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May 1992

Dredging Research Technical Notes

Prediction of Cross-Shore Movement of Dredged Material Berms

Purpose

This technical note describes a quantitative procedure for estimating whether a nearshore berm composed of sand will move onshore or offshore under given wave conditions. The approach is illustrated by application to the dredged material berm placed at Gilgo Beach, New York, and Silver Strand, California. This note revises and extends interim guidance given in *Dredging Research Technical Notes* (TN) DRP-5-02 concerning physical factors influencing berm movement. TN DRP-5-02 can be consulted for managerial and planning aspects of berm design and monitoring.

Background

A nearshore *feeder berm* is a submerged, high-relief mound constructed near the shore and composed of clean, predominately beach-quality dredged material, presumed here to be sand. Feeder berms resemble nearshore linear sand bars in form, and they are expected to function similarly to natural bars in protecting the beach by breaking storm waves and by having the potential to move onshore and nourish the beach profile. These two functions of feeder berms, wave breaking and sediment supply, depend on the characteristics of the incident waves, the depth and crest elevation of the berm, and the grain size of the material composing it. This technical note concerns the second function, specifically, prediction of whether a sand berm of a given grain size will move onshore or offshore. Longshore transport processes are not considered. This note revises and extends concepts and predictive criteria presented in TN DRP-5-02 (McLellan, Kraus, and Burke 1990), which describes planning considerations and engineering design of feeder berms. TN DRP-5-02 also discusses *stable berms*, berms intended not to move and which may not consist of beach-quality sand. TN DRP-5-01 (McLellan 1990) discusses engineering design considerations for nearshore berms, and TN DRP-1-08 (Hands 1992) describes monitoring procedures for a feeder berm and a stable berm located in the Gulf of Mexico off Mobile Harbor, Alabama (see also, McLellan and Imsand 1990, Hands 1991, Hands and Allison 1991).

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Timing of Berm Placement

The annual cycle of beach advance during the summer and recession during the winter (in the Northern Hemisphere) is well known. Onshore sand transport tends to occur during summer, when swell predominates, but sand is moved off the beach by steep waves, such as during local winter storms, hurricanes, and extratropical storms. Material placed in the nearshore in early or mid-summer will more likely reach the beach than material placed just prior to storm season when it will tend to be distributed in the offshore.

Depth of Berm Placement

A feeder berm is optimally placed as close to shore as possible within constraints of safe operation of the dredge. A berm will break waves that have a height approximately equal to the water depth at its crest. Placing the berm closer to shore, thereby decreasing the water depth at the berm crest, will increase its potential to break waves, better protect the beach from erosive wave action, and promote movement of the berm. The greater the frequency of wave breaking on a berm, the greater the potential will be for material to move off the berm and into the littoral environment. Conversely, if waves break infrequently on a berm and the berm is not exposed to strong currents, it will tend to be stable.

Active beach profile change is an indication of the seaward extent of the littoral zone. This limiting depth is a function of the wave height, wave period, and sediment size and composition. It is most reliably determined by reference to repetitive profile surveys and bathymetry maps for the site or a neighboring site that experiences a similar wave climate.

If adequate profile data to determine the active profile zone do not exist, an analytic method introduced by Hallermeier (1981a, 1983) can be used to estimate the limiting depth. Hallermeier defined an annual seaward limiting depth d_s of the littoral zone as

$$\frac{d_s}{(H_o)_{12}} = 2.3 - 10.9 \left(\frac{(H_o)_{12}}{L_o} \right) \qquad (1)$$

in which $(H_o)_{12}$ is the significant wave height in deep water exceeded 12 hr per year, and $L_o = gT^2/(2\pi)$ is the deepwater wavelength calculated with the wave period T associated with $(H_0)_{12}$, where g is the acceleration due to gravity. In metric units, $g/(2\pi) = 1.56\ m/sec^2$, and in U.S. customary units $g/(2\pi) = 5.12\ ft/sec^2$. In arriving at Equation 1, the original expression of Hallermeier was modified by restricting consideration to quartz sand particles. Birkemeier (1985) tested Equation 1 with high-quality data from the Coastal Engineering Research Center's Field Research Facility (FRF) located at Duck, North Carolina, validating the basic functional dependence of the equation.

Figure 1 illustrates the variability in the beach profile at the FRF, showing the average profile and profile envelope measured in approximately 300 surveys over 8 years on FRF Survey Line 62. The standard deviation of the depth change is also shown. It is seen that the profile is most active to approximately 5-m depth (measured from mean sea level). Seaward of this depth, the envelope limits converge, and the standard deviation in depth change also decreases. It is clear that on this beach a berm should be placed in water shallower than 5 m for greatest success.

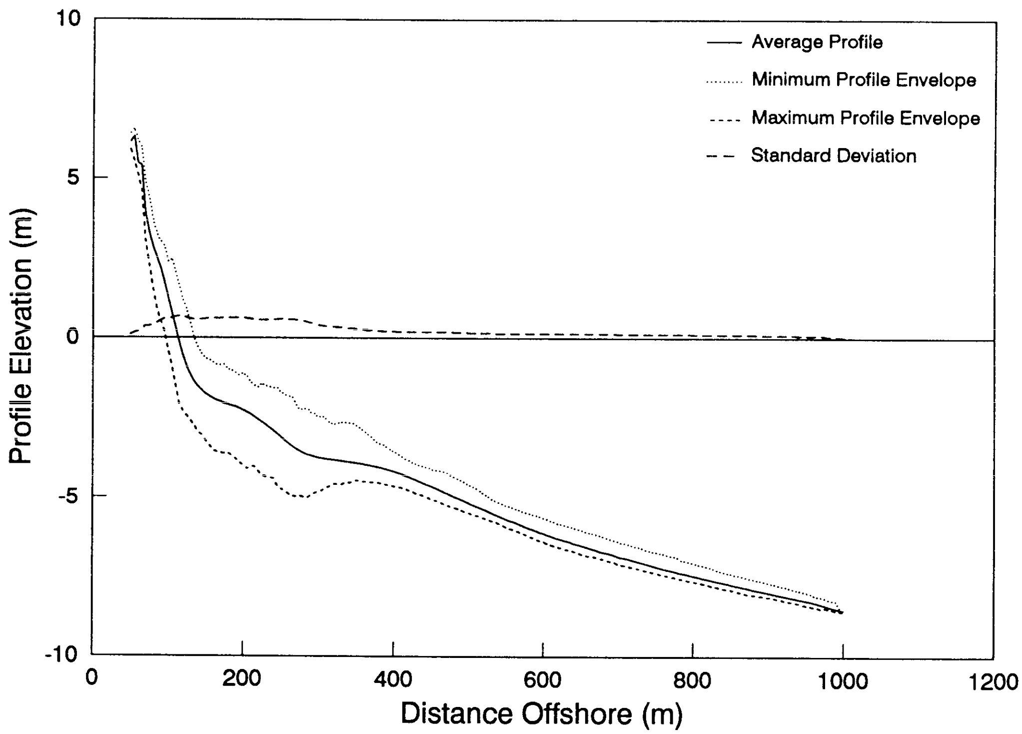

Figure 1. Average beach profile and variability (FRF Line 62)

Direction of Cross-Shore Movement

Although the cross-shore movement of feeder berms (or the absence of such movement) has been observed at a number of sites (Hands 1991), the cost of field monitoring of projects has not yet allowed long-term data acquisition of waves, currents, and bathymetric change that is suitable for unambiguous capture of cause-and-effect mechanisms between waves and cross-shore movement of a berm.

Previous work given in TN DRP-5-02, as described in detail in Larson and Kraus (1989) and Kraus, Larson, and Kriebel (1991), applied a criterion for predicting beach erosion and accretion to feeder berm movement. The rationale was that, as a beach erodes during a storm, a bar is formed that moves offshore to form a "barred" or "storm" profile. Conversely, during recovery or summer-swell conditions, bars tend to move onshore to form a "summer" or "normal" profile in which a bar is not apparent. Therefore, beach change and bar movement are related, and it is expected that criteria for predicting whether a beach will erode or accrete will also predict whether a feeder berm in the form of a bar will move onshore or offshore. McLellan and Kraus (1991) describe applications of the procedure to feeder berms constructed in the United States, and Foster, Healy, and de Lange (1991) found that the criterion predicted the direction of movement of a dredged material mound placed off Mount Maunaganui Beach, New Zealand.

To investigate the prediction of berm movement more directly, as a surrogate for detailed observations of feeder berms, Larson and Kraus (1992, in preparation) analyzed bar movement contained in an 9-year time series of beach profile surveys performed every two weeks or more frequently at the FRF. The FRF faces the Atlantic Ocean on a sandy barrier-island beach, and one to three bars (usually two) are typically present along the profile. This data set provides a time series of approximately 300 surveys on four cross-shore lines extending from the beach dune to a depth of approximately 8 m. From comparison of the survey lines, Line 62 was selected for analysis to correlate wave parameters to the response of the inner, highly active bar located in nominal 2-m depth and to the outer, less active storm bar located in nominal 4-m depth.

Typical configurations of the inner and outer bar at the FRF are shown schematically in Figure 2. The bars are defined by crossing points with a theoretical modified equilibrium profile (Larson 1991) that was fit to the average profile formed from surveys over the 9-year observation interval. The sediment particle size distribution exhibits a near-ubiquitous bimodal distribution comprised of pebbles and fine- to medium-size sand on the foreshore, becoming unimodal and progressively finer with distance offshore. A representative median grain size for the sand on the inner bar is 0.2 mm, and for the outer bar the median grain size is 0.17 mm (quartz sand).

Cross-shore movement of the inner and outer bars at the FRF was analyzed and correlated with the incident wave height and period, which were measured at 3-hr or more frequent intervals at an FRF wave gage located in 8-m depth. Wave characteristics obtained at that depth were transformed to deep water using standard linear-wave assumptions and omitting refraction.

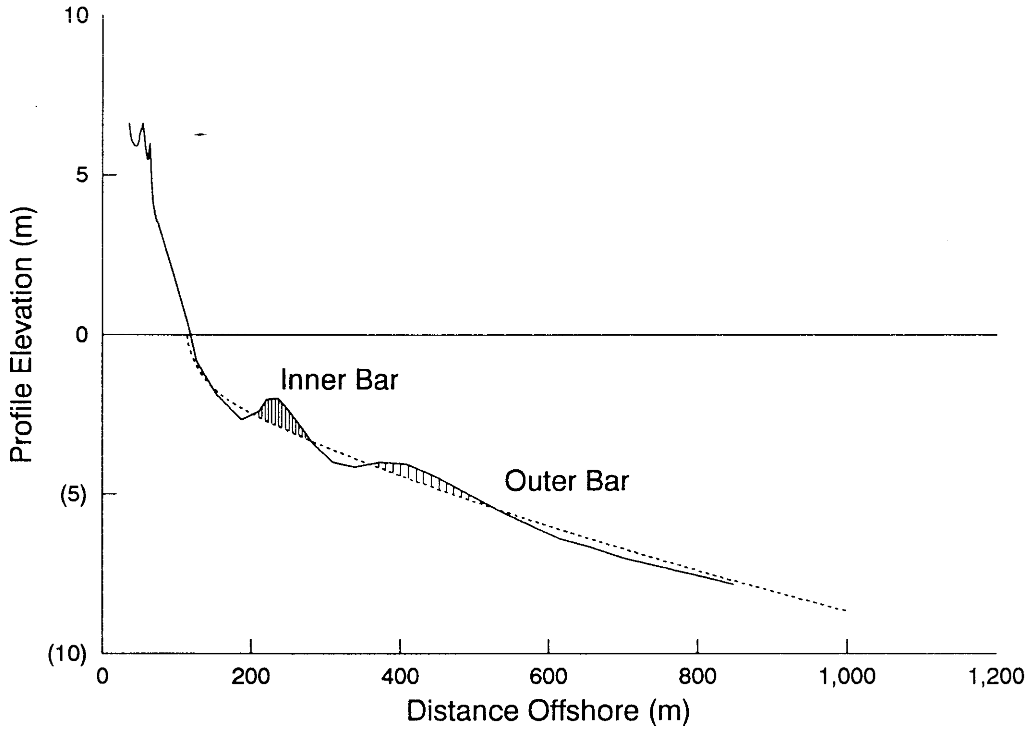

Figure 2. Schematic of inner and outer bars at the FRF

Criteria for predicting beach erosion and accretion were critically examined by Kraus, Larson, and Kriebel (1991). Criteria involving wave height, wave period, and sediment fall speed together were found to be most accurate and general. Fall speeds for selected quartz sand particle size diameters are listed in Table 1, calculated by equations given by Hallermeier (1981b).

Table 1. Short Table of Fall Speed Values (m/sec) for Quartz Sand

Temperature °C	Grain Size, mm					
	0.15	0.20	0.25	0.30	0.35	0.40
10	0.016	0.023	0.029	0.035	0.042	0.048
20	0.017	0.024	0.030	0.037	0.043	0.050
30	0.018	0.025	0.032	0.039	0.046	0.053
40	0.019	0.026	0.034	0.041	0.049	0.055

In the following, H_0 is the significant wave height, and T is the peak spectral period or period associated with the significant waves. Figures 3 and 4 summarize events in the FRF profile survey data on bar movement judged to be unambiguously related to characteristics of the incident

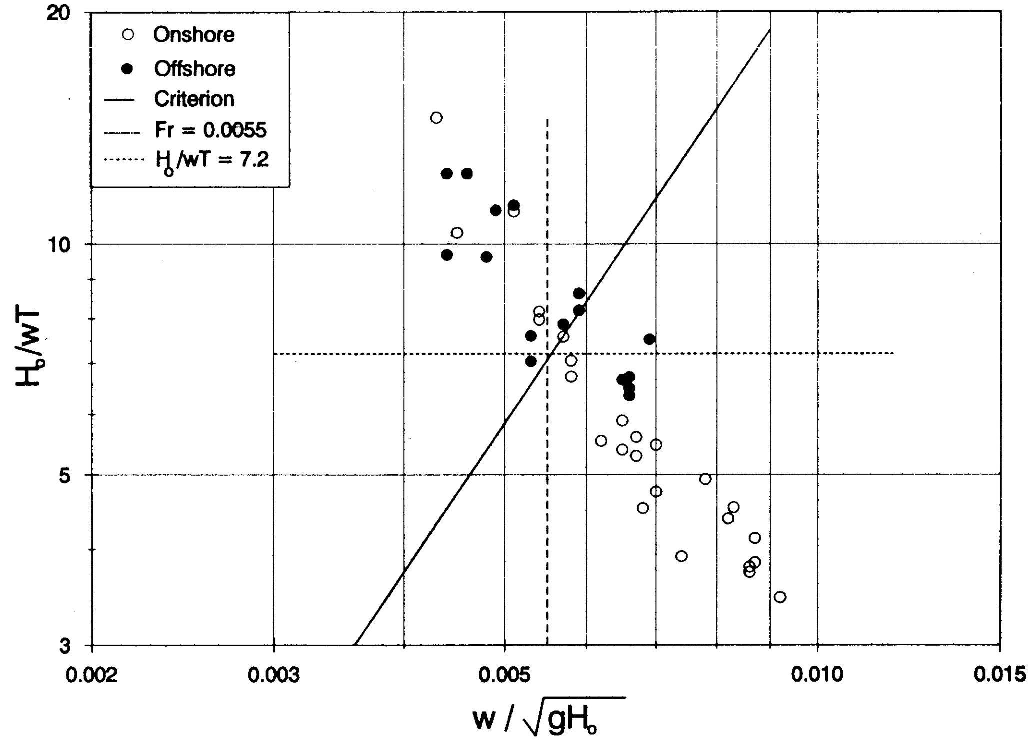

Figure 3. Prediction of cross-shore movement of inner bar

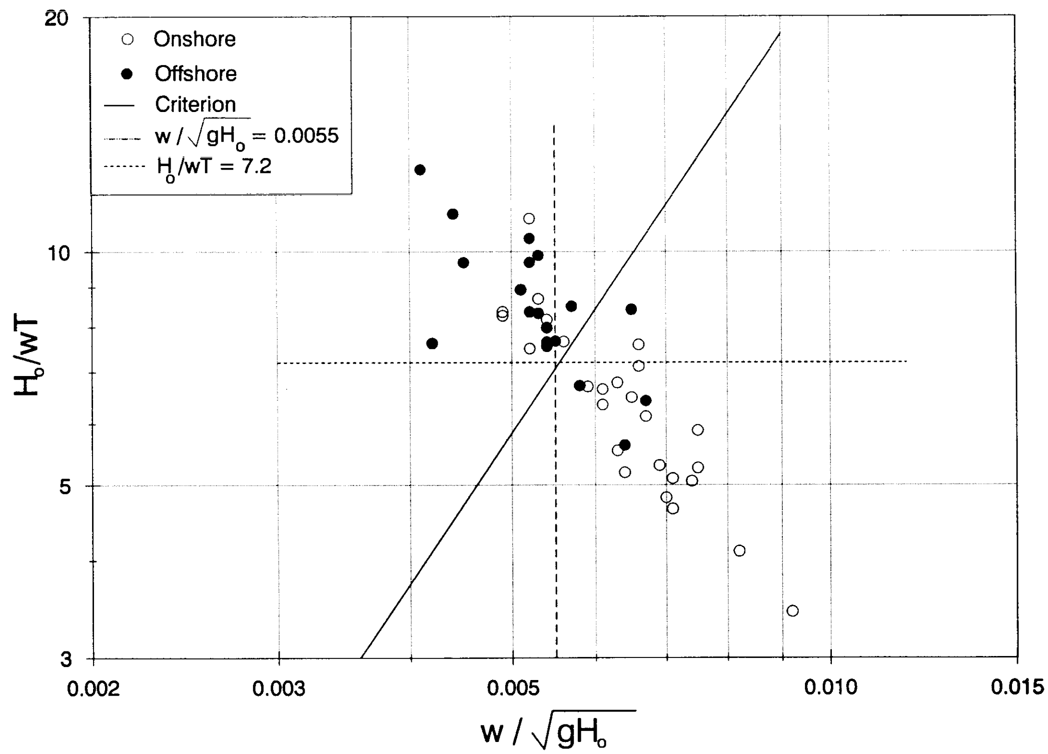

Figure 4. Prediction of cross-shore movement of outer bar

waves that caused the movement. Observed onshore movement of the bars is marked with open circles and offshore movement with asterisks. Data points in these figures show some intermingling, which may be a result of errors introduced by evaluation of wave conditions over a 1- to 2-week interval between profile surveys, or the action of physical processes not described here.

Based on the work described in Kraus, Larson, and Kriebel (1991), two nondimensional parameters that tend to well distinguish erosion and accretion events are the sediment fall-speed parameter H_o/wT and a sediment Froude-type parameter $w/(gH_o)^{1/2}$, where w is the fall speed of sand grains of the representative median grain size. These parameters were evaluated for the observed bar movement, and plotted in Figures 3 and 4. Expressed in terms of these parameters, the diagonal line separating most of the onshore and offshore movement events for both the inner and outer bar is given by

$$\frac{H_o}{wT} = 234{,}000 \left(\frac{w}{\sqrt{gH_o}} \right)^2 \tag{2}$$

Moving all variables to the left side (Dalrymple 1992) gives

$$P = \frac{gH_o^2}{w^3T} = 234{,}000 \tag{3}$$

The quantity P combines the two parameters to form a single parameter that is convenient for calculation. If P is greater (less) than 234,000, the berm will tend to move offshore (onshore).

The dashed lines in Figures 3 and 4 provide simple one-parameter criteria that are almost as accurate as the two-parameter criterion given by Equation 2 (or 3). It is seen that, for example, onshore bar movement is associated with smaller wave heights, implying that bars will tend to move onshore for values of $H_o/wT < 7.2$; similarly, bars will tend to move onshore for values of $w/(gH_o)^{1/2} > 0.0055$. The one-parameter criterion previously found for predicting beach erosion and accretion was $H_o/wT = 3.2$. Therefore, bars or nearshore berms will tend to move toward the shore even under certain wave conditions that erode a beach, indicating a more favorable range of wave conditions for beach nourishment by dredged material berms than previously thought.

In a practical situation, a 10 percent or greater error or uncertainty in wave and sediment variables may be present. Assuming that uncertainties are uncorrelated and do not cancel, a 10 percent uncertainty in all dimensional variables leads to a 30 percent uncertainty in H_o/wT and a

15 percent uncertainty in $w/(gH_0)^{1/2}$. These percentages give a conservative quantitative estimate of the predictive capability of such simple criteria.

Example Calculations

Parallel calculations will be made for examples of two recently constructed feeder berms, one at Gilgo Beach (McLellan, Truitt, and Flax 1988), located on the south shore of Long Island, New York, and the other at Silver Strand Beach, located on the coast of southern California (Juhnke, Mitchell, and Piszker 1989, Andrassy 1991). The sand used for the berm at Gilgo was dredged from the Fire Island Inlet channel and that at Silver Strand from the entrance to San Diego Harbor. Haul distances to the project sites were considerably shorter than to traditional placement areas, representing a cost savings to the dredging and placement operation.

The Gilgo Beach berm was constructed in June 1987 and was approximately 7,500 ft long and 6 ft high. The berm, composed of 410,000 cu yd of medium-size beach-quality sand (median diameter = 0.4 mm), was placed along the 16-ft contour by the 16-ft draft split-hull hopper dredge. A linear berm volume of 56 cu yd/lin ft was placed at the site with some depths reduced to as little as 7.5 ft below mean sea level at the crest. By December 1987, a survey showed only 130,000 cu yd of material remained, indicating that 68 percent of the placed material had moved out of the area.

The Silver Strand berm was constructed intermittently over a 1-month period beginning December 7, 1988. The berm was designed to be 1,200 ft long and 600 ft wide, and it was placed between the depths -10 and -30 ft on the mean lower low water contours, located approximately 800 and 1,400 ft from shore. Depth at the crest was approximately 10 ft. The estimated dredged quantity placed on the berm was 98,000 cu yd, giving a lineal berm volume of 76 cu yd/lin ft of shoreline. Preproject sampling indicated that the dredged material, derived from littoral transport of beach sand and cliff erosion, had a median grain size of 0.18 mm, while the native sand at the site had a median grain size of 0.25 mm. Periodic monitoring over 18 months after berm placement indicated deflation of the berm and movement of its center of mass toward the shore.

Long-term wave hindcasts available from the Wave Information Study (WIS) will be used for both sites. Tables 2 and 3 give statistical summaries of significant wave height H_s and peak spectral period from waves incident from all possible directions for the 20-yr hindcasts (1956 to 1975). Table 2 was adapted from WIS Report 9 (Jensen 1983) and includes both sea and swell. Table 3 was adapted from draft WIS Report 20 (Jensen and others 1990) and includes North Pacific sea and swell, but not southern Pacific swell. WIS tables contain wave information corresponding to 3-hr intervals; this results in 58,440 possible events for a 20-yr period that includes five leap years. Wave heights and periods in Tables 2 and 3 are representative of height and period intervals given in the original WIS reports, and the entries in the tables are the number of events as a percentage, multiplied by 100. The subtotals do not equal 100 percent (for example, the right-hand column in Table 2 sums to 91.7 percent) because calm events are omitted from these tables. For Silver Strand, an approximate two-year wave record from a deepwater buoy was available which had been analyzed by wave direction to provide data for longer period waves incident from the southern quadrant, giving approximate statistics for the southern hemisphere swell; the record resulted in an average wave height of 0.73 m and 14.4-sec period, occurring 36 percent of the year.

Table 2. Percent Wave Occurrence Times 100, Gilgo State Park, New York (WIS Station 50)

Wave Height* m	Wave Period (sec)										
	1.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11 +	Total
0.25	361	712	343	230	711	1040	465	49	64	106	4081
0.75	--	283	787	297	138	925	687	143	93	113	3466
1.25	--	--	63	264	119	251	178	51	77	53	1056
1.75	--	--	--	11	78	134	82	16	29	25	375
2.25	--	--	--	--	15	63	46	13	4	4	145
2.75	--	--	--	--	--	9	20	9	2	1	41
3.25	--	--	--	--	--	--	2	5	1	--	8
3.75	--	--	--	--	--	--	--	--	1	--	1
4.25	--	--	--	--	--	--	--	--	--	--	0
5 +	--	--	--	--	--	--	--	--	--	--	0
Total	361	995	1193	802	1061	2422	1480	286	271	302	--

* Calculated at 10-m depth; 58,440 events; percent times 100.
Mean H_s = 0.6 m; Largest H_s = 4.2 m.

Table 3. **Percent Wave Occurrence Times 100, Silver Strand, California (WIS Station 2)**

Wave Height* m	Wave Period (sec)										
	<4.4	5.2	7.0	8.8	10.0	11.0	12.5	14.4	16.8	20.2	22.3+	Total
0.25	138	86	239	342	87	34	6	4	--	--	--	966
0.75	66	173	804	796	609	559	184	31	1	--	--	3223
1.25	5	102	675	300	333	673	630	121	7	--	--	2846
1.75	--	5	268	221	75	242	612	306	17	--	--	1746
2.25	--	--	26	102	37	49	241	306	34	--	--	795
2.75	--	--	2	23	25	13	59	140	36	--	--	298
3.25	--	--	--	2	3	4	12	37	10	--	--	68
3.75	--	--	--	--	--	1	3	12	6	--	--	22
4.25	--	--	--	--	--	--	--	1	1	--	--	2
5 +	--	--	--	--	--	--	--	--	--	--	--	0
Total	209	366	2044	1786	1169	1575	1747	958	112	00	00	--

* Calculated at 22-m depth; 58,440 events; percent times 100.
Mean H_s = 1.2 m; Largest H_s = 4.1 m.

Seaward Limit of Littoral Zone

The seaward limit of the littoral zone is first calculated to estimate the depth which would approximately separate successful placement of feeder and stable berms. For feeder berm design, the shallower the berm is placed the greater the likelihood for material reaching the beach.

Equation 1 requires an estimate of the average of the highest waves in 12 hr of a year, which translates to 80 3-hr events in 20 yr of WIS summary tables. The 12-hr annual average highest wave occurs with a frequency of (80/58,440)*100 = 0.14 percent. By inspection of Tables 2 and 3 to determine an average wave height corresponding to this percentage, H = 3.0 m and T = 9 sec for Gilgo, and H = 4.5 m and T = 13 sec for Silver Strand are estimated, at the respective hindcast depths of 10 m and 22 m. Shoaling these waves out to deep water and neglecting refraction gives $(H_o)_{12}$ = 3.4 m and $(H_o)_{12}/L_o$ = 0.025 for Gilgo, and approximately 4 m and 0.015 for Silver Strand. Substitution of these quantities into Equation 1 yields:

$$d_s = 3.4*(2.3 - 10.9*0.025) = 6.9 \text{ m} = 23 \text{ ft for Gilgo}$$

$$d_s = 4.0*(2.3 - 10.9*0.015) = 8.5 \text{ m} = 28 \text{ ft for Silver Strand}$$

From the calculations of d_S it is seen that both berms were placed well inside their respective annual seaward limits of the littoral zone. Accordingly, the berms are expected to function as true feeder berms, providing both the indirect benefits of wave attenuation and reduction of erosion, as well as directly nourishing the beach.

Beach Nourishment Potential

To obtain a qualitative estimate of the beach nourishment potential of the two berms under their respective wave environments, wave data in the modified WIS summary Tables 2 and 3 were entered in Equation 3 to predict erosional and accretionary conditions. For the two examples, grain sizes of 0.20 and 0.40 mm were used, yielding fall speeds of 0.025 and 0.053 m/sec, respectively, at a water temperature of 20° C (Table 1). The results of the calculations are given in Tables 4 and 5 for Gilgo and Silver Strand, respectively. In these tables, the symbols (a, A) denote predicted onshore movement of a berm (accretion) for the (0.20 mm, 0.40 mm) sand, and the hyphen denotes predicted offshore movement.

Table 4. Gilgo State Park, New York: Onshore - Offshore Berm Movement Occurrence

Wave Height m	Wave Period (sec)									
	1.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11 +
0.25	aA	aA	aA	aA	aA	aA	aA	aA	aA	aA
0.75		aA	aA	aA	aA	aA	aA	aA	aA	aA
1.25			aA	aA	aA	aA	aA	aA	aA	aA
1.75				-A	-A	-A	aA	aA	aA	aA
2.25					-A	-A	-A	-A	-A	-A
2.75						-A	-A	-A	-A	-A
3.25							-A	-A	-A	-A
3.75									-A	

Note: Symbols (a, A) denote onshore berm movement (accretion) for (0.20-mm, 0.40-mm) quartz sand; hyphen denotes offshore berm movement

Table 5. Silver Strand, California: Onshore - Offshore Berm Movement Occurrence

Wave Height m	Wave Period (sec) <4.4	5.2	7.0	8.8	10.0	11.0	12.5	14.4	16.8
0.25	aA	aA	aA	aA	aA	aA	aA	aA	
0.75	aA	aA	aA	aA	aA	aA	aA	aA	aA
1.25	aA	aA	aA	aA	aA	aA	aA	aA	aA
1.75		-A	-A	aA	aA	aA	aA	aA	aA
2.25			-A	-A	-A	-A	-A	aA	aA
2.75			-A	-A	-A	-A	-A	-A	-A
3.25				-A	-A	-A	-A	-A	-A
3.75						-A	-A	-A	-A
4.25								-A	-A

Note: Symbols (a, A) denote onshore berm movement (accretion) for (0.20-mm, 0.40-mm) quartz sand; hyphen denotes offshore berm movement

Interpreted in combination with the frequencies of wave occurrence, Tables 4 and 5 provide estimates of frequency of onshore and offshore berm movement by cross-shore wave processes. The method cannot, however, predict *magnitude* of the onshore and offshore movement, so that the net balance of cross-shore movement cannot be determined. Nevertheless, the method can be used in a relative sense in assessments of the likelihood for onshore movement of a berm composed of sand of known grain size. Several observations on the behavior of feeder berms and beach nourishment projects are obtained by this methodology:

- Accretion is favored for lower wave heights and longer periods, as is evident from the form of Equation 3. Also, the methodology predicts that a 0.40-mm berm placed in the littoral zone at either site will move onshore under all waves (except perhaps those of very severe storms) in a statistically representative wave climate.
- The longer period waves existing on the west coast tend to promote accretion for episodes of higher waves that are uncommon on the east coast, as readily seen for the 0.20-mm diameter sand. Because onshore movement of material in a feeder berm is expected to occur more rapidly under higher waves, this result implies that feeder berms of the same grain size at the same depth will move onshore more rapidly on the west coast than on the east coast.
- For Gilgo Beach, approximately 88 percent of the waves will tend to promote onshore berm movement for the 0.20-mm sand.

- At Silver Strand, the 0.20-mm sand berm experiences onshore transport conditions 88 percent of the time from the Northern Hemisphere sea and swell, and at least 36 percent of the time by the Southern Hemisphere swell.

Onshore movement of the berm at Silver Strand is shown in Figure 5. At depths greater than 9 m, there is no significant change in the profile, in agreement with the Hallermeier (1983) estimate. Substantial onshore movement of the berm is observed in water shallower than 6 m. By employing any standard wave breaking criterion involving depth, the approximate frequency of occurrence of erosive waves breaking on the berms can be calculated from knowledge of the berm crest depth. Such breaking wave calculations can be performed conveniently with the Dredging Research Program-developed PC model NMLONG (Numerical Model of the LONGshore current) (Kraus and Larson 1991, Larson and Kraus 1991).

The above analysis involved cross-shore transport effects. In the overall project design, characteristics of longshore sand transport at the site should also be considered. For example, at Gilgo Beach there is a tendency for strong net transport to the west, and a significant portion of the material that moved from the berm is believed to have been transported to beaches down coast. In contrast, at Silver Strand, the net longshore transport is believed to be weak, and most of the berm volume has remained on the profiles where it was placed. It is particularly important to

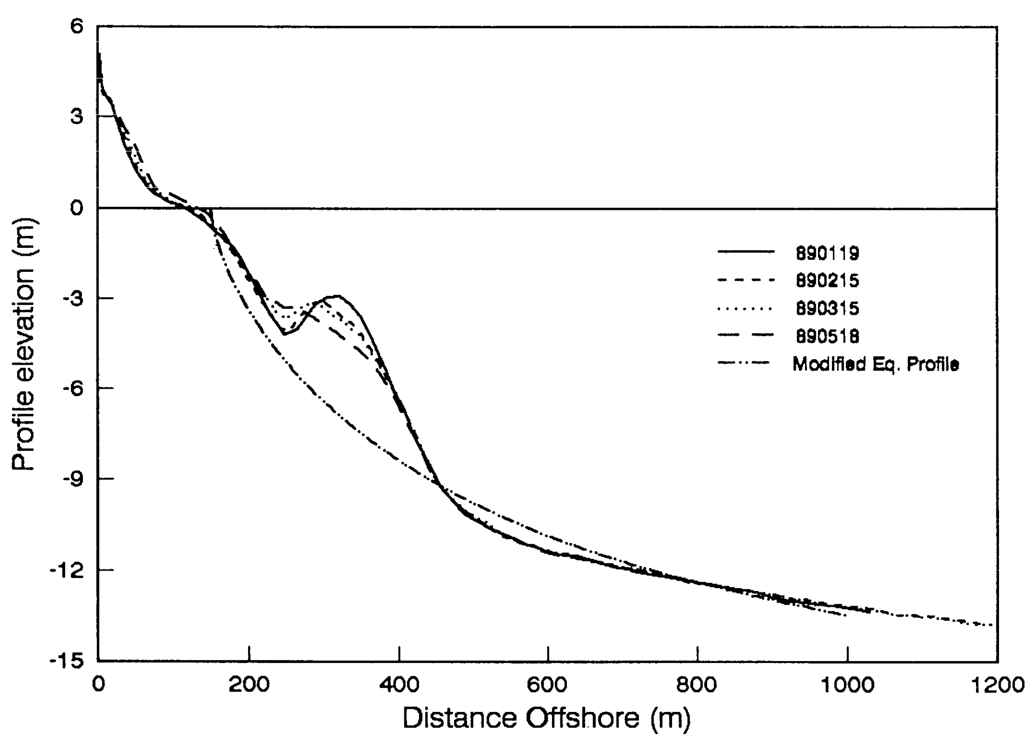

Figure 5. Onshore translation of the placed berm

consider longshore sand transport if the possibility exists for the material to enter a navigation channel or inlet.

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