the supporting finer grained matrix. The predictive equations were calibrated with the results of both laboratory studies (Gessler, 1965; Little and Mayer, 1972; as reported in Shen and Lu, 1983) and field observations (Lane and Carlson, 1953, as reported in Shen and Lu, 1983). The grain size distributions used to develop these relationships were similar to that of the sample from Ambrose Channel so that the forecasts should be reasonable. In terms of the shear velocity, the median grain size of the stationary armoring layer will be

$$d_{50} = D_{50}\ (0.8525)\ (U_x/U_{xc})^{0.9112}\ (\sigma)^{6.8845}$$

$$= 6.77 \text{ mm}$$

The gain size of the armor which is coarser than 84% of the stationary sediment is

$$d_{84} = D_{84}\ (1.189)\ (U_x/U_{xc})^{1.42}\ (\sigma)^{-0.20}$$

$$= 11.21 \text{ mm}$$

A predictive relationship for d_{30} cannot be applied to this case because of the magnitude of the standard deviation in the grain size of the existing sediment (Sutherland, 1987). About 25% of the existing sediment can be retained to form a armoring layer with grains between 2 and 12 mm in diameter and the predicted distribution (Figure 3). This layer would be capable of remaining stationary under the maximum tidal currents. If the winnowing process would reduce the elevation of the channel floor by one foot, an non-eroding layer about 4 inches thick would armor the bottom.

Shoreline erosion and accretion

There is no single, widely accepted method for precisely estimating shoreline erosion or accretion. Models of the complex processes controlling the behavior of the beach continue to evolve. The most sophisticated ones require extensive field measurements for their calibration and verification and, even then, potentially substantial uncertainties must be tolerated. In the Lower Bay of New York Harbor, the difficulties are compounded by its extremely complicated geometry. In addition, the relevant data for conditions in the Lower Bay are sparse. Nevertheless, the following approach is a suggestion for anticipating the magnitude of changing shoreline processes that might result from sand mining in the Lower Bay.

For predictions of a beach response, information is needed on the grain size of the beach sand, the wave characteristics and the water temperature. (The water temperature influences the rate at which sand grains resettle after being disturbed by waves.) Grain size data for Staten Island beaches has been compiled by the U.S. Army Corps of Engineers and reported by Kastens, Fray and Schubel (1978). The median grain size ranged from 0.2 to 0.8 mm at the mean tide level with an average value of 0.34 mm for beaches between Great Kills Park and Fort Wodsworth. Water temperatures in the Lower Bay typically may reach 18°C in the summer and 4°C in the winter (Duedall et al., 1979).

Measurements of the wave conditions inside of the Lower Bay are not available and even observations of ocean waves near the bay's mouth are rare. The distribution of wave heights and periods has been calculated for the ocean entrance to the bay based on the observed weather conditions over a twenty-year period (Jensen, 1983). The technique is called "hindcasting" and these particular estimates are referred to as the "WIS data" (Jensen, 1983). Wave distributions for a water depth of 10 m were calculated near both Sandy Hook and Rockaway. The wave characteristics are similar at the two sites and the combined statistics show the frequency of occurrence of wave height for each one-second band of periods from 17,521 cases (Figure 4). This distribution will be assumed to approximate the waves impinging on the bay from the ocean. Because of the complex series of shoals, channels and shores in the Lower Bay, waves entering the bay undergo complicated transformation (Kinsman et al., 1979). Predicting the results of these transformations is exceedingly difficult and will not be attempted here. Instead, I will assume that the wave climate in the bay, although unknown, is controlled by the wave climate at the bay's mouth as described in Figure 4.

Empirical procedures for distinguishing between those conditions that cause beach erosion and those that cause accretion have been developed by the U.S. Army Corps of Engineers (U.S. Army Corps of Engineers, 1990). A criteria was used that is based on the wave steepness (S_o), which is equal to the ratio of wave height in deepwater, H_o, to its length in deepwater, L_o, and the settling speed of the sand grains (W), which is dependent not only on the grain size but also on the water temperature. The settling velocity is incorporated into a "deepwater fall speed parameter", $N_o = H_o/WT$ where T is the wave period . In deepwater, that is when the wave length is less than twice the water depth, $L_o = gT^2/2\pi$ where g is the acceleration due to gravity. The criterion for the occurrence of erosion is that $S_o < M\ (H_o/WT)^3$ where M is an empirical coefficient; the recommended value of M is 0.00027 based on field observations (Larson and Kraus, 1989). Other criteria have been proposed (e.g., Dean, 1973), but for the most part they give similar results and, since the goal of this exercise is to estimate the change in the beach response due to changes in wave conditions, the precision of the absolute criterion is not critical.

An average grain size of 0.34 mm and a mean water temperature of 11^{o} were chosen for this illustration. Of course, a range of grain sizes and temperatures could also have been selected to give maximum and minimum values for the erosion/accretion criterion, but my purpose is not to accurately forecast erosion or accretion, but to estimate how those conditions would change for a given change in the wave climate.

A computer model developed by the Corps of Engineers (1990) was used to evaluate this criteria for waves in 10 m of water which are those whose distribution has been predicted by Jensen (1983; Figure 4). The diagonal line on Figure 4 separates those combinations of wave periods and heights (as measured in water 10 m deep) that produce accretion from those that produce erosion; some of the values defining that line for g rains 0.34 mm in diameter and a water temperature of 11^{o} are

T(sec)	H (m)
3	0.70
4	0.78
5	0.84
6	0.90
7	0.97
8	1.06
9	1.15
10	1.24
11	1.34
12	1.44

Combinations to the right of the line produce erosion. Sixteen and one-quarter percent (16.25%) of the cases forecast in the 20-year hindcast would have produced erosion.

To see how this potential for erosion would change due to sand mining, the change in the wave characteristics must be calculated. A variety of mining scenarios on the East Bank were examined by Kinsman et al. (1979) ranging from the production of isolated deep borrow pits to mining a large area of East Bank to a depth of 90 feet. For the cases examined, the changes in wave energy reaching the Staten Island shore ranged from increases of 20% to decreases of 6%. Ten percent seems like a reasonable estimate of the magnitude of change for unspecified mining in the Bay. For this illustration, therefore, I will examine the probable effect of a change in wave energy of 10% on the occurrence of erosion.

The wave energy is proportional to the square of the wave height. An increase in wave energy of 10% (1.10) therefore is equivalent to an increase in wave height of 5% (the square root of 1.10 or 1.05). Sand mining in the harbor will not affect the wave distributions offshore. However, without knowing the details of the wave behavior in the bay, it is reasonable to expect that arbitrarily increasing the wave height by 5% outside of the harbor will have the effect of increasing the wave energy impinging on the shoreline by 10% regardless of the transformations the waves undergo in the harbor. The values in parenthesis on Figure 4 are the redistribution of wave heights and periods if the wave heights calculated by Jensen (1983) were all increased by 5%. Making this adjustment increases the number of cases that would produce erosion to 18.36% of the total number calculated in the 20 year hindcast. In other words, increasing the wave energy by 10% produced an increase in the occurrence of erosion of 2.11%.

This increase is insignificant given the range of natural variations; changes in the occurrence of erosion would be undetectable in the face of natural range of conditions. It seems unlikely that the conclusion could be substantially altered even though further analyses could be done to reduce the uncertainty in the prediction. In particular, a range of conditions in wave characteristics, grain sizes, and water temperature could be examined, as mentioned earlier, to explore the extreme conditions or to calculate an average condition from explicit estimates of seasonal variations. Other criteria for erosion could also be applied to examine the sensitivity of the results to alternative criteria. Within the bay, different sections of the shoreline could be treated separately by repeating the calculation to reproduce the redistribution of energy forecast by Kinsman, et al. (1979) in different sections of the bay. Ultimately, new wave models could be designed to explicitly calculate the wave conditions within the bay due to specific mining activity, and an erosion model at the shoreline be applied to include longshore as well as cross-shore sediment transport. This would be an engaging task, however, which may be difficult to justify in light of the calculation done here. Although this calculation does not forecast the change in intensity of erosion as a more sophisticated model might, it suggests to me that the change in occurrence of erosion would be very small and unlikely to have a demonstrable effect on the existing conditions.

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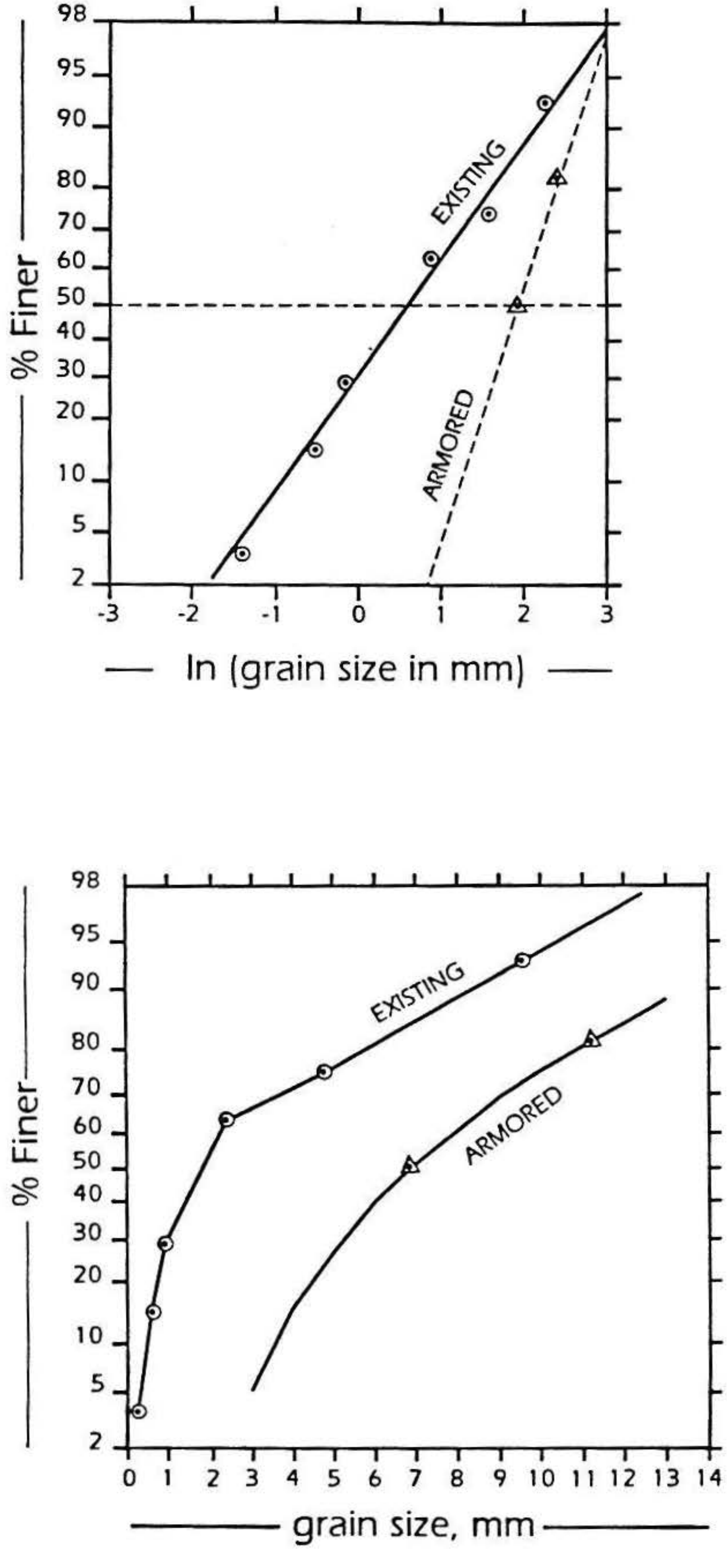
Figure 1. Grain size distribution of the existing sediment in Ambrose Channel over the pipeline crossing and the predicted distribution of an armored lag deposit based on the relationships developed by Shen and Lu (1983).

Figure 2. Critical velocities for sediment transport (McCave, 1984) including the velocities required to prevent the deposition of fine-grained sediment (less than 63 micrometers). The "shear velocity" is a measurement of the stress on the bottom; it is approximately equal to 0.0547 times the flow velocity measured one meter above the bottom (Sternbeg, 1972).

Figure 3. Histogram of the existing grain size distribution in Ambrose Channel and fraction that could comprise the armor with the predicted distribution shown in Figure 1.

Figure 4. The combined distribution of wave heights and periods from two stations in water 10 m deep at the mouth of the Lower Bay (Jensen, 1983). The number in each box is the number of cases when waves were found between the designated periods and range of heights over a 20-year interval. There are a total of 17,526 cases represented. The number in parenthesis in each box is the adjusted distribution if the wave height for all cases was increased by 5%. The area to the right of the oblique, broken line represents cases that would cause erosion according to the criterion described by the U.S. Army Corps of Engineers (1990) for a grain size of 0.34 mm and a water temperature of 11°.


98
95
90
80
70
60
50
40
30
20
10
5
2
% Finer
EXISTING
ARMORED
-3
-2
-1
0
1
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3
ln (grain size in mm)
98
95
90
80
70
60
50
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30
20
10
5
2
% Finer
EXISTING
ARMORED
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9
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12
13
14
grain size, mm

Figure 1

86.891.

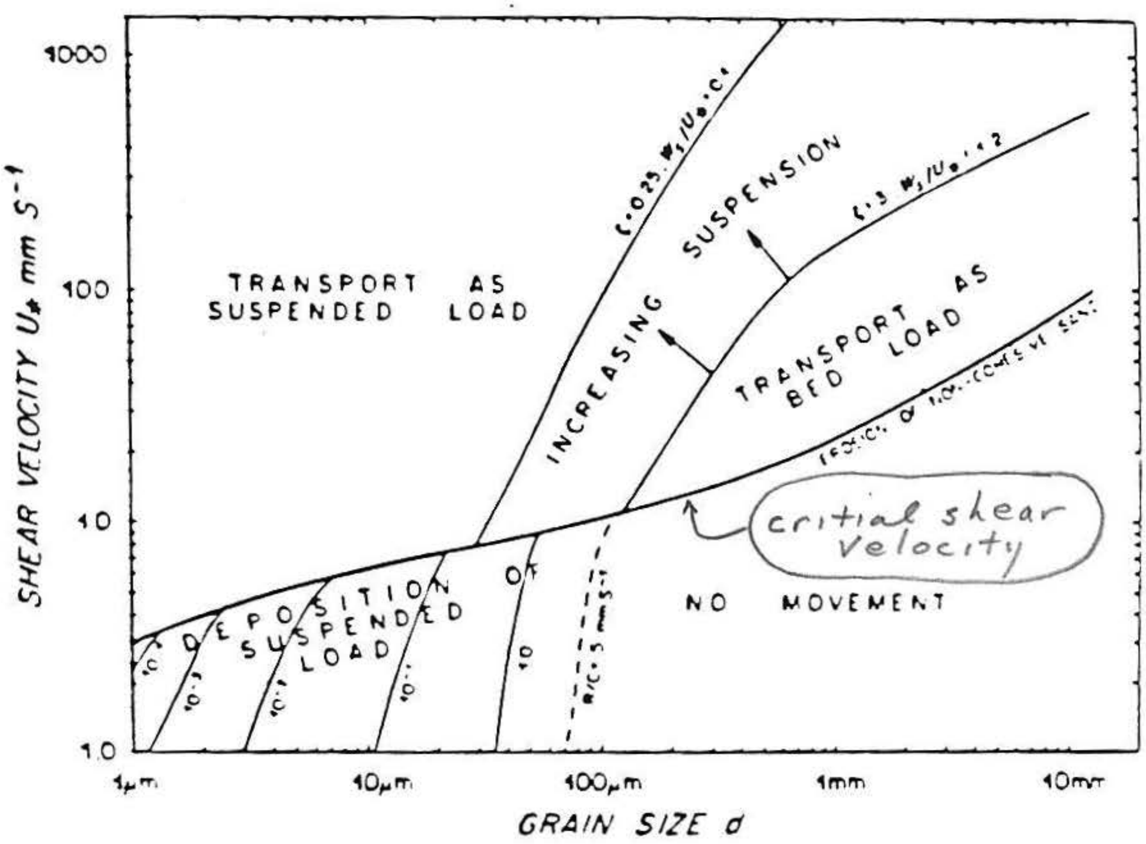


Figure 2

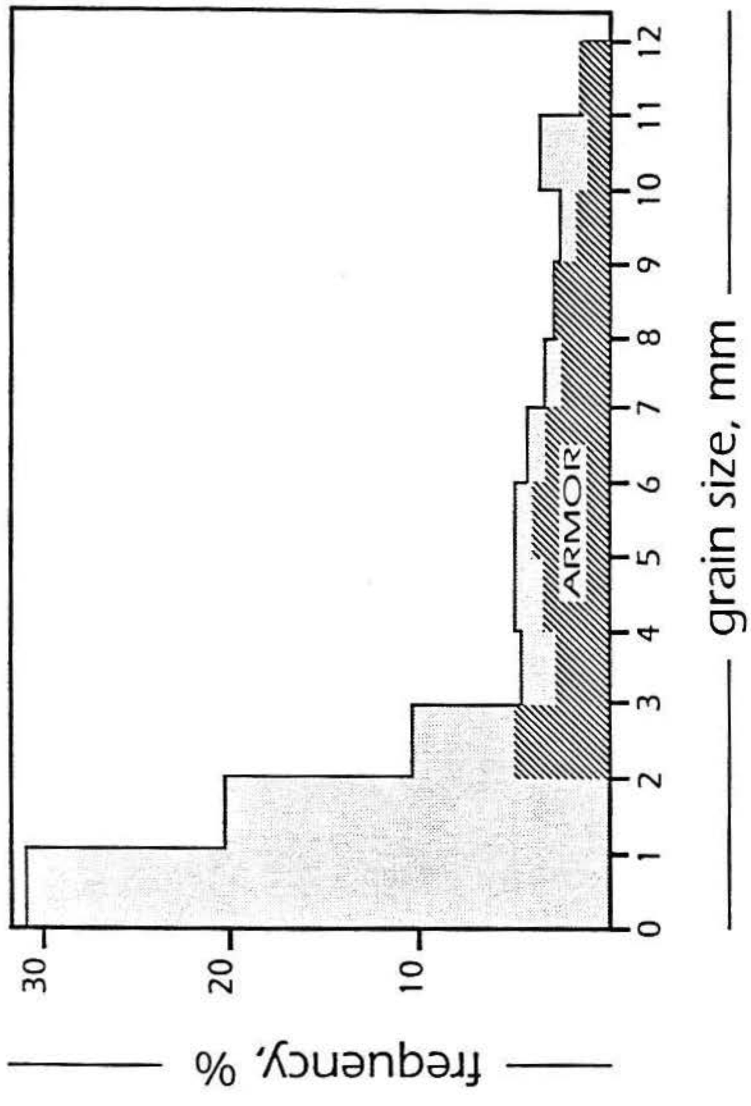
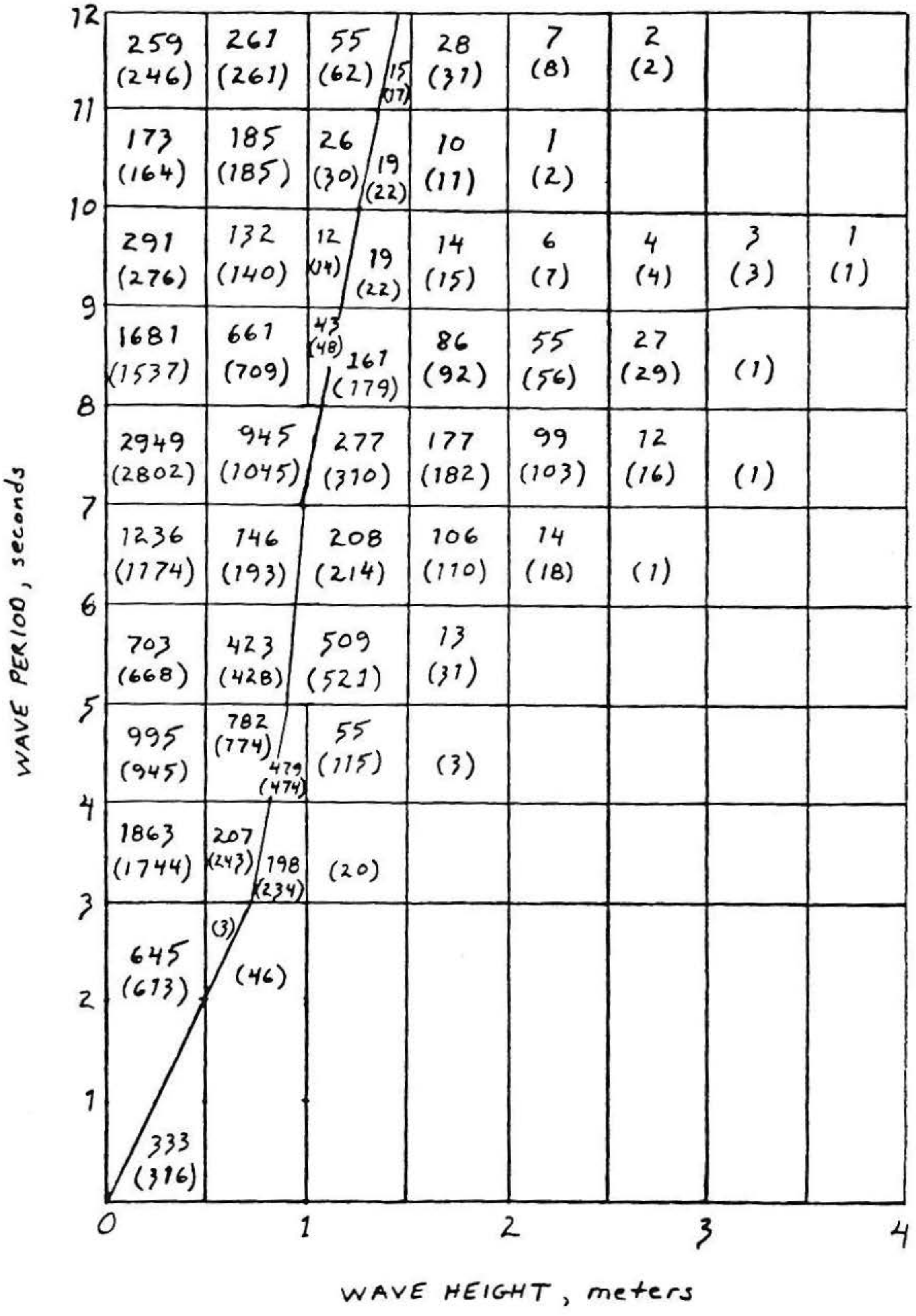


Figure 3


WAVE PERIOD, seconds
WAVE HEIGHT, meters
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259 (246)
261 (261)
55 (62)
15 (17)
28 (31)
7 (8)
2 (2)
173 (164)
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26 (30)
19 (22)
10 (11)
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291 (276)
132 (140)
12 (14)
19 (22)
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4 (4)
3 (3)
1 (1)
1681 (1537)
661 (709)
43 (48)
167 (179)
86 (92)
55 (56)
27 (29)
(1)
2949 (2802)
945 (1045)
277 (310)
177 (182)
99 (103)
12 (16)
(1)
1236 (1174)
146 (193)
208 (214)
106 (110)
14 (18)
(1)
703 (668)
423 (428)
509 (521)
13 (31)
995 (945)
782 (774)
479 (474)
55 (115)
(3)
1863 (1744)
207 (243)
198 (234)
(20)
645 (613)
(3)
(46)
333 (316)

Figure 4