

# DESIGN OF A TSUNAMI BARRIER TO THE NORTH OF PENANG ISLAND

BAHMAN ESFANDIAR JAHROMI

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*To My Beloved Family*

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## **ABSTRACT**

On December 26, 2004 a major earthquake with a magnitude between 9.1 and 9.3 on the Richter scale occurred off the West Coast of Sumatra, Indonesia. This earthquake generated a devastating tsunami. Several countries suffered from the gigantic tsunami, many people died and many more lost their properties. The tsunami struck the West Coast of Peninsular Malaysia and killed 68 people and destroyed many properties. 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 an offshore 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 an efficiency at 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.

## ABSTRAK

Pada tanggal 26 Disember 2004, satu gempa bumi dengan magnitud antara 9.1 dan 9.3 pada skala Richter telah melanda pantai barat Sumatera, Indonesia. Gempa bumi yang kuat ini telah menyebabkan kejadian tsunami berlaku. Beberapa buah negara telah terkena tempias tsunami yang mana banyak kematian dan kemusnahan harta benda telah direkodkan. Malaysia juga tidak terkecuali daripada kejadian tersebut di mana tsunami telah menyerang pantai barat Semenanjung Malaysia, membunuh sebanyak 68 nyawa dan memusnahkan sebahagian harta benda. Pulau Pinang merupakan di antara negeri yang paling teruk dilanda gempa bumi ini di Malaysia. Lima puluh tujuh orang meninggal dunia semasa kebanyakan mereka sedang menghabiskan masa di kawasan perairan pantai. Bagi menangani kemusnahan yang hampir serupa daripada kemungkinan kejadian tsunami berulang, model komputer STWAVE (Steady-State Spectral Wave) yang terdapat di dalam pakej SMS (Surface Water Modelling System) telah digunakan untuk merekabentuk struktur airdalam bagi melemahkan tenaga ombak tsunami di dalam kajian ini. Kejadian tsunami pada Disember 2004 digunakan sebagai titik rujukan. Gelombang ombak tsunami dekat pantai telah diperolehi daripada data ukur tapak yang telah dilakukan pada 9-10 Julai 2005. Manakala ketinggian dan arah ombak diperolehi daripada hasil program TUNAMI-N2. Model yang telah dikalibrasi dengan data ukur tapak telah menunjukkan persetujuan yang baik. Beberapa konfigurasi pemecah ombak yang tenggelam telah disimulasi dengan menggunakan model STWAVE untuk menghasilkan konfigurasi optimal yang dapat melemahkan tenaga ombak tsunami sebelum menghampiri pantai di Pulau Pinang. Daripada analisis yang dilakukan, terdapat sebelas pelan pemecah ombak berupaya menghasilkan kecekapan melebihi 70% untuk melemahkan tenaga ombak tsunami. Pelan kedudukan pemecah ombak yang ke 39 telah dikenalpasti sebagai pelan konfigurasi yang sesuai untuk menyumbang sebanyak 83% kecekapan. Pada kecekapan ini, jika ombak tsunami setinggi 6 m di arahkan ke pantai, ketinggian ombak pada 1.02 m akan terhasil di kawasan pantai.

## TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	TITLE PAGE	i
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xi
	LIST OF SYMBOLS	xv
	LIST OF APPENDICES	xvii
<b>I</b>	<b>INTRODUCTION</b>	
	1.1 Tsunami	1
	1.2 Tsunami Barriers	2
	1.3 Available Computer Models for Wave Simulation	3
	1.4 Problem Statement	4
	1.5 Objectives of Study	6
	1.6 Scope of Study	7

<b>II</b>	<b>LITERATURE REVIEW</b>	
2.1	Tsunami	9
2.2	Causes of Tsunami Generation	11
2.2.1	Earthquakes	11
2.2.2	Landslides	15
2.2.3	Volcanic Eruptions	16
2.2.4	Meteor Impacts	17
2.3	Propagation of Tsunami Wave	17
2.4	The Interaction of Tsunami Wave with Structures	20
2.4.1	Submerged Breakwater	20
2.4.2	Wave Transmission over Low-Crested Structures (LCS)	24
2.5	The December 2004 Tsunami Event	27
<b>III</b>	<b>METHODOLOGY</b>	
3.1	Introduction	31
3.2	Design of the Rubblemound Breakwater	33
3.2.1	Breakwater Design Description	35
3.2.2	Design Parameters	35
3.2.3	Breakwater Design Procedure	36
3.3	Surface Water Modeling System (SMS)	40
3.3.1	Steady State Spectral Wave Model (STWAVE Model)	41
3.3.2	Model Assumption and Limitation	42
3.3.3	Governing Equation of STWAVE	44
3.3.4	Numerical Discretization	46
3.3.5	Model Input and Output Files	47
3.3.5.1	Model Parameter File	48
3.3.5.2	Bathymetry File	48
3.3.5.3	Incident Wave Spectra File	49

<b>IV</b>	<b>DATA COLLECTION AND STWAVE MODEL SETUP</b>	
4.1	Introduction	50
4.2	Data Collection	51
4.2.1	Bathymetric Data	51
4.2.2	Tsunami Wave Data	52
4.3	Generating Input Files	54
4.3.1	Application of Surfer Version 8.0	54
4.3.1	Application of Surface Water Modeling System (SMS) Version 8.1	56
4.4	STWAVE Model Calibration	62
<b>V</b>	<b>DISCUSSION AND ANALYSIS OF THE COMPUTATIONAL RESULTS</b>	
5.1	Introduction	65
5.2	Proposed Breakwater Layout and Optimization	66
<b>VI</b>	<b>CONCLUSIONS AND RECOMMENDATIONS</b>	
6.1	Conclusions	81
6.2	Recommendations	82
	<b>LIST OF REFERENCES</b>	83
	<b>LIST OF APPENDICES</b>	
	Appendix A	86



**LIST OF TABLES**

<b>TABLE NO.</b>	<b>TITLE</b>	<b>PAGE</b>
2.1	Summary of the ranges of parameters involved in 2D wave transmission tests at LCS	26
2.2	Damage and casualties due to the tsunami 2004 event	28
4.1	Results obtained upon calibration of the model	64
5.1	Details of various layouts generated to test for efficiency as modeled in STWAVE	67
5.2	Performance of proposed breakwater layouts to attenuate the tsunami wave height	71
5.3	Details of the tsunami wave heights at the shoreline for barriers which performed at greater than 70% efficiency	74

## LIST OF FIGURES

<b>FIGURE NO.</b>	<b>TITLE</b>	<b>PAGE</b>
1.1	Tsunami disaster in Pulau Pinang	5
1.2	Location of the study area showing the coastline to the North of Penang Island	7
2.1	Terminology of tsunami waves	10
2.2	Different types of faults which can generate an earthquake	12
2.3	Tsunami generated by a normal fault	13
2.4	Rough estimates of the tsunami parameters in the source versus earthquake magnitude using eqn. 2.1	14
2.5	Rough estimates of the tsunami parameters in the source versus earthquake magnitude using eqn. 2.2	14
2.6	Typical changes in tsunami wave as it reaches shallow water	18
2.7	Wave reduction caused by a submerged structure	21
2.8	Wave transmission over reef structure in Amwaj project	22
2.9	Wave propagation passing over (a) rigid mound (b) flexible mound	23
2.10	Definitions of governing parameters involved in wave transmission through LCS	25

2.11	Typical armour type for submerged breakwater used in Van der Meer et al's research works	26
2.12	Countries affected by the 2004 tsunami	28
2.13	Some of the tsunami affected areas in Penang	30
3.1	Flowchart of the proposed methodology	32
3.2	Parameters used in rubblemound design	36
3.3	Rubblemound section for seaward wave exposure with zero-to-moderate overtopping conditions	38
3.4	Rubblemound section for wave exposure on both sides with moderate overtopping conditions	39
3.5	Schematic grid of STWAVE	46
3.6	Schematic input/output files of STWAVE	47
4.1	Bathymetry map of study area	52
4.2	Offshore tsunami wave height generated using TUNAMI N2	53
4.3	Tsunami wave direction generated using TUNAMI N2	53
4.4	Application of SURFER to generate an ASCII XYZ file for the study area	54
4.5	Contour map of study area as generated by SURFER Version 8.0	55
4.6	3D seabed surface within study area as generated by SURFER Version 8.0	55
4.7	Wire frame map of study area as generated by SURFER Version 8.0	56
4.8	Window for opening the ASCII XYZ file in SMS	57
4.9	Window for registering the bathymetry map of the study area	58
4.10	Window to set the coverage type to STWAVE	59

4.11	Creating a polygon around the land	60
4.12	Map to 2-D grid window	60
4.13	Generated 2-D grid for the study area	61
4.14	STWAVE model control windows	62
4.15	Points used in the calibration works	63
4.16	Plot showing observed and computed wave heights at the location points	64
5.1	Typical outputs of wave heights generated by STWAVE for the existing condition without any structure	66
5.2	Distribution of wave height on the shoreline due to the presence of breakwater layout 1	69
5.3	Distribution of wave height along the shoreline due to the presence of breakwater with two arms	70
5.4	Distribution of wave height on the shoreline due to the presence of (a) layout 12 (b) layout 26 (c) layout 31 (d) layout 32 (e) layout 34 (f) layout 35	75
5.5	Distribution of wave height on the shoreline due to the presence of (a) layout 36 (b) layout 37 (c) layout 38 (d) layout 39	76
5.6	Attenuation of tsunami wave height on the shoreline for without structure and with layouts 11, 12 and 26 conditions	77
5.7	Attenuation of tsunami wave height on the shoreline for without structure and with layouts 31, 32 and 34 conditions	77
5.8	Attenuation of tsunami wave height on the shoreline for without structure and with layouts 35, 36 and 37 conditions	78
5.9	Attenuation of tsunami wave height on the shoreline for without structure and with layouts 38 and 39 conditions	78
5.10	Plan of the optimized breakwater for layout no.39	79

5.11	Cross section of segment A for layout no.39	79
5.12	Cross section of segment B for layout no.39	80
5.13	Distribution of tsunami wave on the shoreline with the construction of breakwater layout no. 39	80

## LIST OF SYMBOLS

$B$	-	Crest width
$B_t$	-	Toe apron width
$C$	-	Wave celerity
$D_{n50}$	-	Nominal diameter of armour rock
$d$	-	Water depth
$E$	-	Energy density in a given frequency and direction
$g$	-	Gravitational acceleration
$H$	-	Wave height
$H_e$	-	Water displacement
$H_i$	-	Incident significant wave height
$H_0$	-	Wave height at deep water
$H_r$	-	Wave run-up
$H_{r \max}$	-	Maximum tsunami run-up
$H_s$	-	Significant wave height in front of breakwater
$H_t$	-	Transmitted significant wave height
$h$	-	Water elevation
$h_c$	-	Breakwater crest relative to DHW / structure height
$h_t$	-	Depth of structure toe relative to still water level
$J$	-	Grid row index
$K$	-	Wave number
$K_t$	-	Transmission coefficient
$L$	-	Wave length
$L_0$	-	Wave length in deep water
$L_c$	-	Wave length on the crest
$L_h$	-	Wave length at the toe

$L_{om}$	-	Deepwater wave length corresponding to mean wave period
$L_{op}$	-	Deepwater wave length corresponding to peak wave period
$M_s, M_w$	-	Earthquake magnitude
$M_p, M_u$	-	Overturning moment around the heel
$N$	-	Total number of armour layer
$N_{od}$	-	Number of units displaced out of the armour layer
$N_s$	-	Number of wave
$N_s^*$	-	Spectral stability number
$P$	-	Notional permeability
$P$	-	Wave pressure
$R_c$	-	Crest freeboard
$R_e$	-	Effective radius
$S$	-	Arch length, Relative eroded area
$S_m, S_{op}$	-	Wave Steepness
$T$	-	Wave period
$T_p$	-	Peak period
$t$	-	Thickness of layers
$\tan \alpha$	-	Seaward slop of structure
$U$	-	Uplift force
$u, v$	-	Velocity
$W$	-	Armour unit weight
$x, y$	-	Orthogonal horizontal coordinate
$\alpha$	-	Front slope (seaside)
$\alpha_b$	-	Back slope (lee)
$\delta$	-	Direction of current relative to a reference frame
$\zeta, \eta^*$	-	Height of free surface above the still water level
$\zeta_{op}$	-	Breaker parameter
$\eta$	-	Wave elevation
$\rho_s$	-	Mass density of rock
$\rho_w$	-	Mass density of water
$\omega$	-	Angular frequency

**LIST OF APPENDICES**

<b>APPENDIX</b>	<b>TITLE</b>	<b>PAGE</b>
A	Details of the tsunami wave heights at the shoreline for all the proposed layouts	86



# **CHAPTER 1**

## **INTRODUCTION**

### **1.1 Tsunami**

Tsunami is a Japanese word which means a “harbour wave”. The first character (Tsu) means harbour and the second character (Nami) means wave. It is a series of waves created when a body of water is rapidly displaced. In the past tsunami waves were referred to as tidal waves by the general public and as seismic sea waves by the scientific community. Although a tsunami wave impact upon a coastline is dependent upon the tidal level at the time a tsunami strikes, it cannot be named as tidal wave since tides result from the imbalanced gravitational influences of the moon, sun and earth system.

Tsunami can be generated by many causes such as earthquakes, submarine landslides, volcanic activities, under water explosion and asteroid falls. Tsunami cannot be felt in the open ocean due to its long wave length but as it leaves the deep water and propagates into shallower water near the coast, it undergoes transformations, its speed reduces and its wave height increases. Perhaps this natural disaster cannot be prevented but its result and effects can be reduced through proper planning.

## **1.2 Tsunami Barriers**

Different types of breakwaters, seawalls and even soft structures may provide protection against tsunamis. It may decrease the inundation on land as well as reduce the current velocities and wave magnitude. However, structures may also have undesired effects on other areas (by reflection) or even on the area to be protected, because it may affect the resonant period of bays and harbours so that wave height increases instead of decreases. The energy of a tsunami wave, which is either dissipated on land or reflected when there is no structure, must now be dissipated by the structure (Van der Plas 2007).

Different types of structures which can be used for protection against tsunami waves include:

- (a) High-crested structures which have a crest-level that is at least comparable with the height of the tsunami such as:
  - Vertical walls
  - Rubble-mound structures
- (b) Low-crested and submerged structures (LCS) such as :
  - Detached breakwater
  - Artificial reefs

(c) Soft structures such as:

- Mangroves
- Sea grasses

### **1.3 Available Computer Models for Wave Simulation**

There are many different types of public domain and commercial software available which can be used for wave modelling such as SWAN and STWAVE model as well as CGWAVE model of the Surface-Water Modelling System (SMS). SWAN is a third-generation wave model which can be used for estimating wave parameters in coastal areas, lakes and estuaries from given wind, bottom and current conditions. It also can be used on any scale relevant for wind-generated surface gravity waves. This model is based on the wave action balance equation with sources and sinks (Delft University of Technology 2008). CGWAVE is a model developed at the University of Maine under a contract for the U.S. Army Corps of Engineers, Waterways Experiment Station. It is a finite-element model that is interfaced to the SMS model for graphics and efficient implementation. This model can be used for estimation of wave fields in harbours, open coastal regions, coastal inlets, around islands and around fixed or floating structures (Demirbilek and Panchang 1998).

STWAVE is a steady-state finite difference model based on the wave action balance equation and it is formulated on a Cartesian grid. STWAVE simulates depth-induced wave refraction and shoaling, current induced refraction and shoaling, depth- and steepness-induced wave breaking, diffraction, wind-wave growth, wave-wave interaction and whitecapping that redistribute and dissipate energy in a growing wave field (Smith et al 2001).

As mentioned in the previous paragraphs there are different types of models which can be used for this research. But owing to availability, only the STWAVE of SMS will be used for this research work.

## **1.4 Problem Statement**

Tsunamis are infrequent high impact events. They are among the most terrifying and complex physical phenomena which can cause a considerable number of fatalities, major damages and significant economic losses.

Horikawa and Shuto (1981) used tsunami damage official records to categorise the disaster caused directly by the tsunami. They summarized this into the following groups:

- (a) Death and injury.
- (b) House destroyed, partly destroyed, inundated or flooded and burned.
- (c) Property damage and loss.
- (d) Boats washed away, destroyed and run on the rocks.
- (e) Lumber washed away.
- (f) Marine installations destroyed.
- (g) Disastrous damage of public utilities such as roads, electric power supply installations and water supply installation.

Secondary damages that are indirectly caused by the tsunami can also be divided into four groups:

- (a) Burning houses, oil tank and gas stations
- (b) Drifting matter such as houses, lumber, boats, drums, automobiles and sea culture nursery rafts
- (c) Environmental pollution caused by drifting materials, oil, polluted sea bed and epidemic prevention
- (d) Traffic obstruction due to the destruction of roads and railways

On the 26<sup>th</sup> 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. Pulau Pinang was one of the places which was impacted by this disaster. According to reports from local residents, the tsunami waves hit several times between 1.15 pm and 1.30 pm local time. The maximum height of the breaking wave when it arrived at the beach was reported to be as high as 6 m. In total 615 houses, especially those made of wood were destroyed in Pulau Pinang. Private vehicles were also damaged because of the intrusion of salt water and mud into the vehicles (Komoo and Othman 2006).



**Figure 1.1** Tsunami Disaster in Pulau Pinang

Areas that were flooded included residential areas located on the lower altitude along the beach. According to a survey carried out by Komoo and Othman

(2006) all observed areas showed evidence of flooding, such as mud marks on buildings walls or mangrove trees, as well as damage to plants due to inundation. In the coastal area, flood levels reached up to 1.5 m. The flood water which contained mud damaged many agriculture and ornamental plants along the coastline.

To prevent similar damages due to the recurrence of tsunami wave as mentioned above to Pulau Pinang, the present research work will focus on undertaking a computer model investigation to design an offshore structure to dissipate the tsunami wave energy before it reaches the shoreline. In the present work the STWAVE module of SMS will be used due to its availability.

## **1.5 Objectives of Study**

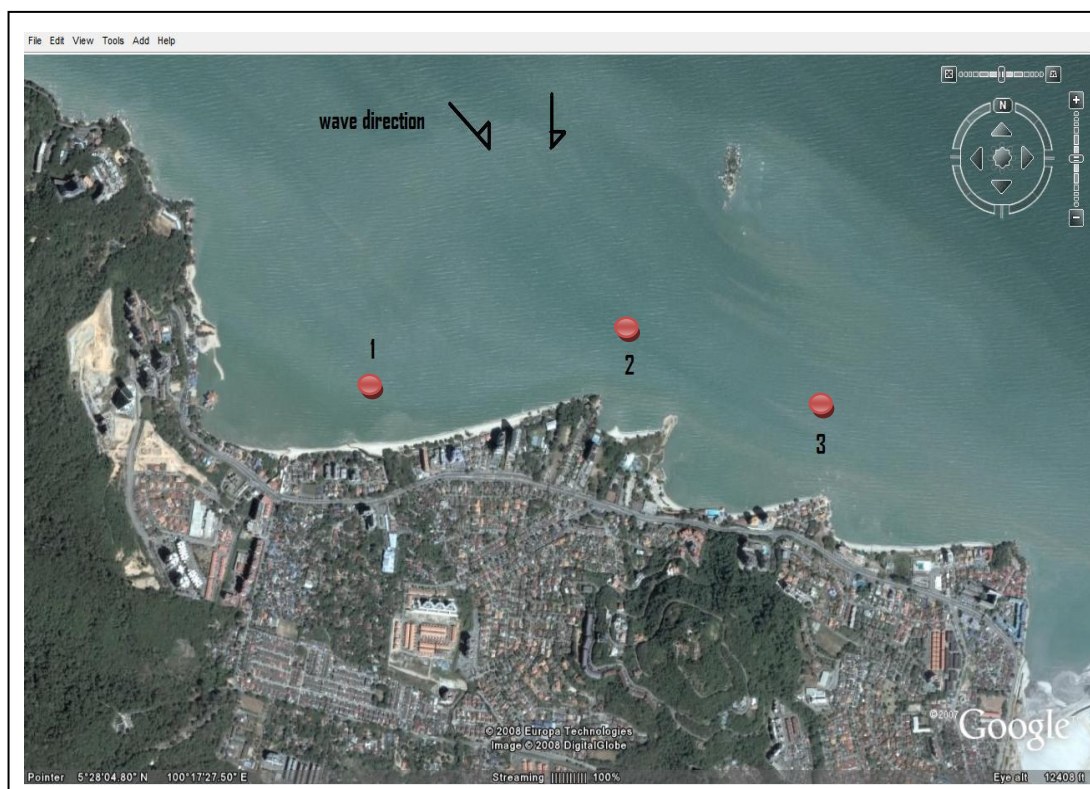
The objectives of this project are:

- (a) To determine and design an appropriate layout of an offshore barrier to dissipate the tsunami wave energy along the shoreline to the north of Penang Island.
- (b) To execute a computer model in particular the STWAVE module of Surface Water Modelling System (SMS) to evaluate the performance of the optimized structure layout in dissipating the tsunami wave energy.

## 1.6 Scope of Study

This study is limited to the following scope of work in order to meet the specified objectives:

- (a) To collect existing data and information relevant to the Study Area, that is the shoreline to the north of Penang Island.
- (b) To design offshore barriers to dissipate the tsunami wave energy at three points namely points 1, 2 and 3 as shown in Figure 1.2.
- (c) To evaluate the response of tsunami wave energy around the barrier by running a computer model typically the STWAVE model of SMS.



**Figure 1.2** Location of the Study Area Showing the Coastline to the North of Penang Island

The three points to be considered in the study area will include:

- Point 1: Point 1 which fronts a wide coastal area which is open and vulnerable to tsunami waves.
- Point 2: There are two headlands near this point from which waves can cause damage to the pocket beach.
- Point 3: This coast accommodates a residential area.