COUNTERMEASURE STUDY TO PROTECT THE LARGEST OFFSHORE BARRIER ISLAND IN TAIWAN

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The objective of this study is to find the suitable measure for mitigating the existing erosion problem of the Wai-San-Ding barrier island, the largest remaining barrier island off the Taiwan coast. After collecting enough hydrodynamic and morphodynamic data from the long-term field investigation, the erosion mechanisms of the barrier island were analyzed in detail. Based on the analysis of the erosion mechanisms, consideration of some measure options were proposed and firstly simulated by numerical model to find the two better solutions. Then, the two better solutions were further investigated and validated by physical model. The results showed that soft groins in the downstream and submerged artificial berms in the midstream are the effectively integrated measure to mitigate the continuing erosion problem of the Wai-San-Ding barrier island. Meanwhile, the plant evolution method and oyster cultch were also proposed to apply in mitigation of wind sand transport and stabilization of sand dune.

Keywords: Wai-San-Ding; barrier island; erosion; soft countermeasure; sand dune

INTRODUCTION

The total length of Taiwan's shoreline is approximately 1,100 kilometers including sand, rock, cliff, gravel and reef coasts (see Figure 1). Almost half of the shoreline has been protected by seawalls. From the viewpoint of shore protection in coastal area, these seawalls actually play an important role of coastal protection that prevents people and infrastructure from coastal disasters. Furthermore, detached breakwater and groyne are built to protect the coastal area with serious erosion problem. These efforts made our land safe over the last fifty years to some extent. Due to the martial law, it was not so easy for people to walk or visit near the coastal area in Taiwan during 1949 to 1987. However, after 1987 people gradually valued the coastline for environmental protection and, recreational use as well as the economic activity. The purpose of the coastal protection is diversified by these new demands. In this study, we will introduce environmentally and user-oriented coastal protection works as well as technically sound creditable coastal protection works to meet these new trends. Therefore, the purpose of this study is to evaluate on how to join soft solution strategies into current shore protection system throughout Taiwan's coast. Moreover, a feasible application for hard solutions complemented by soft issues for beach erosion management has also been evaluated.

In Taiwan, beach erosion has become more serious in the recent past. The time for this beach erosion to become apparent chiefly depends on how fast the rate of longshore sediment transport decreased from the up-coast area and on the river sediment supply. Many industrial, commercial and fishery harbor construction projects were also observed to have disturbed the continuity of littoral sediment transport, and lead to the retreat of the shoreline in the downcoast area. However, sufficient knowledge on nearshore hydrodynamic forcing (incoming wave energy, wave-induced currents in the surf zone and tidal range), sediment transport processes and morphological features along coasts, will be helpful to the improvement of shore protection work. Countermeasures for beach erosion control should depend on the local conditions of hydrodynamic forcing characteristics, littoral sediment transport and various morphologies.

The Wai-San-Ding barrier island (Figure 2) which is located between Yunlin and Chiayi Counties, protruding at about a forty-five-degree angle from the natural trend of the mainland shoreline at the mouth of the Pei-gang Shi River, is the largest remaining barrier island off the Taiwan coast. The overall length of this barrier is twenty kilometers, and her area is around two-thousand hectares during the Mean Water Level (M.W.L.). Much of the island shoreline is investigated to have been eroding at a rate of 50m~60m per year in recent years. Furthermore, this island holds some sort of "land speed" with continuing 0.2 degree/year counter-clockwise rotation to migrate southeast direction to the mainland shoreline and gradual submerging into the sea. The Wai-San-Ding barrier island located on the southwestern Taiwan, is normally treated as natural offshore breakwater. In fact this biggest barrier island can form a defense line of low-lying coastal plains and back-barrier basin against storms attacking the southwestern coastal area in Taiwan. However, the erosion problem of the Wai-San-Ding barrier island has become more serious in the recent past. Therefore, how to protect this barrier island is always an important issue both from the consideration of coastal hazard and sustainable environment in Taiwan. Thus better applications of the various soft methodologies available for beach erosion management for the Wai-San-Ding barrier island will be proposed in this study.

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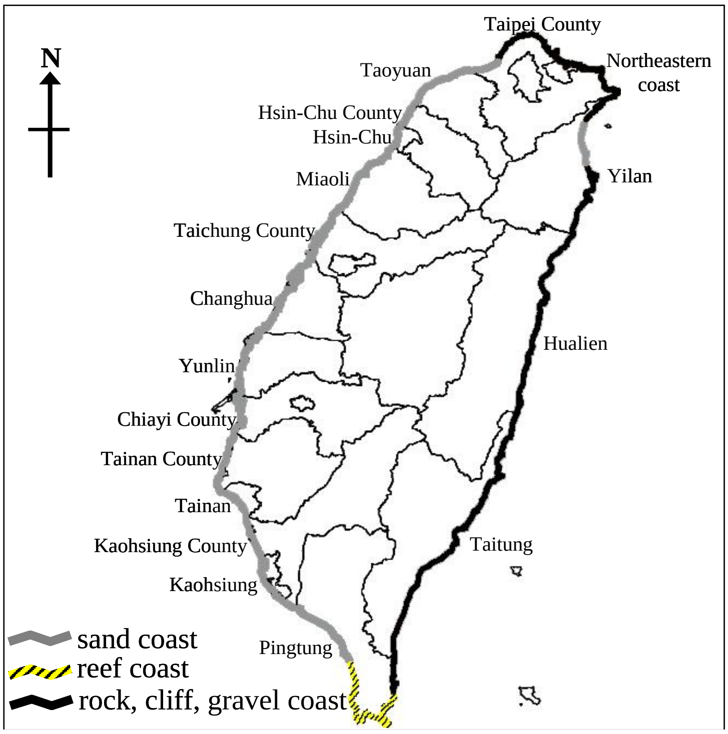

Figure 1. Different types of coasts in Taiwan.

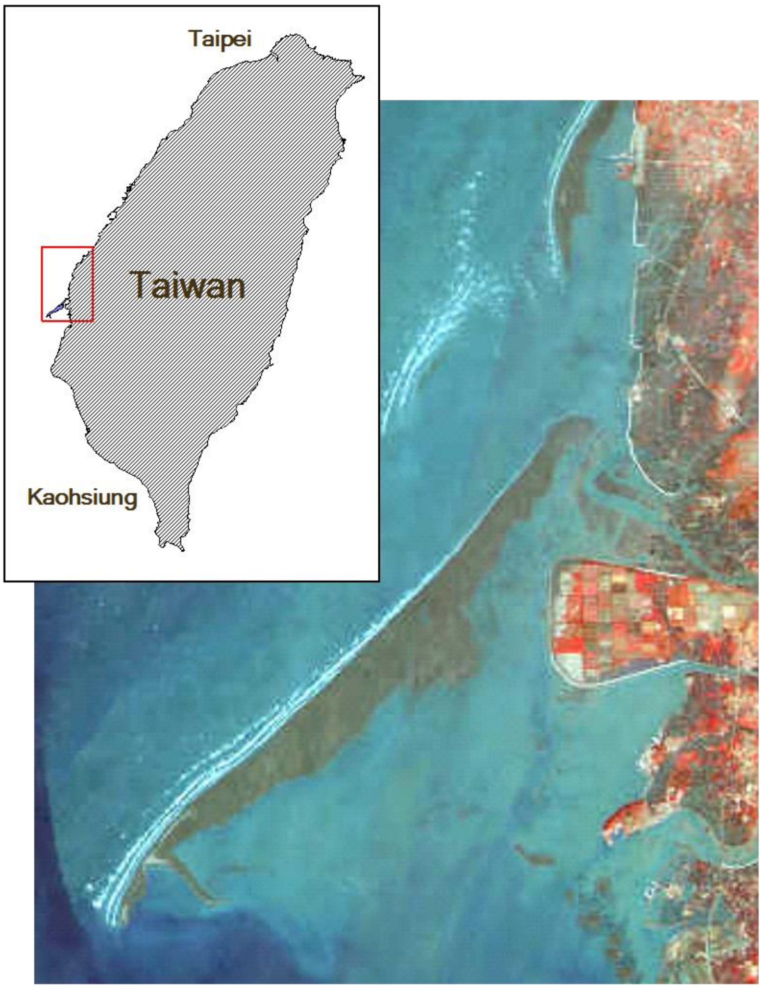

Figure 2. Studied area Wai-San-Ding barrier island image from satellite SPOT(2001).

EVALUTION OF SOFT ENGINEERING COUNTERMEASURE

The protection of beaches against erosion has always been an important aspect of coastal engineering works in Taiwan. History is replete with the loss of valuable coastal lands such as beaches, reclamation areas, harbors, and other valuable coastal property to erosion induced by sea encroaching. On the other hand, there are also some cases of harbors being abandoned because of infilling by sediments, which is quite a different coastal engineering problem but a significant one. Erosion control measures should incorporate a reduction in the cause of the beach erosion where possible, when, for example, the erosion is caused by human activities along the coastal areas such as hard engineering structures or harbors. For each coastal erosion mitigation measure, it is important to know how they work. In fact, some of the mitigation schemes are able to reduce the wave energy at the shoreline, or simply provide a sacrificial beach, whereas others try to impede the long shore transport of sand. In a particular situation, one mitigation scheme will work better than some others owing to the difference in operation. In fact, some methods will fail in one situation and do very well in others. Therefore, in order to mitigate the erosion problems due to the current hard shore protection system around Taiwan coast, detailed evaluation of various feasible soft engineering structures should be conducted in advance. The evaluation of soft countermeasure includes beach nourishment, near shore disposal berms, geosystems, artificial oyster reef, fluid-elastic sheet and aquatic vegetation.

Beach nourishment

Beach nourishment is the mechanical or hydraulic placement of sand on the beach and/or shore-face to advance the shoreline or to maintain the volume of sand in the littoral. It is a soft protective and remedial measure that leaves a beach in a more natural state than hard structures and preserves its recreational value. Of the many remedial measures for beach erosion, beach nourishment is the only approach that introduces additional sand sources into the coastal system. Without the construction of coastal structures, beach nourishment seldom causes damage to the landscape, and can flexibly responds to changes of the littoral environment. Beach nourishment, with its expected widening of beach, is used to accomplish several goals as follows: formation of additional recreational area; land reclamation; maintenance of shoreline; reinforcement of dunes against breaching; protection of coastal structures; reduction of the wave energy near shore and creation of a sacrificial beach to be eroded during a storm; provide, in some cases, environmental habitat for endangered species.

Sand nourishment can be carried out at various locations in the profile or along the shoreline. The options of nourishments in cross-shore profile are shore-face (underwater nourishment or profile nourishment), dune zone (landward and seaward above dune toe), beach and swash zone. Leonard et al. (1990) evaluated 155 beach nourishment projects in the U.S.A. In all, about 300 million m3 of sand was placed along 700km of shoreline (470km along Atlantic coasts, 180km along Gulf coasts and 50km along Pacific coasts). In 1996, Rijkswaterstaat also evaluated nine nourishment projects (volumes between 50 and 100 m3/m/year；sand size between 0.15 and 0.3mm) carried out along the coasts (tidal range of about 2m) of the Netherlands in the period 1975-1994. Several characteristics, including ratio of design nourishment volume and required volume to compensate annual erosion volume in active zone before nourishment and after nourishment, were analyzed in his evaluation. Van Rijn (1998) summarized the sand nourishment characteristics under micro and meso-tidal conditions in great detail from five projects (Delft Hydr. 1987, Dette-Raudkivi 1994, Rijksw. 1996, Work-Dean 1995, Mφller, 1990). From his result, it shows that beach nourishment can be mostly utilized on coastal areas of low or moderate wave energy with micro-tidal condition. Meanwhile, the three basic elements including the eroded area, the borrow area and the transportation/ dumping methods should be investigated in detail when sand nourishment is applied to beach erosion control. Dean (1986) recommended a mitigated approach for armoring on an eroding coastline that calls for the placement of sand annually in the amount that has been prevented from entering the system by the armoring structure. This approach maintains a more natural littoral system. Often, the nourishment scheme is remedial rather than preventive (Hamm et al, 1998). In summary, beach nourishment is the approach that directly addresses the deficit of sand in the coastal system without at least the potential of causing adverse effects on adjacent property. Bridges and Dean (1996) concluded that beach nourishment is the most benign and acceptable approach to beach erosion mitigation. However from the new demands of shore protection now in Taiwan, beach nourishment can not be the only option of beach erosion control.

Near shore disposal berms

Open-water disposal of dredged material has been practiced worldwide for over sixty years. The initial attempts have arisen from the search for a beneficial use of the large amounts of dredged material obtained from navigation channel maintenance operations. The removed material which varies in size and quantity has been placed in near-shore disposal sites seaward of the surf zone. A major cost savings often accrues if beach fill material can be placed offshore rather than on the beach in the expectation that natural processes will move the material to the beach. The performance of underwater berms has been investigated both in the laboratory and through field monitoring programs. Hands (1991) provided a thorough review of the behavior of 11 berms and their performance. Furthermore, Otay (1994) presented a summary of submerged berms and their characteristics, including whether they were judged to be stable or migrated. Of the berms placed to benefit the landward beaches, possible designs could be a feeder berm, in which sand would be transported to the beach from an active berm or as a stable berm that causes damping of the waves and thus sheltering of the landward beach. In his research, Otay also described the monitoring results of an underwater berm placed off Perdido Key, Florida. Monitoring included repetitive beach profiles and wave measurements. His result showed that the berm had exerted a stabilizing effect on the beach leeward of the berm.

Geosystems

Geosystems (tubes, containers) have already found various applications in coastal engineering. The tubes and containers are mainly applicable for construction of groynes, perched beaches, and offshore breakwaters, and as bunds for reclamation works. Application of these systems has executed by a number of projects in the Netherland, Germany, Japan and U.S. Some information on U.S. experience with geotubes can be found in Fowler et al. (1995) including the application of geotubes for dewatering of contaminated maintenance dredged material. Geosystems have much applicability in erosion control, water control (small weirs and reservoirs), flood control, etc. For example, breakwaters made of sandbags, geotubes, etc, have been used successfully in the United States of America under conditions for low tidal range and low wave activity (Krystian, 2000). Under gentle wave climates such structures may not only attenuate waves, but can also encourage the accretion of sediment between them and the shore. Geotube can also be used to assist in dike, groin and breakwater construction. Krystian (2000) summarized the examples of application of geotube, as dune reinforcement, core of breakwater, and bunds for dike construction, from a number of projects executed in the Netherlands and Germany. The main advantages of geosystems in comparison with more traditional methods (rock, concrete armor units, block mats, asphalt, etc.) are: a reduction in work volume, execution time and cost, the use of local materials, low-skilled labor and locally available equipment. However, until now, geosystems were mostly applied as temporary structures. The reason for that was their relatively low resistance to the loading of waves and currents, the lack of proper design criteria, and a low durability in respect to UV-radiation and vandalism.

Artificial oyster reef

There is increasing interest in oyster reefs used to restore eroding coastlines. Occasionally, sub-tidal oyster reefs can be found offshore. These immense natural submerged breakwaters protect the beaches from storms and wave erosion by dissipating wave energy. The study of how artificial and natural reefs have protected shorelines has been conducted by Hamaguchi et al. (1991). They investigated the effects of an artificial reef on the Niigata coast in Japan. It was found that a significant amount of sand was deposited landward of this artificial reef. This reef was developed to mimic the effect of the natural coral reefs in the area. There has been an effort to find different methods of restoring oyster reefs in various estuaries around the world. O’Beirn et al. (2000) conducted the experiments by using oyster shell, concrete, and rubber tire chips as oystercultch material. A structure termed an “oysterbreak” was designed to stimulate the growth of biological structures in an optimal shape to serve as submerged breakwaters (Foret, 2002). Oysterbreak can form immense structures that can protect shorelines and coastal communities by reducing wave energy.

Currently, mineral accretion amelioration on gabion that was filled with oyster cultch & rock to form a new biological unit has been investigated in field experiment by Hwung et al. (2008). It is hoped that this combination of oyster cultch, mineral accretion and cage meshed into berm breakwater can improve the toe revetment and berm advance, and simultaneously enrich the local environment to a higher level.

Fluid-elastic sheet

Fluid-plate hydro-elastic interaction problems have been of common interest for a long time because of their engineering applications. During the past decades, for instance, there has been a gradual increase in interest in the use of flexible plates or membranes as alternative effective inexpensive wave barriers in a beach zone. Currently, developing of the new design of floating wave breakers in a beach zone using coating of the sea surface by an elastic plate, which absorbing the energy of sea waves, is investigated by Hwung et al. (2008). A properly designed horizontal flexible membrane can be a very effective wave barrier and its optimal design can be found through a comprehensive parametric study using the experiments, theory and computer programs developed. In particular, the membrane is light and rapidly deployable; thus, it may be an ideal candidate as a portable temporary breakwater. Since a horizontal membrane does not directly block incoming waves, the transmitted and motion-induced waves need to be properly cancelled for it to be an effective wave barrier.

Aquatic vegetation

Aquatic vegetation provides important ecosystem services to coastal marine systems. They influence their environments through wave attenuation, the stabilization of sediments, increased setting of the suspended particulate particle and nutrient cycling. For environmental and esthetic purposes, projects on natural development of wetlands and restoration of river basins toward natural development have been promoted recently. The growth of vegetation in these areas is favored. Such vegetation increases the resistance of the watercourse, leading to an increase in water depth and reduction of flow velocity. In estuarine and coastal areas with vegetation, in addition to freshwater flow upstream, waves and tidal currents exist and will play a significant role in the hydrodynamics and mixing processes. Waves over vegetation will be attenuated due to the resistance offered by the vegetation. The bidirectional nature of wave motion will increase the mixing between the water column and that within the vegetation (Li and Yan, 2007). Wave motion tends to be highest in the shallow waters where, in combination with tidal currents, water movement imposes a shear stress on bottom sediments. If bottom shear stress exceeds a critical value, sediment will be resuspended, increasing turbidity and light attenuation (Wright 1995).

For waves propagating over vegetation, Kobayashi et al. (1993) developed an analytical model to predict wave attenuation over vegetation by assuming an exponential decay of incoming regular waves. Vegetation meadows can reduce suspended sediment concentrations; friction from vegetation leaves reduces current velocity and attenuates waves, thus reducing the stress on bottom sediments, decreasing resuspension, and promoting sediment settling within the vegetation bed (Fonseca and Cahalan 1992; Rybicki et al. 1997). Vegetation beds may also increase particle settling shoreward of the bed (Chen et al. 2007).

HYDRODYNAMIC ENERGY BACKGROUND

The hydrodynamic and morphological processes in the coastal zone are governed by two primary phenomena, namely, winds and tides. The winds are directly responsible for the transport of sand on the dry beach and for the generation of waves, currents and water-level fluctuations, while the tides express themselves in a periodic rising and falling of the water and in tidal currents. Therefore, coastal classification based on hydrodynamic energy was presented by Davis and Hayes (1984). The classification is shown in Table 1. The wave climate is generally characterized, as: low wave energy, if annual mean significant wave height at edge of surf zone (say, depth of 6m) is $H_{s,am}<0.6$m; moderate wave energy, if $H_{s,am}$ between 0.6m and 1.5m; high wave energy, if $H_{s,am}>1.5$m.

However, tides are classified as micro-tidal, if the tidal range (TR) <2m, meso-tidal for TR between 2m and 4m and macro-tidal for TR>4m. Furthermore, the relative strength of tide-induced (tidal range TR) and wave-induced forces (mean annual near-shore wave height H) acting in coastal system, the following classification may also be given as: wave energy-dominated coasts (TR/H=0.5 to 1.0), tide energy-dominated coasts (TR/H>3); mixed energy coasts (TR/H=1 to 3).

Regarding the long-term marine observation data, we refer to the research reports analyzed by Tainan Hydraulics Laboratory (THL) and then summarize the hydrodynamic energy classification of Taiwan coast shown as Figure 3 and Figure 4. Therefore based on Davis and Hayes's (1984) classification, the results show that Yunlin and Chiayi coasts belong to the nearly meso-tidal coast. As mentioned about classification of wave energy coast, the coast between Yunlin and Tainan (southwestern coast) is moderate wave energy coast. Thus the hydrodynamic energy background of the Wai-San-Ding barrier island is the nearly meso-tidal and moderate wave energy coast.

Table 1. Hydrodynamic forcing in the coastal zone			
Wave Energy	low	moderate	high
	Hs,am<0.6m	0.6m <Hs,am<1.5m	Hs,am>1.5m
Tidal Energy	micro-tidal	meso- tidal	Macro- tidal
	TR<2m	2m<TR<4m	TR>4m
Coastal classification based on hydrodynamic energy			
Wave Energy-dominated			TR/ Hs,am=0.5~1
Tide Energy-dominated			TR/ Hs,am>3
Mixed Energy			1<TR/ Hs,am<3

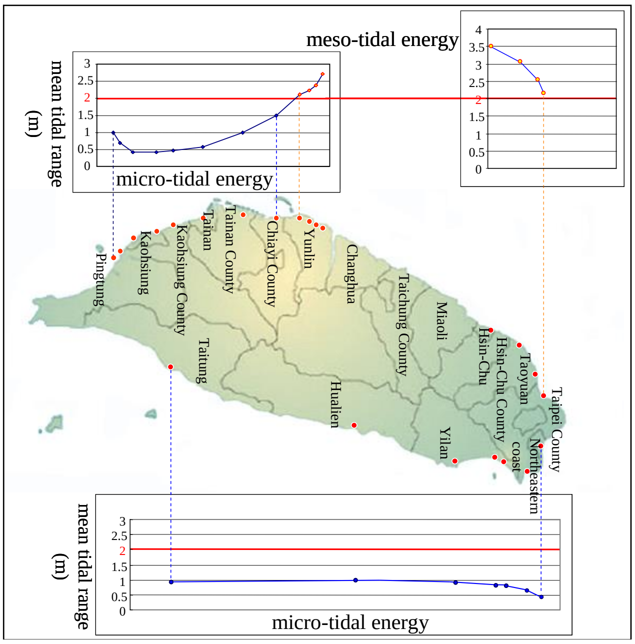

Figure 3. Tidal energy classification of Taiwan coast.

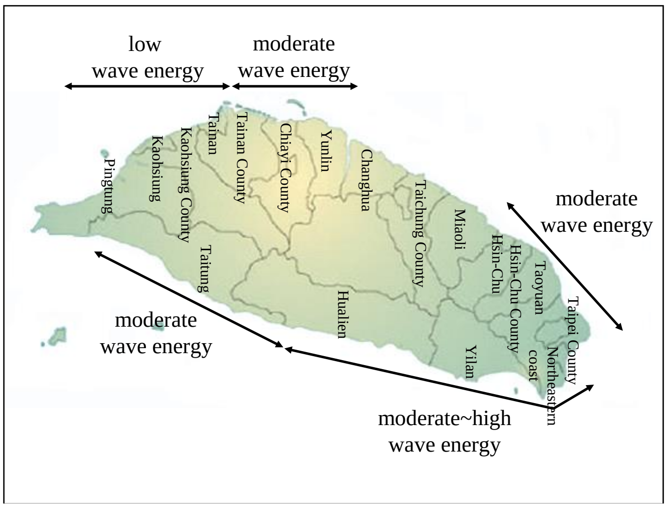

Figure 4. Wave energy classification of Taiwan coast.

DISCUSSION ON APPLICATION OF THE SOFT SOLUTIONS OF WAI-SAN-DING BARRIER ISLAND

Barrier islands as their name implies, they form a protective barrier between coastal shorelines and wave action that originates offshore. Barrier islands are also ecosystems that border coastal shorelines and physically separate the offshore oceanic province from inshore wetlands, bays and estuaries. Coastlines fronted by barrier islands also include some of the greatest concentrations of human populations and accompanying anthropogenic development in the word. The native vegetation and geological stability of these ecosystems are coupled and vulnerable to erosion events, particularly when also disturbed by development.

The objective of this experimental application study is to find the suitable measure for mitigating the existing erosion problem of the Wai-San-Ding barrier island. After collecting enough hydrodynamic and morphodynamic data from the long-term field investigation, the erosion mechanisms of the barrier island were analyzed in detail. Then we summarized the hydrodynamics and sediment transport characteristics around Wai-San-Ding barrier island as followed.

Primary hydrodynamic components

(1) Wave: winter wave, summer typhoon wave,
(2) Current: tidal current dominated, maximum speed up to 2~3 knots,
(3) Wind: monsoon from northeast, 15~25% wind speed up to 10~20 m/s.

Primary sediment transport

(1) Longshore sediment transport induced by wave,
(2) Overwash process during high tide and typhoon period,
(3) Sediment transport volume by sediment transport and overwash up to 5*106 m3/year,
(4) Wind-blown sand of the sand dune can be up to 5.2*105 m3/year.

Sediment source and sink

(1) Source: major from the upstream of barrier island, minor from the rivers.
(2) Sink: sediment transport into Pein-Hou trench.

Figure 5 shows that the time for this beach erosion to become apparently chiefly depends on how fast the rate of longshore sediment transport decreased from the up-coast area and on the river sediment supply. Meanwhile, run up mechanism under various waves, storm surge and overwash threshold on sand barrier during typhoon are also the important factors to be investigated. However, sufficient knowledge on near-shore hydrodynamic forcing, sediment transport processes and morphological features along this offshore barrier island, is helpful to the countermeasure control work. Based on the analysis of the erosion mechanisms, consideration of some measure options were proposed and firstly simulated by one line numerical model (Figure 6) to find the two better solutions. Then two better applications (Figure 7) of the various soft methodologies available for the beach erosion control were proposed after numerical model analysis and further investigated by physical model test (Figure 8) in the Near-shore Wave Basin (NSWB, 150x60x1.5m) at the Tainan Hydraulics Laboratory (THL), National Cheng Kung University (NCKU), Tainan, Taiwan to validate their effect. The results showed that soft groins in the downstream and submerged artificial berms in the midstream are the effectively integrated measure to mitigate the continuing erosion problem of the Wai-San-Ding barrier island. Meanwhile, the plant evolution method and oyster cultch with aquatic vegetation were also proposed to apply in mitigation of wind sand transport and stabilization of sand dune. In order to protect this offshore barrier island, the more detailed field investigations on sediment supply (source and sinks), hydrodynamic forces (waves, tides and rate of sea level change) and geomorphic setting (shore-face profile shape, sub-strata composition) should be continuously conducted. Furthermore, the in-situ experimental study based on two proposed countermeasures is suggested to apply in improving the security as well as to involve ecological and scenic remediation for the erosion problem of Wai-San-Ding barrier island.

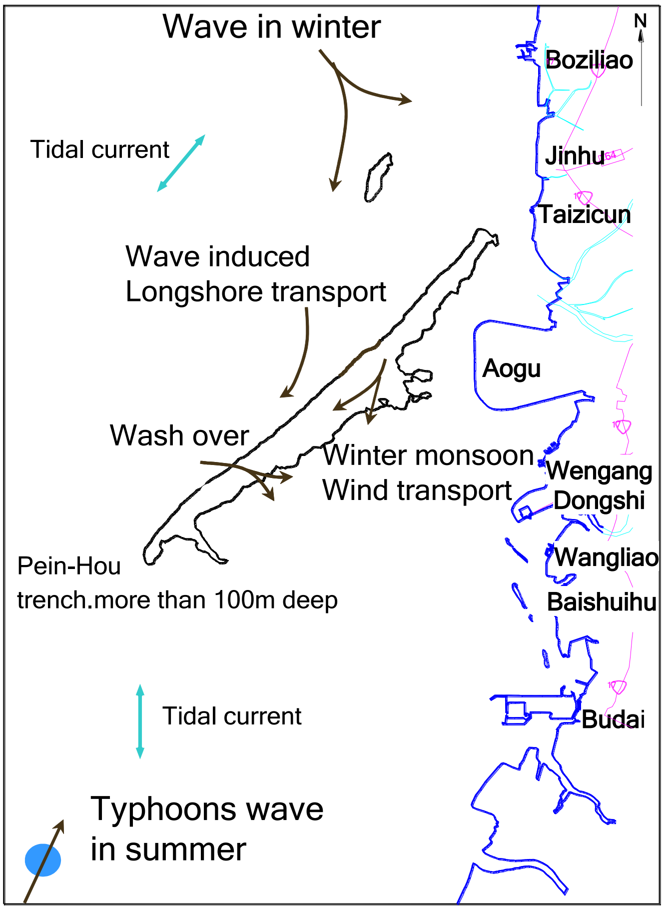

Figure 5. Hydrodynamic forcing characteristics, littoral sediment transport and morphology dynamics of the offshore barrier island.

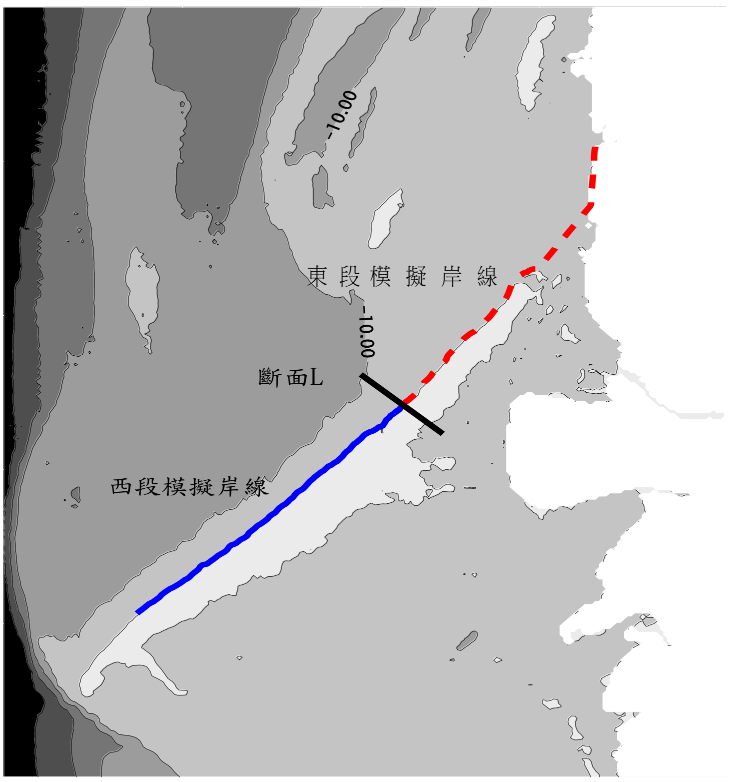

Figure 6. One line model (GENESIS) for coastline changes.

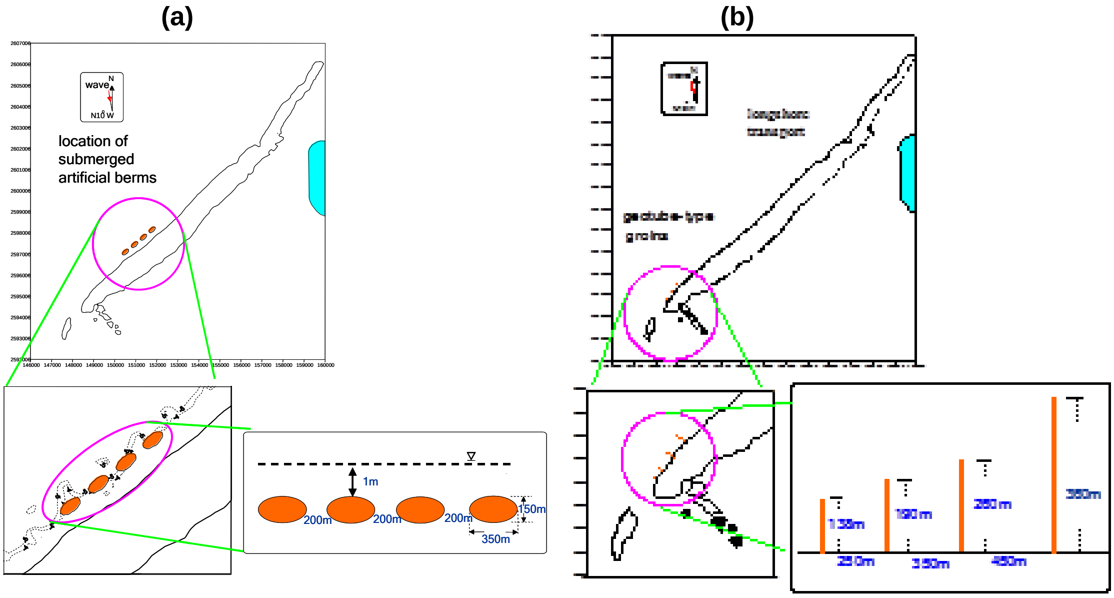

Figure 7. Two better countermeasures for mitigation the erosion problem of Wai-San-Ding Barrier Island. (a) submerged artificial berms (b) soft groins used by geotube.

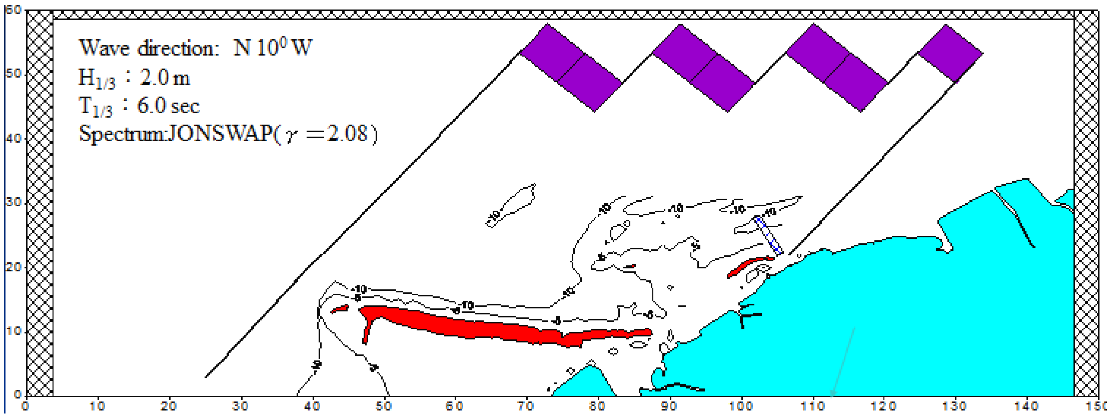

Figure 8. Wai-San-Ding barrier island physical model in the THL, NCKU.

CONCLUSIONS

The objective of this study is to find the suitable countermeasure for mitigating the existing erosion problem of the largest remaining barrier island off the Taiwan coast, the Wai-San-Ding barrier island. After investigating the hydrodynamic and morphodynamic data and simulating our proposed countermeasure by numerical model simulation and physical model tests. We summarized some conclusions as followed:

(1) Wai-San-Ding barrier island is still submerging and moving southward that will affect the security on the lee shore.

(2) Mitigated action should be taken as soon as possible.

(3) The Integrated hard and soft solutions were proposed by our study. In the first stage, geotube-type groins can be built on the downstream site to prevent longshore sediment transport into Pein-Hou trench. In the second stage, submerged sand dunes can be placed on the midstream. Model results show the proposed solutions can mitigate the erosion.

(4) Our research only provide a preliminary solutions, based on the study results, a limited field experiment on site has been proposed and will be performed in the near future.

ACKNOWLEDGMENTS

The authors wish to acknowledge the generous support from Water Resources Agency, Ministry of Economic Affairs and National Science Council through the grant number NSC-100-2923-E-006-001-MY3, Taiwan.

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