DAILY CHANGES IN BEACH PROFILE AND SAND TEXTURE ON DEL MONTE BEACH, CALIFORNIA

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ON

DEL MONTE BEACH, CALIFORNIA

by

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ABSTRACT

Beach-elevation measurements were made and sand samples were collected along a single profile daily at low tide during the period from February 1 through March 31, 1967. Wave and tide data were recorded continuously. The beach, composed of medium-to-fine quartz and feldspar sand, is well sheltered from wave action.

Wave steepness exerts a great influence on the beach profile. An equilibrium profile was found to exist for a given wave steepness. As wave conditions change, the beach profile tends to change toward the equilibrium profile associated with the new wave steepness. Given an initial beach profile, the amounts of cut and fill that will occur with a given change in wave steepness can be predicted.

Textural parameters do not appear to be related to changing wave conditions in a simple way. Equilibrium values of mean grain size, sorting, skewness, and kurtosis exist for any given location on the beach profile. The equilibrium values are apparently independent of wave conditions.

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1. Objective of the Study

This investigation involved measuring a selected beach profile, sampling the beach sand, and observing the waves, with the object of determining how the beach responds to changing wave conditions.

A modest number of laboratory experimental studies have been made to determine the relationship of these factors (Bagnold, 1947; Scott, 1954; Ippen, 1955). Natural beaches and wave conditions are so complex, however, that relationships derived in the laboratory are not easily applied to real beaches. In addition, previous studies of the interrelationship of the beach and wave parameters have yielded little more than qualitative relationships; for example, wind waves tend to cut beaches (Shepard, 1963) and steep beaches tend to have coarser texture (Bascom, 1951).

Field studies of sand beaches (Trask, 1956 and 1959; Inman, 1953) have been conducted with sampling intervals ranging from weeks to months. With such wide sampling intervals, daily and other short-term changes in the character of the beach are not recorded. The object of this study was to observe the short-term variations of the beach.

The period covered by field observations was the months of February and March, 1967. The beach profile studied is located on Del Monte Beach in Southern Monterey Bay, California. Observations were made daily at the time of low tide and were restricted to that portion of the beach which was exposed.

The beach profile was measured and surface sand samples were collected along a line of permanently fixed rails extending across the beach. A continuous wave record was obtained at a location seaward of the surf zone and directly offshore from the beach profile (Figure 1). A photograph of the profile is shown in Figure 2.

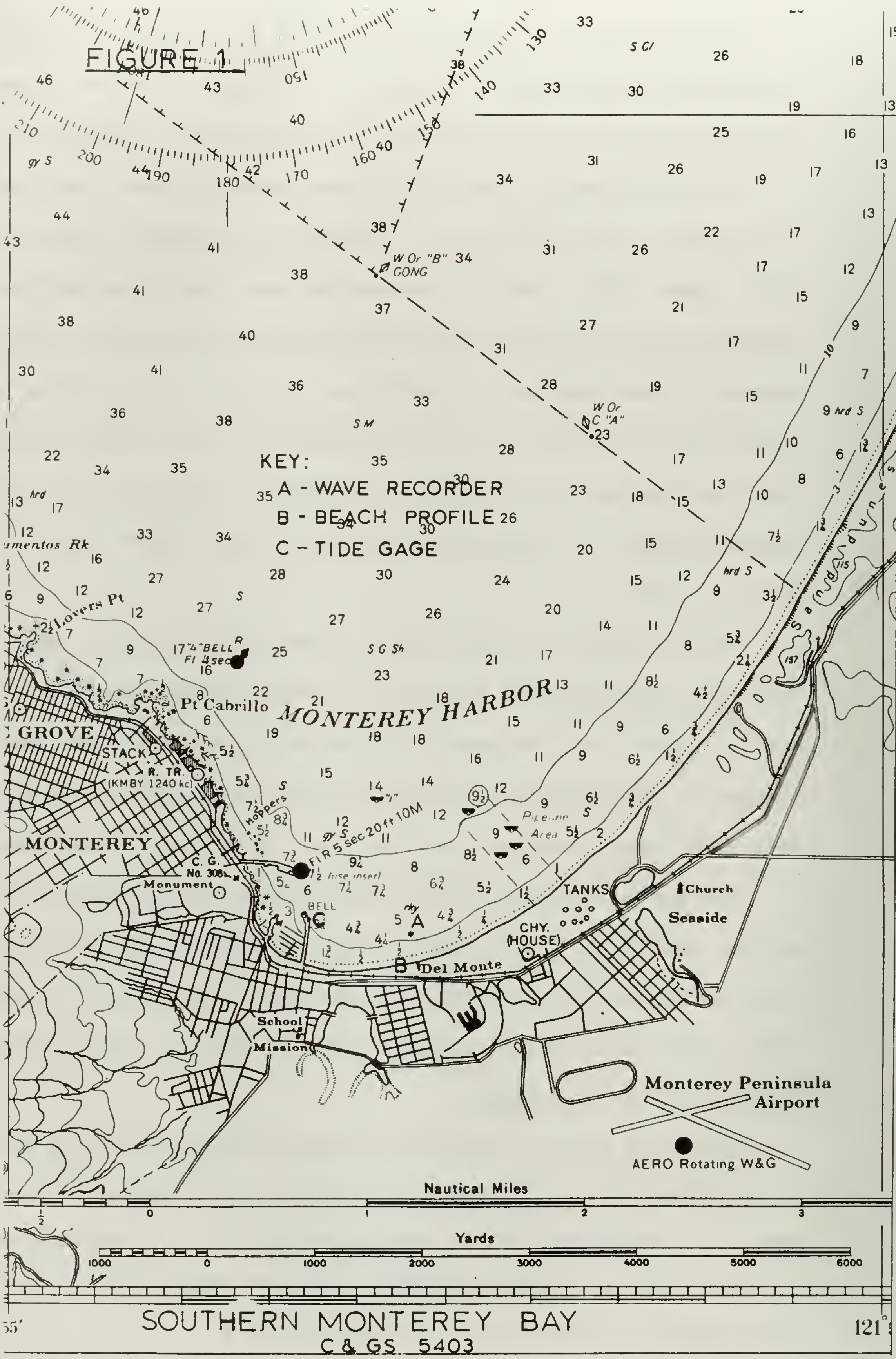


FIGURE 1
KEY:
A - WAVE RECORDER
B - BEACH PROFILE
C - TIDE GAGE
MONTEREY HARBOR
Lovers Pt
Pt Cabrillo
MONTEREY
STACK
R. TR.
(KMBY 1240 kc)
C. G.
No. 306
Monument
School
Mission
Del Monte
TANKS
CHY.
(HOUSE)
Church
Seaside
Monterey Peninsula
Airport
AERO Rotating W&G
Nautical Miles
Yards
SOUTHERN MONTEREY BAY
C & GS 5403

FIGURE 2
BEACH
PROFILE

2. Description of the Area

a. Southern Monterey Bay

The entire inner shoreline of Monterey Bay, extending for approximately 55 kilometers, is an essentially unbroken sand beach. The beach profile described in this report is located near its southern end (Figure 1). About one mile south of the profile the beach ends against outcrops of granite forming a rocky headland.

In the vicinity of the profile and extending northward along the coast, sand dunes parallel the shoreline behind the beach. These dunes are apparently inactive. South of the profile the dunes rapidly decrease in size and disappear within a half-mile.

b. Del Monte Beach

The beach in the area studied has a foreshore slope of about 1:20. Seaward of the profile the seafloor slopes uniformly at a lesser rate. Cusps are often present, predominantly on the upper part of the beach. A well-defined berm is usually absent.

The beach is composed of medium-to-fine sand at the observed profile. The grain size increases to the north along Del Monte Beach and decreases to the south (McCullough and Fleming, 1967). Sorting is characteristically good on all parts of the beach. Quartz, quartzite, feldspar, and varying small amounts of biotite make up the beach material. Occasionally pebbles and coarse shell fragments are deposited on the lower foreshore.

c. Waves and Surf

The beach studied is sheltered by the headlands of the Monterey Peninsula to the extent that waves entering the bay from any direction are reduced by refraction to swell of low steepness by the time they arrive at the shore.

Because of the extreme refraction, all waves arrive with their crests parallel or nearly parallel to the beach. Plunging breakers predominate. In addition, owing to the sheltering effect of the Peninsula, a wave-height gradient occurs along the beach, with larger waves to the north and smaller waves to the south.

Characteristic afternoon sea breezes from the northwest generate short wind waves with crests arriving nearly parallel to the shoreline. These diurnal breezes are most common during the summer. Wind waves from the north, generated locally within the bay, occur only on rare occasions. The dominant waves throughout most of the year are swell. Littoral drift is negligible.

During most of the period of observations long low swell predominated. Significant wind waves were present only on three days, February 14th and March 24th and 29th. Breaker heights were normally below three feet.

d. Tides

The tides in Monterey Bay, as is characteristic of the Pacific Coast, are mixed and are characterized by two daily cycles of differing heights. The average range between lower low water and higher high water is 5.3 feet. The coastwise tidal datum is Mean Lower Low Water (MLLW).

3. Field Observations and Sampling

a. Dates and Intervals of Observation and Sampling

Field observations began February 1 and continued through March 31, 1967. All observations were made daily at a low tide stage when the beach was exposed. On most days the observation time coincided with the occurrence of lower low water. Accordingly, the sampling interval was that of the diurnal tidal period, approximately 25 hours, so that the sampling time advanced about an hour each day. All observations were made during the daylight hours, so when the time of the low-tide observation occurred near sundown it became necessary to shift the next sampling time ahead only 12½ hours (a semi-diurnal tidal period) to the morning low tide. Four such short sampling intervals were needed during the period of observations, occurring on February 13 and every 15 days thereafter. Using these intervals of observations resulted in all but three of the sampling tides being the lower low tide of the day. The relation of the daily sampling times to the tides is shown in the lower graph of Figure 3.

b. Beach Profile

Measurements of the beach elevation were made relative to a series of 20 rails driven into the beach (Figure 4). The rails extend in a line across the beach from a point above the highest wave reach (Rail 1) across the inter-tidal zone to the lowest tide level (Rail 20). The distance between the rails varies slightly but is about three meters, except between Rail 5 and Rail 6 where the interval is about six meters. The tops of the rails were leveled relative to MLLW.

A simple T-shaped staff two meters in length and graduated in millimeters was used to measure the beach elevation relative to the rails.

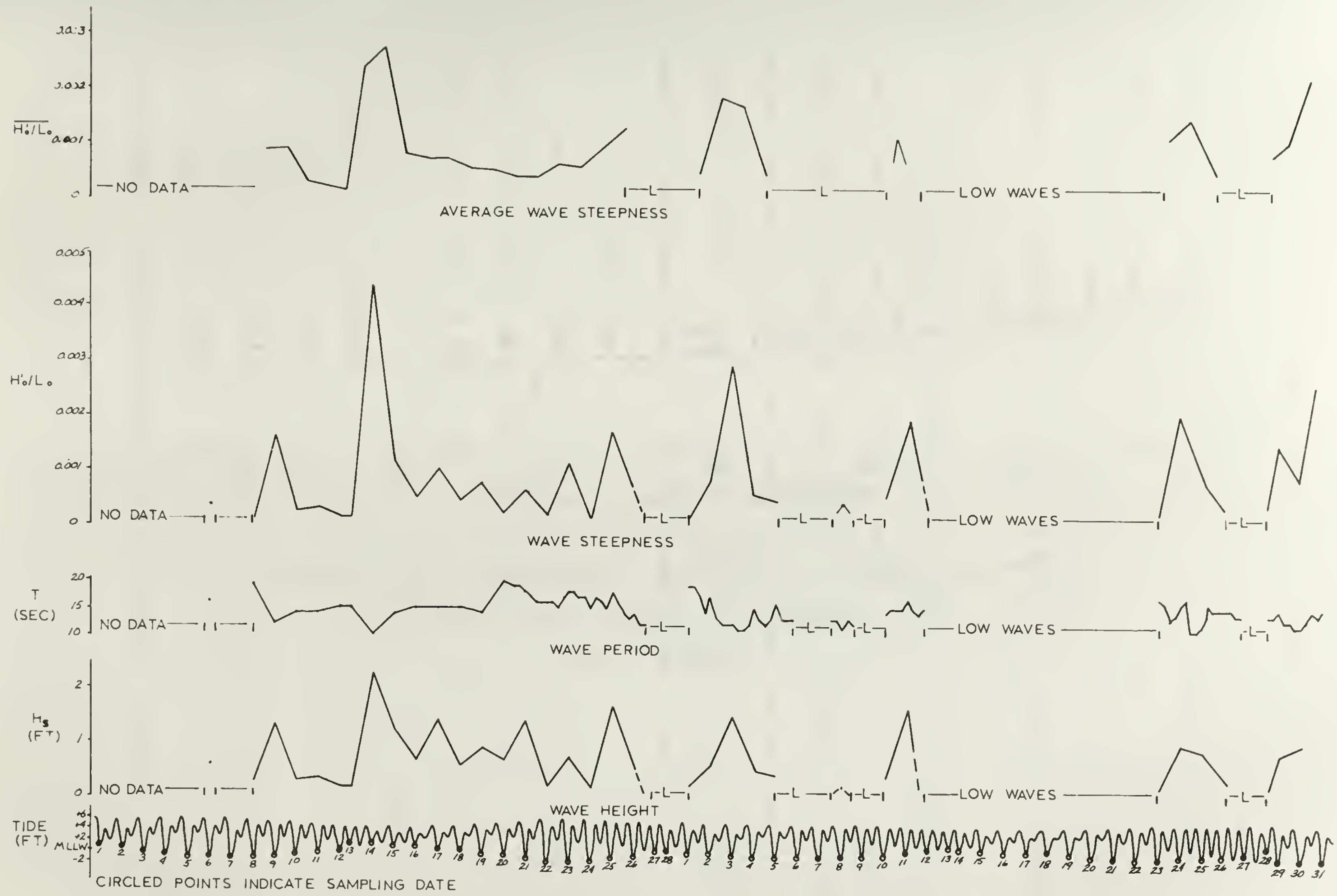
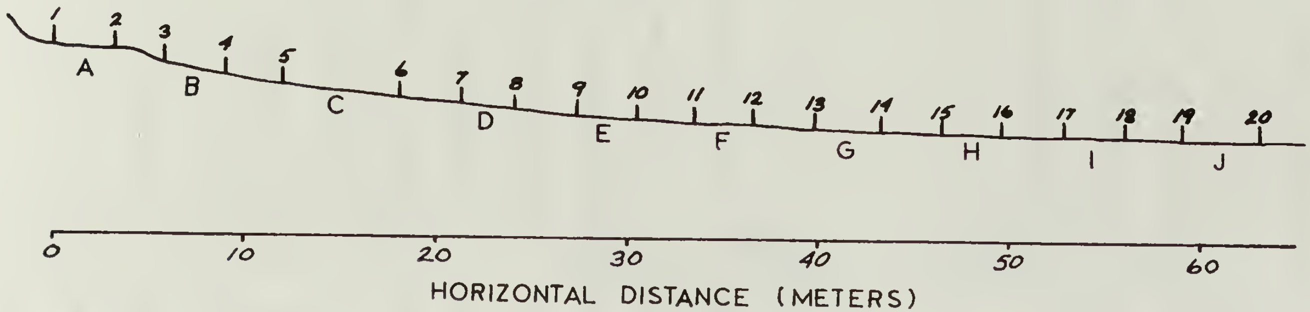


FIGURE 3 DAILY WAVE AND TIDE DATA



TYPICAL BEACH PROFILE SHOWING REFERENCE RAILS AND SEDIMENT SAMPLING STATIONS

FIGURE 4

The base of the staff was constructed with a crossbar about four feet wide to bridge scour depressions that sometimes occur at the base of the rails. The measurement procedure followed was to place the staff vertically against the seaward side of the rail and sight across the rail top to the horizon. The reading on the scale gave the difference in elevation between the sand level and the rail top. Readings were made to the nearest millimeter, but the accuracy of the measurement is probably about ±5 millimeters because of minor undulations in the beach surface.

Daily elevation measurements were made as far to seaward along the profile as surf and tide conditions would permit. At the uppermost rails, when the beach was undisturbed by waves during the preceding period, no new elevation measurements were made because the beach level remained constant. The occurrence of cusps and of other irregular or unusual beach conditions was noted whenever they occurred.

c. Sand Samples

Samples of beach sand were collected daily in conjunction with the profile measurements at 10 sampling stations, A through J in Figure 4. Samples were taken in a line parallel to the rails, and about six feet to the west, in order to avoid any influence the rails might have on sedimentation. Sampling-station intervals were approximately twice the rail interval, or about six meters.

The samples collected were taken from the very uppermost layer of sand using a simple metal scoop designed to sample a two-millimeter thick layer. It was presumed that the textural parameters of the surface layer of the sand were related to the wave conditions occurring on the beach during the 25-hour period since the previous sampling.

The sample volume collected was about 100 cubic centimeters. Care was taken to avoid any non-representative areas such as swash marks. Sampling stations on the upper beach which were clearly undisturbed by waves since a previous sample was collected were not sampled. The sand texture at these stations was assumed to remain constant until the sand was once again acted upon by waves. In this way, sand samples which had been deflated by the wind were avoided.

d. Wave Data

Waves were recorded continuously using a Snodgrass Mark IX pressure-type wave gauge. The sensor is located at a point immediately seaward of the beach profile at a distance of about 230 yards from Rail 20 in about 30 feet of water (Figure 1). It is mounted on a tripod three feet above the bottom.

An analog recorder was located in a laboratory near the beach. During most of the period of the observations, the strip chart was set to run at a rate of four inches per hour (slow speed), with an automatic five-minute run at the rate of four inches per minute (fast speed) occurring every hour. The fast speed resulted in better resolution and made it possible to analyze the record for wave height and period. In addition, the recorder was manually set to run at fast speed during the daily beach observations, thereby providing one long high-resolution record of waves for about 30 minutes during each observation period. During the first five days of February the wave recorder was not operating; no wave record was made during that period.

e. Tide Data

The tide data used in this study were taken from the marigrams recorded on a standard tide gauge located approximately 3/4 mile from the beach profile on Municipal Wharf No. 2 in Monterey Harbor (Figure 1). The gauge is operated and maintained by the Department of Meteorology and Oceanography of the Naval Postgraduate School.

4. Data Reduction and Sample Analysis

a. Beach Profile

The beach elevation above MLLW at each rail was computed by subtracting the scale reading on the staff from the elevation of the rail top. These elevations are tabulated in Appendix A.

b. Sand Analysis

All sand samples were subjected to a textural analysis using an Emery Settling Tube (Emery, 1938). This method was chosen because it combines speed with accuracy, and because of the ease with which the raw results may be converted into useful statistical parameters. The parameters used in this study were mean grain size, sorting coefficient, skewness of the sample, and peakedness of the size-distribution curve. Sediment grain size was expressed in phi units (Krumbein, 1934), where a phi grain diameter is defined as minus the log to the base two of the grain size in millimeters ($\phi = -\log_2 D$).

The basic procedure followed for the settling tube analysis was that described by Poole, Butcher, and Fisher (1951). Sand samples were split to reduce the sample to an amount totaling about 75 millimeters in the graduated lower end of the settling tube. The most satisfactory of several introducing methods tried involved the use of a test tube about three inches in length with the end cut off. With both ends covered by finger and thumb, the introducing tube with its sample and water was shaken vigorously to wet the grains. By holding the tube upright and carefully removing the thumb from the bottom of the tube while still covering the upper end with the forefinger, the sample remained in the introducing tube. Then, holding the sample just above the surface of the water in the settling tube and releasing the forefinger, the entire sample entered the settling tube quickly and uniformly.

As the sand piled up, the lower graduated portion of the settling tube was lightly tapped with a pencil to ensure uniform packing and care was taken to maintain a level sediment-water interface. It was found that without such tapping the finer portion of the accumulated sediment would sometimes compact abruptly during a sample run.

The height of the sand piling up in the graduated tube was recorded at time intervals taken from Poole (1957). Equating the final height of the sand column to 100% converted the readings for a given run into a cumulative size distribution by per cent. The cumulative percentages for each sample were plotted versus grain diameter in phi units on arithmetic probability paper and a smooth curve was drawn through each point. From this curve, the 5th, 16th, 50th, 84th, and 95th percentile phi grain sizes were read. These values are presented in Appendix B.

The parameters used herein to describe sand texture are adapted from Inman (1952) with modification where indicated. The mean grain diameter was chosen to represent the central tendency of the sample. The mean is defined as

$$M_\phi = \frac{1}{2}(\phi_{84} + \phi_{16}) .$$

The sorting coefficient is defined as

$$\sigma_\phi = \frac{1}{2}(\phi_{84} - \phi_{16}) .$$

According to this definition a perfectly sorted sample would have a sorting coefficient of zero.

The skewness of the sample is defined as

$$\alpha_\phi = \frac{\phi_{50} - M_\phi}{\sigma_\phi} .$$

Negative values of α_ϕ represent samples skewed toward a coarser grain size.

For this investigation the coefficient of kurtosis is defined as

$$\beta_\phi = \frac{\phi_{95} - \phi_5}{\phi_{84} - \phi_{16}} .$$

This is related to kurtosis as defined by Inman by

$$\beta_\phi = \beta \text{ (Inman)} + 1.$$

Kurtosis gives a relative measure of the peakedness of the grain-size distribution.

All values of the textural parameters are tabulated in Appendix B.

The accuracy and reproducibility of the settling tube method of size analysis have been discussed in detail by Poole, Butcher, and Fisher (1951). For the range of sediment-sizes found on Del Monte Beach, Poole concluded that the accuracy of the settling tube is comparable to that of sieving.

In the present study, allowing for a ± 1 millimeter error in reading the interface height in the settling tube (which is unlikely), the mean grain diameter is accurate to $\pm 1\%$, the sorting coefficient to $\pm 6\%$, skewness to $\pm 50\%$, and kurtosis to $\pm 10\%$. Skewness is particularly sensitive to error because of the small values of $(\phi_{50} - M_\phi)$ for the sand on Del Monte Beach. For larger values of skewness the possible error in skewness decreases.

c. Wave-Data Reduction

Both the five-minute wave records made on the hour and the 30-minute records made once daily were analyzed to obtain the significant height (H_s) and the average period (T). These in turn were used to obtain the initial wave steepness (H_o'/L_o). Initial wave steepness is defined as the steepness an observed wave would have had in deep water in the absence of refraction.

The average period was computed by counting the number of positive (upward) crossings of the still-water level made by the wave trace and dividing this number into the duration of the trace measured in seconds. The average periods obtained from the five-minute records made hourly and from the 30-minute records made daily were combined into six-hour running means and are plotted in Figure 3. Several times during the two-month period of observation, the waves were so low that the amplitude of the recording trace was insufficient to allow accurate computation of the wave period. These times are represented by the letter L in Figure 3.

Significant height at the sensor depth was computed from the once-daily long wave traces by a simple method devised for the purpose. This involved calculating a cumulative wave amplitude distribution for each long fast trace as follows: the total number of waves was counted first; next, waves with amplitudes greater than one chart scale unit (0.3 feet) were counted, then waves with amplitudes greater than two chart scale units, and so on until all of the waves were accounted for. When these numbers are expressed as percentages of the total number of waves, they represent the cumulative portion of the wave-height frequency distribution having heights greater than a given amplitude. When all waves in a given wave record had amplitudes less than 0.3 feet, no calculations were made, and the wave heights were reported in Figure 3 as Low. The cumulative amplitude distribution was plotted on semi-log graph paper, the total number of waves in the record being equated to 100%. That amplitude which was exceeded by 60% of the waves (A_{60}) was chosen as representative of the energy (E) in the spectrum and was used to obtain the significant wave height (H_s) at the sensor depth by application of the following statistical formulae given by Pierson, Neumann, and James

(1955):

$$A_{60} = 0. \text{[illegible]} E$$

$$H_s = \text{[illegible]}$$

These were combined to give

$$H_s = 3.99\ A_{60}.$$

Although the long fast trace recorded at the time of the daily beach observations was used for wave-height calculations, the entire series of five-minute records for the previous 25-hour period was scanned to determine if the long trace provided a sample which was typical of the waves occurring throughout that period. In every case the long record proved to be representative.

The significant wave height at the sensor depth was converted to surface wave height by division with the pressure response factor K, given in Wiegel's (1964) tables. The pressure response factor, which accounts for the hydrodynamic damping with depth, is a function of the relative depth d/L_o, where d is the bottom depth and L_o is the deep-water wave length. The depth used was 30 feet and L_o was calculated using the relation

$$L_o = \frac{g}{2\pi} T^2$$

where T is the average period in seconds.

Although the recorder sensor was not on the bottom, use of the tabulated values of K introduces a small error that is well within the accuracy limitations of the wave-height analysis. Because the wave recordings used to determine wave height were always made at low tide, the variation of the water depth owing to tidal effects was very small and was neglected.

The initial wave steepness was computed once daily for the time of the field observations in the form H_o'/L_o, where H_o' is the unrefracted deep water wave height. H_o' was calculated from the ratio H/H_o' given in Wiegel's tables as a function of relative depth. H is the significant wave height computed from the wave records. The actual deep-water wave height, H_o, was not calculated.

In addition to wave steepnesses calculated for each daily observation time, the average wave steepness prevailing between observations on successive days was also computed. The latter value is considered to better represent the average wave conditions over the period between observations. It was found that beach profile and texture changes occurring between observations were more closely related to the average steepness over the interval than to the steepness occurring at the end of the interval. Also, the difference in steepness from the beginning to the end of the 25-hour period was calculated.

All of the reduced wave data for the two-month period are plotted in Figure 3.

d. Tide Data

The tide curve for the two-month series of field observations is plotted in Figure 3. The range of the tide and the times of springs and neaps are readily apparent.

5. Observed Beach Data

a. Beach Profiles

The beach profiles measured over the period from February 1 through March 31, 1967 are plotted as a time-series contour chart in Figure 5. The chart shows seaward and shoreward movement of the beach contours from day to day. The contour interval is 20 centimeters on the most active part of the beach and 60 centimeters at the back of the beach where little cut and fill activity occurred. Discontinuous contours on the lower foreshore are a result of the seaward stations being intermittently inaccessible for sampling because of surf and tide conditions.

It will be noted in the figure that the beach tended to build seaward throughout the two-month period, but that large advances and retreats of the beach amounting to as much as 13 meters occurred over a period of two or three days on five occasions. The upper part of the beach was seldom disturbed. Rates of retreat are generally greater than rates of advance as is shown for the period from February 4 to February 13. Nearly the entire beach reacted in some cases (February 4-5) while in others only the upper or the lower part of the beach changed (March 2-3 and February 18-19, respectively). The upper beach retreated while the lower beach filled during the periods March 2-3 and March 23-24, while at other times the upper beach advanced and the lower beach retreated (March 27-28). The spacing of the contours across the beach indicates a flatter gradient near the seaward edge of the profile.

The entire beach profile for each day is shown in Figures 6a, 6b, and 6c. Superimposed on each profile is the profile from the previous day; in this way areas and amounts of cut and fill are apparent. The notation C indicates those days when cusps appeared. The positions of

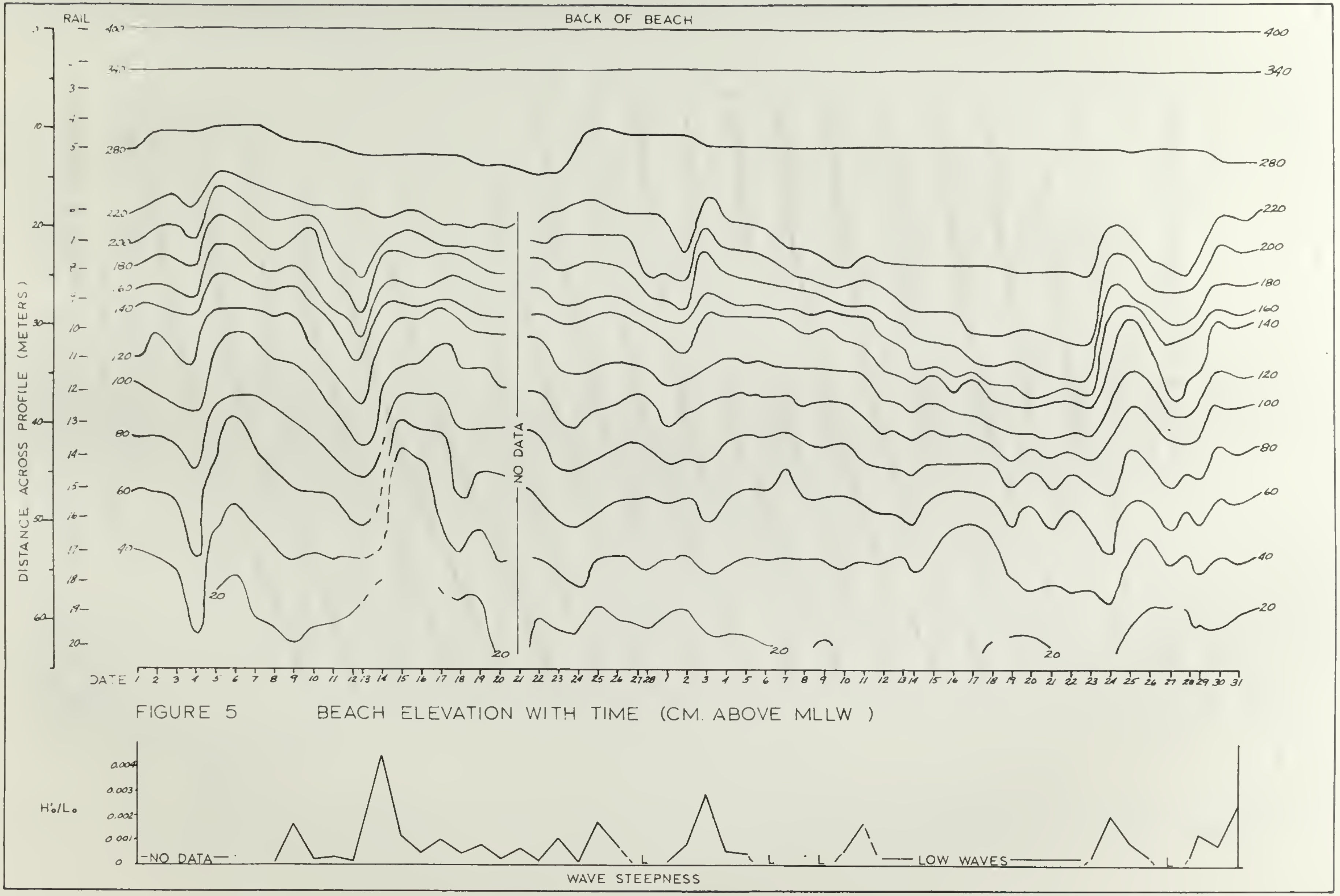


FIGURE 5 BEACH ELEVATION WITH TIME (CM. ABOVE MLLW)

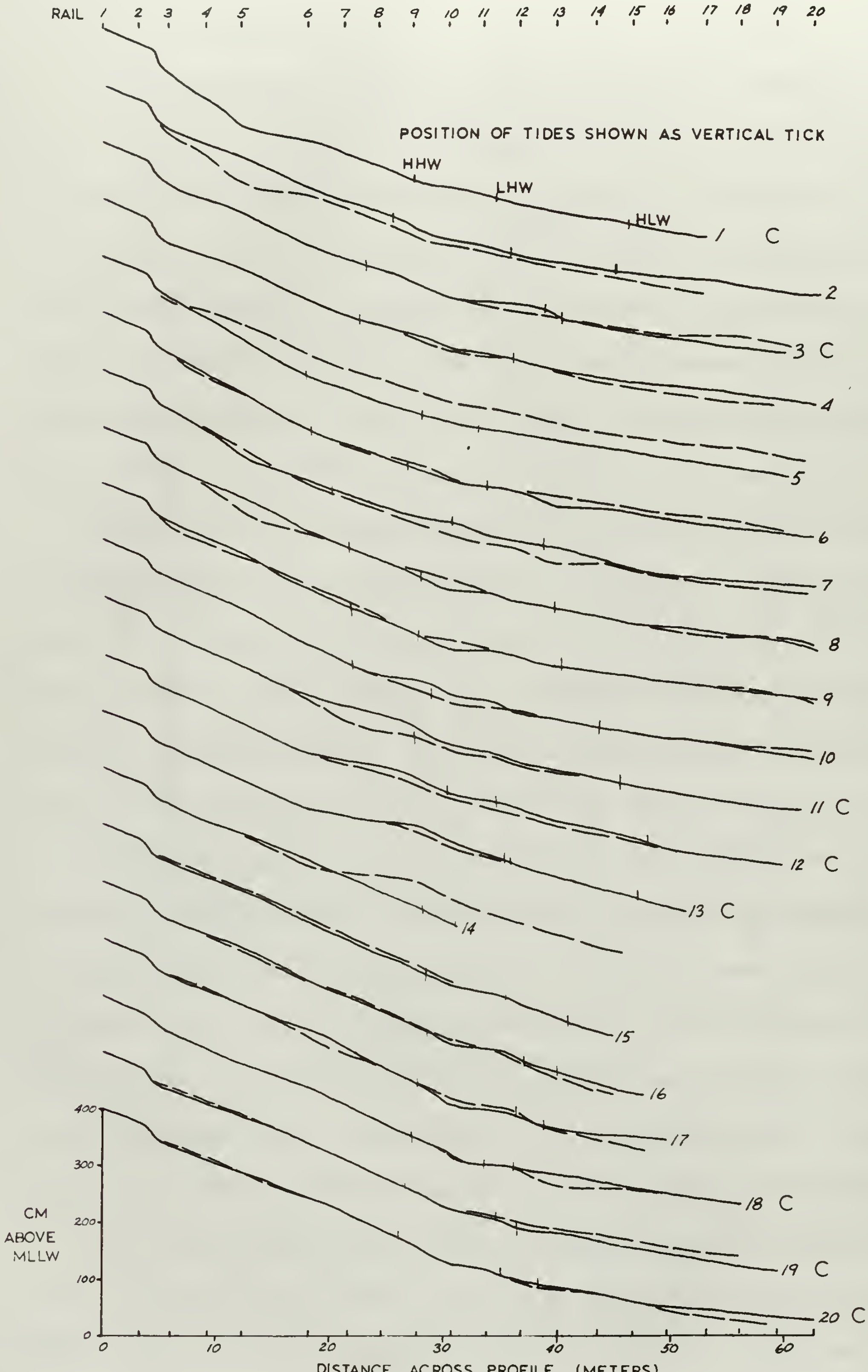


FIGURE 6a
DAILY BEACH PROFILES - PREVIOUS DAY'S PROFILE SHOWN AS DASHED LINE - C DENOTES CUSPS WERE PRESENT
(VERTICAL EXAGGERATION 5:1)

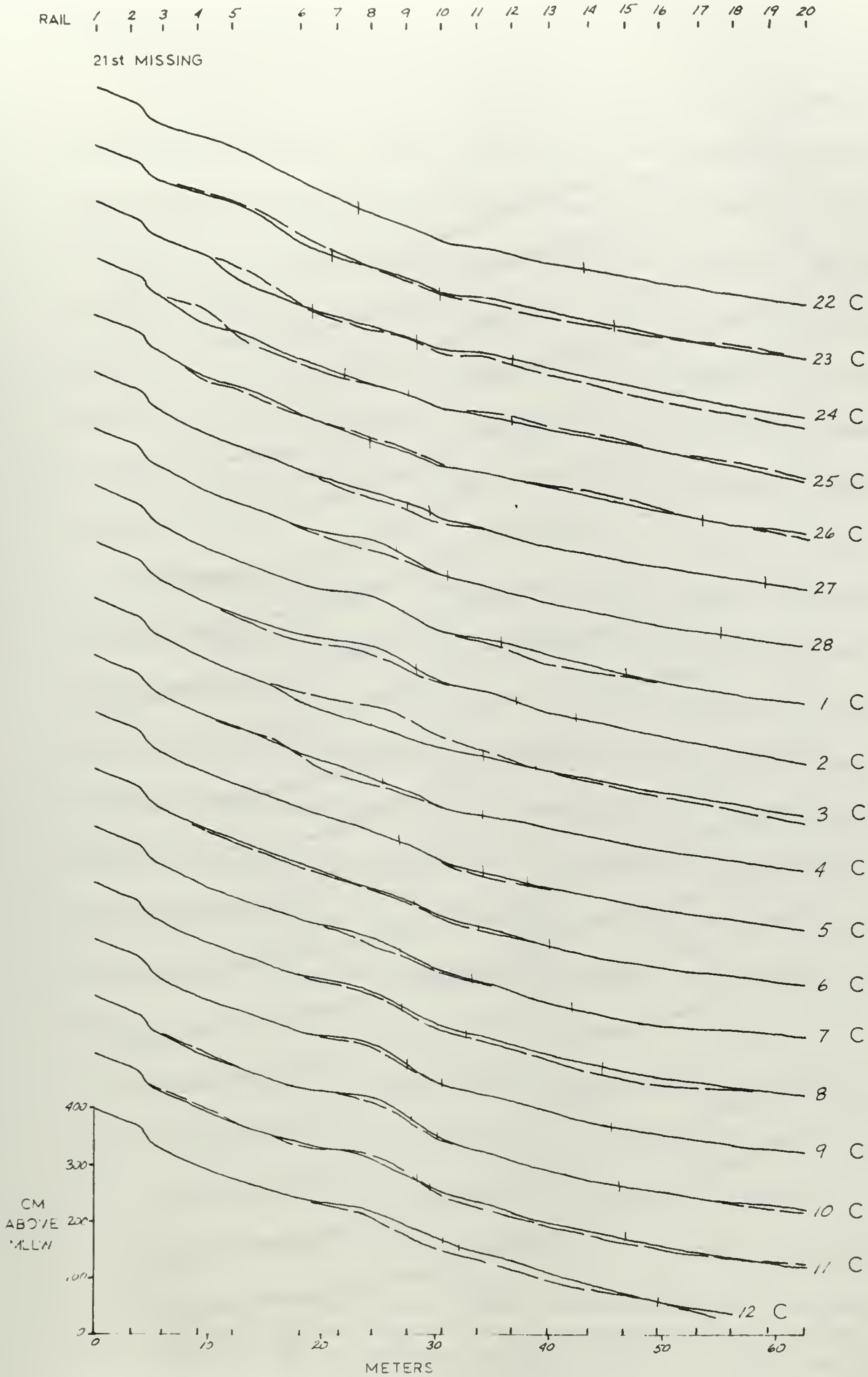


FIGURE 6b DAILY BEACH PROFILES

(VERTICAL EXAGGERATION 5:1)

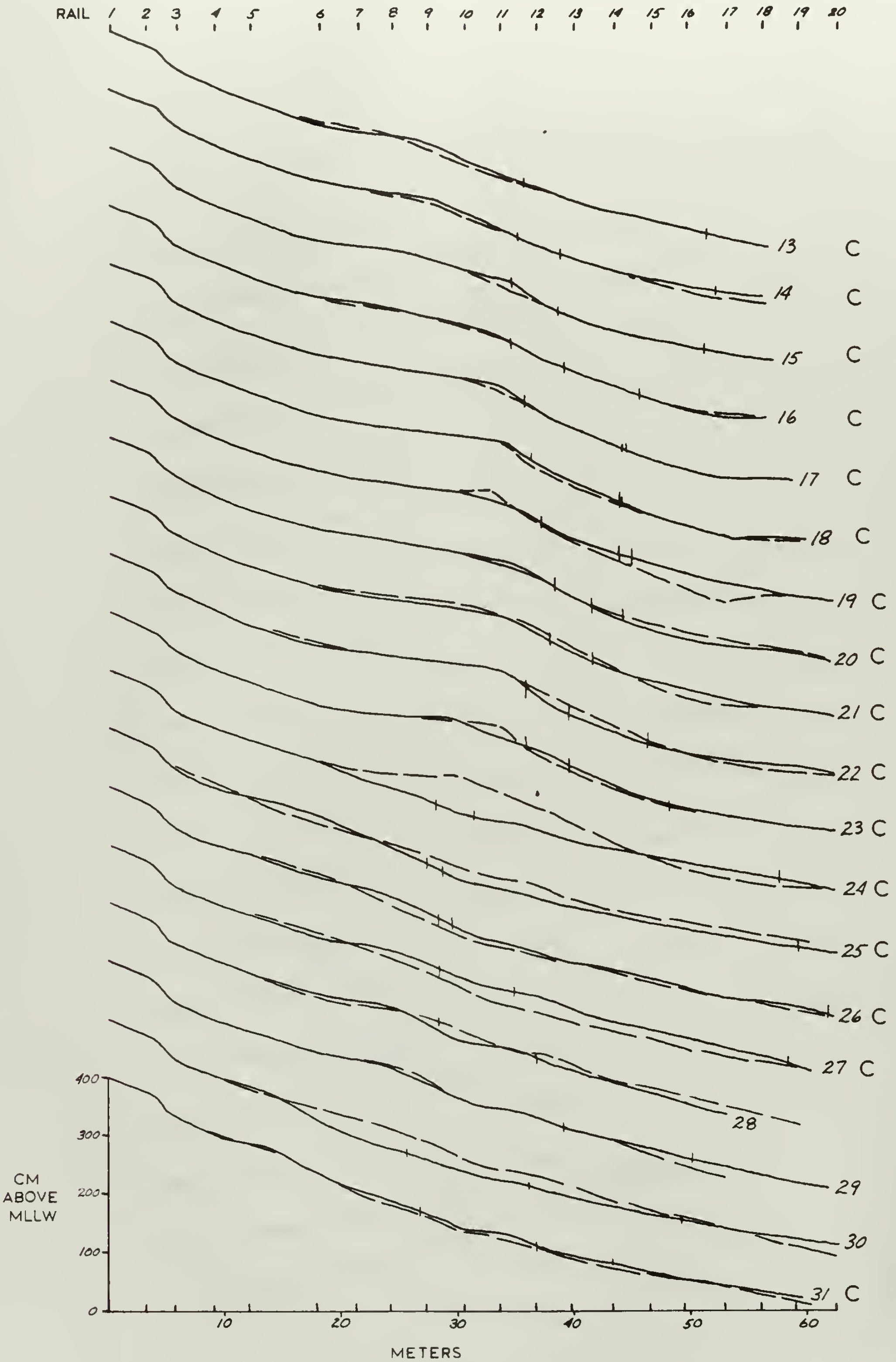


FIGURE 6c DAILY BEACH PROFILES

(VERTICAL EXAGGERATION 5:1)

the day's tides are also noted.

The beach profile was found to change actively with time. Examination of the profiles reveals that cut or fill sometimes occurred generally across the profile but that on most of the days cut and fill were limited in extent and displayed no definite pattern. The profile responded quickly to changing wave conditions, although the nature of the change in the profile to be expected from a change in the character of the waves was not apparent. A primary purpose of this study was, then, to obtain quantitative measures of the beach change in response to wave changes.

Cusps were present a large part of the time. When cusps occurred in the vicinity of the profile, one was invariably situated on the upper beach between Rails 5 and 10. The cusp was nearly always located at the same place with respect to the profile, the apex of the cusp being slightly off to one side of the line of rails. The width of the cusp remained essentially constant, about 120 feet between apices. The common presence of cusps does not appear to have complicated the relationships between changes in beach profile, sand texture, and wave conditions.

A scarp appeared near the back of the beach just before the start of the field studies and remained throughout the course of the observations. No berm was present until mid-March, when, during a long period of low, gentle waves, a berm was built in the mid-foreshore just above the level of the higher high tide. The waves built the berm highest during a time when two successive tides (higher low water and lower high water) had nearly equal heights (March 17-19). This vanishing tide resulted in the water level standing at a moderately high level for about six hours. The berm was subsequently cut down by storm waves and did not reappear.

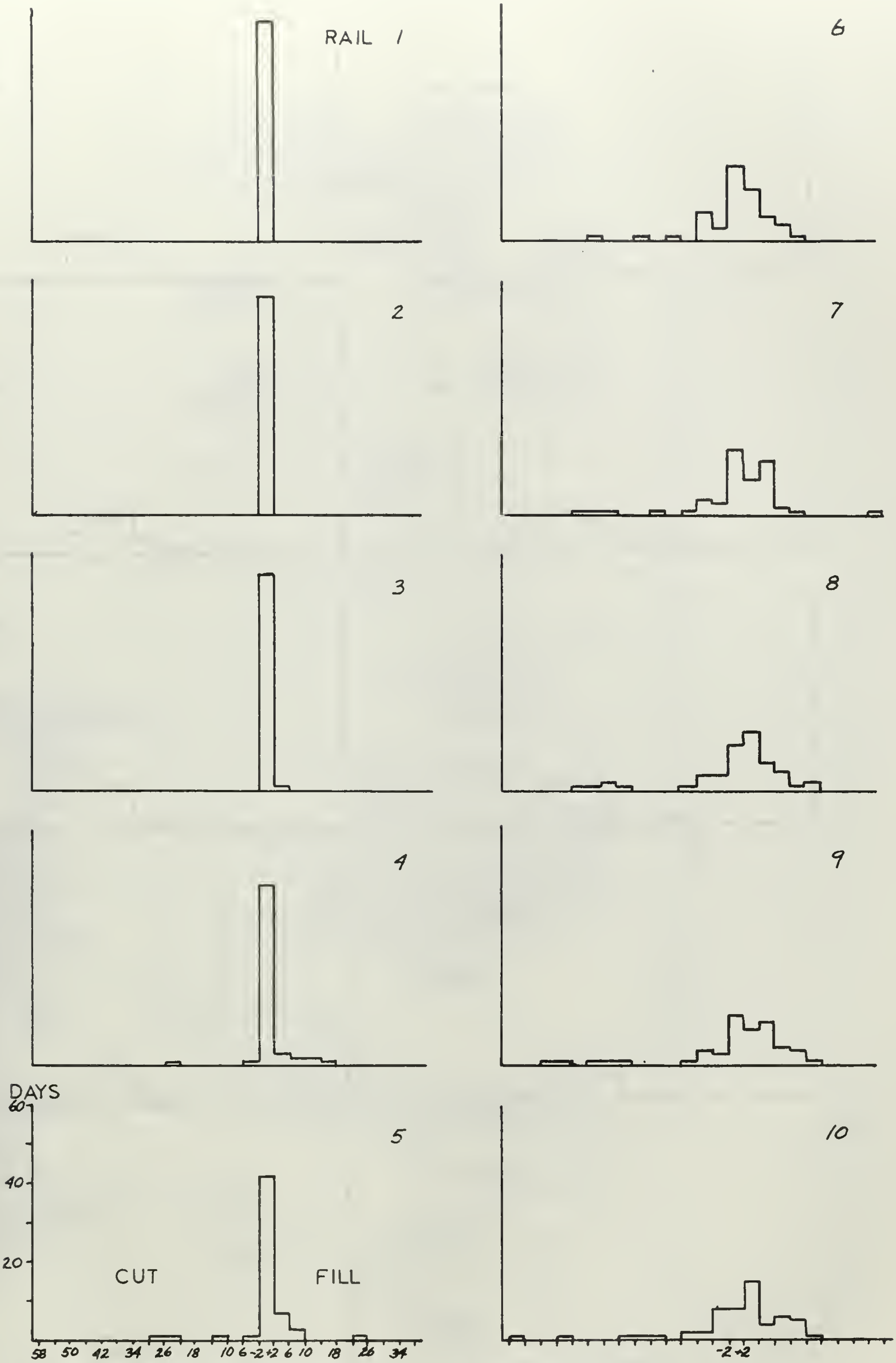
During periods of low wave activity and tides below MLLW, a well-defined low-tide terrace formed. The profiles for March 16 through 18 show this feature. On March 18, when a steep foreshore resulted from the berm-building activity, a trench-like depression about 50 centimeters deep and paralleling the shoreline formed at the intersection of the berm face and the low-tide terrace.

Minor beach features such as swash marks, ripples, rill marks, and sand domes were frequently present.

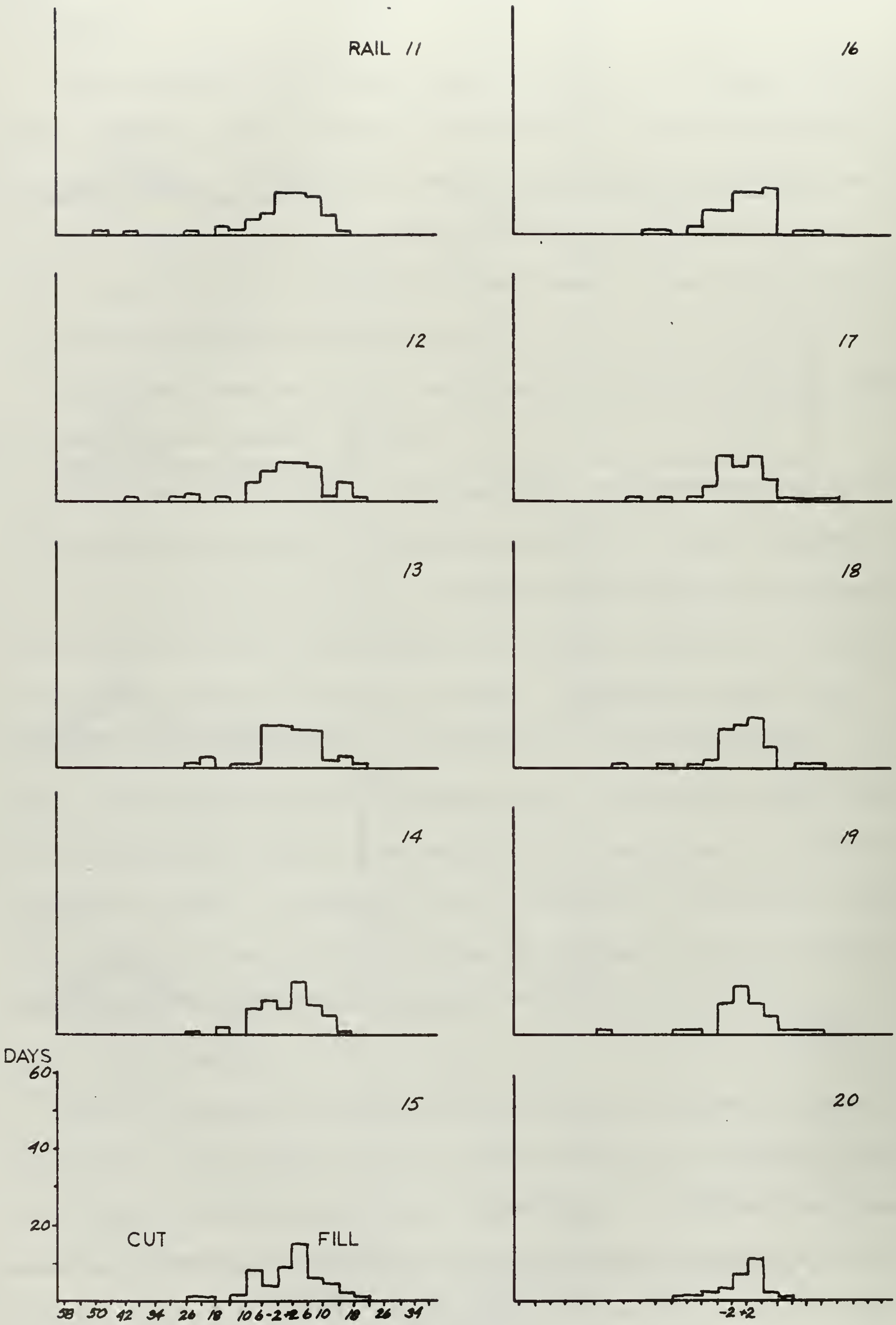
Histograms of the amount of cut and fill, presented in Figures 7a and 7b, show the variability of beach elevation that occurred at each rail. The beach was most active seaward of Rail 8 where the beach was wetted regularly at most tide stages. It would be difficult to single out any given position as the most active. The general shape of the histograms suggests that the beach tended to cut quickly and fill more slowly. The maximum amount of cut occurring in 25 hours at any station was 61 centimeters at Rail 10 on March 23-24. The greatest fill was 34 centimeters at Rail 7 on February 10-11. Ordinarily, the amount of cut during a 25-hour interval was less than 20 centimeters and the amount of fill was less than 15 centimeters.

b. Sand Texture

Figure 8 presents the distribution of mean grain size as a time-series chart. The contour interval is 0.10 phi units. The space-time occurrences of extreme grain sizes coarser than 1.75 phi and finer than 2.05 phi are shaded. The distribution of mean grain diameter with time is highly patchy but appears to show some relationship to the changing



CUT AND FILL HISTOGRAMS
FIGURE 7a



CUT AND FILL HISTOGRAMS

FIGURE 7b

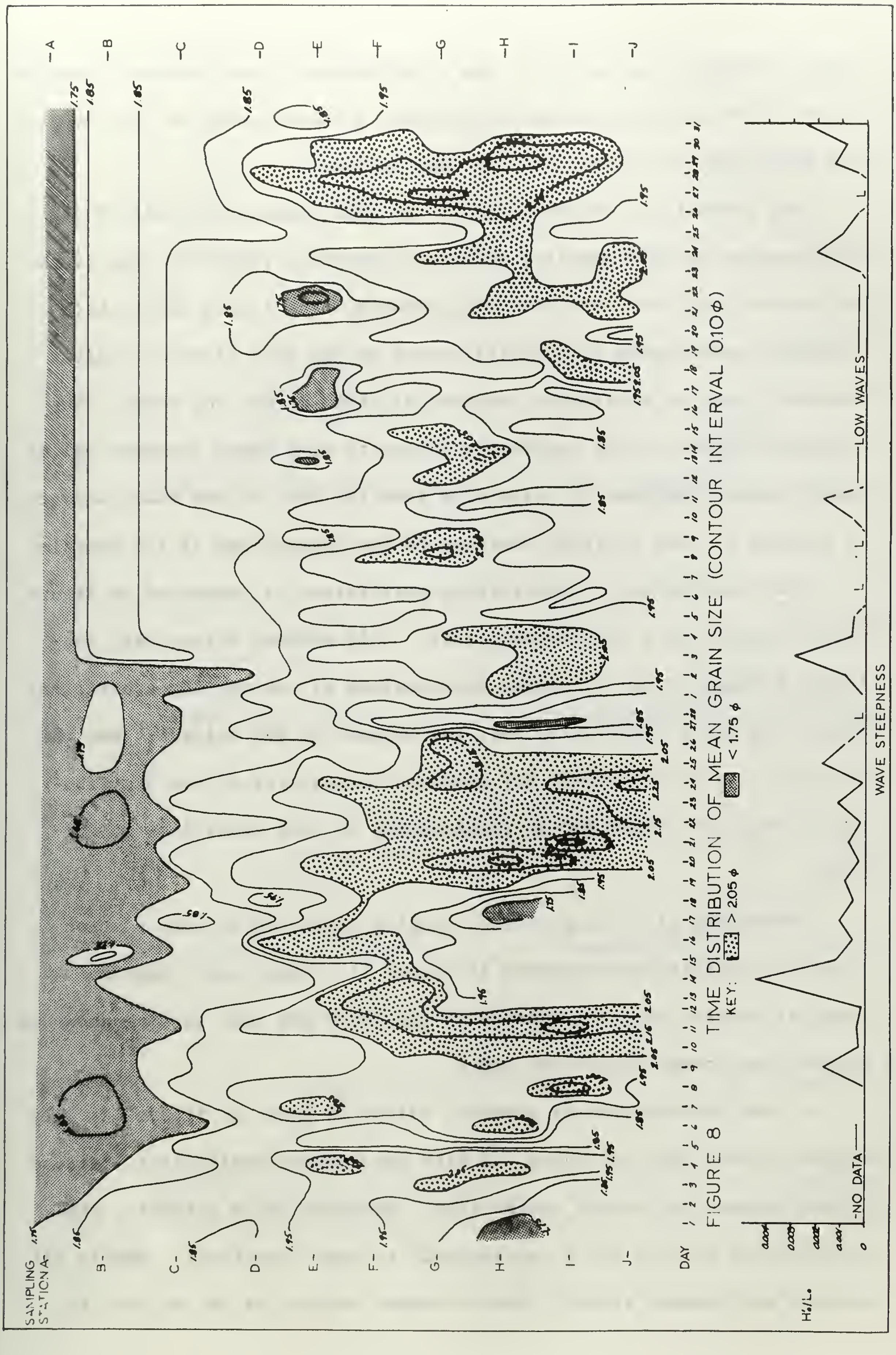


FIGURE 8 TIME DISTRIBUTION OF MEAN GRAIN SIZE (CONTOUR INTERVAL 0.10φ)

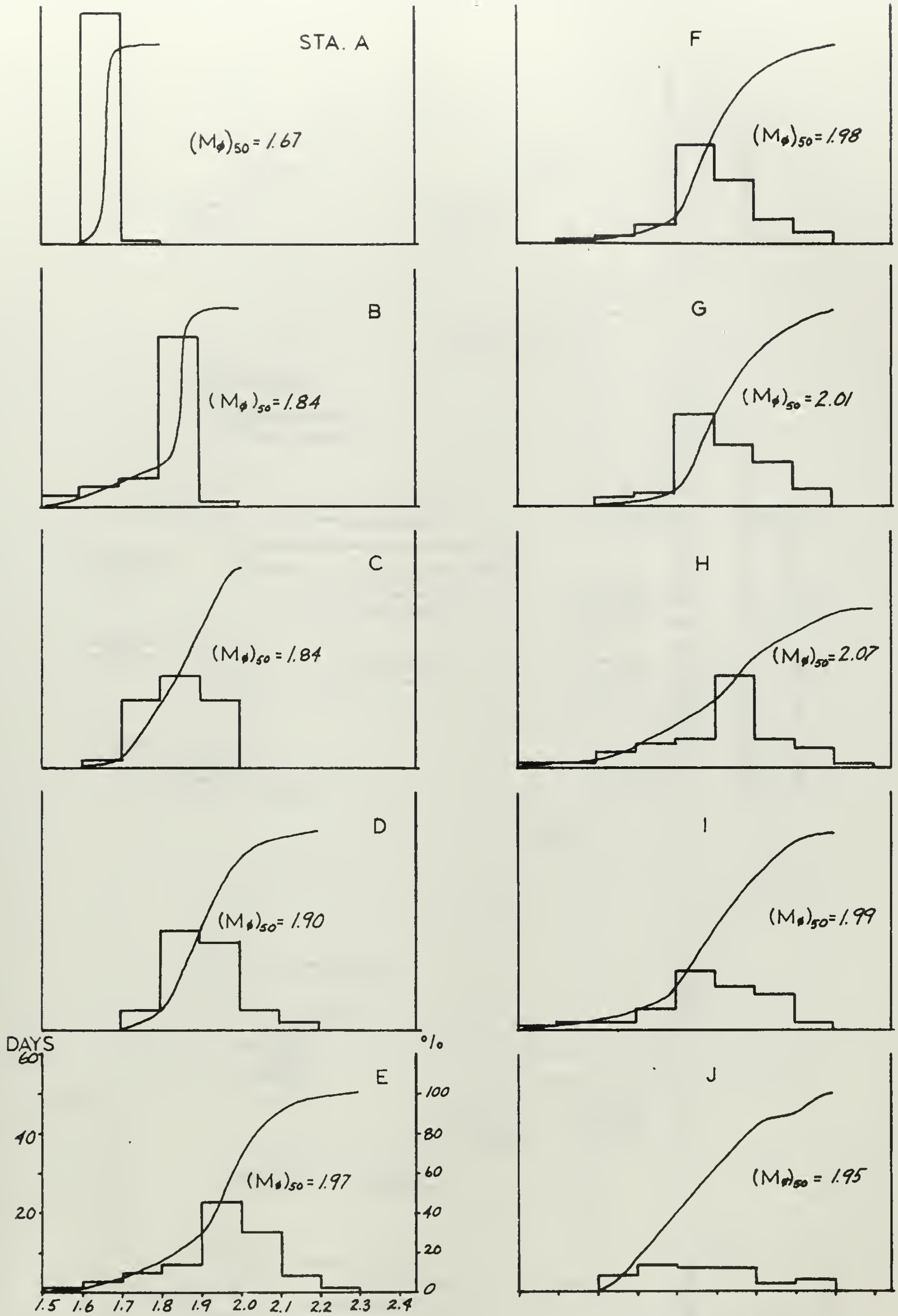
wave conditions; the nature of the relationship is not apparent from the figure. The mean grain diameter displays a narrow range on this beach, and falls into the medium-to-fine sand category.

The statistical distribution of the mean diameters of all of the sand samples at each sampling station is shown in Figure 9. The beach was wetted regularly from Station C seaward. The figure shows that, although considerable variability occurs in the mean sizes at a given station, there is a definite zonation of sizes across the beach. The 50th percentiles of the cumulative curves of mean grain diameter values show a steady decrease in grain size from the rear of the beach seaward to Station H, then a slight increase to the seaward end of the profile.

The distribution of the sorting coefficient is presented in Figure 10 as contours on a time-series chart. Only extreme values were contoured because of the irregular distribution of the sorting coefficient across the beach from day to day, and because it was believed that the extreme values would reveal any distinctive patterns in the distribution. None were found and no relationship to wave conditions is evident.

Histograms of sorting of sand samples collected at each station along the profile are presented in Figure 11. These show that the range of sorting values is narrow on the beach and that sorting shows no progressive change across the beach.

A time distribution of skewness values is shown in Figure 12. Only extreme values were contoured, as with the sorting coefficient, because of the extreme day-to-day variability. Skewness shows neither a time-distribution pattern nor a relationship to wave conditions. Nearly all samples were skewed slightly toward coarse values, as can be seen in



MEAN GRAIN SIZE HISTOGRAMS AND CUMULATIVE CURVES

FIGURE 9

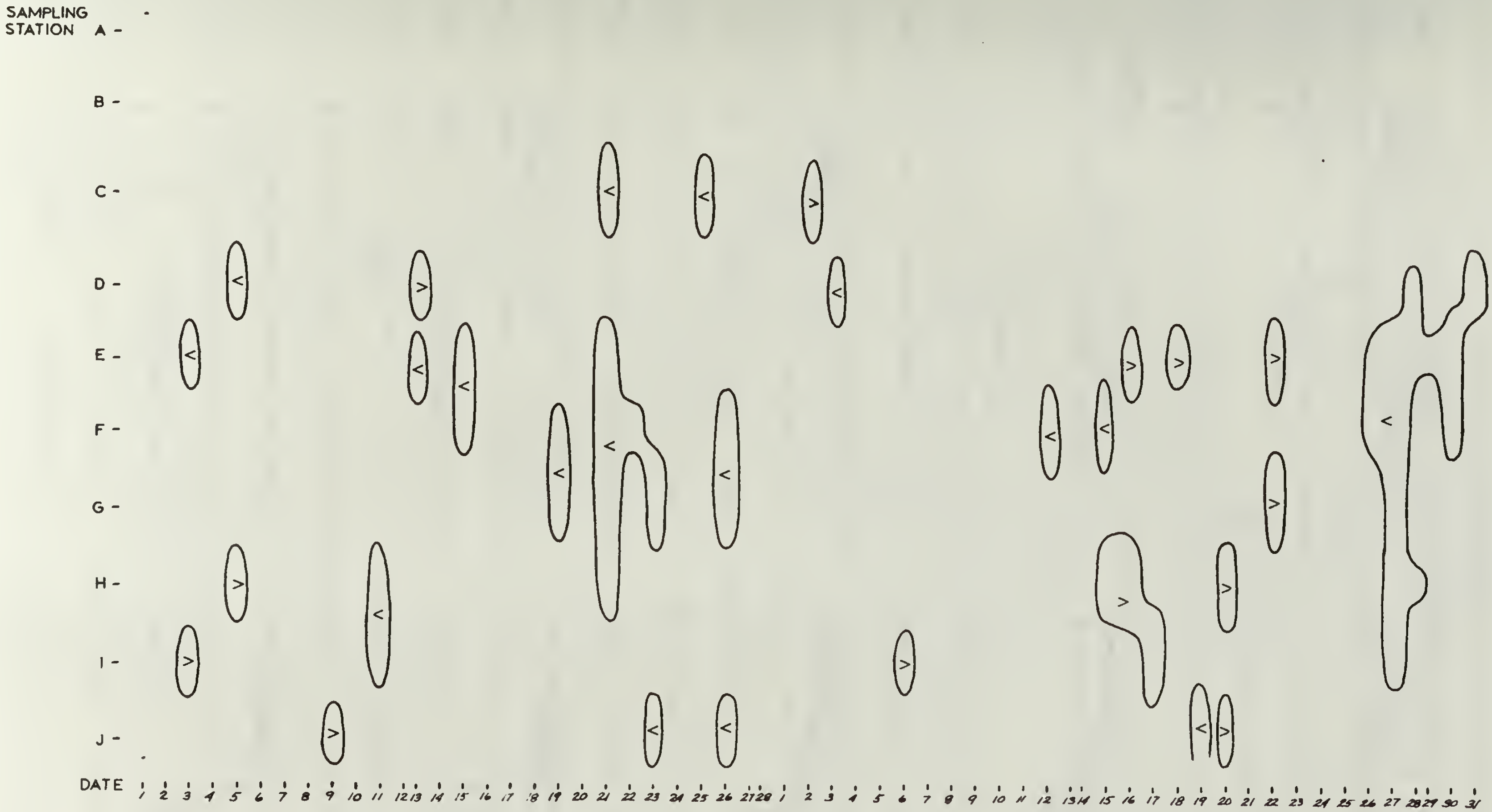


FIGURE 10 TIME DISTRIBUTION OF SORTING VALUES

(CONTOURS ARE < 0.28 AND > 0.42)

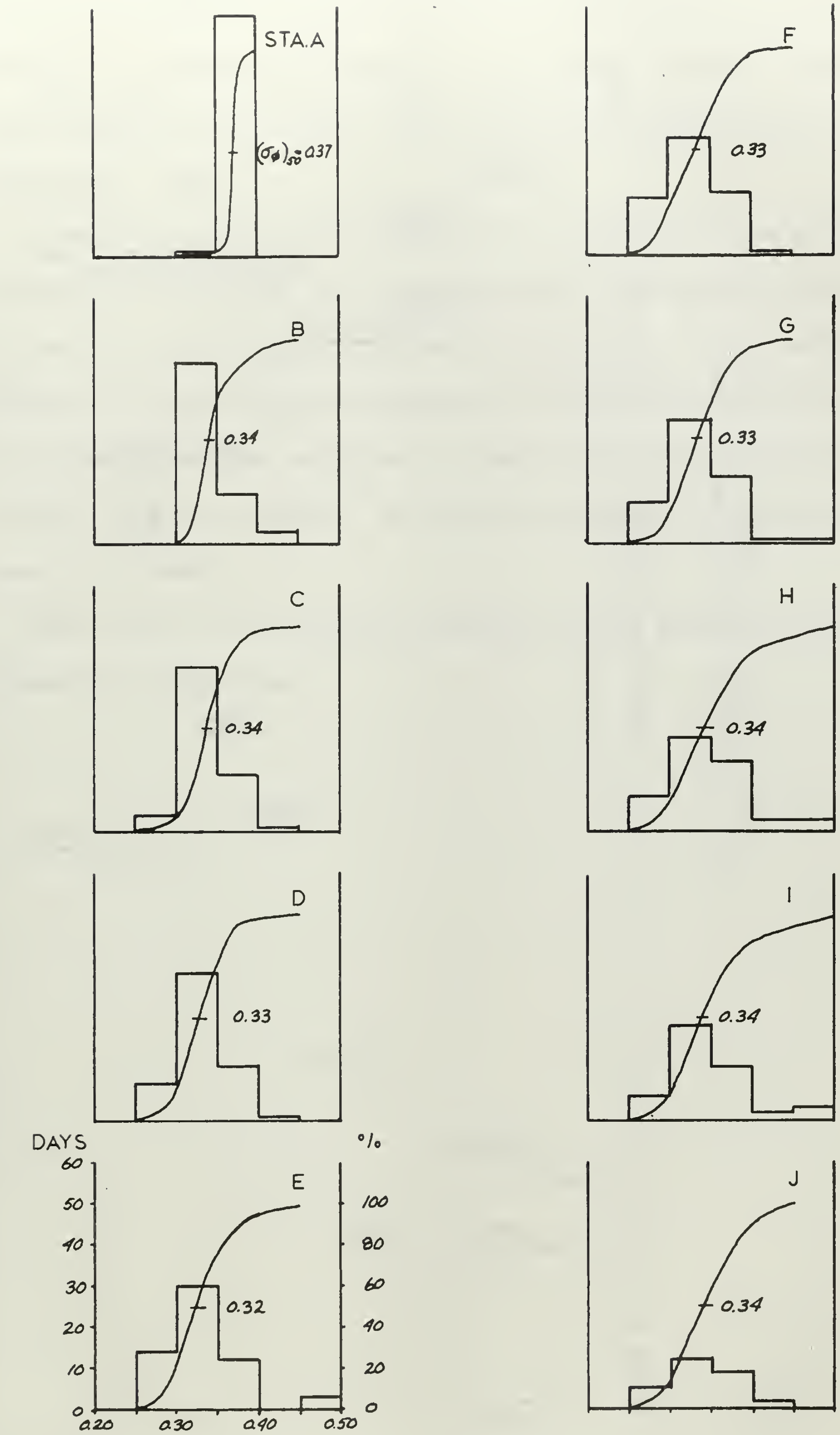


FIGURE 11
SORTING HISTOGRAMS AND CUMULATIVE CURVES

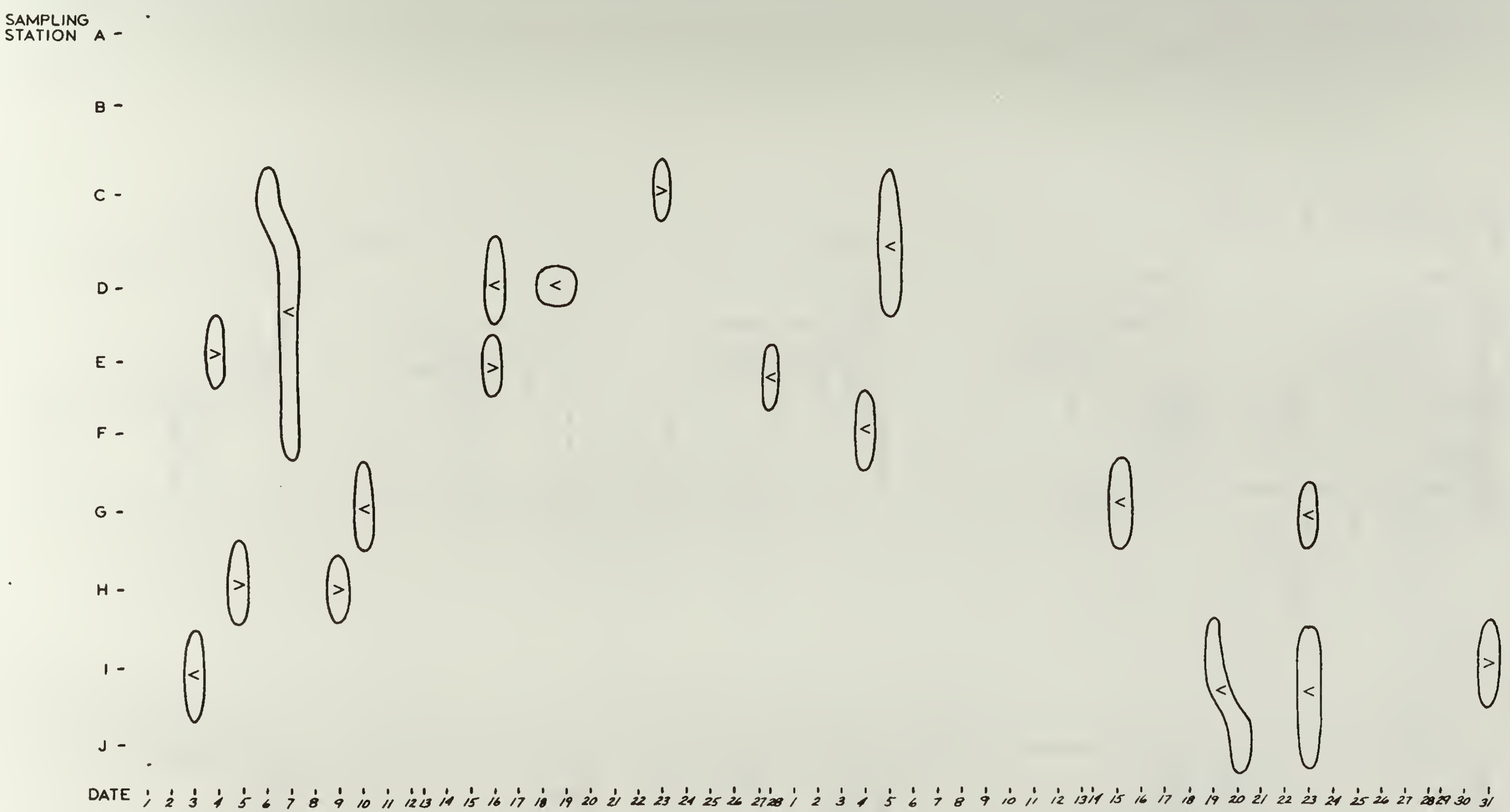


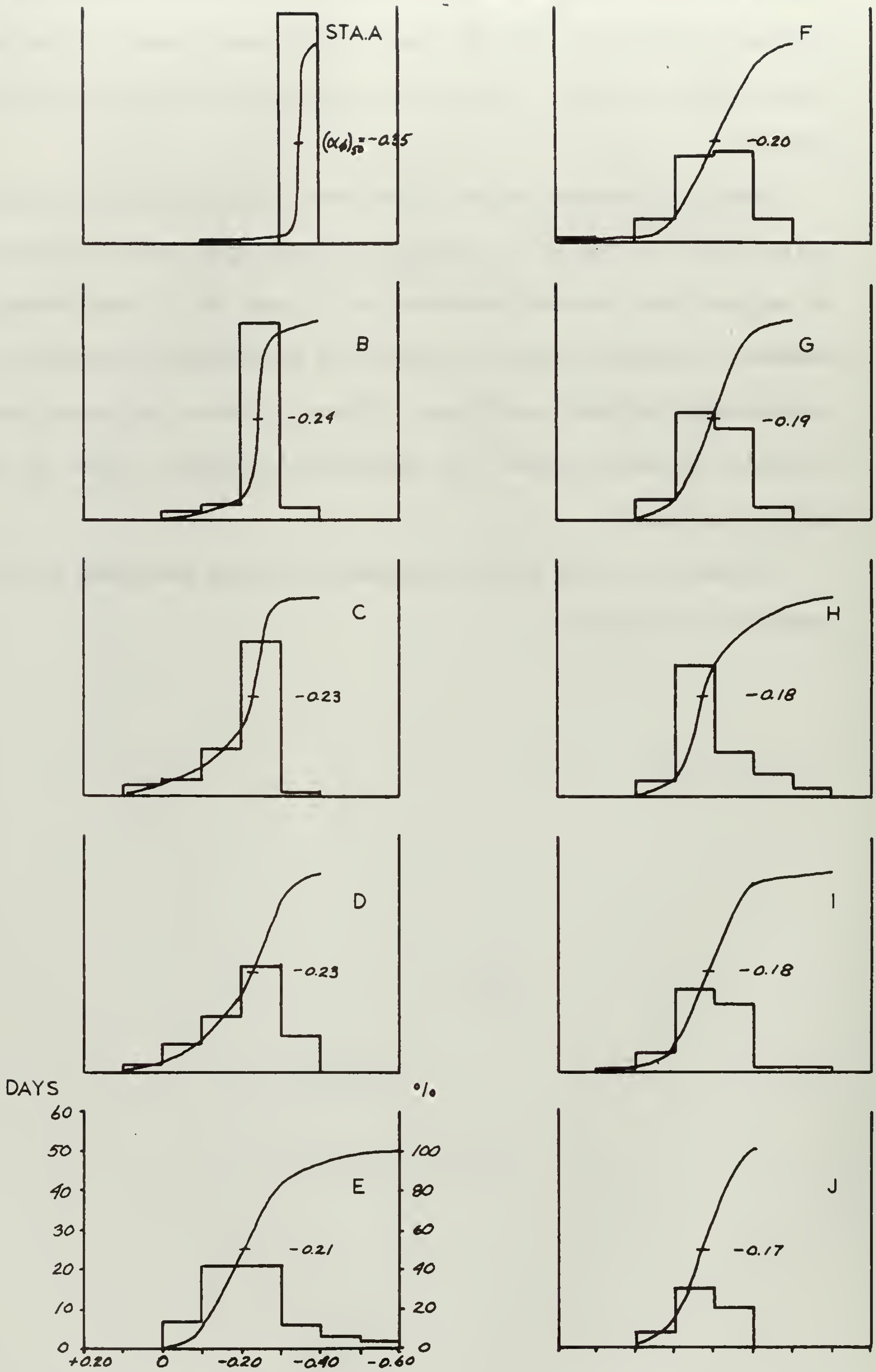
FIGURE 12 TIME DISTRIBUTION OF SKEWNESS VALUES

(CONTOURS ARE <0.04 AND >0.40)

Figure 13. The 50th percentiles of the cumulative curves show a general decrease in skewness from the back of the beach seaward. One should keep in mind, however, that large errors in skewness computations are possible.

Finally, extreme values of kurtosis are contoured on a time-distribution chart in Figure 14. Kurtosis values vary greatly, both from day to day and from station to station on a given day. Like sorting and skewness, kurtosis shows no distinctive distribution pattern nor any relationship to wave conditions. Figure 15 shows the random quality of kurtosis for each station. No zonation of kurtosis values is apparent across the beach.

A summary of the textural parameters along the beach profile is presented in Table 1a.



SKEWNESS HISTOGRAMS AND CUMULATIVE CURVES

FIGURE 13

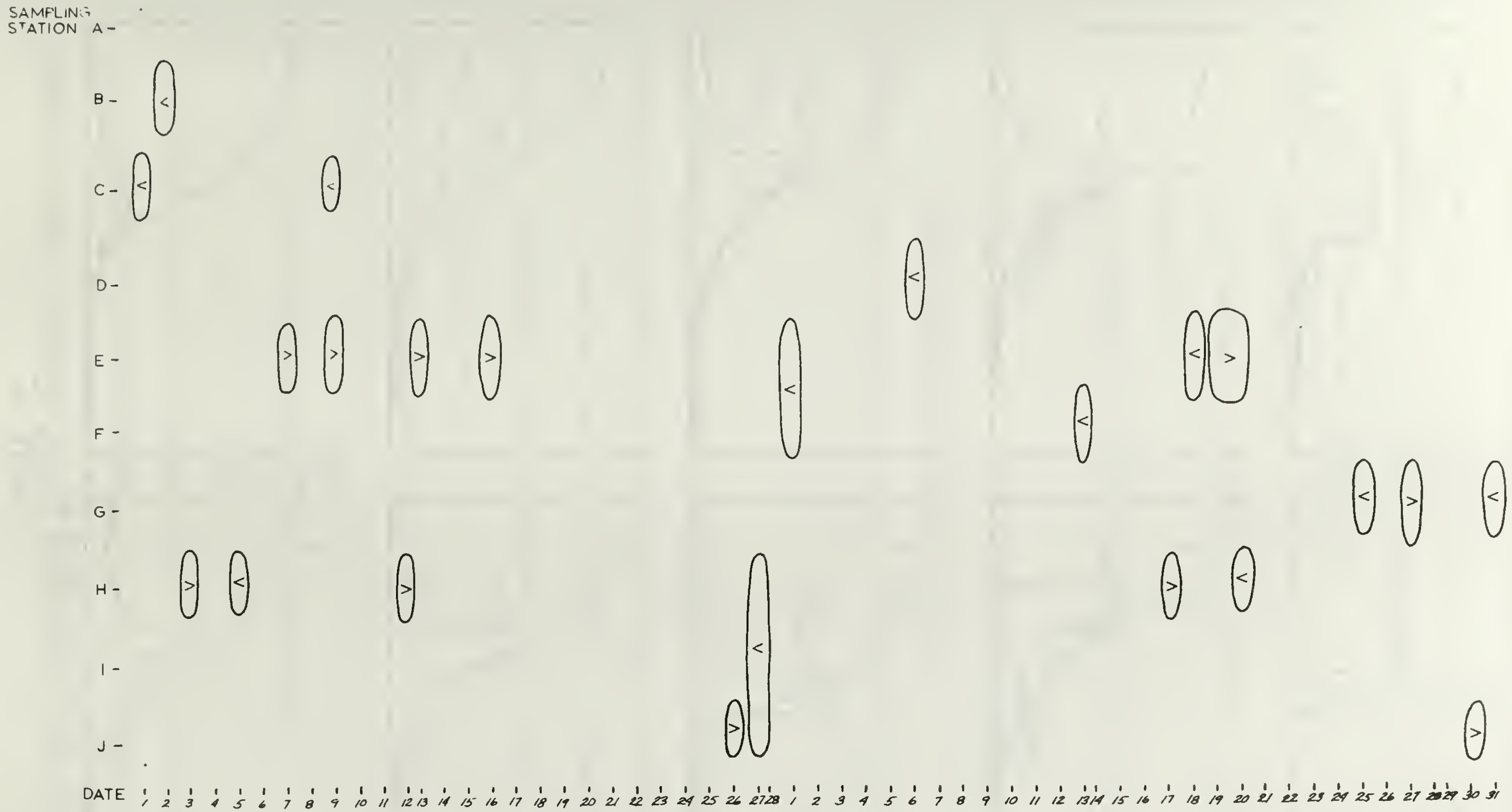
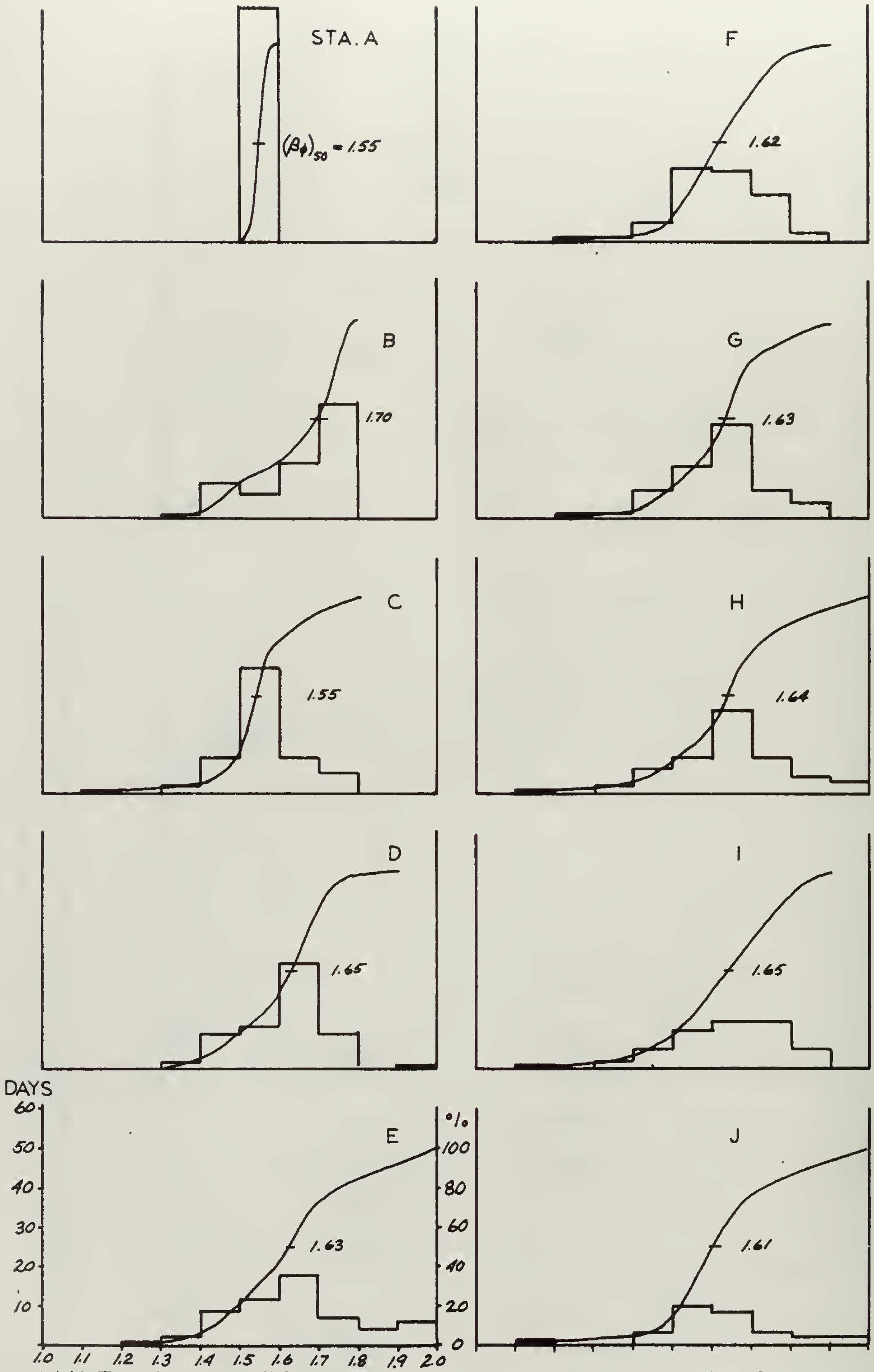


FIGURE 14 TIME DISTRIBUTION OF KURTOSIS VALUES

(CONTOURS ARE <1.36 AND >1.90)



KURTOSIS HISTOGRAMS AND CUMULATIVE CURVES

FIGURE 15

6. Effects of Waves on the Beach

The effect of changing wave conditions on the beach profile is complex. In an effort to discover the wave parameter having the greatest effect on the beach, the following were considered:

1. Significant wave height (H)
2. Average wave period (T)
3. Wave steepness at the end of the 25-hour sampling interval (H_o'/L_o)
4. Wave steepness averaged over the 25-hour sampling interval ($\overline{H_o'/L_o}$)
5. Change in wave steepness from the beginning to the end of the 25-hour sampling period ($\triangle H_o'/L_o$).

Of these, wave steepness was found to exert the greatest influence on the profile. The best correlations were obtained using average wave steepness.

The time interval over which the beach and wave changes were considered is the observation interval of about 25 hours or a lunar day (or 12½ hours when the observation time was shifted from evening to morning). Accordingly, all changes are on the basis of change per 25 hours. It was observed that periods of extreme cut and fill never exceeded one day. Because the beach reacted so quickly to changing wave conditions and because beach changes must occur with tidal periodicity, a 25-hour change rate was considered reasonable.

Figure 16 presents a time distribution of cut (minus values) and fill (plus values) as a contour chart. A bar graph showing change in wave steepness has been placed at the bottom of the graph to facilitate comparison with the beach elevation changes. Unfortunately, no wave

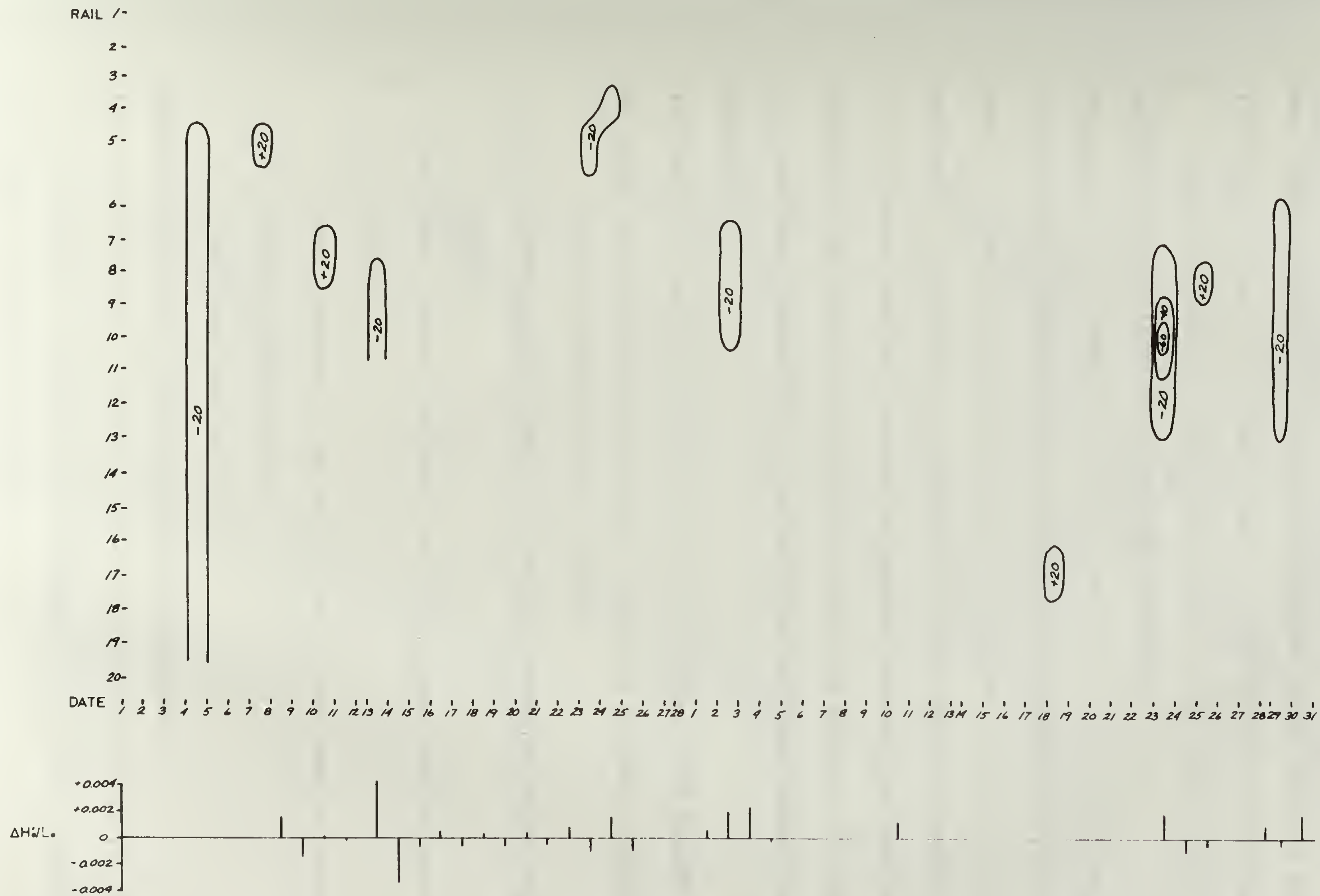


FIGURE 16 EXTREME CUT AND FILL (±20 CM. CONTOURED)

record was available for the period of February 4-5, when extensive cutting occurred across the beach. From field observations this was a period of steep waves. The figure shows that the beach tends to cut with increasing wave steepness and fill with decreasing wave steepness, although no correlation in the magnitude of the changes is apparent.

Extreme change in mean grain size is presented in Figure 17, along with a graph of wave-steepness change. Positive values indicate a decrease in grain size and negative values an increase in grain size. It may be noted that there were three periods when the sand first became much coarser and then in the next sampling interval became much finer at the same sampling stations. This suggests the possibility that a compensating mechanism operates when large changes in grain size occur. Those areas of great change in mean grain size do not coincide with the areas of extreme cut and fill, indicating no direct relationship between the two.

Values of change in mean sand diameter for all samples versus change in wave steepness are plotted in Figure 18. No relationship between the parameters is apparent.

Because beach cut and fill show a relation to wave steepness but change in grain size does not, it was reasoned that grain size is of secondary importance on Del Monte Beach, possibly because of its general uniformity. Accordingly, it was decided to further examine the relationship between wave changes and resulting profile changes, and to assume that the grain size is constant and therefore does not enter into this relationship. It was then reasoned that an equilibrium beach profile may exist for a given wave steepness, and that if the sand level at a given point on the beach face is initially at an elevation higher (or lower) than the equilibrium elevation for a given set of wave

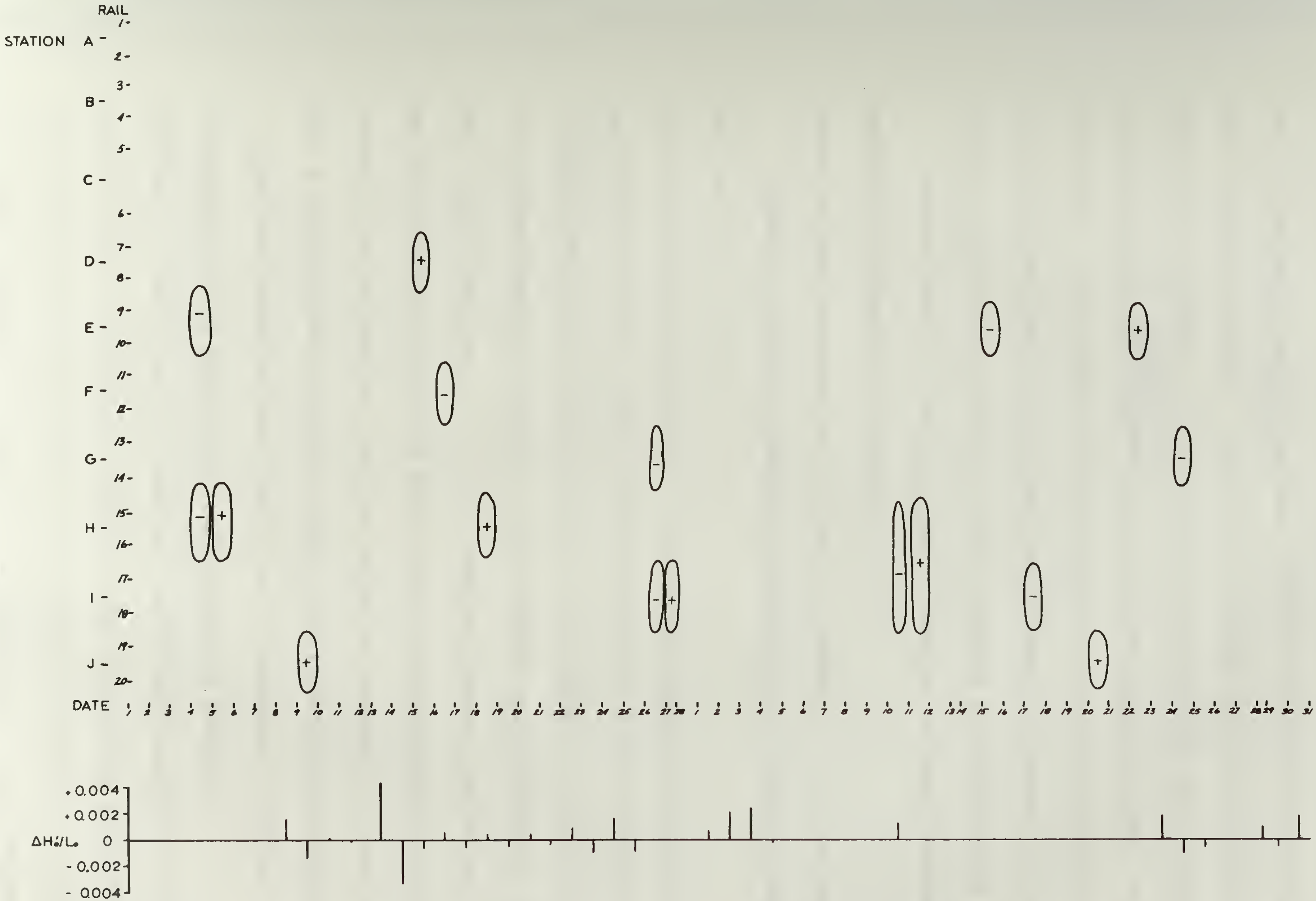
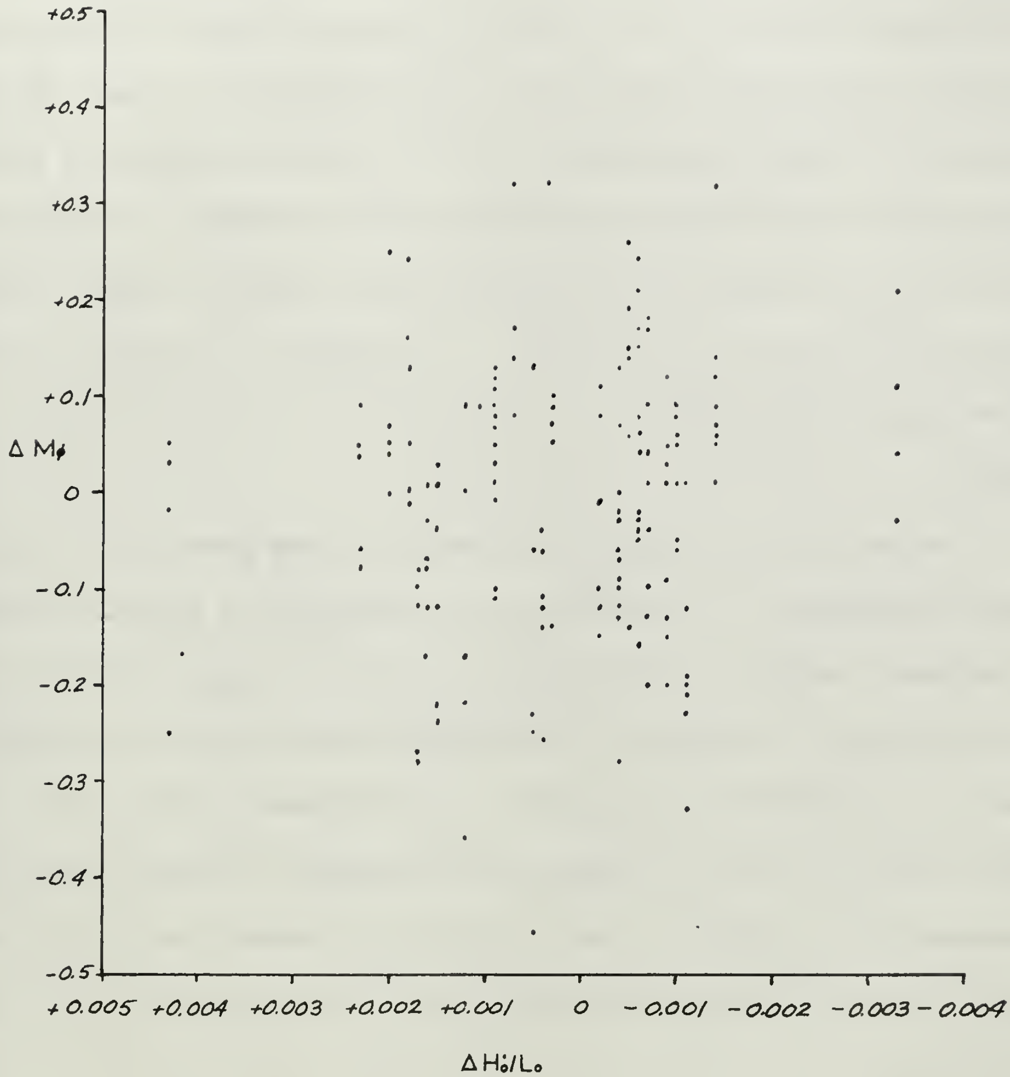


FIGURE 17 MEAN GRAIN SIZE CHANGE (±0.30φ CONTOURED)



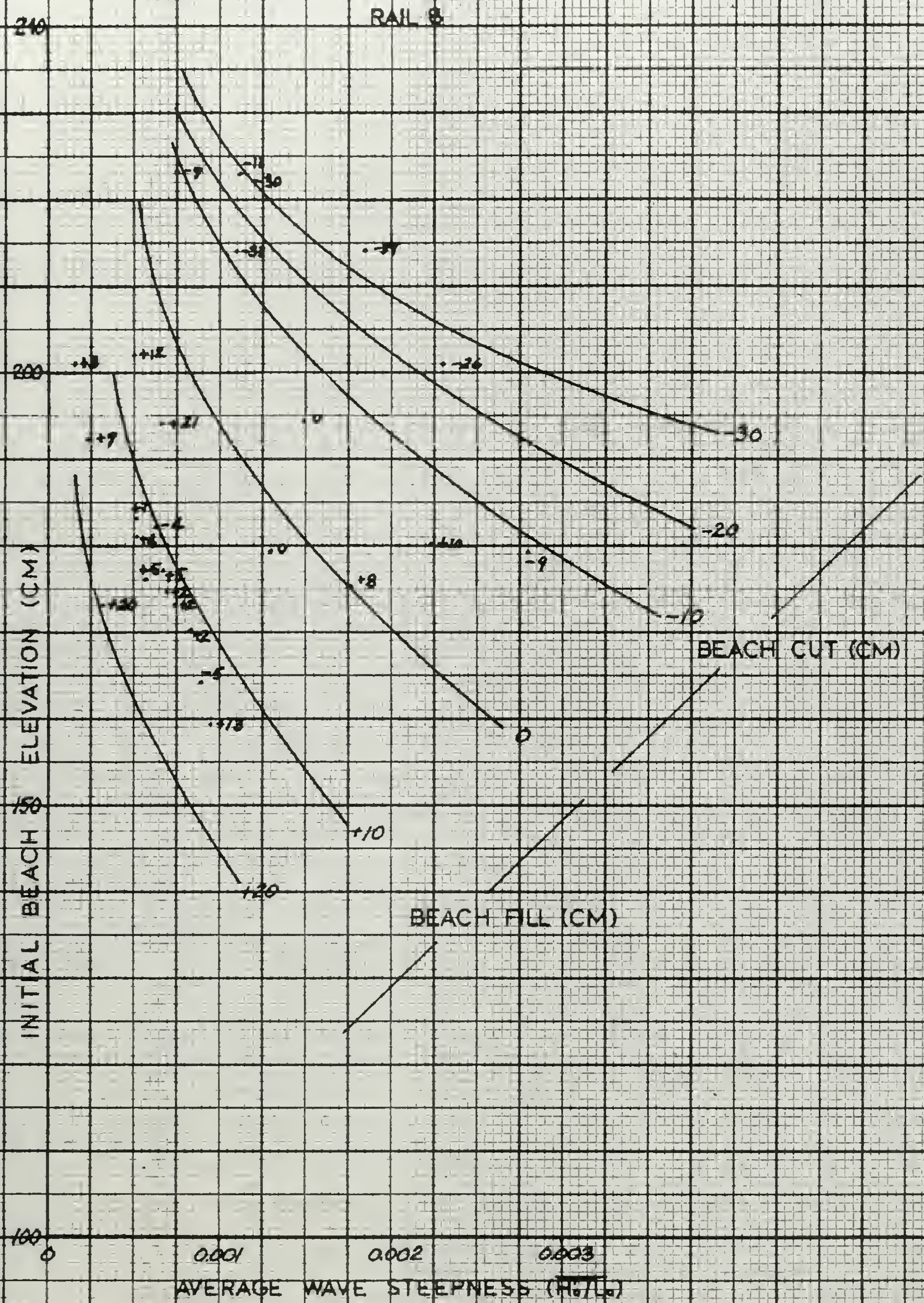
CHANGE IN WAVE STEEPNESS ($\Delta H'_o/L_o$) VS.
CHANGE IN MEAN GRAIN SIZE (ΔM_ϕ)

FIGURE 18

conditions, the beach must cut (or fill) in order to approach the equilibrium profile as long as those waves prevail. Thus, the elevation of the sand on the beach face before a change in wave conditions occurs should be taken into account. This was done by considering the three-factor relationship between the initial beach elevation, the cut or fill during the succeeding 25 hours, and the average wave steepness prevailing over the 25-hour period. Good results were obtained and are shown in Figures 19a through 19m. In the figures, one each for Rails 8 through 20 along the profile, cut and fill is expressed as a function of initial beach elevation and average wave steepness. Because each rail is at a different part of the profile, a set of curves is needed for each location on the profile. The graphs are shown only for that part of the beach which was subjected to wave action nearly all of the time.

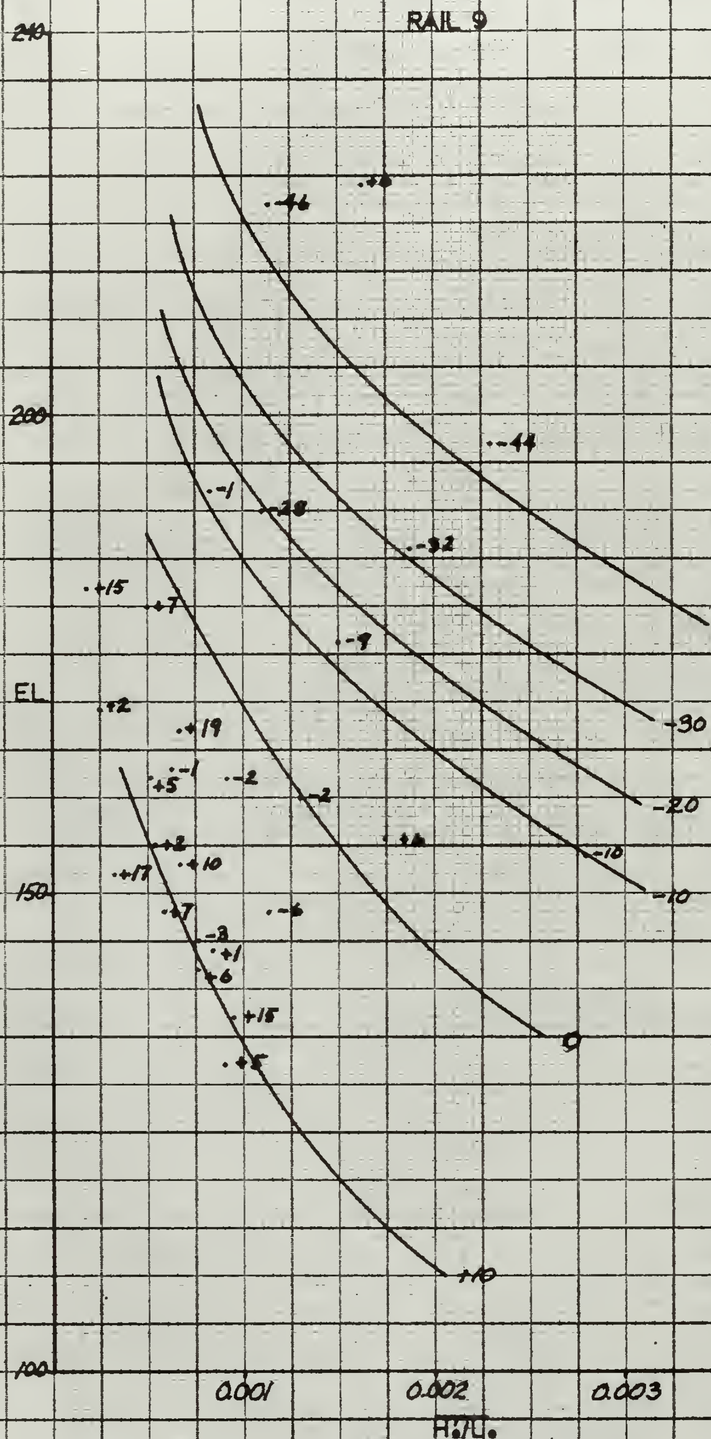
Several relationships can be seen in these graphs. At a given rail there apparently is an equilibrium elevation for a given average wave steepness, expressed by the zero cut-and-fill curve. The higher the beach builds at that point, the smaller becomes the wave steepness which is required for equilibrium. The converse is also true. If at any beach elevation the average wave steepness is greater than that required for equilibrium, the beach will be eroded, but if the average wave steepness is less than that required for equilibrium, the beach will build.

Figure 20 shows equilibrium profiles derived from the zero curves of Figures 19a through 19m for two selected wave steepnesses. When superimposed, it is apparent that the equilibrium profile for the smaller wave steepness is higher and steeper than that for the larger



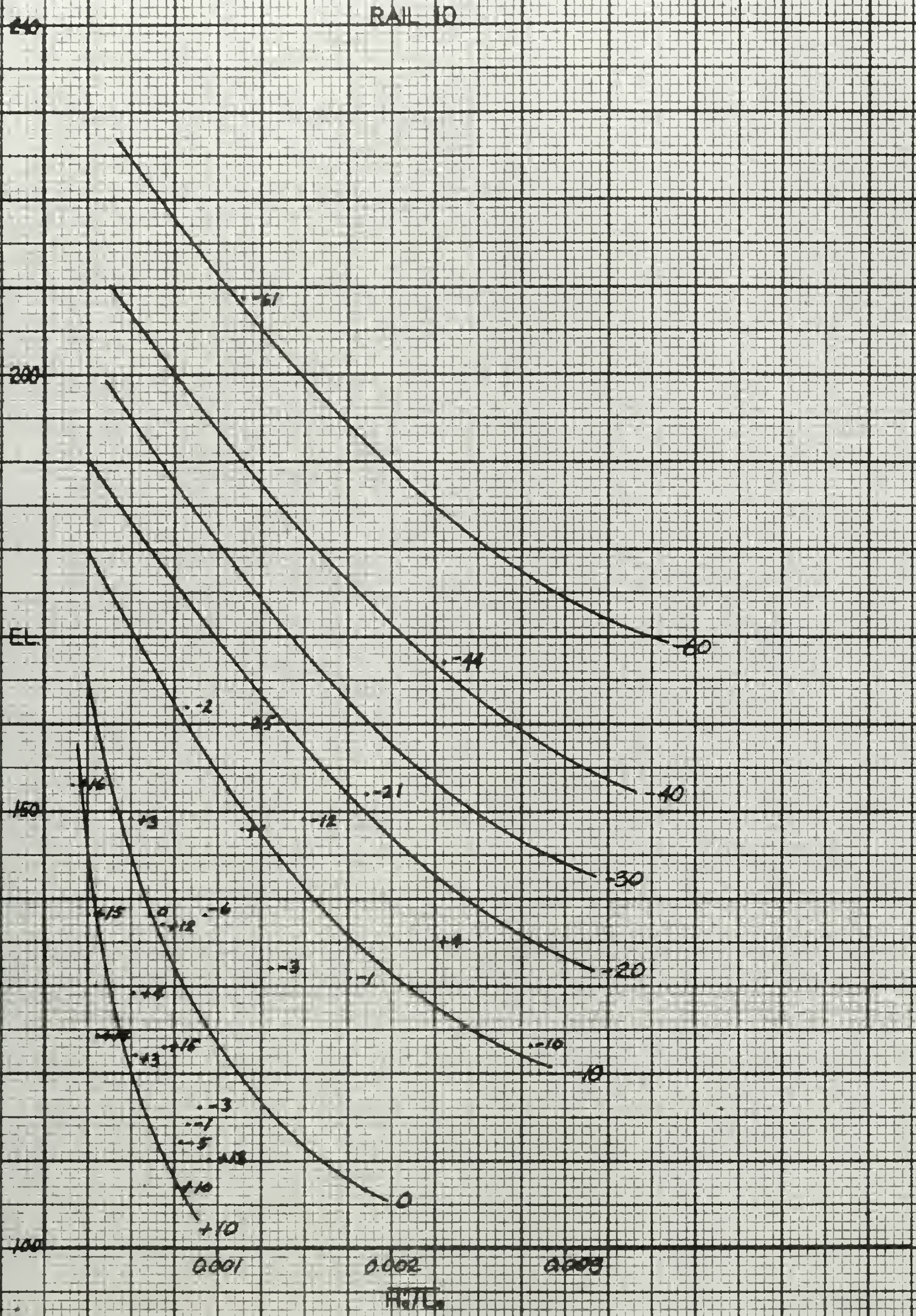
BEACH ELEVATION CHANGE

FIGURE 19a



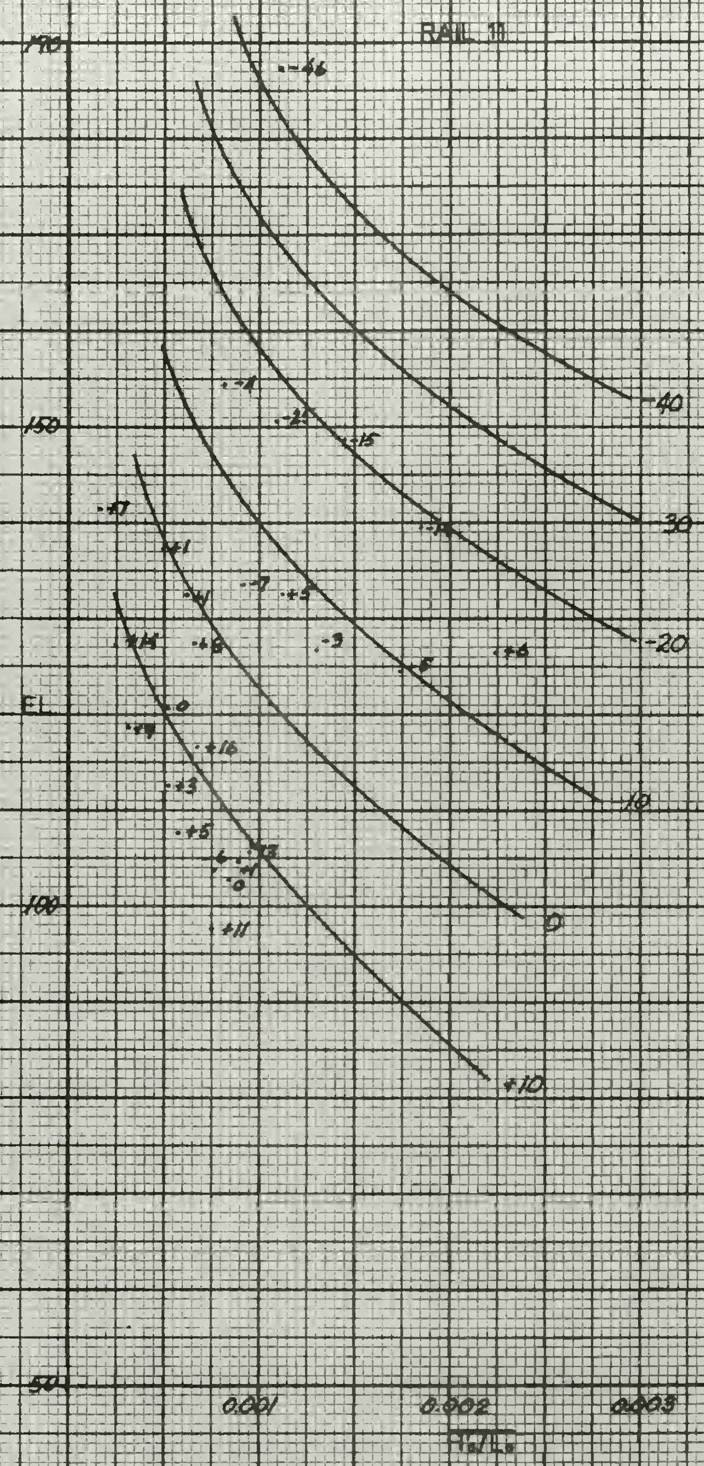
BEACH ELEVATION CHANGE

FIGURE 19b



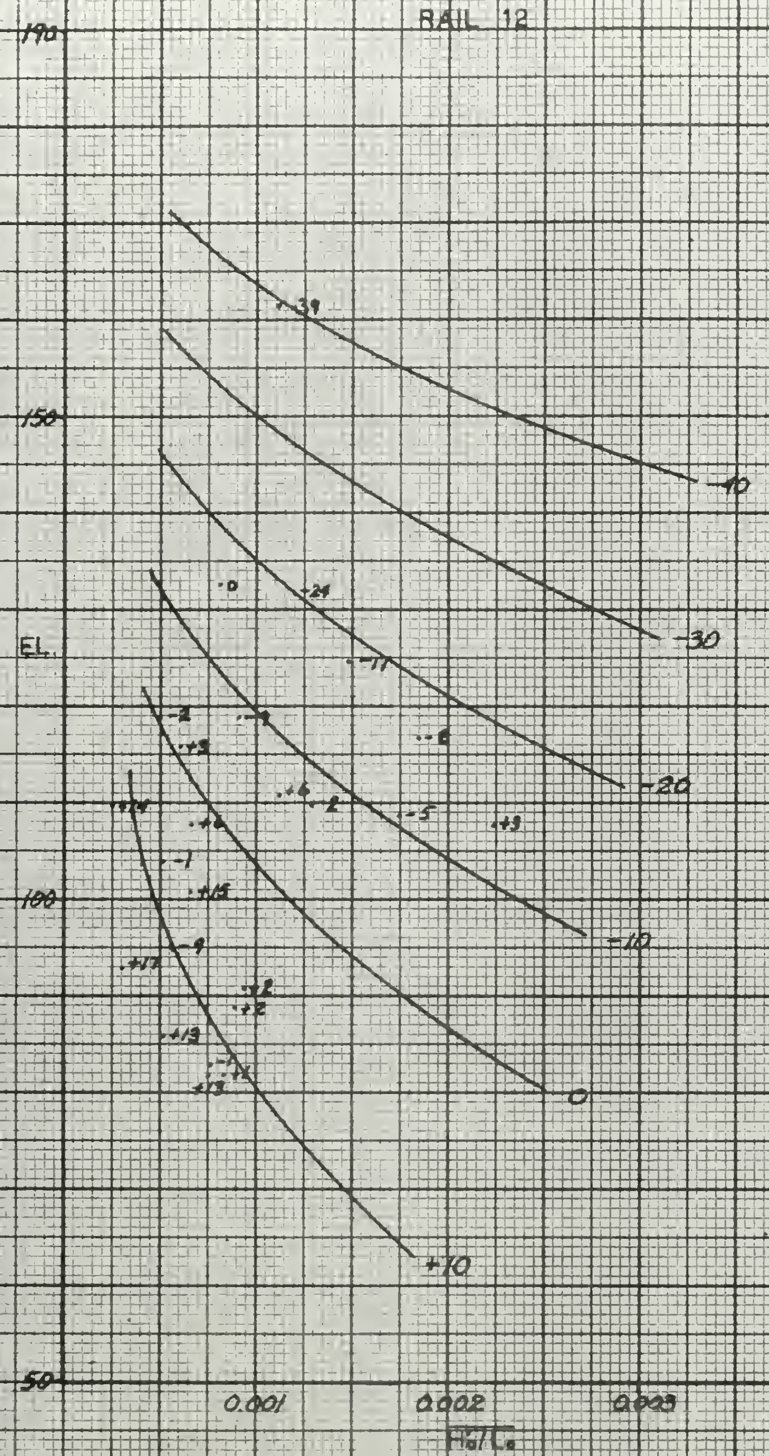
BEACH ELEVATION CHANGE

FIGURE 19c



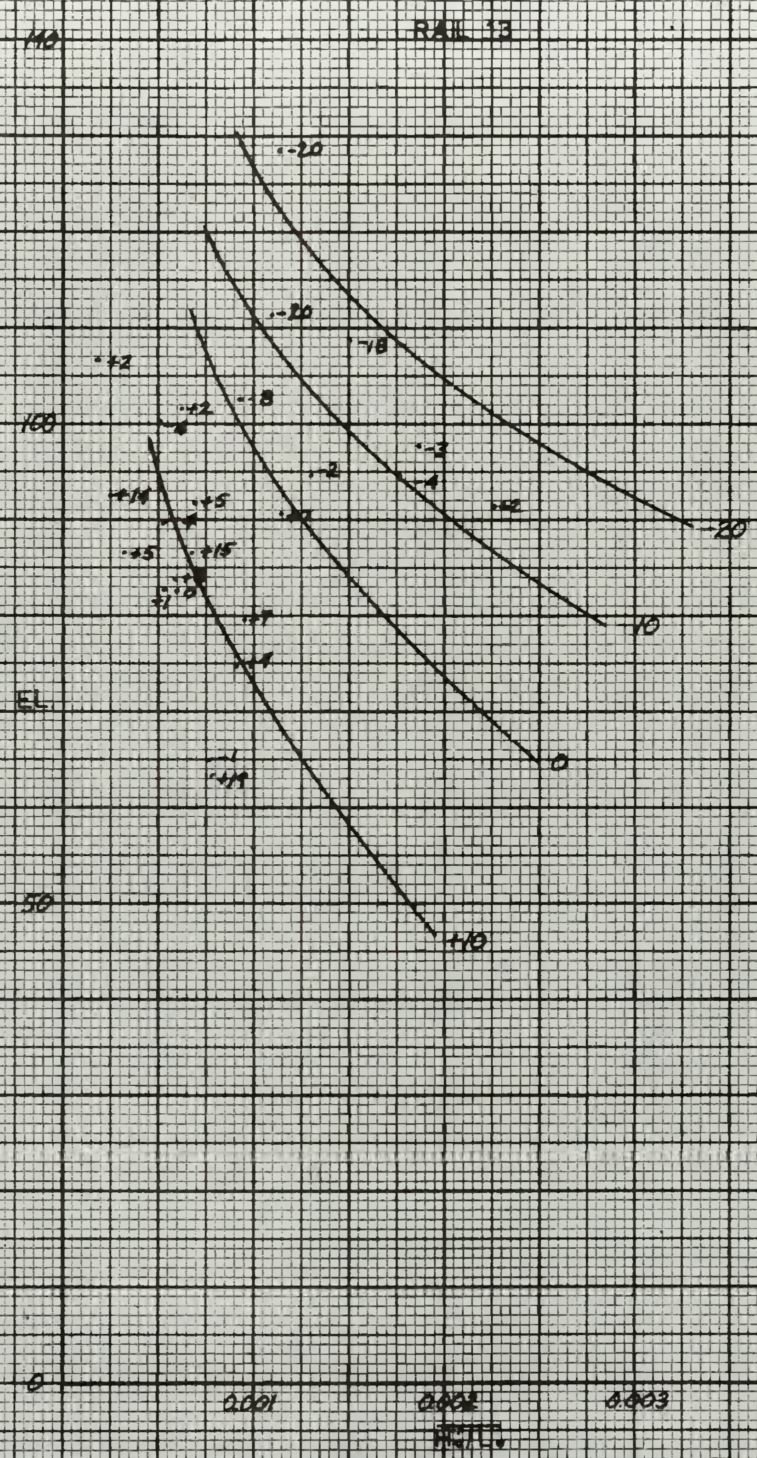
BEACH ELEVATION CHANGE

FIGURE 19d



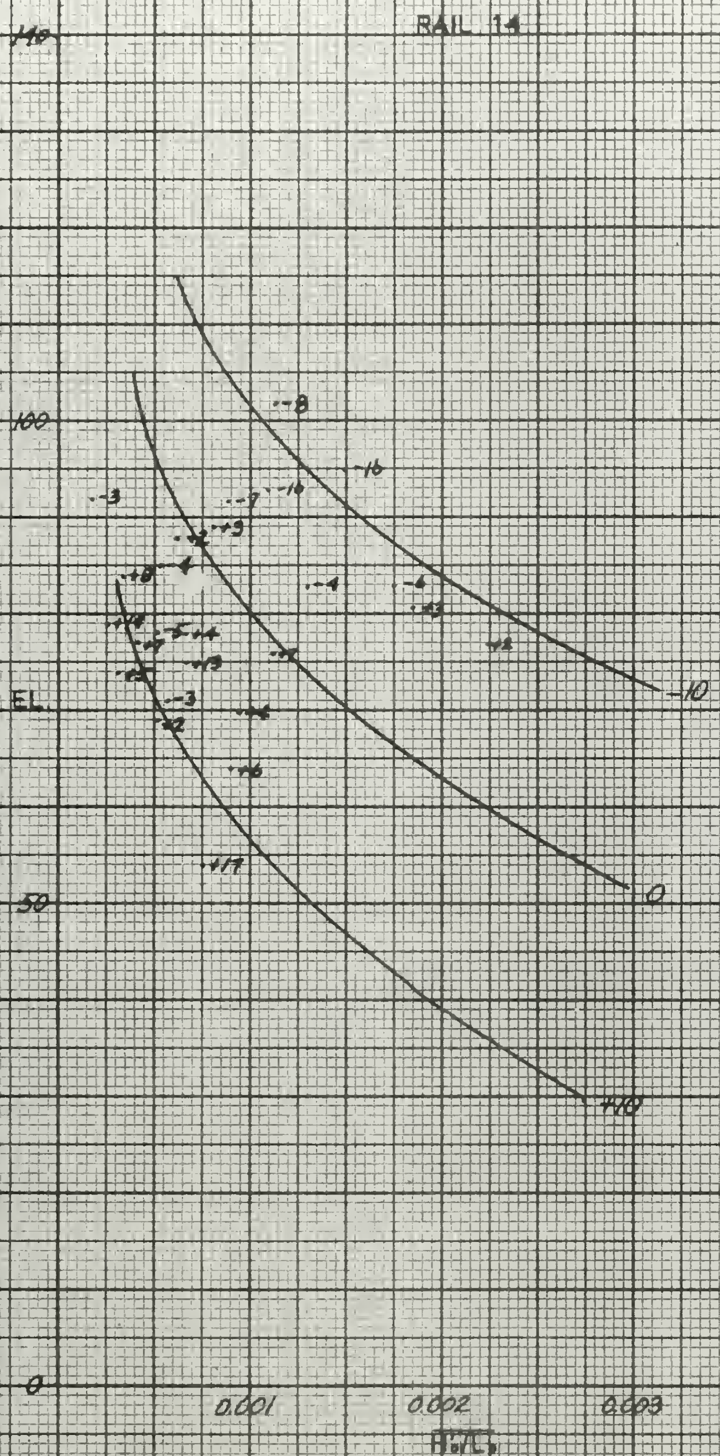
BEACH ELEVATION CHANGE

FIGURE 19e



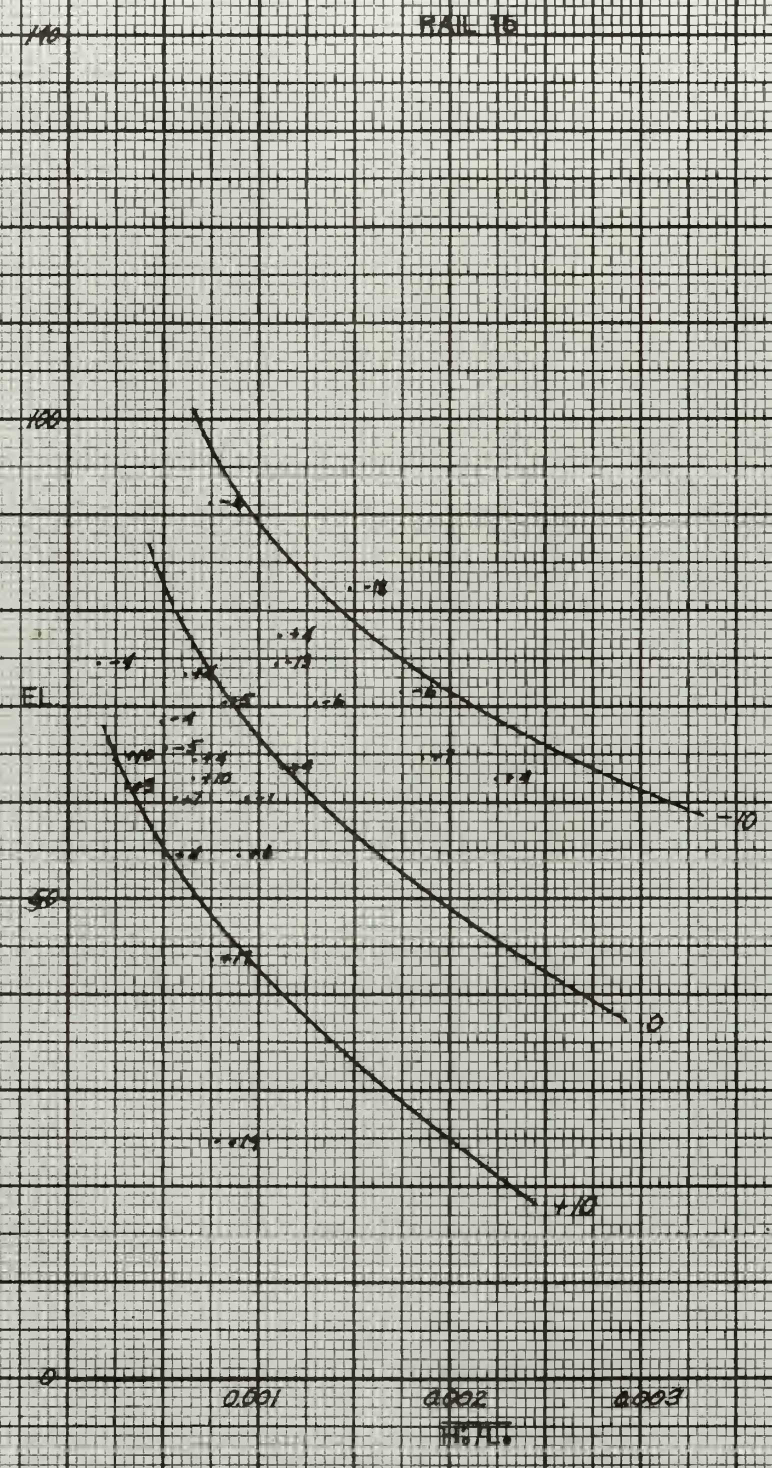
BEACH ELEVATION CHANGE

FIGURE 191



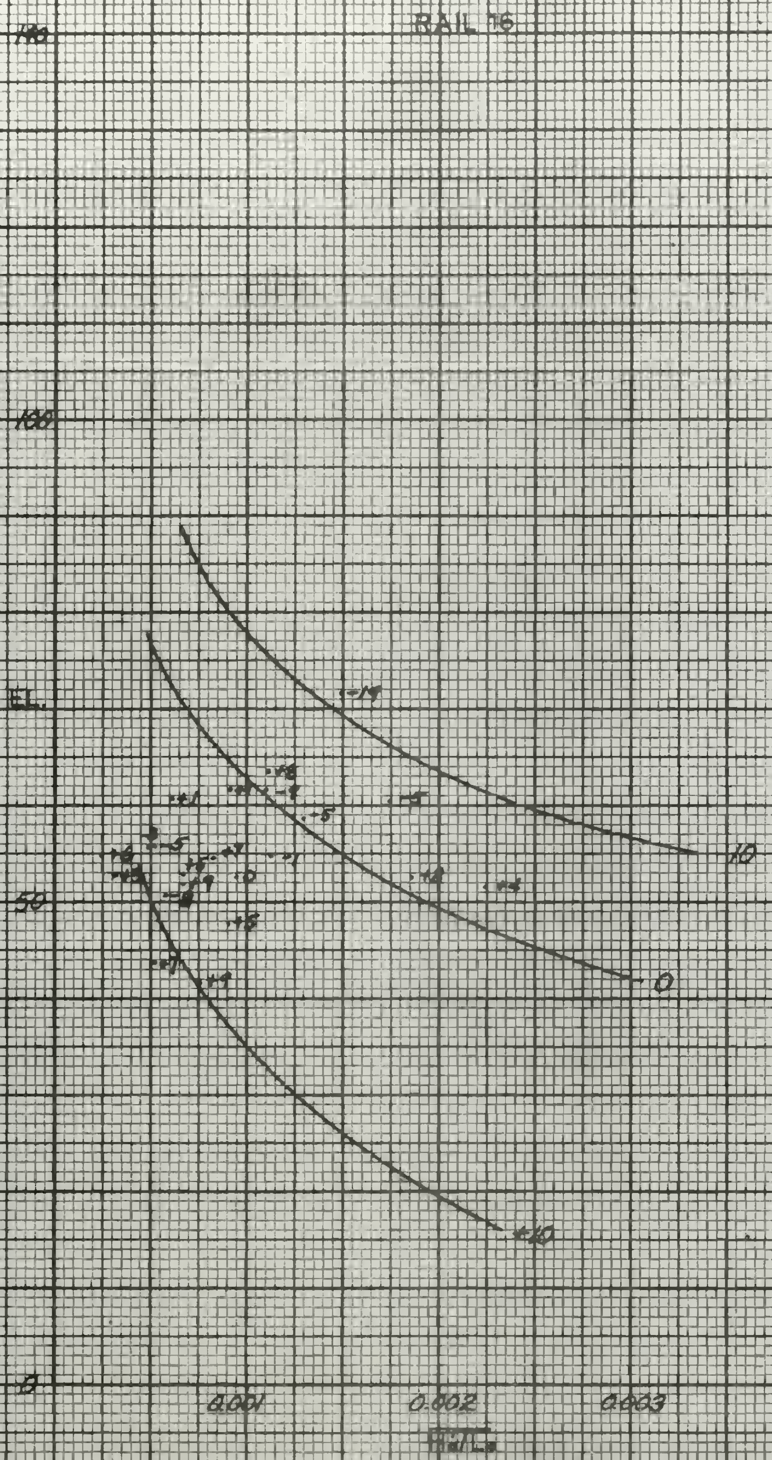
BEACH ELEVATION CHANGE

FIGURE 19g



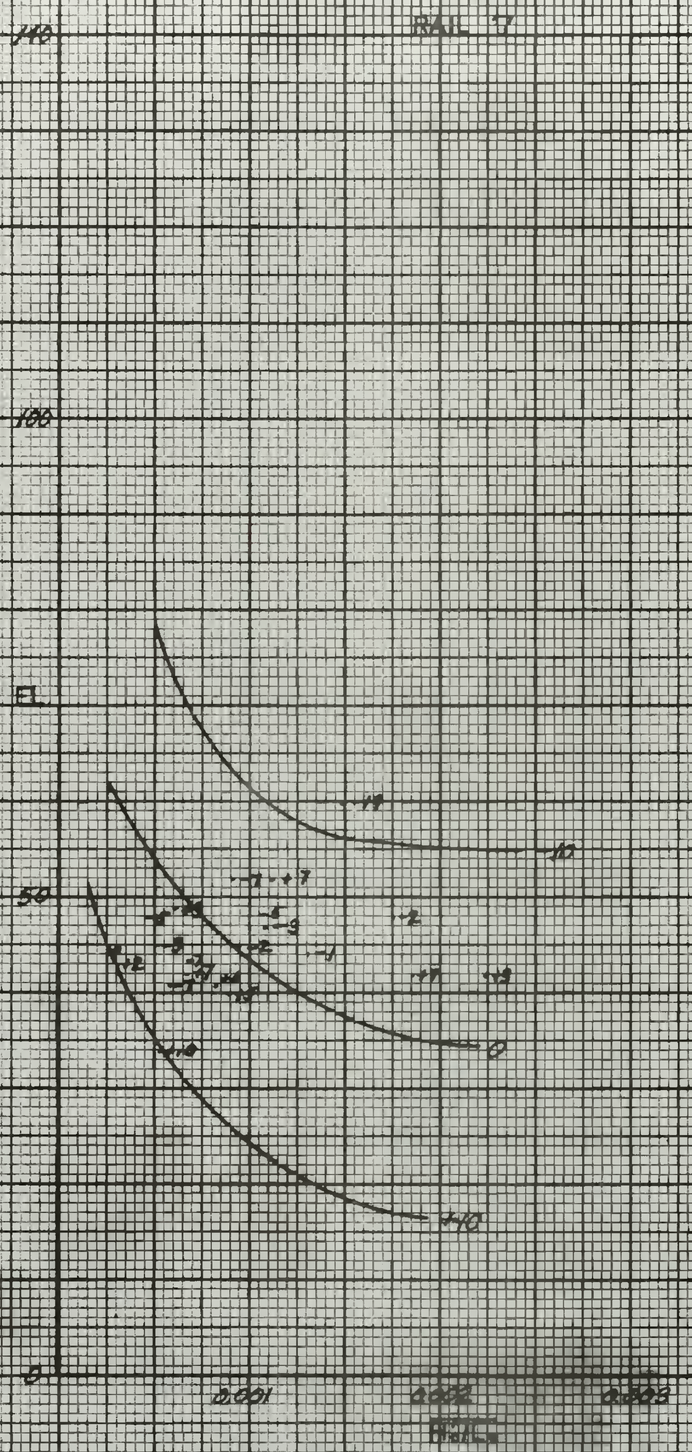
BEACH ELEVATION CHANGE

FIGURE 19h



BEACH ELEVATION CHANGE

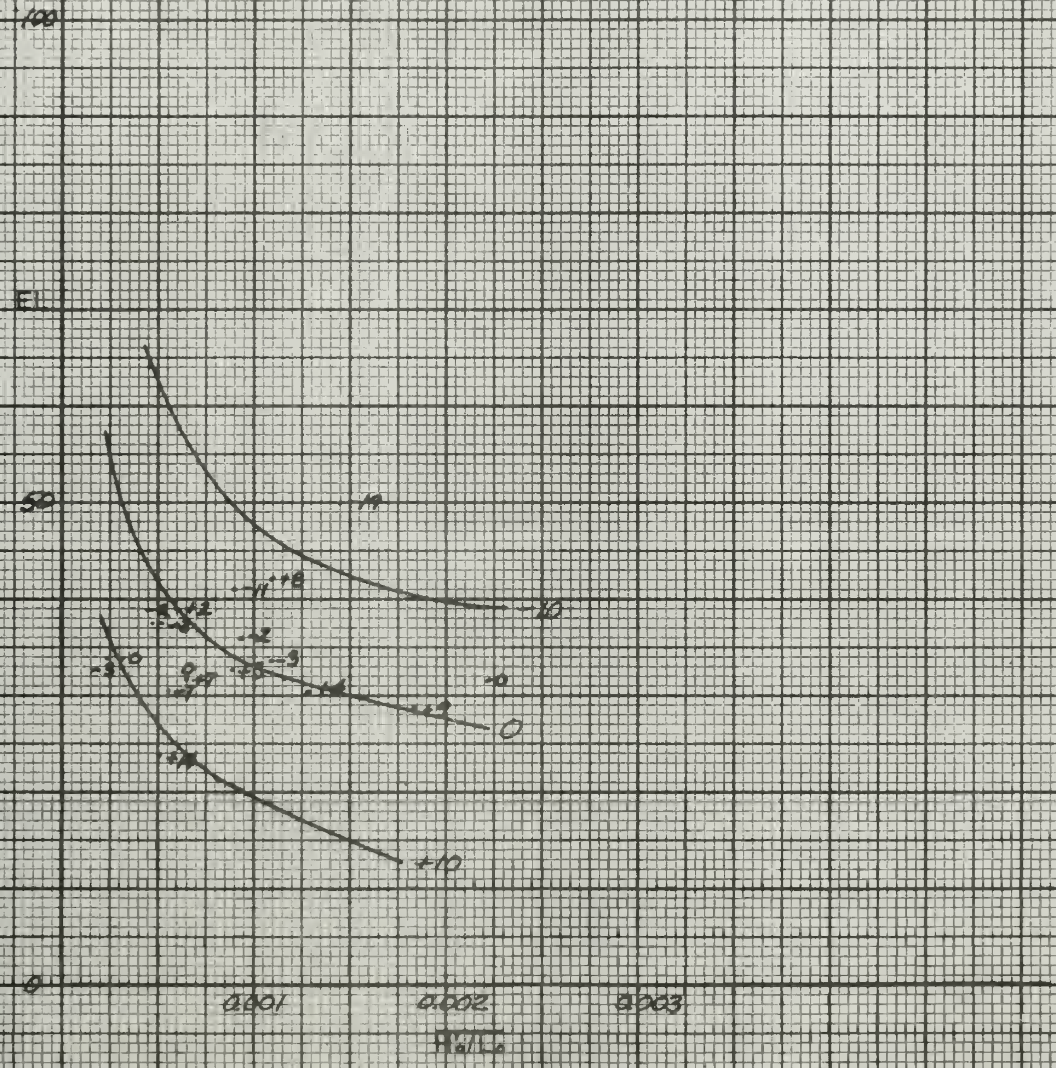
FIGURE 19 I



BEACH ELEVATION CHANGE

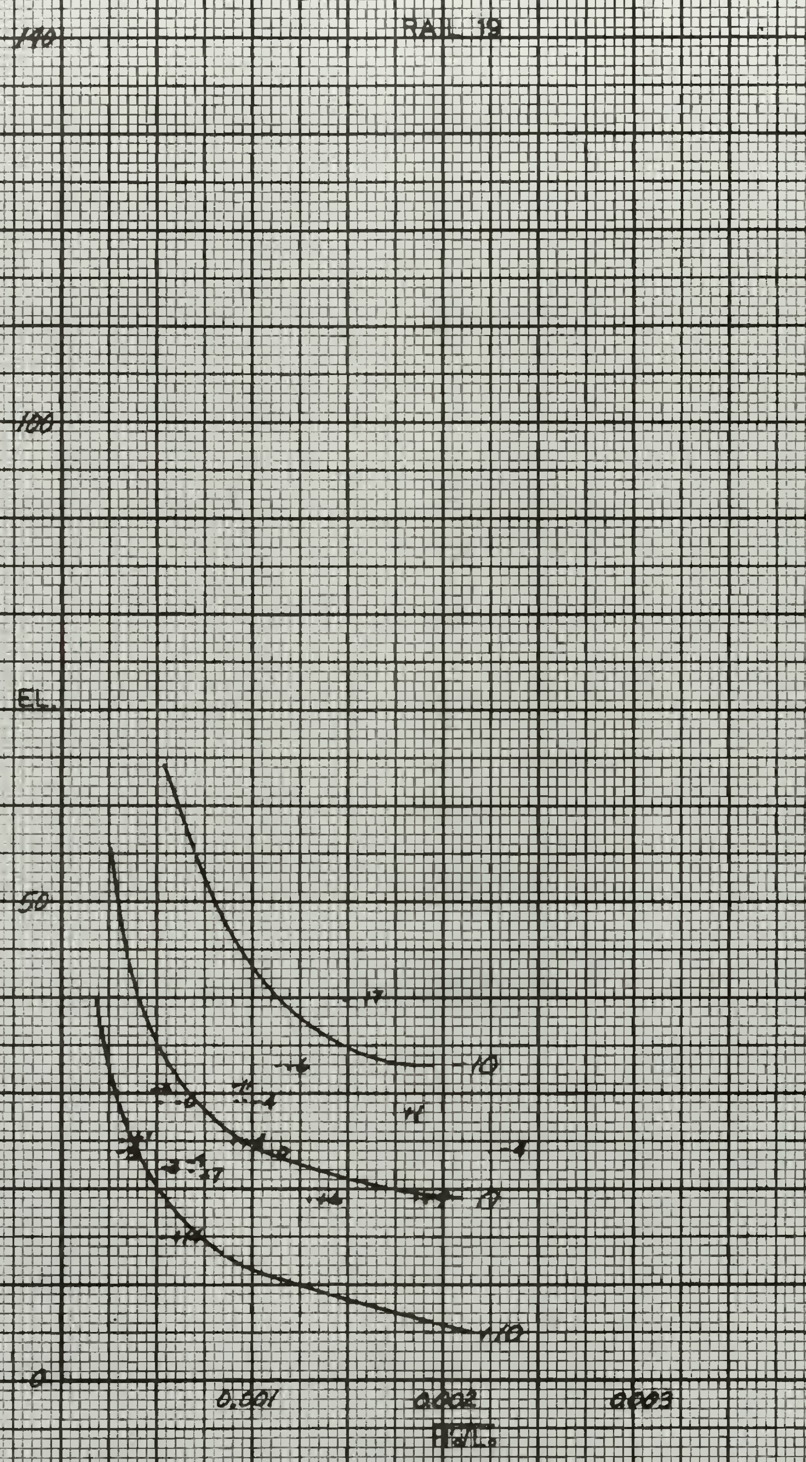
FIGURE 19

RAIL 18



BEACH ELEVATION CHANGE

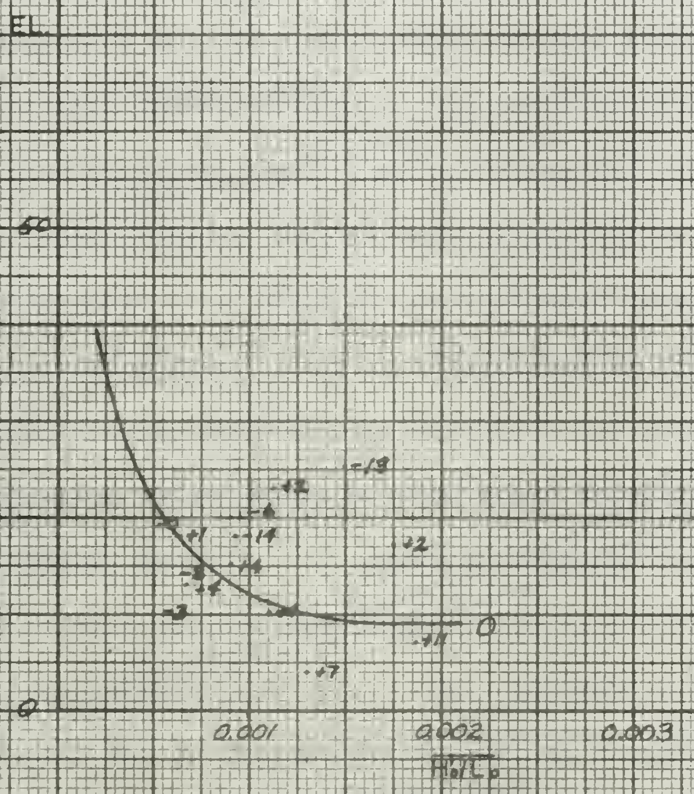
FIGURE 19k



BEACH ELEVATION CHANGE

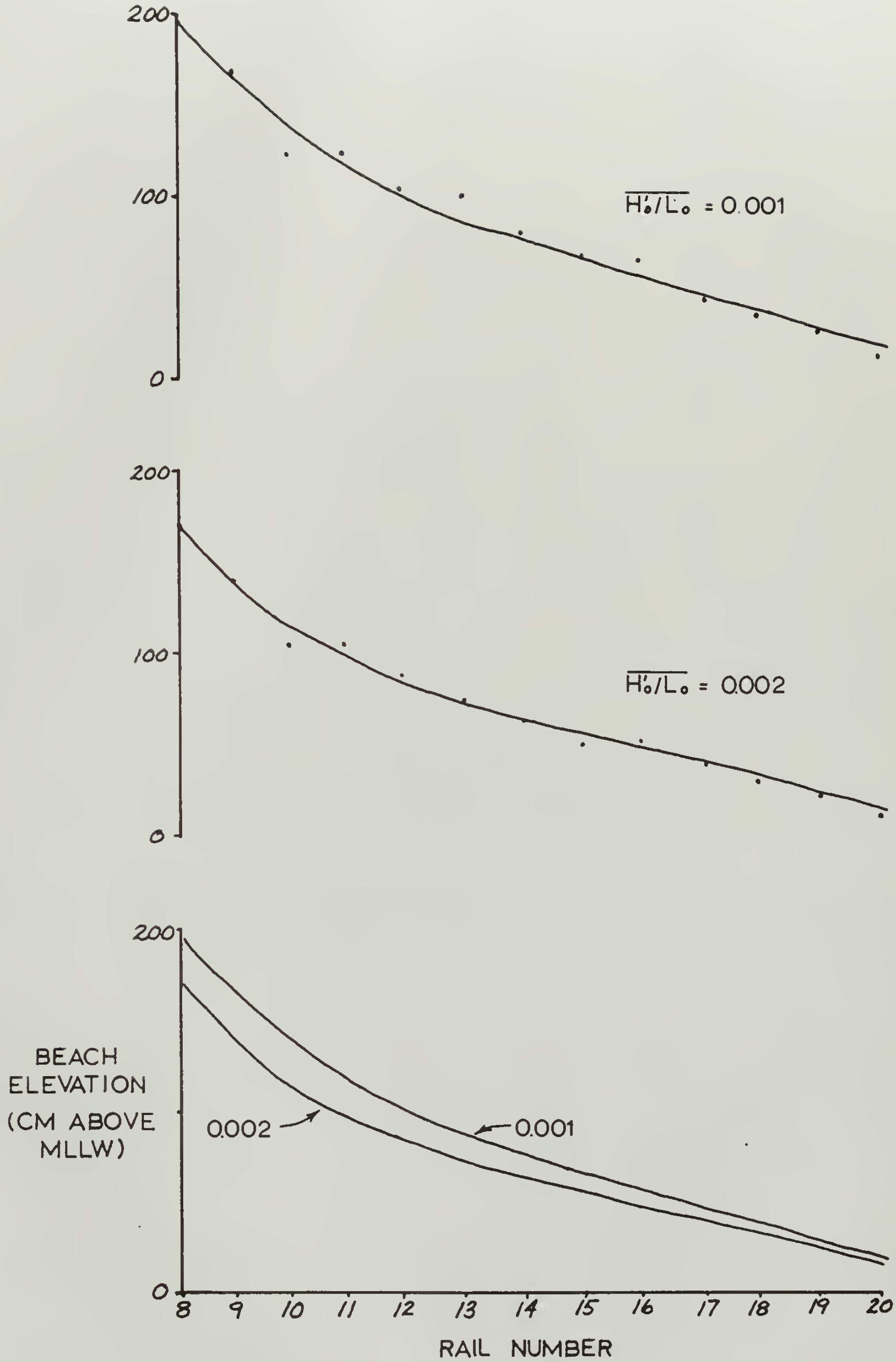
FIGURE 19.1

RAIL 20



BEACH ELEVATION CHANGE

FIGURE 19 m



EQUILIBRIUM BEACH PROFILES DERIVED FOR WAVE STEEPNESSES OF 0.001 AND 0.002

FIGURE 20

wave steepness. This agrees with the qualitative observation of Shepard (1963) and others that flat waves are constructive and steep waves destructive on a beach.

The question next considered was whether, by using a similar three-factor correlation, some relationship could be found between grain-size change and change in the beach elevation. The mean grain size was thus plotted as a function of initial beach elevation and cut and fill. A graph of this relation prepared for three selected sampling stations (E, F, and G) is shown in Figure 21. Although the relationship is by no means strong, it appears that beach fill is often accompanied by a decrease (plus values) in mean grain size and beach cut is accompanied by an increase (minus values) in mean grain size. Having found this relationship and the relationship of wave steepness to cut and fill, the attempt was again made to find a relationship between grain size and wave steepness, this time by taking into account the initial grain size. Accordingly, initial mean grain size was plotted against change in mean grain size, with the average wave steepness values recorded at the plotted points. This is illustrated in Figure 22 for Station E. No relationship between wave steepness and grain size was found. An interesting relationship between grain size and change in grain size did appear, however. It was found that the scatter of points gave a well-defined pattern that suggests that, for each station, there is an equilibrium mean grain size. This relation is shown in Figure 22 for Station E and in Figure 23 for Stations F through J. The equilibrium value is given by the intersection of the zero-change line and the mean line drawn through the data points on the graph. It appears that if the initial mean size for a given day is not at the equilibrium value,

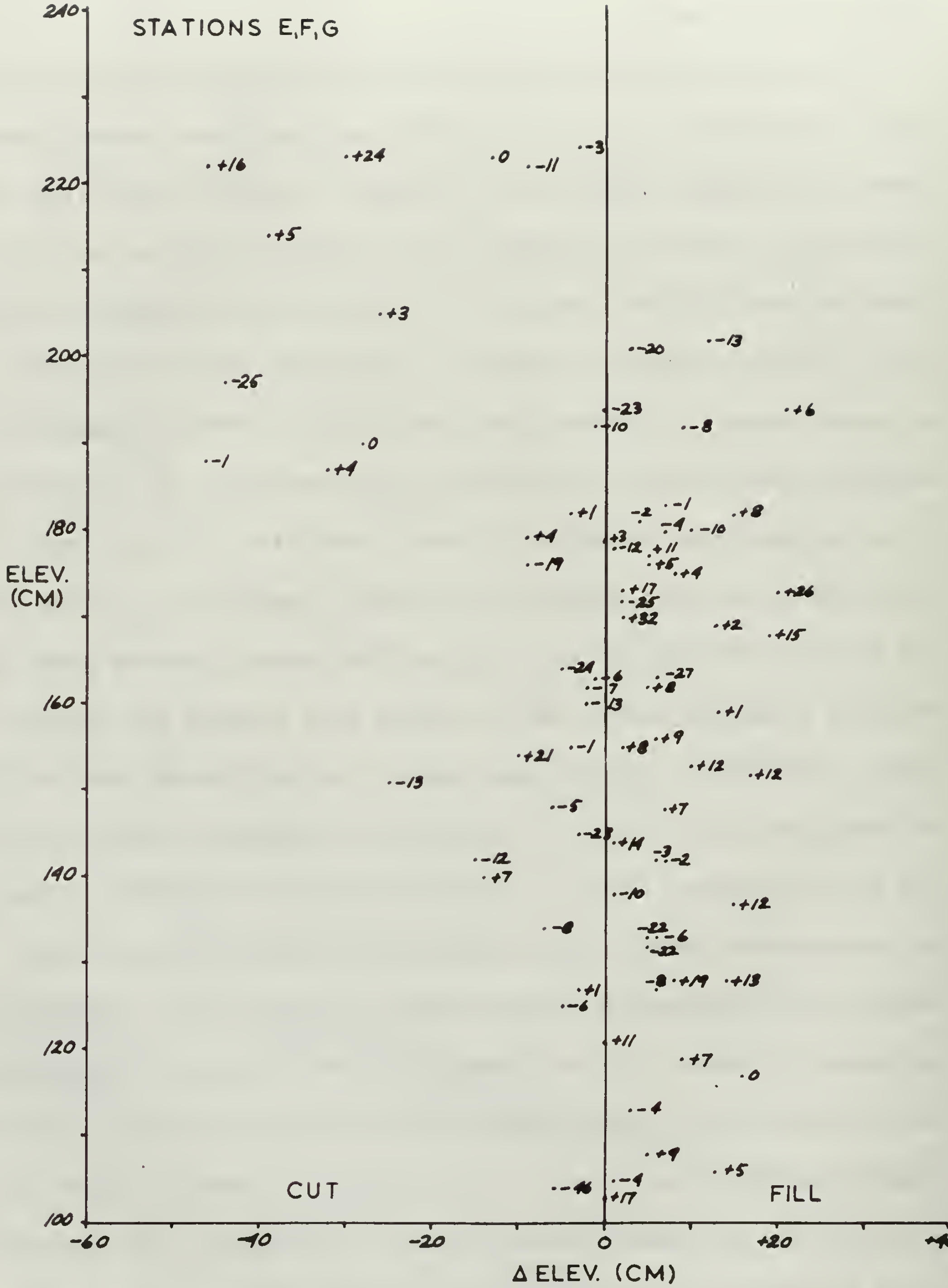
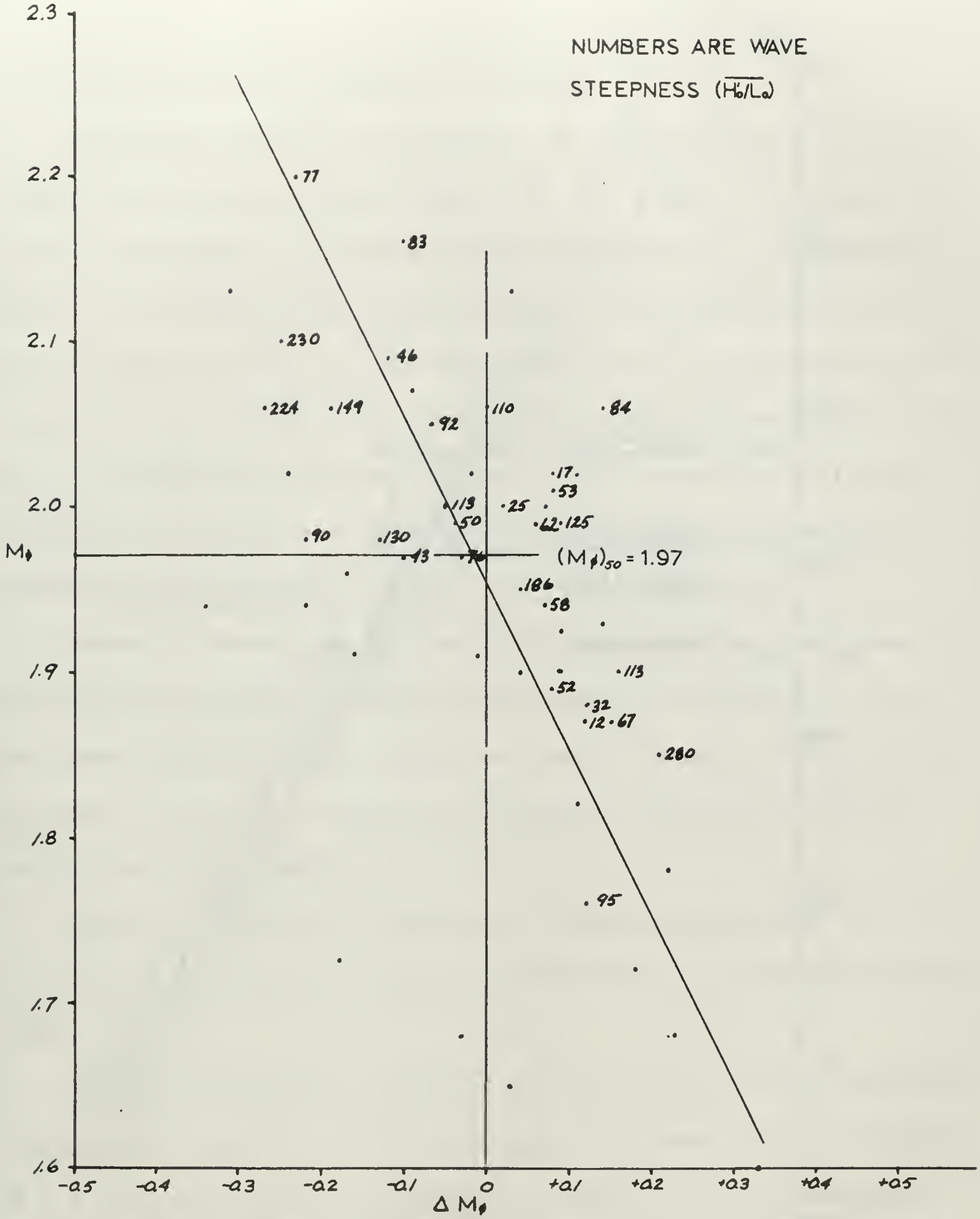


FIGURE 21 CHANGE IN MEAN GRAIN SIZE AS A FUNCTION OF BEACH ELEVATION AND CUT AND FILL



MEAN GRAIN SIZE (M_ϕ) VS. CHANGE IN MEAN (ΔM_ϕ)
STATION E

FIGURE 22

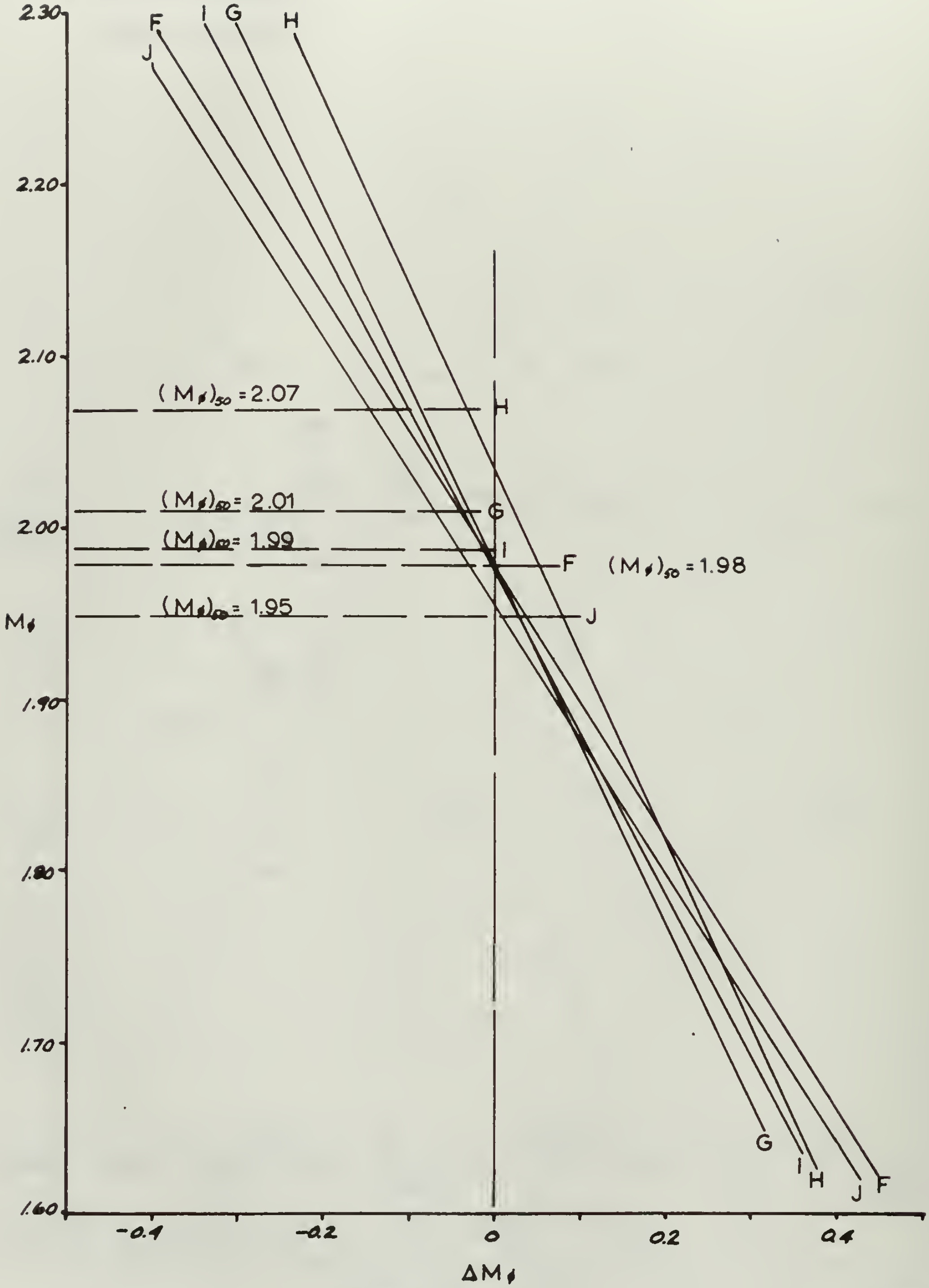


FIGURE 23 MEAN GRAIN SIZE (M_ϕ) VS. CHANGE IN MEAN GRAIN SIZE (ΔM_ϕ)

(STATIONS F THROUGH J)

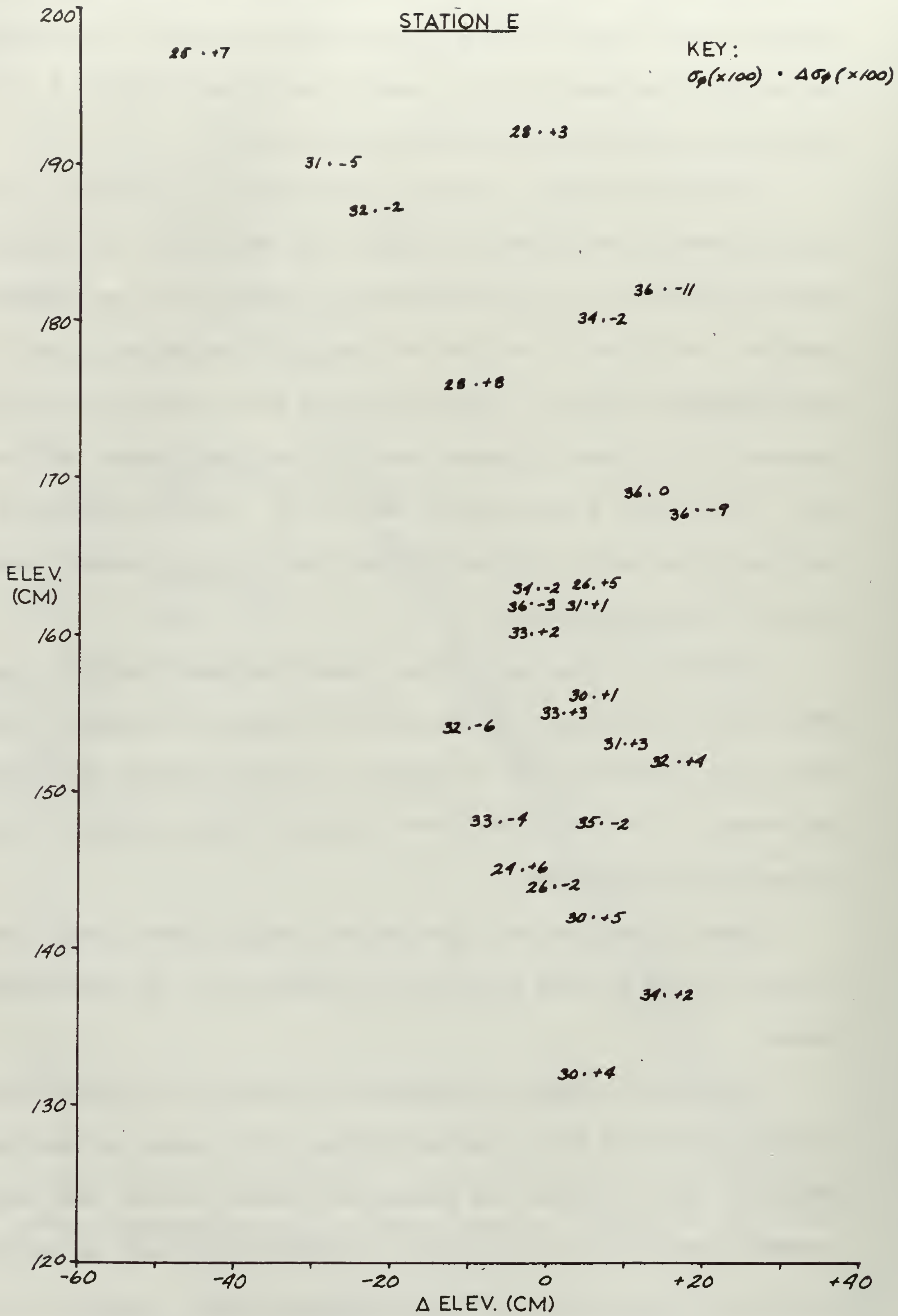
the change in mean size will be in a direction toward the equilibrium value. In all cases the equilibrium value is close to the average value which was taken from the cumulative curves of Figure 9. The equilibrium values are tabulated in Table 1b.

Sorting and change in sorting were tested as functions of initial beach elevation and elevation change, and the results for Station E are shown in Figure 24. No relationship was apparent for any sampling station. In Figure 25 sorting and change of sorting are plotted with wave steepness values. As with the grain size, the only relation which appears is a scatter of points indicating an equilibrium value of sorting. For Station E the value is about 0.32. Because sorting is so uniform on the beach, the equilibrium lines for all stations (not graphed) nearly coincide.

Change in sorting was plotted against values of extreme change in mean grain size for all stations and the results are shown in Figure 26. The figure indicates that, in general, sorting improves when grain size decreases. It was also found that initially finer sand was better sorted than coarser sand.

Change in sorting as a function of change in mean grain size and cut and fill is plotted in Figure 27 (Station E). No relationship was found.

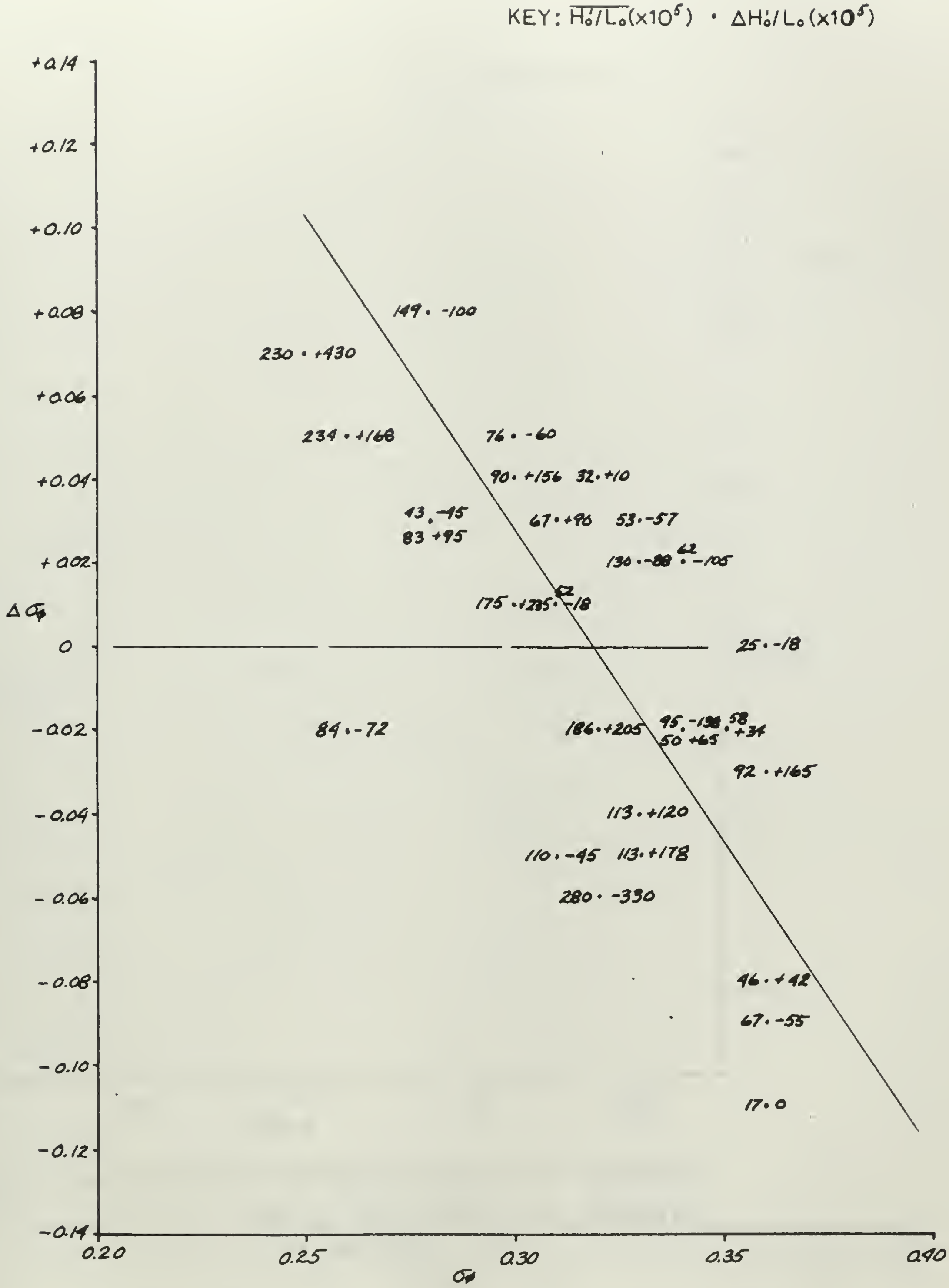
Skewness and change in skewness as functions of initial beach elevation and cut and fill, plotted in Figure 28, showed no relationship. Figure 29 shows skewness and change in skewness plotted with wave-steepness values. As with sorting and mean grain size, an apparent equilibrium value of skewness exists for each station. The equilibrium value at a given station is close to the average values derived from the



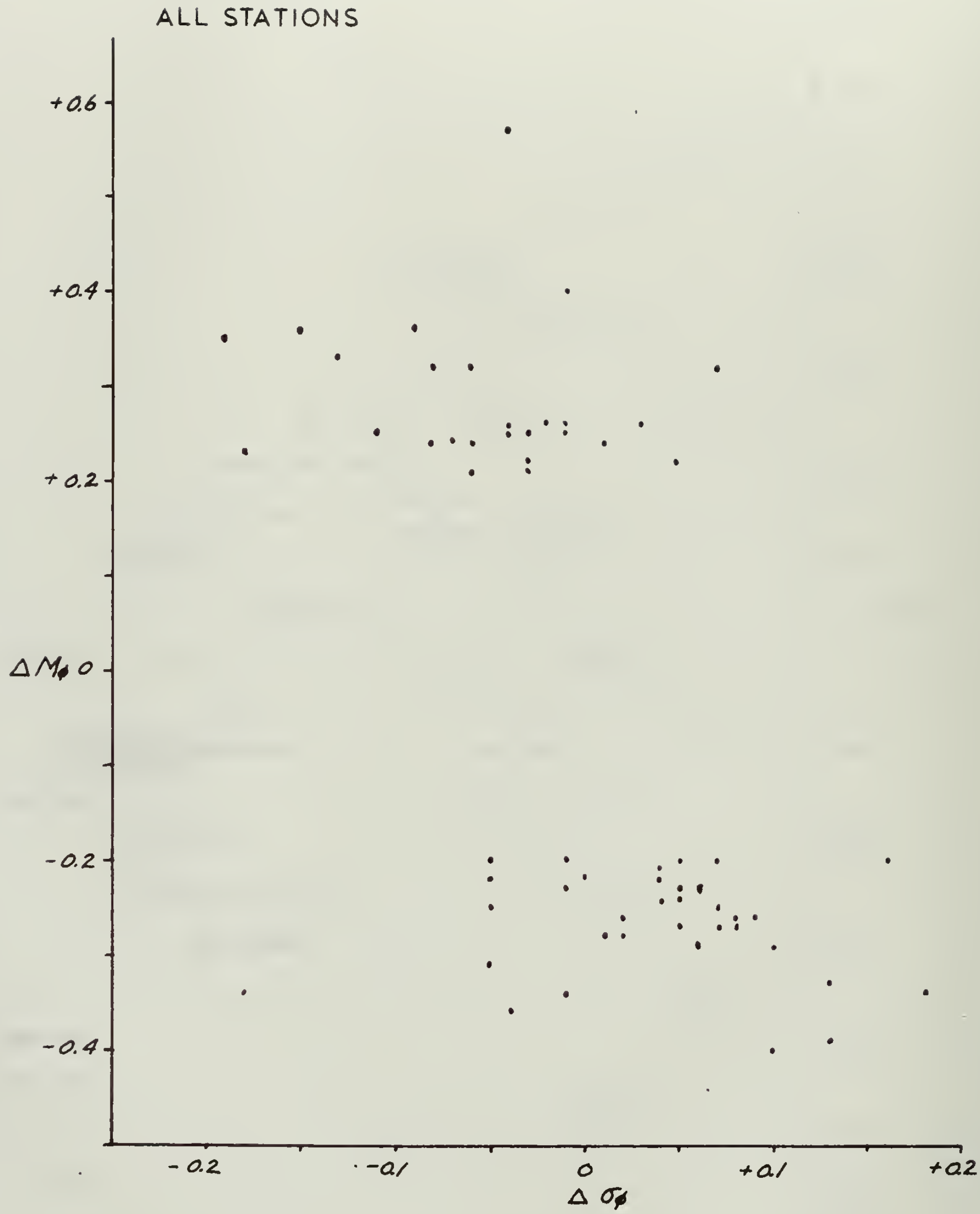
SORTING (σ_ϕ) AND CHANGE IN SORTING ($\Delta\sigma_\phi$) AS FUNCTIONS OF BEACH ELEVATION AND CUT AND FILL

FIGURE 24

STATION E



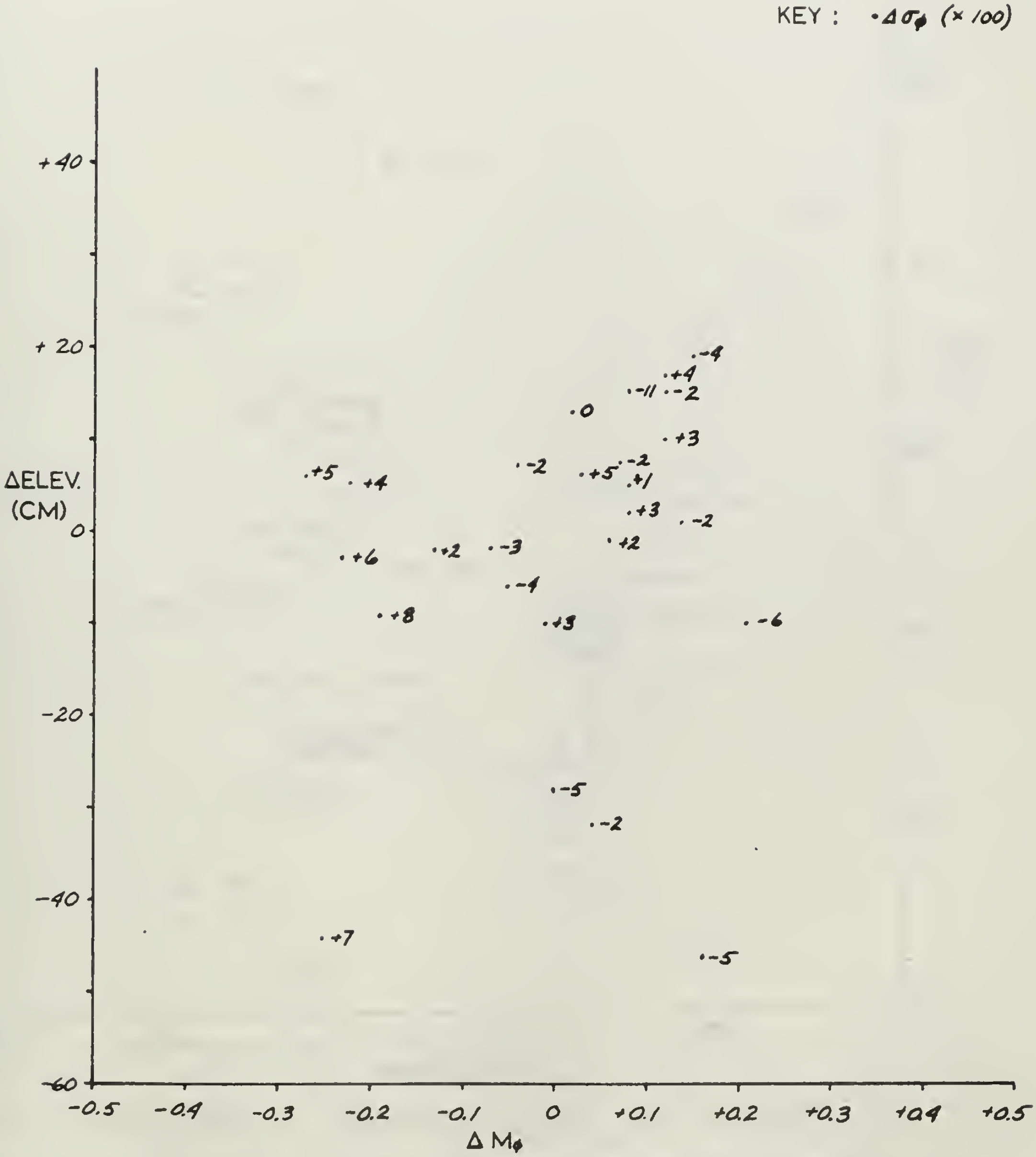
SORTING (σ_ϕ) VS. CHANGE IN SORTING ($\Delta\sigma_\phi$)
(PLOTTED WITH WAVE STEEPNESS VALUES)
FIGURE 25



CHANGE IN MEAN GRAIN SIZE (ΔM_ϕ) VS. CHANGE IN SORTING ($\Delta \sigma_\phi$)

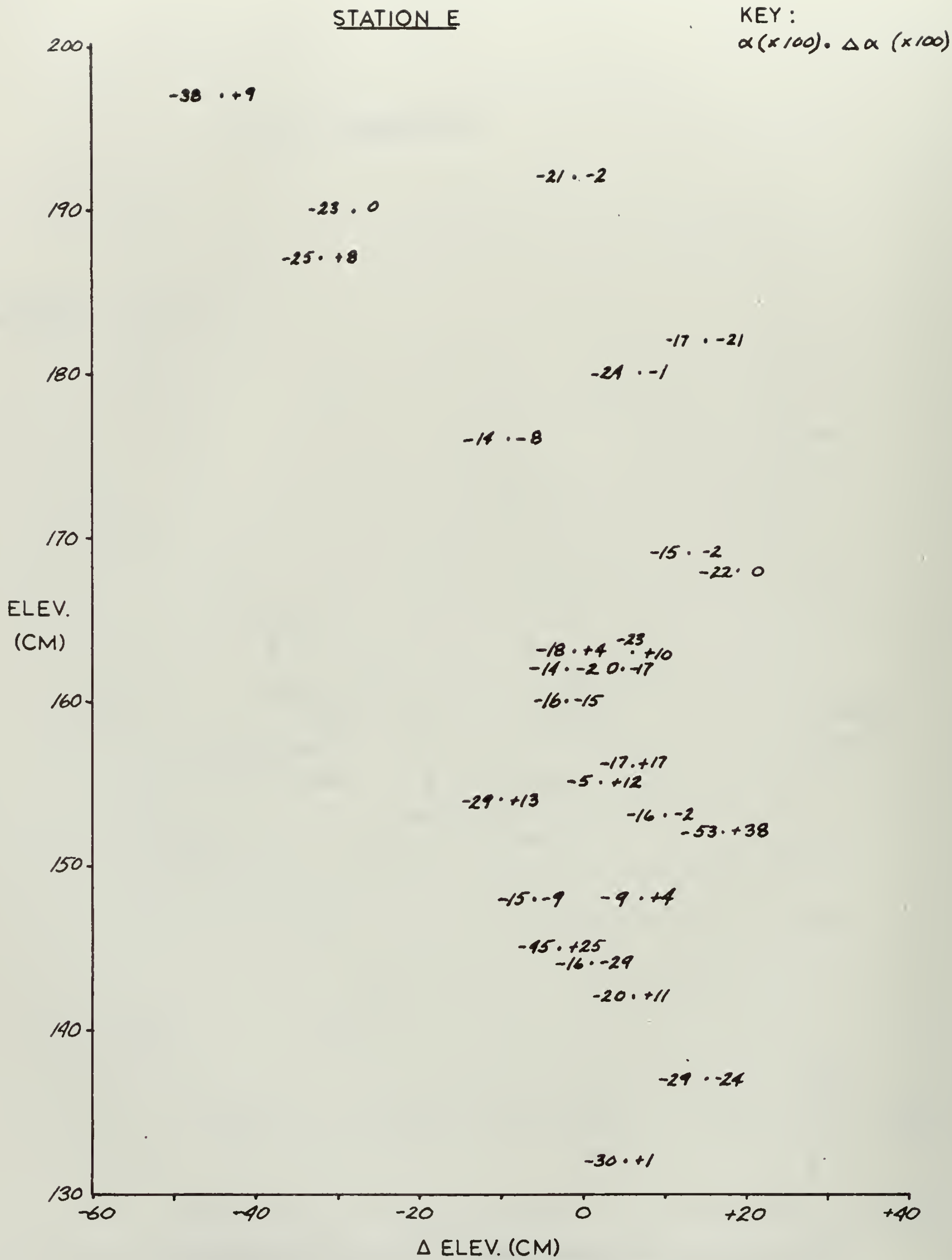
FIGURE 26

STATION E



CHANGE IN SORTING ($\Delta\sigma_\phi$) AS A FUNCTION OF MEAN GRAIN SIZE CHANGE AND CUT AND FILL

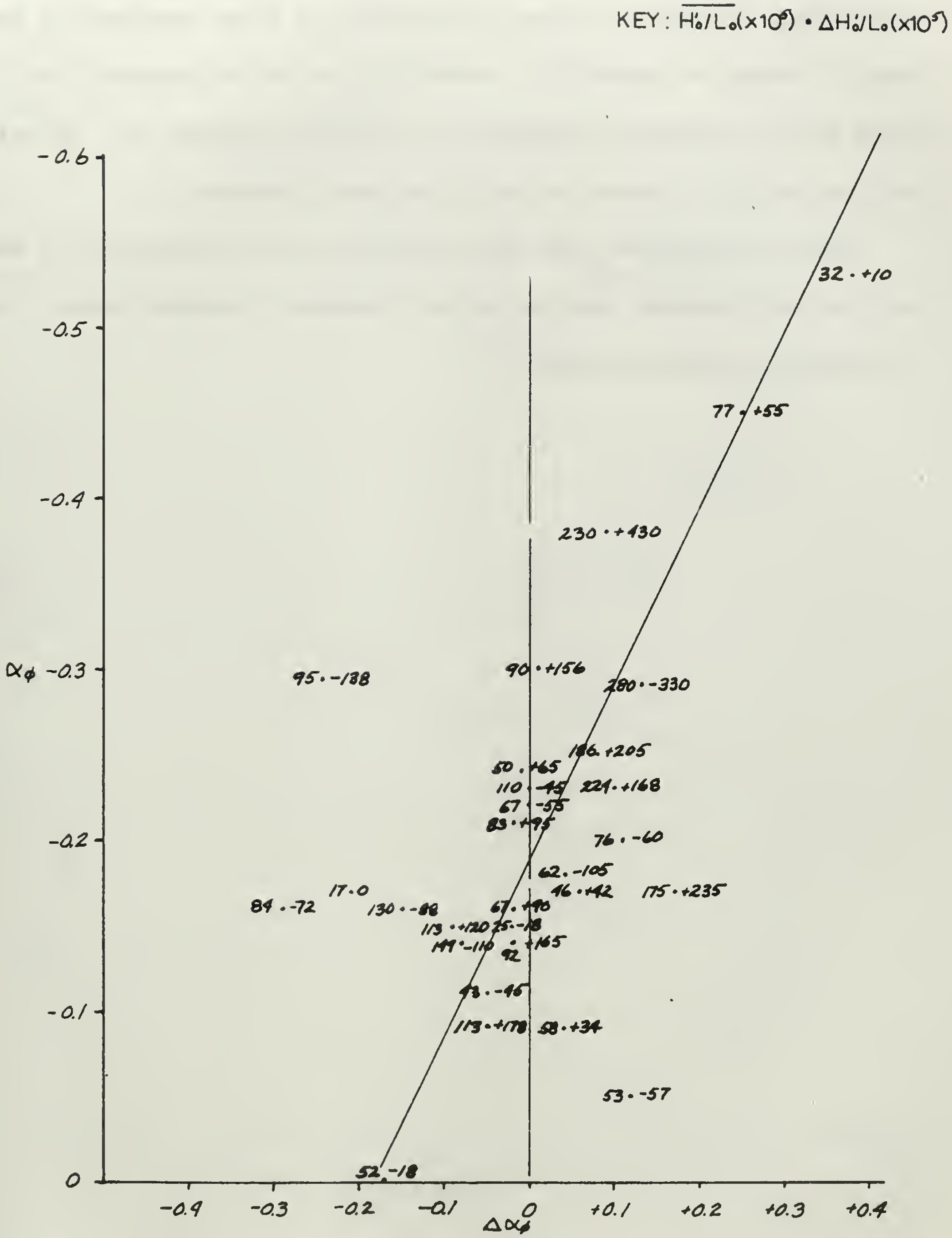
FIGURE 27



SKEWNESS (α_ϕ) AND CHANGE IN SKEWNESS ($\Delta \alpha_\phi$) AS FUNCTIONS OF BEACH ELEVATION AND CUT AND FILL

FIGURE 28

STATION E

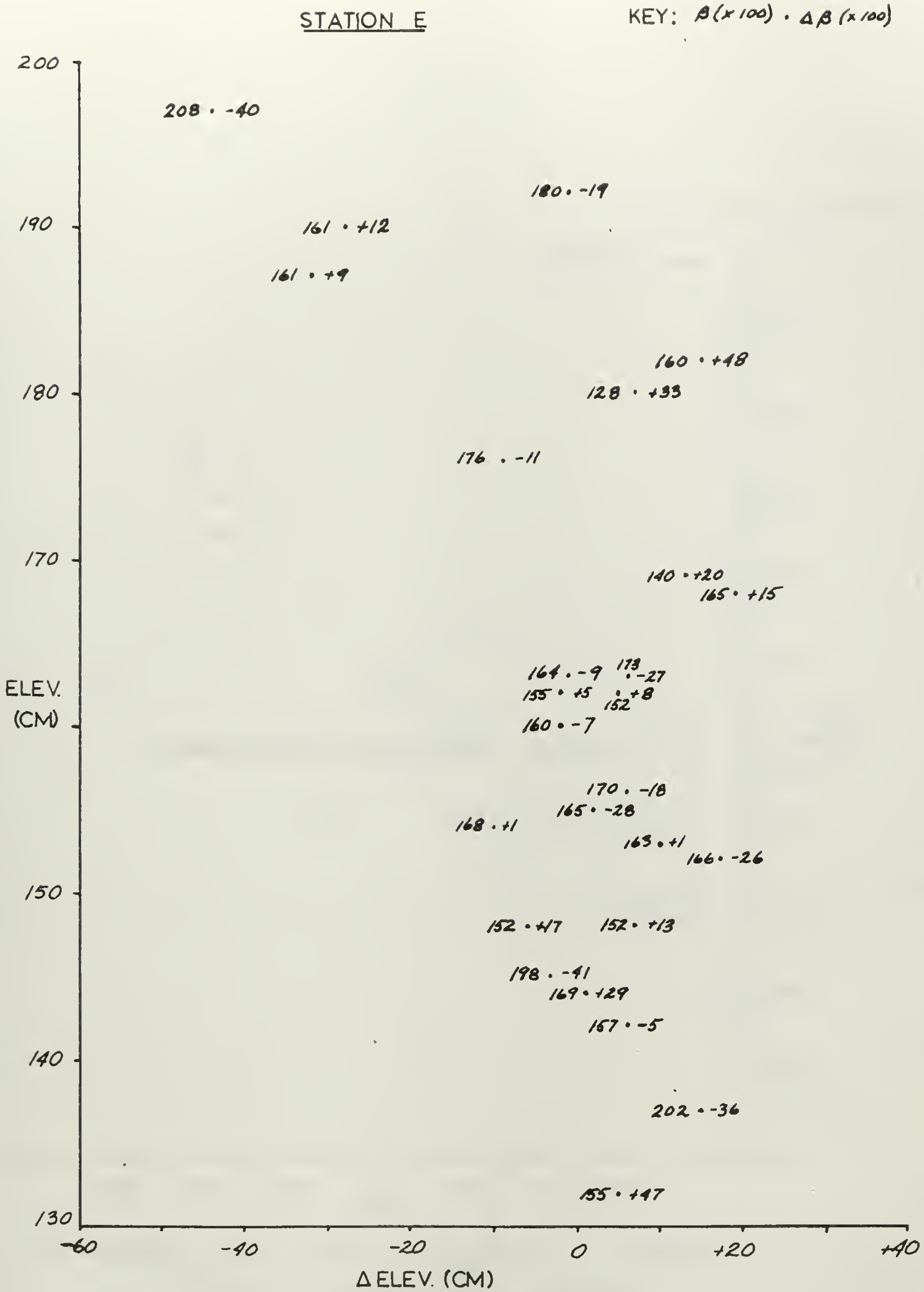


SKEWNESS (α_ϕ) VS. CHANGE IN SKEWNESS ($\Delta\alpha_\phi$)
(PLOTTED WITH WAVE STEEPNESS VALUES)
FIGURE 29

cumulative curves in Figure 13 and tabulated in Table 1.

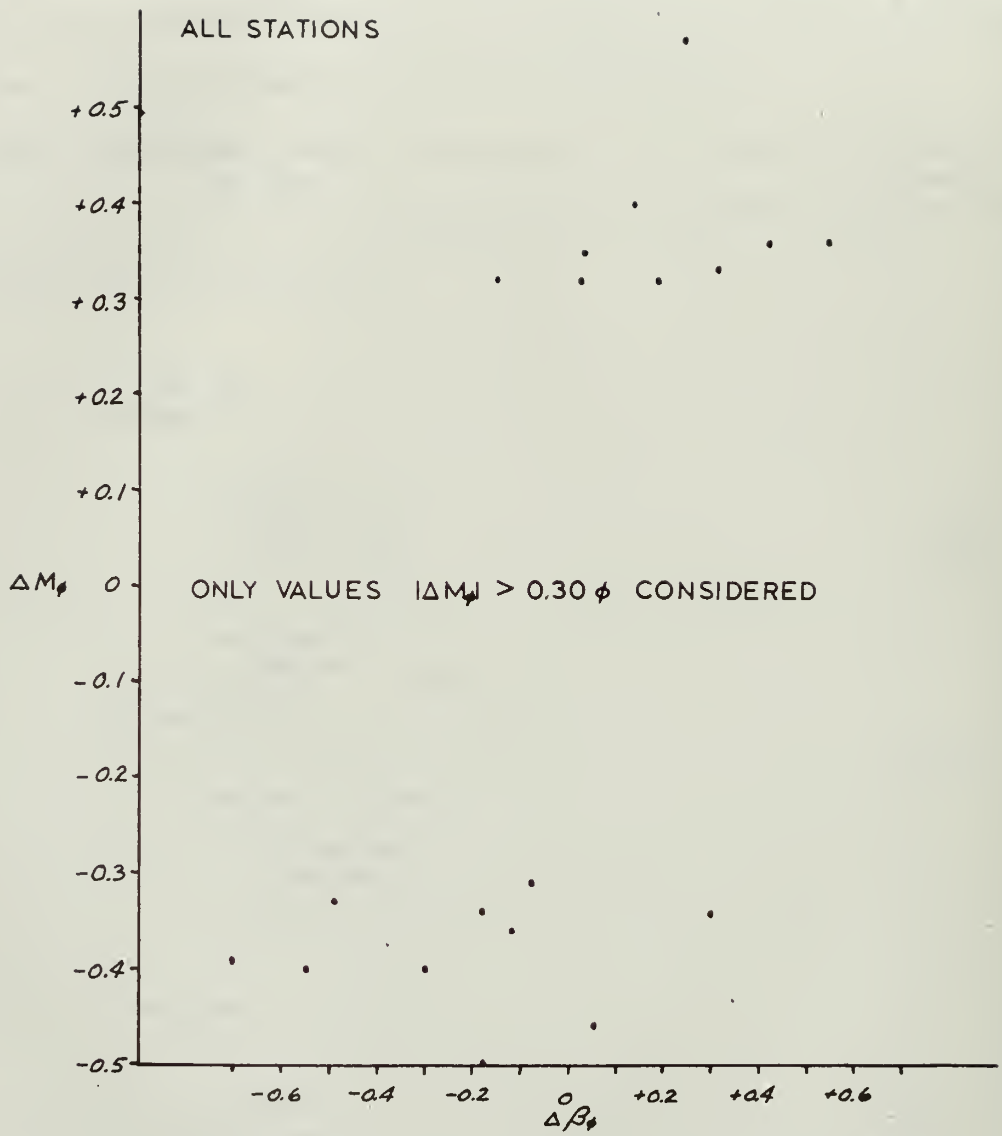
Kurtosis and change in kurtosis showed no relation to initial beach elevation and cut and fill. This graph is shown in Figure 30. A positive change in kurtosis seems to accompany a large decrease in grain size, as shown in Figure 31. Kurtosis also has an apparent equilibrium value at each sampling station, as is shown in Figure 32. No relationship was evident between kurtosis and wave steepness.

Other comparisons made which showed no relationships were mean size versus skewness, sorting versus skewness, skewness versus kurtosis, and mean size versus kurtosis.



KURTOSIS (β_ϕ) AND CHANGE IN KURTOSIS ($\Delta\beta_\phi$) AS FUNCTIONS OF BEACH ELEVATION AND CUT AND FILL

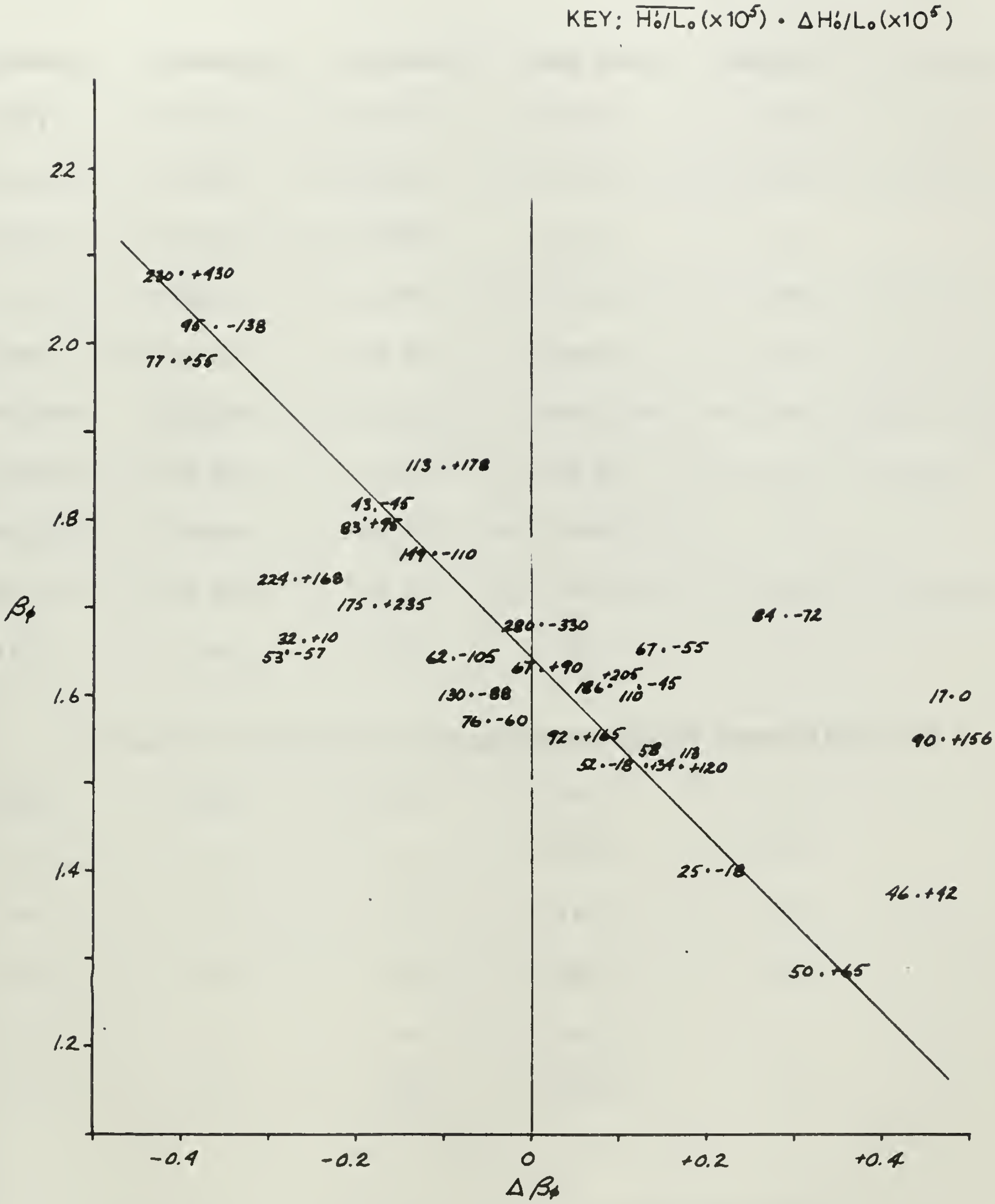
FIGURE 30



CHANGE IN MEAN GRAIN SIZE (ΔM_ϕ) VS. CHANGE IN KURTOSIS ($\Delta \beta_\phi$)

FIGURE 31

STATION E



KURTOSIS (β_ϕ) VS. CHANGE IN KURTOSIS ($\Delta\beta_\phi$)
(PLOTTED WAVE STEEPNESS ALSO SHOWN)

FIGURE 32

TABLE 1

Summary of Textural Parameters Along the Beach Profile

a. 50th Percentile Values Derived from Cumulative Curves in Figures 9, 11, 13, and 15.

STATION	MEAN SIZE	SORTING	SKEWNESS	KURTOSIS
A	1.67	0.37	-0.35	1.55
B	1.84	0.34	-0.24	1.70
C	1.85	0.34	-0.23	1.55
D	1.90	0.33	-0.23	1.65
E	1.97	0.32	-0.21	1.63
F	1.98	0.33	-0.20	1.62
G	2.01	0.33	-0.19	1.63
H	2.07	0.34	-0.18	1.64
I	1.99	0.34	-0.18	1.65
J	1.95	0.34	-0.17	1.61

b. Equilibrium Values from Figures 22, 23, 25, 29, and 32.

E	1.94	0.32	-0.19	1.64
F	1.98	*	*	*
G	1.97	*	*	*
H	2.04	*	*	*
I	1.98	*	*	*
J	1.96	*	*	*

* Not Calculated

7. Effects of Tides on the Beach

During the relatively short period of the observations no strong relationship was apparent between tidal cycles and beach cut and fill. From singular occurrences it appears that when beach cut occurred, the location of the maximum amount of cut was nearer the back of the beach during a period of spring tides (for example on February 4-5 and March 23-24) and further down the beach during neap tides (February 13-14). When fill occurred, the extent of fill across the profile was greater with spring tides (February 5-6).

Finally, during the period of March 17-20 when nearly vanishing tides occurred with very low waves, a large berm was built on the mid-foreshore. The beach was building at this time, and the greatest amount of deposition occurred at the level where the tide stood the longest. The berm was a result of this abnormal deposition.

No relationship was found between the tides and the beach texture.

8. Conclusions

Study of the daily changes in Del Monte Beach revealed that wave steepness exerts a strong influence on the beach profile. Cycles of cut and fill appear to be determined entirely by changes in wave steepness. The amount of cut or fill which will occur over a one-day period depends on the initial beach elevation and the average wave steepness over the period. Because the beach responds quickly to changing wave conditions, the profile will cut or fill in a diurnal tide cycle essentially to the equilibrium profile associated with the existing wave conditions. If the profile is at equilibrium and the wave steepness decreases, the beach will tend to fill until a new equilibrium is reached for the new wave steepness. If the wave steepness increases, the profile will tend to be cut to the new equilibrium profile. Knowing the initial beach elevation and the average wave steepness expected over a 25-hour period, the amount of cut or fill can be predicted.

Study of the textural changes in the sand samples taken from the beach surface revealed no simple relationship to changing wave conditions. A possible correlation was displayed between cut and fill and mean grain size, with finer textures associated with areas of beach fill and coarser textures with areas of cut. No similar relation is apparent for sorting, skewness, or kurtosis. An equilibrium value exists at every station for each of the textural parameters.

Apparently no relationship exists between the tides and the beach profile or the sand texture changes.

It is believed that the nature of the results obtained in this study may apply to any beach where the sand texture is nearly uniform. A longer period of daily observations extending over all seasons would probably be necessary to determine equilibrium profiles for those beaches which experience large seasonal changes.

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APPENDIX A

Beach elevations along the reference profile - cm. above MLLW

DATE	RAIL 1	2	3	4	5	6	7	8	9	10
2/1	400.0	373.9	316.4	294.6	279.6	224.9	201.2	179.1	157.9	128.9
2/2	400.0	373.7	316.8	296.8	272.0	219.1	195.4	173.4	150.3	122.0
2/3	400.0	373.7	317.3	298.3	274.4	216.0	193.5	171.9	152.1	125.7
2/4	400.0	373.7	317.3	298.3	275.7	221.5	199.2	179.1	160.2	133.0
2/5	400.0	373.7	327.9	288.6	252.8	186.1	161.5	142.7	126.1	102.7
2/6	400.0	373.7	331.9	295.7	260.2	194.1	168.2	146.9	126.2	100.1
2/7	400.0	373.7	331.9	295.5	248.7	205.2	177.5	158.9	132.4	106.3
2/8	400.0	373.7	331.9	295.4	273.4	214.8	188.8	164.2	131.5	112.5
2/9	400.0	373.7	332.6	305.7	278.2	211.0	182.8	159.2	136.8	109.7
2/10	400.0	373.7	332.0	306.2	278.4	220.5	173.6	172.5	152.0	124.4
2/11	400.0	373.7	332.0	306.2	278.4	223.7	208.6	192.0	169.3	138.2
2/12	400.0	373.7	332.0	306.2	278.4	225.6	214.9	201.1	181.9	152.8
2/13	400.0	373.7	332.0	306.2	278.4	225.6	215.4	204.5	197.4	167.2
2/14	400.0	373.7	332.0	306.9	285.4	233.2	207.9	178.7	153.8	123.2
2/15	400.0	373.7	332.3	307.1	285.1	228.7	196.3	169.6	143.9	113.5
2/16	400.0	373.7	332.3	307.1	285.1	223.5	199.1	171.6	145.3	111.8
2/17	400.0	373.7	332.3	307.1	285.4	237.5	206.1	173.4	142.1	106.6
2/18	400.0	373.7	332.3	307.1	285.9	241.0	204.2	175.5	148.2	117.0
2/19	400.0	373.7	332.3	307.4	288.5	238.4	205.4	180.7	155.0	122.2
2/20	400.0	373.7	332.3	307.4	288.8	247.2	213.4	185.0	157.2	124.6
2/21	NO RECORD									
2/22	400.0	373.7	331.5	311.6	295.9	232.1	202.9	176.6	153.2	123.1
2/23	400.0	373.7	331.5	311.6	296.9	224.2	199.2	181.7	163.0	138.2
2/24	400.0	373.7	333.0	315.1	267.4	216.5	196.4	178.2	162.0	138.0

DATE	11	12	13	14	15	16	17	18	19	20
2/1	120.3	102.7	88.1	73.7	61.4	51.0	40.8	31.5	-	-
2/2	114.8	99.2	85.2	73.6	62.5	53.3	44.3	35.4	28.0	-
2/3	119.8	113.9	89.5	77.9	65.4	55.6	45.5	37.4	29.3	-
2/4	126.9	112.3	98.8	87.7	77.8	69.8	63.2	56.9	48.7	36.9
2/5	98.9	86.0	74.1	63.3	52.4	45.2	35.0	26.1	13.6	-
2/6	95.8	81.3	58.6	57.1	46.3	37.3	28.0	19.7	12.9	5.8
2/7	98.3	82.6	69.1	58.1	48.6	41.5	34.8	29.0	22.8	13.3
2/8	104.7	89.2	75.3	63.8	54.9	47.9	40.2	32.5	25.3	15.2
2/9	105.7	91.1	79.5	70.1	61.4	53.3	44.9	35.5	29.0	19.4
2/10	119.0	92.7	87.3	73.7	62.4	52.8	42.5	33.8	24.8	13.0
2/11	127.7	109.6	92.5	78.6	64.8	55.2	44.4	34.2	23.6	-
2/12	141.9	123.7	106.8	92.1	75.2	61.3	44.1	31.3	20.5	-
2/13	148.4	126.7	108.8	88.9	71.5	-	-	-	-	-
2/14	-	-	-	-	-	-	-	-	-	-
2/15	103.3	82.3	57.6	34.4	-	-	-	-	-	-
2/16	103.7	82.9	65.3	41.9	24.7	-	-	-	-	-
2/17	97.7	81.7	64.3	54.3	43.9	42.3	-	-	-	-
2/18	108.3	94.7	82.8	71.3	61.2	51.3	41.2	30.9	-	-
2/19	113.2	86.3	83.1	68.6	54.7	43.8	33.8	23.5	15.3	-
2/20	116.1	99.1	83.5	70.7	58.7	51.0	43.5	37.5	31.8	24.0
2/21	NO RECORD									
2/22	116,7	100.9	87.1	75.3	63.4	52.2	41.7	31.7	22.2	13.4
2/23	132.9	115.7	101.8	87.9	73.8	60.9	48.7	38.5	28.9	17.8
2/24	133.9	118.7	103.3	89.4	74.6	62.4	51.5	41.0	29.3	18.2

Dash indicates position was inaccessible

DATE	1	2	3	4	5	6	7	8	9	10
2/25	400.0	373.7	332.5	288.6	271.1	218.7	197.3	178.7	160.1	132.0
2/26	400.0	373.7	332.5	294.4	276.0	223.0	198.9	179.1	158.4	128.9
2/27	400.0	373.7	332.5	294.4	275.9	223.1	204.2	187.9	170.4	139.9
2/28	400.0	373.7	332.5	294.4	275.9	223.7	212.7	204.7	176.4	139.4
3/1	400.0	373.7	332.5	294.4	275.9	230.3	216.4	202.4	180.1	148.6
3/2	400.0	373.7	332.5	294.4	275.9	235.2	225.9	214.2	187.3	151.7
3/3	400.0	373.7	332.5	297.3	277.4	218.1	194.5	175.1	155.7	130.5
3/4	400.0	373.7	332.5	297.3	277.6	228.2	205.9	183.4	161.8	129.0
3/5	400.0	373.7	332.5	297.3	277.8	230.5	210.4	190.7	166.4	133.4
3/6	400.0	373.7	332.5	297.3	277.8	232.0	215.9	195.6	169.6	135.1
3/7	400.0	373.7	332.5	297.3	277.8	232.6	222.6	205.2	175.2	138.1
3/8	400.0	373.7	332.5	297.3	277.8	236.6	228.7	210.0	176.9	143.3
3/9	400.0	373.7	332.5	297.3	277.8	236.7	230.9	216.7	178.6	140.9
3/10	400.0	373.7	332.5	297.3	277.8	231.4	222.5	190.4	148.4	132.8
3/11	400.0	373.7	332.5	297.3	277.8	241.4	229.6	209.8	184.4	149.4
3/12	400.0	373.7	332.5	297.3	277.8	241.4	231.0	218.2	198.7	163.0
3/13	400.0	373.7	332.5	297.3	277.8	241.4	231.0	218.2	206.8	175.1
3/14	400.0	373.7	332.5	297.3	277.8	241.4	231.0	218.2	210.0	184.0
3/15	400.0	373.7	332.5	297.3	277.8	241.4	231.0	218.2	210.5	185.8
3/16	400.0	373.7	332.5	297.3	277.8	241.4	231.0	218.2	210.9	196.5
3/17	400.0	373.7	332.5	297.3	277.8	241.4	231.0	218.9	211.9	200.2
3/18	400.0	373.7	332.5	297.3	277.8	241.4	231.0	218.7	212.4	203.6
3/19	400.0	373.7	332.5	297.3	277.8	241.4	231.0	220.2	213.9	200.2
3/20	400.0	373.7	332.5	297.3	277.8	241.4	231.0	220.2	212.9	200.2
3/21	400.0	373.7	332.5	297.3	277.8	241.4	231.0	220.2	213.9	204.7

DATE	11	12	13	14	15	16	17	18	19	20
2/25	126.5	109.6	95.2	82.6	70.6	59.3	44.3	30.5	18.8	4.5
2/26	123.4	107.7	93.2	78.9	64.7	54.7	43.0	33.6	24.8	11.5
2/27	128.4	106.0	89.2	76.5	64.9	55.2	45.0	35.2	25.2	12.5
2/28	125.7	104.4	87.8	75.2	64.4	55.8	47.2	36.9	27.3	11.0
3/1	138.2	118.9	101.1	84.7	68.8	56.3	44.6	33.0	21.8	9.5
3/2	139.6	116.8	97.6	80.5	65.0	53.3	41.7	29.4	19.2	6.5
3/3	125.2	108.9	94.7	83.2	71.8	61.3	48.0	38.0	28.5	17.0
3/4	120.7	104.2	90.3	77.7	65.9	56.3	46.7	37.5	29.0	18.8
3/5	121.3	102.9	86.8	72.5	60.4	51.3	42.0	35.1	26.3	18.1
3/6	124.6	105.8	87.3	73.4	61.9	52.4	42.6	34.7	28.8	20.0
3/7	125.7	103.7	84.3	67.9	52.9	47.8	42.5	36.4	30.8	23.0
3/8	131.8	112.0	93.4	76.9	63.1	53.5	43.8	37.5	31.1	22.5
3/9	128.9	109.9	93.5	78.5	65.2	54.3	44.3	35.2	26.8	17.0
3/10	132.8	110.7	91.3	76.4	64.1	55.2	46.5	39.1	32.3	21.5
3/11	137.0	116.1	98.0	83.2	68.2	55.8	43.1	-	-	-
3/12	148.4	124.7	104.8	88.4	72.4	59.4	46.5	36.2	-	-
3/13	156.0	129.8	106.4	87.9	71.3	58.4	44.5	32.5	-	-
3/14	164.0	130.9	108.0	89.2	73.8	61.7	47.9	36.2	-	-
3/15	175.6	131.2	104.8	83.9	66.5	53.5	43.0	33.8	-	-
3/16	177.8	140.6	110.6	83.8	60.2	42.6	35.2	33.3	-	-
3/17	192.1	148.1	116.5	87.7	61.4	41.3	30.4	28.1	25.3	-
3/18	193.9	153.7	120.4	92.4	66.8	44.9	28.3	32.0	28.8	-
3/19	184.0	153.9	125.6	104.5	80.8	63.1	50.1	39.4	29.5	17.9
3/20	192.4	167.9	126.5	95.5	72.9	56.6	50.0	41.0	30.1	18.5
3/21	196.5	160.7	127.3	100.9	80.5	65.1	51.8	40.6	31.6	20.1

DATE	1	2	3	4	5	6	7	8	9	10
3/22	400.0	373.7	332.5	297.3	277.8	241.4	231.0	220.2	213.9	207.2
3/23	400.0	373.7	332.5	297.3	277.8	241.4	231.0	223.2	222.4	209.2
3/24	400.0	373.7	332.5	299.4	281.9	236.1	211.7	193.9	176.1	148.5
3/25	400.0	373.7	332.5	299.4	284.0	248.1	217.7	193.8	167.8	136.8
3/26	400.0	373.7	332.5	299.4	284.0	242.3	232.3	214.7	186.1	148.5
3/27	400.0	373.7	332.5	299.4	284.0	242.3	235.1	218.9	197.1	166.6
3/28	400.0	373.7	332.5	299.4	284.0	244.7	235.6	222.2	191.6	161.7
3/29	400.0	373.7	332.5	299.4	284.0	246.3	235.9	213.4	190.4	160.4
3/30	400.0	373.7	332.3	301.1	289.3	224.7	201.7	179.7	162.9	135.0
3/31	400.0	373.7	332.3	301.1	283.3	233.4	208.8	189.5	168.2	139.4

DATE	11	12	13	14	15	16	17	18	19	20
3/22	199.1	154.9	122.0	94.9	72.7	57.3	48.3	42.4	34.6	23.5
3/23	187.9	163.4	129.0	102.2	78.2	63.9	51.8	41.7	33.4	23.4
3/24	141.7	124.9	109.2	94.9	82.7	71.5	60.5	50.3	39.6	25.2
3/25	126.7	107.8	91.5	78.2	65.2	52.9	41.7	31.5	22.3	12.5
3/26	134.9	113.6	96.6	82.9	68.9	57.2	34.9	31.9	18.8	4.5
3/27	155.0	141.8	110.8	94.9	80.3	65.3	50.0	32.7	16.7	-
3/28	155.4	133.1	111.4	89.4	70.5	55.3	40.8	-	-	-
3/29	151.3	132.9	111.5	92.7	75.2	61.8	47.3	34.4	23.8	10.0
3/30	126.9	108.4	91.8	76.9	62.9	52.3	42.0	31.9	24.0	13.7
3/31	132.8	111.4	93.2	79.1	66.4	56.1	45.5	32.3	20.2	-

APPENDIX B

PHI PERCENTILES AND TEXTURAL PARAMETERS OF THE BEACH SAND

The sample number indicates the day of the month, the month, and the sampling station (A-J), in that order. When waves did not reach the sampling station during the period since the previous sample was collected, values for that station are omitted. The locations of the sampling stations are shown in Figure 4.

Column headings are as follows:

ϕ_n, the phi grain size at percentile n

M_ϕ, the mean grain diameter

σ_ϕ, the sorting coefficient

α_ϕ, the skewness coefficient

β_ϕ, the kurtosis of the sample.

SAMPLE	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	M_ϕ	σ_ϕ	α_ϕ	β_ϕ
1-2-A	1.16	1.42	1.83	2.13	2.26	1.77	0.35	-0.17	1.57
1-2-B	1.38	1.58	1.91	2.20	2.29	1.89	0.31	-0.07	1.48
1-2-C	1.22	1.52	1.88	2.21	2.31	1.86	0.38	-0.05	1.34
1-2-D	1.33	1.53	1.88	2.18	2.26	1.85	0.33	-0.09	1.43
1-2-E	1.43	1.67	2.05	2.33	2.40	2.00	0.33	-0.16	1.48
1-2-F	1.43	1.68	2.11	2.36	2.53	2.02	0.34	-0.27	1.61
1-2-G	1.24	1.50	1.83	2.13	2.28	1.91	0.31	-0.27	1.66
1-2-H	1.12	1.35	1.77	2.10	2.33	1.73	0.38	-0.12	1.62
2-2-A	0.93	1.26	1.83	2.12	2.25	1.69	0.43	-0.33	1.54
2-2-B	1.33	1.58	1.98	2.23	2.33	1.90	0.37	-0.21	1.34
2-2-C	1.18	1.47	1.92	2.13	2.25	1.90	0.38	-0.05	1.41
2-2-D	1.31	1.57	1.94	2.22	2.37	1.89	0.33	-0.17	1.63
2-2-E	1.49	1.67	2.05	2.38	2.51	2.02	0.35	-0.08	1.45
2-2-F	1.36	1.59	1.98	2.28	2.42	1.93	0.35	-0.14	1.53
2-2-G	1.38	1.60	2.02	2.29	2.40	1.95	0.35	-0.22	1.48
2-2-H	1.20	1.50	1.93	2.24	2.38	1.87	0.37	-0.16	1.60
2-2-I	1.23	1.48	1.88	2.18	2.35	1.83	0.35	-0.14	1.61
3-2-B	1.01	1.37	1.83	2.15	2.28	1.76	0.39	-0.17	1.62
3-2-C	1.21	1.55	1.95	2.18	2.27	1.86	0.31	-0.28	1.70
3-2-D	1.13	1.54	1.94	2.20	2.32	1.87	0.33	-0.20	1.81
3-2-E	1.38	1.68	2.00	2.24	2.37	1.96	0.28	-0.16	1.77
3-2-F	1.38	1.70	2.06	2.29	2.44	1.99	0.29	-0.26	1.81
3-2-G	1.37	1.75	2.08	2.38	2.52	2.06	0.31	-0.05	1.84
3-2-H	1.37	1.73	2.08	2.32	2.55	2.02	0.30	-0.19	1.97
3-2-I	1.13	1.37	1.83	2.29	2.48	1.83	0.46	+0.01	1.47

SAMPLE	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	M_ϕ	σ_ϕ	α_ϕ	β_ϕ
4-2-C	1.33	1.53	1.89	2.11	2.21	1.82	0.29	-0.24	1.52
4-2-D	1.39	1.63	2.02	2.25	2.37	1.94	0.31	-0.26	1.57
4-2-E	1.52	1.79	2.29	2.46	2.57	2.13	0.34	-0.49	1.57
4-2-F	1.48	1.63	2.09	2.32	2.47	1.97	0.34	-0.34	1.45
4-2-G	1.41	1.68	2.12	2.38	2.65	2.02	0.35	-0.28	1.76
4-2-H	1.35	1.69	2.18	2.40	2.63	2.05	0.36	-0.37	1.80
4-2-I	1.31	1.65	2.14	2.38	2.55	2.02	0.37	-0.34	1.70
5-2-B	1.07	1.32	1.73	2.06	2.20	1.69	0.37	-0.11	1.53
5-2-C	1.34	1.62	1.99	2.24	2.37	1.93	0.31	-0.20	1.65
5-2-D	1.39	1.63	1.99	2.16	2.31	1.90	0.27	-0.36	1.74
5-2-E	1.34	1.53	1.92	2.11	2.21	1.82	0.29	-0.35	1.49
5-2-F	1.14	1.45	1.87	2.19	2.33	1.82	0.37	-0.14	1.61
5-2-G	1.22	1.49	1.91	2.15	2.28	1.82	0.33	-0.27	1.61
5-2-H	1.16	1.14	1.82	2.11	2.23	1.63	0.49	-0.40	1.10
6-2-B	1.04	1.24	1.67	1.91	2.04	1.58	0.34	-0.28	1.49
6-2-C	1.12	1.27	1.63	2.00	2.23	1.64	0.37	+0.03	1.52
6-2-D	1.31	1.60	1.92	2.18	2.28	1.89	0.29	-0.10	1.65
6-2-E	1.36	1.64	1.97	2.22	2.30	1.93	0.29	-0.07	1.61
6-2-F	1.16	1.48	1.77	2.13	2.27	1.81	0.33	+0.12	1.55
6-2-G	1.29	1.47	1.89	2.15	2.33	1.81	0.34	-0.22	1.53
6-2-H	1.38	1.66	2.07	2.33	2.48	1.99	0.34	-0.25	1.64
6-2-I	1.53	1.78	2.14	2.40	2.57	2.09	0.31	-0.17	1.69
6-2-J	1.17	1.41	1.93	2.18	2.37	1.79	0.38	-0.17	1.57

SAMPLE	ϕ_5	ϕ_{16}	ϕ[illegible]	[illegible]		M_ϕ	σ_ϕ	α_ϕ	β_ϕ
7-2-C	1.17	1.43	1.79	2.08	2.20	1.76	0.33	-0.11	1.59
7-2-D	1.34	1.68	1.98	2.27	2.38	1.97	0.30	-0.02	1.74
7-2-E	1.38	1.78	2.09	2.37	2.51	2.07	0.30	-0.04	2.27
7-2-F	1.40	1.67	1.97	2.25	2.43	1.96	0.29	-0.04	1.77
7-2-G	1.45	1.63	2.03	2.30	2.44	1.96	0.34	-0.20	1.47
7-2-H	1.32	1.57	1.93	2.23	2.37	1.90	0.33	-0.10	1.60
7-2-I	1.39	1.57	1.99	2.25	2.40	1.91	0.34	-0.24	1.49
7-2-J	1.45	1.66	2.03	2.26	2.41	1.96	0.30	-0.24	1.59
8-2-C	1.26	1.58	1.98	2.20	2.27	1.89	0.31	-0.29	1.62
8-2-D	1.48	1.69	2.10	2.32	2.45	2.01	0.32	-0.30	1.55
8-2-E	1.46	1.68	2.07	2.28	2.42	1.98	0.30	-0.30	1.55
8-2-F	1.38	1.65	2.14	2.38	2.51	2.02	0.36	-0.34	1.55
8-2-G	1.35	1.58	2.00	2.35	2.53	1.96	0.39	-0.10	1.52
8-2-H	1.42	1.69	2.10	2.38	2.53	2.04	0.35	-0.19	1.60
8-2-I	1.59	1.83	2.23	2.49	2.64	2.16	0.33	-0.22	1.58
8-2-J	1.25	1.52	1.95	2.24	2.39	1.88	0.36	-0.18	1.58
9-2-B	1.13	1.37	1.79	2.06	2.18	1.72	0.35	-0.22	1.52
9-2-C	1.32	1.43	1.88	2.10	2.19	1.77	0.34	-0.34	1.15
9-2-D	1.21	1.41	1.88	2.13	2.22	1.77	0.36	-0.16	1.41
9-2-E	1.26	1.42	1.86	2.10	2.24	1.76	0.34	-0.29	2.02
9-2-F	1.36	1.68	2.05	2.27	2.39	1.98	0.30	-0.25	1.75
9-2-G	1.43	1.68	2.07	2.29	2.46	1.99	0.31	-0.26	1.70
9-2-H	1.47	1.75	2.13	2.35	2.48	2.05	0.30	-0.45	1.67
9-2-I	1.33	1.57	2.02	2.30	2.43	1.94	0.37	-0.23	1.51
9-2-J	1.00	1.33	1.83	2.19	2.31	1.76	0.43	-0.17	1.51

SAMPLE	ϕ_{5}	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	M_z	σ_1		
10-2-B	1.12	1.36	1.82	2.08	2.20	1.72	0.36	-0.26	1.53
10-2-C	1.30	1.51	1.88	2.14	2.27	1.83	0.32	-0.17	1.54
10-2-D	1.16	1.40	1.83	2.15	2.29	1.78	0.38	-0.13	1.51
10-2-E	1.37	1.66	2.05	2.30	2.43	1.88	0.32	-0.53	1.66
10-2-F	1.53	1.73	2.08	2.32	2.44	2.03	0.30	-0.19	1.55
10-2-G	1.46	1.76	2.09	2.40	2.52	2.08	0.32	-0.03	1.66
10-2-H	1.52	1.82	2.18	2.43	2.55	2.12	0.30	-0.17	1.70
10-2-I	1.47	1.76	2.13	2.40	2.53	2.08	0.32	-0.14	1.65
10-2-J	1.35	1.72	2.15	2.43	2.55	2.08	0.35	-0.22	1.70
11-2-C	1.26	1.45	1.80	2.05	2.18	1.75	0.30	-0.17	1.53
11-2-D	1.44	1.70	2.06	2.37	2.35	2.04	0.34	-0.08	1.37
11-2-E	1.42	1.64	2.05	2.36	2.42	2.00	0.36	-0.15	1.40
11-2-F	1.52	1.77	2.15	2.42	2.53	2.10	0.33	-0.17	1.56
11-2-G	1.50	1.82	2.25	2.50	2.61	2.16	0.34	-0.27	1.63
11-2-H	1.66	1.96	2.28	2.53	2.64	2.24	0.28	-0.13	1.50
11-2-I	1.71	2.00	2.32	2.54	2.67	2.27	0.27	-0.19	1.77
12-2-C	1.18	1.42	1.83	2.19	2.41	1.81	0.39	-0.05	1.60
12-2-D	1.08	1.61	2.03	2.31	2.47	1.96	0.35	-0.20	1.99
12-2-E	1.37	1.66	2.08	2.38	2.52	2.02	0.36	-0.17	1.60
12-2-F	1.70	1.97	2.28	2.49	2.58	2.23	0.26	-0.19	1.68
12-2-G	1.44	1.73	2.12	2.30	2.40	2.02	0.29	-0.37	1.69
12-2-H	1.23	1.72	2.14	2.38	2.52	2.05	0.33	-0.29	1.96
12-2-I	1.38	1.75	2.16	2.39	2.53	2.07	0.32	-0.28	1.80

SAMPLE	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	M_ϕ	σ_ϕ	α_ϕ	β_ϕ
13-2-D	0.99	1.34	1.90	2.17	2.31	1.76	0.42	-0.35	1.59
13-2-E	1.48	1.85	2.20	2.36	2.53	2.10	0.25	-0.38	2.08
13-2-F	1.58	1.91	2.25	2.51	2.62	2.21	0.30	-0.15	1.73
13-2-G	1.71	2.01	2.32	2.53	2.65	2.27	0.26	-0.19	1.85
14-2-B	1.13	1.38	1.79	2.15	2.25	1.77	0.39	-0.07	1.46
14-2-C	1.13	1.42	1.82	2.15	2.25	1.79	0.37	-0.10	1.54
14-2-D	1.13	1.42	1.82	2.15	2.25	1.79	0.37	-0.10	1.54
14-2-E	1.17	1.53	1.94	2.17	2.25	1.85	0.32	-0.29	1.68
15.2-B	1.28	1.58	1.97	2.19	2.27	1.88	0.31	-0.27	1.60
15-2-C	1.23	1.44	1.82	2.09	2.20	1.76	0.33	-0.17	1.48
15-2-D	1.25	1.53	1.87	2.14	2.22	1.83	0.31	-0.12	1.58
15-2-E	1.56	1.81	2.10	2.32	2.42	2.06	0.26	-0.16	1.69
15-2-F	1.49	1.68	2.03	2.22	2.28	1.95	0.27	-0.28	1.46
15-2-G	1.33	1.60	1.94	2.19	2.31	1.90	0.30	-0.15	1.65
16-2-D	1.48	1.77	2.15	2.52	2.55	2.15	0.38	-0.01	1.43
16-2-E	1.71	1.96	2.30	2.43	2.64	2.20	0.24	-0.45	1.98
16-2-F	1.60	1.81	2.18	2.43	2.54	2.12	0.31	-0.20	1.53
16-2-G	1.38	1.68	2.07	2.29	2.39	1.98	0.30	-0.27	1.68
17-2-C	1.30	1.58	1.87	2.20	2.26	1.89	0.31	+0.06	1.56
17-2-D	1.26	1.47	1.88	2.13	2.25	1.80	0.33	-0.24	1.50
17-2-E	1.41	1.67	2.04	2.28	2.40	1.97	0.30	-0.20	1.57
17-2-F	1.12	1.31	1.68	2.01	2.23	1.66	0.35	-0.06	1.58
17-2-G	1.40	1.61	1.99	2.23	2.37	1.92	0.31	-0.22	1.58
17-2-H	0.78	1.23	1.84	2.18	2.33	1.70	0.47	-0.28	1.64

SAMPLE	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	M_ϕ	σ_ϕ	α_ϕ	β_ϕ
18-2-C	1.22	1.52	1.91	2.16	2.31	1.84	0.32	-0.20	1.70
18-2-D	1.45	1.70	1.97	2.25	2.42	1.97	0.28	+0.01	1.74
18-2-E	1.39	1.59	1.97	2.29	2.45	1.94	0.35	-0.09	1.52
18-2-F	1.41	1.60	2.00	2.25	2.38	1.92	0.33	-0.24	1.48
18-2-G	1.36	1.64	2.01	2.29	2.44	1.96	0.33	-0.13	1.64
18-2-H	1.13	1.39	1.84	2.13	2.38	1.76	0.37	-0.22	1.69
19-2-C	1.18	1.38	1.77	2.02	2.18	1.70	0.32	-0.22	1.56
19-2-D	1.53	1.73	2.03	2.31	2.49	2.02	0.29	-0.02	1.66
19-2-E	1.41	1.69	2.03	2.34	2.48	2.01	0.33	-0.05	1.65
19-2-F	1.61	1.83	2.08	2.39	2.48	2.11	0.28	-0.10	1.54
19-2-G	1.62	1.78	2.09	2.34	2.48	2.06	0.28	-0.09	1.54
19-2-H	1.48	1.79	2.10	2.37	2.46	2.08	0.29	-0.06	1.71
19-2-I	1.42	1.63	1.95	2.22	2.38	1.93	0.30	-0.09	1.62
20-2-C	1.43	1.68	1.98	2.22	2.34	1.95	0.27	-0.11	1.67
20-2-D	1.37	1.69	2.05	2.31	2.43	2.00	0.36	-0.14	1.49
20-2-E	1.49	1.78	2.15	2.40	2.48	2.09	0.36	-0.17	1.37
20-2-F	1.54	1.77	2.10	2.37	2.50	2.07	0.30	-0.10	1.60
20-2-G	1.61	1.88	2.28	2.56	2.73	2.22	0.39	-0.15	1.63
20-2-H	1.73	1.95	2.29	2.55	2.70	2.25	0.30	-0.12	1.62
20-2-I	1.48	1.86	2.23	2.48	2.62	2.17	0.31	-0.19	1.84
20-2-J	1.55	1.84	2.28	2.59	2.75	2.21	0.38	-0.18	1.61

SAMPLE	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	N		α	β
21-2-B	0.98	1.23	1.71	1.99	2.15	1.61	0.39	-0.23	1.40
21-2-C	1.28	1.56	1.92	2.12	2.23	1.84	0.28	-0.28	1.70
21-2-D	1.43	1.66	1.99	2.23	2.38	1.94	0.29	-0.17	1.65
21-2-E	1.43	1.69	2.01	2.25	2.45	1.97	0.28	-0.11	1.81
21-2-F	1.58	1.74	2.07	2.32	2.44	2.03	0.28	-0.12	1.55
21-2-G	1.60	1.83	2.17	2.39	2.48	2.11	0.28	-0.21	1.57
21-2-H	1.58	1.83	2.14	2.39	2.52	2.11	0.28	-0.11	1.68
21-2-I	1.23	1.58	1.98	2.24	2.39	1.91	0.33	-0.21	1.76
22-2-B	1.00	1.21	1.73	2.01	2.14	1.61	0.40	-0.33	1.42
22-2-C	1.23	1.44	1.81	2.05	2.17	1.75	0.31	-0.19	1.51
22-2-D	1.30	1.50	1.84	2.13	2.30	1.82	0.32	-0.06	1.56
22-2-E	1.30	1.56	1.92	2.18	2.33	1.87	0.31	-0.16	1.63
22-2-F	1.54	1.79	2.07	2.33	2.48	2.06	0.27	-0.04	1.74
22-2-G	1.37	1.65	2.07	2.37	2.54	2.01	0.36	-0.17	1.63
22-2-H	1.42	1.70	2.10	2.38	2.55	2.04	0.34	-0.18	1.66
22-2-I	1.53	1.75	2.07	2.33	2.48	2.04	0.29	-0.11	1.64
22-2-J	1.61	1.84	2.19	2.45	2.58	2.15	0.32	-0.13	1.52
23-2-C	1.25	1.58	2.02	2.18	2.28	1.88	0.30	-0.47	1.72
23-2-D	1.31	1.63	1.99	2.23	2.38	1.93	0.30	-0.20	1.78
23-2-E	1.35	1.65	2.05	2.32	2.47	1.99	0.34	-0.18	1.64
23-2-F	1.48	1.76	2.09	2.36	2.56	2.06	0.30	-0.10	1.80
23-2-G	1.58	1.82	2.14	2.37	2.53	2.10	0.28	-0.14	1.69
23-2-H	1.41	1.73	2.09	2.36	2.56	2.05	0.32	-0.13	1.79
23-2-I	1.58	1.83	2.15	2.40	2.59	2.12	0.29	-0.10	1.74
23-2-J	1.71	1.95	2.24	2.49	2.65	2.22	0.27	-0.07	1.74

SAMPLE	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	M_ϕ	σ_ϕ	α_ϕ	β_ϕ
24-2-C	1.18	1.48	1.87	2.17	2.30	1.83	0.35	-0.11	1.60
24-2-D	1.20	1.60	1.97	2.27	2.41	1.94	0.34	-0.09	1.78
24-2-E	1.42	1.69	2.10	2.40	2.54	2.05	0.36	-0.14	1.55
24-2-F	1.51	1.68	2.05	2.32	2.47	2.00	0.32	-0.16	1.50
24-2-G	1.65	1.87	2.23	2.50	2.65	2.19	0.32	-0.16	1.56
24-2-H	1.63	1.83	2.16	2.42	2.58	2.13	0.30	-0.10	1.58
24-2-I	1.62	1.82	2.20	2.51	2.67	2.17	0.35	-0.09	1.52
24-2-J	1.74	1.98	2.33	2.56	2.70	2.27	0.29	-0.21	1.65
25-2-B	1.12	1.45	1.86	2.15	2.26	1.80	0.35	-0.17	1.63
25-2-C	1.20	1.51	1.88	2.17	2.27	1.84	0.28	-0.14	1.91
25-2-D	1.29	1.49	1.87	2.12	2.30	1.82	0.32	-0.16	1.60
25-2-E	1.42	1.66	2.06	2.31	2.44	1.98	0.33	-0.24	1.57
25-2-F	1.39	1.62	1.97	2.22	2.37	1.92	0.30	-0.17	1.63
25-2-G	1.38	1.78	2.19	2.44	2.55	2.11	0.33	-0.24	1.77
25-2-H	1.65	1.86	2.17	2.42	2.53	2.14	0.28	-0.11	1.57
25-2-I	1.55	1.83	2.22	2.37	2.45	2.10	0.27	-0.44	1.67
26-2-B	1.16	1.47	1.89	2.13	2.22	1.80	0.33	-0.27	1.61
26-2-C	1.09	1.41	1.83	2.09	2.24	1.75	0.34	-0.24	1.69
26-2-D	1.29	1.55	1.95	2.15	2.27	1.85	0.30	-0.33	1.63
26-2-E	1.33	1.53	1.95	2.17	2.31	1.85	0.32	-0.31	1.53
26-2-F	1.40	1.66	2.00	2.20	2.31	1.93	0.27	-0.26	1.68
26-2-G	1.60	1.88	2.21	2.44	2.56	2.16	0.28	-0.18	1.71
26-2-H	1.36	1.67	2.05	2.30	2.44	1.99	0.32	-0.19	1.71
26-2-I	1.38	1.68	2.06	2.33	2.51	2.01	0.33	-0.15	1.74
26-2-J	1.39	1.75	2.06	2.27	2.38	2.01	0.26	-0.19	1.90

SAMPLE	ϕ_5	[illegible]	ϕ_{50}	ϕ_{84}	ϕ_{95}	M_ϕ	σ_ϕ	α_ϕ	[illegible]
27-2-D	1.37	1.55	1.97	2.22	2.31	1.89	0.34	-0.24	1.40
27-2-E	1.38	1.58	2.02	2.24	2.33	1.91	0.33	-0.33	1.44
27-2-F	1.26	1.43	1.87	2.13	2.25	1.78	0.35	-0.26	1.41
27-2-G	1.20	1.38	1.83	2.13	2.26	1.76	0.38	-0.18	1.41
27-2-H	1.21	1.32	1.78	2.14	2.28	1.73	0.41	-0.12	1.30
27-2-I	1.25	1.33	1.73	2.00	2.17	1.67	0.34	-0.18	1.19
27-2-J	1.34	1.41	1.83	2.08	2.19	1.75	0.34	-0.24	1.10
28-2-D	1.26	1.53	1.97	2.16	2.32	1.85	0.32	-0.37	1.68
28-2-E	1.12	1.52	1.90	2.27	2.41	1.90	0.38	0.00	1.63
28-2-F	1.16	1.48	1.90	2.23	2.39	1.86	0.38	-0.11	1.64
28-2-G	0.92	1.30	1.78	2.12	2.28	1.71	0.41	-0.17	1.66
28-2-H	1.24	1.51	1.96	2.22	2.37	1.87	0.36	-0.25	1.59
28-2-I	1.59	1.78	2.07	2.27	2.38	2.03	0.25	-0.16	1.61
28-2-J	1.17	1.43	1.90	2.13	2.24	1.78	0.35	-0.17	1.53
1-3-C	1.09	1.50	1.92	2.23	2.38	1.87	0.37	-0.16	1.77
1-3-D	1.28	1.57	1.95	2.18	2.26	1.88	0.32	-0.22	1.61
1-3-E	1.37	1.66	2.07	2.32	2.47	1.99	0.34	-0.24	1.28
1-3-F	1.48	1.72	2.12	2.32	2.42	2.02	0.35	-0.29	1.34
1-3-G	1.37	1.54	1.96	2.29	2.48	1.92	0.38	-0.11	1.48
1-3-H	1.45	1.69	2.10	2.43	2.63	2.06	0.37	-0.11	1.59
1-3-I	1.35	1.57	2.00	2.27	2.42	1.92	0.35	-0.23	1.53
1-3-J	1.33	1.50	1.92	2.19	2.32	1.85	0.35	-0.20	1.44

SAMPLE	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	M_ϕ	σ_ϕ	α_ϕ	β_ϕ
2-3-C	0.92	1.25	1.78	2.09	2.25	1.67	0.42	-0.26	1.58
2-3-D	1.13	1.37	1.87	2.13	2.23	1.75	0.38	-0.32	1.45
2-3-E	1.37	1.63	2.03	2.26	2.40	1.95	0.32	-0.25	1.61
2-3-F	1.35	1.58	2.02	2.25	2.40	1.92	0.34	-0.29	1.57
2-3-G	1.36	1.69	2.11	2.33	2.44	2.01	0.32	-0.31	1.69
2-3-H	1.40	1.67	2.07	2.42	2.56	2.05	0.38	-0.05	1.48
2-3-I	1.45	1.74	2.15	2.44	2.56	2.09	0.35	-0.17	1.58
2-3-J	1.37	1.67	2.09	2.39	2.51	2.03	0.36	-0.17	1.58
3-3-B	1.18	1.56	1.97	2.20	2.28	1.88	0.32	-0.28	1.72
3-3-C	1.35	1.61	2.00	2.23	2.32	1.92	0.31	-0.26	1.56
3-3-D	1.33	1.52	1.88	2.09	2.18	1.80	0.28	-0.31	1.55
3-3-E	1.36	1.67	2.04	2.27	2.36	1.99	0.30	-0.17	1.70
3-3-F	1.38	1.67	2.03	2.24	2.37	1.99	0.29	-0.14	1.74
3-3-G	1.48	1.72	2.06	2.29	2.41	2.01	0.29	-0.17	1.63
3-3-H	1.39	1.68	2.08	2.31	2.45	2.00	0.32	-0.25	1.68
4-3-C	1.31	1.51	1.93	2.17	2.24	1.84	0.33	-0.27	1.41
4-3-D	1.35	1.53	1.93	2.15	2.24	1.84	0.31	-0.29	1.44
4-3-E	1.41	1.58	2.02	2.20	2.28	1.89	0.31	-0.42	1.40
4-3-F	1.38	1.60	1.93	2.26	2.38	1.93	0.33	0.00	1.52
4-3-G	1.48	1.75	2.10	2.34	2.45	2.05	0.30	-0.17	1.62
4-3-H	1.36	1.72	2.10	2.37	2.49	2.05	0.33	-0.15	1.71
4-3-I	1.43	1.78	2.14	2.38	2.48	2.08	0.30	-0.20	1.75
4-3-J	1.40	1.67	2.04	2.28	2.42	1.98	0.31	-0.19	1.84

SAMPLE	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	M_ϕ	σ_ϕ	α_ϕ	β_ϕ
5-3-C	1.25	1.51	1.82	2.15	2.25	1.83	0.32	+0.03	1.56
5-3-D	1.35	1.53	1.82	2.13	2.28	1.83	0.30	+0.03	1.55
5-3-E	1.47	1.68	2.02	2.25	2.38	1.97	0.29	-0.17	1.60
5-3-F	1.45	1.72	2.08	2.36	2.48	2.04	0.32	-0.13	1.61
5-3-G	1.38	1.64	1.99	2.25	2.41	1.95	0.31	-0.13	1.69
5-3-H	1.37	1.60	1.97	2.25	2.38	1.93	0.33	-0.12	1.53
5-3-I	1.34	1.60	1.97	2.25	2.38	1.93	0.33	-0.12	1.57
5-3-J	1.47	1.67	2.03	2.29	2.47	1.98	0.31	-0.16	1.64
6-3-C	1.25	1.48	1.92	2.18	2.31	1.83	0.35	-0.28	1.52
6-3-D	1.35	1.58	1.95	2.12	2.26	1.85	0.35	-0.29	1.30
6-3-E	1.33	1.51	1.89	2.18	2.33	1.85	0.34	-0.12	1.49
6-3-F	1.33	1.57	1.98	2.24	2.38	1.91	0.34	-0.21	1.57
6-3-G	1.31	1.60	2.00	2.31	2.48	1.96	0.36	-0.11	1.62
6-3-H	1.40	1.68	2.08	2.33	2.50	2.01	0.33	-0.21	1.67
6-3-I	1.07	1.35	1.89	2.26	2.43	1.81	0.46	-0.15	1.49
6-3-J	1.21	1.48	1.94	2.27	2.43	1.88	0.40	-0.15	1.54
7-3-D	1.27	1.58	1.99	2.23	2.32	1.91	0.33	-0.24	1.61
7-3-E	1.28	1.58	1.97	2.29	2.46	1.94	0.36	-0.08	1.64
7-3-F	1.41	1.67	2.06	2.31	2.47	1.99	0.32	-0.22	1.66
7-3-G	1.36	1.63	2.10	2.39	2.55	2.01	0.38	-0.24	1.57
7-3-H	1.44	1.73	2.12	2.37	2.53	2.00	0.32	-0.37	1.70
7-3-I	1.32	1.64	2.08	2.35	2.50	2.00	0.36	-0.22	1.65
7-3-J	1.14	1.60	1.98	2.27	2.42	1.94	0.34	-0.12	1.88

SAMPLE	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	M_ϕ	σ_ϕ	α_ϕ	β_ϕ
8-3-D	1.37	1.63	2.01	2.24	2.37	1.94	0.32	-0.22	1.64
8-3-E	1.47	1.71	2.10	2.33	2.46	2.02	0.31	-0.26	1.60
8-3-F	1.43	1.77	2.15	2.40	2.52	2.09	0.32	-0.19	1.70
8-3-G	1.57	1.82	2.19	2.47	2.62	2.15	0.33	-0.12	1.59
8-3-H	1.27	1.52	1.96	2.29	2.53	1.91	0.38	-0.13	1.68
9-3-D	1.32	1.53	1.88	2.15	2.23	1.84	0.31	-0.13	1.47
9-3-E	1.17	1.42	1.82	2.13	2.28	1.78	0.36	-0.11	1.54
9-3-F	1.31	1.57	2.03	2.30	2.45	1.94	0.37	-0.24	1.56
9-3-G	1.53	1.75	2.08	2.35	2.48	2.05	0.30	-0.10	1.58
9-3-H	1.48	1.70	2.07	2.29	2.47	2.00	0.30	-0.23	1.65
9-3-I	1.40	1.59	2.00	2.27	2.42	1.94	0.34	-0.18	1.50
9-3-J	1.36	1.58	1.95	2.20	2.33	1.89	0.31	-0.19	1.57
10-3-D	1.39	1.65	2.01	2.26	2.38	1.96	0.31	-0.16	1.60
10-3-E	1.47	1.67	2.05	2.32	2.46	2.00	0.33	-0.15	1.52
10-3-F	1.55	1.84	2.23	2.55	2.75	2.20	0.36	-0.08	1.67
10-3-G	1.39	1.61	2.01	2.29	2.49	1.95	0.34	-0.18	1.62
10-3-H	1.45	1.70	2.08	2.34	2.51	2.02	0.32	-0.19	1.65
10-3-I	1.27	1.56	1.95	2.27	2.48	1.92	0.36	-0.08	1.68
10-3-J	1.39	1.64	2.02	2.26	2.38	1.95	0.31	-0.23	1.60

SAMPLE	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	M_ϕ	σ_ϕ	α_ϕ	β_ϕ
11-3-C	1.35	1.62	2.00	2.22	2.29	1.92	0.30	-0.27	1.57
11-3-D	1.33	1.65	2.04	2.27	2.40	1.96	0.31	-0.26	1.73
11-3-E	1.39	1.66	2.02	2.24	2.37	1.95	0.29	-0.24	1.69
11-3-F	1.44	1.67	2.07	2.28	2.40	1.98	0.31	-0.29	1.55
11-3-G	1.32	1.55	1.97	2.21	2.35	1.88	0.33	-0.27	1.57
11-3-H	0.81	1.04	1.48	1.80	1.93	1.42	0.38	-0.16	1.47
11-3-I	0.98	1.27	1.67	1.90	1.98	1.59	0.32	-0.25	1.56
12-3-D	1.30	1.60	1.99	2.21	2.29	1.92	0.31	-0.23	1.60
12-3-E	1.42	1.64	2.02	2.23	2.34	1.94	0.30	-0.20	1.53
12-3-F	1.46	1.70	2.05	2.26	2.38	1.98	0.28	-0.25	1.64
12-3-G	1.57	1.84	2.17	2.42	2.55	2.13	0.29	-0.14	1.69
12-3-H	1.33	1.65	2.03	2.32	2.49	1.99	0.34	-0.12	1.71
12-3-I	1.45	1.68	2.06	2.30	2.44	1.99	0.31	-0.23	1.60
13-3-E	1.18	1.42	1.80	2.02	2.15	1.72	0.30	-0.27	1.62
13-3-F	1.37	1.58	1.97	2.24	2.34	1.91	0.38	-0.16	1.28
13-3-G	1.46	1.63	2.03	2.32	2.48	1.98	0.35	-0.14	1.48
13-3-H	1.34	1.66	2.05	2.34	2.47	2.00	0.34	-0.14	1.66
14-3-E	1.31	1.59	1.96	2.20	2.27	1.90	0.30	-0.20	1.63
14-3-F	1.35	1.62	2.05	2.28	2.41	1.95	0.35	-0.29	1.51
14-3-G	1.46	1.74	2.12	2.38	2.55	2.06	0.32	-0.19	1.70
14-3-H	1.51	1.73	2.10	2.37	2.50	2.05	0.32	-0.16	1.55
14-3-I	1.30	1.53	1.95	2.25	2.38	1.89	0.36	-0.17	1.50

SAMPLE	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	M_ϕ	σ_ϕ	α_ϕ	β_ϕ
15-3-E	1.27	1.62	2.00	2.25	2.38	1.94	0.32	-0.19	1.73
15-3-F	1.47	1.76	2.08	2.32	2.46	2.04	0.28	-0.14	1.77
15-3-G	1.38	1.77	2.13	2.46	2.63	2.12	0.35	-0.03	1.79
15-3-H	0.93	1.37	1.90	2.32	2.55	1.85	0.48	-0.10	1.45
15-3-I	1.08	1.34	1.73	2.03	2.20	1.69	0.35	-0.11	1.62
16-3-E	0.78	1.18	1.79	2.18	2.33	1.68	0.50	-0.22	1.55
16-3-F	1.22	1.55	1.97	2.26	2.42	1.91	0.36	-0.17	1.69
16-3-G	1.33	1.63	2.02	2.32	2.48	1.98	0.35	-0.11	1.67
16-3-H	1.24	1.44	1.94	2.28	2.48	1.86	0.42	-0.19	1.48
16-3-I	1.07	1.51	2.01	2.30	2.47	1.91	0.40	-0.25	1.77
17-3-E	1.09	1.26	1.76	2.04	2.20	1.65	0.39	-0.28	1.42
17-3-F	1.37	1.63	2.04	2.28	2.42	1.96	0.33	-0.24	1.62
17-3-G	1.38	1.62	2.01	2.28	2.44	1.95	0.33	-0.18	1.61
17-3-H	1.24	1.68	2.07	2.37	2.58	2.03	0.35	-0.11	1.94
17-3-I	0.97	1.24	1.79	2.17	2.36	1.71	0.47	-0.17	1.49
18-3-E	0.95	1.24	1.80	2.11	2.27	1.68	0.49	-0.24	1.36
18-3-F	1.32	1.61	2.00	2.25	2.41	1.93	0.32	-0.22	1.70
18-3-G	1.18	1.44	1.91	2.19	2.37	1.82	0.38	-0.24	1.59
18-3-H	1.28	1.48	1.94	2.24	2.42	1.86	0.38	-0.21	1.50
18-3-I	1.45	1.76	2.08	2.34	2.49	2.05	0.29	-0.10	1.79

SAMPLE	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	M_ϕ	σ_ϕ	α_ϕ	β_ϕ
19-3-D	1.12	1.45	1.89	2.16	2.30	1.81	0.36	-0.22	1.64
19-3-E	1.16	1.60	1.96	2.21	2.33	1.91	0.31	-0.16	1.92
19-3-F	1.36	1.56	1.98	2.19	2.31	1.88	0.32	-0.31	1.56
19-3-G	1.31	1.58	2.01	2.28	2.44	1.93	0.35	-0.23	1.61
19-3-H	1.34	1.64	2.06	2.39	2.58	2.02	0.38	-0.11	1.65
19-3-I	1.49	1.79	2.10	2.40	2.55	2.10	0.31	0.00	1.74
19-3-J	1.53	1.75	2.04	2.27	2.41	2.01	0.26	-0.12	1.69
20-3-F	1.44	1.77	2.14	2.36	2.47	2.07	0.30	-0.23	1.75
20-3-G	1.37	1.58	2.02	2.28	2.41	1.93	0.35	-0.26	1.49
20-3-H	1.33	1.56	2.02	2.42	2.48	1.99	0.43	-0.07	1.34
20-3-I	1.47	1.67	2.08	2.30	2.58	1.99	0.32	-0.28	1.76
20-3-J	0.95	1.23	1.75	2.28	2.55	1.76	0.53	-0.01	1.53
21-3-E	0.99	1.36	1.86	2.13	2.26	1.75	0.37	-0.30	1.74
21-3-F	1.12	1.38	1.86	2.17	2.27	1.78	0.40	-0.20	1.46
21-3-G	1.42	1.66	2.07	2.33	2.47	2.00	0.34	-0.21	1.57
21-3-H	1.45	1.73	2.17	2.47	2.63	2.10	0.37	-0.19	1.59
21-3-I	1.34	1.57	2.04	2.34	2.51	1.96	0.39	-0.21	1.52
21-3-J	1.52	1.77	2.17	2.45	2.51	2.11	0.34	-0.24	1.46
22-3-E	0.74	1.11	1.68	2.03	2.17	1.57	0.46	-0.24	1.55
22-3-F	1.39	1.62	2.02	2.24	2.38	1.93	0.31	-0.29	1.60
22-3-G	1.26	1.53	2.13	2.43	2.58	1.98	0.45	-0.33	1.47
22-3-H	1.41	1.78	2.17	2.45	2.64	2.12	0.34	-0.15	1.81
22-3-I	1.52	1.84	2.19	2.43	2.55	2.14	0.30	-0.17	1.74
22-3-J	1.20	1.48	1.85	2.17	2.35	1.83	0.35	-0.06	1.67

SAMPLE	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	$M\phi$	σ_ϕ	$\alpha\phi$	β_ϕ
23-3-E	1.09	1.57	1.93	2.22	2.30	1.90	0.33	-0.09	1.86
23-3-F	1.42	1.70	2.10	2.30	2.40	2.00	0.30	-0.33	1.63
23-3-G	1.38	1.66	2.00	2.31	2.49	1.99	0.33	-0.03	1.71
23-3-H	1.22	1.53	1.99	2.26	2.43	1.95	0.37	-0.05	1.64
23-3-I	1.37	1.59	1.99	2.38	2.48	1.99	0.40	0.00	1.40
23-3-J	1.42	1.77	2.08	2.39	2.50	2.08	0.31	0.00	1.74
24-3-C	1.37	1.58	2.03	2.36	2.44	1.97	0.39	-0.15	1.37
24-3-D	1.45	1.76	2.10	2.33	2.47	2.05	0.29	-0.17	1.79
24-3-E	1.46	1.78	2.10	2.33	2.43	2.06	0.28	-0.14	1.76
24-3-F	1.37	1.64	2.08	2.33	2.43	1.99	0.35	-0.26	1.54
24-3-G	1.72	1.98	2.27	2.48	2.63	2.23	0.25	-0.16	1.82
24-3-H	1.48	1.78	2.14	2.38	2.48	2.08	0.30	-0.20	1.67
24-3-I	1.29	1.67	2.04	2.30	2.43	1.99	0.32	-0.16	1.81
24-3-J	1.52	1.78	2.14	2.35	2.45	2.07	0.29	-0.24	1.63
25-3-C	1.21	1.43	1.85	2.11	2.21	1.77	0.34	-0.24	1.47
25-3-D	1.18	1.48	1.88	2.15	2.28	1.82	0.34	-0.18	1.64
25-3-E	1.18	1.51	1.95	2.22	2.35	1.87	0.36	-0.22	1.65
25-3-F	1.18	1.49	1.98	2.25	2.39	1.87	0.38	-0.29	1.59
25-3-G	1.35	1.57	1.98	2.23	2.36	1.90	0.38	-0.21	1.33
25-3-H	1.60	1.82	2.17	2.36	2.46	2.09	0.27	-0.30	1.48
25-3-I	1.29	1.54	1.98	2.23	2.39	1.89	0.35	-0.26	1.30
25-3-J	1.37	1.53	1.94	2.18	2.34	1.86	0.33	-0.24	1.49

SAMPLE	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	M_ϕ	σ_ϕ	α_ϕ	β_ϕ
26-3-D	1.23	1.57	1.92	2.18	2.25	1.88	0.31	-0.13	1.67
26-3-E	1.44	1.75	2.08	2.29	2.41	2.02	0.27	-0.22	1.80
26-3-F	1.52	1.78	2.14	2.33	2.43	2.06	0.28	-0.29	1.65
26-3-G	1.32	1.73	2.12	2.37	2.49	2.05	0.32	-0.22	1.83
26-3-H	1.68	2.05	2.46	2.65	2.75	2.35	0.30	-0.37	1.78
26-3-I	1.31	1.71	2.10	2.34	2.45	2.03	0.32	-0.22	1.81
26-3-J	1.14	1.50	1.92	2.22	2.36	1.86	0.36	-0.17	1.65
26-3-D	1.25	1.62	2.08	2.28	2.38	1.95	0.33	-0.39	1.71
27-3-E	1.62	1.88	2.20	2.37	2.46	2.13	0.25	-0.28	1.71
27-3-F	1.55	1.87	2.20	2.43	2.54	2.15	0.28	-0.09	1.77
27-3-G	1.68	2.03	2.32	2.54	2.67	2.29	0.26	-0.12	1.94
27-3-H	1.67	1.95	2.27	2.44	2.53	2.20	0.25	-0.28	1.76
27-3-I	1.54	1.86	2.20	2.40	2.49	2.14	0.26	-0.23	1.83
28-3-D	1.51	1.83	2.16	2.36	2.44	2.10	0.27	-0.22	1.76
28-3-E	1.58	1.88	2.22	2.43	2.57	2.16	0.28	-0.21	1.80
28-3-F	1.66	1.88	2.24	2.49	2.64	2.19	0.31	-0.16	1.61
28-3-G	1.58	1.81	2.19	2.46	2.62	2.13	0.33	-0.18	1.61
28-3-H	1.58	1.93	2.24	2.47	2.60	2.20	0.27	-0.15	1.89
29-3-D	1.38	1.66	2.08	2.31	2.42	1.99	0.33	-0.27	1.60
29-3-E	1.48	1.75	2.13	2.36	2.46	2.06	0.31	-0.23	1.61
29-3-F	1.57	1.87	2.27	2.48	2.58	2.18	0.31	-0.32	1.66
29-3-G	1.60	1.86	2.26	2.50	2.64	2.18	0.32	-0.25	1.65
29-3-H	1.64	2.00	2.33	2.58	2.69	2.29	0.29	-0.14	1.81
29-3-I	1.66	1.92	2.29	2.52	2.65	2.22	0.30	-0.23	1.65

SAMPLE	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	M_ϕ	σ_ϕ	α_ϕ	β_ϕ
30-3-C	1.21	1.52	1.91	2.15	2.22	1.84	0.32	-0.22	1.58
30-3-D	1.38	1.65	2.04	2.26	2.39	1.96	0.31	-0.26	1.63
30-3-E	1.52	1.80	2.12	2.32	2.42	2.06	0.26	-0.23	1.73
30-3-F	1.54	1.80	2.08	2.29	2.41	2.05	0.25	-0.12	1.77
30-3-G	1.34	1.56	2.00	2.23	2.37	1.90	0.34	-0.29	1.54
30-3-H	1.68	1.90	2.23	2.48	2.63	2.19	0.29	-0.14	1.64
30-3-I	1.56	1.85	2.22	2.46	2.60	2.16	0.31	-0.19	1.70
30-3-J	1.26	1.67	2.07	2.28	2.38	1.98	0.31	-0.29	1.90
31-3-D	1.38	1.58	1.96	2.14	2.23	1.86	0.28	-0.36	1.52
31-3-E	1.35	1.48	1.83	2.09	2.24	1.79	0.31	-0.13	1.46
31-3-F	1.27	1.63	2.08	2.31	2.43	1.97	0.34	-0.32	1.71
31-3-G	1.43	1.72	2.08	2.32	2.19	2.02	0.30	-0.20	1.27
31-3-H	1.17	1.53	2.01	2.24	2.17	1.89	0.36	-0.33	1.41
31-3-I	1.12	1.63	2.12	2.23	2.32	1.93	0.30	-0.50	1.35

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13. ABSTRACT

Beach-elevation measurements were made and sand samples were collected along a single profile daily at low tide during the period from February 1 through March 31, 1967. Wave and tide data were recorded continuously. The beach, composed of medium-to-fine quartz and feldspar sand, is well sheltered from wave action.

Wave steepness exerts a great influence on the beach profile. An equilibrium profile was found to exist for a given wave steepness. As wave conditions change, the beach profile tends to change toward the equilibrium profile associated with the new wave steepness. Given an initial beach profile, the amounts of cut and fill that will occur with a given change in wave steepness can be predicted.

Textural parameters do not appear to be related to changing wave conditions in a simple way. Equilibrium values of mean grain size, sorting, skewness, and kurtosis exist for any given location on the beach profile. The equilibrium values are apparently independent of wave conditions.

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