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CONCEPTUALIZATION OF SUBMERGED STRUCTURES AS TSUNAMI BARRIER

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Abstract : On December 26, 2004 a devastating tsunami struck the west coast of peninsular malaysia. The island of penang was one of the places that suffered from the disaster. Fifty seven people died in this area when most of them were enjoying their time on the beach. Many home appliances, several boats and fishing equipments were also destroyed in the area. In order to prevent similar damages from a possible recurring tsunami event, the steady-state spectral wave (stwave) model of surface water modelling system (sms) has been used to design a nearshore barrier to dissipate the tsunami wave energy in this study. The december 2004 tsunami was used as a reference case. Nearshore tsunami wave amplitude was obtained from field surveying data conducted on july 9-10, 2005. Whilst, offshore tsunami wave height and direction have been acquired from an output of tunami-n2 program. The model which has been calibrated against field survey data showed good agreement. Several breakwater layouts were simulated in the stwave model to derive an optimal configuration which could dissipate the tsunami wave energy before it reaches the penang island shoreline. From analysis made, it was found that eleven layouts reduced the tsunami wave heights by more than 70%. After extensive evaluation, breakwater layout number 39 was selected as the optimized layout showing the efficiency to reduce wave energy by 83%. At this efficiency, a wave height of 1.02 meter would impact the shoreline should a 6.0 m tsunami wave was made to propagate from offshore.

Keywords: *Tsunami; STWAVE; submerged breakwater; SMS Model, Penang Island*

1.0 Introduction

Tsunami is a series of waves generated when a large body of water such as an ocean or a lake displace rapidly. This natural phenomenon may be triggered by earthquakes, landslides, volcanic eruptions and even meteorite impact. The term “tsunami” is a Japanese word which means harbour waves and coined by fishermen who returned to port to find the area surrounding the harbour devastated, although they had not been aware of any wave in deep water (Rajendran 2005). Perhaps this natural disaster cannot be prevented but its result and effects can be reduced through proper planning.

Several methods have been adopted to provide protection from the Tsunami hazard. Fast evacuation from the coastal area after the earthquake can be the most important regional countermeasure to tsunami, although the elderly and young children could have difficulties to evacuate quickly (Haraishi and Harada, 2003). Constructing hard barriers such as breakwaters and seawalls are necessary in areas with high tsunami risk. The structure may assist to mitigate the incident wave by reducing its wave magnitude or decrease inundation on land and also current velocities. The energy of a tsunami wave, which is either dissipated on land or reflected when there is no structure, must be dissipated by the structure to reduce damage onshore.

For instance, in Japan where tsunamis are one of several major natural disasters and causes of many losses of human lives, infrastructures and properties, several hard and soft structures have been used to provide the necessary protection. Construction of a seawall in Taro and Yoshihama after Showa-Sanriku earthquake tsunami in 1933 and the construction of Tsunami bay-mouth Break Water (Ofunato) after Chile Earthquake tsunami in 1960 are two examples of using hard structures for tsunami protection. Besides the hard structures, vegetation in particular pine trees, have been raised as coastal protection measures in almost all tsunami affected areas in the northern part of Japan after the 1933 Showa Sanriku Tsunami (Edward et al. 2006).

Although hard structures such as seawalls and breakwaters have played important roles in protecting coastal areas from natural hazards such as a tsunami, they exhibit some disadvantages too. These include high cost of construction and maintenance, modification of the existing environment and inconvenience in optimally utilizing the coastal area for development (Harada and Imamura 2005). In order to reduce the negative impact of hard structures in its vicinity, natural barriers such as coastal forests or more environmental friendly structures such as submerged breakwaters may be applied. The application of submerged breakwaters as a tsunami barrier is highlighted in this paper where a concept is tested to design a tsunami barrier to the north of Penang Island.

2.0 Methodology

Submerged breakwaters are commonly used for coastal protection and erosion control at beaches. A desirable feature of submerged breakwaters (and low-crested structures, in general) is that they do not interrupt the clear view of the sea from the beach. This aesthetic feature is important for maintaining the touristic value of many beaches and it is usually one of the considerations in using such structures for shoreline protection (Prions et al 2004). The main idea of using this type of structure is to reduce the wave energy which is going to reach the beach by dissipating its energy over the structure. In other words, their purpose is to reduce the hydraulic loading to a required level that maintains the dynamic equilibrium of the shoreline. To attain this goal, they are designed to allow the transmission of a certain amount of wave energy over the structure by overtopping and also some transmission through the porous structure as in permeable breakwaters or wave breaking and energy dissipation on the shallow crest as at submerged structures (Pilarczyk 2003).

On the 26th of December 2004, a tsunami struck the West Coast of Peninsular Malaysia and killed 68 lives, caused injuries to hundreds of people and destroyed many properties and fishing equipment. Penang Island was one of the places affected by catastrophic tsunami. 52 people were killed in Penang where most of them were trapped while swimming and having a picnic on the beach. In total 615 houses, especially those made of wood were destroyed in Penang. Private vehicles were also damaged because of the intrusion of salt water and mud into the vehicles. The maximum height of the breaking wave when it arrived at the beach was reported to be as high as 6 m (Komoo and Othman 2006). The affected area is a tourist attraction area. The construction of seawalls and high crested breakwaters are not suitable for use as protection since they cannot preserve the touristic value of the area and may create several adverse impacts to the environment of the surrounding area. Therefore to prevent similar damages due to the recurrence of tsunami wave as mentioned above to the Island, the adoption of a submerged nearshore breakwater has been proposed for the area. Its effectiveness to dissipate similar damage by tsunami wave energy has been investigated through computer model simulation by using the STWAVE model of Surface Water Modelling System (SMS).

2.1 Stwave Model Setup

STWAVE is a steady-state finite difference numerical model which is based on the wave action balance equation and formulated on a Cartesian grid. Some of the governing equations which are used in STWAVE can be listed as follows:

The wave dispersion relationship is given in the moving reference frame as:

(1)

Where ω_r is the angular frequency (hz), g is gravitational acceleration (m/s²), k is wave number and d is the water depth (m). In the absolute frame of reference, the dispersion equation is:

(2)

Where U is current speed (m/s), δ is direction of the current relative to a reference frame or the x-axis (deg) and α is wave orthogonal direction or normal to the wave crest (deg). Refraction and shoaling are calculated from the conservation of wave action along a ray by using the following equation:

— ——————— — (3)

Where E is wave energy density divided by ($\rho w\ g$), where ρw is density of water, S is energy source and sink terms, C_{ga} is group celerity (m/s), μ is wave ray direction (deg), ωr is dispersion in moving reference, ω_a is dispersion in absolute frame of reference, α is wave orthogonal direction (deg) and C_a is wave celerity in absolute reference (m/s).Wave breaking is applied in STWAVE Version 3 by using the following equation as a maximum limit on the zero moment wave height.

(4)

Where L is wave length (m), k is wave number and d is water depth (m)

There exist thirteen places affected by tsunami in the western and northern parts of Penang Island. This study is limited to the area bounded between longitudes 100˚16′ E and 100˚18′ E and latitudes 5˚27′40″ N and 5˚30′ N. A rectangular grid is established based on Admiralty Chart No.1366, Approaches to Penang Harbour with a scale of 1:60000 published by Hydrographer of the Navy, United Kingdom (2002) which cover coordinates

(5˚25′ N, 100˚15′ E) to (5˚32′ N, 100˚15′ E) and (5˚32′ N, 100˚20′ E) to (5˚25′ N, 100˚20′ E). The wave height data is obtained from a tsunami field survey which was conducted on July 2005 by Yalciner et al (2005). The offshore wave height and the wave direction have been obtained from the output of TUNAMI-N2 program. This output data has been made available with courtesy from the Coastal and Offshore Engineering Institute of Universiti Teknologi Malaysia International Campus. Nearshore tsunami wave amplitude has been obtained from the 2005 tsunami field surveying data.

The model has been calibrated against field data which was obtained from the tsunami field surveying conducted on July 9-10, 2005 by Yalciner et al (2005). Field data at three points in the study area was available for use to calibrate the model as shown in Figures 1 and 2. The results of the calibration showed good agreement where the percentage differences between computed and observed wave heights at three points were found to be less than 15%.

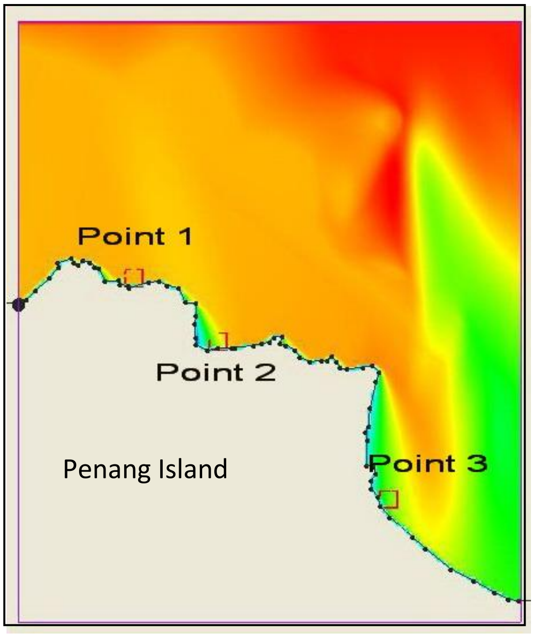

Figure 1: Points Used in the Calibration Works

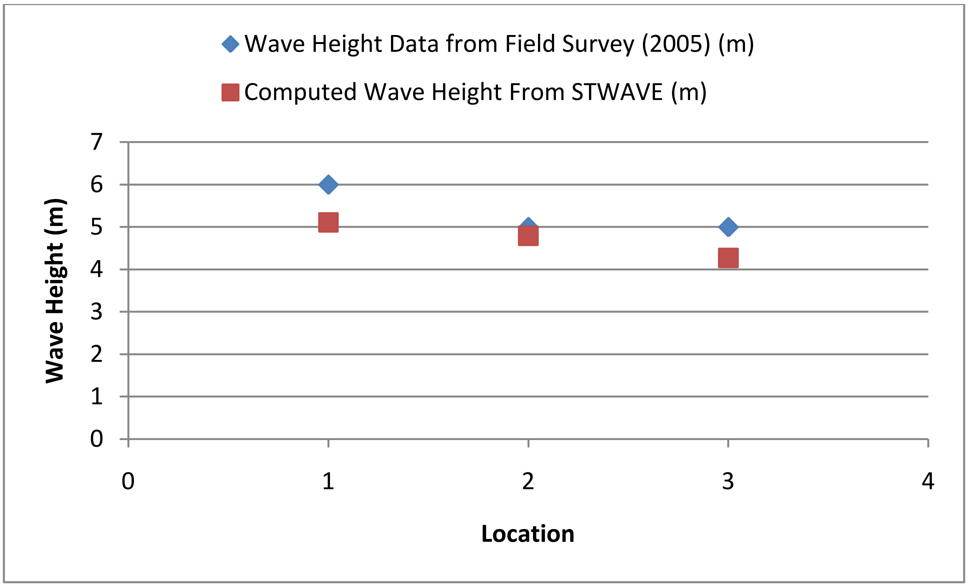

Figure 2: Plot Showing Observed and Computed Wave Heights at the Location Points

3.0 Discussion Of Computation Results

The STWAVE wave height distribution plot was relevant for use in this study. The main objectives of the study have been to design an optimised offshore breakwater layout and to determine the wave height distribution at the lee side of breakwater impacting on the shoreline. Therefore the following procedure has been employed to determine the optimal layout of the proposed breakwater which could function to appropriately attenuate tsunami wave energy along the North East coastline of Penang Island.

Once the calibration of the model has been completed, several breakwater layouts to be located around the study area were proposed for the modelling exercises. Thirty nine different breakwater layouts were tested and wave height distribution patterns around them were simulated in the model domain. The wave heights obtained at ten points along the shoreline were compared to that of the existing condition (that is, without the breakwater condition). The overall results obtained from the whole modelling exercise showed that, 11 layouts produced efficiencies where the reduction in wave heights at the shoreline was greater than 70% as shown in Table 1. The attenuation of the tsunami wave height at the shoreline for these layouts is illustrated in Figure 3 to 6.

Table 1: Details of the Tsunami Wave Heights at the Shoreline for Barriers which Performed at Greater than 70% Efficiency

	Without Structure	Layout 11	Layout 12	Layout 26	Layout 31	Layout 32	Layout 34	Layout 35	Layout 36	Layout 37	Layout 38	Layout 39
Point Number	Wave Height at Shoreline (m)	Wave Height at Shoreline (m)	Wave Height at Shoreline (m)	Wave Height at Shoreline (m)	Wave Height at Shoreline (m)	Wave Height at Shoreline (m)	Wave Height at Shoreline (m)	Wave Height at Shoreline (m)	Wave Height at Shoreline (m)	Wave Height at Shoreline (m)	Wave Height at Shoreline (m)	Wave Height at Shoreline (m)
1	3.500	2.039	1.679	0.939	1.509	0.600	1.070	0.540	0.949	0.949	1.559	0.689
2	4.710	2.339	1.909	1.090	1.639	0.730	1.429	0.680	1.230	1.220	1.759	0.860
3	5.099	1.789	1.470	1.029	1.269	0.959	1.809	0.860	1.289	1.289	1.350	0.484
4	5.050	0.940	0.959	0.709	0.829	0.200	1.179	0.340	0.949	0.959	0.959	0.293
5	5.170	0.400	0.209	0.019	0.019	0.007	0.310	0.310	0.939	0.949	0.600	0.680
6	5.090	0.670	0.560	0.419	0.230	0.009	0.550	0.310	0.879	1.000	0.529	0.790
7	5.190	0.610	0.569	0.550	0.569	0.119	1.529	0.389	0.930	1.169	0.490	0.939
8	5.190	0.740	0.649	0.629	0.610	0.449	1.830	0.519	1.050	1.389	0.610	1.090
9	5.289	2.150	1.940	2.029	1.759	0.879	1.080	0.910	1.220	1.759	1.019	1.129
10	5.329	2.780	2.589	2.710	2.490	1.470	1.539	1.470	1.659	2.220	1.600	1.299

Amongst these layouts, layout number 39 was selected as the optimal layout due to the following reasons:

(a) Segment A with a total length of 1236 m was placed 1 km from the shoreline in deep water in the model domain. Segment A is a partially submerged breakwater which is visible during low tide but it is located away from the shoreline to not affect the aesthetic value of the shoreline in the study area.
(b) Segment B with a total length of 1234 m is nearer to the shoreline being at 700 meter from shoreline. Since the freeboard is 2 meter below MSL the breakwater is totally submerged at all times and is not visible at all during the low tide.
(c) A 300 m gap between the two segments allows self circulation of water. During normal condition this gap may provide a safe passage for vessels manoeuvring around its lee.

Schematic diagrams of layout 39 are represented in Figures 7. Wave height distribution pattern around the breakwater as generated by STWAVE is illustrated in Figure 8.

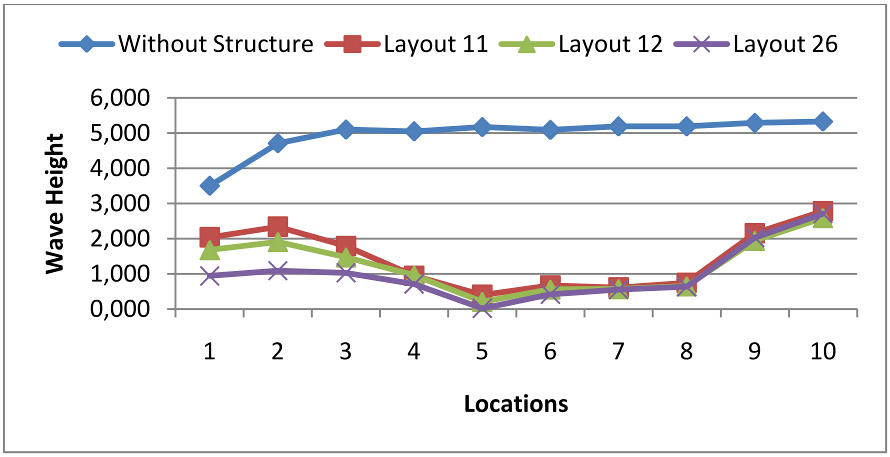

Figure 3: Attenuation of Tsunami Wave Height on the Shoreline for Without Structure and With Layouts 11, 12 and 26 Conditions

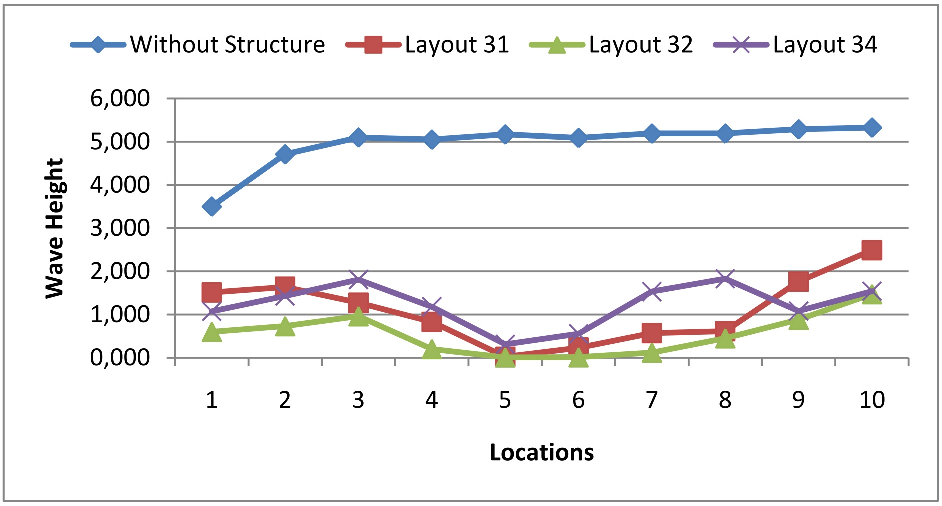

Figure 4: Attenuation of Tsunami Wave Height on the Shoreline for Without Structure and With Layouts 31, 32 and 34 Conditions

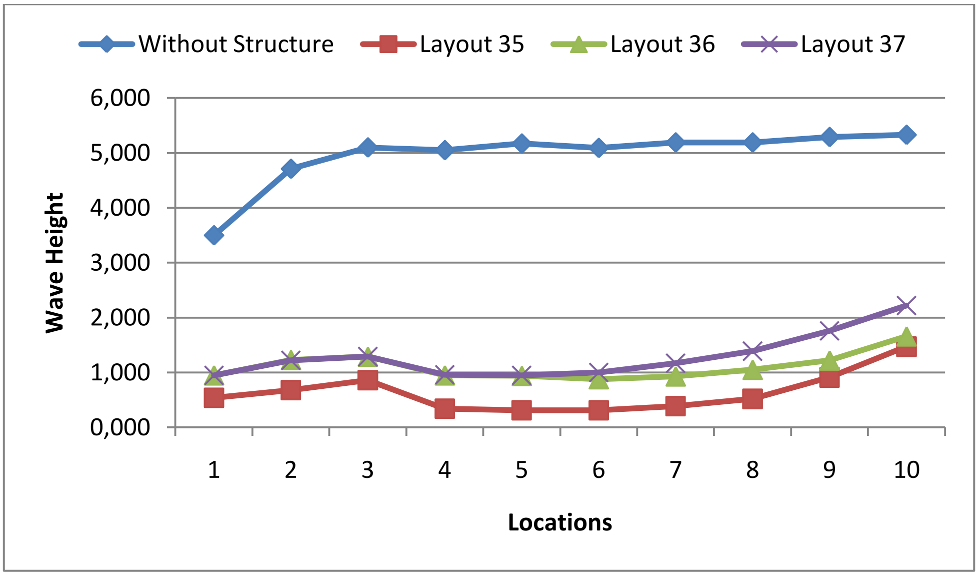

Figure 5: Attenuation of Tsunami Wave Height on the Shoreline for Without Structure and With Layouts 35, 36 and 37 Conditions

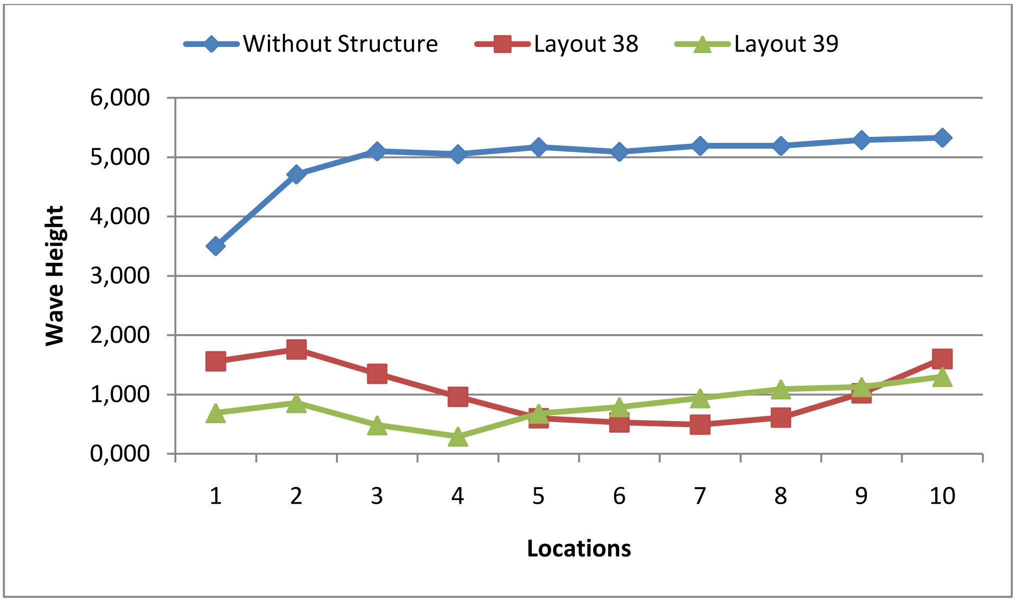

Figure 6: Attenuation of Tsunami Wave Height on the Shoreline for Without Structure and With Layouts 38 and 39 Conditions

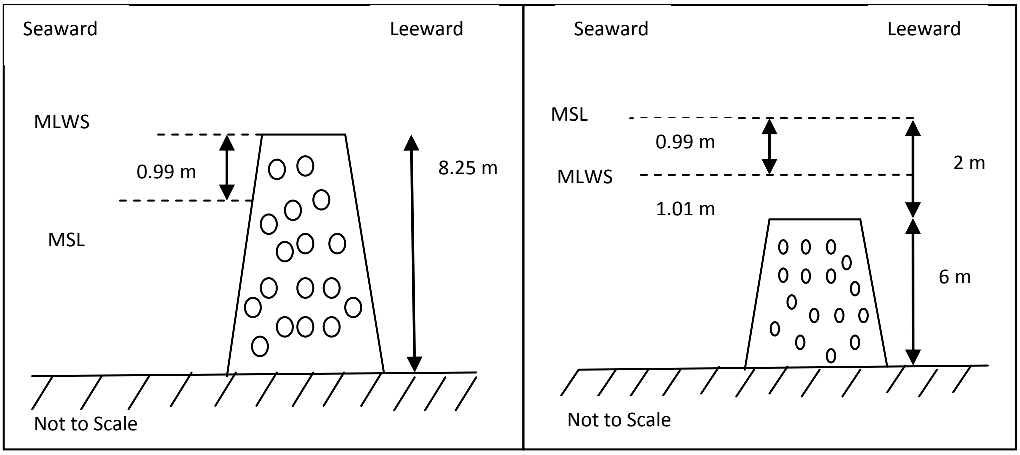

Figure 7: Cross Section of Segment A and B for Layout No.39

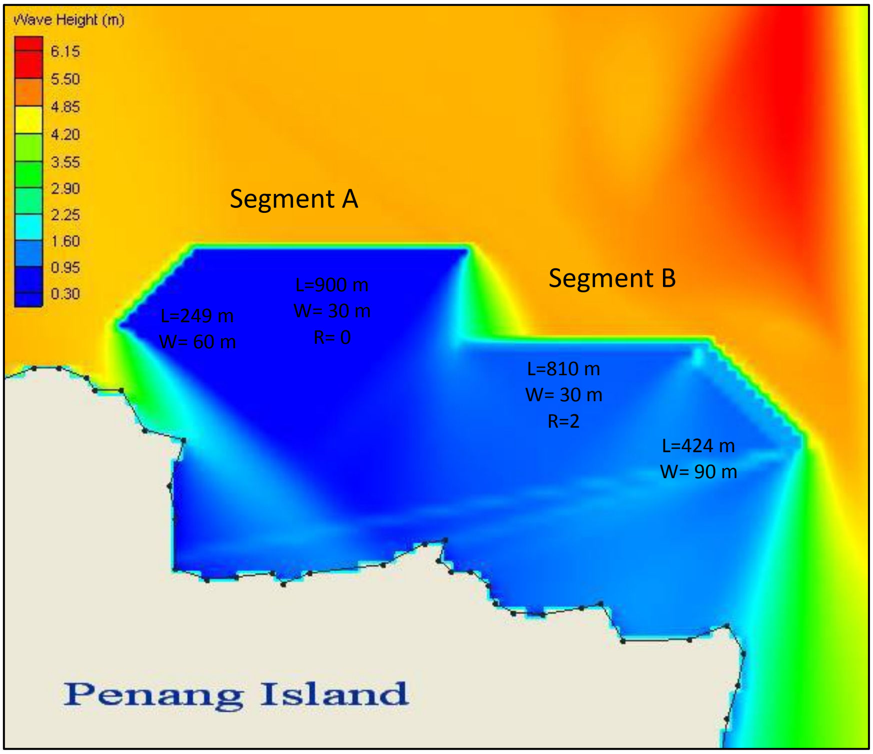

Figure 8: Distribution of Tsunami Wave Heights on the Shoreline with the Construction of Breakwater Layout 39

4.0 Conclusions

The Steady-State Spectral Wave (STWAVE) Module of the Surface Water Modelling System (SMS) has been applied to simulate the impact of a tsunami wave when directed towards the north of Penang Island. The model has been calibrated against field data which was collected during a tsunami field survey by Yalciner et al (2005) for three points in the study area.

A nearshore breakwater has been conceptually designed to dissipate tsunami wave energy. Thirty nine different layouts have been tested in the STWAVE model in order to find the most suitable conceptualized layout to construct in the study area. Eleven layouts showed that an efficiency of greater than 70% was obtained whereby the breakwaters managed to reduce the tsunami wave heights from a range of 0.6 to 1.5 meter at the shoreline. From the analysis, breakwater layout number 39 has been selected as the optimized layout in which the breakwater performed to reduce the tsunami wave height by 83%. The layout was also selected because it was thought that it would be able to preserve the aesthetic value of the study area better and provided sufficient safe passage for vessel movements to manoeuvre nearshore during normal wave conditions.

Acknowledgment

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