CHAPTER 245

SHORELINE EROSION DUE TO OFFSHORE TIN MINING

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ABSTRACT

Phuket is a well-known island resort on the west coast of the peninsula of Thailand and it is rich in tin deposits. Tourist and tin mining are conflicting especially in Bang Tao Bay. Before offshore tin mining in the bay, the bathymetry is quite simple/natural and the bay is almost in equilibrium with offshore sand movement by storm waves and onshore sand movement by swell. After tin mining in 1987, people in Villages 4 and 5 sent a petition to district and city officers from May to June 1988 to the effect that offshore tin mining in the bay had caused beach erosion and road damage, and that the dredger owner should be responsible for the cost of repairs. The sounding map makes in this study reveals that deep holes are created by dredgers, those nearshore are found to interrupt the cyclic changes and sand movement on the beach that results in a permanent loss of sand into the dredged holes and causes shoreline erosion; the maximum erosion in the middle of the bay is 40 meters in the 3 years from 1987 to 1990. A field test during May to June 1991 confirms that the high rate of shoreline erosion is consistent with that found in large wave tank experiments. Offshore tin or sand mining should not be made in shallow water where sand is mobile. If offshore mining were allowed nearshore, conditions should be imposed so that the bathymetry in the vicinity of the offshore mining should not change significantly.

INTRODUCTION

Phuket is a well-known island resort on the west coast of the peninsula of Thailand as shown in Fig.1. In general, tin mining is not presently allowed in most of the beach resorts of the island except in Bang Tao Bay where two concessions were granted for offshore tin mining in the belief that the dredged materials, after the sorting out for tin by the dredgers, would be replaced in the dredged holes, which would not change the bathymetry much.

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The study area in the vicinity of the Dusit Laguna beach of the Bang Tao Bay on the west coast of Phuket island is shown in Fig. 1. The bay is attacked by waves during the southwest monsoon from May to September. Predominant waves attacking the bay are mainly from the west and they cause onshore-offshore transport with not so much alongshore transport. During the northeast monsoon, the wind blows from land to sea over the bay; therefore, there is negligible wave action in the bay. In addition to these monsoons, the bay is occasionally attacked by cyclonic waves prevailing in the Andaman Sea. The bathymetry of Bang Tao Bay before offshore tin mining is quite natural as shown in Fig. 1c.

From May to June 1988, at the beginning of southwest monsoon, severe waves caused erosion of the shoreline and road damage in the Bang Tao Bay. People in Villages 4 and 5 sent a petition to district and city officers to the effect that offshore tin mining in the bay was the cause of beach erosion and road damage and that the dredger owner should be responsible for the cost of repairs. On October 15, 1988 the Minister of Industry visited the site and asked the Mineral Resources Department to order the dredger to dredge beyond 500 meters from the shoreline. The Mineral Resources Department (1990) studied the cause of erosion of the Bang Tao Bay with the assistance of the Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas (CCOP) and concluded that (i) severe waves caused erosion of all beaches on the west coast of Phuket in 1988 and (ii) the instability of the BangTao shoreline due to previous tin mining on land might be the cause of erosion. Due to the limited time of the study, no reason for erosion caused by offshore tin mining could be found, however the search would be studied further.

The causes of the shoreline erosion can be initially listed as follows:

1. Storm waves with high wave steepness generated by cyclones or southwest monsoon move sand on the beach offshore.
2. Alongshore currents generated by inclined breaking waves move sands alongshore and deposit it somewhere.
3. Offshore tin mining close to the beach creates holes which draw beach sand.

The objectives of this study are as follows:

1. To make field surveys to collect relevant data and to monitor dredger activity.
2. To find out the causes of beach erosion.
3. To recommend remedial measures to conserve the beach resorts from erosion.

Steps to solve the problem are as follows: a review of the literature is made first on the effects of the offshore dredged holes on shoreline erosion. The most important part of this study is the field survey which is then described, while field data and their interpretation are finally presented.

REVIEW OF LITERATURE

There are limited reports on the effects of offshore dredged holes on shoreline erosion; the followings are some examples.

Motyka and Willis (1974) presented the preliminary results of a study of the beach erosion by wave refraction over offshore dredged holes. A mathematical model was used of an idealized sand beach, typical of those on the English Channel and the North Sea coasts of Great Britain. Depth and side slopes of dredged area and original water depth before dredging were varied. Beach erosion increased with increasing hole depth and with depth. At present, dredging was not allowed shoreward of the 18 m depth contour on sediment supply considerations. Their results suggested that for the North Sea and the English Channel coasts, the effects of wave refraction also point to an 18 m minimum depth. This is approximately half the wavelength of the most common wave period, and a fifth of the length of the extreme wave period; hence it might be possible to extrapolate these results to other areas on a wavelength basis. Beach erosion due to holes in water depths greater than half the length of "normal" waves, or a fifth of the length of extreme waves, was negligible. They concluded that results were conservative, that the study was predicting larger amounts of erosion than would occur in nature. This was due to the fact that erosion was caused by differences in sediment transport along the beach, and the assumption in the refraction calculation that wave energy could not propagate along the wave front tended to exaggerate these difference.

Price, Motyka and Jaffrey (1978) dealt with the licensing procedure of dredging and assessed how dredging might affect the coastline. They provided some guidelines on the monitoring of shoreline erosion due to dredging:

(1) Beach drawdown - This usually occurs during storms due to the action of high steep waves. Beach material is eroded from the upper foreshore and moved seawards. However, during periods of calmer weather the material is returned to the beach by long low swell. If the dredged area is to near the coastline then this dynamic equilibrium can be upset, in that material may be transported from the upper portion of the beach into the dredged hole and erosion of the foreshore may result. The active zone of offshore-onshore movements extends to a certain depth of water and a certain distance from the shore. Thus, with respect to beach drawdown, there are two criteria - a minimum depth of water and a minimum offshore distance.

(2) Interception of sediment - If the beach is being fed from offshore by current and wave action then dredging may trap a proportion of this material and interrupt the supply to the shore. It is very important, therefore, that dredging should be excluded from any deposits which are moving actively. The threshold of movement of sediments. The dredged trenches above a certain depth within the active zone of littoral movement may interrupt the beach littoral system in that they serve as a trap to littoral sediment that would travel either onshore of alongshore.

(3) Dredging area included offshore banks - Offshore banks help to protect the coastline form wave attack either by dissipating wave energy as a result of bed friction, by partial breaking of the waves, by refraction or by any combination of these three. A permanent lowering of the crest of the bank due to dredging can result in changes of the wave refraction pattern and hence changes in the net angle of wave attack at the shoreline. Thus, under certain circumstances, dredging from offshore banks can alter the rate of littoral drift and hence affect the stability of the shoreline.

(4) The effect of changes in wave refraction - As waves approach the shore, they travel with a group velocity that is dependent upon their period and upon the depth of water. If the water depth increases locally, e.g., over a dredged hole, the velocity and wavelength change. The local increase in wave celerity due to the increase water depth causes changes in the angle of wave approach to the beach. Such changes result in a variation in the rate of littoral drift along the shoreline and can cause either accretion or erosion.

Kojima, Ijima and Nakamuta (1986) carried out comprehensive coastal engineering studies over four years in order to evaluate the impact of offshore dredging on shorelines as well as the adjacent seabed along the Genkai Sea , Japan. The results (data presented) indicated a possible relationship between sand mining and the shoreline changes. Although the available data were not sufficient to establish a direct cause-and-effect relationship between offshore mining and beach instability, the correlation was sufficient to serve as a warning of a potentially serious problem. Moreover, dredged holes above the water depth of about 30 meters were found to be refilled with sand which would be mainly transported from the onshore side, thereby interrupting the beach littoral system by trapping sand which might travel in the on-offshore or alongshore direction and causing a steeper beach slope in the long run. It was advisable, therefore, that the indiscriminate removal of sand from seabed be avoided at such water depth of 35 meters. Thus, offshore mining that would minimize interruption of beach littoral system should be operated below a depth of 35 meters in the study area.

Uda, Agemori and Chujo (1986) investigated the conditions of the dredging of the offshore bed on the Kochi Coast, facing Tosa Bay, Japan. Aerial photographs and the sounding data of the coast were analyzed to obtain the beach changes accompanied by the formation of the dredged hole. The flood of the Niyodo river brought large amount of sediment to the coast; the sediment outflow from the river fell into the dredged hole by eastward littoral drift. The hole was refilled slowly from the west side by the littoral drift directing eastward. An abrupt change of the topography due to the onshore-offshore sand transport did not happen as the dredged hole was filled by river sediment carried by the flood and littoral current.

Larson, Kraus and Sunamura (1988) developed a numerical model for simulating beach profile change in the surf zone produced by wave-induced cross-shore sand transport. Model development was founded on two data sets from large wave tank experiments performed by the U.S. Army Corps of Engineers in the years 1956-1957 and 1962 while the second data set was from experiments performed at the Central Research Institute of Electric Power Industry in Japan.

Storm waves with high wave steepness erode the beach producing offshore bars while swells with low wave steepness accrete the beach bringing back bar material onto the beach; the cyclic changes of beach are shown in Fig.2. When storm waves attack a beach for a sufficiently long time, its beach profile would approach an equilibrium. In other words, when sand moves offshore the offshore bar simultaneously increases in volume to approach an equilibrium size as shown in Fig. 3. Their chronological changes of beach profiles for 2 cases are shown in Fig.4. At the beginning of an attack by storm waves, the beaches change rather quickly but they change rather slowly when they approach the equilibrium. Correlation analysis involving wave and beach profile parameters showed that equilibrium bar volume was most closely related to wave height H_o and sand fall velocity w (or grain size). A large wave height implied a larger bar volume, and a higher fall velocity (or larger grain size) produced a small bar volume. A regression relationship was derived relating the non-dimensional equilibrium bar volume V_{eg}/L_o^2 to the quantities $H_o/(wT)$ and H_o/L_o according to

$$\frac{V_{eq}}{L_o^2} = 0.028\left(\frac{H_o}{wT}\right)^{1.32}\left(\frac{H_o}{L_o}\right)^{1.05} \qquad (1)$$

where deepwater wavelength $L_o = gT^2/(2\pi)$ and T = wave period.

Note that the active zone of sand movement is confined mainly in the surfzone where waves are broken due to their instability in shallow water when the water depth is about equal to the wave height. Therefore, the higher wave would create a wider surfzone and would result in much more active sand transport.

Dette and Uiczka (1987) investigated dune recession and beach erosion at prototype scale in the big wave flume in Hannover, Germany. Results on time

-dependent erosion volume and recession of dune were presented for "**dune without foreshore**" and " **dune with foreshore**" in Figs.5 and 6. The simulated wave had a significant height of 1.5 m and peak period of 6 sec at 5 m depth of water, while the sand used had a median diameter of 0.33 mm. In the presence of the foreshore, compared to the profile development due to regular waves, the recession of the dune's edge was only about one-third of that recession measured for dune without the foreshore. The bar location was about 10 m further seaward. Hence, the breaking occurred further away from the dune's face and a wider surf zone provided additional dissipation of wave energy.

FIELD SURVEY AND RESULTS

Program of Field Survey

Field data on wave climate, alongshore current, wind and resulting beach erosion were collected to obtain pertinent information on morphological changes and offshore dredging effects on the shoreline. The characteristics and behavior of the beach were monitored by field measurements of beach shape and profile, soundings and bed material sampling. Locations of dredgers operating in the bay were measured daily by reading the angles of the dredger at two observation locations onshore.

Three soundings have been made for an area of 2.5 km alongshore by 1.5 km offshore, the first at the end of October 1990 before the arrival of dredgers; the second at the end of April 1991 by the end of dredging; and lastly at the end of October 1991 after the attacks of southwest monsoon waves. The first and the last soundings were accompanied by beach profile measurement and beach material samplings.

Waves and winds were measured at two locations about 300 m offshore, together with alongshore current at one hour intervals during the daytime.

Topographical Change

From the above three soundings maps surveyed in October 1990, and April and October 1991, the following topographical changes could be seen.

(1) Shoreline erosion - Comparing contour lines of soundings in 1990 with those in 1987 for the shorelines, it was found that severe erosion occurred between DL3 and DL5. Average erosion rate from 1987-1990 was about 7 meters per year with the maximum of about 13 meters per year in the vicinity of Inlet 2.

(2) Creation of deep holes nearshore - It can be seen form Fig.7 of the sounding of the Bang Tao Bay in October 1990, that many deep holes were created by dredgers operating nearshore from 1987 to 1990 as compared with the natural bathymetry before offshore tin mining, shown in Fig.1c. These nearshore deep holes interrupted the cyclic changes of the beach in terms of erosion by storm waves and subsequent accretion by swells (Fig.2) and, therefore, resulted in a permanent loss of sands from the erosion of beach into the

dredged holes. It can be seen from the beach profiles at DL1, DL2, DL3 and DL4, plotted in Figs.8 (a), (b), (c) and (d) respectively, that deep holes existed at an offshore distance of about 300 meters, while the beach profiles at DL5 and DL6 in Figs.8(e) and (f) respectively are more natural, namely without deep holes nearshore. The onshore sides of these nearshore deep holes in the active zone of sediment movement by wave action; the mobile sediment will fall down the steep slopes of the deep holes especially the deep hole A4 at DL4. Comparing these beach profiles with those in Fig.6, it can be seen that profile DL4 is similar to that of dune without foreshore while profiles DL5 and DL6 are similar to that dune with foreshore. Therefore, nearshore deep holes changed the natural beach of dune with foreshore to dune without foreshore which experienced a much higher rate of erosion.

(3) Field test of shoreline erosion - In order to obtain an order of magnitude estimate of shoreline erosion, a test was made by dumping about 6,000 m^3 of sand on the beach for alongshore distance of 300 m. The beach-fill was agitated by the southwest storm waves on June 2-4, 1991 and approximately half of the filled sand was eroded while the remaining half was eroded during June 5-13, 1991. Practically, no erosion occurred on May 15 to June 1, 1991. According to the wave data collected during May 18 - June 13, 1991, wave heights were the largest on June 2 - 4 and 9 - 13 with a range of 1.0 - 2.5 m while the wave period was about 6.4 sec. During the period of June 5 - 8 , wave heights were around 0.8 - 1.4 m with a wave period of 8.1 sec. The wave condition was calmer from May 18 - June 1 with wave height of 0.4 - 0.9 m and period of 8.2 sec. Slope of beach at the upper section is steeper compared to that of the offshore side in the mid tidal zone. When waves attacked upper section of the beach at high tide the erosion rate was higher. The average erosion volume per meter of beach was 20m^3/m.

Field Conditions

Winds and waves change from year to year. However, their trends or orders of of magnitude are common. The most probable of commonly recorded waves measured in this study during the southwest monsoon by Vongvisessomjai and Huq in 1991, as compared with those measured earlier in 1980 shown in brackets (Gayman, 1983) are as follows:

Month	Wave Height (m)		Period (sec)	
	1991	(1980)	1991	(1980)
May	0.3-0.5	(0.0-0.5)	7.0	(4.5)
June	0.5-1.5	(0.5-1.0)	7.0	(6.5)
July	0.5-1.5	(0.5-1.0)	7.0	(6.5)
August	0.5-1.5	(0.5-1.0)	7.0	(6.5)

The above wave characteristics could serve as commonly recorded waves on the west coast of Phuket during the southwest monsoon.

The southwest monsoon waves are mainly from the southwest or west or northwest. As they propagate into shallow water and break near the shoreline, their crestlines are almost parallel or make some small angles with respect to the shoreline. Therefore, they generate no alongshore current or alongshore current towards the north/south direction. The magnitudes of alongshore current measured in this study are about 0.15 - 0.20 m/sec. with a north or south direction in May, a predominantly north direction in June and a predominantly south direction in July and August 1991.

The erosion volume V_{eq} of the equilibrium profile (Eq.1) depends on deepwater wave height and fall velocity (or grain size). A larger wave height implies a larger erosion volume, and a higher fall velocity (or larger grain size) produces a smaller erosion volume. Using typical median diameters of 0.5 and 0.2 mm, wave period of 6.5 sec and wave heights of 0.5 - 2.0 m, the computed erosion volumes V_{eq} are listed below:

d_{50}(mm) (1)	H_o(m) (2)	T(sec) (3)	L_o(m) (4)	w(m/s) (5)	H_o/L_o (6)	$H_o/(wT)$ (7)	V_{eq}(m^3/m) (8)
0.5	0.5	6.5	66	0.074	0.008	1.01	1
	1.0				0.015	2.08	4
	1.5				0.023	3.12	10
	2.0				0.030	4.16	20
0.2	0.5	6.5	66	0.027	0.008	2.85	3
	1.0				0.015	5.70	15
	1.5				0.023	8.55	39
	2.0				0.030	11.40	77

The erosion volumes of fine sand (d_{50}=0.2 mm) are about four times those of coarse sand (d_{50} = 0.5 mm). These computed erosion volumes agree well with those tested in the field of shoreline erosion of 20m^3/m.

RECOMMENDATION

1. Offshore tin mining or sand mining should not be made on the west coast of Phuket in shallower water than 15 meters based on wave conditions and sand characteristics at the site compared with those of England and Japan of 18 and 35 meters respectively.

2. If offshore tin mining were allowed nearshore in shallower water than 15 meters, conditions should be imposed so that the bathymetry in the vicinity of offshore mining should not change significantly.

3. Beach nourishment should be made around Inlet 2 in order to restore the beach of Dusit Laguna; structural control of shoreline erosion would not be effective here due to the presence of nearshore deep holes.

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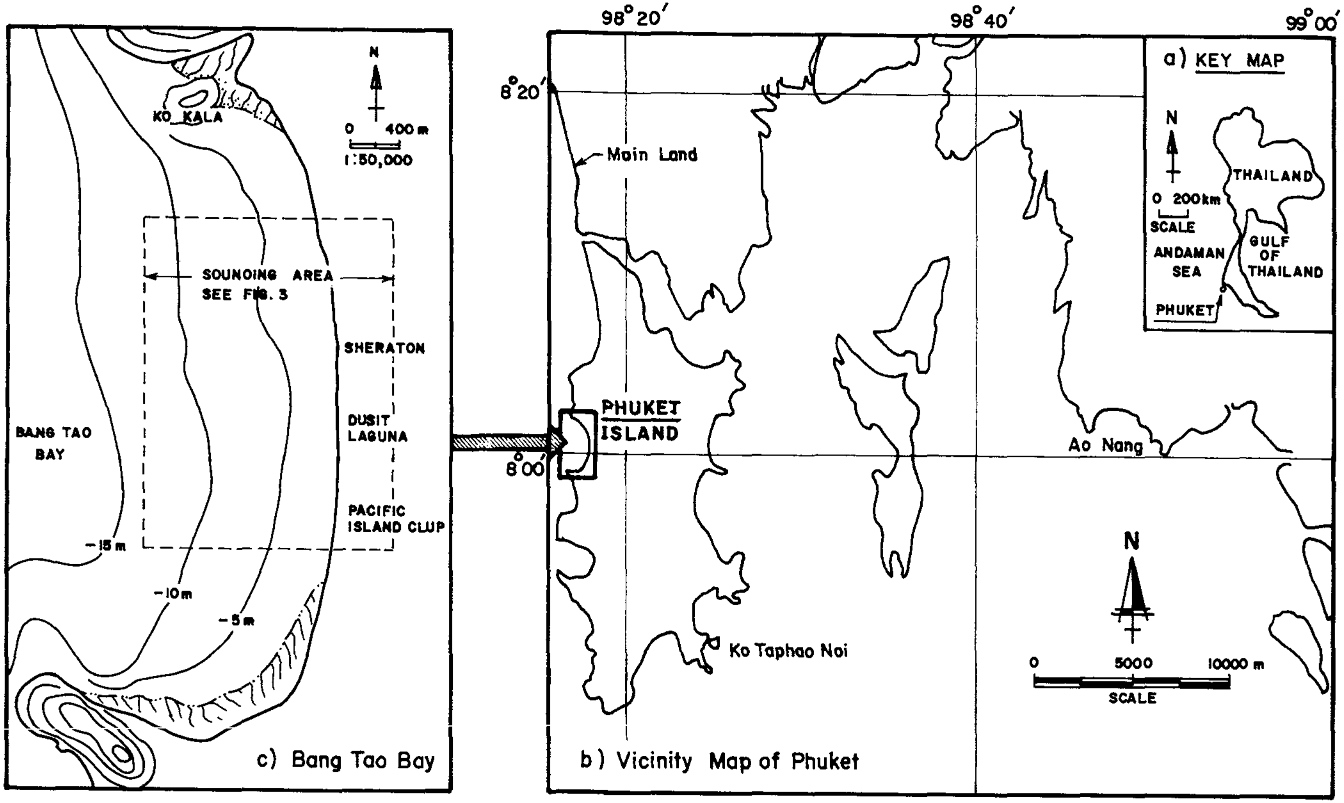
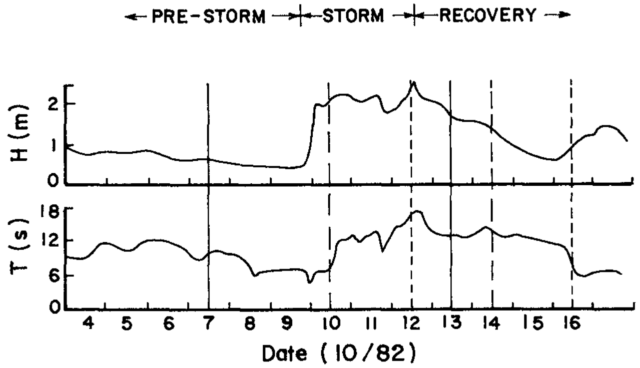
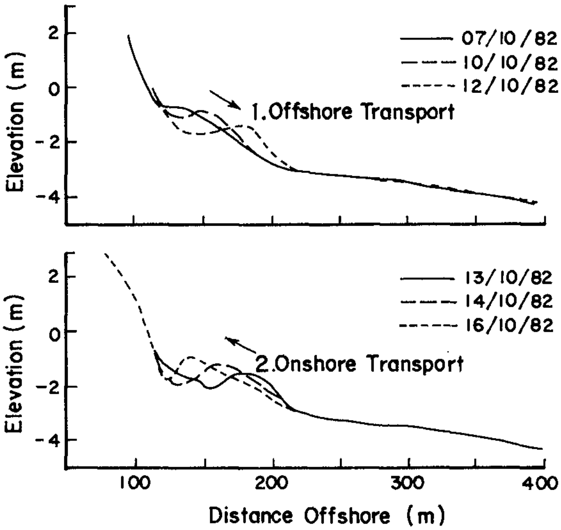


FIG. 1 – a) Key Map and b) Vicinity Map of Phuket as well as c) Bang Tao Bay and Its Bathymetry before Offshore Tin Mining



(a) Significant Wave Height and Period



(b) Beach Profiles

FIG. 2 - Actual Offshore and Onshore Transports at Duck, North Carolina (Sallenger et al., 1985)

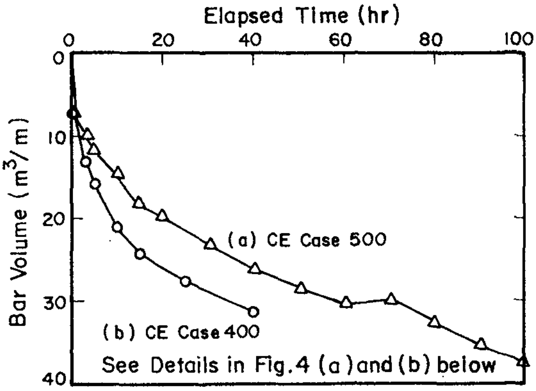


FIG.3 - Growth of Bar Volume with Elapsed Time (Larson et al., 1988)

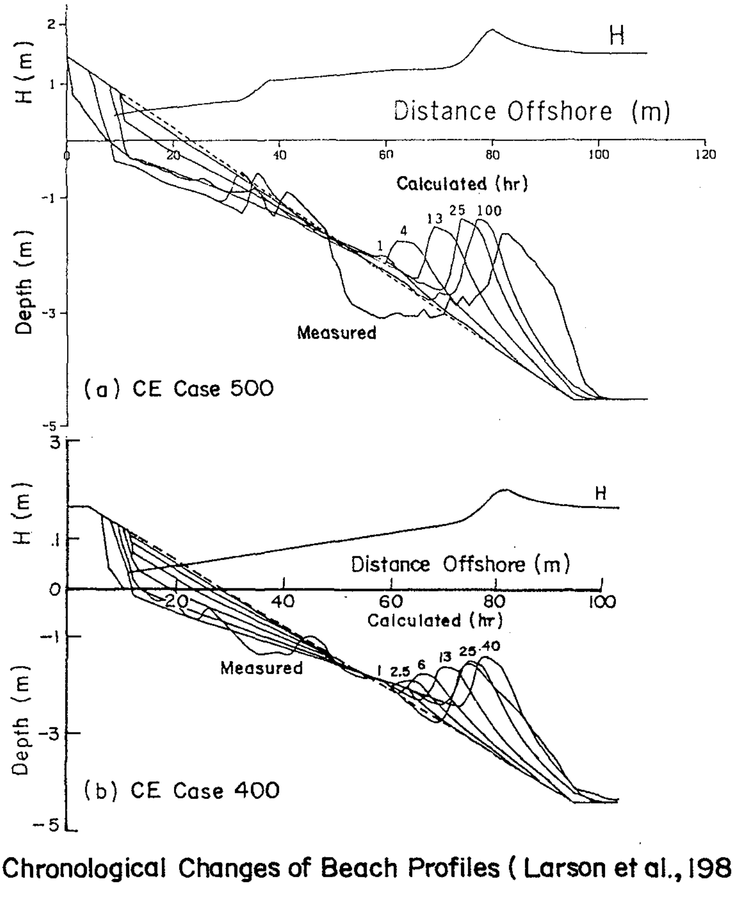


FIG.4 - Chronological Changes of Beach Profiles (Larson et al., 1988)

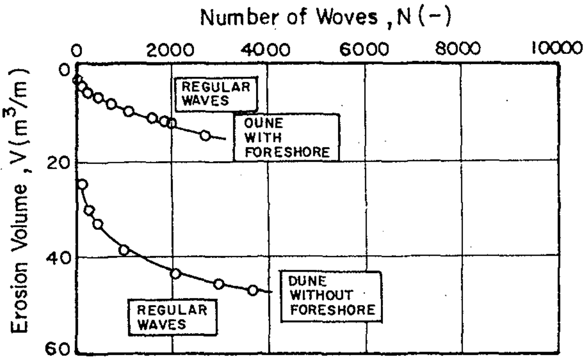
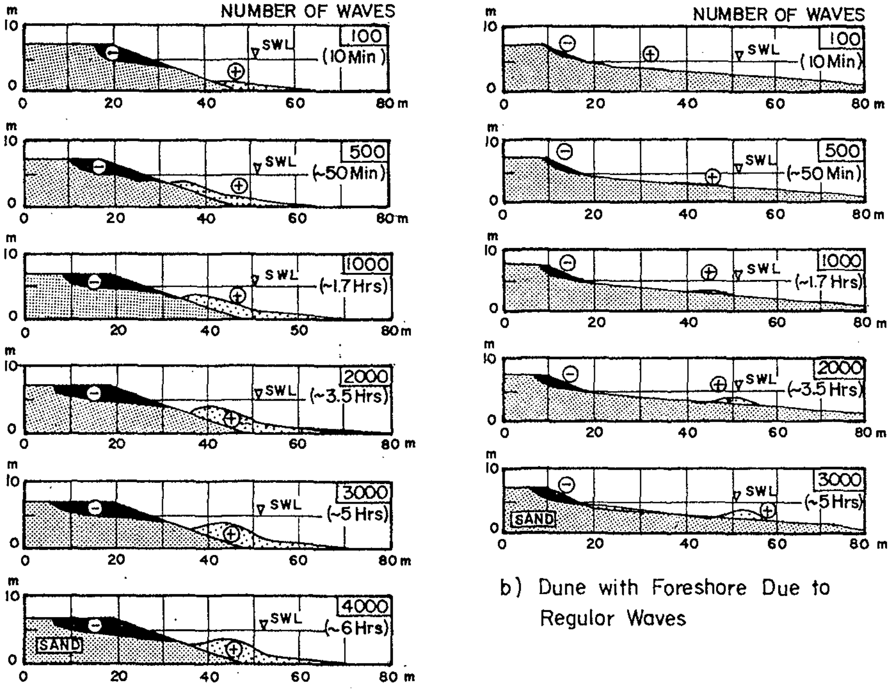


FIG. 5 - Erosion Volume with Elapsed Time of Beach Profiles of Dune with and without Foreshore (Dette and Uliczka, 1987)



a) Dune without Foreshore Due to Regular Waves

b) Dune with Foreshore Due to Regular Waves

FIG. 6 - Time-Dependant Development of Dune and Beach Profile (Dette and Ulicka, 1987)

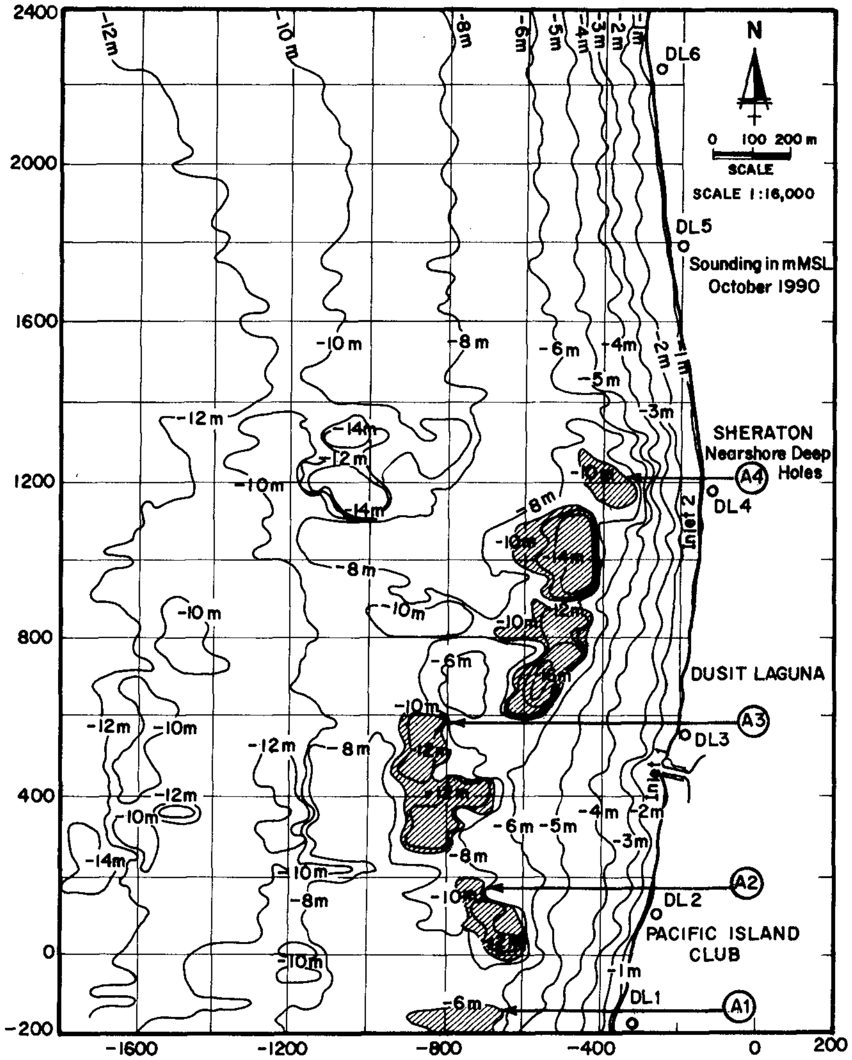


FIG. 7 - Sounding Map in October 1990 Showing Nearshore Deep Holes A1 to A4

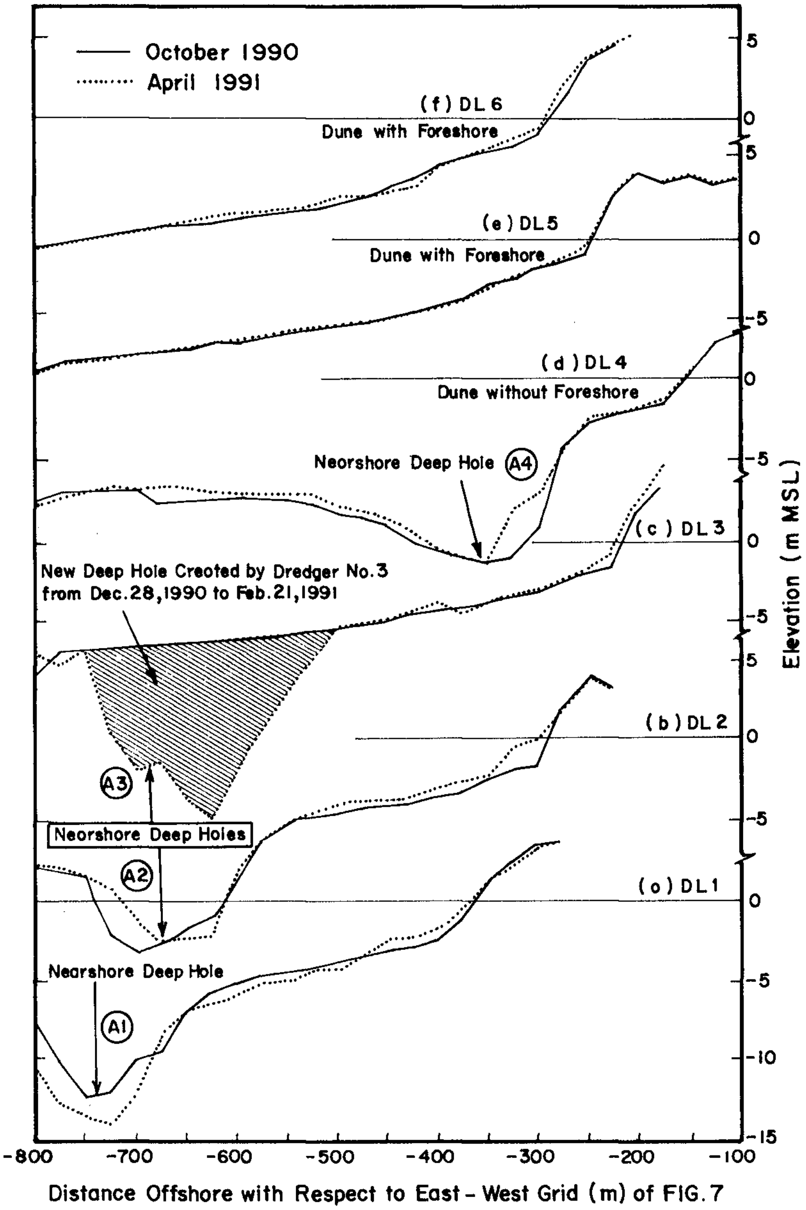


FIG. 8 - Beach Profiles at DL1 to DL6