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Conservation of Unique Fossilized Shell Beds at Ban Laem Pho, Krabi, Thailand

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Abstract

The ancient natural fossilized shell bed at Ban Laem Pho is situated at the shoreline of Krabi Province, Thailand. It is the only one of its kind in the world and is being subjected to rapid severe erosion. A geotechnical investigation was carried out to determine the causes of degradation and this found (i) direct wave attack and (ii) unfavorable conditions of the geologic structure beneath the fossil bed. Appropriate remedial measures are proposed with different types of structures to fully protect the fossil beds from wave impact. An initial environmental impact evaluation was conducted to determine the change of tidal current circulation as well as the change of adjacent coastal morphology. The preliminary results from a mathematical model simulation shows that there would not be any significant change of flow pattern nor shoreline morphology from the proposed measure.

1. Introduction

Fossilized shell beds are located at Ban Laem Pho, Tambon Sai Thai, Amphoe Muang, Krabi province, approximately 900 km south-southwest of Bangkok as shown in Figure 1. The bed outcrops at three places along a 2 km stretch shoreline from west to east at Laem Pho 1, Laem Pho 2 and Laem Pho 3. The area has been incorporated as a part of Nopparat Beach-Pee Pee Island National Park since 1983.

The topography is flat and most of the land is beach and marine terraces. The shoreline in this area consists of 2 to 10 m high sea cliffs bordering the marine terraces and 2 to 10 m wide pocket beaches separated by beds of fossilized shells of Vivipara freshwater gastropods between limestone and shale layers. The fossilized beds are cemented firmly together. At Ban Laem Pho, there are obvious layers with many beautiful shells. The lateral extent of each outcrop is several hundred meters long with a bed thickness of approximately one meter.

At present, the fossil beds are being severely and rapidly eroded and it is essential to protect them if they are to be conserved. The department of mineral resources (1994) estimated that the age of the fossilized shell bed is approximately 40 million years as indicated by Ducrocq et al (1992). In addition, pollen and spores of ancient plants recently found under the fossil bed indicate an age of 20 to 40 million years.

2. Geologic Setting

The generalized stratigraphic succession of Ban Laem Pho area consists of a near flat lying Cenozoic sedimentary sequence, which broadly constitutes the following units:

- A Quaternary unit of sandy clay, sand, gravel and laterites. Some laterite beds are up to 1 m thick and are massively eroded and laterite boulders partly cover shell layers. Others are red lateritic soil with a rich dark brown humus layer on top. This layer is 1 to 3 m thick.
- The Tertiary Krabi Group consists of sandstone, siltstone, mudstone, limestone, shale and lignite. At Ban Laem Pho, it mainly consists of limestone/mudstone bed and lignite bed.
- Limestone/mudstone beds are the " fossilized beds". These consist of shells of Vivipara and other gastropods and some bivalves which were piled up and firmly cemented together into hard concrete-like slabs. Shell layers of about 1 m thick occur mainly between limestone/mudstone and shale layers.
- A lignite bed exists in the lower part of the succession. It consists of dark gray shale interbedded with thin lignite layers and black

lentils of lignitic shale rich in shells of small Vivipara. The thickness of this layer is about 0.5 to 1.0 m. This layer is easily disintegrated when subjected to wave attacks. Generally, the Krabi Group rests uncomfortably on the Mesozoic rocks.

Generally, outcrops of rock along the beach at locations where severe deterioration occurs, show well defined near flat lying bedding. The top layers are calcareous claystone to fossiliferous limestone which contain numerous shell fossils, most of which are gastropod (Viviparidae). Underlying these are thin layers or lenses of black lignite and whitish gray to greenish gray claystone. The lignite and claystone have low durability and resistance to degradation from the wave attack resulting in undercutting and collapse of the fossilized beds. The landward dipping of the beds and the presence of many steep-dipping cross-cutting joints at close spacing further promotes the rapid rate of collapse and erosion.

Figure 2 shows a composite stratigraphic sequence at Ban Laem Pho along the shoreline. Figures 3 and 4 are schematics showing erosion conditions at Laem Pho 1 and 2. Figure 5 is a photograph showing deterioration conditions of fossilized shell beds at Laem Pho 2.

3. Coastal Engineering

3.1 <u>Wave Data</u>

Wave data at the fossil beds, Ban Laem Pho are unfortunately not available and no government office has ever made a recording of wave data in this area over a long period. The nearest source of recorded wave data is at Phuket. A summary of statistics of waves from a Tin mining project on the west coast of Phuket from Gayman (1983), shown in Table 1, is used in the present study.

During the Southwest monsoon season from May to August, the significant wave heights are between 0.3 and 1.5 m. Significant wave periods vary from 4.5 to 7.0 seconds. From wave measurement taken by AIT (1991) in Bang Tao bay, Phuket, it was shown that for most of the time, waves propagate from west, northwest and southwest directions except in July when waves approach the shoreline from the south. However, islands and other topographic conditions of the study area can obstruct wave attack from different directions and only waves from the southwest and south can approach the study area as shown in Figure 6.

Wave transformation from deep to shallow water can be computed using southwest direction in May (Case 1), June and August (Case 2) and from the south in July (Case 3).

3.2 <u>Tidal Data</u>

The tidal variation in Krabi is quite high. Records of Hydrographic Department, Royal Thai Navy at Koh Ta Pao Noi show the following data:

Highest High Water	(HHW)	1.72 m
Mean High Water Spring	(MHWS)	0.91m
Mean High Water Neap	(MHWN)	0.14m
Mean Sea Level	(MSL)	0.00m
Mean Low Water Neap	(MLWN)	-0.70m
Mean Low Water Spring	(MLWS)	-1.53m
Lowest Low Water	(LLW)	-2.29m

It is remarkable that the study area has high tides with a range of up to 2.44 m during the spring tide.

3.3 <u>Computation of Wave Transformation</u>

When waves propagate to the study area, the wave direction will gradually alter from the deep water direction. This is because of the variation in bottom configuration from deeper to shallower zones in which waves refract by adjusting the direction to be more normal to the shoreline. Meanwhile, wave height increases and wave length decreases due to the conservation law of energy flux. When wave height reaches a stability limit where waves can be maintained at a particular depth, breaking occurs and wave height drops.

Transformation of wave height and direction can be computed using the method of conservation of wave ray. Plots of wave rays at Mean Sea Level (MSL) conditions are shown in Figure 7. At MSL, waves in May, June and August which come from the southwest, will converge their energy (similar to a convex lens) to Laem Pho 1. Breaking wave energy in this area will then be strong due to high waves. At Laem Pho 2 and 3, wave rays diverge. However the orientations of coastlines at Laem Pho 1 and 2 are almost normal to the wave direction so that they are exposed to direct wave attack. Thus strong wave energy directly impacts this area. Waves in July from the south have less refraction, wave rays are almost parallel except at Laem Pho 3, where a combination of convergence and divergence of wave rays can be seen.

At High Water Level (HWL) which is 0.91 m above the Mean Sea Level, the pattern of wave refraction does not change much from MSL. However, it is important to note that waves can propagate close to the shoreline and break directly at the fossil beds. At breaking point, the wave energy is dissipated and transferred through water columns down to the sea floor, where the fossil beds exist, causing successive erosion even for small continuous wave trains with a height of only 0.5 m, as shown in Figure 8.

Breaking wave heights from the south in July have the highest value for both (a) MSL and (b) HWL. The maximum breaking wave heights at Laem Pho 1, 2 and 3 at MSL are approximately 2.0 , 2.1 and 1.6 m, respectively. Those of HWL are 2.0, 2.1 and 1.2 m respectively, and they do not differ significantly from that of MSL. Convergence of wave rays can be observed from plots of peak wave heights at Laem Pho 1 and 2 in Figure 8. Nevertheless, for case 2 at HWL, there is quite a difference from MSL. The breaking wave heights are 1.3, 1.0 and 0.7 m for Laem Pho 1, 2 and 3, respectively. It is noted that breaking wave height at Laem Pho 3 is always the lowest.

3.4 Computation of Wave Energy and Wave Force

Having computed the breaking wave heights along the shoreline in the previous section, it is necessary to quantify the energy of wave and wave pressure or force that impact the shell fossil beds. Results of calculations are shown in Figs. 9 and 10. It should be noted that wave force is calculated from wave pressure under wave crest for the maximum value and it is integrated from bottom to MSL. Wave energy at Laem Pho 1 and 2 is always higher than that of Laem Pho 3. At HWL, wave energy at Laem Pho 3 is less than the highest wave energy by approximately 2 to 4 times. Characteristics of wave force or pressure at Laem Pho 1, 2 and 3 exhibit the same tendency as wave energy. Wave force at Laem Pho 1, 2 and 3 are 7,000, 7,200 and 4,500 kg/m. Laem Pho 3 always has the lowest value by approximately 1.5 - 5 times. Laem Pho 2 has been found to be severely eroded which is consistent with the prevailing highest erosive wave force there. Therefore, it can be concluded that waves are the primary cause of degradation of the fossilized beds.

4. Causes of Erosion and Remedial Measures

4.1 Causes of Erosion

It is clearly shown from the wave analysis that waves are the major cause of the degradation of all outcrops and fossil beds at Ban Laem Pho with different degrees of erosion. The most severe degradation occurs at Laem Pho 2 area where the situation is at a critical stage. At Laem Pho 3, the degradation is minimum. The unfavorable condition of the geologic structure and low durability of some outcropped rock beds presented in the Geology section is the supplementary cause of the degradation. These two causes have led to rapid erosion at the locations.

4.2 Remedial Measures

Grouting is one of the potential preventive measures. There are investigations into its application feasibility as it would cause little environment at impact in terms of appearance of the existing shoreline. Considering the causes and mechanism of the degradation of the fossil beds, it can be concluded that grouting will not solve the problem and its implementation is limited as well as difficult. The reasons are as follows:

- In order for grouting to be effective, the method must be able to solidify less durable beds of claystone and unsolidated beds in addition to filling in joints. However, these beds are hard and have very low permeability and can not be grouted. Cement grouting only works in medium sand.

- Underwater grouting is difficult. Cement grouting can not be used. A cofferdam may be neccessary for grouting in the beach area where waves are strong.
- Grouting may be used as a secondary measure to backfill the undercut at less durable beds in order to reinforce the overlaying layer preventing further collapse.
- For erosion protection, shotcrete to seal the surface from wave attack will be more effective than grouting. However, its application would result in an unpleasant appearance.

4.3 Priliminary Layout of Shore Protected Structures

The purpose of erecting a shore protection structure such as offshore detached breakwaters and/or seawalls is to fully protect the fossil beds from direct wave attack at Laem Pho 1, 2 and 3. This type of structure prevents wave attack and provides a calm area behind. Only a few small waves can be transmitted through the breakwater.

Using the results of wave analysis, the preliminary layout of shore protected structures is made in such a way that their orientation can obstruct waves from the southwest and south. The preliminary lay out of strutures can be made with the following conditions:

- Structures can prevent direct wave attack on shell fossil beds.
- Location of structures should not disturb the existing coral reefs located nearby in shallow water.
- Geometric design of structures should be made so that sand does not accumulate behind the structure and deposits on fossil beds.
- Structures should not alter the present flow field and consequently create erosion at nearby locations.

There are two alternatives to the layout of shore protection structures which will not disturb the existing coral reef: (i) A structure is located on the offshore side of the coral reef where plenty of space is available. This type of structure may be an offshore breakwater. (ii) A structure is placed in between the shell fossil beds and the coral reef. This space is limited with a width of 20 to 70 m at Laem Pho 1,2 and 70 m for Laem Pho 3. A seawall requires less space, especially for the foundation.

4.3.1 Breakwaters

Two offshore breakwaters are initially proposed to be constructed at Laem Pho 1 and 2 in order to prevent two different wave directions, i.e. southwest and south. However it is found that the breakwater at Laem Pho 2 should extend almost to Laem Pho 1. Since the spacing between the two breakwaters is very small, the nearshore current at this location can be strong, hence it would be better to link the two breakwaters into one. An offshore or detached breakwater at Laem Pho 1 and 2 located at a water depth of 2.7 to 3.5 m from MSL is proposed. It would be approximately 1,000 m long. Figure 11 illustrates the layout and functions of the proposed offshore breakwater. That is, to interrupt and obstruct wave rays currently reaching the shoreline.

At Laem Pho 3, an offshore breakwater 300 m long is proposed at a water depth of 2.6 m. It is possible to make a breakwater to attach to the shoreline in order to reduce the construction cost and protect the fossil beds from the southwest monsoon. However, it is difficult to follow that idea because there are coral reefs situated in this alignment. Consequently, the detached type of breakwater is proposed.

4.3.2 Seawalls

When shore protected structures are studied and proposed for the shell beds where not enough space is left to construct a mound breakwater, a seawall is proposed as an alternative. This type of structure can prevent wave attack but it would distract from the natural scenery when tides are low. In order to harmonize structures with the fossilized shell bed, a concrete seawall construction should have the same colour as the fossil bed. This is difficult work. When seawalls are constructed, it is possible that any beach in front of them will disappear due to reflected waves so this alternative has a low priority.

4.4 Initial Environmental Impact Evaluation

The impacts of construction of offshore breakwaters on local environments are change of tidal circulation and change of coastal morphology.

4.4.1 Change of Tidal Current Circulation

A mathematical model of 2-dimensional depth average flow is applied to compute the circulated flow induced by the construction of a breakwater. More details can be found in AIT (1995). Since the recorded tidal elevation used as a boundary condition is far from the study area, simulations were made for two stages, i.e. coarse grid and fine grid size modelling. The coarse grid has grid size of 2 km while that of fine grid is 125 m. Output tidal velocity resulting from the coarse grid model are then utilized as the input to the fine grid. Figure 12 shows the comparison plots of tidal velocity with and without an offshore breakwater. It indicates no circulation and only slight changes in velocity, magnitude and direction are found.

4.4.2 Change of Coastal Morphology

To study sand transport behind the offshore breakwater, the design criteria for beach formations proposed by Rosati et al. (1992) is applied. There are three types of morphological response to geometric design of offshore or segmented breakwaters, i.e. limited response, salient and tombolo. The tombolo is the shape of the shoreline which has the most accumulated sand so that the shoreline can extend to the breakwater. For limited response and salient type, there is less deposited sand. After computation using a wide range of wave characteristics, the maximum beach response is in a border of salient and limited response types. Also, sand supply in the study bay is limited so there would not be a significant change of shoreline morphology.

5. Conclusion

A detached breakwater provides the least environmental impact, is easy to construct and is the most appropriate structure to protect the fossil beds from eroding.

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[6] Rosati, J. D., Gravens, M. B. and Chasten, M. A. (1992), Development of Detached Breakwater Design Criteria Using a Shoreline Response Model, Coastal '92, pp.814-829.

Table 1 Significant Wave Height Data from the West Coast of Thailand (Gayman, 1983)

Month/Year	Range of Signicant Wave Height (m)	Range of Wave Period (second)	Most Commonly Recorded Wave	
			Height (m)	Period (s)
Oct 1979	0.0-2.0	4.5-14.5	1.5-2.0	5.5
Jan 1980	0.0-0.5	2.5-4.5	0.0-0.5	3.5
Feb 1980	-	-	-	-
Mar 1980	0.0-0.5	4.5-14.5	0.0-0.5	8.5
Apr 1980	0.0-0.5	4.5-14.5	0.0-0.5	6.5
Apr 1981	-	-	-	5.5
May 1980	0.0-1.5	3.5-16.5	0.0-0.5	4.5
May 1981	0.0-2.5	3.5-12.5	0.5-1.0	5.5
Jun 1981	0.0-1.5	4.5-13.5	0.5-1.0	6.5
Jun 1980	0.5-3.0	3.5-9.5	2.0-2.5	6.5
Jul 1981	0.0-1.5	5.3-13.5	0.5-1.0	6.5
Aug 1980	0.0-1.5	5.5-17.5	0.5-1.0	6.5
Sep 1980	0.0-1.0	3.5-14.5	0.0-1.0	6.5
Oct 1980	0.0-1.0	3.5-16.5	0.0-0.5	8.5
Nov 1980	-	-	-	-
Dec 1980	-	-	-	-

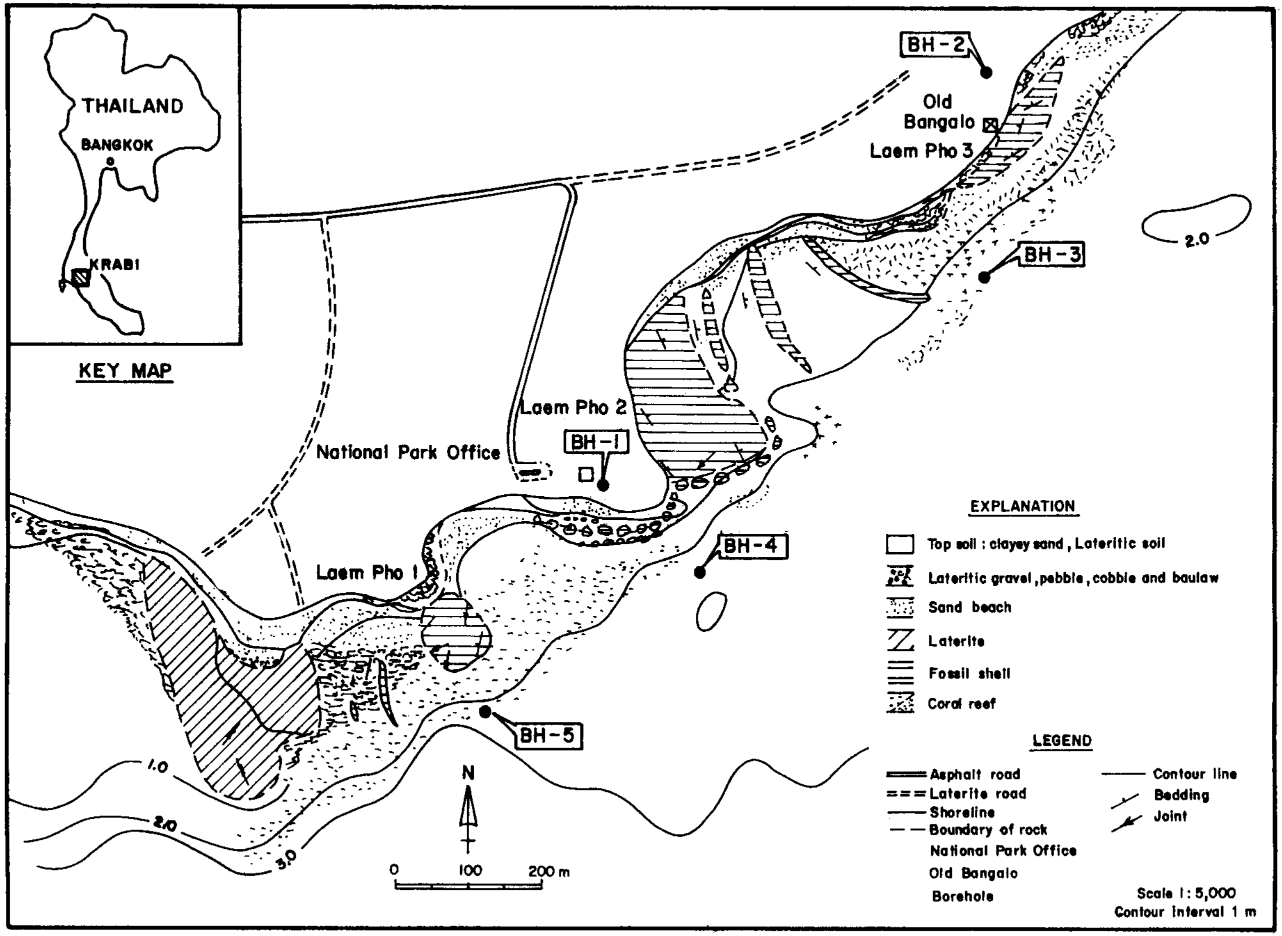


Fig. 1 Locations of Various Rock Units and Coral Reef Existing along Shoreline of the Study Area

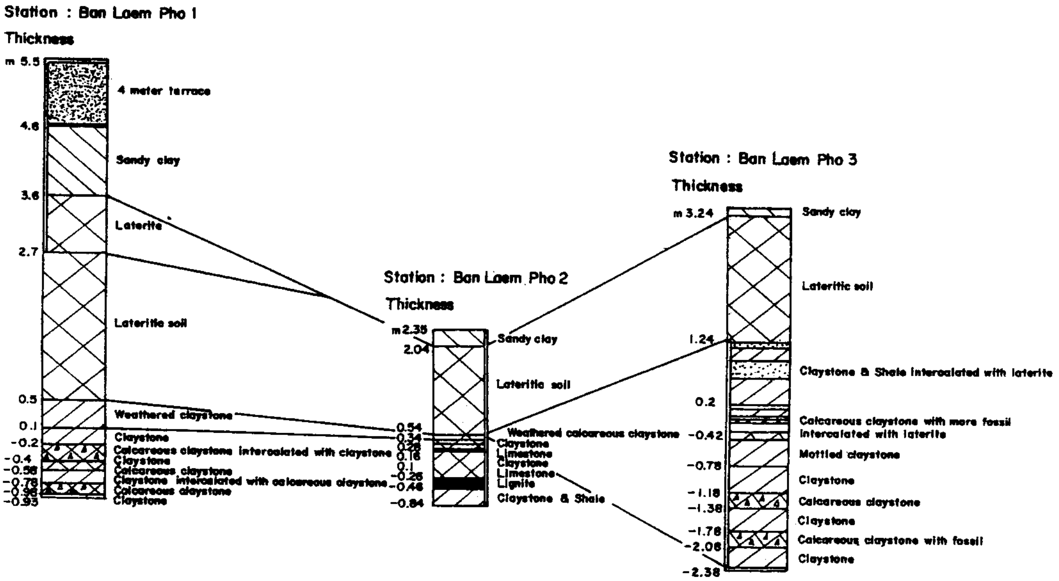


Fig.2 Composite Stratigraphic Sequence at Ban Laem Pho from Surface Mapping of Shoreline

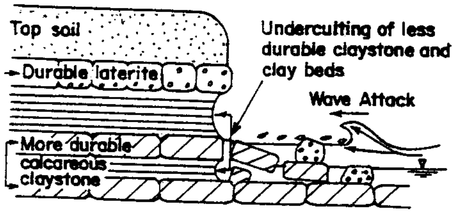


Fig. 3 Schematic of Degradation Process of Fossillized Bed Slabs Outcropped at Laem Pho 2

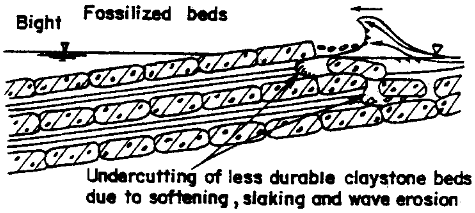


Fig.4 Schematic of Degradation of Fossillized Beds at Laem Pho Outcrop Slabs

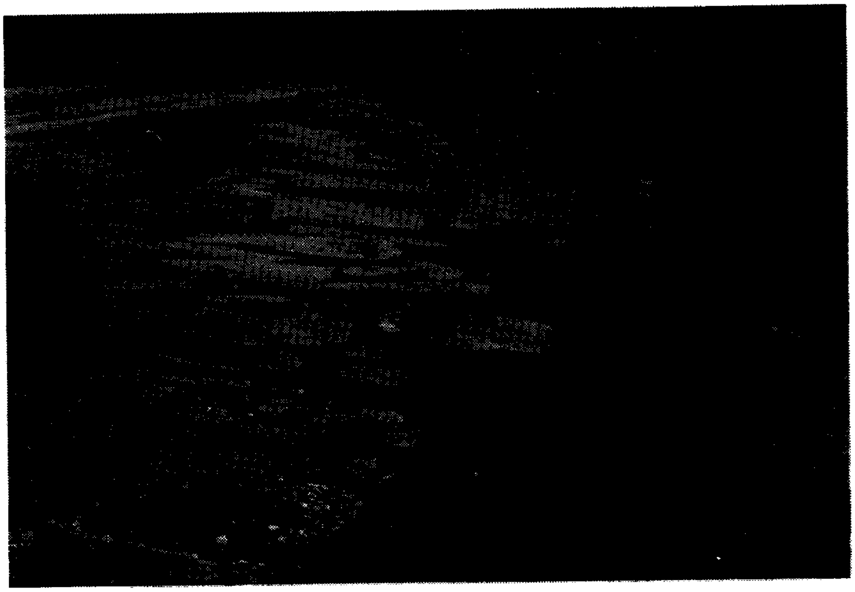


Fig. 5 Photograph Shows Erosion of Fossilized Shell Bed at Laem Pho 2 during Low Tide

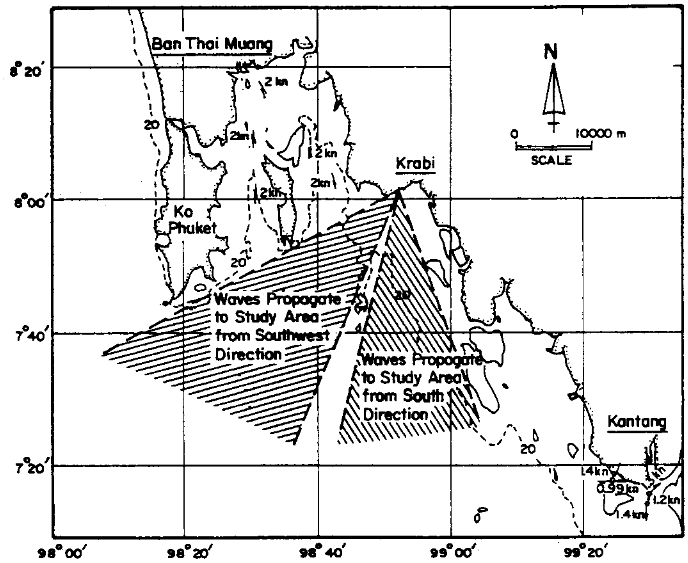
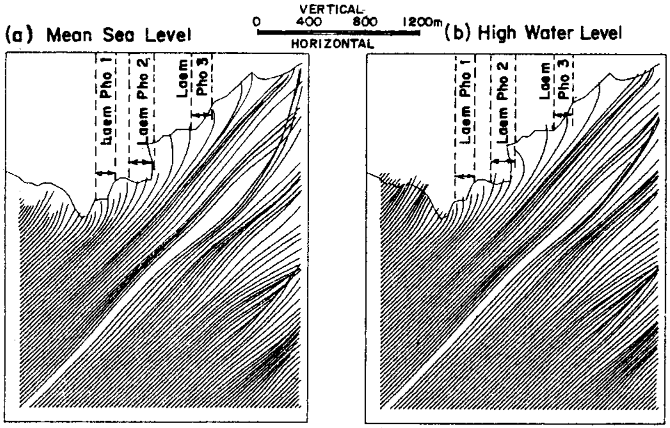
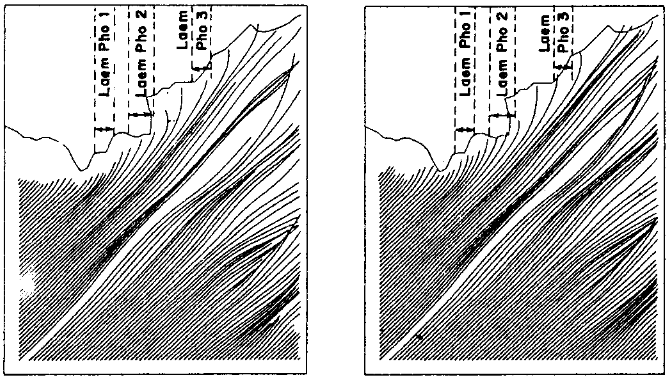


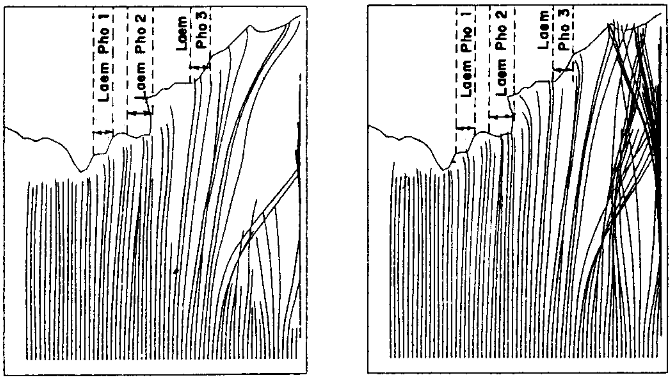
Fig. 6 Direction of Wave Propagation to Study Area



Case 1 Wave Refraction in May, H = 0.5 m, T = 4.5 s, Southwest Direction



Case 2 Wave Refraction in June and August, H = 1.5 m, T = 6.5 s, Southwest Direction



Case 3 Wave Refraction in July, H = 1.5 m, T = 6.5 s, South Direction

Fig. 7 Wave Refraction in Southwest Monsoon Season

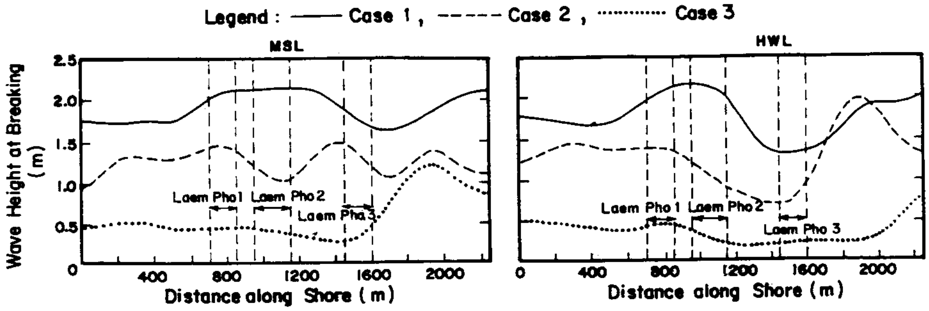


Fig. 8 The Variation of Breaking Wave Height along Shore

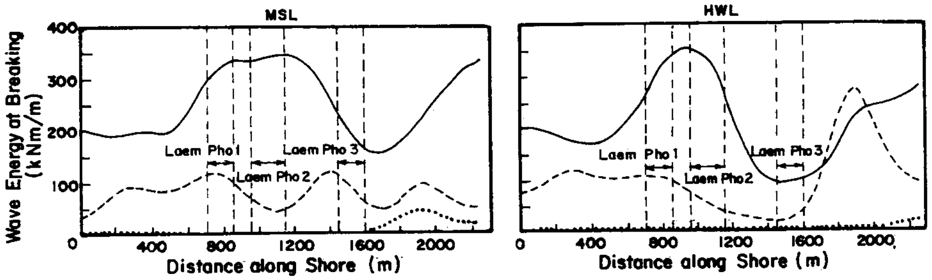


Fig . 9 The Variation of Wave Energy at Breaking along Shore

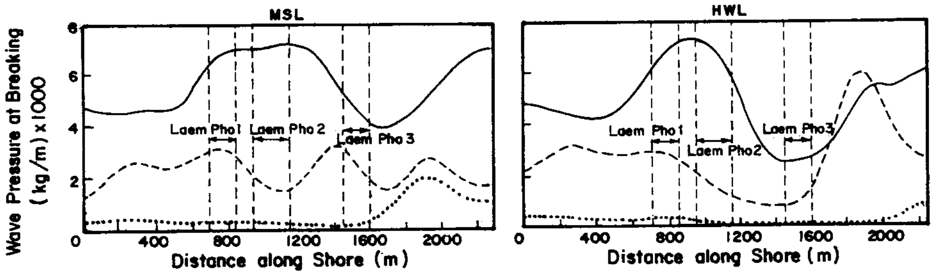


Fig. 10 The Variation of Wave Pressure at Breaking along Shore

Note :

Case 1 : H = 0.5 (m) , T = 4.5 (s) , southwest direction , May
Case 2 : H = 1.5 (m) , T = 6.5 (s) , southwest direction , June, August
Case 3 : H = 1.5 (m) , T = 6.5 (s) , south direction , July

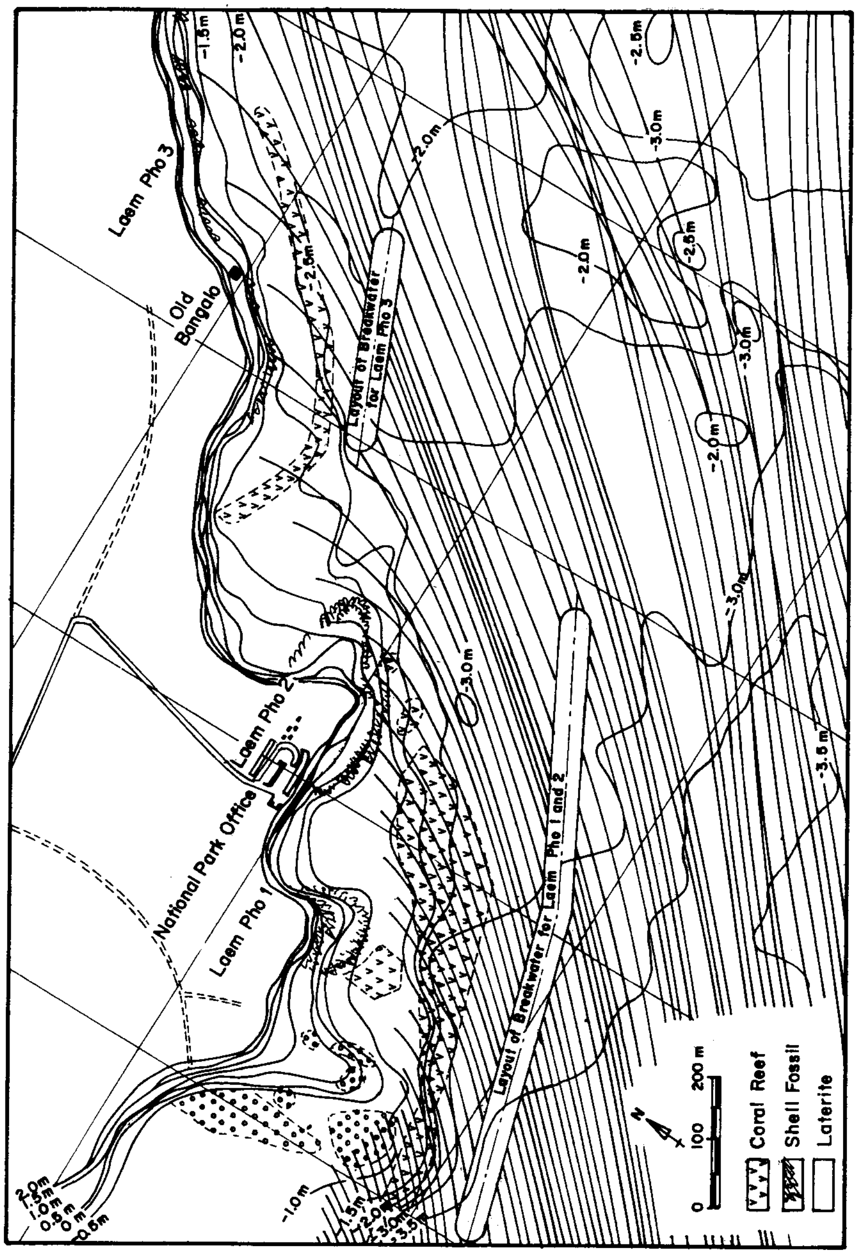


Fig. 11 Protection of Refracted Wave by Offshore Breakwaters

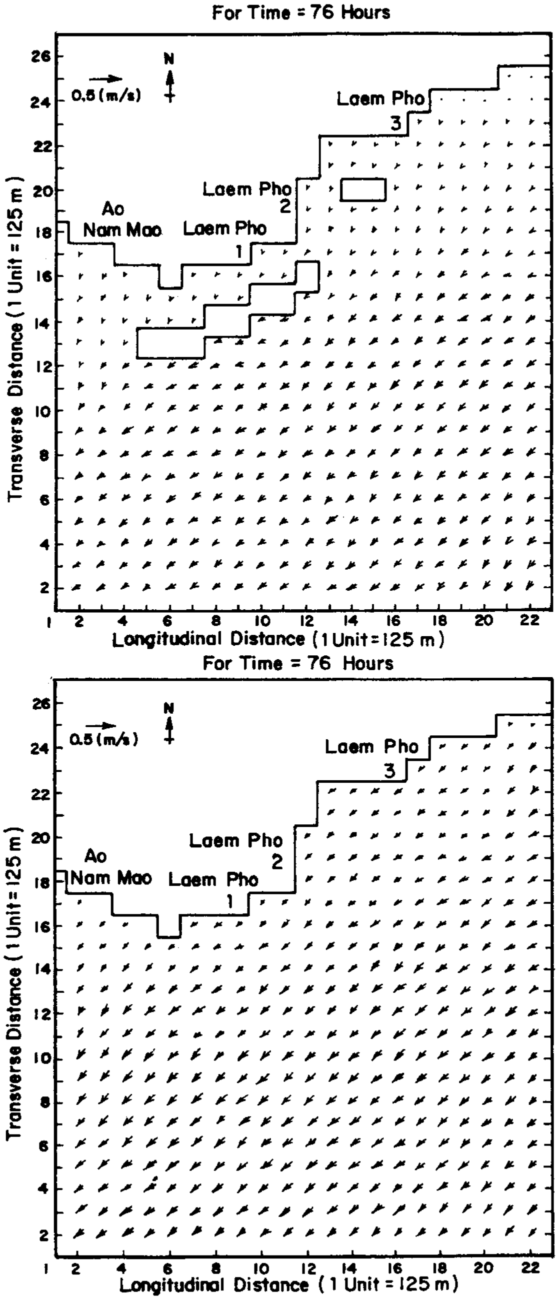


Fig.12 The Tidal Flow Variation with and without Offshore Breakwaters at Time = 76 Hrs