DESIGN OF A TSUNAMI BARRIER TO THE NORTH OF PENANG ISLAND

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A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Civil-Hydraulics and Hydrology)

Faculty of Civil Engineering
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JUNE 2009

To My Beloved Family

ACKNOWLEDGMENT

In preparing this thesis, I was in contact with many people, researchers, and academicians. I have been looking forward to this moment to be able to thank everyone whom has helped me to succeed in completing this thesis. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my supervisor, Assoc. Prof. Ir. Faridah Jaffar Sidek, for her encouragement, guidance and advice.

My sincere appreciation also extends to Mr. Ibrahim research engineer from the Coastal and Offshore Engineering Institute of Universiti Teknologi Malaysia for his comprehensive support and help and Mr. Radzuan Sa'ari, a lecturer of the Faculty of Civil Engineering at Universiti Teknologi Malaysia for his assistance and guidance on SURFER. My colleague, Mr. Shahrizal Ab Razak, who has provided assistance at various occasions should also be recognised for his support.

Last but not least, it is my pleasure to acknowledge my family whom have always been supportive. They have motivated me a lot during the completion of this Master Project. Their hope and encouragement have inspired me to complete this project successfully.

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 9.1dan 9.3 pada skala Ritcher 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) yaug 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 menggunkan 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.

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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,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
α	-	Front slope (seaside)
α_b	-	Back slope (lee)
δ	-	Direction of current relative to a reference frame
ζ,η^*	-	Height of free surface above the still water level
ζ_{op}	-	Breaker parameter
η	-	Wave elevation
ρ_s	-	Mass density of rock
ρ_w	-	Mass density of water
ω	-	Angular frequency

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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 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. 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.

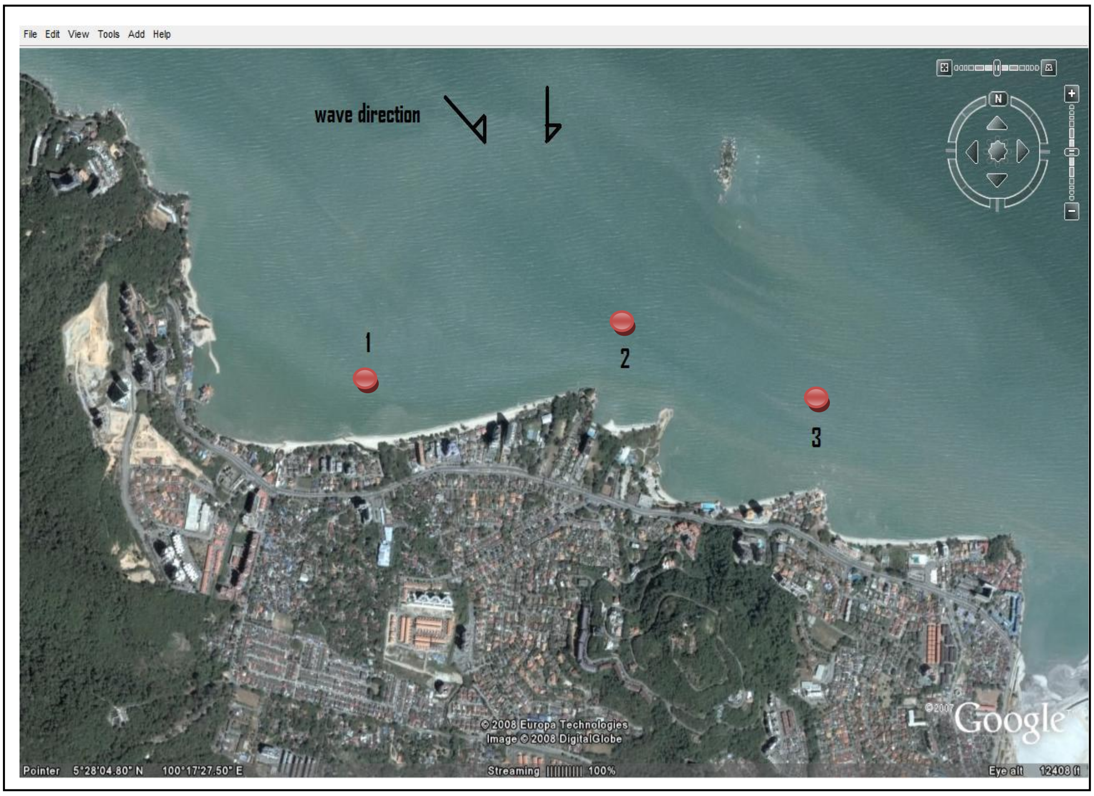

Figure 1.2 Location of the Study Area Showing the Coastline to the North of Penang Island

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.