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Coastal Erosion at Tanjong Piai, Johor, Malaysia

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ABSTRACT

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Tanjung Piai, Johor, Malaysia, is a ramsar site, located at the southern-most tip of mainland Asia, and consists mainly of mudflats and mangrove forests. The coast has experienced severe erosion for several decades, in spite of the construction of various coastal defense structures. The reported rates of shoreline retreat were between 2 to 4 m/year. Hydrodynamic modeling using 2008 field data indicate that the maximum current speed observed along the east coast of Tanjung Piai ranges from 0.2 - 0.5 m/s, while the west coast experiences lower current speeds of less than 0.2 m/s. Strong currents occur at the tip of Tanjung Piai with a speed of 0.5 to 0.8 m/s. The simulation also indicates that some local current patterns are formed near the tip due to the presence of a small island as the flow entering the study area during flooding were reflected to the east while the flow during the ebb tide tend to move toward the opposite direction. Wave simulations show that most of the waves come from Singapore and the Straits of Malacca, with amplitudes of over 1.5 m, are reduced to less than 0.8 m as they travel towards Tanjong Piai coast. These local hydrodynamic conditions, combined with the existence of regular ship wakes, are believed to be the reason for the intensive erosion at Tanjung Piai. Model simulations incorporating the proposed coastal protection measures indicated positive and negative impacts of the hydrodynamic changes around the study area. The results shown that the magnitude of the current speed and wave height would be reduced in the area behind the structures but slightly increased on the other parts of the coast. These changes will determine the sediment transport movement in the area. Therefore, it is necessary to understand the hydrodynamic characteristics before implementing any kind of coastal protection measures because they may protect some area from erosion, but may not be favourable to the other parts of the coast.

ADDITIONAL INDEX WORDS: *Navigation, coastal inlets, numerical wave modeling, nearshore wave processes.*

INTRODUCTION

Hydrodynamic forces, sediment supply and antecedent topography play an important role in the geomorphological conditions of coastal zones. In Malaysia, not many studies have been carried out around the Malacca and Singapore Straits in relation to the coastal hydrodynamics and geomorphology. The study area Tanjung Piai, Johor, is located at the southern-most tip of Peninsular Malaysia, with approximate coordinates of 1°15'50.64" N and 103°30'36.57" E (Figure 1). The local climate is strongly influenced by the two prevailing monsoons, *i.e*. Southwest Monsoon (June - September) and Northeast Monsoon (November - March) (Tkalich *et al*., 2002). Tanjung Piai is characterised by its mudflats and mangrove forests. It has a high diversity of mangrove species (22), which are ecologically important and a natural barrier to protect the inland villages and agricultural lands from extreme wave events, including tsunamis. It is also an important habitat for migratory and resident birds, which includes the International Union for Conservation of Nature (IUCN) Listed Vulnerable Species, the Lesser Adjutant Stork. It is part of the Important Bird Area (IBA) of South-west Johore, which extends from Parit Jawa to Tanjung Piai.

Due to its geomorphology and diverse species of fauna and flora, Tanjung Piai was declared a Ramsar Site (under the Convention of Wetland, Ramsar, Iran 1971) in 2003 (Azlan and Othman, 2009; KNB, 2012). The mangroves provide a range of valuable benefits to local communities, local businesses and the wider economy of Johor, as well as to the global society (KNB, 2012).

Tanjung Piai has a high socio-economic value for eco-tourism and fisheries. The site attracted 32,000 visitors in 2006 (Wetland International and Johor National Park Corporation, 2007). In fact, it is a national icon, being the southern-most tip of mainland Asia and is a priority site for national eco-tourism, being the third designated park of Johor National Park Corporation.

Coastal Issues and Human Interferences

The mudflats and mangrove forests of Tanjung Piai have been eroded significantly over the years. It was reported that the erosion at the east coast of Tanjung Piai had taken place since at least the 1930's. Similarly, the western coast of Tanjung Piai was also facing critical erosion with an estimated rate of about 2 - 4 m/year (Abdullah, 1992). The erosion escalated rapidly after the dredging of a navigation channel in 2002 (DID, 2013). Figure 2 presents a shoreline comparison between 1974

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Topographic Map, Landsat TM images of 1989 and 1994, and Spot 5 images from 2004, 2009 and 2011. Although the comparison may have some errors due to the different resolution of the Topography Map, Landsat TM and Spot 5 images, somehow it gives a general idea of how much the shoreline has been eroded since 1974.

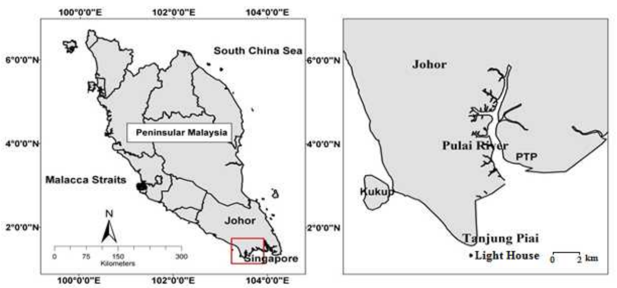

Figure 1. Location of Tanjung Piai National Park and Port of the Tanjung Pelepas(PTP) in Johor, Malaysia.

Figure 2. Shoreline changes due to coastal erosion at Tanjung Piai from 1974 to 2011 (DID, 2013).

Under the Ramsar Convention, the government and relevant stakeholders have an obligation to ensure that the mangrove ecosystem is maintained (Wetland International and Johor National Park Corporation, 2007). Therefore, the erosion hazard at site needs to be eliminated or minimized to safeguard the ecological integrity of the mangrove ecosystem. At the same time, the Malaysian Government has invested MYR 5.0 Million (~USD 1.5 Million) for infrastructure development at Tanjung Piai.

The study area is subjected to several coastal development and human interferences. The reported causes of erosion at Tanjung Piai were coastal development (such as land reclamation, building of breakwaters, artificial islands, and dredging of port channels in the surrounding area); waves generated from heavy shipping activities which had disturbed the growth of the existing mangroves, oil spills, and water pollution originated from ship cleaning processes. Near the study area, the Johor State Government developed the Port of Tanjung Pelepas (PTP) (see Figure 1) which was completed in 1999 to act as an alternative route for the East and West Bound Trade Lane. At the end of 1999, the PTP terminals handled about 20,000 twenty-foot equivalent units (TEU), which had increased to 423,710 TEUs in 2000 and 2.05 million TEUs in 2001. In 2003, the number of TEUs had increased to 3.48 million, establishing PTP as the largest port in Malaysia, while an increase by 15.3 % (*i.e*. 4.02 million TEUs), registered in 2004 made it the world's 16th busiest container port. The number of TEUs kept on increasing every year, with 7.7 million TEUs registered in 2012 (http://en.wikipedia.org/wiki/Port_of_Tanjung_Pelepas).

Recently, the port authority announced that it will expand its quay by two berths costing MYR 1.4 billion. The length of the quay will be increased to 5.0 km long and expected to be fully operational in the first quarter of 2014. The expansion activities should bring handling capacity to 10.4 million TEUs (http://en.wikipedia.org/wiki/Port_of_Tanjung_Pelepas).

Tai and Seow (2004) stated that before 1997, the erosion rate at Tanjung Piai was about 0.25 m/year. However, the rate of erosion is increased tremendously, possibly up to 3.0 m/year after the opening of the PTP in 1999. They deduced that the increase rate of erosion was due to the higher energy waves generated by ships navigating through Tanjung Piai waters, based on the photographs taken in 2003. This could possibly be true when we analyse the increased number of ships that went through Johor Straits to PTP. Although the increased in wave height is not so obvious, the regularity of the waves do have some effects on the soft soil of Tanjung Piai. Table 1 shows the increased number of ships that berthed at PTP which may have given a significant impact on the coastline.

Table 1: *Number of ships that went berthed in PTP (unpublished).*

Year	Number of ships
1999	124
2000	1194
2001	3388
2002	3551
2003	4077
2004	4996
2005	5379
2006	3977 (till August)

The coastal area of Tanjung Piai has also been facing the problem from oil spill incidents that occurred in 1997 and 2012 which caused the failure of mangroves and eventually increased the erosion process.

This paper was prepared with the main objectives: (i) to observe and analyze the coastal changes caused by erosion and accretion activities in the study area; (ii) to describe the history of engineered interventions; (iii) to investigate the hydrodynamic characteristics based on the hydrodynamic variables of currents, winds and waves that actively eroded the tip of Tanjung Piai; and (iv) to suggest alternatives for management approaches.

METHODS

Coastal Protection Approach

The construction of coastal protection structure generally lead to significant changes in the hydrodynamic characteristics which can modifiy the currents, waves and sediment transport in the project area. Several attemps has been taken in identifying the most suitable design in protecting the coastline features. This section will generally discuss a few approaches applied by the Malaysian Government in protecting the severe condition in Tanjung Piai mangrove area. In the coastal protection aspects, the Drainage and Irrigation Department (DID), under the Ministry of Natural Resources and Environment (MNRE) is the agency in-charge of the planning and monitoring of coastal erosion in Malaysia. The department also responsible for the design, budget application, tendering, contract management, supervision and all relevant activities concerning construction of coastal protection structures all over Malaysia. Since 2003, DID have constructed various types of structures to protect Tanjung Piai, however, erosion still continues.

Field Measurement

Investigation on coastal changes due to hydrodynamic forces is very important. Although extensive research regarding this matter has been carried out over a long period of time, it is still poorly understood. Coastal morphological changes are the results from the variability in the waves and currents which can take place in timescales of a few hours to years (Reeve, 2012), therefore analysis of long term data should be considered.

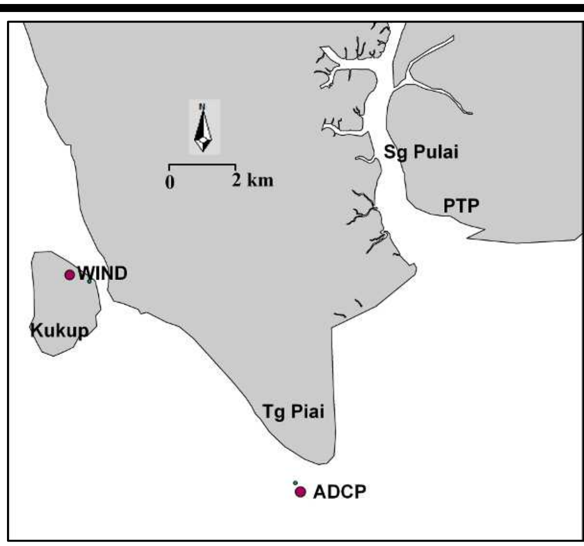

Figure 3. Location of the measument equipment.

Since a data collection campaign would be very expensive, analysis were done using available data (collected from July to December 2008) to have some understanding of the hydrodynamic forcing that characterise the Tanjung Piai coast. Figure 3 shows the location of the equipment, installed for the previous measurement campaign. Description of the available data such as the bathymetry, wave, wind and current profile is given in the next subsection.

Bathymetry

The bathymetry data was obtained from a survey carried out in 2007 that covered the area from Kukup to Tanjung Piai and extended further into Sungai Pulai, 40 km from Tanjung Piai. The resolution of the survey was 300 m. Figure 4 shows the measured bathymetry referred to Mean Sea Level (MSL), which indicates that the water depth around the study area is quite shallow, less than 7 m water depth. The bathymetry at the tip of Tanjung Piai is very steep indicating that severe erosion has taken place.

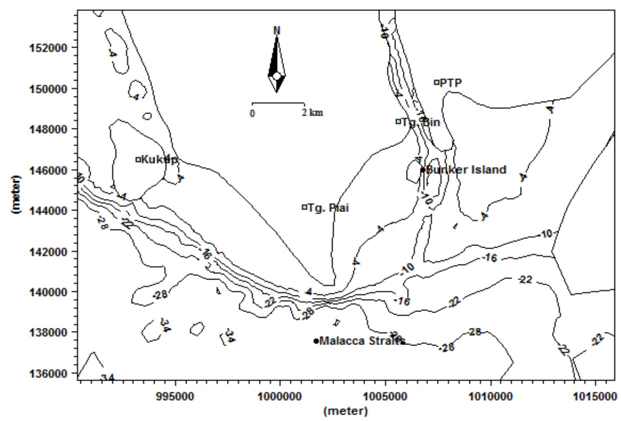

Figure 4. Measured bathymetry in meters referred to Mean Sea Level (MSL).

Wave Climate

The available wave data was measured from July to October, 2008, using an Acoustic Doppler Current Profiler (ADCP) which was installed at Tanjung Piai Light House, approximately 650 meter offshore from the tip of Tanjung Piai. The instrument was deployed to record wave profiles at every 1 meter water column with an interval of ten minutes. The wave measurement data includes significant wave heights (H_s), maximum wave heights (H_{max}) and wave period (T_p). H_s is a statistical assessment of wave height and can be defined as the average height of one third of the highest waves (Suursaar *et al*., 2008). However, with the ADCP and the numerical model, H_s is directly estimated from the wave energy spectrum, *i.e.* $H_s = 4\sqrt{m_o}$, where m_o is the zero-order moment of the wave spectrum (Broman *et al*., 2006).

Figure 5 shows time series of wave heights, directions and periods measured at Tanjung Piai Light House Station, while Table 2 presents the statistical analysis of the measured wave data. The statistical mean for the significant wave height was 0.35 m with the lowest amplitude of wave of 0.28 m, measured in October. On the other hand, the statistical maximum wave height was 1.5 m, measured in August, while the dominant wave direction was from 347°. The recorded maximum wave period was 6.9 s, measured in September. Shorter period waves were observed between July and August 2008, when the wave heights were higher. On the other hand, longer wave periods can be observed with comparatively lower wave heights occurring in late October. During the entire period of observation, most of the waves came from 180° to 200° directions.

Table 2: *Statistical analysis of the waves measured from July to October, 2008 (std. dev.= standard deviation).*

Month		July	Aug	Sept	Oct
Hs [m]	min	0.16	0.13	0.11	0.06
	max	0.70	1.50	0.93	1.03
	mean	0.34	0.36	0.34	0.28
	std. dev.	0.11	0.13	0.12	0.09
Direction [°]	min	70.72	39.94	6.06	7.48
	max	356.70	347.40	348.90	348.20
	mean	180.30	185.60	194.40	194.50
	std. dev.	49.53	49.53	55.41	65.07
Tp [s]	min	1.57	0.00	0.00	0.00
	max	6.04	6.43	6.90	6.74
	mean	2.92	2.99	3.13	3.12
	std. dev.	0.73	0.78	0.87	1.08

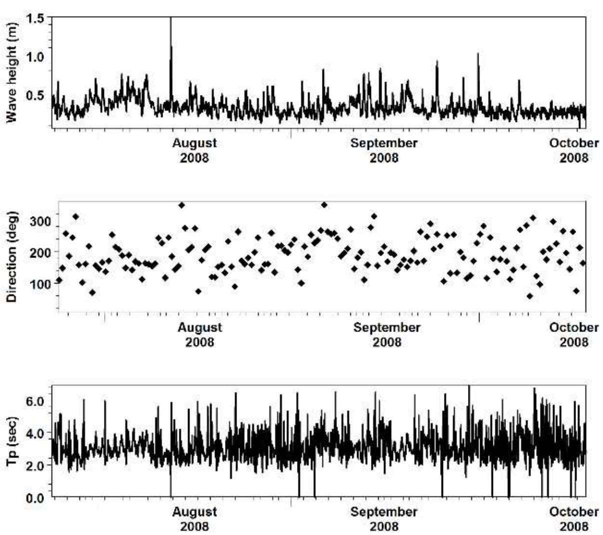

Figure 5. Measured wave height, direction and period at Tanjung Piai Light House Station.

Wind Data

For wind measurement, Kukup Station was selected because it is located at a higher altitude (50 m) compared to Tanjung Piai Light House Station and it was believed that wind condition at Kukup is best to represent the wind condition in Tanjung Piai. The wind data was recorded at an interval of ten minutes. Figure 6 shows the plotted wind speeds and directions at Kukup from July to October 2008, while Table 3 presents the results from the statistical analysis carried out on the measured wind speed and direction. The results indicate that the mean wind speed in July was 0.60 m/s, slightly higher than the mean wind speed for the other months, *i.e.* 0.54 m/s in August, 0.22 m/s in September and 0.55 m/s in October. Similarly, the statistical mean for wind direction in July was from 230.9°, compared to the statistical mean for wind direction in the other months, *i.e.* 216.5° in August, 201.5° in September and 168.8° in October.

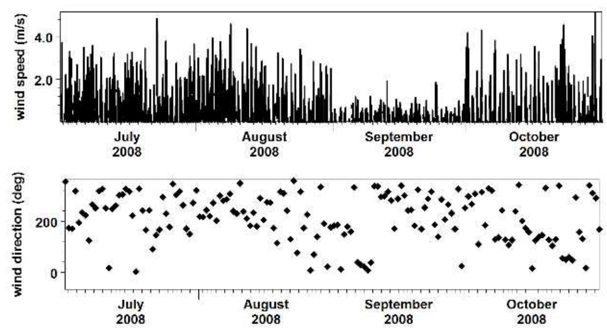

Figure 6. Measured wind speed and direction at Kukup Station from July to October 2008.

Table 3: *Statistical analysis of wind speed and direction measured at Kukup Station from July to October 2008 (std. dev.= standard deviation).*

Month		July	Aug	Sept	Oct
Wind speed [m/s]	min	0.01	0.01	0.01	0.01
	max	4.83	4.57	1.90	6.02
	mean	0.60	0.54	0.22	0.55
	std. dev.	0.66	0.68	0.22	0.75
Wind direction [°]	min	-66.50	-66.90	0.36	1.20
	Max	361.80	362.00	357.00	355.00
	Mean	230.90	216.50	201.10	168.60
	std. dev.	80.74	85.38	106.40	101.40

Current Profile

Current speeds and directions around the study area were measured from July to October, 2008. The currentmeter was deployed at the same station as the wave measurement. The equipment was set to record data at an interval of ten minutes, at every 1 meter water column which correspond to one cell for each meter. The mooring depth was about 15 m, but varied with sea level change. The current data were obtained from 10 layers, excluding the top 2-3 m layers that have been contaminated by wave motions at the surface.The measured data was plotted to obtain the trends of the current speed and direction throughout the measurement period. Figure 7 shows the recorded current data near Tanjung Piai Light House, while Table 4 presents the statistical analysis of the measured data, which provided the values of minimum, maximum, mean and standard deviation for each parameter. From the analysis, the average mean current speed, recorded during the measuring period, was approximately 0.32 m/s with the main direction from 210°. However, the mean current speed was greater in October, at approximately 0.34 m/s and higher compared to the mean current speed in the other months (July, August and September).

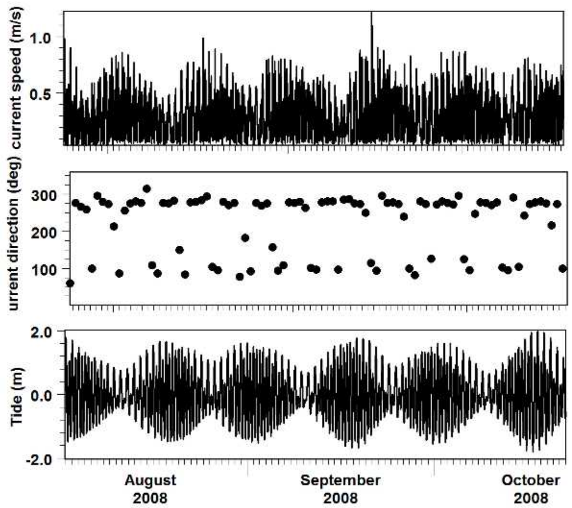

Figure 7. Measured current speeds and directions at Tanjung Piai Light House Station.

Table 4: *Statistical analysis of current measured from July to October 2008 (std. dev.= standard deviation).*

Month		July	Aug	Sept	Oct
Current speed [m/s]	min	0.01	0.04	0.04	0.04
	max	0.98	0.99	1.22	0.87
	mean	0.28	0.32	0.32	0.34
	med	0.26	0.29	0.3	0.34
	std. dev.	0.17	0.18	0.18	0.18
Current direction [°]	min	0.58	38.6	31.1	51.6
	max	359.2	329.1	330.9	322.4
	mean	207.5	220.9	210.5	221.3
	med	272.8	274.6	274.1	275.8
	std. dev.	91.58	79.95	84.7	81.5

Numerical Modeling

Numerical modeling was carried out for Tanjung Piai using the 2008 data (as described in the previous subsection) to understand the hydrodynamic forces controlling the geomorphology of the study area. The modeling was done using MIKE 21 Hydrodynamic (HD) and Spectral Wave (SW) modules, developed by Danish Hydraulic Institute (DHI). This model is based on flexible mesh approach and is mainly used for applications within oceanographic, coastal and estuarine environments (DHI, 2011). The model consists of mesh grid with sizes that varies from approximately 300 m to 600 m around Tanjung Piai coast and up to over 1000 m at the open boundaries (Figure 8). The bathymetry was generated based on measured data and MIKE 21 C-MAP with the average depth ranges from -2 m near the coast to approximately -40 m offshore. The model was simulated within the boundary covering large parts of the seas around the Malacca and Singapore Straits and the connection of Java and South China Sea.

The water level forcing for the three open boundaries *i.e.* north boundary (bnd2), south boundary (bnd3) and east boundary (bnd4) were specified based on global tide model prediction provided in MIKE 21. They were applied in varying time and along the boundary format and basically generated the flow for the entire model domain. The hydrodynamic model was forced by a series of wind data collected at Kukup station which acting as varying in time along the whole boundary. The calibrations were carried out by comparing the measured current speed and direction at Tanjung Piai Light House with the extracted model output at the same locations.

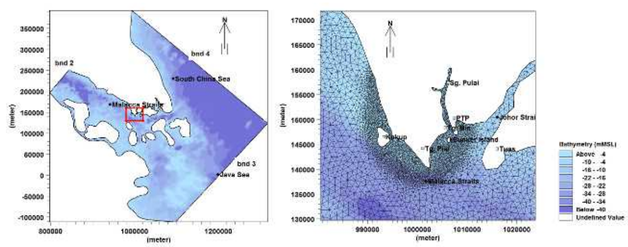

Figure 8. Boundary condition and computational mesh.

Case Study on Shoreline protection alternatives

Currently, the Department of Irrigation and Drainage (DID) is in the process of appointing consultants to carry out a hydrographic survey, a comprehensive hydrodynamic study, and a design of a suitable shore protection scheme that will minimize erosion at Tanjung Piai. Figure 9 shows one of the proposed offshore submerged and segmented breakwaters that may be effective.

Therefore, this section is an attempt to study the effect of these proposed structures to the changes of hydrodynamics around Tanjung Piai. MIKE 21 HD and MIKE 21 SW models were developed to assess the potential impact of this proposed structure on the current and wave characteristics. Six offshore submerged and segmented breakwaters were incorporated into the model, approximately 250 m from the shoreline with the emergent height of 2 m. Both existing and proposed model condition were simulated with the time series input of measured wind speed while the wave design was assumed to be 3 m height, wave period of 6 seconds, and the dominant wave directions from 80°, 150° and 300°.

RESULTS AND DISCUSSIONS

Erosion Protection Structures at Tanjung Piai

A variety of coastal protective measures have been installed by DID Malaysia in order to mitigate the erosion caused naturally as well as due to human interference. A series of coastal structures were implemented phase by phase correspond to the continuous occurences of erosion along the mangrove line in Tanjung Piai RAMSAR site. Some of the typical coastal protection structures installed were geotextiles-tubes, seawall and revetment.

These coastal protective measures have their own advantages and disadvantages to the coastal environment and described in the following subsections.

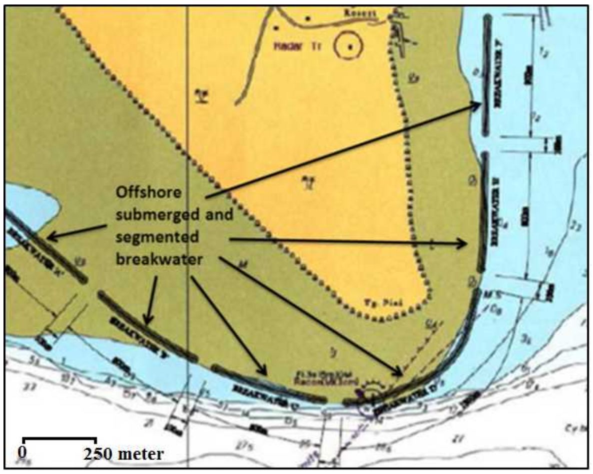

Figure 9. Proposed offshore, submerged and segmented breakwaters to minimise erosion (DID Malaysia).

Geotextiles-Tubes

Geotextile tubes, filled with sand and laid parallel to the shoreline reduce the wave heights generated naturally and also by wakes of the passing ships. Current and wave energy was expected to be reduced, creating a calm condition behind the geo-tubes that would promote sediment accretion. The 1,500 m long geo-tubes (Figure 10) were built in three phases between 2003 and 2006 with a total cost of MYR 2.9 Million (0.91 Million USD). However, due to the soft soil structure of the mudflat, the geo-tubes sank to the sea floor and their heights are no longer enough to protect the Tanjung Piai coast.

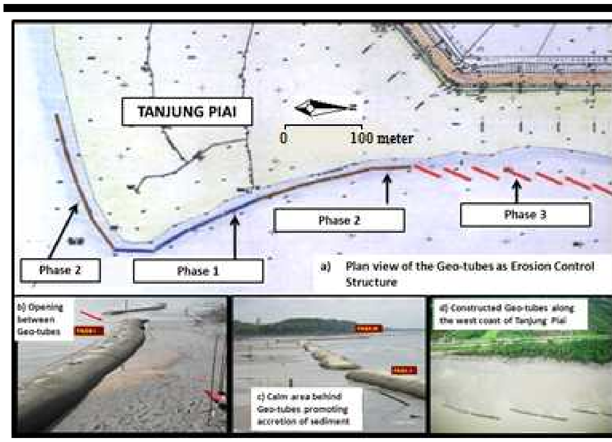

Figure 10. Geo-tubes along the Tanjung Piai coast: (a) plan; (b) opening between geo-tubes; (c) calm area behind the geo-tubes promoting accretion of sediment; (d) geo-tubes along the east coast of Tanjung Piai, seen from above (DID Malaysia).

Seawalls

In 2006, as erosion was still occurring along the east coast of Tanjung Piai, a 707 m long seawall was constructed to protect the coast from further erosion (Figure 11). This seawall cost about MYR 389,000 (~USD 126,000). However, erosion still occurred as shown in Figure 11c. Therefore, several layers of rock were added to the top of the seawall to prevent wave overtopping. The construction of seawall may lead wave to attack the seawall progressively as the steed impermeable slope of seawall tends to cause reflection of the wave resulting in the depletion of the beach on the foreshore (Kudale, 2010).

Rock Revetment

A 270 m long rock revetment was built between 2007 and 2009 to protect the west coast of Tanjung Piai from further erosion. This project cost about MYR 636,000 (~USD 181,700). Figures 12a-c show some of the construction phases of the revetment. In the environmental aspect, the implementation of revetment would diminished the natural state of the shoreline mangroves and essentially lessen the chances of mangrove regeneration (Seng *et al.*, 2007). Therefore, the hard structure such revetment is not a suitable approach to be applied in the mangrove area.

Figure 11. Erosion at the east coast of Tanjung Piai (a); completed seawall (well-guard) (b); well-guard topped by rocks to prevent from wave overtopping (DID Malaysia) (c).

Figure 12. Activities during revetment construction: (a) laying of the geo-textile; (b) laying of the under-layer for the revetment; (c) completed revetment on the east coast of Tanjung Piai (DID Malaysia).

Soft Rock and Rock Revetment

In 2010, there was still erosion occurring along both the west and east coasts of Tanjung Piai. A 1,700 m long soft rock (made of 1 m × 1 m geotextile bag, filled with sand) combined with 220 m of revetment were then constructed along both coasts to protect Tanjung Piai from further erosion (Figure 13). This combined project cost about MYR 8.0 Million (~USD 2.28 Million). But erosion still occurred at Tanjung Piai despite all the various structures that had been constructed. It is expected that the future expansion of the port will increase further erosion at Tanjung Piai.

Figure 13. Completed soft rock: a) on the east coast of Tanjung Piai; b) on the west coast; c) completed revetment on the east coast (DID Malaysia).

Numerical Modeling

The modeling results show that in the existing condition, the maximum current speeds observed along the east and west coast of Tanjung Piai, ranged from 0.2 to 0.5 m/s and very strong currents occurred at the tip of Tanjung Piai with speeds of 0.5 m/s to 0.8 m/s (Figure 14). During flood tide, Tanjung Piai is subjected to current speeds of 0.1 - 0.3 m/s compared to current speeds of 0.3 - 0.6 m/s during ebb tide (Figure 15). Results also show that there are some local current patterns formed within the study area due to the presence of small islands (Figure 16).

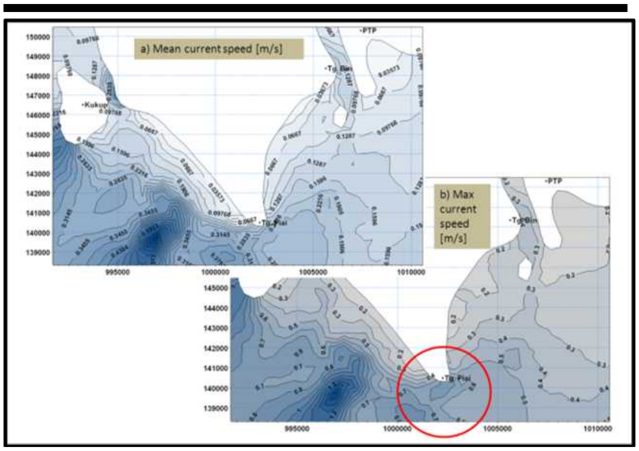

Figure 14. Statistical analysis of current speed forced by tide and wind: a) mean current speed; b) maximum current speed in the study area; red circle indicates that Tanjung Piai is subjected to a maximum current speed of more than 0.6 m/s (Wan Hasliza *et al*., 2013).

Wave modeling using MIKE 21 SW results show that the dominant waves came from Singapore (south) and Malacca Straits (northeast) with amplitudes of over 1.5 m, reducing their heights to less than 0.8 m as they propagate towards Tanjung Piai. Since the bed sediment at Tanjung Piai is very soft, these high waves, combined with the strong tidal currents, which occur during spring tide and storm events, will dislodge and transport the sediment away. This is devastating to the existing mangroves growing in Tanjung Piai, because the mangrove roots are also regularly subjected to the wakes of the passing ships which will loosen their grip on the soft mud, causing them to fall and eventually die. The statistical analysis (Figure 17) shown that the mean significant wave height is in the range of 0.45 m while the maximum wave can reach up to 1.0 m particularly at the tip area. However, the waves that approach the east and west coastline are relatively low which usually do not exceed 0.4 meter.

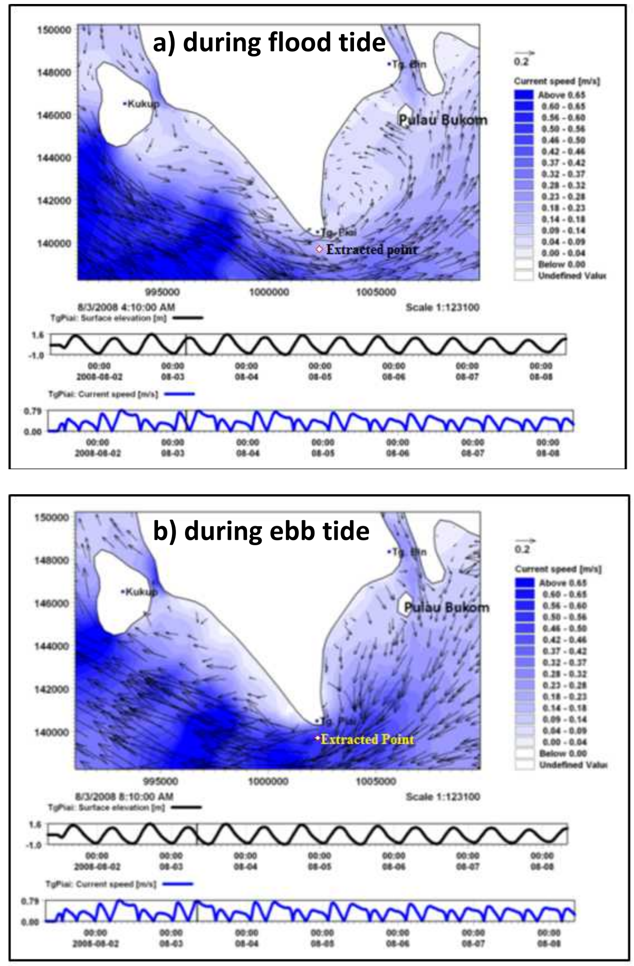

Figure 15. Current speeds around Tanjung Piai: a) during flood tide (0.1-0.3 m/s); b) during ebb tide (0.3 - 0.6 m/s) (Wan Hasliza *et al*., 2013).

Case Study on Shoreline Protection Alternatives

The results from the Hydrodynamic (HD) and Spectral Wave (SW) simulations were compared between the existing condition and after the proposed structure has been implemented. From the results, it is noted that the study area will face both positive and negative impacts. After the proposed structures were implemented, the current speed and wave height behind the structure will be reduced to 0.6 m/s and 0.7 m, respectively as presented in Figure 18 and 19. The construction of breakwaters in the coastal inlets will generally cause prominent effects on the shorelines as there would be an accumulation of sediment on the updrift side and corresponding erosion on the downdrfit side (Kudale 2010). For this present study, the construction of breakwater would create such effect where the accumulation might occur just behind the proposed breakwater while erosion may occur along the upper region due to the minor growth of current speed. In the model result, the increment of approximately 0.2 m/s current speed along the small part on the west coast (Figure 18) is also a worrying matter, and to be considered in redesigning the coastal structure in the future. However, if proper monitoring could be done to observe the impact on real situations, future problem concerning erosion could be reduced or eliminated.

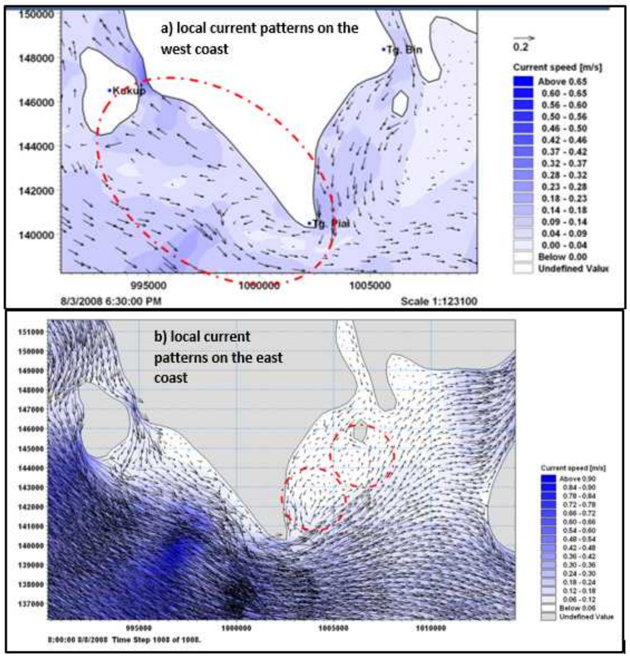

Figure 16. Local current patterns (red circles) at the: a) west coast; b) east coast of Tanjung Piai, formed by the existing islands located around Tanjung Piai (Wan Hasliza *et al*., 2013).

CONCLUSIONS

The condition in the coastal mangrove area of Tanjung Piai has been discussed in this present study with relation to the hydrodynamic characteristics of the current and wave as they will determine the direction of the sediment transport in the area of concern. A hydrodynamic modelling incorporating the proposed coastal protection measures has shown positive and negative impacts of the hydrodynamic changes around the study area. The results indicated that the magnitude of the current speed and wave height would be reduced in the area behind the structures but slightly increased in some parts of the coastal area. These changes will also determine the amount of sediment that will be eroded or accreted. As such, it is necessary to understand the hydrodynamic characteristics before implementing any kind of coastal protection measures. At Tanjung Piai, the contribution of high current speed and wave height are some of the major factors in generating the occurrence of coastal problem. The implementation of the coastal structure can protect the area in the vicinity of the structure, however, it may be unfavourable to the other parts of the coast.

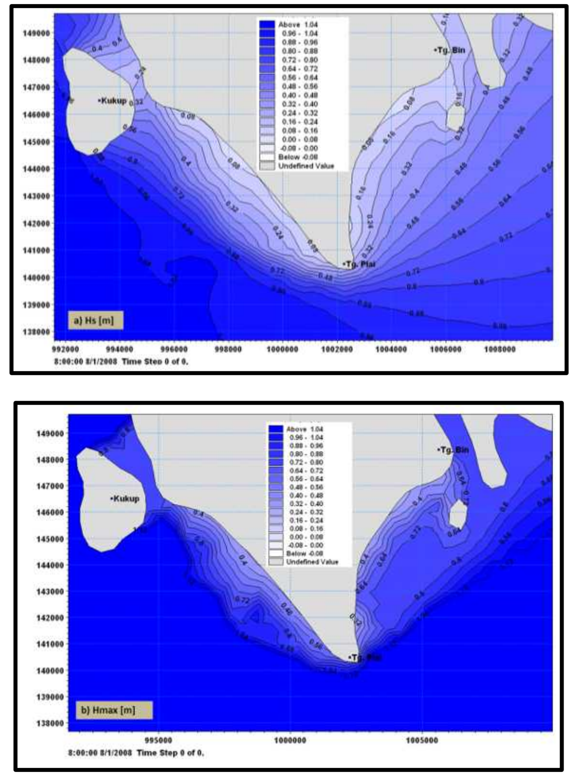

Figure 17. Statistical analysis of: (a) significant wave height; (b) maximum wave height in the study area (Wan Hasliza *et al*., 2013).

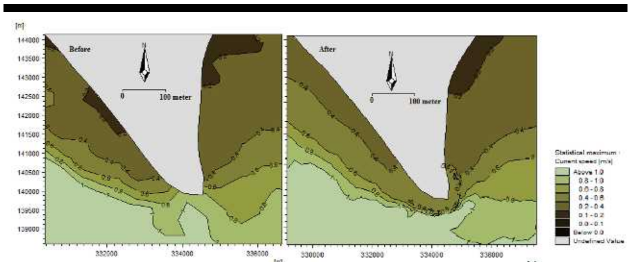

Figure 18. Difference in the modelled current speed, before and after the implementation of the proposed structure.

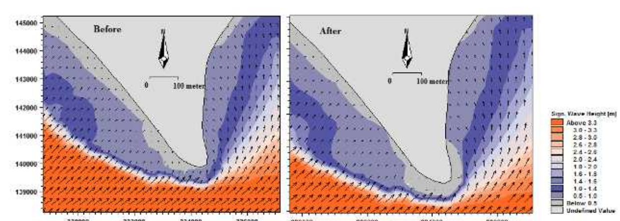

Figure 19. Difference in the modelled significant wave height, before and after the implementation of the proposed structure.

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