CHAPTER 80

BEHAVIOR OF BEACH FILL
AT ATLANTIC CITY, NEW JERSEY

by

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ABSTRACT

A beach monitoring program between 1962 and 1972 at Atlantic City, New Jersey was designed to observe the response of beaches to waves and tides of specific intensity and duration as a first step in developing a storm warning system for low-lying coastal communities. As a by-product of that study the behavior of beach sand following two beach replenishment projects in 1963, and again in 1970, was determined. Monitoring was done using repetitive beach surveys above mean sea level (MSL) at seven profile lines. Survey results show that following replenishment, losses of the fill material above MSL were between nine and twelve times the losses measured in adjacent non-fill areas. Loss rates were largest at the updrift end of the fill region. About two and one-half times more material appeared to move in a seasonal on-offshore direction than moved permanently alongshore and above MSL to the southwest. For each meter of beach retreat, 5 to 6 m^3/lineal meter of fill were lost.

INTRODUCTION

Protective and recreational beaches sometimes require a periodic artificial replenishment of sand. The high cost and often recurring need for such replenishment justifies a study of what happens to the sand emplaced as beach fill to determine the most effective and economical method to rehabilitate the beach in the future. In addition, general information may be acquired for improving the design of fill projects at other locations.

Effective beach fill design involves many physical factors. Among them are the selection of a suitable fill material, the method to be used in transporting the fill material from its source to the beach, and the

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manner of placing the fill material on the beach. Fill placement is the subject of this paper which is a by-product of an Atlantic City, New Jersey study to observe beach changes in response to waves and tides of specific intensity and duration as a first step in developing a storm warning system for low-lying coastal communities (Galvin, 1968). The study, a part of the Beach Evaluation Program of the Coastal Engineering Research Center (CERC), included two beach replenishment projects in 1963 and 1970. Survey data were acquired only above mean sea level (MSL). A beach loss using these data may, therefore, indicate an accretion below MSL, or a real loss to the beach system by longshore transport.

ATLANTIC CITY ENVIRONMENT

Physical Setting. Atlantic City is located on the New Jersey coast about 130 km south of New York City (Figure 1). It lies on the northern one-half of Absecon Island which is a 13.2-km long by 0.8 to 2.4-km wide barrier island with an average ground elevation of less than 3 m above MSL. Its beaches are characterized by berms averaging 80 m in width and 2.2 m in elevation (Table 1). Natural dunes have been replaced by a boardwalk or

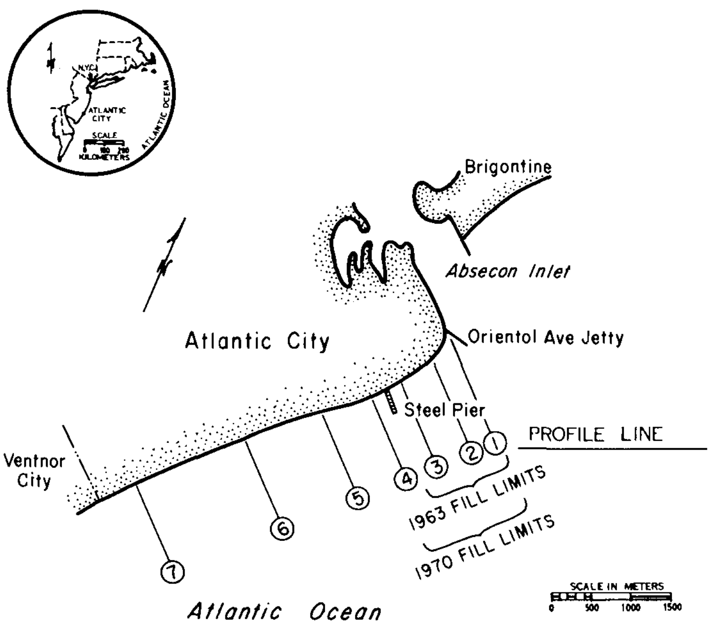

Figure 1. Location of Atlantic City Study Area and Profile Lines

seawall. The 5000 m northeast-southwest trending study reach includes the entire Atlantic City beachfront from Absecon Inlet (Oriental Avenue) on the north end to the Ventnor City limits. Approximately 94% of that shorefront, one of the East coast's most popular recreational beaches, is publically owned.

Table 1. NATURAL BERM CHARACTERISTICS - ATLANTIC CITY

Profile Line	Average Berm Width (from boardwalk in meters)	Average Berm Elevation (meters above MSL)	Average Foreshore Slope
1	180	1.3	.039
2	5	2.3	.066
3	75	3.0	.047
4	50	2.4	.046
5	60	2.2	.046
6	90	2.1	.039
7	110	2.0	.045

Beach Material. Natural beach material at Atlantic City is medium to fine-grained sand (McMaster, 1954; and Ramsey and Galvin, 1971). Median grain diameters range from 0.22 to 0.33 mm. McMaster found the sands to be composed of approximately 98% well-rounded quartz.

Wave and Tide Data. Wave data were obtained at Atlantic City between 1957 and 1967 from a CERC staff gage located in 5.5 m of water on the Steel Pier (Figure 1). Based on 18,132 observations, Thompson and Harris (1972) determined the mean wave height at Atlantic City to be 0.9 m. Less than 1% of the waves exceeded 3 m. Figure 2 shows the weighted time duration, in hours per month, of waves which exceeded a height of 1.2 m for the survey years 1962-1967. The percent of the total monthly record which was available is given in the upper center of each monthly record. Using the mean monthly wave period of 8 sec, a wave height of 1.2 m results in a wave steepness (wave height/wave length) of 0.021 at the gage.

Eight hundred twelve visual observations of the direction of wave approach at the outer breaker zone were made at irregular time intervals at Atlantic City between 1968 and 1973. A distribution of these data is shown in Figure 3. The percent of the total monthly observations is given for one of five possible sectors of wave approach identified in the upper portion of the figure. Waves from Sectors 1 or 2, for example, approach the shore at an angle north of the shore-normal orientation (Sector 3).

At Atlantic City, the mean tidal range is 1.2 m and the spring range is 1.5 m. The maximum storm surge recorded was 2.0 m in 1951. In 1962, 1963, and 1964 the maximum storm surges were 1.3, 1.1, and 1.2 m, respectively. In 1965 the maximum surge was 0.8 m, and in 1966, 1967, and 1968 the maximum storm surges were 1.0, 0.9, and 0.8 m.

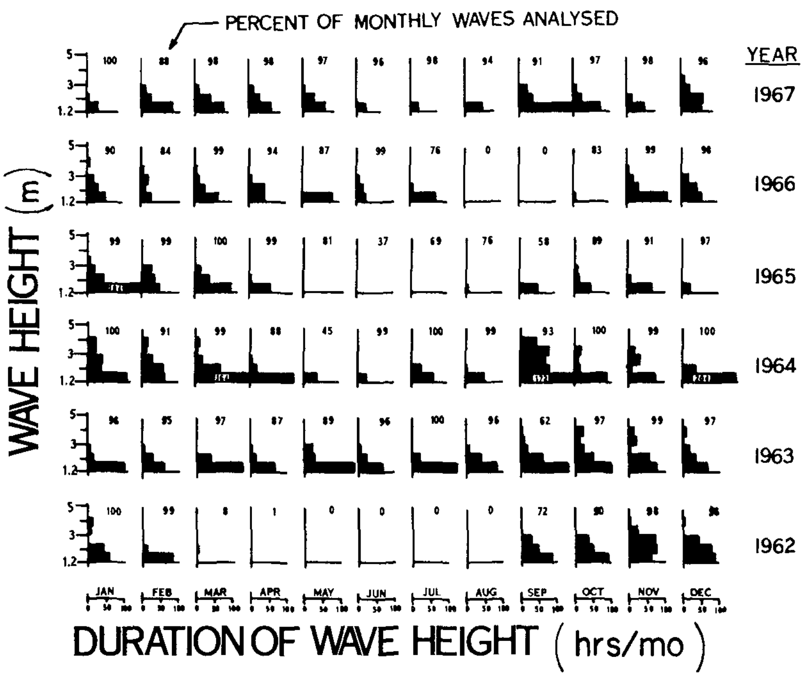

Figure 2. Monthly Time Duration of Waves which Exceeded 1.2 m at Atlantic City (1962-1967)

Coastal Structures. In 1948 a 244-m long stone jetty (Oriental Avenue jetty) was constructed on the north end of Atlantic City. Its purpose was to stabilize Absecon Inlet which had migrated 183 m southwest between 1840 and 1935. The jetty was extended to its present 359 m length in 1961 and 1962. Groin construction at Atlantic City began in 1928 and since then twelve groins have been built on the northeastern half of the study beach. Eight, which were built between 1930 and 1950, are in existence today.

DATA COLLECTION AND ANALYSIS

Field Procedure. Repeated surveys of the seven non-equally spaced profile lines shown in Figure 1 were made between October 1962 and April 1972 on an irregular basis. A standard level and tape survey method was used. Each profile began at a semi-permanent base station at the landward end with data collected along a line normal to the shore at each change in beach slope or every 15 m from the base station out to an elevation of about -0.3 to -0.6 m MSL. Horizontal and vertical data were recorded to

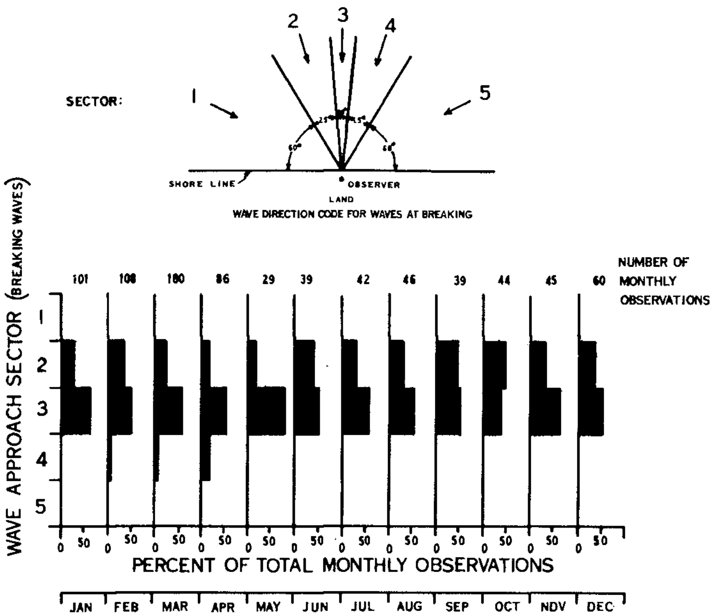

Figure 3. Direction of Wave Approach, by Month, at Atlantic City

0.3 and 0.03 m, respectively.

Data Handling and Analysis. Survey data, recorded in standard notebooks in the field, were later transferred to plots or to optical scanning forms and sent to CERC. Upon receipt, the data were automatically compiled, edited, and put on magnetic tape. For each profile line, the data were analyzed to obtain the sand volume (cross-sectional area under the profile times a unit distance parallel to the coast) change between each survey and the volume under the profile at the time of the first survey. Fixed bounds in computing the volume change were the profile (upper bound), the MSL elevation (lower bound), and the fixed base station (landward bound) near the boardwalk. Few elevation changes occurred at the latter location so the computed value is an accurate representation of the change in sand volume above MSL. Changes in the position of the MSL shoreline were also computed.

BEACH FILL PROJECTS

Two general procedures for artificial beach restoration and improvement are stockpiling and direct placement (Hall and Watts, 1957). Stockpiling is the establishment and periodic replenishment of a volume of suitable beach material at the updrift sector of a problem area. Direct fill placement is restoration by fill placed along the entire eroded sector. The 1963 and 1970 Atlantic City projects were a combination of the two procedures. In the northeast sector of the beach direct fill placement was used. This material, however, acted as a stockpile and moved to the southwest to nourish the downdrift beaches.

In February-May 1963, 430,000 m^3 of fill, an average of 440 m^3 per lineal meter of beach (m^3/m), were placed along 1160 m of beach southwest of the Oriental Avenue jetty (Figure 1). The purpose of this fill was to restore the beach after it was severely eroded by a March 1962 storm. The beach deteriorated after the 1963 fill and in June and July of 1970 an additional 610,000 m^3 of material were placed on 1460 m of beach southwest of the jetty (an average of 416 m^3/m). Fill material in each case was dredged from Absecon Inlet and pumped south to the beaches. It had a mean grain size (0.3 mm) similar to that occurring naturally on the beach.

Profiles before and after fill placement are shown superimposed in Figure 4. Surveys in 1963 indicated that 145, 246 and 168 m^3/m on Profile Lines 1, 2, and 3, respectively, were placed above MSL, or 43% of the total volume of fill. Following the 1970 fill, 216, 183, and 193 m^3/m were placed above MSL on the same profile lines, or 48% of the total fill volume.

For both the 1963 and 1970 fills, the post-fill shape of the profile varied considerably along the coast (Figure 4). However, the shape was similar at each profile line. At Profile Line 1 fill was placed mainly on top of the 137-m wide berm while it was placed seaward of the pre-fill

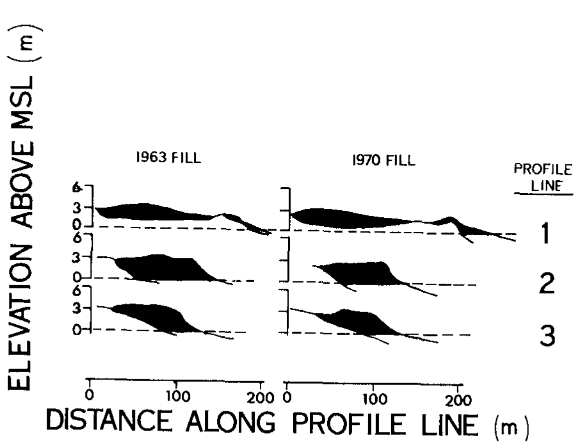

Figure 4. Cross-section of Beach from Profiles Taken Before and After Beach Nourishment in 1963 and 1970

berm on Profile Lines 2 and 3. The artificial berm elevations were 2.4 to 3.0 m. The foreshore slope of the profiles varied from .02 (Profile Line 1, 1963) to 0.11 (Profile Line 2, 1970).

RESULTS

Changes Following Beach Replenishment. The volume loss rate of sand from the fill region above MSL was greatest immediately following placement. Thereafter the rate decreased with time in a consistant manner. On individual profile lines, loss rates following the two fills appear to be similar. This is shown in Figure 5 where the cumulative change in sediment volume is plotted for the period 1962-1972. Note that volume is related to the pre-fill datum volume = 0 of the initial survey of 27 October 1962.

In the fill area the volume loss rate is also a function of distance southwest of the Oriental Avenue jetty (Figure 6). At Profile Line 1 the loss rate was rapid and constant until the profile line returned to the pre-fill profile volume shown in Figure 5. Ninety percent of the fill volume was lost at Profile Line 1 in six months following replenishment in 1963 and in eight months subsequent to the 1970 fill. These were mostly storm changes with few accretional recoveries observed in the intervening periods. Initially the loss rate on Profile Line 2 was similar to that on Profile Line 1, but when 70% of the fill placed above MSL was lost the rate dropped to less than one-half the initial rate. A maximum natural accretion of 10 m^3/m between surveys was measured before all of the fill above MSL was lost. On Profile Line 3 the fill loss rate was uniformly low, however, large natural recoveries of material were observed. For instance, during the spring of 1965 a mean accretion above MSL of 51 m^3/m was calculated which returned Profile Line 3 to near its maximum volume as measured at the time of the fill. This situation was nearly duplicated in the summer of 1967 when a recovery of 44 m^3/m was measured.

Following beach replenishment, steep artificial foreshore slopes rapidly adjusted to the more gradual natural slope for that season of the year. The adjustment frequently occurred at the expense of some fill sand above MSL. The beach at Profile Line 2, for example, adjusted in less than 20 days to a more gradual slope which was maintained throughout the summer of 1963. The slope flattening was accompanied by a sand loss of 11 m^3/m from the subaerial beach.

Temporal Aspects of Beach Change. Three frequencies of beach change can be identified in the survey data:

(1) *Changes Between Surveys (Including Storms)*. Considerable variation was observed in the beach volume as a result of four storms for which post-storm surveys were available (Table 2). The post-storm surveys were usually made within two days following the storm. When weighted by the distance between profile lines, these changes provide the average sand loss for the entire Atlantic City coast as shown at the bottom of the table. Maximum storm erosion occurred during the November 1963 storm (Hurricane

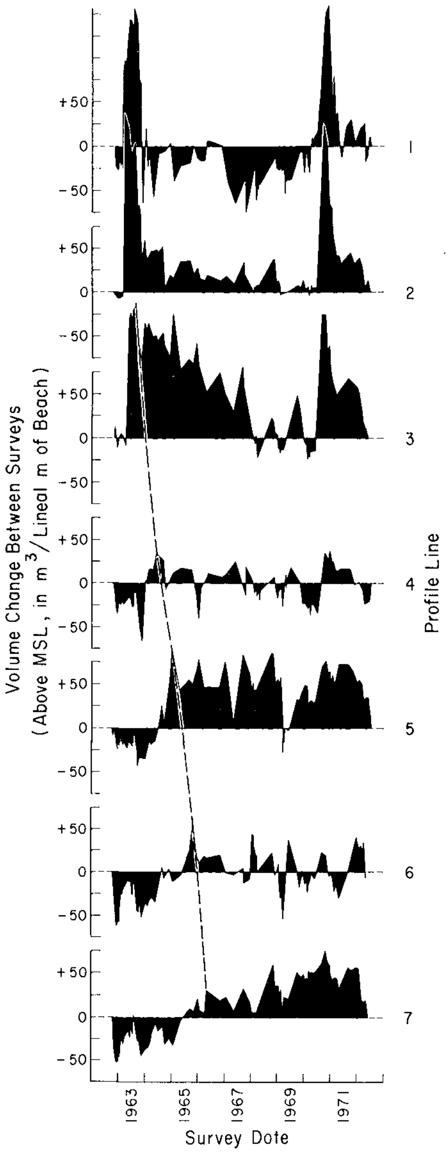

Figure 5. Change in Sediment Volume Between Surveys

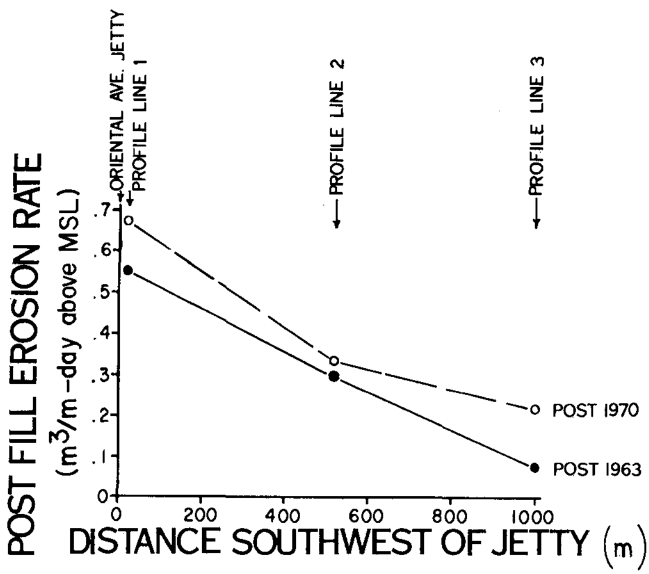

Figure 6. Loss Rates Following the 1963 and 1970 Beach Fills During the Time Interval in which the Fill Volume was Reduced by 90 Percent Above MSL

Ginny) when an average 20 m^3/m, or 100,000 m^3 for the entire beach, was lost. The average loss per lineal meter of beach for the four storms was 13 m^3/m. Largest losses occurred on the northeast (fill) end of the study area.

The largest volume loss measured between any two consecutive surveys, which averaged about a month apart, is plotted in Figure 7 vs the associated beach recession at MSL. The resulting volume loss above MSL per meter of beach recession was 2.45 m^3/m. Maximum accretion between any two consecutive surveys was of nearly the same magnitude as maximum erosion except on Profile Lines 1 and 2, where maximum accretion values were only 32.6 and 27.6 m^3/m, respectively. The relationship with shoreline recession or progradation, as shown in Figure 7 was not always observed for lower volume losses and gains.

(2) *Seasonal Changes*. Clear trends of volume in storage above MSL were evident when volume data are averaged by month. Figure 8 shows the monthly sand volume, referenced to a mean zero datum, for all the profile lines averaged for all survey years (1962-1972). The May-June interval was a time of accretion above MSL while the period September - February is one of sand loss. From June through October the subaerial beach lost an average of 61 m^3/m of sand. The northeast beaches experienced the greatest losses and gains of sand between months. Large variations between the

Table 2. BEACH CHANGES ABOVE MSL (m^3/m) CAUSED BY STORMS AT ATLANTIC CITY

Profile Line	Storm Date				
	Nov 63	Dec 70	4 Feb 72	19 Feb 72	Average
1	-130	+52	+3.5	-43	-29
2	-61	-23	-20	-4.5	-27
3	-12	-24	-18	-7.0	-15
4	-19	+8.3	-12	-6.8	-7.4
5	-8.8	-18	-5.0	-19	-12.7
6	-7.5	+2.8	+3.3	-16	-4.3
7	-17	-9.0	-33	-22	-20
Average:	-20	-5.3	-10	-16	-13
Days Between Surveys:	36	9	8	7	

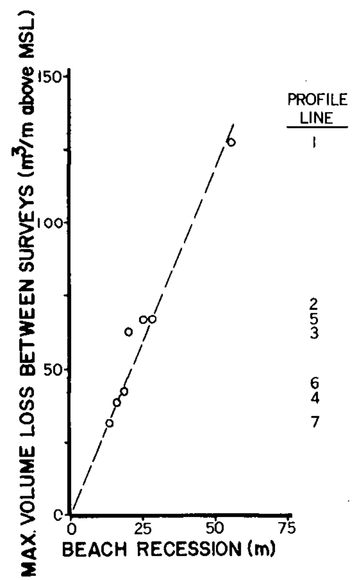

Figure 7. Maximum Volume Losses on the Profile Lines vs Beach Recession at MSL

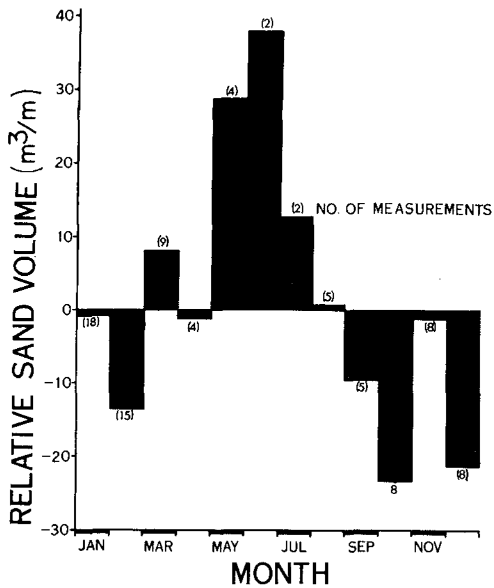

Figure 8. Change in Sand Volume Above MSL on the Beach, by Month

same months occurred from one year to the next.

(3) *Yearly Variations.* Variations between years in the mean sand volume on the beach were only partially related to the volume placed during the fill projects. Figure 9 illustrates the average yearly volume change relative to the beach volume in October 1962.

Alongshore Redistribution of Beach Material. Sand volumes on beaches southwest of the nourished areas increased in a time ordered sequence after the fill was placed while during the same period the nourished beaches experienced erosion. Cumulative yearly mean volume change for each profile line relative to the volume immediately after the beach was nourished in 1963 is illustrated in Figure 10. Maximum accretion occurred on Profile Line 4 in 1964, on Profile Line 5 in 1965, on Profile Line 6 in 1968 and on Profile Line 7 in 1969.

The dashed lines in Figure 5 also illustrates what appears to be a progressive shift in beach volume maxima above MSL after the 1963 fill. The migrating beach material, which caused the shoreline to prograde seaward as it passed, decreased in volume with time and with distance along the shore from Profile Line 3. The locus of the maximum loss, trailed, in time, the peak accretion and also moved to the southwest.

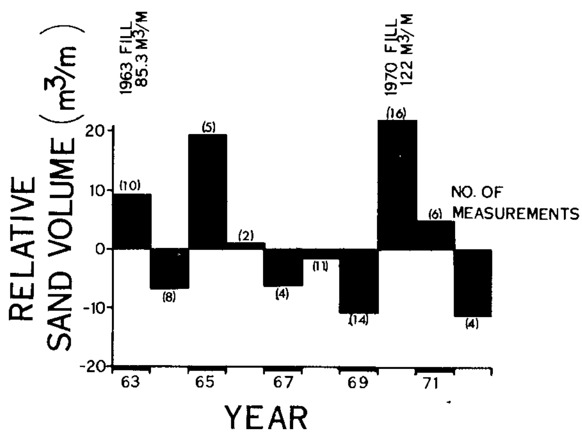

Figure 9. Change in Sand Volume Above MSL on the Beach, by Year

DISCUSSION AND CONCLUSIONS

The behavior of fill material following nourishment projects at Atlantic City in 1963 and 1970 was consistent. It was also in what appears to be a qualitatively predictible manner. Beach survey data and wave data provide the following information on where, when, and how much artificial and natural beach material is eroded or deposited, and in what direction it is transported:

(1) *Volume Loss vs Beach Retreat.* An estimate of the short and long term beach volume fluctuations, especially those that accompany shoreline retreat, is important in designing the safe width of a protective beach. At Atlantic City the maximum measured volume loss above MSL per meter of shoreline retreat at MSL was 2.45 m^3/m (Figure 7). Since 43 and 48%, respectively, of the fill was placed above MSL in 1963 and 1970, a meter of beach retreat might be expected to be accompanied by an actual loss of 5-6 m^3/m of fill material.

(2) *Beach Fill Losses.* Loss rates for fill material were much larger than loss rates of adjacent natural material. Following the 1963 fill program 50,000 m^3 were lost in eight months, while 84,000 m^3 were lost in 15 months subsequent to the 1970 fill. When averaged over the fill area the loss rates were 65 and 47 m^3/m-yr, respectively, or twelve and nine times the mean annual loss from the entire subaerial Atlantic City beach.

(3) *Foreshore Slope Adjustment.* Foreshore slopes in the fill region of Atlantic City adjusted rapidly to the natural slope of the season, and, though other factors were involved, when the fill was placed on slopes

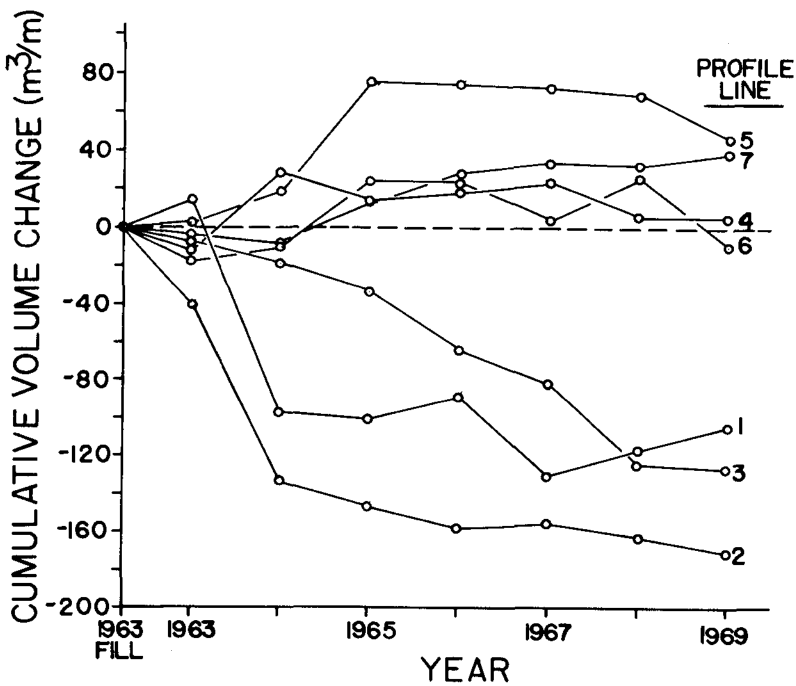

Figure 10. Yearly Change in Sand Volume Above MSL at each Profile Line

greater than the natural slope a small volume of sand (about 10 m^3/m) was lost. Conversely, were the fill slope was less than the natural slopes, the foreshore slope remained stable.

(4) *Net Yearly Sand Loss.* Between the non-fill years 1965 and 1969 the mean annual sand loss from the entire 5000 m shoreline averaged 5.3 m^3/m-yr above MSL (Figure 9). This is the best approximation to the natural beach loss available; however, the gain or loss of sand from one year to the next was highly variable. Consequently, a useful expected yearly sand loss, or gain, is difficult to predict.

(5) *Annual Sand Losses.* The mean yearly gain or loss of sand to the subaerial beach (Figure 9) appears fairly well characterized by the number and severity of autumn and winter storms. In 1965, for example, a year of few storms, 95,000 m^3 (19 m^3/m) of sand were added to the beaches. Conversely, in 1964, a year of frequent storms, 33,000 m^3 (6.6 m^3/m) of sand were lost from the subaerial beach. The duration of waves that exceeded a steepness of 0.021, which were usually associated with storms, was, in

1964, more than twice that of 1965 (Figure 2). A wave steepness of 0.021 was used because a steepness between 0.02 and 0.025 is frequently applied to the design of prototype beaches to designate the cutoff point between waves causing erosion and those causing accretion. Saville and Watts (1969), however, have pointed out that although these values are commonly used, they are derived mostly from laboratory studies and are doubtful when applied to a field situation. For the North Sea coast, Schijf (1959) observed a relationship between winter gales and their effect on beaches which was similar to that of Atlantic City.

(6) *Monthly Changes in Beach Volume.* Summer was the season of natural beach accretion and autumn and winter were predominately seasons of erosion (Figure 8). As observed with yearly changes, there was a direct relationship between monthly sand volume above MSL and the monthly frequency of waves greater than 1.2 m (Figure 2). Frequent high waves in the period September-February resulted in a low volume of sand in storage above MSL, while the absence of such waves between May-July allowed sand accretion. A mean 38 m^3/m above the average of all surveys was observed in June, and a mean 23 m^3/m less than the average was observed in October.

(7) *Storm Losses.* An average storm loss, based on four storms, for the entire Atlantic City beach above MSL was 13 m^3/m (Table 2). The maximum loss for a single storm was 20 m^3/m averaged for the entire coast, and the minimum was 5.3 m^3/m. Losses on the nourished profile lines were two to five times greater than on other profile lines. The maximum loss on any profile line was 130 m^3/m (Profile Line 1) resulting in a MSL shoreline retreat of 53 m.

(8) *Beach Change Intervals.* An analysis of the survey data indicates that the long term erosion problem in the fill region was caused primarily by abrupt events (storms). These storm losses (Table 2), for which there was incomplete later recovery, accompany cyclic seasonal changes and yearly changes (Figure 8 and 9). Figure 11 summarizes beach volume changes measured during the 1962 and 1972 study period. For the entire study beach the magnitude of storm losses was greater than the sand volume change between years and less than that between months. Monthly changes were about twice the variation observed between years while yearly variations were two to three times as large as the mean annual loss for the 1965-1969 interval. These data may be of use in determining when it is necessary to artifically replenish the protective beach, and in determining when a natural recovery may be expected.

(9) *Direction of Alongshore Movement.* Periods of shoreline advance which alternated with periods of shoreline retreat indicate beach material moved alongshore (and above MSL) in "humps" or waves. These features have been observed elsewhere, e.g. Bruun (1954) along the North Sea coast. The time dependent movement of the sand volume maximum in Figures 5 and 10 also indicate transport to be in a net southwest direction. This movement was directly related to the direction anticipated using wave data (Figure 3). The mean direction of wave approach for all months except April was northeast of shore-normal which suggests that net alongshore currents should

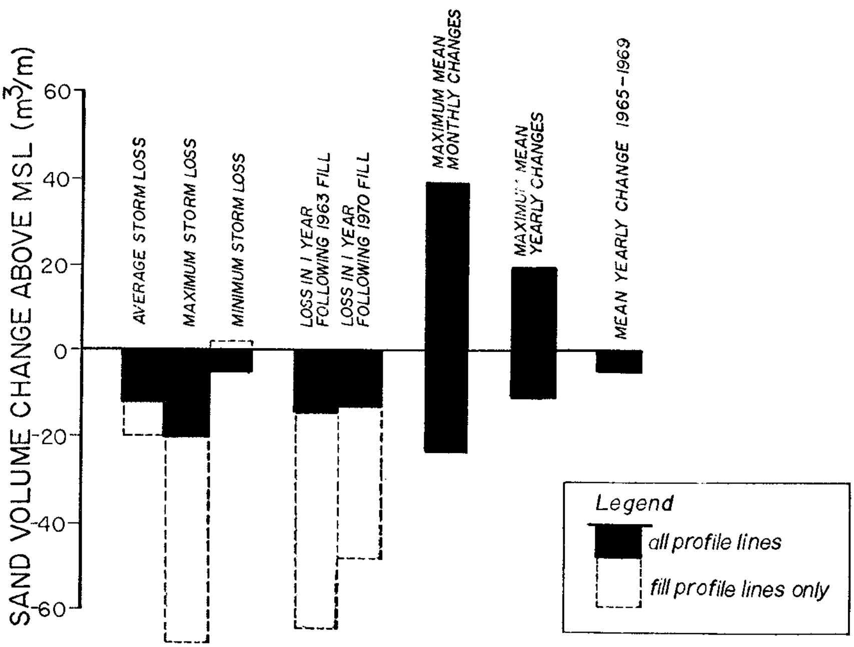

Figure 11. Maximum Volume Changes Above MSL Measured During the Period 1962-1972

be to the southwest. Waves from southwest of shore-normal were as common as those from the northeast during April. March and April were the only months in which a significant portion of the waves approached from south of shore-normal, and they were also the only months in which the survey data indicated a reversal in the direction of sand movement. Figure 10 reflects this reversal and shows the increase in volume at the Oriental Avenue jetty (Profile Line 1) measured during the second quarter in 1963 (Figure 5).

(10) *Rate of Alongshore Movement.* The migration rate of the volume maximum following the 1963 fill was 2 m/day while that following the 1970 fill was 3 m/day (Figure 5).

(11) *Volume of Alongshore Movement.* In 1964 the sand volume within the subaerial "hump" was 46 m^3/m above MSL, while in 1965 it was 40 m^3/m. At a southwestward rate of movement of 2 m/day, the maximum transport above MSL on Profile Line 4 in 1964 was 34,000 m^3/yr. This assumes that the entire "hump" was moving at a constant rate. In 1965, the maximum volume transported above MSL was 30,000 m^3/yr which indicates the volume decreased with time and distance from the date and location of the fill. Near Absecon Inlet, Caldwell (1966) estimated a net longshore transport rate to the south-

east, above and below MSL, of 76,000 m^3/yr, or slightly over twice that observed above MSL following the 1963 beach fill.

(12) *On-Offshore Sand Movement.* It is difficult to determine the total volume of sand that moved in an on-offshore direction vs an alongshore direction because surveys were not available below MSL. However, since the difference in sand volume above MSL between summer and winter was similar at all seven profile lines and relatively consistent from year to year, much of the average 60 m^3/m seasonal change must have been the result of on-offshore exchange. Such on-offshore movement has been noted by many observers, including Watts (1956) at Ocean City, New Jersey; in Harrison County, Mississippi (1958); and at Virginia Beach, Virginia (1959); and Perdikis (1961) on a number of replenished New England beaches They found that fill material lost from the beach above MSL was transported directly offshore. They also found that, subsequently, much of it was moved onshore again or moved in an alongshore direction. Based on the available data at Atlantic City, the on-offshore movement is about two and one-half times the volume which moved alongshore and above MSL following the 1963 fill. The importance of the net longshore movement is that it results in a permanent loss to the study beach while the on-offshore movement is cyclic and mostly non-permanent.

GENERAL IMPLICATIONS

(1) A localized feeder beach near the jetty (Figure 1) would result in the maximum residence time of fill sand on the problem beaches. Residence time is the time interval that a unit volume of fill material remains in the eroding beach region. Because the updrift fill areas nourish fill areas to the southwest, fill loss rates above MSL decrease away from the jetty and material placed at the most updrift location remains in the problem beach system the longest. The beach near the jetty is, in addition, closest to the present fill source at Absecon Inlet. The jetty inhibits return flow of fill material to the inlet.

(2) The predominant sand movement to the offshore region appears to occur between September and March. The greatest subaerial fill losses would be expected to occur then and the residence time of fill placed during that period would be less than for fill placed during the spring.

(3) When natural conditions are similar, large volume beach fills placed within the reach of waves generally experience loss rates considerably above the average non-fill loss rate. Smaller volumes of fill, placed more frequently, would probably lessen the loss rate and increase the residence time of fill on the problem beach.

(4) It appears that optimum feeder beach use at Atlantic City would be after April when longshore current reversals are at a minimum. Following April nearly all material that moves alongshore would be expected to move and nourish the beaches to the southwest.

(5) The possibility of migrating accretional features, even three or four years after the fill, should be considered when using surveys to

evaluate the total effectiveness of a beach fill project since the accretional phase at any location may not be permanent, but may be followed by an erosional phase.

(6) The offshore area should be surveyed to account, as much as possible, for the total sand budget.

(7) A survey made in the spring or summer will generally indicate a larger sand volume on the beach than one from the autumn or winter, even when the mean yearly volume is unchanging. One survey per season would provide a better means to determine net sand loss than a single survey per year.

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