Application of Geotextile Tubes as Submerged Dykes for Long Term Shoreline Management in Malaysia

E.C. Lee[1], R.S. Douglas[2], Che Kamaruddin Bahar[3]
[1]Director, LEC Geo Consult, Malaysia
[2]Managing Director, Kiaratex Exports Pte. Ltd., Singapore
[3]Senior Assistant Director, JKR Terengganu, Malaysia
E-mail: engchoy@gmail.com

ABSTRACT: The shoreline in Malaysia has experienced severe erosion due to the impact of high energy waves, both on the predominantly mud coasts and the predominantly sandy coasts. This perennial process has resulted in the deterioration of the quality of the beach on the sandy coasts and loss of valuable land. Several measures had, in the past, been implemented to mitigate these adverse effects but these had predominantly been hard solutions. The application of geosynthetic tubes for shoreline management was introduced in the State of Terengganu on the east coast of Peninsular Malaysia which experiences severe erosion during the North-East Monsoon period. A pilot project by the Public Works Department, utilizing geotextile tubes installed as submerged dykes, was undertaken in 2006 to address the erosion problems and arrest the further erosion of the shoreline at Teluk Kalong, Kemaman, Terengganu. The geotextile tubes comprise of high strength woven geotextile infilled with sand slurry. Subsequently in 2008, the department implemented a similar shoreline protection project at Pantai Batu Buruk in Kuala Terengganu, protecting a 5km stretch of beach. These works comprise of the installation of 3.5m diameter geotextile tubes, infilled with sand slurry, as submerged dykes at a distance approximately 150m offshore. The permeable geotextile fabric allows consolidation of the sand to create a long sausage-like gravity structure. The structure interacts with the hydraulic forces to achieve a stable form. Stability of the structure are derived from resistance against bursting stresses, prevention of loss of infill sediments, settlement and scouring of foundation soil, and sliding or overturning of the structure. The primary functions of the tube include a) contain and retain the sand infills to form a gravity structure, b) act as a submerged breakwater, c) promote sedimentation on foreshore area, d) reduce wave energy impacting the shoreline and e) reduce further erosion of the shoreline. Post-installation surveys carried out indicated that the shoreline has improved with much wider foreshore area. Significant sand deposition was also recorded on the foreshore area, which contributes to the long term shoreline management and promoting sustainable protection of the shoreline. This paper discusses the concept of shoreline management using geotextile tubes as submerged dykes. The details of these two projects and the outcome of the projects will also be presented.

1. INTRODUCTION

Erosion of shorelines is a widespread universal problem throughout the world and Malaysia is no exception. The Malaysian shoreline is in excess of 4,800 km and a large portion of this comprise of sandy coasts. Sandy shorelines dominate the east coasts of Peninsular Malaysia and occupy a significant portion of the coasts of Sabah and Sarawak. The National Coastal Erosion Study (1986) reported that about 30% of the Malaysian shoreline suffers from erosion, with a high percentage of the eroded areas largely along the shoreline of Peninsular Malaysia.

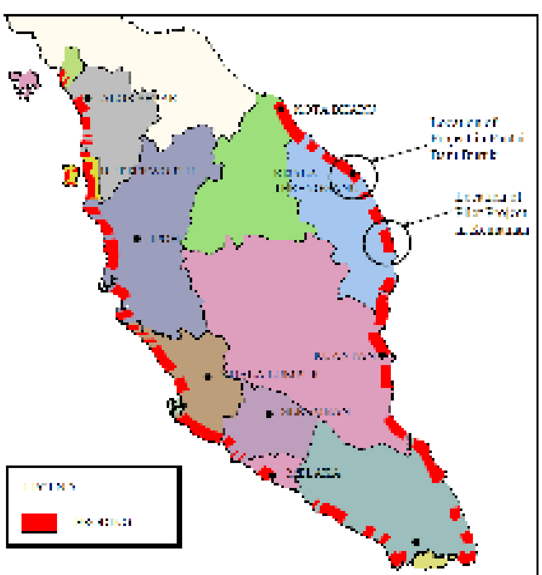

Figure 1: Shoreline undergoing erosion in Peninsular Malaysia (EPU, 1985)

Development of coastal areas to serve important economic and social needs often interferes with natural processes to the extent of causing the shoreline to respond differently and to alter the erosion and accretion patterns. Erosion of coastal lands in Malaysia has reached an alarming stage and the number of problem sites has increased over the last 12 years, and is a serious problem. The consequences of coastal erosion are severe in Malaysia as much of the economic and social life of Malaysia depends on activities in its coastal areas. Many of these activities are served by facilities that have either already been damaged or will be damaged in the near future. The affected activities include agriculture community life, recreation, transportation and tourism.

World wide climatic changes have resulted in significantly increased incidences of shoreline erosion worldwide and effective control measures are necessary to protect these shorelines.

Teluk Kalong in the district of Kemaman in Terengganu, Malaysia has encountered erosion of the shoreline. This paper describes a case study of the shoreline protection measure in a pilot project in protecting the eroding shoreline at Teluk Kalong.

Pantai Baruk Buruk is located in Kuala Terengganu, the capital city of the state of Terengganu in Malaysia. The shoreline at Pantai Batu Buruk is exposed to the direct impacts of severe storms, especially during the North-East Monsoon periods, causing widespread erosion. The result of the continuous erosion had created a sandy beach which, however, is not conducive to beach users, particularly with the steepened beach profile. The second case study in this paper describes the shoreline protection measures at this beach front and the results of preliminary performance assessments carried out.

2. SHORELINE EROSION PROTECTION MEASURES

2.1 Structural Measures

Structural control measures have been employed in the past throughout Malaysia. The measures used are generally designed to harden and armour selected areas against wave attack as well as the use of groynes to trap sediments and alter long-shore transport. These include rock revetments, concrete-faced bunds and dykes, and rock-filled or concrete groyne structures. Examples of these are indicated in Figures 2 to 4.

Figure 2: Concrete units used for erosion protection

Figure 3: Rock revetment used for erosion

Figure 4: Concrete groyne structures protection

The erosion problems in Malaysia have resulted in the construction of over 60km of revetments. Even with this effort, continuous erosion still persists, paving the way for a search of alternative forms of protection.

The function of the revetment structure is to prevent the loss of shore sediment and to limit wave run-up from overtopping the structure. Wave run-up is reduced by the roughness of the revetment surface and the size of the rocks is determined by wave height. Soil bearing capacity will determine the strength of the foundation support of the structure. Commonly, a layer of geotextile is incorporated into the revetment structure as a filter and separator.

Figure 5: Failure of protection measure protection

Common causes of failure to these hard structural measures are undermining of toe, excessive settlement, failure due to lateral movement, overtopping and flanking. Failure of filter system will also result in excessive loss of materials behind the structure (Figure 5) and may result in excessive settlement.

2.2 Soft Approach

Amongst the various products within the range of soft structural measures, the geotextile tubes are considered to be very effective in coastal and marine works if properly designed and installed. These geotextile tubes can be used in a variety of coastal environments. These geotextile tubes has been used as nearshore breakwaters (Oh & Shin, 2006). They can be used to substitute rock revetments or form the core of a rock bund. When used as a submerged breakwater, the geotextile tube provides a barrier or act as a dyke whereby sediment deposition behind these barriers can be formed. This sediment deposition can be natural or it can be artificially filled with suitable soil.

Filling pouches are fabricated onto the geotextile tube at regular intervals for pumping with a sand-water mix. The pouches may be designed to suite equipment available on site.

When adequately filled with sand to form a tubular or sausage tube, these geotextile tubes rely upon their mass to withstand wave action. With geotextile tube breakwaters, its function is alleviated from just being a separator and a filter, to being the main component in an coastal erosion protection structure.

These huge geotextile tubes are commonly supported on a layer of geotextile, which also acts as a scour apron.

2.3 Hydraulic and Stiffness Properties of Geotextile Tubes

Commonly, these geotextile tubes are fabricated with high strength polypropylene woven geotextiles with ultimate tensile strengths in the region of 100 kN/m (in warp and weft direction) to more than 200 kN/m (in warp and weft direction). The geotextile is treated for high ultra-violet resistance during the manufacturing of the yarns with the addition of UV stabilizers. The geotextile tube fabric also has significant resistance against weathering and abrasion. These are important properties for the fabric to be used in coastal and marine applications.

The polypropylene woven fabric has an ideal mix of strength, stiffness modulus and filtration for such applications. The effective pore size of the geotextile fabric is commonly less than 180 microns to enable the geotextile fabric to retain the sand infill. The filtration capacity of the geotextile fabric is controlled by limiting the ratio,

$$\frac{O_{95}}{D_{85}} \leq 3 \qquad (1)$$

where O_{95} = pore size of fabric with 95% passing
D_{85} = grain size of sand infill with 85% passing

2.4 Applications of Geotextile Tubes in Coastal Erosion Protection

Geotextile tubes are used for a wide range of hydraulic and coastal applications where mass gravity barrier-type structures are required. These applications include the following:

- As a revetment structure
  Geotextile tubes are used for revetment structures by providing mass gravity stability. Scour aprons, consisting of geotextile filter layer is laid beneath the tube to prevent scouring of the foundation soil.
- As an offshore dyke
  Geotextile tubes are used as an offshore dyke to prevent erosion of a land development. The filled tube is placed a certain distance offshore to dissipate wave forces before they can reach the shoreline. These tubes may either be submerged or exposed.
- As groyne structures
  Geotextile tubes may also be used as groynes to prevent littoral drift of sediments. These tubes may be exposed or a rock covering may be provided depending on the circumstances.

An example of the application of the geotextile tube in coastal protection works is shown in Figure 6.

Figure 6: Geotextile tube used for coastal protection works

2.5 Design

The design of a geotextile tube system encompasses the internal limit state analysis and an external limit state analysis. The internal limit state looks at three failure modes, i..e. geotextile fabric rupture, geotextile fabric hydraulic resistance, and deformation of the contained fill.

The external limit state looks at bearing capacity, resistance of the unit to sliding and overturning, foundation scour, foundation settlement and global stability of the system.

3. CONSTRUCTION OF GEOTEXTILE TUBE AS A SUBMERGED BREAKWATER

Geotextile tubes are described in terms of theoretical diameter or the circumference. Geotextile tubes with diameters ranging from 1.5m up to 5m have been used for coastal and river protection works.

In the construction of the geotextile tubes, the fabricated tubes are laid out with the inlet tubes facing upwards and filled hydraulically onsite to their required geometrical shape. Hydraulic fill, comprising of sand slurry, is pumped into the geotextile tube through the specially manufactured inlet tubes located at specific intervals along the top of the tube.

During filling, the geotextile tube, being permeable, allows excess water to pass through the geotextile skin while the retained fill attains a compacted, stable mass within the tube. The sand used as the infill material compacts to a good density by hydraulic means, and will no undergo further consolidation which would change the filled shape of the tube and affect its ability to act in its intended function.

The geotextile skin performs three important functions that are critical to the performance of the filled geotextile tube. Firstly, the geoxtextile fabric forming the skin of the tube must have the required tensile strength and stiffness to resist the mechanical stresses applied during filling and throughout the design life of the units, and must not continue to deform such that the tube changes shape over time. Secondly, the geotextile fabric must have the required hydraulic properties to retain the sand fill and prevent erosion. These properties include the effective pore size of the geotextile fabric. Thirdly, the geotextile fabric must have the required durability over the design life of the units.

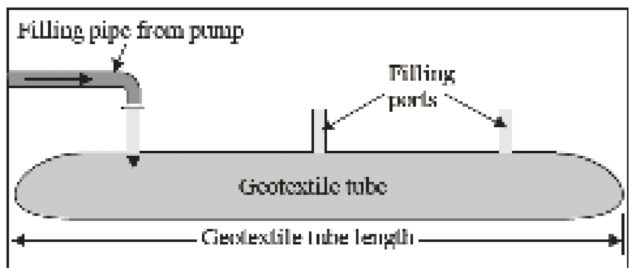

Figure 7: Typical features of a geotextile tube

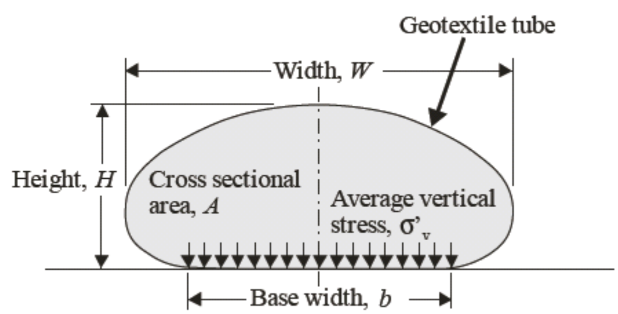

Figure 8: Typical shape of a filled geotextile tube

4. CASE STUDY NO. 1: PILOT PROJECT AT TELUK KALONG, KEMAMAN, TERENGGANU

The shoreline along the coast of Teluk Kalong is composed mainly of granular materials, i.e. loose sand. These sediments are easily erodible when subjected to wave forces and if not adequately protected.

A length of about 500m in length of this existing shoreline had been exposed to severe erosion, resulting in instability of the existing seawall, which consisted of precast concrete slabs as shown in Figure 9.

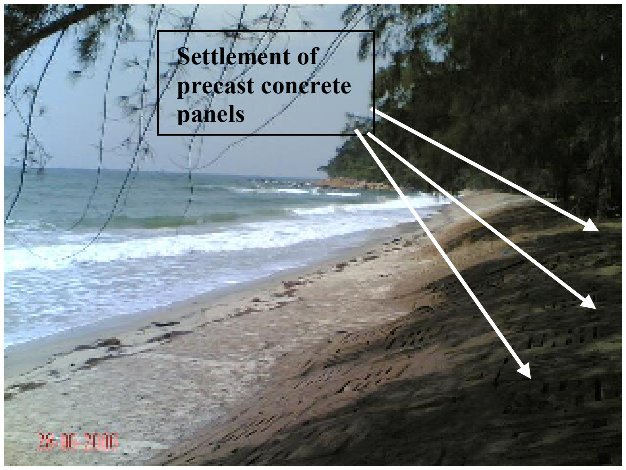

Figure 9: Condition of shoreline before application geotextile tube protection works (June 2006)

Figure 9 indicated the severity of the shoreline erosion and the strength of the waves approaching the shoreline. Loss of sandy materials behind the concrete panels due to severe erosion had resulted in large and uneven settlements of the panels. The condition of the beach front was also not suitable for recreational activities due to the rather narrow and steep foreshore area.

A pilot project was initiated in 2006 by the Public Works Department to remedy the situation by using the geotextile tube as a submerged dyke (PWD, 2008). The design concept for the coastal erosion protection and beach enhancement at Teluk Kalong, Kemaman, Terengganu is to use a system of geotextile tubes sitting over a layer of apron mattress, as shown in the typical cross section in Figure 10. The inner structure of these geotextile tubes consist of high strength woven polypropylene geotextile with ultimate tensile strengths of 150 kN/m in waft and weft directions. An outer layer of woven polypropylene geotextile having ultimate tensile strength of 40 kN/m in waft and weft directions was stitched onto the inner reinforcement layer, to increase the durability of the tube due to abrasion and ultra violet degradation. The fabrics are all tested for compliance to high seam strengths in excess of 80% of the ultimate tensile strength.

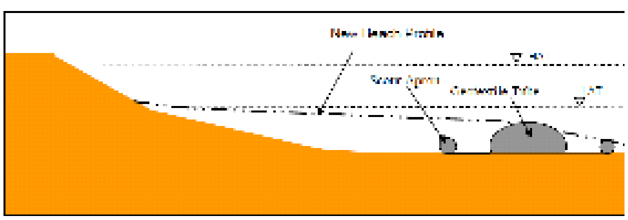

Figure 10: Cross Section of Design Concept

These Geotextile Tubes were installed for a total length of 500m along the beach front. The design requirements adopted for the development of the system included:

a. The geotextile tubes are to be sited at approximately 150m from the shoreline.
b. The geotextile tubes shall be totally submerged at low tide condition.

The lowest astronomical tide (LAT) for the project site is +0.0m CD, whereas the highest astronomical tide (HAT) is +3.67m CD.

The main functions of these geotextile tubes were:

i. To protect and reduce further erosion of the shoreline.
ii. To accelerate deposition of sediments on the foreshore and enhance the beach front.

This pilot project for the beach protection and enhancement works thus involved the installation of submerged geotextile tubes of a height of 2.0m on an apron fabric. Upon installation of the geotextile tubes, these tubes acted as a submerged dyke system to retain sediments carried alongshore and enhance the beach front.

The design data, including tidal elevations, wave characteristics, wind and current direction and velocity were obtained from the Maritime authority. As the project site is situated in a bay area and the geotextile tube dyke is in a submerged condition, current and wind conditions do not significantly affect the performance of the tube. The bathymetry and ground levels were obtained by a licensed surveyor. Marine soil samples were extracted for examination and testing. Bearing capacity was not in question since the seabed consisted of compacted sand deposits.

The design process adopted checked for the following:

- External limit state of the geotextile tube system under the forces from the waves, currents and wind. The final height over width ratio achieved will be analysed for optimum stability. The limiting factor of safety obtained for sliding is 1.2, whereas the factor of safety for overturning is 1.4.
- Internal limit state of the geotextile tube under the applied hydraulic pressure. This analysis is carried out using the GEOCOPS software.

4.1. Pilot Project Outcomes

The installation works were completed before the onset of the monsoon season in December 2006. Following two monsoon seasons in 2007 and 2008, a visual inspection of the project site was carried out. Figure 11 shows the improved condition of the beach profile with accumulation of sediments on the foreshore following completion of the submerged geodykes.

Figure 11: Condition of shoreline and beach in December 2009 after completion of submerged geodykes installation

The widespread deposition of sand deposits along the foreshore area has resulted in widening of the foreshore area. A post-construction bathymetry survey was also carried out and the results indicated that sand had accumulated to a thickness exceeding 1.8m, with a total volume estimated as 87,317 m^3. Figure 12 shows a typical cross section at CH 200.

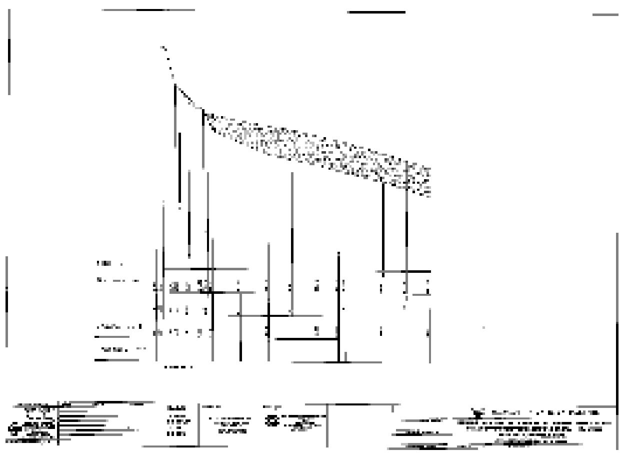

Figure 12: Typical post-construction survey (CH200)

The post-construction survey results were superimposed on the pre-construction survey plan, as shown in Figure 10. This provided further evidence on the deposition of sand on the foreshore area which had resulted in the shifting of the shoreline. In Figure 13, the initial shoreline is indicated by the BLUE line while the shoreline after the protection works is indicated by the RED line.

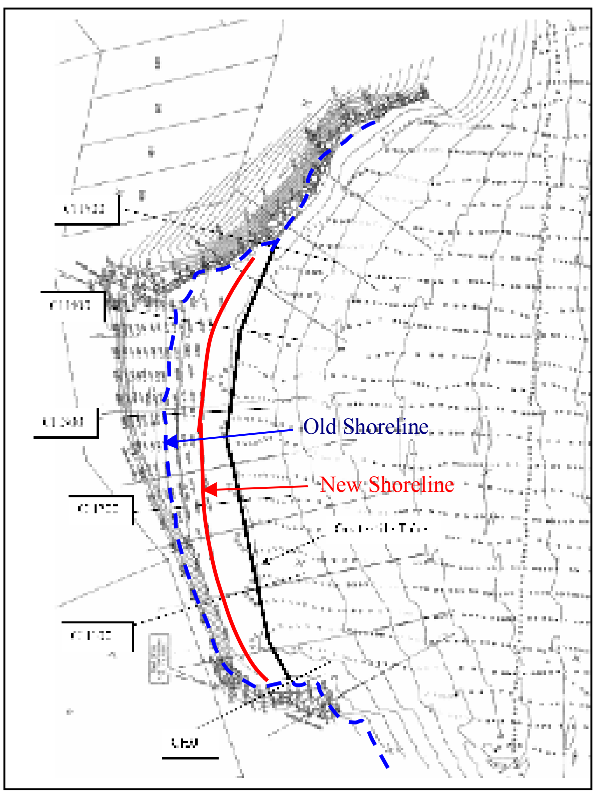

Figure 13: Position of shoreline before and after implementation of shoreline protection works

The benefits that are obtained from this pilot project included the following:

i. A wider foreshore area with a gentler beach profile has created a safer and more conducive environment for beach users and has thus increased the potential for more extensive usage of the beach. The potential for increased usage for recreational beach activities is greatly enhanced.
ii. The deposition f sand on the foreshore area has resulted in subdued waves approaching the shoreline due to the reduced depth of water at the near-shore areas. This has resulted in reduced energies of the approaching waves. The energy of waves travelling in shallow water conditions is a function of the water depth and the speed of wave travel. These empirical relationships are illustrated in Equations 2 and 3 below (US Army Corps of Engineers, 1984).

$$s = \sqrt{gd} \qquad (2)$$

where s = speed of wave travel (m/s)
g = acceleration due to gravity (m/s^2)
d = depth of water (m)

$$\overline{P} = \frac{\rho g H^2}{8}\sqrt{gd} \qquad (3)$$

Where P = Total wave energy per m crest width (Nm/s)
ρ = density of sea water (N/m^3)
g = acceleration due to gravity (m/s^2)
H = wave height (m)

iii. The Geotextile Tube System has reduced the potential for further erosion of the shoreline, thus reducing the cost outlay to rehabilitate incidences of shoreline erosion.
iv. Additionally, the geotextile tube system has improved the view across the beach profile due to the deposition of sand deposits on the foreshore area.
v. Generally, the geotextile tube system has increased the potential value of the beach front.

5. CASE STUDY NO. 2: BEACH PROTECTION PROJECT AT PANTAI BATU BURUK, TERENGGANU

Pantai Batu Buruk is a sandy beach in Kuala Terengganu, State of Terengganu, frequented by tourist and local residence for recreation activities. However, the beach profile is rather steep due to the process of continuous erosion of the shoreline, particularly during the monsoon storms. The project required the protection measures for a 5 kilometre stretch of the beach to enhance the quality of the beach front. Geotextile tubes were designed to be installed as submerged dykes in an offshore position along the shoreline to prevent further erosion of the shoreline and to enhance the beach.

The design concept is similar to the pilot project at Teluk Kalong, i.e. it adopted the submerged dyke system using the geotextile tube infilled with sand slurry (see Figure 10). The structure of the tube comprises of a single layer of high strength woven polypropylene geotextile having ultimate tensile strength of 200kN/m in warp and weft directions. These high strength geotextiles possess high seam strengths, and good resistance to abrasion and weathering. The height of the tubes was designed as 2.5m, and these were placed on a geotexile scour apron. The design requirements adopted for the development of the concept design proposal are:

a. Approximately 5km shoreline shall be protected (Figure 14).
b. The Geotextile Tubes shall be sited approximately 100m to 150m offshore from the shoreline.
c. The estimated water depth at low tide at the proposed location of the Geotextile Tubes shall be 3.0m.
d. The Geotextile Tubes shall be totally submerged at low tide conditions.

The Geotextile Tubes were checked for internal and external limit state adequacy.

Figure 14: Location of Pantai Batu Buruk in Kuala Terengganu

Figures 15 and 16 illustrate the condition of the beach in 2008, prior to the commencement of the project.

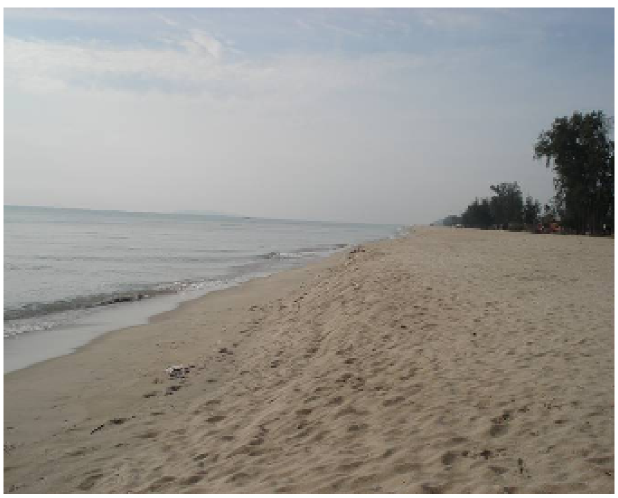

Figure 15: View of Beach at Pantai Batu Buruk (June 2008)

Figure 16: View of Beach at Pantai Batu Buruk (June 2008)

The installation of the tubes commenced in July 2008 and the length of 5,000m was completed by August 2009. Mid-way through the project, the installed tubes were impacted by the monsoon storms between November 2008 and January 2009. A post-monsoon hydrographic and topographic survey of the project was carried out in February-March 2009 to investigate the extent of changes to the beach brought about by the storm.

5.1 Assessment of Beach Condition following Monsoon after Partial Installation of Submerged Geotextile Tubes

The results of the post-monsoon hydrographic and topographic survey indicated that at the sections where geotextile tubes have been installed, the beach has not suffered further erosion. In contrast, sand deposits were clearly noted where previously there were steep scarps. The gradient of the foreshore area had also become gentler (PWD, 2009). These changes are illustrated by the following photographs taken after monsoon storms.

Figure 17: View of beach after the monsoon storm (March 2009)

Figure 18: Sand deposited on foreshore area (March 2009)

The post-monsoon survey results further confirmed that significant quantity of sand had deposited on the foreshore area, as illustrated by a typical cross section shown in Figure 19. The blue line in the figure indicates the survey levels obtained during the design stage (June 2008), whereas the pink line indicates the survey levels obtained during the survey carried out in March 2009. The figure shows that there is some erosion on the beach front and accretion of sediments on the foreshore. There is however net accretion of sediments.

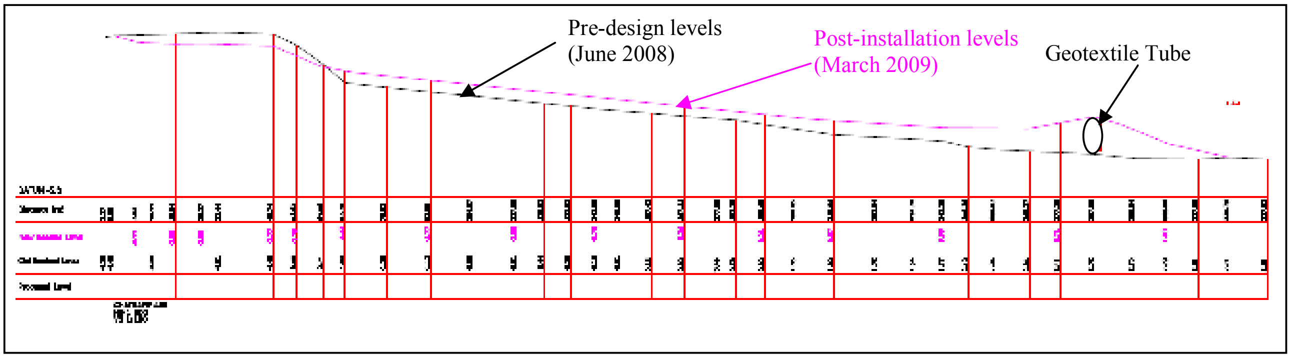

Figure 19: Typical Cross Section at CH400 (March 2009)

6. CONCLUSION

Geotextile tubes has been used as submerged dykes for shoreline protection in Malaysia. The installation of geotextile tubes as an offshore submerged dyke system had improved the beach conditions at Teluk Kalong and Pantai Batu Buruk in the State of Terengganu, Malaysia. The submerged geotextile tubes were placed in an offshore position and were totally submerged at low tide conditions. The final outcomes of the installations were the accumulation of sediments, consisting predominantly of sand, on the foreshore area behind the geotextile tubes. Post-installation hydrographic and topographic surveys carried out indicated that significant quantities of sand had accumulated. The shoreline has migrated seawards, thereby providing a widened foreshore area with a gentler gradient. As a consequence, the water depth at the foreshore area becomes shallower and the wave energy impacting the shoreline becomes diminished. This had reduced the potential for further erosion of the shoreline.

7. ACKNOWLEDGEMENT

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