CHAPTER 86

UNDULATED BOTTOM PROFILES AND ONSHORE-OFFSHORE TRANSPORT

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ABSTRACT: Underwater bars, the characteristic features of oceans and lakes occur singly or in a series along the coast. Nearest bar to the shore, namely the break-point bar moves shoreward in summer, joins the coast and is replaced by another bar in its original place. The other seaward bars are storm bars, more or less permanent though they may shift slightly in orientation, position and shape depending upon the wave climate and state of the coastal processes. With the sediment and bottom profiles changing constantly with differing wave characteristics and beach exposure, a rigorous mathematical analysis for long range variability of profiles and therefore coastal processes in not possible. Therefore, the concept of medium depth and steepness characteristics is introduced to distinguish the profiles and their major dimensions.

Onshore-offshore sediment motion is sometimes far in excess of longshore transport mostly confined in the breaker zone. When submarine bars are present, such motion is considerable mainly as a result of the hydrodynamic reaction between the rotating eddies generated over the bars and the bar surface. By means of dimensional analysis, it is possible to relate the quantity of onshore-offshore motion to the bar dimensions, wave period, water depth and transport direction by profile steepness characteristics.

The above two concepts are then applied to the Nile Delta coastal processes with satisfactory results.

INTRODUCTION: Longhsore bars, are a series of submerged sand bars which often form parallel or nearly parallel to the coast. They occur either singly or in a series in the nearshore and offshore zones extending many kilometers into the sea or lake. They develope in both tidal and tideless seas, moving back and forth in the former depending upon the water level fluctuations and are more or less stationary in the latter. A common feature of both is a breakpoint bar - a well developed high and narrow bar at the point of breaking. Offshore of this bar, one, two or three storm bars also develop depending upon the wave climate and they are more or less low in height and wide at base. Lake Michigan (Hands, 1976) and Chesapeake Bay (Ludwick, 1972) areas manifest bars belonging to the tidal seas, whereas Nile Delta coast of the Mediterranean Sea *UNESCO et al 1973) is a typical example having more or less stationary bars of a sea of small tides.

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Waves are known to be the main agents for bar development. Longshore currents may modify them but are not essential for their formation (Keulegan (1948)). The shape of bars depends greatly on wave, beach and sediment characteristics. Overnourished profiles (accretion areas) have flat slopes and fine sediment, whereas undernourished profiles (erosion areas) are steeper with coarser sediment. The bars on the former have wide base unlike the latter. Bars on equilibrium profiles (a stable profile with maximum steepness - Bruun and Manohar, 1963) have features similar to the undernourished profiles. The number of bars is greater on flatter profiles. Generally, the break-point bars and storm bars can be considered as independent features supposedly related to separate events. Further bars over accretion profiles are highly variable in shape, position, orientation and stability whereas those on erosion profiles are known for their regularity.

Whereas within the breaker zone, longshore transport is the predominate transport mode, seaward of the breaker zone, longshore currents unless external, are negligible and therefore in such cases longshore sediment motion may be insignificant. However, in areas where fine sediment and considerable swell and storm activity exist, intense onshore-offshore motion with consequent formation of submarine bars, and they (bars) acting as focus, and area between them acting as transport zone, can be expected. In many coastal area devoid of source nourishment for longshore motion, onshore-offshore transport seaward of the breakpoint bar is several times larger than the longshore movement landward of it.

One of the first laboratory experiments (Manohar, 1955) on onshore-offshore sediment motion emphasized on the nature of the boundary layer at the bottom, the type of bars generated by oscillatory motion at the bottom, and the sediment transport mechanism and the resulting rates. Subsequent laboratory research (Rector, 1954; Eagleson, 1961; Nayak, 1970) showed beach profile characteristics to be functions of wave steepness, height and sediment characteristics. Sitarz (1963) analyzed swell built profiles without bars theoretically and found the shape to be parabolic. Swarts (1974) in his laboratory studies on offshore barless profiles, obtained from regular waves and uniform sand, found them (called D-profile) to be functions of deep-water wave characteristics and sediment size. He found all such transport from his studies, to be offshore. Unfortunately in nature, every variable involved in the generation of profiles, bars and in onshore-offshore motion changes continuously and even for short term variability, no two analyses seem to agree as to the exact relationships between the variables (Saville, 1957). Therefore, these and other similar laboratory studies, though useful for an understanding of the mechanisms involved in the coastal processes, are not of much value in the study of natural beach profiles.

Assuming that onshore-offshore motion is considerable, it is necessary to know its direction. According to Carter et al (1973), some degree of beach reflection is always present and it is related to the foreshore slope and offshore topography which in turn depends upon the profile type existing in the area. For flat slopes with bed sediment being smaller than the boundary layer thickness, net sand transport is mainly onshore because of weak reflection. If reflection coefficient is large (Moraes, 1970) as on steep slopes or with low amplitude waves, sand movement may occur offshore eventually stopping in sufficiently deep water when mass transport becomes negligible at the bottom.

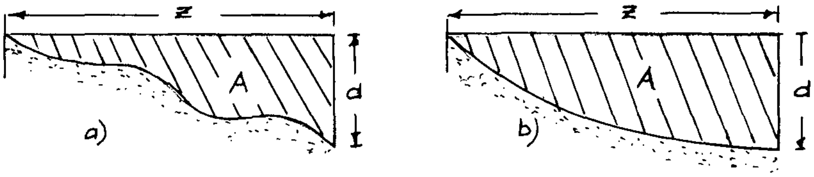
Keulegan (1948), in his experimental study of submarine sand bars, found the following: Water depth remaining constant, depth of bar base and consequently bar position formed by a singly system of waves, is a function of wave height and wave steepness. If the water depth and wave steepness are constant, an increase in wave height will move the bar seaward. If the water and wave height are constant, an increase in wave steepness will move the bar shoreward. If the wave height and wave length are constant, any increase in water depth will move the bar seaward.

VARIABILITY OF PROFILES: Beach profiles being variable in character can be studied by repeated observations over time spans of varying duration. But to interpret the variations one must know the variables causing the changes namely the characteristics of waves, currents, sediments and other interrelated quantities which themselves vary from time to time. Further the controlling processes are different in the nearshore and offshore zones. No doubt statistical analysis of waves may indicate a pattern in its behavior but, such analysis will need many years of data rarely available. Thus analysis on short-term variability basis (Zeigler and Tuttle, 1961; Harrison, 1969), though useful to a limited extent may not be of much help in the analysis of coastal changes on long term basis.

PROFILE VARIABILITY ON LONG TERM BASIS: As already stated, a dynamic equilibrium gradient of a natural beach continuously adjusts itself to the changing variables on which it depends. But, it is safe to assume that its dynamic state will fluctuate within some inner, outer and mean limits for a long term time span. The same may be said to occur on over-nourished and under-nourished beaches also. The concept of medium depth and steepness characteristics of profiles used to define beach steepnesses of the North Sea coast (Bruun, 1954) may be used with advantage to determine the nature of the profiles.

Consider two profiles, namely one of erosion (under-nourished) and another of accretion (over-nourished) (Fig. 1) with the distance of the outer depth limit from the shoreline being the same in both cases. In the former, medium profile depth ($d_m = A/Z$) will be larger than in the latter and the profile steepness ($S_t = A/Z^2$) defined as the medium depth divided by the distance from the shoreline will be larger also. For an equilibrium profile, it will have a constant value.

The importance of these two parameters is that when the analysis of profiles in the field which fluctuate continuously with even a small change in wave and sediment characteristics is difficult, they (the two parameters) give a valuable insight in the dynamic nature of the profiles on a long term basis. Their advantage lies in the fact that changes within area "A" need not be taken into consideration except



a) Overnourished profile

b) Undernourished profile

Medium Profile Depth $= d_m = \frac{A}{z}$

Profile Steepness $= S_t = \frac{A}{z^2}$

FIG. 1: PROFILE DEPTH AND STEEPNESS DEFINITION

the knowledge as to whether they are eroding or accreting which in turn can be determined from a few hydrographic surveys. This approach, therefore, avoids the analysis of profile changes as functions of wave and sediment characteristics. The latter analysis will result in so many numbers of profile shapes (mostly smooth shapes without bars) that it will be difficult to interpret the results for long term analysis. No doubt, each coast will have its own limiting medium depth and profile steepness characteristic but, these can be obtained from a few surveys.

NEARSHORE SEDIMENT MOVEMENT: In the analysis of nearshore processes, as stated earlier, it is preferrable to study the changes within and beyond the breaker zone separately. It is also necessary to determine the influence of the various bars on sediment transport and its direction.

Out of the two or three bars developed on beach profiles, the nearest one (break-point bar), frequently joins the shore in summer since swells with longer periods and smaller wave steepnesses cause a net shoreward sediment transport. When this bar joins the coast, a new bar is formed at its previous location and the process is repeated. This onshore sediment in motion trapped between the break point bar and the shore is the primary sediment source for alongshore transport unless external sources such as river sediments are available. Further, the nearshore circulation systems being more regular in summer than in winter, localize the coastal processes. Also the alongshore transport is much less in summer than winter, the major summer process being the shoreward transport.

With relatively large waves of the winter (large wave steepness), angle between the breaker line and shoreline in the breaker zone becomes the controlling factor for longshore current direction. Similarly, there is greater turbulence in the surface zone which keeps the sediment in suspension particularly in the shallow water zone. With mass transport from high waves being greater, substantial translation waves are also generated on wave breaking resulting in shoreward flow of water at the surface and seaward current at the bottom. Thus in winter, these flow systems cause formation of undulations, large and small, at the bottom.

Seaward of the break point bar, the onshore-offshore sediment exchange is likely to be as follows: When deep water waves travelling towards the shore start feeling the bottom (approx. when $d/L < 0.5$), ripples are formed which eventually become large size bars in the nearshore zone orienting themselves parallel to the wave crests. With the passage of waves, sediments will move from one side by the bar crest to the other (Fig. 2). When depth decreases, bottom velocity distribution with time changes from approximately sinusoidal to one that has a high shoreward component associated with the brief passage of wave crest and smaller seaward velocities associated with the longer time interval of the trough passage (CERC, 1973). When the shoreward velocity decreases with the crest passage and begins to reverse direction, sediment is placed in suspension from the landward side of the bar and this is transported with the seaward flow under the trough. Generally landward flow drops material shoreward as bed load and suspended load

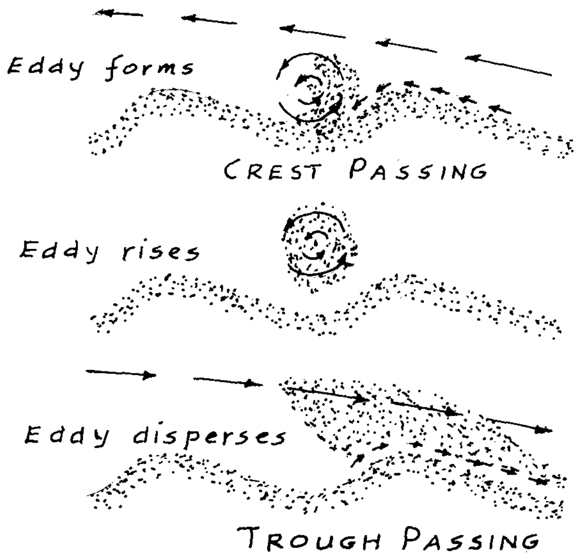


FIG. 2: ONSHORE-OFFSHORE EXCHANGE AROUND BARS

goes seaward. Thus in areas having coarser sand and lesser fines, net shoreward movement may be higher. Vice versa is likely to occur for more fines and less coarse material. Further, most storms move large amounts of sediment from the beach offshore but after each storm, the smaller waves which follow, tend to restore this loss shoreward to some extent unless another storm intervenes in the process. Successive storms in the same area may generate sufficient transport in the opposite directions causing insignificant net coastal changes whereas if the transportion direction before, during and after the storms is the same, changes can be considerable.

FACTORS AFFECTING ONSHORE-OFFSHORE TRANSPORT OVER BARS

In his classical analysis of onshore-offshore sediment transport over the bars, Keulegan (1948) showed that correlation exists between the sediment transport rate and total displacement of water surface during the passage of a wave. Using dimensional analysis, it can be shown that:

$$\frac{QT}{\rho_s g\, d^2} = f\left(\frac{\Delta H}{d}, \frac{\rho_w}{\rho_s}, \frac{\sqrt{gd}\, D}{\nu}, \frac{d}{gT^2}, \frac{D}{d}, m, \sigma_\phi\right)$$

defining the laws of sediment motion. In this,

Q = sediment transport rate

ρ_w & ρ_s = densities of water and sediment respy

ΔH = total displacement of water during the passage of a wave

d = depth of water at the seaward toe of the bar

T = wave period

D = characteristic grain size

ν = kinematic viscosity of water

m = bed slope

σ_ϕ = sand dispersion coefficient

Assuming other quantities to be constant for a given wave condition,

$$\frac{QT}{\rho_s g\, d^2} = f\left(\frac{\Delta H}{d}\right) .$$

Since the total displacement ΔH is composed of the maximum elevation of the surface above the undisturbed water level and the corresponding maximum depression during the passage of a wave, it may be further approximated, to be the breaking wave height over the bar. Further assuming the breaking wave height = depth of water at the point of breaking, ΔH is equal to the depth H on top of the bar. In other words

$$\frac{QT}{\rho_s g d^2} = f\left(\frac{H}{d}\right)$$

The significance of this equation (as confirmed by model experiments) can be understood if one looks at each of the quantities in the equation. The wave period T, specifies the type of waves, density ρ_s, the weight characteristics of the sediment; d, the depth seaward of the bar; and H, the depth of water over the bar. These basic variables govern the sediment transport rate. The term (d-H) namely the height of the bar governs the hydrodynamic reaction between the rotating eddies between the bars and the sediment surface of the bars.

DIRECTION OF ONSHORE-OFFSHORE TRANSPORT: The influence of water depth, wave height, and wave steepness in moving the sediment seaward or shoreward has already been mentioned. Unfortunately, because of their continuous variability, their use for long range interpretation of direction of transport is impractical. One likely solution to this problem is again the use of medium depth and profile steepness concept. If the value of the steepness characteristic decreases as compared to its previous value, the predominent transport will be onshore and vice versa will occur for offshore transport. Similar use of medium depth is possible.

APPLICATION TO FIELD DATA

The above concepts were applied by the author on the Nile Delta coastal studies spanning from 1971 to 1977. During that period, annual and semi-annual hydrographic surveys were conducted, waves and currents were measured, and erosion and accretion trends of the 240km long coastal stretch (Fig. 3) were monitored and continuously analysed.

BAR ANALYSIS: The characteristic feature of the Nile Delta coast of the Mediterranean Sea is that it has a series of longshore bars, typical of a tideless sea. In general, there are three bars, one nearest to the shore being the break-point bar in one to two meter depth, with the middle one (in three to four meter depths) and the outer one (in five to six meter depths) being the storm bars. The breaker zone bar is mobile and shifts landward during summer accretional processes, joins the coast and is replaced by another similar bar. The other two bars are permanent features adjusting back and forth consistant with wave climate. Field observations confirm that the first bar is formed by the short steep waves and swells with the middle and outermost bars being formed by storm waves. As regards to their heights, there is no regular pattern. They may be as high as one meter and sometimes wide at base and low. Generally, greater heights cause greater onshore-offshore motion. Typical barred profiles are shown in Fig. 4.

UNDERWATER PROFILES: All three types of profiles, namely undernourished, equilibrium and overnourished profiles exist on the Nile Delta coast (Fig. 5), though equilibrium profiles are found only on very short stretches.

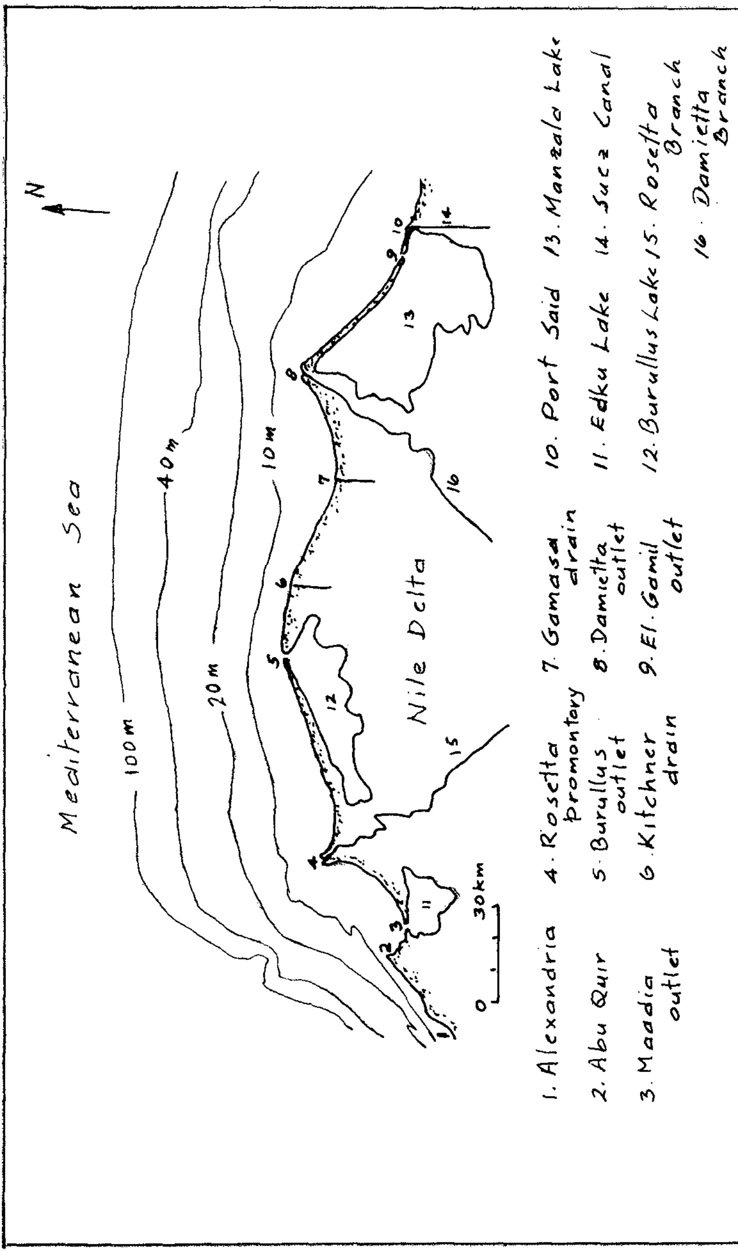


FIG. 3: NILE DELTA COAST

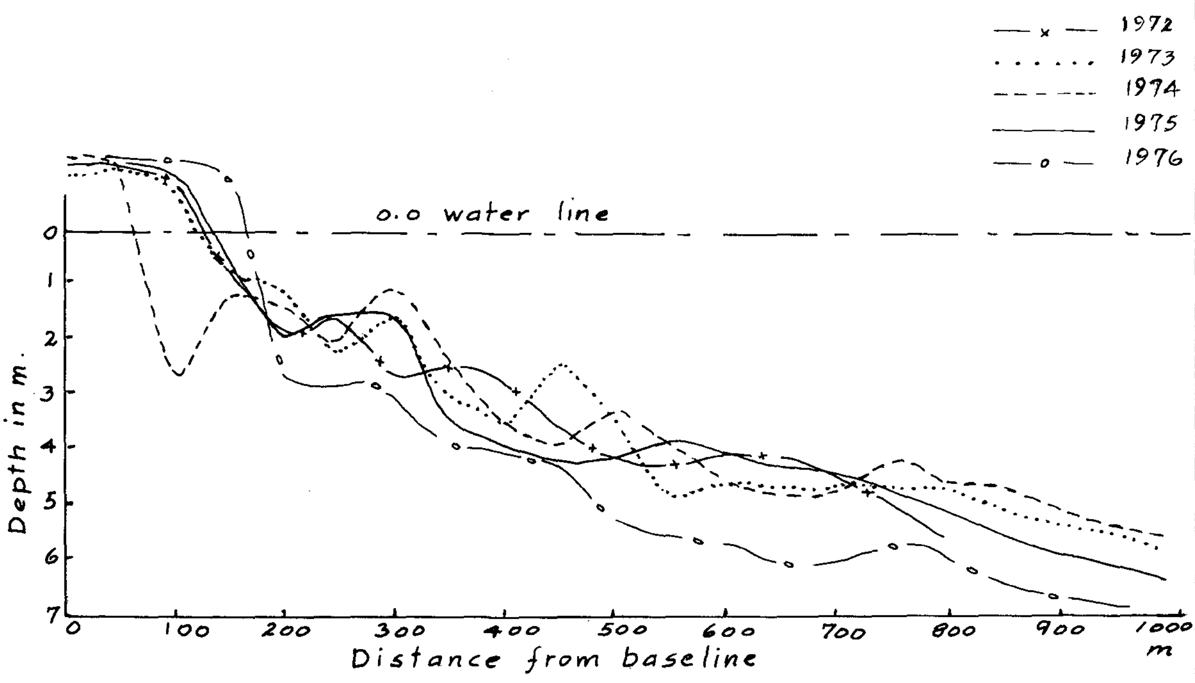


FIG. 4: TYPICAL PROFILES WITH BARS

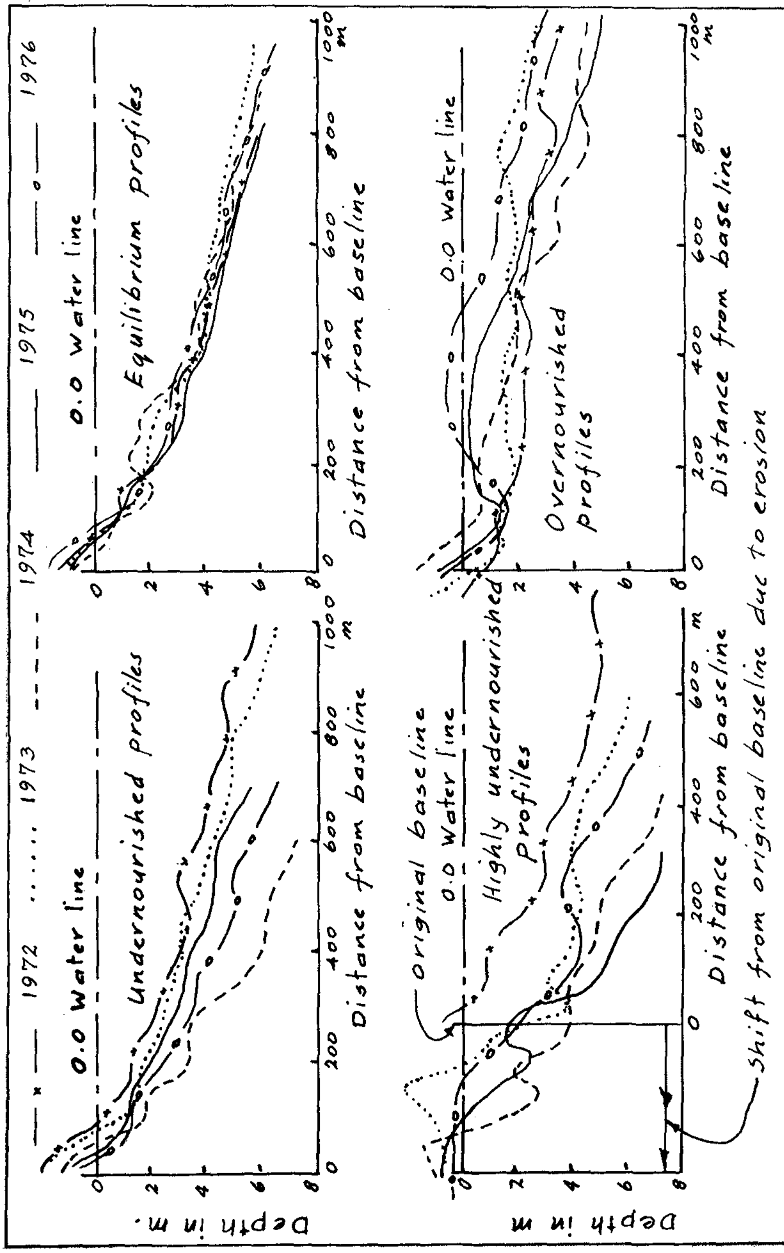


FIG.5: TYPES OF PROFILES

Analysis based on medium depth and steepness criteria shows that the limiting value of profile steepness represents equilibrium profiles with a value of $A/Z^2 = 0.0049$ with accretion profiles having lower values and erosion profiles having higher values (Fig. 6). Medium depth criterion for different types of profiles is shown in Fig. 7. Fig. 6 is also useful for preliminary determination of area A and type of profile from a measurement of depth d beyond the bars and the corresponding distance from the shoreline. Fig. 8 shows the status of the Nile Delta coast profiles based on profile steepness.

SEDIMENT TRANSPORT: Continuous monitoring of the coast for six years, analysis of yearly and semi-annual hydrographic surveys, calculation of gross volume and net volume changes, determination of alongshore transport by actual measurements and refraction analysis in the breaker zone, and analysis of sediment movement patterns by T-X diagram (a 3-dimensional representation with time on the vertical axis and baseline distance along the shore on the horizontal axis) indicate the following:

i) alongshore transport in the breaker zone is small compared to the total sediment in motion;

ii) bottom changes do not follow any set pattern or alongshore direction;

iii) there is no predominent direction in which the sediment moves;

iv) net volume changes appear independent of time, that is, volume changes in an interval of four to five years is not anywhere equal to the volume change per year multiplied by time even if overall change in wave climate is insignificant;

v) movement is compartmentalized in various stretches (physiographic units) and;

vi) changes beyond the breaker zone in the onshore-offshore direction within the physiographic units are several times more than the alongshore changes.

Using the already described dimensional analysis as the tool and assuming the sediment trapped between the bars is mainly the result of onshore-offshore transport, quantity Q, in movement between the bars was calculated as a function of height of the bars (d-H), wave period T and depth d seaward of the bars. Figs. 9, 10, and 11 show that relationships do exist between them. Fig. 9 also shows that beyond a certain increase in bar height, the rate of increase in quantity trapped, drops considerably because under those conditions, waves are liable to break on the bars and the transport mechanism becomes different. The quantities so calculated, agree well with the erosion and accretion rates calculated from hydrographic surveys using the bar steepness criterion for finding the transport directions.

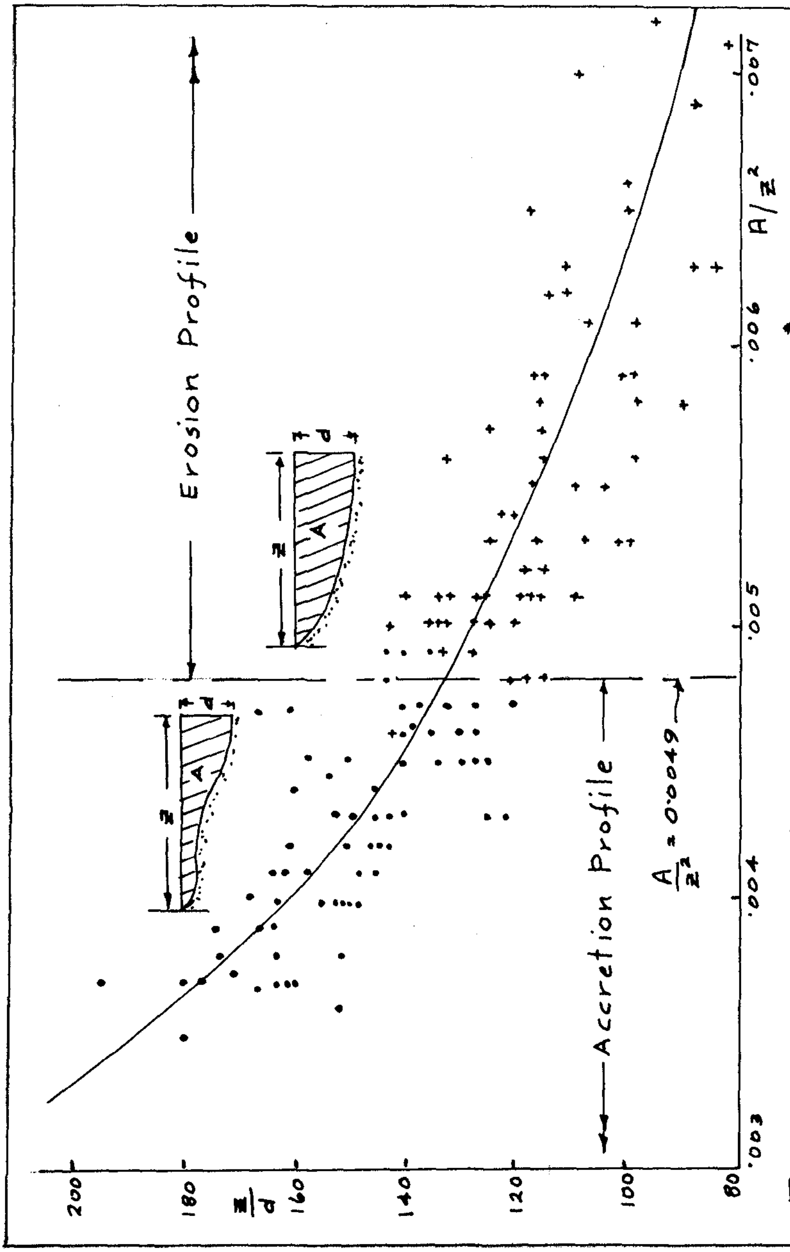


FIG. 6: PROFILE STEEPNESS FOR N.D.C.* PROFILES

* Nile Delta Coast

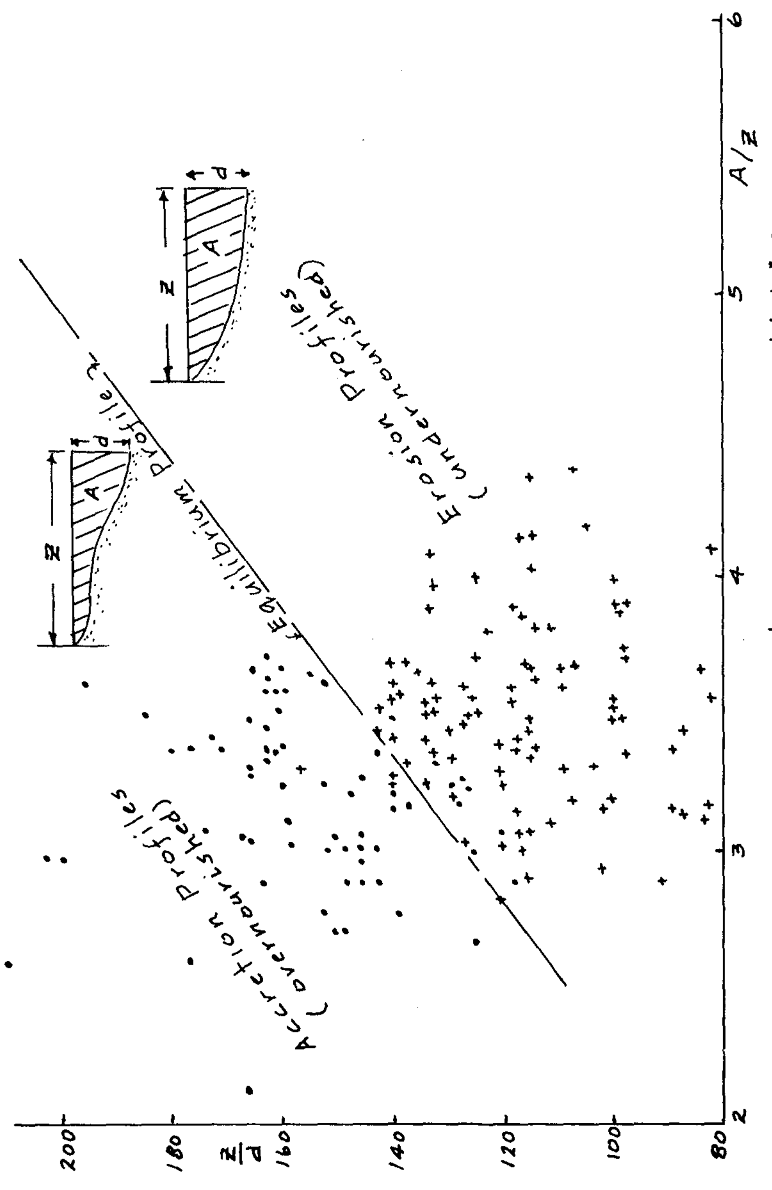


FIG. 7: PROFILE MEDIUM DEPTH FOR N.D.* COAST

* Nile Delta

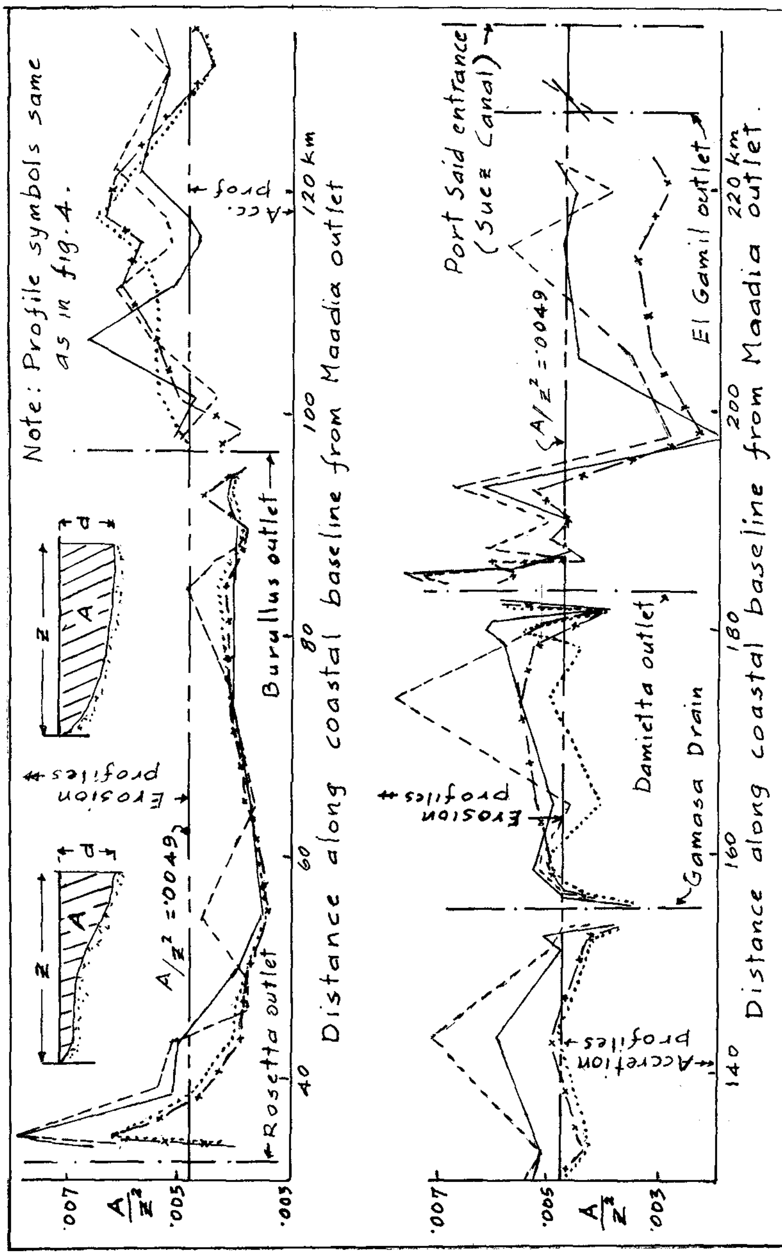
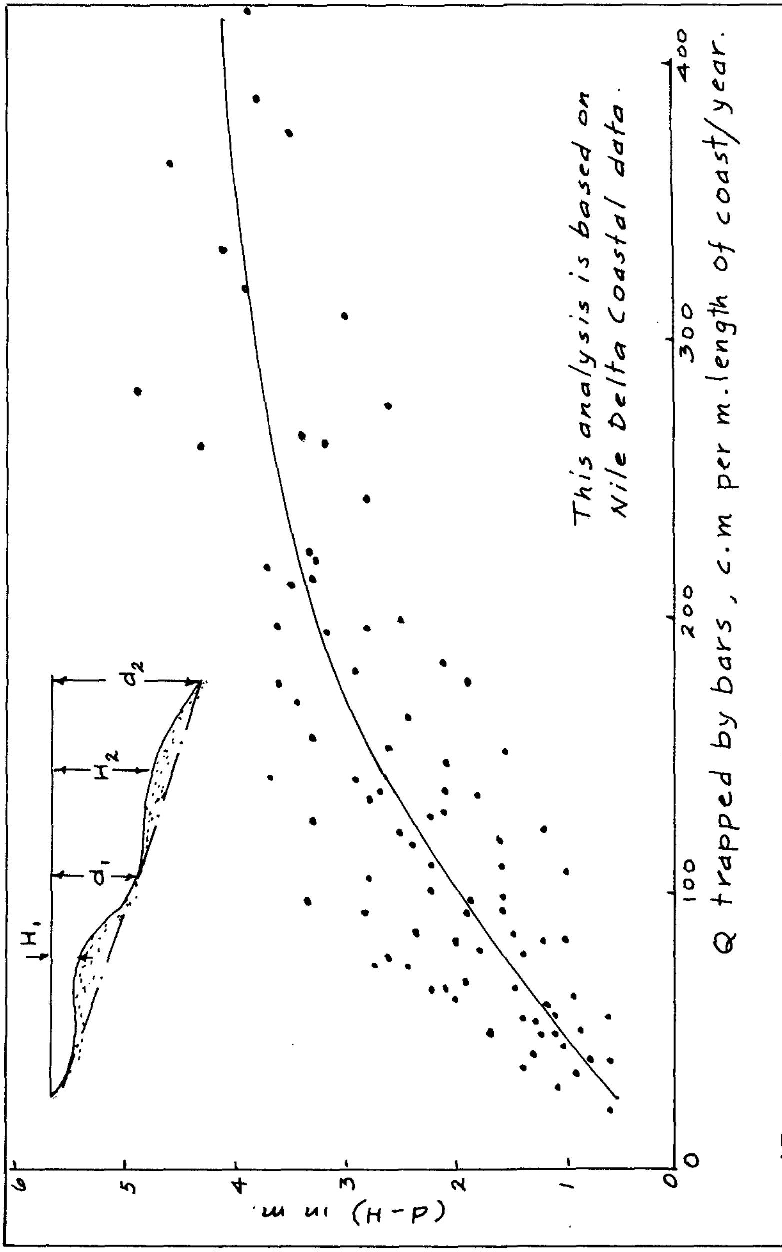
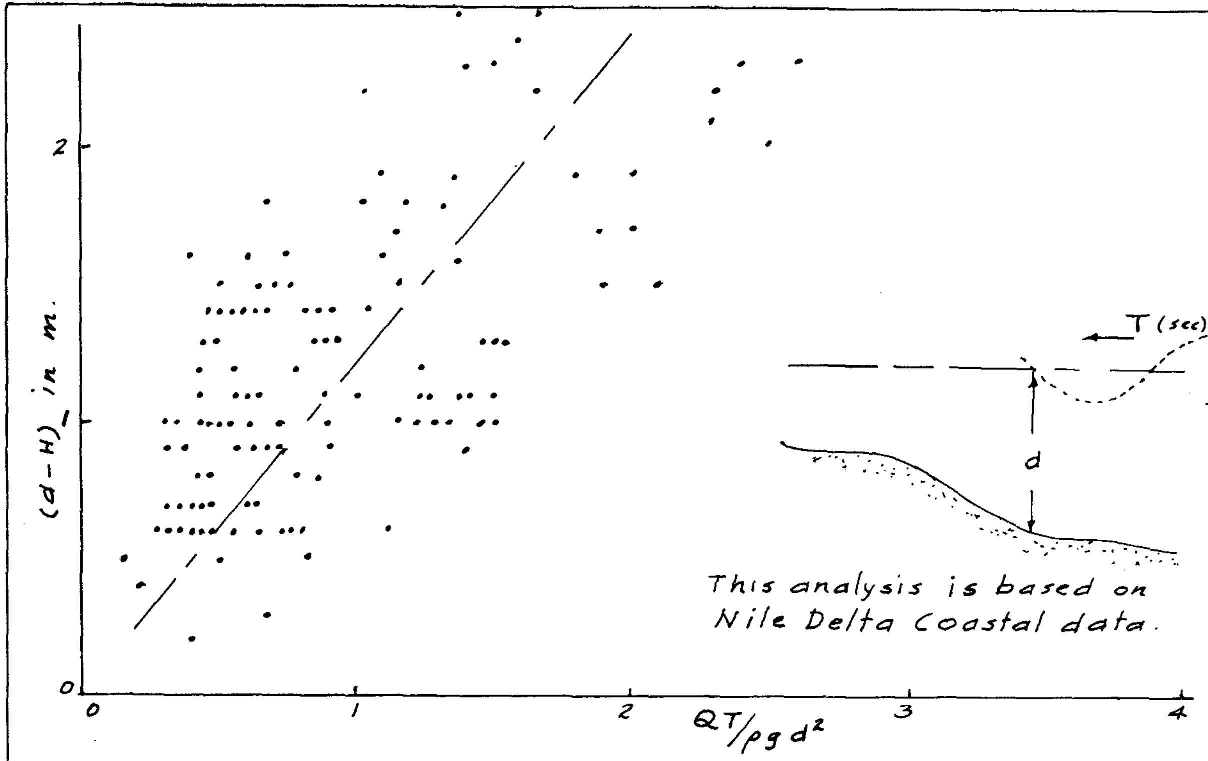


FIG. 8: PROFILE STEEPNESS - NILE DELTA COAST



This analysis is based on Nile Delta Coastal data.

FIG. 9: ONSHORE-OFFSHORE Q VS BAR HEIGHT



This analysis is based on Nile Delta Coastal data.

FIG. 10: ONSHORE-OFFSHORE Q AS FUNCTION OF T, d, & H

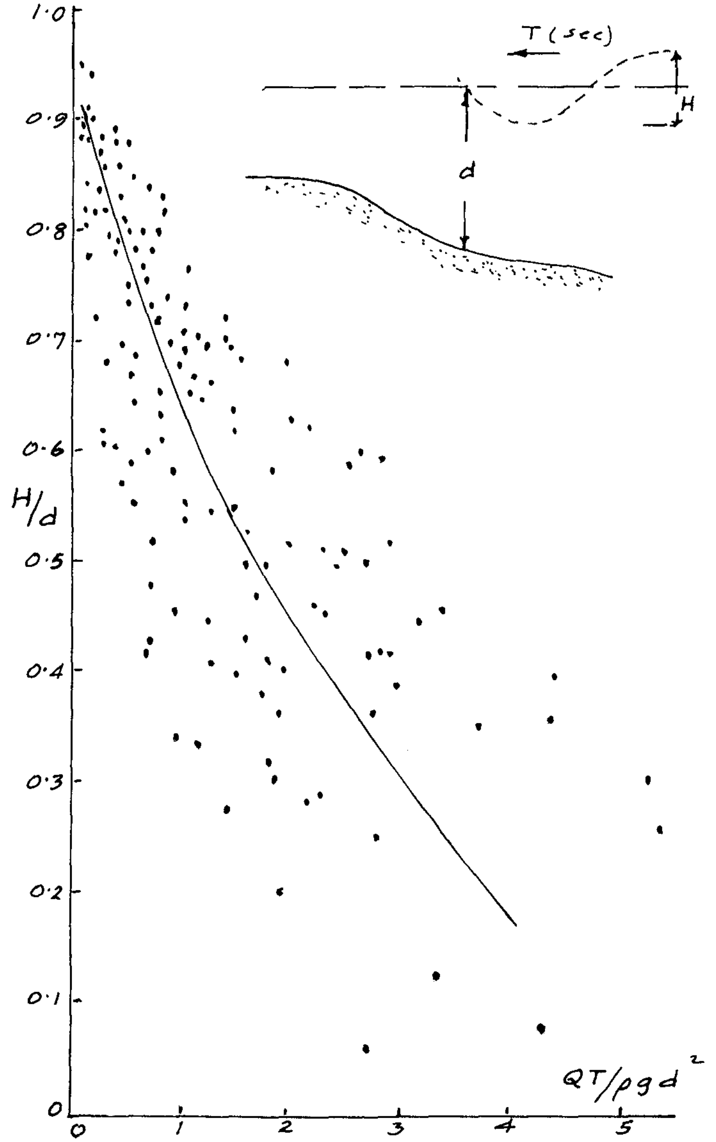


FIG.11: $\frac{QT}{\rho g d^2}$ VS $\frac{H}{d}$ FOR N.D.C*

* Nile Delta Coast

CONCLUSIONS

1. Characteristic features of majority of coasts facing seas with moderate or no tidal action are the existance of one or more submarine bars beyond the breaker zone and a break point bar in the breaker zone.

2. Underwater profiles with or without bars can be divided into three categories, namely, undernourished profiles in erosion areas, equilibrium profiles in dynamically stable areas and overnourished profiles in accretion areas.

On long term basis, they can be distinguished by medium depth and profile steepness criteria which will have certain limiting values for different types of profiles for a particular coast.

3. Though alongshore transport may predominate in the breaker zone, onshore-offshore transport beyond may be many times more influencing the coastal processes on a far bigger scale than has been anticipated at present. Submarine bars influence such motion to a considerable extent. Using dimensional analysis as the tool, onshore-offshore motion or vice versa can be calculated as functions of bar height, sediment density, wave period and depth behind the bars.

4. The methods described in 2. and 3. are applied to the Nile Delta coast where a comprehensive study of coastal processes has been in existance since 1971.

5. The fact that the coastal processes beyond the breaker zone especially in the onshore-offshore direction influence the erosion and accretion patterns much more than the alongshore transport, emphasizes the view held by many coastal engineers that the engineering project study of a coast should be extended far into the offshore zone.

ACKNOWLEDGEMENTS

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