Morphological Changes in the Vicinity of Detached Breakwater at Sungai Haji Dorani, Peninsular Malaysia

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Detached breakwater, morphological change, mangrove restoration project, coastal rehabilitation.

Abstract
Human activities in the coastal zones of Malaysia for the last fifty years had impacted its coastline. Serious efforts had been planned and implemented to improve or stabilize these affected areas. One of the relevant agencies, the Forestry Research Institute of Malaysia (FRIM), has carried out several coastal rehabilitation projects along the coast of Malaysia. In one of the projects, mangrove replanting was initiated to restore the depleting mangroves due to development projects and illegal harvesting activities. A detached breakwater was introduced to shelter a mangrove restoration area in Sungai Haji Dorani, on the west coast of Peninsular Malaysia. Construction of the breakwater on this muddy coast was successfully completed in July 2008. One of the main objectives of the breakwater was to facilitate sediment accretion behind the breakwater. The morphological changes in the vicinity of the breakwater have been monitored on a quarterly basis between July 2008 and December 2009. Numerical simulations with the 2DH model MIKE 21 have then been carried out. Field monitoring indicates that a significant volume of sediments was deposited in the lee of the breakwater, which is in good agreement with the results of the numerical simulations.

INTRODUCTION

The shorelines of the west coast of Peninsular Malaysia are threatened by erosion, due mainly to degradation of mangrove forests that are disappearing in an alarming rate of 1% per year (Gong and Ong, 1990). The consequences of such habitat loss are not limited to coastal erosion. Habitat loss could affect marine species diversity, fishery, and the intertidal zone ecosystem as a whole. Therefore, there is a vital need for sustainable coastal protection plans that could mitigate erosion and improve coastal habitat and associated biota. Such plans are likely to enhance ecological and socioeconomic aspects of coastal areas as well. In recent years, the importance of coastal erosion management has increased on account of the growing importance of coastal areas in economical, political, and environmental issues. Accordingly, managers and policy makers have increasingly become aware of this mounting problem, making great efforts and spending large amounts of governmental funds to find sustainable solutions and adopt appropriate policies.

Unfortunately, the industrialisation process over the past decades, directly or indirectly, has led to degradation of the natural ecosystem of coastal zones and deterioration of water quality. As reported by the Malaysian Department of Irrigation and Drainage, 29% of Malaysian coastlines face ongoing erosion impacts (DID, 2006). Worldwide, coastal development has often resulted in degradation and environmental ramifications, especially in the past, because coastal areas have been used for urban development and industrialisation with little or no attention paid to environmental problems. For example, approximately a kilometre of coastline was developed each day between 1960 and 1995 in Europe, causing losses of coastal wetlands and seagrasses (Airoldi and Beck, 2007). While coastal development has to continue promoting industrial and recreational activities, a sustainable coastal management strategy should be able to manage and protect coastal resources against erosion, degradation, and pollution.

To prevent tidal flooding and reclaim land, dykes (often called 'coastal bunds' in Southeast Asia) and revetments were constructed along the shorelines of Peninsular Malaysia. These structures are very common on the west coast, especially in more developed states such as Selangor, Johor, Perak, and Melaka. Since the 1950s, based on a national policy to develop coastal areas, mangrove swamps have been converted to agricultural land, particularly oil palm cultivation, along the west coast of Peninsular Malaysia. The Department of Irrigation and Drainage constructed bunds to protect these agricultural areas from tidal inundation; a strip of mangroves were left between the dykes and the sea to reduce wave energy (Othman, 1994). Apparently, mangroves were not often considered as productive or important unique ecosystems. Consequently, mangroves were cleared because their ecological and socioeconomic values were overlooked. Airoldi et al. (2008) argued that "the limited focus on marine habitat loss is also related to the fact that the consequences of these losses are not fully explored."

Although dykes and revetments are often successful in providing protection for low-lying coastal areas, their construction process has often accelerated the degradation of natural ecosystems (i.e., mangrove forests) along the protected coastlines. These conventional methods of coastal protection may result in irreversible environmental ramifications. Worldwide, these conventional coastal structures are becoming increasingly less popular, due mainly to their adverse impact on amenity and visual values of the coast (Ranasinghe and Turner, 2006). There is, therefore, a vital need for new environmentally friendly methods of coastal management that can provide safe protection against erosion and flooding, with minimised adverse environmental and ecological impacts.

The overall aim of the research is to assess the efficiency of a habitat stabilisation approach using low crested breakwaters in combination with mangrove replanting project for coastal erosion management. The research was carried out on the muddy beach of Sungai Haji Dorani (SHD) located in the state of Selangor, Malaysia. The objectives of the research were 1) to examine at a local scale the effect of breakwater on the surrounding environment; 2) to investigate the influence of the applied method on the environmental conditions of the study site such as hydrologic regime, beach elevation and morphology; 3) to suggest a more efficient method for improving the coastal erosion management projects on tropical and subtropical shorelines. The focus of this paper is to study the morphological changes in the vicinity of the breakwater.

MATERIALS AND METHODS

Coastal erosion management techniques

Coastal erosion and accretion are parts of a natural phenomenon that shapes the coastlines. Coastal erosion is not a problem for undeveloped (natural) shorelines where no one lives. In developed coastal areas, however, coastal erosion can threaten infrastructures, properties, and tourism, necessitating a coastal protection strategy. In order to design a successful erosion management plan the causes of the erosion should be understood and the natural habitat should be considered as a part of coastal erosion management plan which could provide effective coastline stabilisation and habitat enhancement (Hardaway et al., 2002).

Techniques of coastal erosion management are manifold. From the engineering viewpoint, these techniques can generally be divided into two main types: "hard" and "soft" techniques. Hard techniques are more conventional responses to erosion and involve intervention of artificial structures which protect the shoreline from tidal inundation, storm surges, and wave action. The main shortcoming of hard structures is that these structures are often aimed at protecting a localised shoreline that beach erosion could increase along the downdrift sides of these protective structures if their effects on the surrounding environment were not carefully studied prior to construction. Soft techniques of erosion management are often aimed at promoting natural systems/ecosystems such as beaches and salt marshes that protect the coast. These alternatives are usually cheaper to construct and maintain than hard construction methods and may be self-sustaining. A third option is the "integrated approach". This term is used for a method that comprises both hard and soft techniques.

Depending on the objectives of the project and the site-specific conditions, various types of coastal structures may be applied for coastal protection. These structures are sea dyke, seawall, revetment, bulkhead, groyne, detached breakwater, reef breakwater, floating breakwater, and jetty (CEM, 2006). Among these structures detached breakwaters have widely been built around the world since the 1970s. These structures are more common in Japan, Europe, and the United States (Herbich, 2000).

A detached breakwater is generally constructed parallel to the shoreline aimed at protecting the shore from wave action and promoting sediment deposition on the shoreward side of the breakwater. Detached breakwaters are also called offshore breakwaters (Herbich, 2000). The layout of a breakwater is designed based on the size and shape of the area that should be protected and the predominant directions of waves, currents and littoral drift (CEM, 2006).

Soft engineering solutions to erosion include beach nourishment, planting vegetation for stabilisation of sediments dunes, mangrove restoration etc. Beach nourishment is often utilised in sandy beaches to promote recreational activities, whereas mangrove restoration could provide an effective natural protection for tropical and subtropical beaches. Both beach nourishment and mangrove restoration could improve the socioeconomic aspects of the coastal area, thus attracting more tourists to the beach for recreational activities. In addition, mangrove restoration could enhance aesthetic values and water quality as well as the economic aspects of the beach (Lewis, 2005; Bosire et al., 2008).

In practice, soft-solution features could be incorporated into hard construction techniques to design a successful integrated approach to sustainable coastal management. An integrated approach can ensure the sustainability of coastal management efforts by setting goals in coastal protection as well as ecological restoration. Main objectives of an integrated approach are to improve safety and promote the quality of life in coastal zones.

Study area

The study area is located in SHD (03°38'N and 101°00'E) on the west coast of Peninsular Malaysia, some 90 km to the north of Kuala Lumpur (Fig.1). Destruction of the coastal forest and mismanagement during past decades has deteriorated the beach. Mangroves have been degraded and most of them have disappeared. Consequently, the beach has become exposed to direct wave action, resulting in severe erosion. The presence of mangroves could reduce the wave energy, and hence the erosion rate (Kathiresan and Rajendran, 2005; Thampanya et al., 2006). Therefore, it was expected that mangrove replanting in this area could stabilise the beach and improve the habitat.

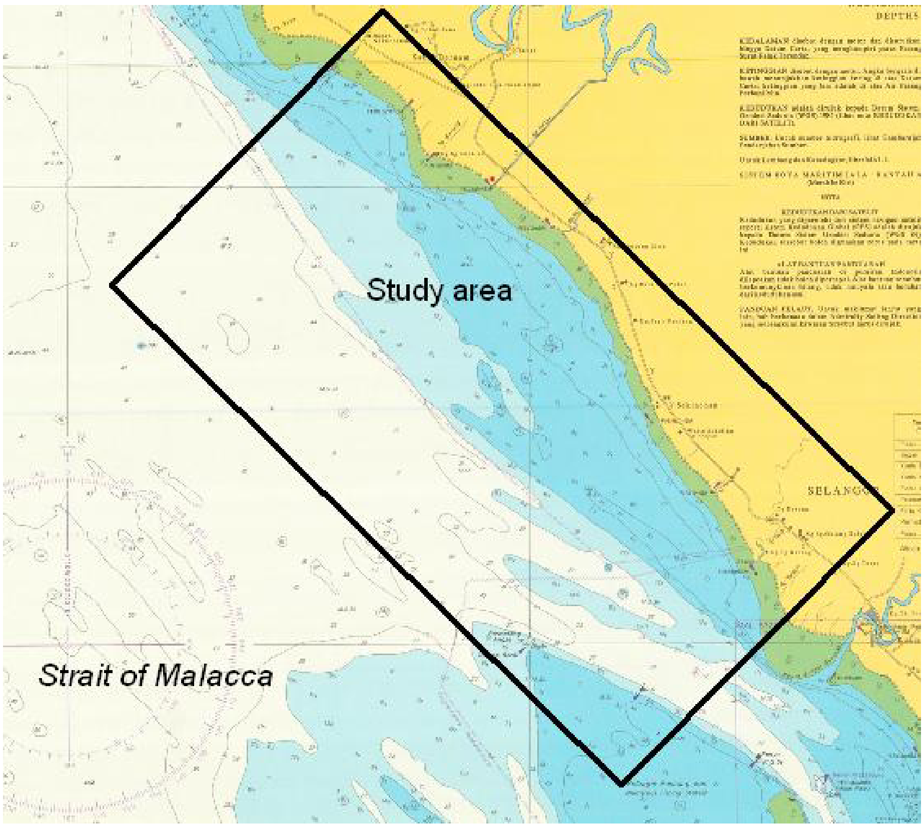

Figure 1. Map of the study area.

SHD has a semi-diurnal tidal regime with a maximum annual tidal range of 3.2 m. The beach is exposed to direct wave attack from SW and WNW. According to the Metrological Department of Malaysia, the frequent wave height is lower than 1 m; the significant offshore wave height is about 1.50 m with a return period of 10 years.

Habitat stabilisation
On the basis of a desk study, a detached low crested breakwater was designed and constructed shoreward of the study area. The objectives that the breakwater was designed to fulfil are 1) to protect the shoreline from ongoing erosion, 2) to shelter the study area designated for mangrove restoration, and 3) to improve sediment deposition in the sheltered area.

A low crested rubble mound breakwater was constructed in July 2008 in SHD. Rubble mound structures are composed of a bedding layer and a core of fine materials (quarry-run stone) covered by layer/layers of larger stones and armoured by layer/layers of large stones or concrete armour units with or without superstructures. However, in the case of low crested breakwaters the rubble mounds are often a homogenous pile of rocks covered by the armour layer. In shallow waters, rubble mound breakwaters are usually built with low crest levels that allow wave overtopping during storms. From the environmental point of view, low crested breakwaters are more acceptable on account of visual aspects and water quality (Zanuttigh et al., 2005). Intervention of these structures to near-shore waters produce lower catastrophic environmental impacts and minimised morphological side effects compared to traditional (emerged) structures.

The SDH breakwater is composed of three segments separated by 5 m gaps to allow water circulation avoiding adverse ecological effects (Figure 2). This structure was designed as a homogenous rubble mound and built of quarried granite rock with a seaward slope of 1.5. The structural design was described in details by Hashim et al. (2010).

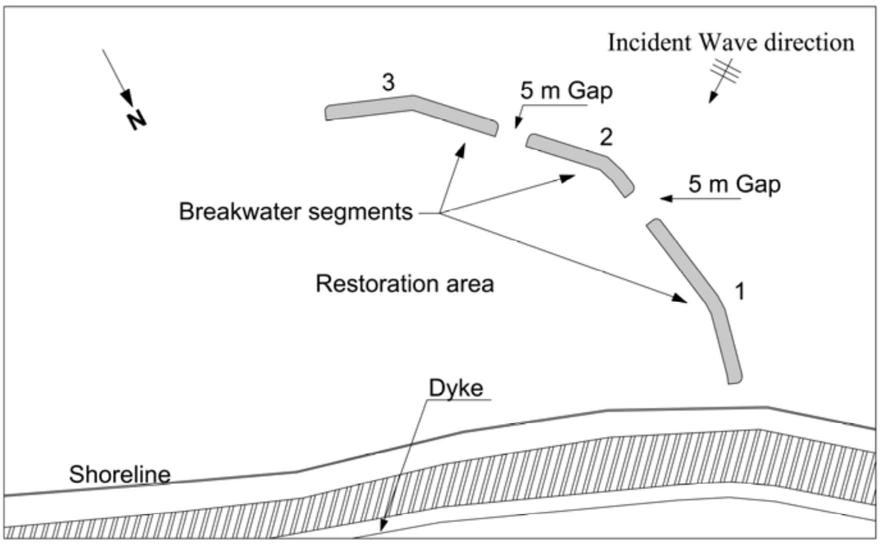

Figure 2. Breakwater comprised of 3 segments which are separated by small gaps.

Coastal rehabilitation

Natural ecosystem degradation and clear-cutting of mangroves for coastal development have made it impossible to bring back the pre-developed conditions. After clearing the mangroves, the barren mudflat in front of degraded forest has been exposed to wave action for a long time resulting in reduction of the beach elevation. Hence, the hydrologic regime (depth, duration, and frequency of inundation by high tides) was changed. To promote the natural recovery process, the correct hydrologic pattern should be re-established by increasing the beach elevation. The presence of a breakwater could improve the sedimentation process.

The next step to facilitate and accelerate the rehabilitation process was to plant mangrove seedlings raised in the nursery. Therefore, seedlings of *Avicennia marina* were transplanted to the site. *A. marina* seedlings were selected for transplantation because wild *Avicennia* spp seedlings are the main recruits within the study area (Hashim et al., 2010).

MIKE 21 Simulations

Bathymetry of the area was created using a rectified map (Figure 3). The bathymetry was reconstructed following field observations. Water levels at boundaries were created using MIKE 21 Tool box, Tide prediction of Heights. The hydrodynamic simulations account both for predicted tide variation and for wind.

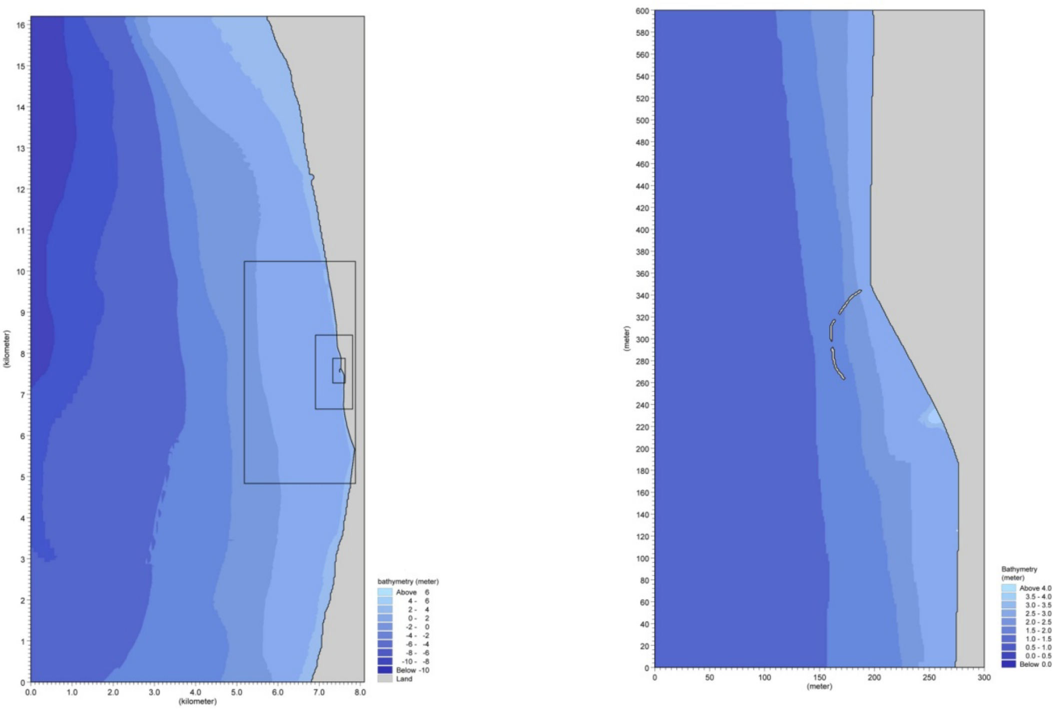

Figure 3. Bathymetry map of the study area

RESULTS AND DISCUSSION

The presence of the breakwater resulted in sediment deposition shoreward of the structure in the restoration area. Initially, the elevation of the site was about

0.75 m above mean sea level (MSL) near the shoreline and 0.25 m above MSL about 50 m seaward the shoreline. In February 2009, eight months after construction of the breakwater, an average elevation of 0.71 m above MSL was achieved in the sheltered area which is very close to the target elevation required to provide the correct hydrologic regime. The lowest elevation of the existing mangrove in the reference site was about +0.70 m MSL as reported by Hashim et al. (2010). In October 2009, the mean elevation of the site was about 0.78 m above MSL (Figure 4). A steady morphological state was achieved in the rehabilitation area behind the breakwater by February 2009 which was necessary for habitat stabilisation.

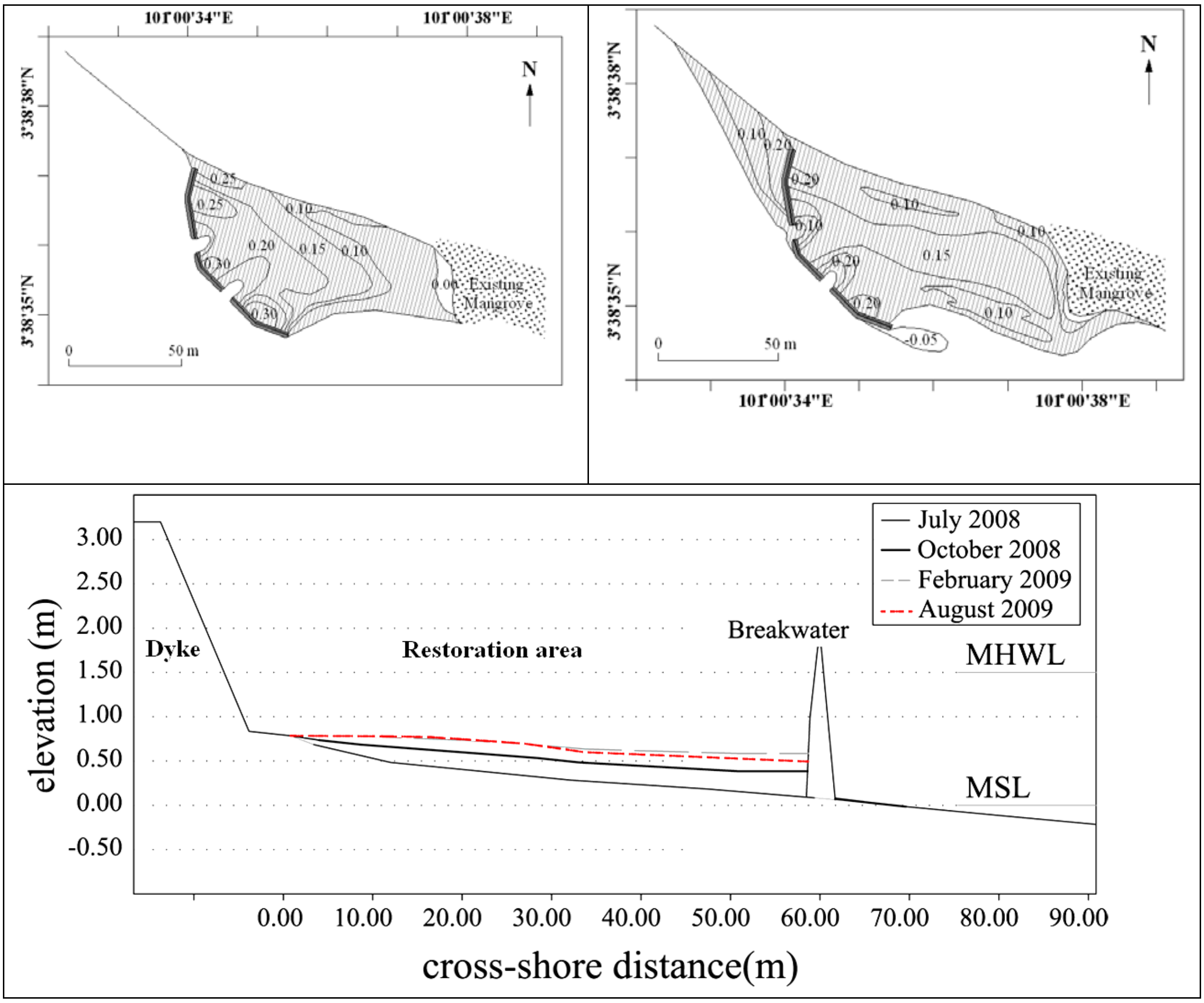

Figure 4. Morphological changes of the study area behind the breakwater

The breakwater was placed near the shoreline facing the incident waves, with the first segment near and the last segment about 60 m away from the shoreline. In addition, the small gaps reduced the wave energy diffracting into the sheltered area. This orientation of breakwater segments enhanced the sediment deposition and thus led to an appropriate increase in the substrate elevation which provided the normal hydrologic regime for mangroves.

Initially, the result of mangrove transplanting was not satisfactory. Only 30% of transplanted mangrove saplings survived eight months after the initial planting.

Hashim et al. (2010) stated that "about 70% mortality of mangrove saplings during eight months, from July 2008 to February 2009, could be attributed to infestation of barnacles, active sedimentation, and fishermen disturbance of the restoration site." By March 2009, almost all of the transplanted mangrove saplings had died. However, this was not the end.

Subsequently in October 2009, the site (restoration area behind the breakwater) was covered with hundreds of waterborne mangrove seedlings, mostly *Avicennia marina*. More than 300 of these volunteer seedlings survived as was observed on 1st December 2009. The Calm area (protected by breakwater) and correct hydrologic regime provided the suitable environmental conditions for the natural regeneration process to recover the mangrove ecosystem. The natural recovery process was stimulated when the environmental conditions were appropriate for mangrove seedlings to grow. Mangroves could recover naturally when given an opportunity, removing stressors and promoting conservation and sustainable use of mangrove ecosystem, if the geomorphological and hydrological features were not alerted (Lewis, 2005; Martinuzzi et al., 2009).

Coastlines of the west coast of Peninsular Malaya have been historically occupied by mangroves. The erosion has only become a problem when these valuable forests have been cleared for development. Therefore, the most acceptable and sustainable solution to the coastal erosion of most mangrove-colonised tropical shorelines around the world is restoring the mangrove forests. There is also a crucial need to impose regulations on coastal development in order to prevent further destruction of the coastal ecosystems. Instead of erecting dykes on shorelines, detached breakwaters can be constructed offshore to protect the coastal area and degraded mangrove forests.

Worldwide, planting mangrove on exposed muddy beaches has often failed (Clarke and Myerscough, 1993; Riley and Kent, 1999; Kairo et al., 2001; Thampanya et al., 2002). Therefore, when the rehabilitation site is exposed to wave action, a detached breakwater could be used to provide the calm area suitable for mangrove seedlings.

The main problem along the west coast of Peninsular Malaysia is not the difficulty in replanting mangrove. The main problem is that the existing mangrove forests of Malaysia are disappearing at a rate of 1% per year. In addition, most attempts have been made to develop effective methods for mangrove planting and re-planting without stabilising the habitat and providing suitable conditions required for natural recovery. It can be recommended that the main effort should be focused on saving the existing natural mangrove forests that are threatened by human activity and coastal erosion.

The west coast of Peninsular Malaysia could be kept safe and natural by stabilising the natural habitat along the coastlines and reducing stressors on the mangroves. The true value of mangroves as unique productive ecosystems that could improve tourism should be further promoted to the stakeholders and policy makers.

The hydrodynamic simulations account both for predicted tide variation and for wind. The results provided by Hydrodynamic Module can be used to investigate the efficiency of the breakwater in decreasing the incident wave impact and currents speed. This could be also useful for identifying potential areas of erosion or deposition on the site, but not to determine the actual bathymetry at the end of the simulation period.

Current speed induced by wind and tide variation was lower on shoreward side of the breakwaters. Therefore, it was expected that sediment accretion occur at the area protected by the breakwater. The structure reduces the current intensity only in the protected area and it does not affect the longshore drift in the whole area.

CONCLUSION

In conclusion, this paper presents initial results on the performance of a detached low-crested breakwater constructed as a part of an eco-engineering solution for mangroves reestablishment. The detached low-crested breakwater is an alternative approach to coastal erosion management that can ensure the sustainability of efforts by setting goals in providing safety (i.e., coastal protection) and restoring the ecosystem. This alternative approach is the integrated approach that comprised both hard and soft engineering techniques and could be the most effective method for coastal rehabilitation on the exposed beaches. Keeping the coast safe and natural can promote tourism industry and improve natural resources.

Detached low-crested breakwaters could be used to protect eroding shorelines with less adverse impacts than other hard structures such as dykes. Intervention of breakwaters can provide suitable environmental conditions for mangroves to stimulate natural regeneration processes without replanting.

Simulation results indicated that the current speed induced by wind and tide variation was lower on shoreward side of the breakwaters. Therefore, it was expected that sediment accretion occur at the area protected by the breakwater. The structure reduces the current intensity only in the protected area and it does not affect the littoral drift in the whole area.

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