CHAPTER 31

TOPOGRAPHIC CHANGES IN THE SURF ZONE PROFILE

Choule J. Sonu
Associate Professor, Coastal Studies Institute
Louisiana State University
Baton Rouge, Louisiana

Richard J. Russell
Boyd Professor, Coastal Studies Institute
Louisiana State University
Baton Rouge, Louisiana

ABSTRACT

The conventional method of dealing with relationships between wave action and topographic response on a beach is to reduce the problem to a two-dimensional scheme that regards basic processes as taking place in a vertical plane normal to the shoreline. This scheme is valid only if the waves arrive at right angles to the shore and the nearshore contours are reasonably straight and parallel the beach. As these conditions are not realized in many cases another analytical method is necessary - one that recognizes effects of other than normal wave arrival and systematic patterns of diversification in nearshore topography. This study, based on a long period of field investigation on the Outer Banks, North Carolina, examines a three-dimensional approach. Observations from a long pier were used to explain nearshore topographic diversification and resulted in conclusions that were confirmed by subsequent field observation.

INTRODUCTION

Conventional, two-dimensional consideration of relationships between wave action and topographic response have resulted in well-known theories of profile equilibrium of Larras (1959), Kemp (1960), Sitarz (1963), Miyazaki (1957), and Eagleson, et al (1963). The validity of these theories holds if waves arrive normal to the shore and nearshore contours are straight and parallel. These conditions may be approximated in a laboratory wave flume but in many cases are not found along actual beaches, where departures from contour parallelism commonly occur - particularly in the surf zone, where topographic changes take place most rapidly. Patterns of systematic diversification are manifest as lunate bars and sand waves moving along the shoreline.

This study is an analysis of continuous profile data obtained along a straight beach, remote from inlets or other causes of disturbance, on the Outer Banks of North Carolina north of Cape Hatteras. Offshore contours are relatively straight but those in the surf zone display systematic patterns of diversification characteristic of migrating sand waves which have been described as rhythmic topography (Hom-ma and Sonu, 1962).

Profile data revealed two distinct types of topographic response· (1) changes that involve only the shifting of bed materials along the profile when waves arrived normal to the shoreline; (2) alongshore displacements of nearshore topography when the approach was oblique and currents developed parallel to the shoreline. It was found that the latter process could be demonstrated by analysis of observations taken on profiles parallel to a long pier.

The analysis introduced here establishes a Lagrangian picture of profile behavior in three-dimensional coordinates, as opposed to the conventional two-dimensional approach that amounts to reducing observations to a Eulerian picture along a fixed control section across the surf zone.

THE DATA

A stationary traverse was established 20 feet away from a fishing pier near Nags Head, North Carolina. Profiles were measured between October, 1963, and May, 1964, by soundings at half-tide intervals, for 720 feet, between the upper limit of wave run-up, across inner bar area, to an outer bar (Figures 1 and 2). A record was kept of water levels, longshore currents, swash activities, water and air temperatures, winds, and sediment samples that were collected regularly. Wave data were recorded on a step-resistance wave gage supplied by the Coastal Engineering Research Center of the U. S. Army Corps of Engineers and located toward the end of the pier in water averaging 15 feet deep.

Preliminary analysis of data suggested effects of sand-wave phenomena. A photograph (Figure 3) taken approximately 5 miles south of the study area was also suggestive. A more complete analysis confirmed the suggestions. The subsequent field check resulted in identifying the nearshore topography (Figure 4-A) by showing a diversified contour system with a curved bar, shoal, shoreline projection and embayment. These features are characteristic of a coastal sand wave.

The shoreline projection in Figure 5 is associated with a shallow water profile seaward. Profiles extending out from embayments along the shore are, on the whole, deeper than those out from shoreline projections, and also cross the deepest parts of bar crests, as shown in Figure 4-B. Should a sand wave associated with a shoreline projection move along the coast, a consistent displacement of profiles would occur when observed along a stationary traverse, in our case parallel to a pier. Any observed profile is replaced by other profiles arriving from either side, depending on the angle of wave approach. As our pier extended eastward, profile displacements were associated with waves coming from northeast or southeast quadrants. A similar pattern of profile response was reported by Shepard and LaFond (1940) from data obtained along the Scripps Institution pier, La Jolla, California. They state:

> 'One of the cases where currents appear to be especially important is in February where a general cut along the pier is interrupted during a series of days of north flowing current by a fill which lasted

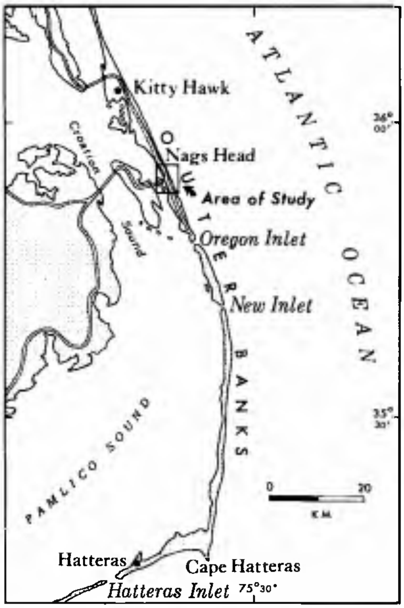

Fig. 1. Location of study site - Nags Head, the Outer Banks, North Carolina.

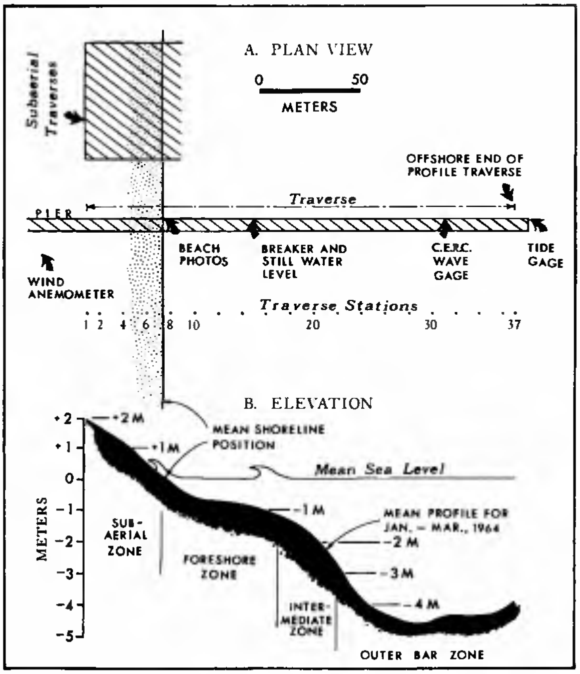

Fig. 2. A. Arrangements of field instrumentation.
B. Mean profile.

Fig. 3. Aerial photograph showing sand wave phenomena approximately 5 miles south of study site, taken December, 1957 (Courtesy of Cape Hatteras National Park Service).

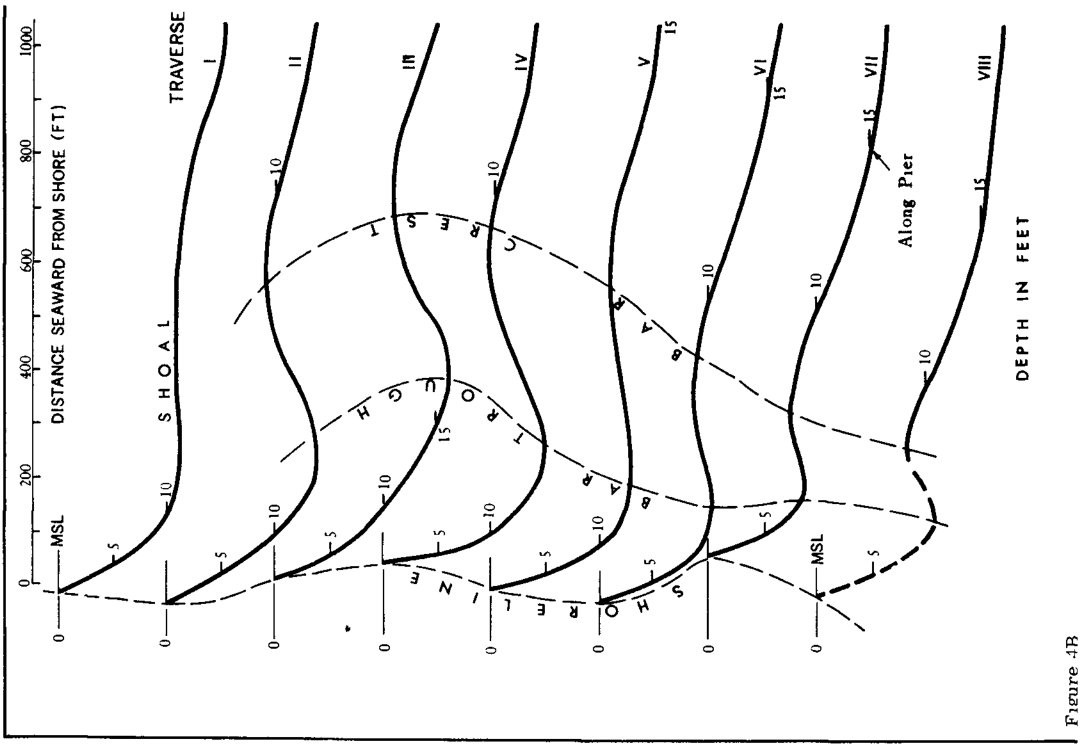

Figure 4B

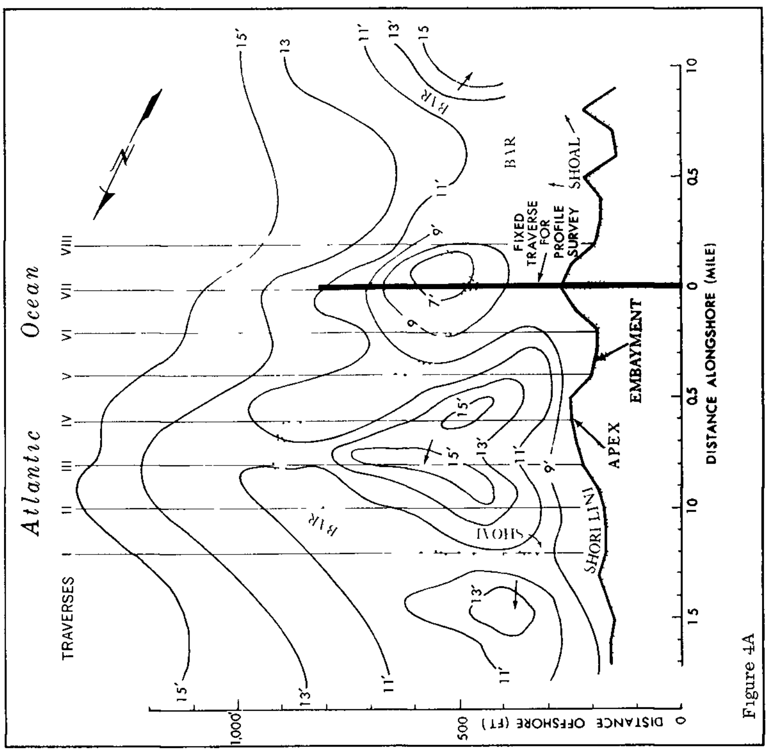

Fig. 4. Bottom topography near observational traverse, fathometer soundings on Oct. 24, 1965. A. Plan-view; B. Profiles.

Fig. 5. Hourly beach photography indicating a persistent shoreline projection north of traverse.

Fig. 6. Sand waves revealed by aerial photography on the Caspian Sea coast (Kobets, 1958).

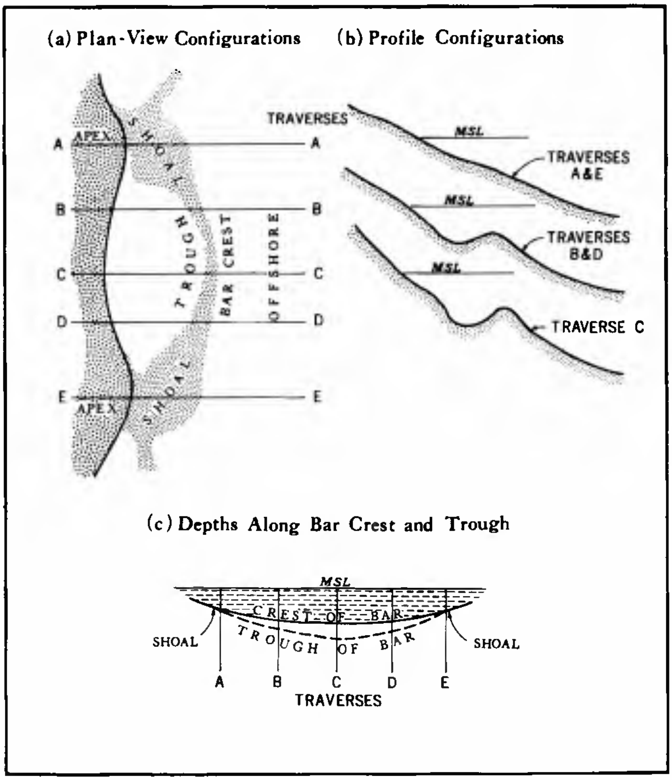

Fig. 7.

Idealized schematic of coastal sand wave (adapted from Hom-ma and Sonu, 1962).

for about a month. The strongest north flowing current, which occurred in the middle of April, was followed by a fill that was distinctly ahead of the average seasonal trend Still more significant, the three strongest south flowing currents correspond with the largest cuts along the pier.'

Characteristics of coastal sand waves have been described by Hom-ma and Sonu (1962), Krumbein and Oshiek (1950), Evans (1939), Kashechkin and Uglev, Bruun (1954), Sonu (1961,1964), Taney (1963), and Sitarz (1963). The sand waves develop when longshore currents are present. The basic geometry consists of elongate ridges and troughs oriented at angles to the shore (Figure 6). Figure 7 shows schematically sand-wave nearshore topography. The shoreline embayment is associated with a wave trough and the projection a wave crest, without an offshore bar.

The migration of sand-wave topography also has been reported. Egorov (1951a) noted from 15 to 32 m migration in 24 hours. Bruun (1954) reported an average annual displacement of 1,000 m. Mogi (1960) and Hom-ma and Sonu (1962) found short-term fluctuations, yet no net long-term migration, on an unobstructed beach. Similar conditions were found on the Outer Banks near an observational pier. Just to the north is a persistent projection that appears in hourly photographs taken for more than 6 months (Figure 5). As shown in Figure 8 the winds arrived mainly from northeast or southeast quadrants, as did waves. Thus short-term fluctuations may have balanced each other, leaving a zero balance over the long term.

TRANSVERSAL VERSUS ALONGSHORE RESPONSES

The following analysis is based on 64 profiles, each with 37 stations 20 feet apart (Figure 2-A). Figure 2-B shows the mean profile for all the observations. The observed sequence in profile configuration is shown by the envelopes in Figure 9. It was found that by introducing an alternative measure, instead of true water depth, basic configurations in individual profiles could be discriminated. The measure used is the deviation of individual water depths from the mean depth at corresponding stations on other profiles, viz.,

$$D'_{i,j} = D_{i,j} - \bar{D}_i$$

where $D_{i,j}$ denotes the true water depth at the i-th station of the j-th profile, $\bar{D}_i$ the mean of all the depth readings made at the same i-th station, and $D'_{i,j}$ the alternative measure. Figure 10 is the time history of the surf-zone profiles using this alternative measure, shown also by the envelopes.

Out of the 64 profiles, only 7 different profile configurations can be discriminated. This suggests that two differing types of topographic response

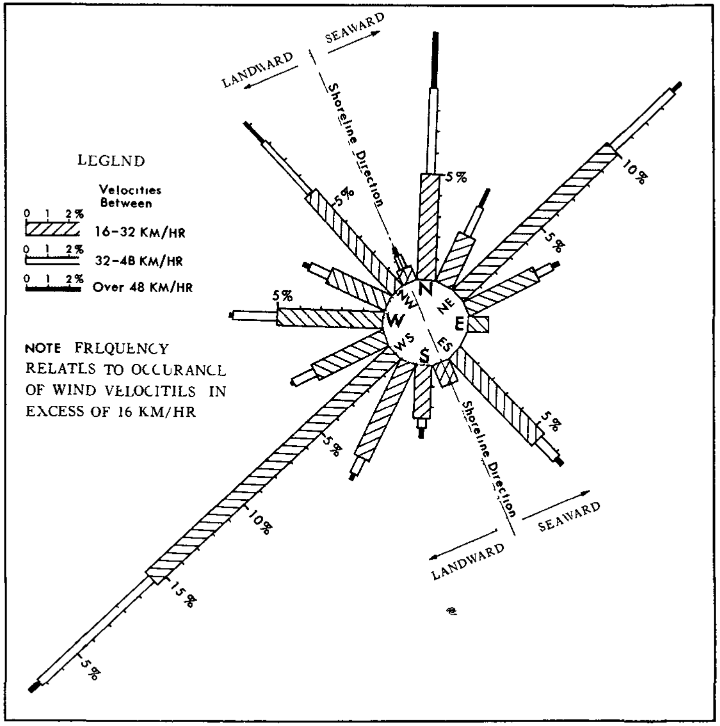

Fig. 8. Wind rose diagram from 2-hourly average velocities taken at Nags Head, Outer Banks, during observation of the 64 profiles analyzed here, January to March, 1964.

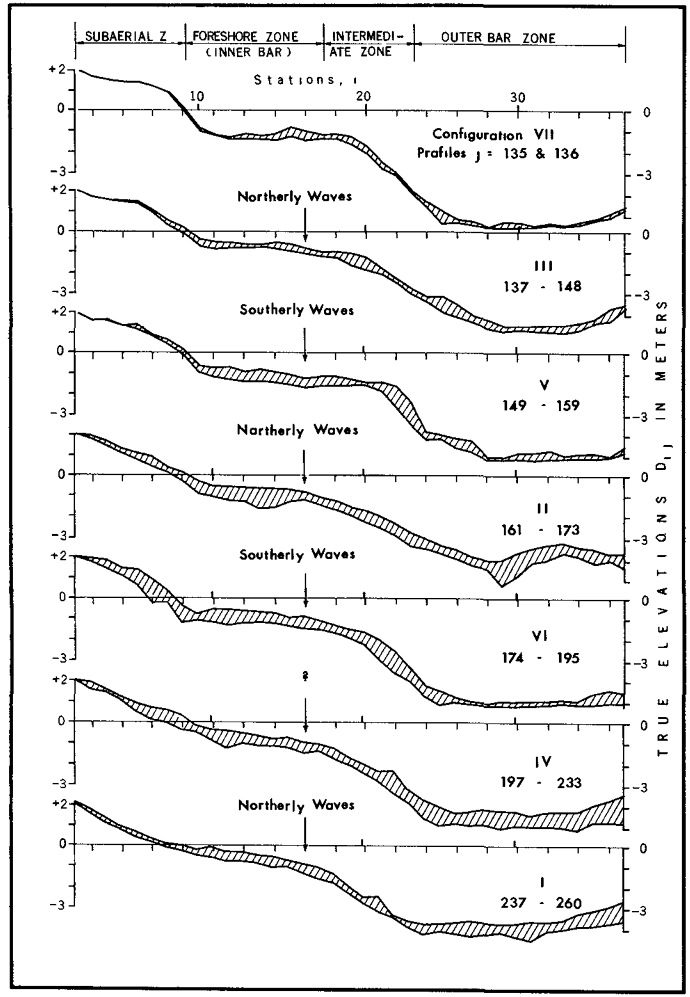

Fig. 9. Time history of profiles shown by true water depth $D_{i,j}$ below mean sea level. All 64 profiles are contained in these envelopes.

occurred: (1) profile change within each envelope, and (2) transition between envelopes.

Of particular interest is the influence of angle of wave incidence on profile responses. Changes within envelopes occurred when waves arrived normal to the shore and between envelopes during oblique wave incidence. Cut and fill suggested by changes in the fixed traverse were associated, respectively, to southerly and northerly wave incidences. In Figures 9 and 10, the transitions from envelopes III to V and from II to VI represent deepening associated with southerly waves, the transition from VII to III, from V to II, and from IV to I represent shoaling associated with northerly waves. From these observations it is inferred that profile change within an envelope results primarily from individual displacements of sediment along profiles, whereas the transition from one envelope to another results from profile displacements parallel to the shore. For sake of brevity, these two processes will be called transversal and alongshore responses.

RELATIONSHIPS WITH WAVE POWER

The physical criterion requires that energy influx be equivalent to the work produced. Consequently, certain relationships might be expected between the wave power and the capacity of the profile to accomodate it, and between the wave power and movement of material associated with the profile responses.

Airy's first-order approximation gives the wave power transmitted shoreward per unit width of wave crest by the following equation:

$$P = (\rho g H^2/8)\,(L/T) \cdot \tanh \frac{2\pi d}{L} \cdot n$$

in which ρ = specific gravity of sea water; g = gravity acceleration, H = wave height at depth d, L = wave length; T = wave period, and

$$n = 1/2[1 + (4\pi d/L)/(\sin 4\pi d/L)]$$

The profile capacity for accomodation can be represented by the sum of the water depths at all the stations within each profile, which is also an indicator of the general depth of this profile. Thus,

$$Y_j = \sum_{i=1}^{n} D_{i,j}$$

The relationships between P and Y_j are shown in Figure 11. The profile configurations are discriminated by different symbols and numbered in the increasing

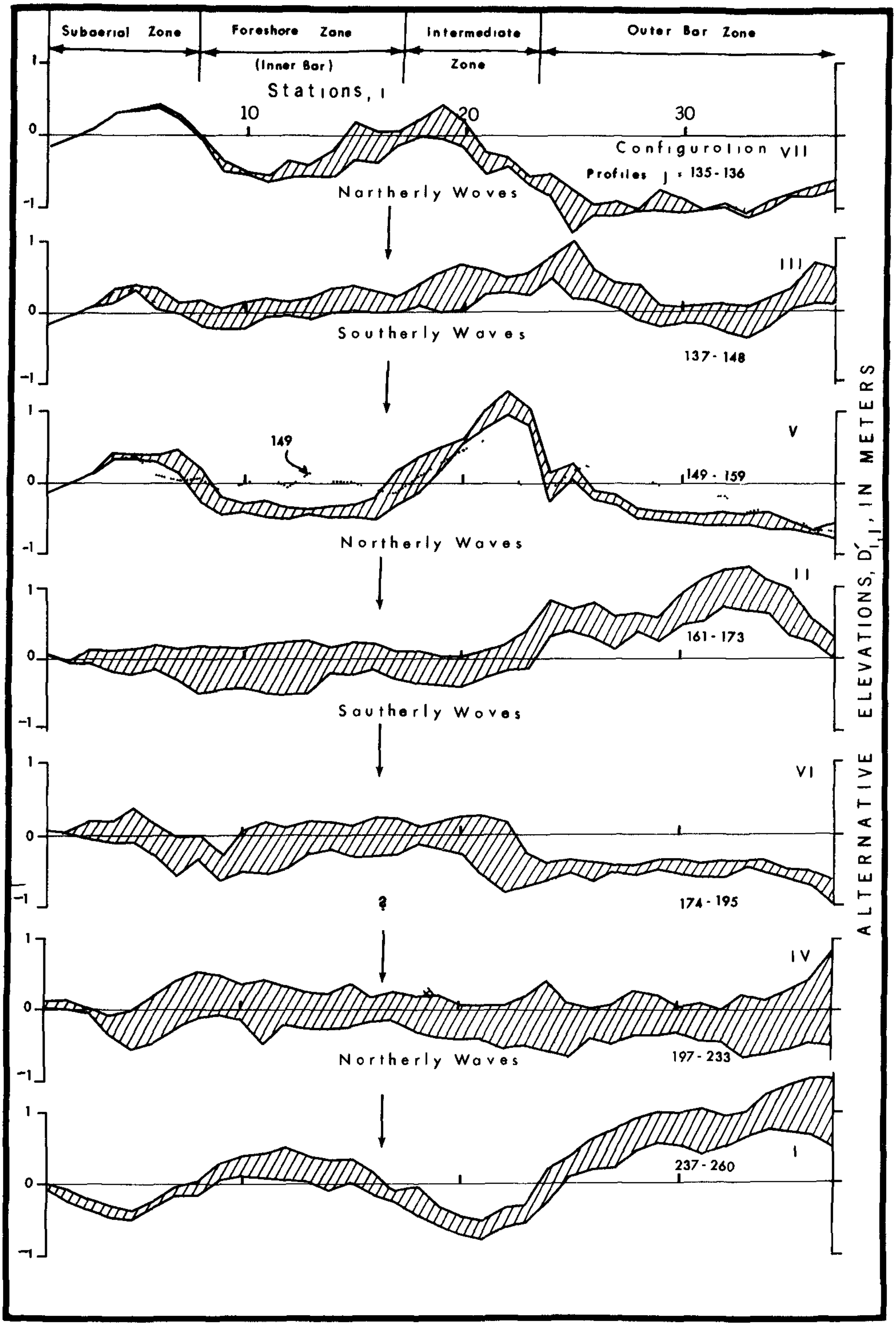

Fig. 10. Time history of profiles, shown by alternative depth: $D'_{i,j} = D_{i,j} - \overline{D}_i$. Envelopes

order of the general depths of profiles.

Two interesting relationships are implied: (1) In the transversal response - that is the changes within envelope - as the wave power increased, the depth of a profile also increased gradually, and (2) In the alongshore response - that is the changes from one envelope to another - the southerly waves caused deep profiles (shown by broken arrows) and the northerly waves shallow profiles (shown by solid arrows) at the traverse. In this case, as indicated by the coordinates of the arrows relative to the ordinate (wave power), the change was not influenced by the wave power but by whether the waves arrived from northerly or southerly quadrants.

Figure 12 shows the relationships between the wave power indicator (square of wave height) and the material movement involved in the 12-hour profile change. The latter term was computed by:

$$Q_j = \sum_{i=1}^{n} \left| D_{i,j+1} - D_{i,j} \right|$$

The plots were further discriminated by the following indicator to show whether or not the net material comprising the profile topography was preserved as a result of the profile responses, i.e.

$$Q'_j = \sum_{i=1}^{n} (D_{i,j+1} - D_{i,j}) \equiv \sum_{i=1}^{n} (\Delta D_{i,j})$$

in which n is the number of stations contained in the profile. Our data indicate that in 82 per cent of all the cases, the net material balance resulted in zero, i.e.

$$Q'_j \doteqdot 0$$

and in the remaining 18 per cent, in either erosion or accretion, i.e.

$$Q'_j \gtrless 0.$$

A further check with the wave data indicates that the former change was associated with perpendicular wave arrivals, while the latter with oblique wave arrivals. Thus, the transversal and the alongshore responses are again discriminated. The interpretation of Figure 12 is summarized as follows:

(1) In the transversal response - represented by blank plots - the scatter is small and indicates that the material moved in the traverse is proportional to

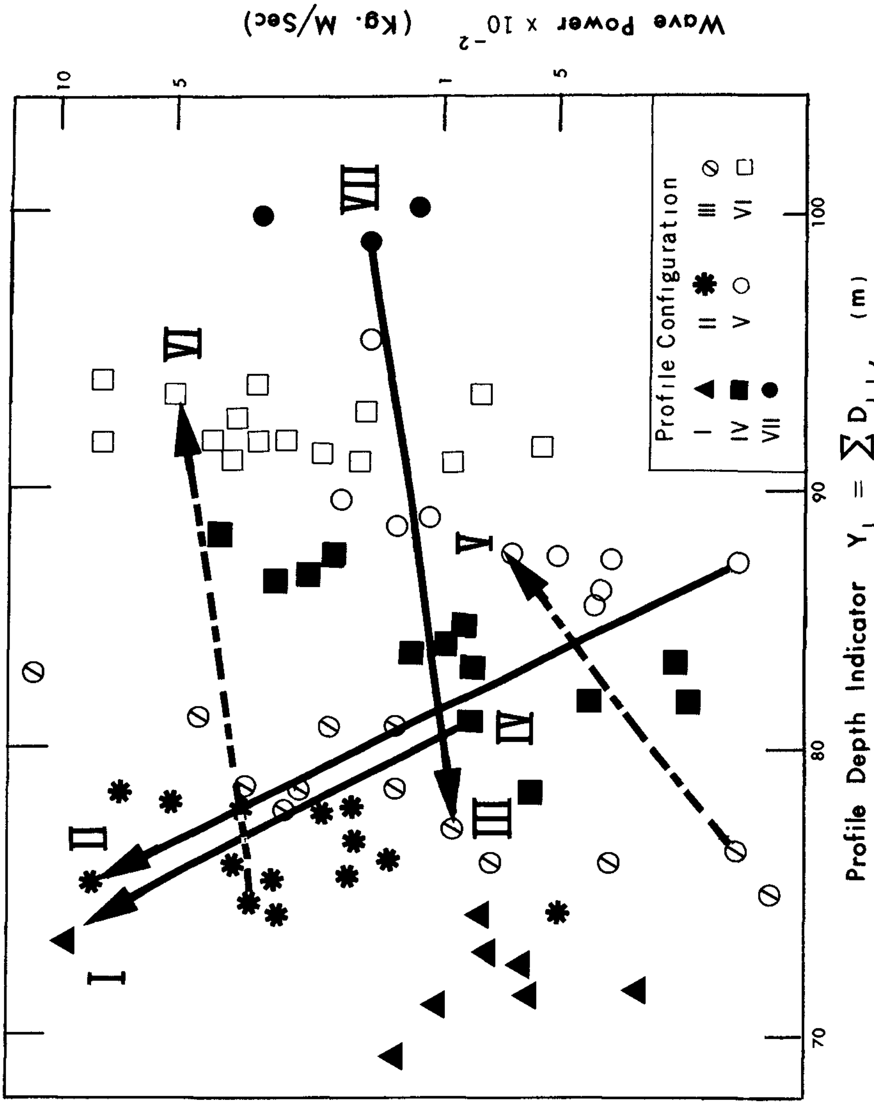

Fig. 11. Relationships between wave power, P, and general depth of profile, Y_j. Profiles discriminated by general depths and shown by corresponding symbols (see inset).

the square root of wave height, namely,

$$Q_j = 2\ 1\ H^{\frac{1}{2}} \quad \text{(H in meters)}$$

(2) In the alongshore response - represented by the rest of the plots - the material moved in the traverse is several times greater than in the case of traversal response, and is not necessarily correlated with wave power. In other words, the profile change associated with alongshore response could take place with waves of very small power but arriving at oblique angles of incidence.

It is evident that these systematic relationships can be distinguished only by discriminating the plots on the basis of transversal and alongshore profile responses. Thus, the interpretation of Figure 12 can be extended further Let the wave power indicator H^2 be substituted by its transversal component, $H^2 \sin^2\Theta$, and plotted against the same indicator of material movement, Q_j, which is also the transversal component, so that a purely two-dimensional scheme may be simulated. However, since

$$H^2 >> H^2 \sin^2 \Theta$$

this procedure amounts to transposing the original plots for the alongshore response in Figure 12 toward the left side of the diagram, resulting in an even greater departure between the alongshore and the transversal responses. It then follows that contrary to a general belief, an interaction between wave and topography involving obliquely arriving waves may not simply be converted to a two-dimensional scheme by projecting wave variables onto a vertical plane perpendicular to the shore. By the same token, waves having an identical amount of transversal energy components but arriving at different angles of incidence, may not be expected to induce an equal amount of topographic response when (1) the observation is fixed at a stationary traverse and (2) the beach topography has a diversified contour system.

Figure 12 may be supplemented by simple statistics. Figure 13 shows histograms of 12-hourly elevation changes at individual stations for transversal and alongshore responses. The elementary term is expressed by

$$\Delta D_{i,j} = D_{i,j+1} - D_{i,j}$$

The histogram representing the transversal response resembles a normal distribution with the mean approximately at $\Delta D_{i,j} = 0$. This implies that in the transversal response the elevation changes at individual stations may be similar to a random fluctuation around the zero mean. The data representing the alongshore

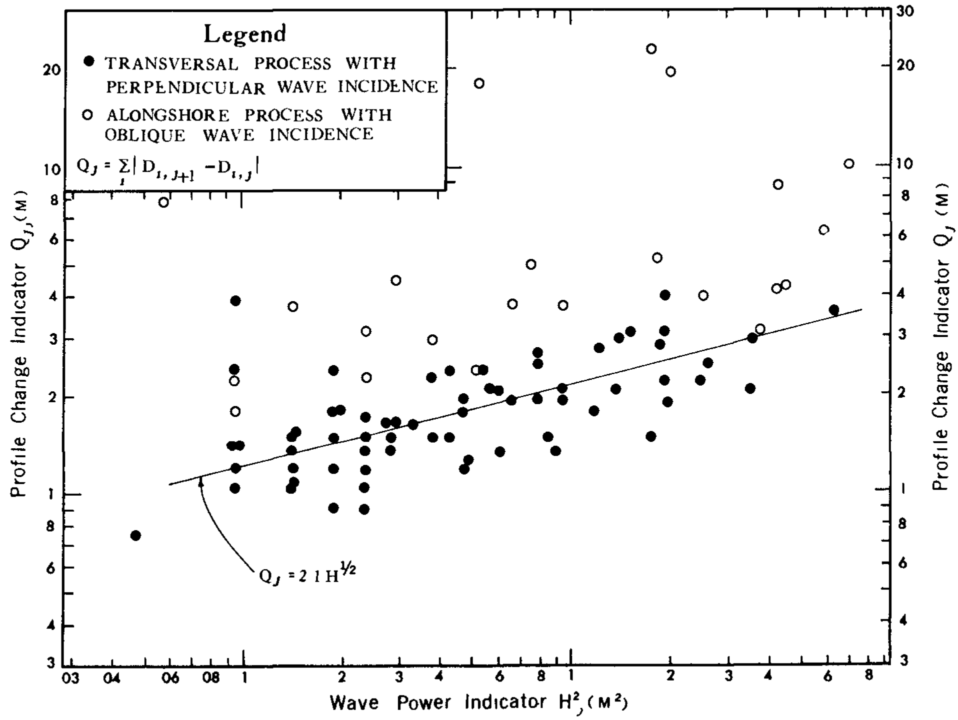

Fig. 12. Relationships between wave power indicator, H^2, and depth changes between 12-hourly consecutive profiles.

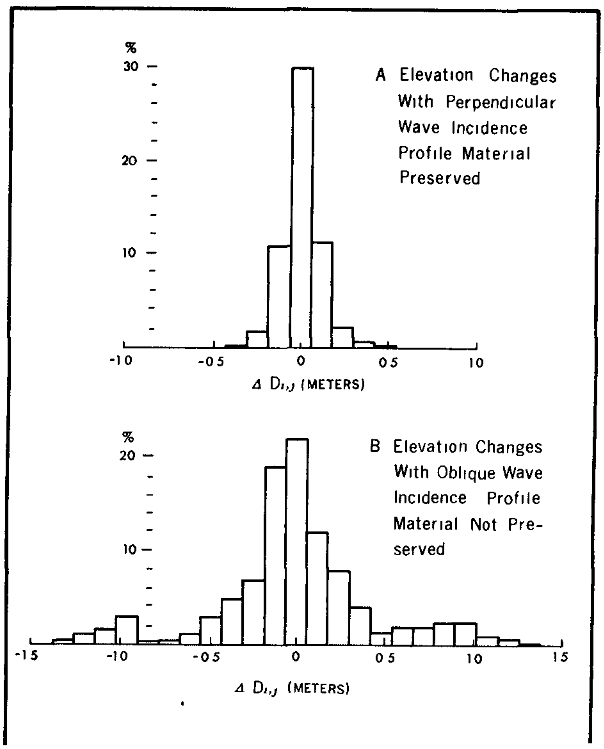

Fig. 13. Histograms of 12-hourly elevation changes combining all the stations of all the profiles.
A. Transversal response;
B. Alongshore response.

response result in a trimodal histogram, with the modes located approximately at $\Delta D_{i,j} = 0$ and ± 3.0 ft. Implications are that two alien processes are involved in this case. one similar to the preceding example of random fluctuation and the other involving an abrupt change of a larger order. Because of the extra modes, the standard deviation of $\Delta D_{i,j}$ in this case is nearly twice that of the preceding case, namely 1.13 ft/0.58 ft $\doteqdot$ 2/1

ZONAL CORRELATION WITHIN A PROFILE

The degree to which the change at a given station is related to the simultaneous change occurring at other stations in the profile can be expressed by the correlation coefficient as follows·

$$R_{i,k} = 1/N\text{-}1 \sum_{j=1}^{N-1} \frac{(\Delta D_{i,j} - \Delta\bar{D}_i)(\Delta D_k - \Delta\bar{D}_k)}{\sigma_i \times \sigma_k}$$

$$\Delta\bar{D}_i = 1/N\text{-}1 \sum_{j=1}^{N-1} \Delta D_{i,j}$$

$$\sigma_i^2 = 1/N\text{-}1 \sum_{j=1}^{N-1} (\Delta D_{i,j} - \Delta\bar{D}_i)^2$$

i, k = 1, 2, ... n, station number, and
j = 1, 2, ... N, profile number.

The correlation coefficient, $R_{i,k}$, was computed for every pair of stations, and plotted in Figures 14 - A and B separately for the transversal and the alongshore processes of profile response. Again, a clear distinction is noted between the two processes. In the transversal response (Figure 14-A), the correlation level is generally low, and little or no pattern exists. However, in the alongshore response (Figure 14-B), a well definable pattern as well as the high level of correlation emerge. For instance, let us follow the correlation curve denoted by $R_{i,5}$, which represents the correlation between Station 5, located on the subaerial beach, and all other stations in the profile (Figure 14-B). Naturally, the correlation with itself is plus one, at Station 5, but this shifts to negative correlation with the stations of the foreshore (inner bar) zone, and then back to positive correlation with stations of the outer bar zone.

Accordingly, the surf-zone profile may be divided into four different segments - the subaerial zone (stations 1-7), the foreshore (inner bar) zone (stations 8-17), the intermediate zone (stations 18-23) and the outer bar zone (stations 24-37). It is then seen that in the case of alongshore response (Figure 14-B) the correlation is always negative between two adjacent zones and always positive between alternate zones. This feature appears to support the conventional notion regarding the transversal exchange of material in the beach profile, namely that material

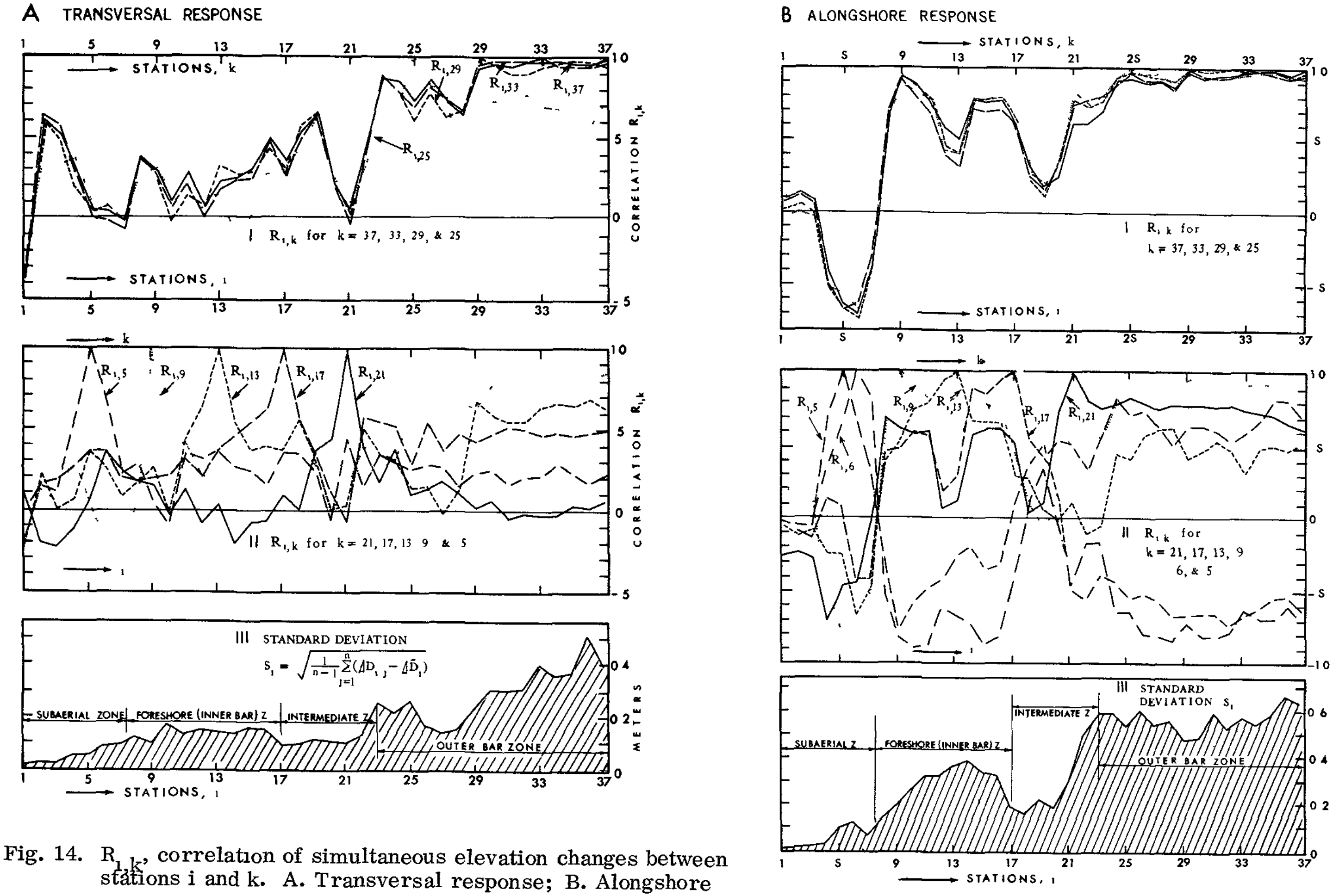

Fig. 14. $R_{1,k}$, correlation of simultaneous elevation changes between stations i and k. A. Transversal response; B. Alongshore reponse.

eroded from the subaerial beach is deposited in the foreshore (inner bar) zone, and vice versa. However, it is to be recalled that this systematic feature of station-to-station (or zonal) correlation emerges only with the alongshore response, which involves the displacement of profiles parallel to the shore. This then implies that the analysis of the field data based only on the transversal concept can lead to a misleading or distorted interpretation.

This point is further demonstrated by the station-to-station correlation using the elevation $D_{i,j}$ instead of the elevation changes, $\Delta D_{i,j}$, as follows:

$$G_{i,k} = 1/N\text{-}1 \sum_{j=1}^{N-1} \frac{(D_{i,j} - \bar{D}_i)(D_{k,j} - \bar{D}_k)}{\sigma_i \times \sigma_k}$$

$$\bar{D}_i = 1/N\text{-}1 \sum_{j=1}^{N-1} D_{i,j}$$

$$\sigma^2 = 1/N\text{-}1 \sum_{j=1}^{N-1} (D_{i,j} - \bar{D}_i)^2$$

$i, k = 1, 2 \ldots n$: station number, and
$j = 1, 2 \ldots N$: profile number.

The result is plotted separately for the transversal process (Figure 15A) and the alongshore process (Figure 15B). Note a striking similarity between Figure 15A (correlation of elevation) and the previous Figure 14A (correlation of elevation changes), both representing the alongshore process. Implications are that the zonal correlation previously recognized in terms of consecutive elevation changes is attributed to the systematic difference in configuration of the profiles which came to rest in the fixed traverse as a result of alongshore displacements. The similarity between Figures 15A (transversal process) and 15B (alongshore process), both representing the correlation in elevation, is then duly expected since the number of different types of profile configurations contained in both groups of data is the same.

The lower diagrams in Figures 14-A and B show the standard deviation of the elevation changes at individual stations. It is seen that the peaks in the standard deviation occur at positions where the difference in profile configuration is most pronounced between individual profiles - in the inner bar and the outer bar zones (Figure 16). Inspection of Figure 4-B indicates that the same statement holds with respect to the profiles contained in the diversified system of sand waves.

DISCUSSIONS

The extent to which the relationships between wave action and topographic

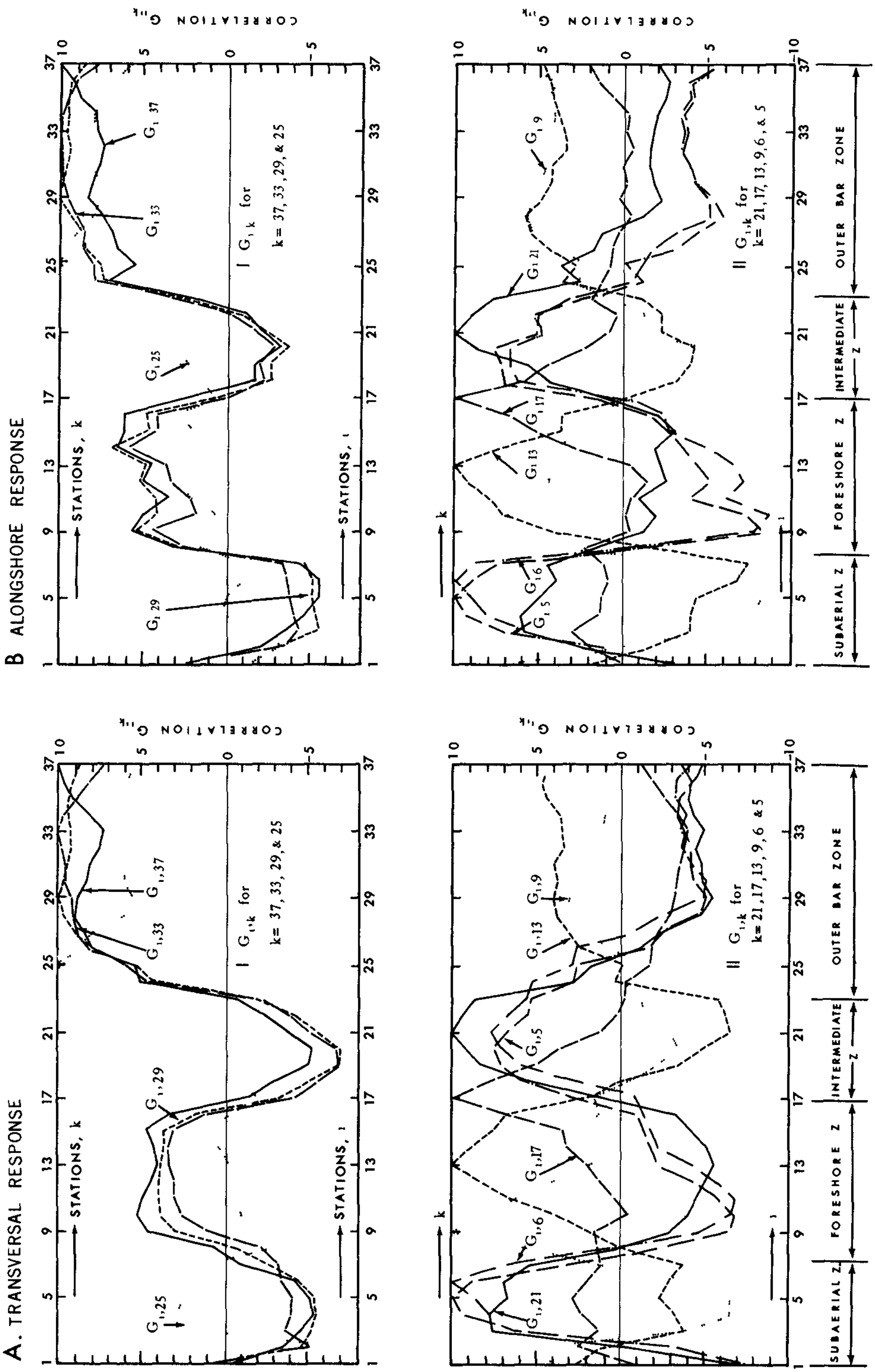

Fig. 15. $G_{i,k}$ correlation of simultaneous elevations between stations i and k.

responses are explained by the concept advanced here appears encouraging. Past studies based on the transversal two-dimensional concept alone have not been as successful. The results of the two-dimensional approach best apply to the offshore area where (a) the bottom contours may be approximated by smooth and parallel curves, (b) the areal variation of wave refraction is not pronounced, and (c) the topography is relatively stable. The agreement between the analytical prediction and the prototype observation has been found to deteriorate sharply in the vicinity of the surf zone (Eagleson-Glenne-Dracup, 1963). It has been shown recently (Russell and Dyke, 1963) that in a laboratory wave flume, the similitude of the net sediment transport in a transversal profile cannot be expected, much less the similitude of the net direction of sediment transport.

It appears that the processes occurring under natural conditions normally exhibit predominant alongshore components, with the reflux of the water mass channeled out by an alongshore-rip current system instead of a general transversal out-flow such as the undertow (Inman and Bagnold, 1962). This was demonstrated by the observation of longshore currents performed in the vicinity of the stationary traverse during the supplemental investigation of the Outer Banks beach in October 1965 (Sonu et al, 1966). In the presence of an active alongshore drag by waves and currents, it is not difficult to comprehend that a system of rhythmic sand waves could develop on the nearshore bed with a magnitude similar to those encountered on a river bed or tidal channel (Cartwright, 1959). In fact, this type of topography has been reported from widely scattered areas of the world, including Lake Michigan (Evans, 1939, Krumbein and Oshiek, 1950), Virginia Beach (Harrison and Wagner, 1964), Cape Hatteras and Outer Banks beaches, Gulf of Mexico (Psuty, 1966), Caspian Sea (Kobets, 1958), Black Sea (Egorov, 1951b), Mediterranean Sea (King and Williams, 1949, Riviere et al, 1961), Denmark (Bruun, 1954), The Netherlands (van Bendegom, 1949), and the Japan Sea and the Pacific coasts of Japan (Hom-ma and Sonu, 1963).

The dynamic behavior of rhythmic topography reported by these investigators varies considerably. Apparently, the case reported in this study may represent but one of the many possible modes which are perhaps a function of the seasonal and regional regimes of wave and current activities. Figure 17 summarizes various modes of wave-topography interaction depending upon the combination of the wave shear components and boundary conditions. As long as the waves arrive perpendicular to the shore, the net material comprising the profile topography may be preserved in a closed or a quasi-closed system. As the alongshore components of wave shear increases by oblique wave incidences, displacements of material take place parallel to the shore. The bed material is not preserved within a single profile but the net balance is still maintained under the boundary conditions characterized by straight and parallel contours A completely open system of material transfer occurs, however, in the presence of a sand wave topography coupled with the predominance of alongshore bed shear components. Under natural conditions in which the wave-topography interaction will seldom attain the steady state of equilibrium, however, one may only encounter the intermediate or transitional versions of these idealized regimes.

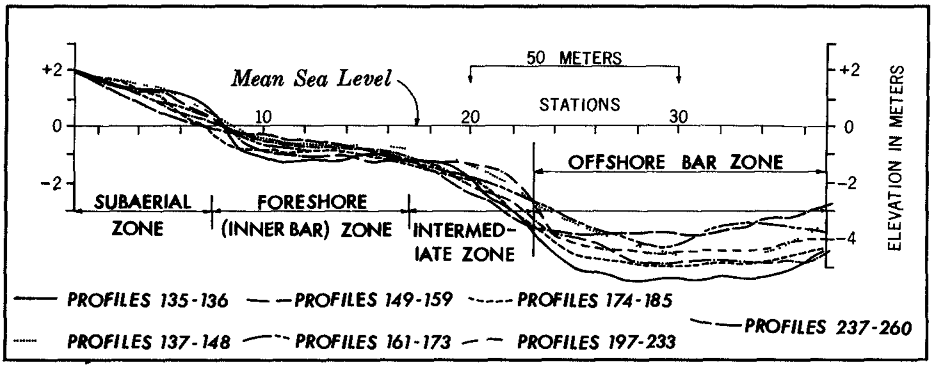

Fig. 16. Superposition of 7 discriminated profiles. (Refer to Fig. 9).

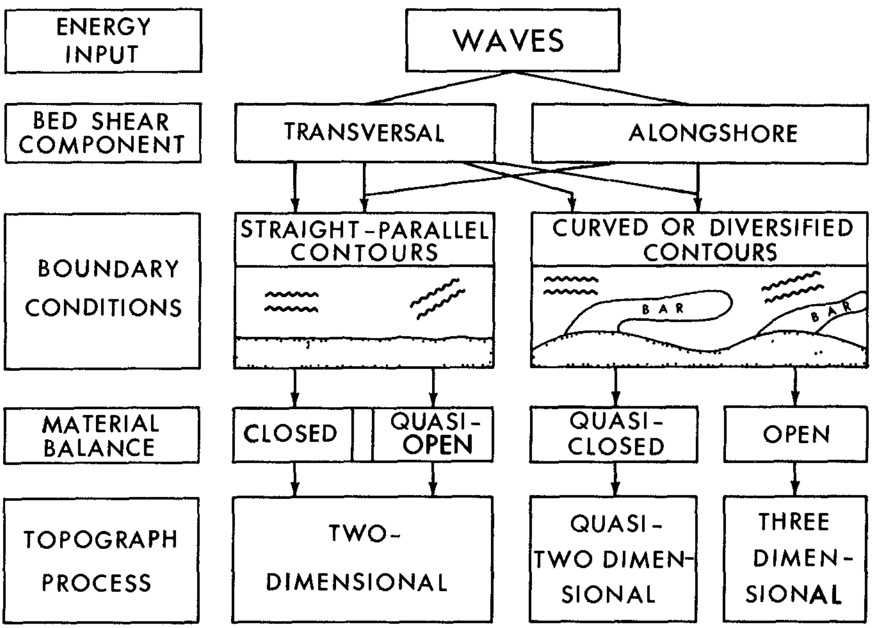

Fig. 17. Four basic modes of wave-topography interaction.

SUMMARY

The relationships which most likely affected the wave-topography interaction observed along a stationary traverse in the Outer Banks between January and March, 1964, are as follows:

1. Because of the presence of systematically diversified bottom contours (Figure 4), the interaction consisted of two separable processes: the transversal two-dimensional process and the alongshore process. The transversal process occurred only when waves arrived perpendicular to the shore, while the obliquity of wave incidence caused the alongshore process regardless of the level of wave power.

2. The transversal process failed to transform the basic profile configuration, while tending to increase slightly the overall depth of the profile with the increase of wave power (Figure 11). The net amount of the material comprising the profile topography was essentially preserved (Figure 13A), but the material moved in the traverse was proportional to the square root of wave height (Figure 12):

$$Q_J = 2.1\ H^{\frac{1}{2}} \quad \text{(in meters)}$$

3. The alongshore process was a combination of the profile transformation and the profile displacements. In terms of the material moved in and out of the traverse, the effect of the latter was several times greater than that of the former. Since the displacements occurred as fluctuating movements toward north and south, the long-term position of the rhythmic topography remained stable relative to the traverse. As a result, the regular cut and fill was observed along the traverse with wave incidences from south and north, respectively.

4. The sand wave topography, along with its dynamic behavior, appears not an infrequent phenomenon on the Outer Banks beach where, macroscopically, the configurations of the shoreline and the offshore bottom contours are generally smooth and only gently curved (Figure 1).

5. Recognition of the sand wave phenomenon allows some revised insights in the dynamics of coastal topography. Profiles resembling the accepted <u>summer</u> and <u>winter</u>-types are encountered barely several hundred feet apart on the same stretch of beach. In the presence of a sand wave system, a two-dimensional scheme may not be simulated by projecting the related variables on a vertical plane perpendicular to the shore, when the waves arrive at angles to the shore. Because of the progressive differentiation of profile configurations in a sand wave system, the profile displacements parallel to the shore may produce a false effect as if an active exchange of material is in process between adjacent zones within a stationary traverse. Although King (1959) seems to believe that the rhythmic

topography or the sand wave phenomenon occurs only on the tideless coast, our data on the Outer Banks beach as well as evidence from many other localities indicates that the effect of tide is essentially negligible.

ACKNOWLEDGMENTS

This study was financed by contract Nonr 1575(03), NR 388 002 with the Office of Naval Research, Geography Branch. Personnel of the Coastal Studies Institute, Louisiana State University, participated in the acquisition of field data, particularly Dr. R. Dolan, now with the University of Virginia, J. M. McCloy, and Nils Meland, graduate assistants of Louisiana State University. Mr. David S. McArthur, graduate assistant, assisted in data analysis and reviewed the manuscript. Other colleagues of the Coastal Studies Institute, particularly Dr. Wm. G. McIntire, Director, kindly participated in discussions and provided valuable suggestions. A grateful acknowledgement is due to all of these people.

REFERENCES

Bruun, P. M. (1954). Migrating sand waves and sand humps, with special reference to investigations carried out on the Danish North Sea coast, Proc. Vth Conference on Coastal Engineering, Council on Wave Research.

Cartwright, D. E. (1959). On submarine sand waves and tidal leewaves, Proc. Royal Society of London, A., Vol 253.

Eagleson, P. S., Glenne, B., and Dracup, J. A. (1963). Equilibrium characteristics of sand beaches, Journal, Hydraulics Division, Proc. American Society of Civil Engineers, Vol. 89, No. HY1.

Egorov, E. N. (1951a). On some accretive beach forms related to alongshore sand movements, (in Russian), Doklady, Adademii Nauk, U. S. S. R., Tom LXXX, No. 5.

Egorov, E. N. (1951b). Observations of dynamic behaviors of submerged sand bars, (in Russian), Trudy, Okeahologii Instituta, Akademii Nauk, U. S. S. R., vol. 6.

Evans, O. F. (1939). Mass transport of sediments on subaqueous terraces, Journal of Geology, Vol. 47.

Harrison, W. and Wagner, K. A. (1964). Beach changes at Virginia Beach, Virginia, Misc. Paper No. 6-64, U. S. Army Coastal Engineering Research Center, Corps of Engineers.

Hom-ma, M. and Sonu, C. J. (1962). Rhythmic pattern of longshore bars related with sediment characteristics, Proc. VIIIth Conference on Coastal Engineering, Council on Wave Research.

Inman, D. L. and Bagnold, R. A. (1962). Beach and nearshore processes: littoral processes, The Sea, vol. 2, chapter 2, John Wiley & Sons, New York.

Kashechkin, B. I. and Uglev, Iu. V. Some problems of formation and dynamics of submerged bars (through air-photographic data), (in Russian), Trudy, Laboratoria Aerometodov, Tom X.

Kemp, P. H. (1960). The relationship between wave action and beach profile characteristics, Proc. VIIth conference on Coastal Engineering, Council on Wave Research.

King, C. A. M. and Williams, W. W. (1940). The formation and movement of sand bars by wave action, Geographical Journal, Vol. CXII.

King, C. A. M. (1959). Beaches and Coasts, Edward Arnold Ltd., London.

Kobets, N. V. (1958). Accretive forms of underwater bottom reliefs of the Caspian Sea, Southwest Turkmen coast, (in Russian), Trudy, Laboratoria Aerometodov, Vol. VI, Adademii Nauk, U. S. S. R.

Krumbein, W. C. and Oshiek, L. E. (1950). Pulsation transport of sand by shore agents, Transactions, American Geophysical Union, Vol. 31

Larras, J. (1959). Les profils d'equilibre des fonds de sable sous la mer, Annales des ponts et chaussees, n° 18.

Miyazaki, M. (1957). On stable geometry of nearshore topographies, Bulletin, Meterological Research, Japan.

Mogi, A. (1960). On the topographical change of the beach of Tokai, Japan, Japan Geographical Review, (in Japanese with English abstract).

Psuty, N. H. (1966). Caleta beach forms on the Tabasco beach, Mexico, personal communication.

Riviere, A. F., Arbey and Vernhet, S. (1961). Remarque sur l'evolution et l'origine des structures de plage a caractare periodique, Comptes Rendus Acad. Sci., vol. 252.

Russell, R. C. H. and Dyke, J. R. J. (1963). The direction of net sediment transport caused by waves passing over a horizontal bed, International Assoc. Hydraulics Research, Proc. of Congress, London.

Shepard, F. P. and LaFond, E. C. (1940). Sand movement along the Scripps Institution Pier, American Journal of Science, Vol. 238.

Sitarz, J. A. (1963). Contribution a l'etude de l'evolution des plages a partir de la connaissance des profiles d'equilibre, Travaux du Centre de Recherches et d'Etudes Oceanographiques, Tome V.

Sonu, C. J. (1961). A treatise on shore processes and their engineering significances, Pt. II, Mechanics of individual variables, Univ. of Tokyo Ph. D. dissertation.

Sonu, C. J. (1964). Study of shore processes with aid of aerial photogrammetry, Photogrammetric Engineering, American Society of Photogrammetry, Vol. XXX, No. 6.

Sonu, C. J., McCloy, J. M., and McArthur, D. S. (1966). Longshore currents and nearshore topographies, Proc. Xth Conference on Coastal Engineering, Council on Wave Research.

Taney, N. E. (1963). Laboratory applications of radioisotopic tracers to follow beach sediments, Proc. VIIth Conference on Coastal Engineering, Council on Wave Research.

Van Bendegom, L. (1949). Beschouwingen over de gorondslegen van Kustvendediging (Considerations of the Fundamentals of Coastal Protection), Mimeographed Thesis, the Netherlands.