NEW INNOVATIONS AND TECHNOLOGIES IN COASTAL REHABILITATION

By

Ir. Nor Hisham M. Ghazali
Senior Assistant Director Coastal Eng. Division
Department of Irrigation and Drainage Malaysia
Jalan Sultan Salahuddin
50626 Kuala Lumpur MALAYSIA

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Introduction

The erosion of shorelines is often accompanied by considerable loss in coastal vegetation and natural habitats. In the present day, the survival of local economies and livelihoods depend on the preservation of these habitats. Coastal protection structures such as seawalls and rock revetments have been used for centuries to protect and prevent further loss of coastal lands that are bases of these economic activities. Whilst successful in preventing shoreline retreat, their presence often contributes to the denigration of natural coastal habitats. These concerns were the impetus for research into alternatives to hard protection.

Over the last two decades, as the importance of preserving natural coastal resources were realised on a global scale, efforts have been made to migrate from the conventional approach of hard engineering to *soft* engineering and eco-engineering especially in environmentally sensitive areas. The novelty of these solutions is their ability to sustain natural resources and even add-value to the coastline. This paper presents a description of some of the new innovative solutions with a focus on Malaysian experience, and discusses their strengths, limitations and related issues.

Coastal Restoration and Erosion Control

In the past, protection works were focussed only on solving the local problem. Such piece-meal protection works are now known to contribute to the erosion of adjacent shorelines. For example, the selection of certain protection methods involving shore-normal structures such as groynes interrupt the natural littoral drift depleting sediment supply to downdrift beaches. Similar problems arise due to the construction of rivermouth breakwaters which are for improving navigation.

When considering coastal restoration, it is useful to differentiate between protecting the shoreline and the coastline. Shoreline protection halts the retreat of the shoreline while safeguarding, preserving or restoring the shore and the dynamic coastal landscape. Coastal protection aims at protection of housing and infrastructure and the hinterland with strategies even at the expense of losing the beach and the dynamic coastal landscape (Mangor 1998). The options chosen for erosion control at a particular stretch could actually determine the fate of the entire shoreline and its natural resources. Nowadays, coastal protection strategies can be better planned under a shoreline management plan which takes into account the response of the neighbouring shoreline and its potential affect on economic activities, habitats and ecosystems. More importantly, shoreline management plan studies have been instrumental in bringing engineers and scientists together to solve coastal protection, resource management and development strategies. Under shoreline management plans, protection options are studied with respect to local conditions and resource management needs as shown in Table 1.

Table 1: Alternatives to Shore Protection (adapted from Coastal Engineering Manual (US Army Corps of Engineers, 2002)

	Type	**Description**	**Method**
1	Armouring	Defending the shoreline at its current position	Revetments
2	Stabilisation	Reducing the erosion rate by slowing down the loss of sediments	Groynes, breakwaters
3	Beach nourishment	Fill up the beach with similar material	Beach nourishment, new technologies
4	Adaptation and retreat	Modify current usage or relocation of existing population or activities	
5	Combination and new technologies	Combination of above methods or innovative methods	Nourishment and groynes, geotextile bags, eco-engineering techniques
6	Do nothing	Allow the beach to change without intervention (usually applied to areas with insignificant or no economic importance)	Allow natural changes

Hard and Soft Engineering

Coastal protection can generally be divided into hard engineering and soft engineering. Hard engineering structures such as revetments, seawalls, bulkheads and groynes are considered traditional erosion protection structures with distinct functions. These are typically constructed of quarry stones or concrete units. Seawalls and revetments are constructed parallel to the shoreline and form a barrier between waves and the coast. Whilst preventing any further loss of material landwards, waves reflected by the seawall causes scouring at the toe in front of the seawall and eventual lowering of the beach. Thus where recreational space is concerned, the use of seawalls and revetments are not beneficial in the long run as the end result is a deepening or steepening of the sea bed in front of the structure resulting in loss of beach space. As illustrated in Figure 1, low beaches can become submerged entirely during high tide thereby confining activities to the backshore area.

Figure 1: The vertical face of seawalls often enhance wave reflection and cause a lowering of the beach; Port Dickson.

The term 'soft engineering' is normally used to describe methods that depart from hard protection structures that use quarry stones or concrete blocks as the main structural component. The use of sand either as a fill material placed directly on the eroding beach or encased within geotextiles are amongst the methods that qualify as soft engineering. In beach nourishment, loose sediments are imported and placed on the target beach to form a wider beach berm as a buffer for waves. The 'new' beach will then continue to be shaped by the natural forces i.e. wind, wave and tidal currents, to an equilibrium shape. Beach nourishment is now common and is the preferred method of protecting or rehabilitating eroding recreational beaches (Ghazali 2004). The construction process however involves dredging, transport and placement of sand in a marine environment which causes water quality problems, habitat displacement and stress to marine life. Beach nourishment is also considered semi-permanent and requires replenishment as time progresses.

Figure 2: Rock revetments usually results in the narrowing of beaches

Figure 3: Beach nourishment creates additional beach space enhancing local economic potential (Port Dickson, Negeri Sembilan; November 2004)

Innovations in Erosion Control

Earlier innovations in coastal erosion control arose from the need to solve specific site problems. These include special structural arrangements or the combination of two or more structure types to achieve a desired coastal protection effect. Examples of this include the use of groynes to confine beach nourishment sand within a certain stretch of shoreline. Revetments (Figure 2) are typically constructed with seaward slopes of 1:3 to 1:4 (1 vertical to 4 horizontal) and a crest level based on an allowable run-up distance. Critical to the design is the mean weight (in kilograms) of the individual armour unit, W_{50} which can be calculated using the Hudson's Formula (CERC, 1984) below:

$W_{50} = (W_r H_s^3)/K_D(S_r-1)^3 \cot \theta$ …………………………… Equation (1)

where,

W_r = unit weight of seawater

H_s = design wave height in meters

K_D = coefficient of stability; varies primarily with shape, roughness of armour unit surface, sharpness of edges and degree of interlocking in placement

S_r = relative weight of armour unit W_r / W_s

θ = angle of structure slope measured from horizontal

Scientists have developed several types of interlocking concrete units which are lighter and possess higher K_D values to provide the equivalent stability of heavier quarry stone armour. Research into interlocking concrete armour units has continued over the years and on the local scene products such as the SAUH (Department of

Irrigation and Drainage), SineSlab® (Universiti Teknologi Malaysia) and L-units (University Malaya) have emerged.

More recent innovations have exploited advancements in specific areas of engineering associated with erosion control namely geotextiles and beach drainage.

Geotextiles

For many years, polyester or polypropylene geotextiles have been used as filters to prevent sediment loss which is a critical component in ensuring stable foundations for construction. High strength geotextiles can be tailored into casings or tubes that can be hydraulically filled with sediments to form 'soft' structures. These are discussed below:-

Geotextile Breakwaters

Geotextile bags, 'sausages' or tubes filled with sand are now gaining wide acceptance in coastal protection. They have been used as nearshore breakwaters (placed parallel to shore), as groynes (placed perpendicular to shore) and even as revetments. Nearshore, low geotextile breakwaters are designed to a height sufficient enough to eliminate storm waves from reaching the shoreline but allows smaller waves to penetrate. In Malaysia, a series of partially submerged woven geotextile breakwaters have recently been built in front of the mangrove-fringed shoreline of Tanjung Piai (state of Johor) (Ghazali & Ong 2005). The design and placement of the geotextile breakwaters takes into account the height of the incident waves, depth, tidal range and site conditions. The geotextile sand-filled breakwaters create a calmer wave environment in their lee (see Figure 8) as larger waves break upon them. The calmer state behind the breakwaters induces substrate build-up allowing a setting for the regeneration of mangroves either naturally or through re-planting. Their utilisation is however not intended as a solid wall against all waves but purely to eliminate the damaging storm waves and reduce their energy within the project locality. At Tanjung Piai, the geotextile breakwaters are placed along the pre-erosion alignment of the shoreline nearly 30 meters in front of the existing shoreline.

Figure 4: Sand-filled geotextile tubes used in Tanjung Piai, Johor to reduce wave energy on mangrove shoreline.

Geotextile Revetments

Sand-filled geotextile containers can also be stacked to form a revetment as opposed to using rocks. These have been used mostly along river banks in Malaysia but not as extensively for coastal protection. Figure 9 illustrates one such system being tested on a stretch of coastline in Portugal (Neves *et al,* 2004). The system has been designed to prevent erosion of a 3 km dune ridge of Estela in the municipality of Povoa de Varzim.

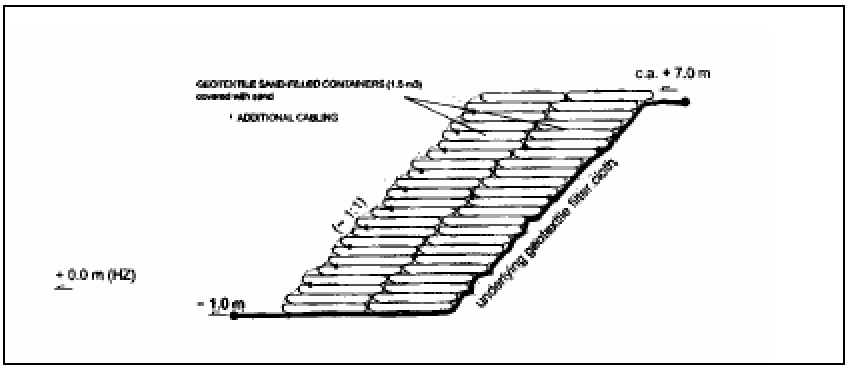

Figure 5: Sand-filled geotextile containers stacked to form revetment

Beach Drainage Systems

A significant difference in some of the newer innovations is that, rather than creating an energy dissipating barrier to waves, they instead improve the drainage capacity of the beach which then leads to more compact beach sediments. It has long been observed that there is a relationship between the beach groundwater table and erosion. Earliest observations were by Grant (1984) on swash zone processes revealed that high water table under a beach accelerates its erosion and that low water table may lead to accretion This lead to the design of beach de-watering techniques to stabilise beaches. In Malaysia, two innovations based on improving the beach drainage have been tried and are discussed below:

Beach Management System

The Beach Management System (BMS) works on the principle that a saturated beach is more erodible than an unsaturated beach. When saturated, the density of individual grains of sand is less and there is also less inter-particle contact which makes the beach material prone to movement by up-rush and down-rush forces. Thus, if a beach is well-drained, particles are more closely packed and the beach sand is better consolidated. The BMS is a system which combines drainage pipes and electrical pumps to drain a beach. Figure 4 presents a schematisation of the BMS.

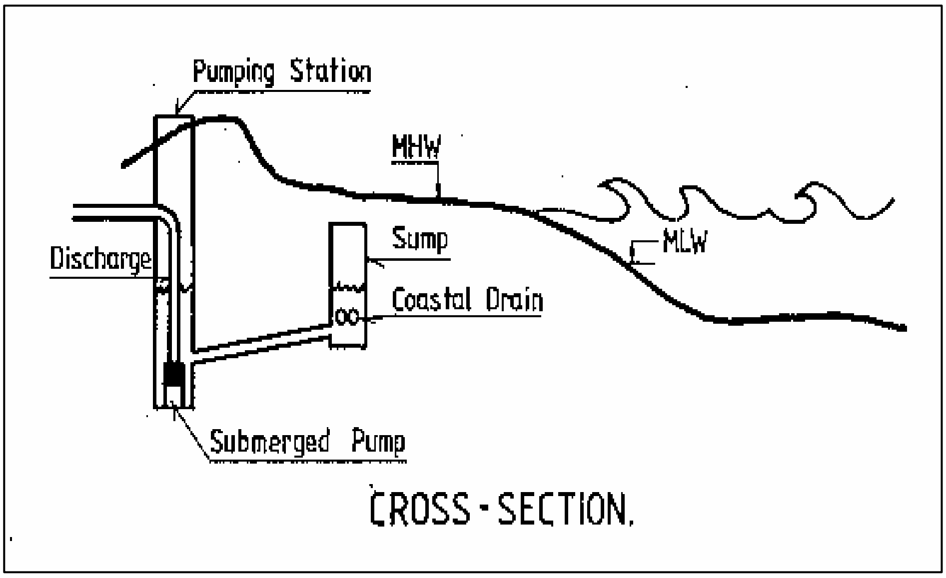

Figure 6: Beach Management System - schematisation

The buried shore-parallel drains of the BMS are in the form of perforated pipes wrapped in geotextile. They are placed parallel to the shoreline slightly above the Mean High Water line and within the wave uprush zone (zone of wave run-up). The drains channel the collected water into a sump which flows into the pumping chamber built further to the backshore. Sensor-activated submersible pumps will start to pump the drained water out and away from the beach as soon as the water level in the chamber reaches a pre-set level. Pilot installations have been completed in Kelantan and Port Dickson (Negeri Sembilan).

Pressure Equalisation Modules

The pressure equalisation module (PEM) system is another relatively new system currently being tested in Kuantan, Pahang. The PEM functions in the uprush zone of the beach where wave runs up the beach face and, upon reaching its limit, runs down and at the same time infiltrates into the bed (see Figure 5 and 6).

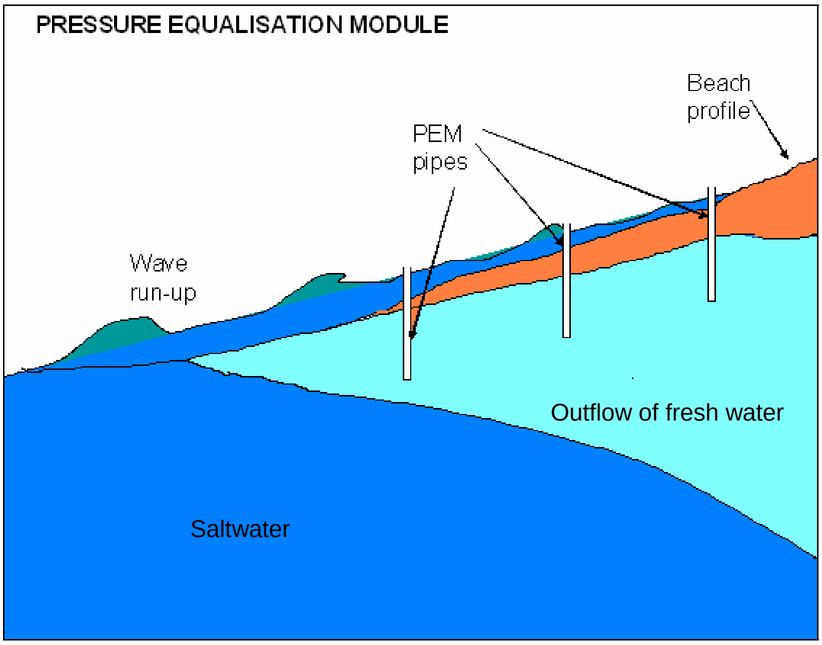

Figure 7: Pressure Equalisation Module - schematisation

Figure 8: Pressure Equalisation Module pipe at Teluk Cempedak beach

The infiltration of seawater into the bed is limited by the existing level of groundwater. Hence, if the groundwater can be lowered, more water from the run-up can percolate into the bed and less will run down the surface dragging sediments with the flow. The lowering of the local groundwater table can be achieved with the PEM system which relieves the pressure within the beach by physically ‘connecting’ it with the atmosphere. In summary, the PEM increases vertical infiltration of uprush in the swash zone.

Rows of perforated PVC pipes about 15 cm in diameter are installed normal to the shoreline in the area between the uppershore limit of the swash zone (area influenced by wave run-up) and the mean low water line. The pipes behave as a vertical filter which equalises groundwater pressure within the beach allowing increased circulation of seawater within the beach profile[1]. The PEM pipe design is illustrated in Figure 7.

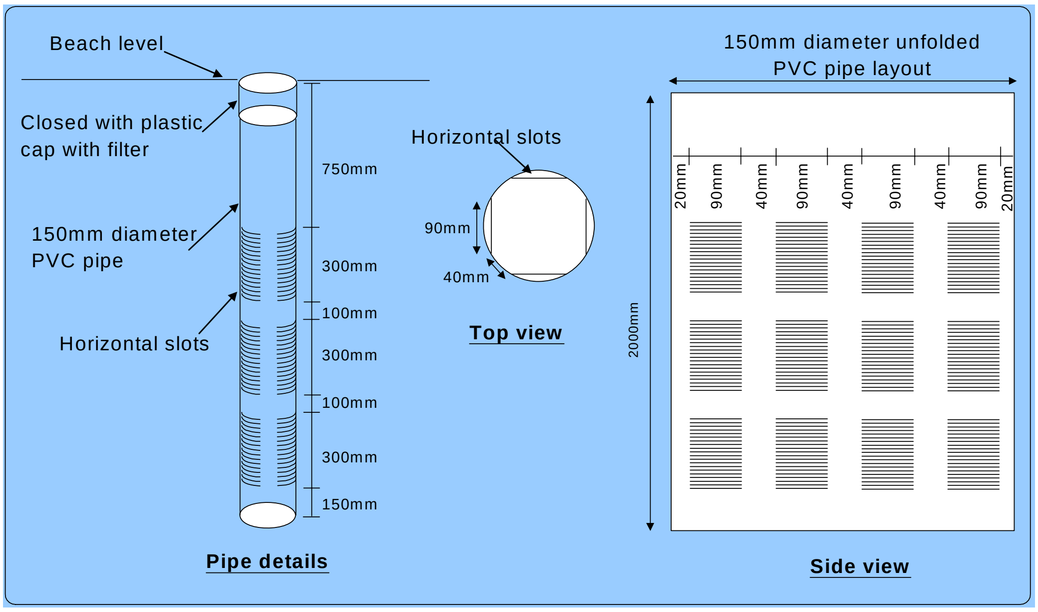

Figure 9: Design of Pressure Equalisation Module Pipes

Each PEM pipe is 2.0 m long with perforations measuring 400 to 900 microns (1 micron = 0.001 mm) and are placed vertically into the beach with the bottom end penetrating the phreatic line. Any water pressure build-up within the beach will be transferred into the pipes. The PEM system is suited for littoral coastlines with a natural supply of sand from the coast. In cases where the natural sand supply has been depleted, beach nourishment is necessary. The presence of the PEM system causes the beach to retain more material on the foreshore area (between the low water line and the high water line) and form a more erosion-resistant beach. Its immediate affect will be in lowering the sediment transport capacity of wave down-rush. In the medium term, the shoreline undergoes a change whereby sediment mounds will form normal to the shore along the position of the PEM pipes. These then behave like groynes and trap sediment movement in the alongshore direction (Jakobsen 2002). With a more erosion-resistant beach, beach nourishment replenishment intervals is expected to increase. Another notable benefit is that the PEM system creates minimal disruption to the shoreline both in the physical and ecological sense. The construction phase of a PEM project, unless beach nourishment is required, uses very little machinery causing minimal disturbance to beach activities (Ghazali, 2005).

Eco-engineering

Buoyed by the global agenda for sustainable development, ‘green’ concepts have already been incorporated into coastal protection strategies. The term eco-engineering (or bio-engineering) has been loosely applied to methods that combine the understanding of ecosystems with engineering technology. Mangrove re-planting is the most common example of eco-engineering and such efforts have been done worldwide including in Malaysia. The tsunami event of December 2004 revealed that the preservation and continual proliferation of the mangrove habitat is a key component in protecting coastal communities from tsunami. It has also been established that natural mangrove regeneration follows accretion (Erftemeijer & Lewis 1999) leading to the hypothesis that if engineering structures could be used to prompt or accentuate the accretion process, mangroves would than re-establish in the area.

The role of coastal vegetation, mangroves in particular, in attenuating wave energy has long been appreciated by coastal engineers and mangrove-replanting in tandem with structural measures are not new. In 1987, a low revetment of interlocking concrete units was used to protect the escarpment on the shoreline at Sungai Burung in the state of Selangor whilst mangrove seedlings were planted in the thinning mangrove belt behind it (Othman 2003). This was one of the recorded successes of mangrove replanting on an eroding shoreline and highlighted the significant role played by a protective hard structure in the process. Without protection from the waves, the roots of young mangrove saplings are unable to hold on to the substrate. Another notable effort was that of the National Hydraulic Institute of Malaysia-Data Raya[*] in Kuala Sala (district of Yan, Kedah Malaysia). Targeted at re-generating a mangrove belt on an eroding shoreline, mangrove seedlings were planted into coir rolls[#] which served as a geo-material substrate (Noraini Tamin *et al,* 2002). The coir rolls provided young saplings with both stability and protection from crabs. The installation included low geotextile breakwaters at slightly below mean sea level (MSL) and brush fascines above MSL. The attempt successfully built up the local substrate levels in the upper shore (the area is in fact just in front of a coastal bund or levee). Although design limitations and to a certain extent, pests, prevented the project from fully re-establishing mangroves in the eroding foreshore area, this effort improved the understanding of how low breakwaters, coir rolls and fascines worked in an entirely exposed shoreline condition.

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[*] A Malaysian Government Intensified Research Priority Area project conducted by the National Hydraulic Institute of Malaysia with physical works done by private contractor Data Raya Sdn. Bhd.

[#] made of coconut fiber

Bio-technical Concepts

More recently, bio-technical concepts have been incorporated into producing coastal restoration products. As explained by Hadibah Ismail (2005), while bio or eco-engineering involves the planting of vegetation to stabilise the shoreline, bio-technical methods combine structural with bio-engineering to create artificial plants that should achieve the same effect. Bio-technical methods are designed to emulate the hydraulic properties of natural bio-systems and are utilised where the natural plants grow. These artificial systems are configured to create a porous or friction barrier that dissipates wave and current energy. Founded on this, products such as artificial reefs, artificial sea grass and submerged berms have emerged.

Artificial Sea grass

Sea grass fields behave as current attenuators in their natural state and several products have been produced to serve as scour prevention systems. Artificial sea grass or seaweed systems have fronds that are made of polypropylene, synthetic or natural rubber. Placed in clumps or patches anchored firmly to the bed, these systems reduce water current velocity and induce sediments in the water column to settle. Universiti Teknologi Malaysia has successfully tested an artificial sea grass system comprising fronds made of natural rubber. With a specific gravity of 0.5, the fronds stand afloat in water and have a current reduction capability of up to 70% (Hadibah Ismail 2005). As it behaves as a drag barrier against often strong currents, much of the success of artificial grass systems are dependent on secure anchoring to the sea bed. Concrete block bases are frequently used as the anchoring mechanism.

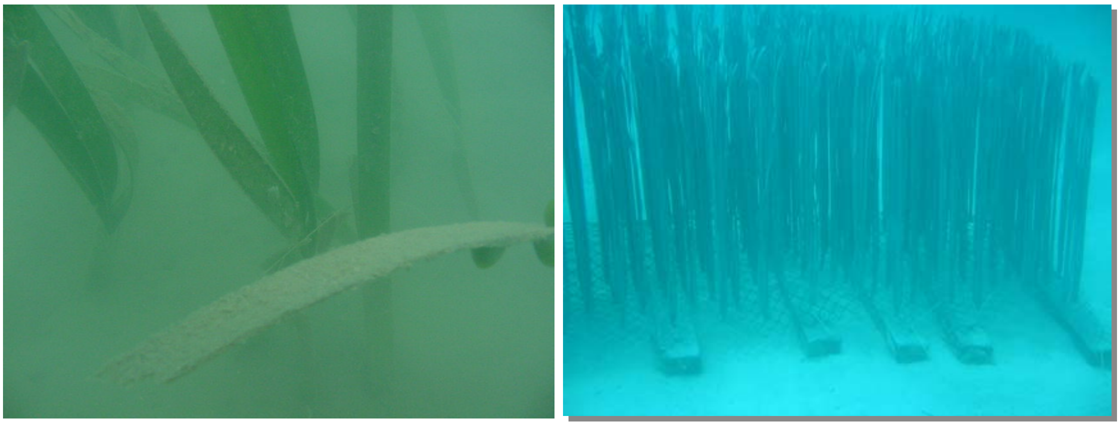

Figure 10: Natural sea grass (left) and artificial sea grass

Artificial Mangrove Root Systems

The root systems of mangroves play a key role in wave attenuation. Othman (Othman 1994) observed that the roots and trunks of Avicennia slow down water currents caused by both the tide and hinterland discharge hence causing sediment to settle. The closer the distance between trees the greater the reduction in wave energy. The influence of strength, shape and configuration (or arrangement) of an ‘engineered’ mangrove root-system is currently being studied by local researchers to determine how they interact with waves. Initial flume experiments on the Artificial Mangrove Root System proved that it can successfully attenuate wave energy (Eldina *et al* 2005). The model of the product is shown in Figure 11.

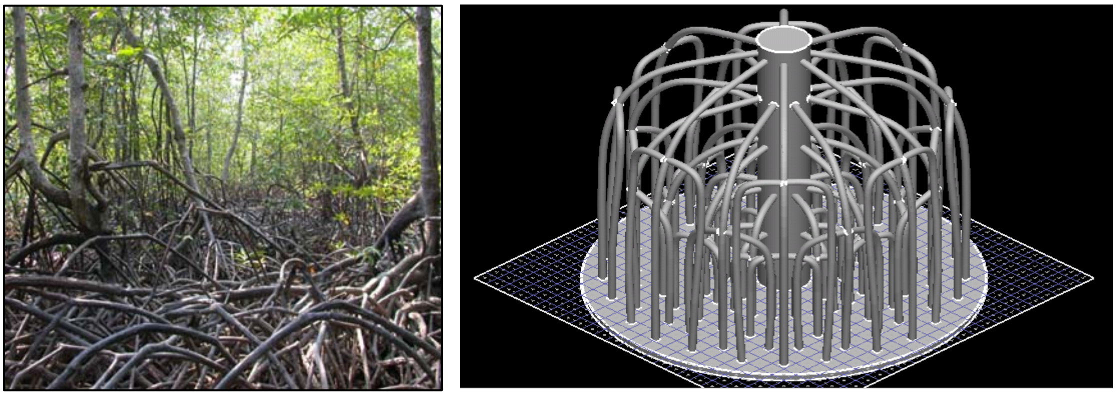

Figure 11: Natural mangrove roots (left) and a model of an artificial mangrove roots system (below).
Courtesy of University Technology Malaysia

Issues related to Bio-technical Efforts

Construction time and Management of Bio-technical Projects

The use of bio-technical methods is expected to bring about the natural rehabilitation of coastlines. Factors in their favour include their ability to blend better into the existing environment as they are less obtrusive compared to hard structures. Most ‘eco-based’ techniques are placed in the inter-tidal areas without causing significant construction related disruptions to the nearby shoreline. However, the actual field performances of the systems mentioned above especially how fast the shore responds to the system are still largely undocumented. Full-scale field projects are probably the only way to determine the effectiveness of eco-based techniques. However, when coastal projects are implemented, tried and tested methods are generally preferred over new innovations unless sufficient proof of success at pilot sites have been confirmed. Without major scale field experiments, bio-technical systems may be confined to be used as ancillary protection schemes. Hadibah Ismail (2005) argues that there should be flexibility in the management of projects using bio-technical products to allow for modifications to be made on site as the ecological system changes over time. As opposed to typical coastal protection works, on-site configuration adjustments of bio-technical projects should be expected and incorporated in the project design and costs.

It is still arguable whether bio-engineering and bio-technical systems can be compared side-by-side with traditional methods. Hence, researchers and engineers should work towards a better definition of their application. Both bio-engineering and bio-technical systems are designed to shorten the time natural coastal processes would normally take towards recovery if at all. It may take five years for a belt of mangrove saplings to evolve into trees and eventually an energy-attenuating barrier assuming favourable tidal and wave conditions. Bio-technical systems could however be placed in less propitious conditions as they first become the agent of change then prompt re-generation by natural or man-made methods. In a critically eroding area where infrastructure is in imminent danger, the longer response time of bio-technical systems may render it an inappropriate alternative. Nevertheless, when it is used in an eroding area, erosion should be expected to continue for a period since coastal processes require time to adjust to the new situation. It exposes a possibility that casual observers may misjudge this outcome as a failure. The need for diligent monitoring of the site is therefore imperative. Since the response time of the site to the bio-technical method cannot yet be ascertained, it would also be prudent to use them in areas where the erosion rate is slow or not yet critical. In the Malaysian context, this would mean Category II (significant erosion) areas where the current rate of erosion will start to threaten economic activities or infrastructure within 5 to 10 years (Economic Planning Unit, 1986) (see Table 2).

Table 2: Classification of Coastal Erosion (National Coastal Erosion Study)

Category 1:	Shorelines currently in a state of erosion and where shore-based facilities or infrastructure are in immediate danger of collapse or damage;
Category 2:	Shorelines eroding at a rate whereby public property and agriculture land of value will become threatened within 5 to 10 years unless remedial action is taken;
Category 3:	Undeveloped shorelines experiencing erosion but with no or minor consequent economic loss if left unchecked.

Effect on the Eco-system

When considering eco-engineering or bio-technical methods in coastal restoration, the expected change in the local habitat is only presumed to be similar to what their original natural changes would bring about. In the case of mangroves, the reduction in wave energy brought about by the bio-technical system is first expected to initiate accretion. Obviously, these artificial systems do not change in size and shape over time as natural plants do as they develop. How this affects the habitat of the immediate area is not really known. A different environment is thus introduced which may be either beneficial or detrimental (or both!) to the existing habitat. Erftemeijer and Lewis (1999) observed that large-scale mangrove re-planting efforts on inter-tidal mudflats actually substitutes one valuable habitat for another. If artificial systems induce regeneration faster than natural ones, therefore the substitution will become faster. Mangrove-free mudflats are feeding grounds for various species of shorebirds with different feeding adaptations. If the mangrove-cover of mudflats are altered, more so artificially and within a short period, the feeding patterns of shorebirds are bound to suddenly change creating a new pattern of feeding and species interaction. A frequent question posed to the developers of artificial sea grass was the chances that the artificial fronds would be mistaken for the real thing by turtles and dugongs with detrimental side effects. Hence, the design of artificial systems must take into account how they would be perceived by marine life. The artificial sea grass featured above is supposedly designed to have a high yield strength that can resist the grazing of dugongs (Hadibah Ismail, 2003). The above arguments indicate the importance of collaboration between engineers and marine scientists in developing innovative coastal rehabilitation systems.

Conclusion

Innovative methods in erosion control have developed from clever combinations of structural engineering structures to those that creating conducive environments for favourable coastal processes to take place. Soft engineering methods such as beach nourishment or beach drainage protect shorelines in a relatively more natural way but not all methods are free from construction-related environmental impacts. The success of innovative projects is dependent on a thorough understanding of the resident processes in the project site and that the interim and final outcome are tenable to all stakeholders. A clear difficulty in promoting full-scale bio-technical projects is in determining the shoreline's response time despite knowing from model and small-scale tests what the physical and hydraulic changes would be. To incorporate these timing uncertainties within the project scope, sites for large-scale bio-technical solutions would best be in areas where infrastructure would only be threatened within 5 to 10 years. However, at the current level of knowledge, bio- (or eco-) engineering and bio-technical solutions can readily be applied as an anticipatory measure when early signs of degradation or erosion have manifested on an area of shoreline.

Bio-technical and eco-engineering has now expanded the alternatives upon which mankind can call upon to combat erosion. The project implementation using these innovative methods however requires some flexibility under existing contract management practise. The melding of environmental sciences and civil engineering under the coastal rehabilitation effort has in fact started a hybrid form of engineering science which is no less complex than their individual parts.

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