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Assessment of Wave Attenuation Performance of the Tanjung Piai Breakwater Using Spectral Wave Analysis

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Abstract: Tanjung Piai is a Malaysian heritage site situated at the southernmost tip of the Asian continent. Tanjung Piai provides a conducive coastal habitat for many mangrove species. Coastal erosion resulting in shoreline retreat was detected dating back to the 1930s. The erosion rate had accelerated until the early 21st century due to various factors including to coastal developments in the vicinity of Tanjung Piai. This led to significant land mass losses threatening the coastal eco-system. Previously, various measures were adopted to permanently harden the shoreline. Nevertheless, these approaches prevented sea water from reaching the mangroves, which in turn resulted in significant mangrove depletion along the shoreline. A series of offshore breakwaters were subsequently planned and constructed to reduce the wave energy prior to reaching the mangrove shoreline. The breakwaters are anticipated to be able to mitigate the erosion problems and extend the width of the existing mangroves belts along the wave-exposed coastline. The wave climate of Tanjung Piai has changed drastically in the past decades, potentially due to rapid coastal development in the vicinity. This study aims at re-evaluating the wave attenuation performance of the Tanjung Piai breakwaters subjected to the latest wave climate (i.e., offshore waves, squalls, and wind-generated waves) and bathymetry by means of two-dimensional numerical modelling – MIKE21 SW. The latest survey of the site and the most recent breakwater design details have been incorporated in this modelling study. Two scenarios have been conducted to determine the wave climates i.e., pre- and post-construction of the breakwaters. The alterations of the wave heights for both scenarios are taken as a basis to ascertain the actual wave attenuation performance of the breakwaters. The numerical results show that the breakwaters are able to reduce offshore wave heights up to 66%. The breakwaters can attenuate offshore waves more effectively than squalls and wind-generated waves.

Keywords: Mangrove, coastal erosion, waves, breakwaters, coastal sustainability

1. Introduction

About 35% of the world's mangroves have been lost or degraded [1]. Mangrove forests provide a natural barrier to reduce coastal hazard risks such as extreme wave attacks, storm surges, and tsunamis [2]. Mangrove rehabilitation programs implemented as part of the ecosystem services rendered to the coastal environment include coastal protection and biodiversity conservation [3]. Tanjung Piai's mangrove-fringed coastline experienced prolonged erosion over many decades. Various mitigation measures implemented failed to arrest the problem effectively. The use of offshore breakwaters provided an opportunity for mangrove regeneration due to the calm waters that occur leeward of the breakwaters [4]. Numerical modelling is done to assess the effect of the breakwaters to the coastline to assess the degree of wave protection provided by the breakwaters to the immediate coastline.

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Tanjung Piai is situated in the state of Johor in Malaysia (Fig. 1). It is recognized as the southernmost tip of the Asian continent. With 526 ha of mangrove swamp and 400 ha of mud flat, the area was declared a Ramsar site in 2003 [5]. Subsequently, it was also declared as a Johor National Park in 2004. Since then, the park is a national heritage site. Various facilities were introduced at Tanjung Piai National Park ever since it was declared the Ramsar site. A concrete slab path was constructed to provide a proper access to the visitors from the ticketing counter located near the existing tidal gate to the inner part of the park (Fig. 2).

Fig. 1 - Location of Tanjung Piai, Johor

Fig. 2 - Plan of Tanjung Piai National Park in 2003 [9]

There is an abundance of flora and fauna in Tanjung Piai. The waters are home to a variety of fish and shellfish, which indicates that it is a significant location for food and reproduction [6]. It is an important breeding ground and habitat for many fishes, including commercially important species such as sea bass (*Lates calcarifer*), snapper (*Lutjanus argentimaculatus*) and white pomfret (*Pampus argenteus*). Tanjung Piai is also a stopover site for migratory water birds during the winter migration season (September until March). Migrants that have been recorded include two critically endangered species - Spoon-billed Sandpiper (*Eurynorhynchus pygmeus*) and Chinese Crested Tern (*Sterna bernsteini*). Tanjung Piai is one of the few places in Peninsular Malaysia where the rare Lesser Adjutant Stork (*Leptoptilos javanicus*) is found. There are 29 mangrove and mangrove-associated species with at least two distinct vegetation zones based on the trees that dominate those zones. The Avicennia-Sonneratia zone occupies the seaward edge of the mangrove forests while the Rhizophora-Bruguiera zone is situated at the landward side [7].

Tanjung Piai's coast was reported to experience gradual erosion since 1930s [8]. Nevertheless, the impact was not significant until the vegetation on its hinterland was cleared for agriculture purposes. The change in land use modified the drainage patterns within the mangrove domain. As a result, the coastline eroded by about 8.1 m/year between 1974 and 2014 [9]. This means that the shoreline receded about 324 m over 40 years. Based on the 2015 National Erosion Study [10], the erosion rate at Tanjung Piai was up to 7.5 m/year between 2004 and 2014 with its shoreline categorized as experiencing Category 2 erosion or significant erosion. Fig. 3 shows the various degree of erosion along the Tanjung Piai shoreline. The uncontrolled erosion had eventually damaged the concrete slab path and ticketing counter. The gazebos and camping facilities on stilts provided within the park where team building and bird-watching activities could be held, have also been destroyed by the erosion. The back mangroves were threatened by prolonged inundation that caused many trees to die due to hypoxia. Despite mangrove replanting efforts implemented at the site, there was very limited number of regenerating undergrowth or saplings. This is likely due to traces of oil spill and rubbish observed on the forest floor.

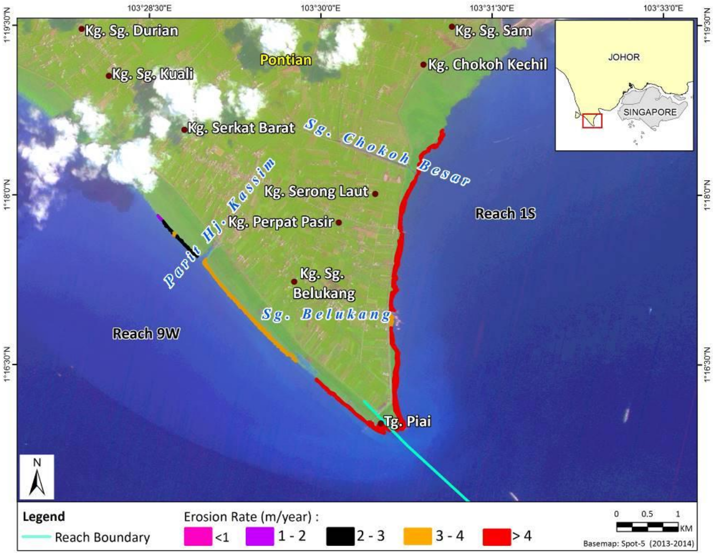


Fig. 3 - Location and the rate of coastal erosion at Tanjung Piai, Johor [10]

Tanjung Piai is exposed to the open sea as it is located at the confluence of the Straits of Malacca and Straits of Johor. Tanjung Piai has an extensive mudflat extending up to about 1.4 km seaward of the shoreline. Waves propagating from far field are able to penetrate into the mangrove fridge, posing some extents of destruction to the coast, particularly at the eastern Tanjung Piai shorelines (Fig. 4). This stretch of the shoreline is subjected to short-crested waves. The effect of wave breaking on mud re-suspension is more pronounced on the shorelines of the eastern coast. The wave breaking associated with a more concentrated decay of wave energy induces strong localized erosion [11]. Erosion was also attributed to the extensive development of the region and the increase in marine activities in the waters of Singapore Straits [12]. Periodic occurrences of oil spills as well as illegal discharges of oily waste, sewage and garbage discharged from passing vessels brought ashore by incoming tides also exacerbates the problem [13]. The rapid erosion and loss of mangroves are detrimental to various types of fauna that live in the coastal habitat. If the problems persist, the Ramsar site status of Tanjung Piai might be threatened due to significant loss of the mangroves and land area. In view of its ecological and heritage significance, it is crucial to preserve and enhance the mangrove-fringed coastline of Tanjung Piai using hard coastal engineering structures.


(a) (b)

Fig. 4 - Wave activity at the Tanjung Piai shoreline in September 2013 (a) high wave activity in front of the mangrove-vegetated coast; (b) wave activity occurring at the mangrove root system

Various coastal structures have been adopted in Malaysia to control beach erosion at many vulnerable sites, including Tanjung Piai [14]. Numerous efforts were made to mitigate erosion in Tanjung Piai since 2002. Some of the coastal structures installed at the site were mangrove tree trunks as piles, vertical sea walls and rip-rap. When these approaches failed to meet the expectations, sand-filled geotextile containers were placed off and along several stretches of the Tanjung Piai shoreline. A rock revetment was later constructed to fix the shoreline. Nevertheless, the revetment was still unable to provide the desired level of coastal protection to the mangrove forests in Tanjung Piai.

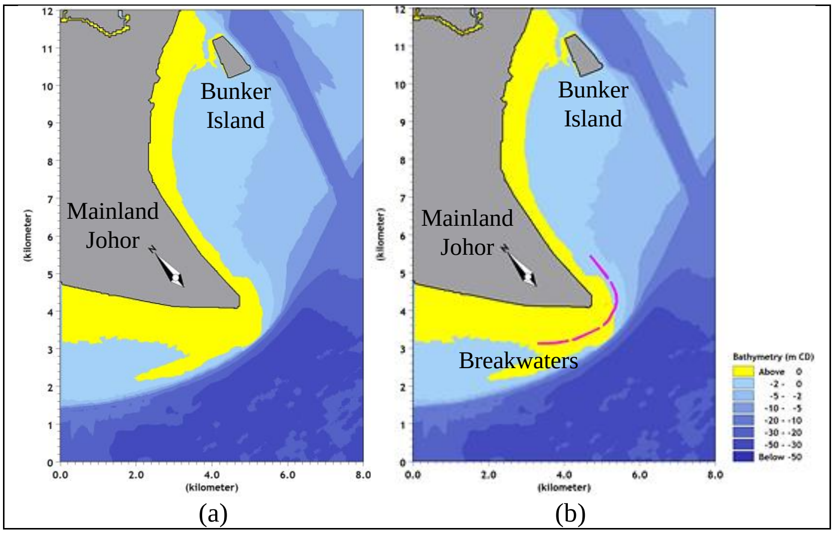
Very careful thoughts must be given to the protective measures or structures implemented along the coast of Tanjung Piai. The mangroves would likely die as a relatively impermeable structure is built high enough to preclude overtopping, hindering sea water from reaching the mangroves. Hence, a series of low-crested offshore breakwaters sited seaward of the shoreline were proposed to not only halt the erosion but also protect the existing vegetation in Tanjung Piai. The breakwaters were designed to allow water to enter the mangrove-fringed coast unimpeded during periods of high water. The low-crested breakwaters are also less visually intrusive.

There are limited number of studies focusing on interaction of waves with breakwaters and reclamation in Malaysia [15]- [20]. A number of these studies are based on laboratory tests and analyses. To the knowledge of the authors, no literature has been reported to specifically address the use of the breakwater in mangrove protection in Tanjung Piai. Therefore, this research is established to assess the wave conditions along the coast of Tanjung Piai during pre-and-post construction of the low-crested breakwaters using a two-dimensional numerical modelling approach. This study will provide some useful insights about the change of wave climates adjacent to the breakwater. This information will help policy makers and the private sectors in dealing with the mangrove deletion problems particularly in Tanjung Piai. This research seeks to be a catalyst for similarly themed studies at other sites within and beyond Malaysia. In addition, the research also imparts awareness to the public about mangrove conservation using structural intervention measures. However, this study does not consider the effect of sea level rise.

2. Methodology

Numerical modelling was conducted using the two-dimensional MIKE 21 Spectral Wave (SW) model, which is one of the modules of the MIKE 21 software suite. MIKE 21 SW is particularly applicable for simultaneous wave prediction and analysis on regional and local scales. A mesh of the study area was constructed to provide the basis for the simulations. Coarse spatial and temporal resolution was used for the regional part of the mesh. A depth-adaptive mesh was adopted to describe the shallow water environment at the study area. This software has been used to simulate nearshore waves in Malaysia [21], [22] and other parts of the world [23], [24]. MIKE 21 SW simulates growth, decay and transformation of wind-generated waves as well as swells in offshore and coastal areas. MIKE 21 SW solves the spectral wave action balance equations formulated in either Cartesian or spherical coordinates. The time integration was performed using an efficient multi-sequential integration scheme. The directionally decoupled parametric formulation is based on parameterization of the wave action conservation equation [25].

The numerical model was setup prior to actual computer simulations to represent the physical characteristics of the study site in an input format that can be understood by a numerical model. Two different model scenarios representing the base line condition (without breakwaters) and with the presence of the breakwaters were prepared. The setup of both models is displayed in Fig. 5. The details of the breakwaters are given in Table 1. The breakwaters' crest level coincided with the highest astronomical tide (HAT) level. The maximum allowable overtopping rate adopted was 10 l/s/m for the rock revetment built at the seaward edge of the mangrove shoreline. This limit is considered acceptable for a revetment to perform its primary function whilst allowing sea water to overtop the structure transmitting the wave though the mangroves fridge and not damaging them.



(a) (b)

Fig. 5 - Bathymetries of test model scenarios (a) without breakwaters as baseline condition; (b) with breakwaters

Table 1 - Breakwater details

Description	Remark
Breakwater type	Low-crested, segmented
Breakwater material	Rubble-mound
Number of breakwaters	4 nos.
Length of breakwaters	3 nos. @800 m length, 1 no. @ 1,300 m length
Distance between breakwaters	100 m
Breakwater crest level	3.7 m above Chart Datum (CD)
Breakwater crest width (trunk)	2.8 m
Side slope gradient	1 (vertical): 3 (horizontal)

Discretization of the governing equation in geographical and spectral space was performed using the cell-centered finite volume method. An unstructured mesh technique was used in the geographical domain. A model mesh covering the project area, as shown in Fig. 6, was created using the bathymetry data. A coarse mesh size of up to 1 km was used to define the model boundary but a higher resolution mesh size of up to 10 m was used to describe the shallow water environment along the shoreline. The model boundaries were sited in deeper waters sufficiently far from the area of interest. The offshore wave extraction point that provides the sea states for the numerical modelling is located along the model's offshore boundary. Time integration was performed using the fractional step approach where a multi-sequence explicit method was applied for the modelling of wave propagation. Two sets of site-specific survey covering different areas were utilized in this study. As the numerical model covers a wider area, the data from the C-MAP electronic navigation chart was incorporated to supplement the survey data.

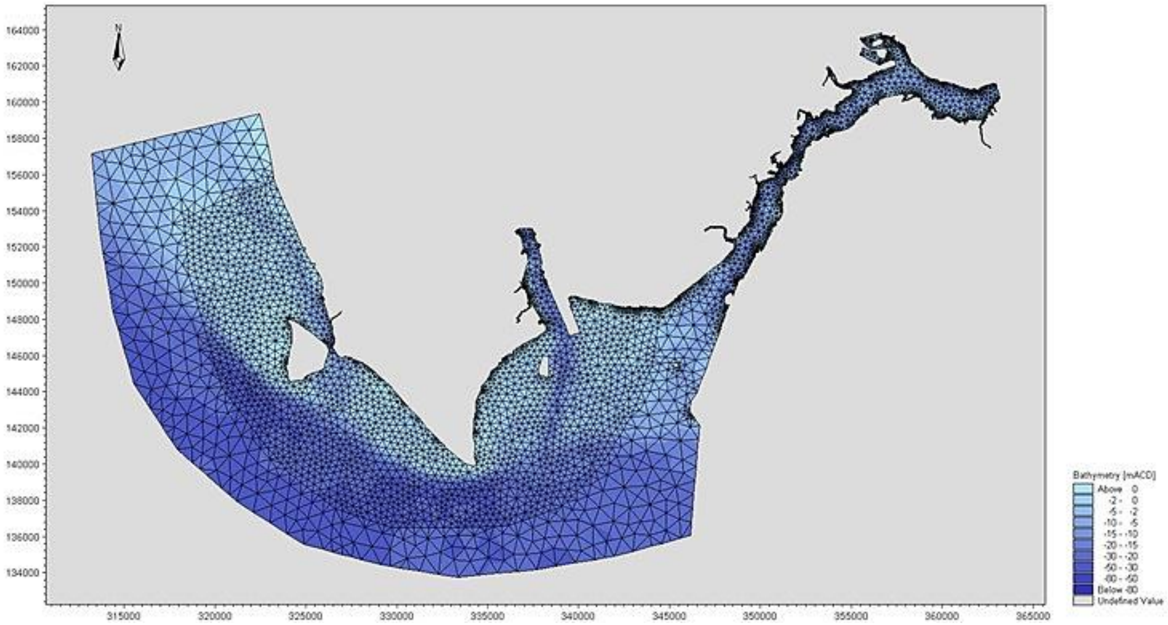


Fig. 6 - Bathymetry for MIKE 21 SW

The offshore boundary conditions are represented by the significant wave height (H_s), Mean Wave Direction (MWD), mean wave period (T_m), directional spreading index (n) and wind speed (for wind-generated wave simulations only). Three types of wave simulations for various types of waves commonly occurring in the vicinity of the study area were undertaken (Table 2):

a) Offshore waves - Characteristic offshore wave condition of 0.9 m (wave height, H_{m0}) and 2.9 s (wave period, T_m) corresponding with a 100-year return period was determined based on GlobOcean's 17-year (1992 to 2008) offshore wave data [26] (Fig. 7). Offshore waves approaching the project site from a Mean Wave Direction of 150°N were found to have the highest wave height along Tanjung Piai's shoreline.
b) Squalls - Thunderstorm squalls occur in the Inter-Tropical Convergence Zone around the Equator. Although they can be very violent, they last for a relatively short duration, i.e., up to 1 hr. Simulations were conducted for wave condition of 1.5 m (H_{m0}) and 4.0 s (T_m) for a 100-year return period determined from 10 years of wind records (1973 to 2003) [26]. Squalls approaching the project site from a Mean Wave Direction of 150°N were found to generate the highest height along the Tanjung Piai shoreline.
c) Wind-generated waves - Wind speeds of 12 m/s were propagated in the model to assess the development of waves due to wind alone [27]. Wind-generated waves approaching the project site from a Mean Wave Direction of 90°N were found to cause the highest wave height along the Tanjung Piai shoreline.

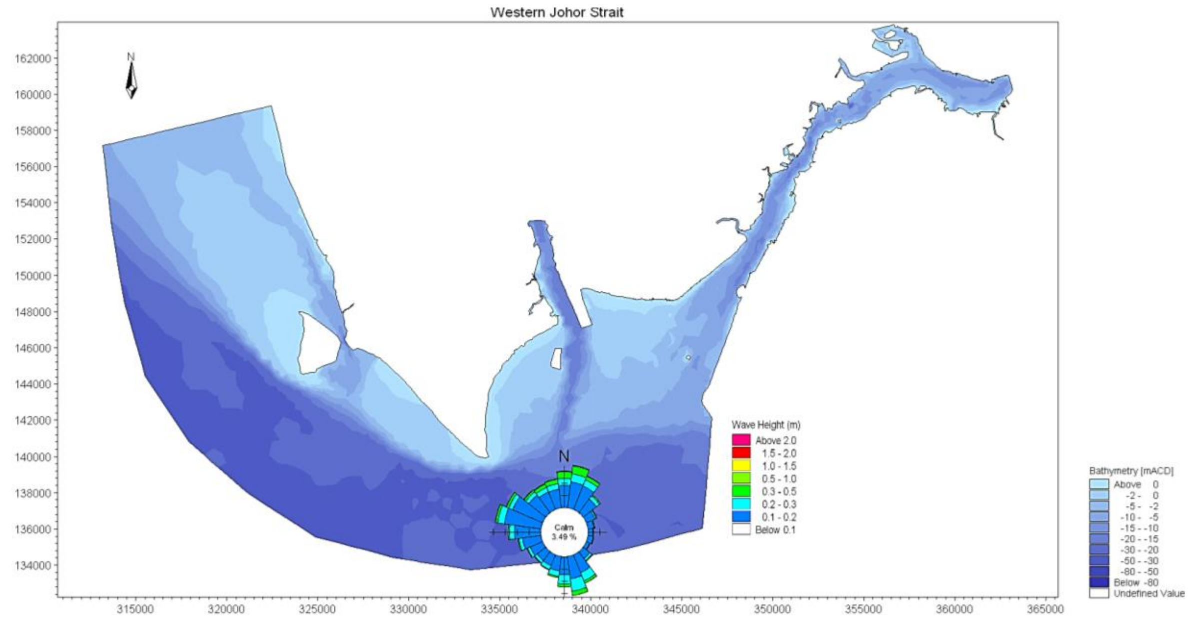


Fig. 7 - Annual wave rose overlaid on bathymetry indicating location of wave boundary

Table 2 - Wave simulation details

Wave Simulation	**Source of Data**	**Return Period (Years)**	**Parameter**
Offshore waves	17 years (1992 to 2008) of offshore wave data from GlobOcean Sarl database [26]	100	MWD = 150ºN H_{m0} = 0.9 m T_m = 2.9 s
Squalls	10 years (1973 to 2003) of wind data recorded at Singapore Tengah meteorological station [26]	100	MWD = 150ºN H_{m0} = 1.5 m T_m = 4.0 s
Wind-generated waves	Detailed Studies on Tuas View Extension and Pulau Tekong Land Reclamation: Volume IV - Wave Impact Assessment' [27]	Extreme wind speed	MWD = 90ºN U_{10} = 12 m/s

Data from various sources were used as the model boundary conditions. Offshore wave data of 17 years (1992 to 2008) from GlobOcean Sarl database were adopted in this study. The elaboration of wave chronologies was derived from a combined use of met-ocean models and satellite measurements. The hindcasted sea states were elaborated using the WaveWatch III model where the available satellite sea state measurements were assimilated. The assimilation process, which nests simulations outputs and measurements, provides a high level of confidence in the quality of the constituted sea state databases. A quantitative analysis of the effects of squalls was performed by running a SWAN model using synthetic wind fields construed to represent squalls of different extremities. The initial sea states were set to H_s = 0.2 m, T_p = 7.5 s, Dir_p = 270°N before the constant wind fields of varying strengths corresponding to varying extreme wind velocities from a westerly direction were applied during a 1 hr period [26]. The extreme wind speed used in simulating the wind-generated waves was based on a study on waves within the Straits of Johor [27].

The model parameters used in the numerical simulations are outlined below:

a) The site experiences semi-diurnal tides [28]. The tide level was set at mean high water spring (MHWS) level. Higher water levels allow larger waves to propagate towards the coast due to less energy loss. Higher water levels result in reduced wave dissipation due to bottom friction and wave breaking. Lower water levels cause waves to break relatively seaward.

b) The dissipation source function used is based on the quadratic friction law and linear wave kinematic theory. The dissipation coefficient depends on the hydrodynamic and sediment conditions. Bottom friction parameter (Nikuradse roughness), k_N = 2 mm was used in the modelling.

c) Depth-induced wave breaking occurs as waves dissipate energy when the waves are too high to be supported by the water depth. Wave breaking parameters, γ_1 = 1.0 and γ_2 = 0.8 (controls the wave steepness condition and is used in the directionally decoupled parametric formulation) with α = 1.0 (controls the rate of dissipation and is a proportional factor on the wave breaking source function) were adopted.

The test matrix is given in Table 3. Model calibration was done for the baseline condition. The model calibration parameters and values adopted are summarized in Table 4.

Table 3 - Test matrix

Wave Simulation	Condition	
	Baseline	With Breakwaters
Offshore waves	√	√
Squalls	√	√
Wind-generated waves	√	√

Table 4 - Model calibration parameters and values

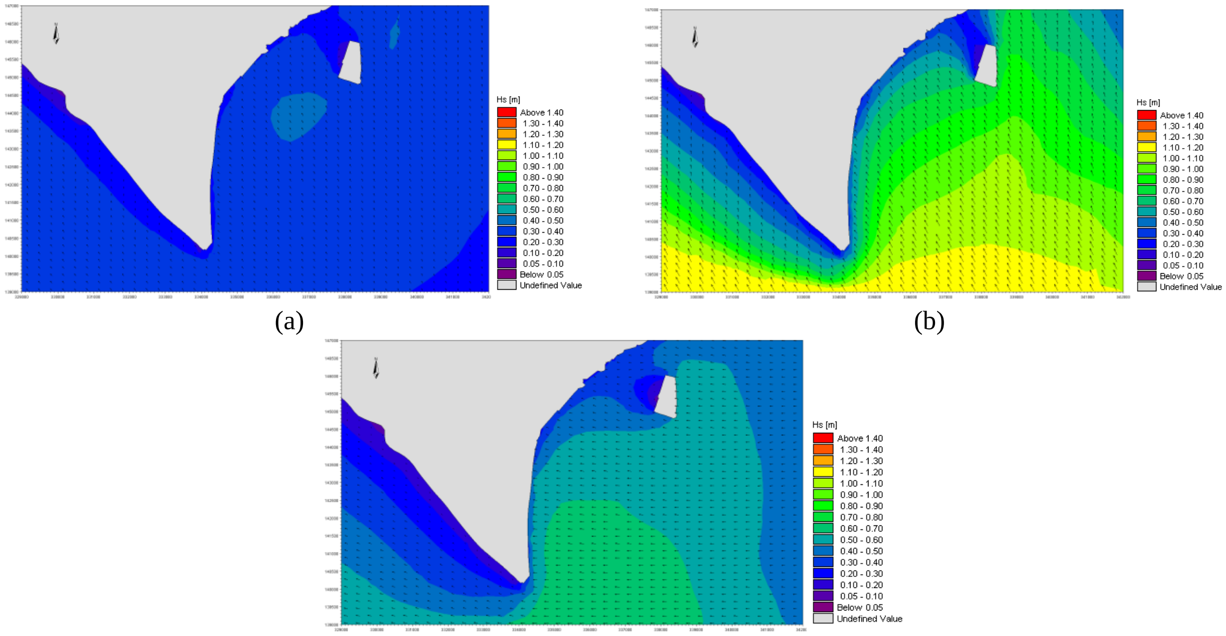
Parameter	Description	Remark
Water level	Mean high water spring	3.03 m above CD
Wave dissipation	Bottom friction	k_N = 2 mm
	Wave breaking	$\gamma_1 = 1.0$ $\gamma_2 = 0.8$ $\alpha = 1.0$

3. Results and Discussion

The simulations indicate that results are significantly influenced by the bathymetry of the study area and the wave data extracted at the model's offshore boundary. Both datasets are considered adequate for the purpose of this research.

3.1 Scenario 1: Baseline Condition

Without any form of coastal protection, the Tanjung Piai shoreline is openly exposed to various types of waves. Fig. 8 shows wave simulations for the baseline condition with different wave types, i.e. offshore waves, squalls and wind-generated waves. The plots present the direction of waves propagating from offshore to nearshore (represented by arrows) overlaid on wave height contours. The simulation results imply that the mangroves along the east coast and Tanjung Piai's southern tip are more susceptible to destruction by the waves compared to the western coast.

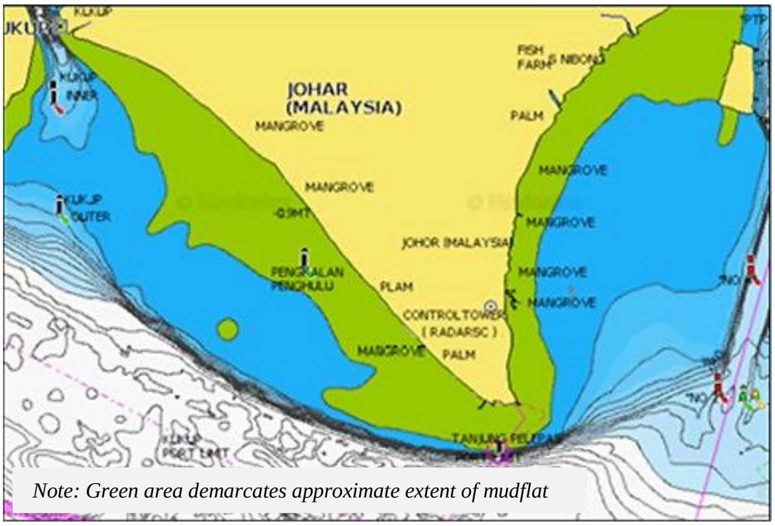


(a) (b) (c)

Fig. 8 - Wave simulations for the baseline condition (a) offshore waves: Mean Wave Direction (MWD) = 150ºN; (b) squalls: MWD = 150ºN; (c) wind-generated waves: MWD = 90ºN

In Fig. 8(a), the study area is subjected to an offshore Mean Wave Direction of 150°N. The waves generally break relatively close to the eastern shore due to its steep nearshore slope (Fig. 9). It is evident from the figures that the eastern and southern shores of Tanjung Piai are exposed to greater wave energy ($0.3 \leq H_s \leq 0.4$ m) compared to the western coast

($0.1 \leq H_s \leq 0.3$ m), as far as offshore waves are concerned. The phenomenon is principally due to the protection of the land mass from direct wave attack. Some level of wave protection is also noticed northwest of Bunker Island when exposed to waves with a dominant angle of 120°N.



Note: Green area demarcates approximate extent of mudflat

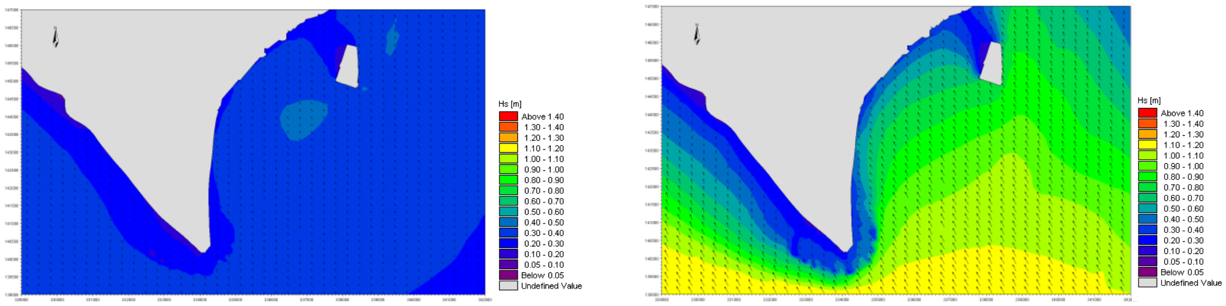
Fig. 9 - Bathymetry of the Tanjung Piai coastal water [29]

The wave energy content due to squalls in the vicinity of Tanjung Piai is greatly amplified due to increased wave activities with higher significant wave height and the mean period (Fig. 8(b) and Table 2). The wave contour presented is more refined, with a reduction of an offshore wave height of 1.2 m to a nearshore wave height as small as 0.3 m. Similar to the case of the offshore wave condition (Fig. 8(a)), the sheltered waves at the west coast of Tanjung Piai are anticipated to be small ($0.1 \leq H_s \leq 0.3$ m) due to wave diffraction at the tip of the land mass, wave refraction and shoaling processes. Hence, the mangroves at this area are spared from destruction by the wave action.

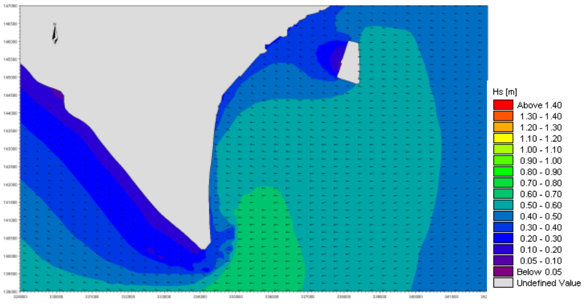
Under the influence of wind-generated waves (see Fig. 8(c)), the Mean Wave Direction is 90°N and U_{10} is 12 m/s. The east coast and the southern tip of Tanjung Piai are directly exposed to the head-on, wind-induced waves, resulting in near-shore waves of $0.4 \leq H_s \leq 0.5$ m along the coastline. On the contrary, the west coast of Tanjung Piai is greatly protected from the 90°N wind-waves. The simulated significant waves along the coastline are not more than 0.2 m in height.

3.2 Scenario 2: With Breakwaters

With the presence of the low-crested breakwaters, the wave heights near Tanjung Piai's mudflat and mangrove areas are significantly reduced. Fig. 10 illustrates wave simulation results with the breakwaters' presence for the different types of waves, i.e. offshore waves, squalls and wind-generated waves. Fig. 10(a) shows that the waves generally break in front of the breakwaters when subjected to offshore waves propagating with Mean Wave Direction of 150°N. It is evident from the figures that the eastern and southern coasts of Tanjung Piai are exposed to wave energy of less than 0.2 m (as compared with $0.3 \leq H_s \leq 0.4$ m for the baseline condition) and also less than 0.2 m along the western coast (compared with $0.1 \leq H_s \leq 0.3$ m for the baseline condition). There is no change in wave heights northwest of Bunker Island when compared with the baseline condition.



(a) (b)



(c)

Fig. 10 - Wave simulations with presence of breakwaters; (a) offshore waves: Mean Wave Direction (MWD) = 150ºN, (b) squalls: MWD = 150ºN, and; (c) wind-generated waves: MWD = 90ºN

The wave energy due to squalls along Tanjung Piai’s coastline (Fig. 10(b)) is reduced by up to about 30% due to wave breaking caused by the breakwaters. Similar to the offshore wave condition, the relatively sheltered west coast of Tanjung Piai is less than 0.2 m due to wave breaking processes near the land mass’ tip.

The east coast and the southern tip of Tanjung Piai are directly exposed to the wind-induced waves, resulting in nearshore waves of less than 0.4 m along the coastline even with the presence of the breakwaters (Fig. 10(c)). The west coast of Tanjung Piai is protected from the 90°N wind-waves due to its geographical location; the simulated significant wave heights along the coastline are less than 0.2 m.

3.3 Wave Attenuation by Breakwaters

To measure wave attenuation by the detached breakwaters, five measurement points, i.e. A, B, C, D and E, were identified as shown in Fig. 11. Points A, B, C and D are located behind the respective detached breakwaters whilst Point E is located at the mudflat fronting the southern tip of Tanjung Piai. Points A, B, C and E are located on the mudflat, i.e., the area that is higher than 0 m CD. The wave height at each point was extracted from the numerical modelling results. The incident wave heights (prior to installation of the breakwaters) and the transmitted wave heights (after installation of the breakwaters) of all measurement points for the three wave scenarios are presented in Table 5. A wave transmission coefficient C_t, which is the ratio of transmitted wave height-to-incident wave height, is computed to indicate the level of wave attenuation at each measurement point. The lower the wave transmission coefficient, the higher will be the wave attenuation ability of the breakwaters.

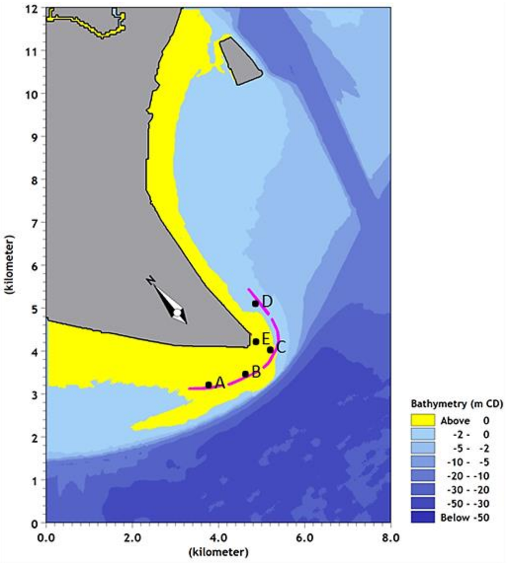


Fig. 11 - Locations of the measurement points

Table 5 - Comparison of extracted wave heights between the baseline condition and with presence of the breakwaters

Wave Scenario	Point	Wave Height, H_{m0} (m)		Wave Transmission Coefficient, C_t
		Baseline	With Break-waters	

Offshore waves	A	0.55	0.19	0.34
	B	0.61	0.23	0.37
	C	0.74	0.36	0.49
	D	0.69	0.30	0.43
	E	0.58	0.27	0.47
Squalls	A	0.61	0.28	0.46
	B	0.63	0.34	0.54
	C	0.95	0.53	0.56
	D	0.87	0.73	0.84
	E	0.60	0.43	0.72
Wind-generated waves	A	0.36	0.17	0.47
	B	0.46	0.44	0.96
	C	0.62	0.57	0.92
	D	0.63	0.57	0.90
	E	0.47	0.34	0.72

It can be inferred from the result that the breakwaters are able to reduce wave heights along Tanjung Piai's shoreline at different levels depending on the wave type and location of the measurement points. The breakwaters can attenuate the offshore waves more effectively compared to squalls and wind-generated waves. The reduction in wave height along the shoreline for offshore waves ranges from 51 to 66%. The presence of the breakwaters reduces nearshore waves from squalls by 16 to 54%. Wind-generated waves behind the breakwaters are reduced from 4 to 53%. The wind-generated waves are normally low at the site as winds are of short duration. The prevailing wind conditions are rather mild with average wind speeds in the order of 5 m/s. The majority of the sea states are generated within a radius of a few kilometres [24]. Wave energy from wind-generated waves is relatively higher compared with that of offshore waves and squalls. The breakwaters are effective and efficient in dissipating wave energy especially from offshore waves.

Fig. 12 presents wave transmission of breakwater A, B, C, D and E for the three wave scenarios, i.e., offshore waves, squalls and wind-generated waves. Intensive wave energy is received by breakwaters B, C and D due to their direct exposure to open seas. Due to the sheltering effect resulted from the tip of Tanjung Piai, the C_t of Point A remains small. The results show that the locations and alignment of the breakwaters are effective in dissipating nearshore waves due to offshore-propagated waves, squalls and wind-generated waves. The reduced wave height and wave energy along the shoreline would create a conducive environment for mangroves to grow.

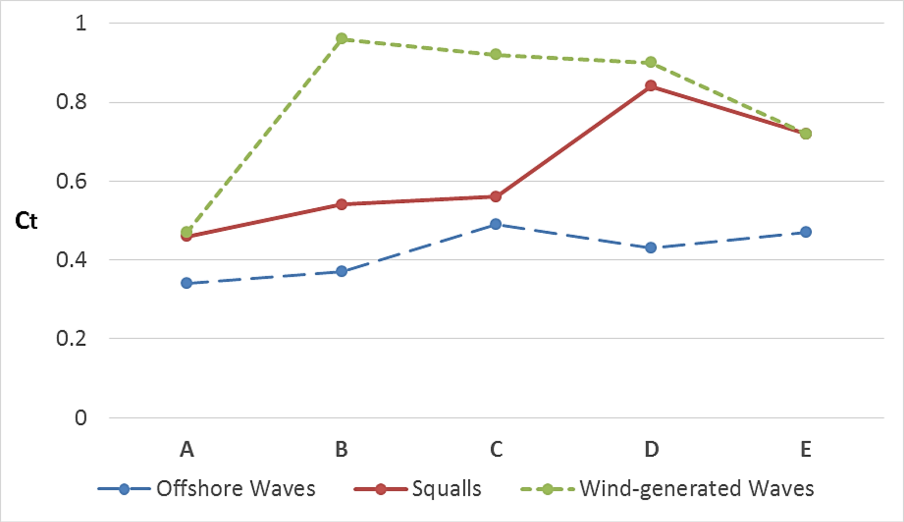


Fig. 12 - Wave transmission coefficient at various locations along Tanjung Piai's shoreline with the presence of breakwaters

3.4 Implications

The shorelines of Tanjung Piai have been eroded for almost a century. Various coastal protection structures that had been constructed since 2002 failed to effectively protect the shore from erosion. The segmented breakwaters encircling the southern tip of Tanjung Piai were fully completed in 2018. Fig. 13 shows a bird's eye view of the detached breakwaters with breakwater D in the foreground. By comparing satellite imageries and topographic maps, it was deduced that the breakwaters had significantly reduced and arrested the coastal erosion since 2017 (Fig. 14).

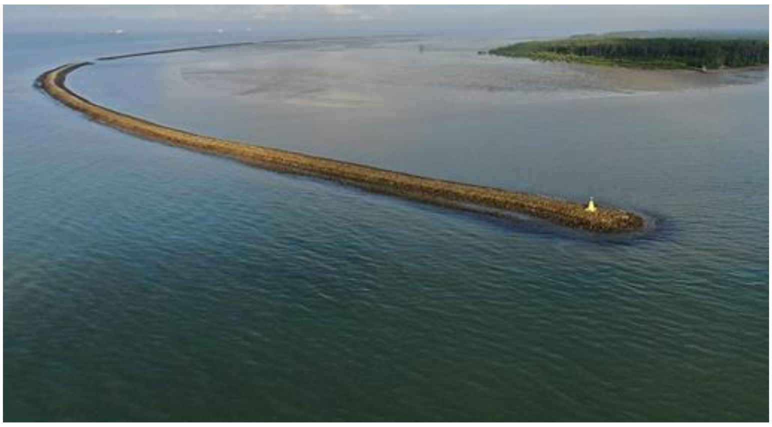


Fig. 13 - Offshore breakwaters constructed at Tanjung Piai, Johor

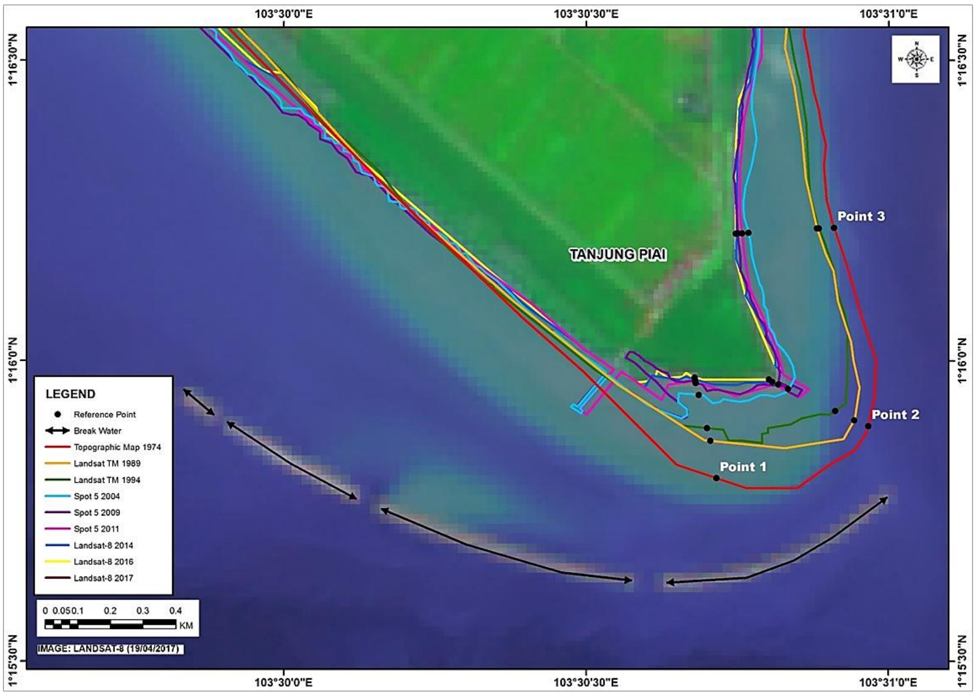


Fig. 14 - Coastline evolution at Tanjung Piai between 1974 and 2017 [9]

The results in Fig. 12 indicate that wave sheltering due to the presence of the breakwaters has stabilized the eroded coastline allowing mangroves to propagate and thrive. The breakwaters have not only successfully reduced the rate of erosion but also aids in rejuvenating the mudflats and mangrove ecosystem. The breakwaters were proven to provide an effective wave sheltering effect and reduction of erosion and pollution rates within six months after the completion [30]. Soon after the breakwaters were constructed, mangroves were seen populating the barren mudflats due to the sheltering effect provided by the breakwaters (Fig. 15). The simulation results and comparison of satellite images illustrate the effectiveness of breakwaters as they reduce wave heights and wave energy along the shoreline. The shorelines of Tanjung Piai would experience reduced wave energy that is conducive for regeneration of the mangroves. Juvenile mangroves will be able to propagate and extend seaward. Once matured, these juvenile mangroves will provide added protection to the hinterland, which in turn creates a good habitat for marine and terrestrial flora and fauna.

Fig. 15 - Mangroves have regenerated along the coastline sheltered by breakwaters at Tanjung Piai

4. Conclusion

The eastern and southern shores of Tanjung Piai are exposed to greater wave energy compared to the western coast due to offshore waves and squalls but the east coast and the southern tip are directly exposed to the head-on, wind-induced waves. Wave energy from wind-generated waves is relatively higher compared with that of offshore waves and squalls. The breakwaters can attenuate offshore waves more effectively compared to squalls and wind-generated waves. The presence of the breakwaters reduces nearshore waves generated by offshore waves, squalls and wind-generated waves by up to 66, 54 and 53% respectively. By comparing satellite imageries and topographic maps, it was also deduced that the breakwaters had significantly reduced and arrested the coastal erosion since 2017.

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References

[1] Kay R. & Alder J. (2017). Coastal planning and management (2nd edition). CRC Press London

[2] Beck M. W. & Lange G. M. (2016). Managing Coasts with Natural Solutions: Guidelines for Measuring and Valuing the Coastal Protection Services of Mangroves and Coral Reefs. World Bank, Washington, DC, USA

[3] Ellison A. M., Felson A. J. & Friess D. A. (2020). Mangrove rehabilitation and restoration as experimental adaptive management. Frontiers in Marine Science, 7, 327. https://doi.org/10.3389/fmars.2020.00327

[4] Fauzi N. F. M., Teh H. M. & Hashim A. M. (2020). Assessment of mangrove replanting site at Kg Tanjung Kepah, Lekir, Perak. IOP Conference Series: Earth and Environmental Science, 549, 012054. https://doi.org/10.1088/1755-1315/549/1/012054

[5] Hamdan O., Shah I. A. & Afizzul M. (2017). Atlas of the Ramsar Sites in Johor, Malaysia. Forest Research Institute Malaysia

[6] Devi V. (2019). Tanjung Piai National Park a crowd-puller. TheStar. https://www.thestar.com.my/metro/metro-news/2019/11/02/tanjung-piai-national-park-a-crowd-puller

[7] Johor National Parks (2021). Tanjung Piai - Flora and fauna. https://www.johornationalparks.gov.my/v3/tanjung-piai-florafauna

[8] Awang N. A., Jusoh W. H. W. & Hamid M. R. A. (2014). Coastal erosion at Tanjong Piai, Johor, Malaysia. Journal of Coastal Research, 71(10071), 122-130. https://doi.org/10.2112/SI71-015.1

[9] Sharifah Mastura S. A. (2018) An analysis of accelerated coastal erosion and mitigation at Tanjung Piai. International Symposium on Coastal Erosion and Environment, Putrajaya, Malaysia

[10] Department of Irrigation and Drainage Malaysia (2015). National Coastal Erosion Study.

[11] Jensen J. H., Savioli J. C. & Saaban K. (2016). The impact of wave blocking from ship hulls on the stability of Tg. Piai coastline. International Journal of Environmental Science and Development 7, 2016. https://doi.org/10.18178/ijesd.2016.7.7.836

[12] Samion M. K. H., Hamzah S. B. & Desa S. M. (2020). Stability and overtopping assessment of Tanjung Piai stone revetment via two-dimensional hydraulic modelling. Proceedings of AWAM International Conference on Civil Engineering 2019. https://doi.org/10.1007/978-3-030-32816-0_32.

[13] International Maritime Organisation (2017). Identification and protection of special areas and PSSAs: Protection of Pulau Kukup (Kukup Island) and Tanjung Piai (Cape Piai). MEPC 71/INF.24.

[14] Mohamed Rashidi A. H., Jamal M. H., Hassan M. Z., Mohd Sendek S. S., Mohd Sopie S. L.& Abd Hamid M. R. (2021). Coastal structures as beach erosion control and sea level rise adaptation in Malaysia: A review. Water, 13(13), 1741. https://doi.org/10.3390/w13131741

[15] Tan I. S., Mohd Kamel N. & Teh H. M. (2021). Impact of coastal development on hydrodynamic change of the mangrove coastline in Tanjung Piai, Malaysia. Proceedings of the 6th International Conference on Civil, Offshore and Environmental Engineering. https://doi.org/10.1007/978-981-33-6311-3_25

[16] Hassan N. M. K.N., Kamel N. A. M. N. M., Pauzi M. F. & Teh H. M. (2018). Construction technology used for the reclamation of Seri Tanjung Pinang (Phase 2), MATEC Web of Conferences 203. https://doi.org/10.1051/MATECCONF/201820301016.

[17] Atkins T. (2019). Design of a partial depth wave screen to protect the Tawau Ferry Terminal, Malaysia. Australasian Coasts and Ports 2019 Conference, Hobart, Australia.

[18] Ariffin E. H., Yaakob M. A. M., Wei Sheng C., Muslim A. M., Zulfakar M. S. Z., Akhir M. F. & Awang N. A. (2020). The effect of coastal protections on the shoreline evolution at Kuala Nerus, Terengganu (Malaysia). Journal of Sustainability Science and Management, 15, 71-85

[19] Desa S. M., Karim O. A., Melini W. H., Mohamed A., Mohammad F. & Chatta I. (2016). Wave energy dissipation laboratory modelling of submerged breakwater for shoreline erosion control. Defence S and T Technical Bulletin, 9, 68-74.

[20] Ibrahim I. N., Razak M. S. A., Yusof & Desa S. M. (2020). The performance of narrow and broad-crested submerged breakwaters in dissipating wave heights. Jurnal Teknologi. 82. https://doi.org/10.11113/jt.v82.13974

[21] Ling S. Y., Veerasamy K., Hidayat Jamal M. & Razak M. S. A. (2019). Preliminary modelling assessment of hydrodynamic simulation due to Terengganu Airport runway extension. IOP Conference Series: Earth and Environmental Science, 357, 012036. https://doi.org/10.1088/1755-1315/357/1/012036

[22] Norzilah M. F. Ahmad A., Jusoh N. T., Yaacob R. & Muslim A. M. (2016). Hydrodynamics modelling at Setiu Wetland, Terengganu. Journal of Environmental Science and Technology, 9. 437-445. https://doi.org/10.3923/jest.2016

[23] Tay M. T. W., Mitchell S. B., Chen J. & Williams J. (2016). Numerical modelling approach for the management of seasonal influenced river channel entrance. Ocean & Coastal Management 130. 79-94. https://doi.org/10.1016/j.ocecoaman.2016.06.004

[24] El-Tahan M., Elsafty A. & Soliman A. (2020). Optimization of storm effect on breakwater construction for Egyptian north coast: A case study (Al-Mansoura New City). Journal of Environmental Science, Computer Science and Engineering & Technology 9(4). 631-642. https://doi.org/10.24214/jecet.C.9.4.63142

[25] DHI (2017). MIKE 21 spectral waves FM: Spectral wave module user guide.

[26] GlobOcean Sarl (2009). Study report: Wind and wave long term statistics (at selected locations in) Malaysia.

[27] DHI Water and Environment (2004). Detailed studies on Tuas view extension and Pulau Tekong land reclamation. Ministry of Foreign Affairs Malaysia and Ministry of National Development Singapore.

[28] National Hydrographic Centre. (2020). Tide Tables for Malaysia.

[29] https://webapp.navionics.com/

[30] Ibrahim I. (2020) Benteng pemecah ombak piramid selamatkan bumi Tanjung Piai. BH Online. https://www.bharian.com.my/kolumnis/2017/11/347912/benteng-pemecah-ombak-piramid-selamatkan-bumi-tanjung-piai