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RAJAMANGALA UNIVERSITY OF TECHNOLOGY SRIVIJAYA

RESEARCH REPORT

(รายงานการวิจัย)

ON

THE UTILISATION OF BREAKWATER AND DESIGN OF ONE-STOREY HOUSE FOR TSUNAMI PRONE AREAS

(การใช้เขื่อนกันคลื่นและการออกแบบบ้านพักอาศัยชั้นเดียวสำหรับบริเวณเสี่ยงภัยสึนามิ)

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(ได้รับการสนับสนุนทุนวิจัยจากมหาวิทยาลัยเทคโนโลยีราชมงคลศรีวิชัย งบประมาณแผ่นดิน พ.ศ. 2558)

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คำนำ

งานวิจัยนี้ศึกษารูปแบบของบ้านพักอาศัยชั้นเดียวที่มีการปรับเปลี่ยนผนังด้านหน้าที่ต้องก่อสร้างบริเวณชายหาดซึ่งอาจเกิดคลื่นสินามิในขณะที่เกิดแผ่นดินไหว การปรับเปลี่ยนรูปแบบผนังก็เพื่ออาศัยหลักการทางวิศวกรรมในการลดแรงกระแทกจากคลื่นสึนามิ โดยหวังว่าจะยังคงตัวโครงสร้างหลักของบ้านหรือโครงสร้างไว้ได้ ถึงแม้ว่าโครงสร้างส่วนย่อยอื่นๆ อาจพังเสียหายไปบ้าง นอกจากจากการปรับเปลี่ยนรูปแบบผนังแล้ว ยังมีการยกระดับพื้นให้เหนือจากพื้นดินเพื่อเป็นการเพิ่มการลดแรงกระทำจากคลื่นอีกด้วย การตรวจสอบความแตกต่างของขนาดแรงคลื่นที่กระทำต่อบ้านแบบต่างๆ ทำได้โดยการติดตั้งสเตรนเกจเพื่อวัดค่าความเครียดและนำไปเปรียบเทียบกัน ผลการศึกษาพบว่า การสร้างบ้านให้มีช่องว่างตรงกลาง ร่วมกับผนังด้านหน้ามีความโค้ง และยกระดับพื้นให้เหนือพื้นดิน 1 เมตร สามารถลดแรงกระทำจากคลื่นได้สูงสุด ซึ่งผลดังกล่าวอาจนำไปสู่การออกแบบบ้านพักอาศัยในพื้นที่เสี่ยงภัยสึนามิได้

นักวิจัยได้เลือกภาษาอังกฤษสำหรับการเขียนรายงานวิจัยฉบับนี้ เนื่องจากวัตถุประสงค์หลักอีกอย่างหนึ่งของโครงการวิจัย คือ การนำผลงานวิจัยออกไปเผยแพร่ในระดับนานาชาติ ซึ่งหมายความว่าต้องใช้ภาษาอังกฤษเป็นภาษาหลัก ดังนั้นการเขียนรายงานวิจัยเป็นภาษาอังกฤษจะทำให้สามารถนำผลการวิจัยออกไปเผยแพร่ในระดับนานาขาติได้ทันทีไม่ต้องมีการเขียนใหม่เป็นครั้งที่สอง หรืออาจมีการปรับปรุงเพียงเล็กน้อยเมื่อมีข้อมูลใหม่เพิ่มเติมเข้ามา

อนึ่ง เนื่องจากภาษาอังกฤษไม่ใช่ภาษาแม่ของนักวิจัย ดังนั้นข้อผิดพลาดทางด้านภาษา เช่น หลักไวยกรณ์ต่างๆ อาจเกิดขึ้นได้ กรณีที่มีข้อผิดพลาดใดๆ ที่เกี่ยวข้องกับหลักการใช้ภาษาอังกฤษ ผู้วิจัยขอน้อมรับไว้แต่เพียงผู้เดียว

งานวิจัยครั้งนี้สำเร็จลงได้ตามแผนงานวิจัย ก็เนื่องจากว่าได้รับความช่วยเหลือจากหลายฝ่าย โดยเฉพาะในส่วนของงบประมาณโครงการ ซึ่งได้รับการสนับสนุนจากมหาวิทยาลัยเทคโนโลยีราชมงคลศรีวิชัย งบประมาณแผ่นดิน พ.ศ. 2558 ซึ่งผู้วิจัยขอกราบขอบพระคุณมา ณ ที่นี้ เป็นอย่างสูง

ABSTRACT

This research was concerned with the completely collapse of a house constructed on a beach that is prone to tsunami. During such incidents, huge waves travelling at a very fast speed would hit a house thereby causing it to either partial or complete collapse. A system was first designed and built in order to simulate the tsunami. It comprised a steel chamber housing a model sea and beach and a dropping weight that can be freely dropped into the sea to generate the tsunami. Two types of house forms were built to withstand such waves, including normal wall- and hollow wall house. Both had two types of front walls, including plane- and curve walls. In addition, there were two levels of slab experimented, on the ground and 1 m over the ground. To measure the effects of the wave on the house walls strain gauged were installed behind the walls. A total of 16 different house forms were tested in order to obtain a best solution in terms of minimising the wave forces acting on a wall.

Overall, it was found that between the normal wall- and hollow wall houses, the strain level generated by the latter was much lower. In addition, between the houses having the slab on ground and 1 m over the ground, it was observed that the former has lower stain level, owing to the waves could not reach the wall. Of all of the 16 test configurations, it was found that the hollow wall house with wall curves having the slab raised to 1 m above the ground has the best performance in terms of reducing the wave forces generated by simulated tsunamis. This result may be employed for future construction of a house to be constructed close to a beach that is very likely to be hit by a tsunami.

Keywords: tsunami, house form, strain gauge, wave forces, damage

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TABLE OF CONTENTS

NOTATION

A_w	Wetted area
b	Width of wall panel
E	Elastic modulus
F	Seismic load
F_b	Buoyant force
F_D	Buoyant force
F_h	Hydrostatic force acting on a panel
F_I	Impact force
F_s	Surge force
g	Gravity acceleration (9.81 m/s^2)
h_{max}	Maximum water height
h_w	Height of wall panel
m_b	Body wave magnitude
M_s	Surface wave magnitude
M_w	Moment magnitude
M_o	Seismic moment
p_c	Hydrostatic pressure at the centroid of the wetted portion of a wall
S, Fs, I, C, W	Factors affecting the seismic load
v_p	Wave speed for p-waves
v_s	Wave speed for s-waves
γ	Unit weight (kN/m^3)
ν	Poisson's ratio
ρ	Mass density (normally in kg/m^3)

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Research context

According to the theory, our planet earth has been created from the big bang for over 4,500 billion years ago. Since then, natural disasters have always been with her. Examples of the natural disasters are storm, flood, landslide, sinkhole, earthquake, and tsunami. In the past as the population was not as dense as present they were able to choose a place to inhabit in order to avoid encountering any potential disasters. For example, they tended to build a house far away from flooding paths, earthquake-prone areas, shorelines that were risky to tsunamis.

From the survey conducted by the United States Agency for International Development (USAID, 2012), it was found that in 2012 the world population was approximately 7 billion. However, in the next 40 years, the population would substantially increase to about 9 billion. It should be noted herein that 40 years ago there were only 2.5 billion people around the world. In the case of Thailand, the population in 1910 (BE 2453) was only 8 million. Then, the number was dramatically increased to 64, eight times of the year 1910 (Prasartkul and Wapattanawong, 2011).

These figures indicate that the population was always increasing. In the mean times inhabitant areas safely from the natural disasters are becoming scarce. This is mainly because as the population is increasing, more and more lands are needed for farming. In addition, the climate change phenomenon is causing the sea level to rise thereby reducing the once habitable areas in islands. This certainly contributes to why people are moving to live in risky areas.

There are several causes that could trigger a tsunami. They include landslides under the sea, falls of ice from land into the sea, and movements of faults under the sea. Please be noted that the movement of faults could trigger an earthquake as well. For all of those, the tsunami caused by an earthquake may be the most devastating disaster.

Even though Thailand is not located near the ring of fire in which the earthquake mostly occurs, it does not mean the country is safe from the tremor as well as the tsunami. This was evident in 2004 as the earthquake struck on the 26th of March under the sea off the coast of Sumatra, Indonesia. This event caused hugely devastated the countries extending from Southeast Asia, Indian Ocean, and East Africa, resulting in the dead of over 200,000. Thailand has a very long coastline, especially in the South. As such, there are some people living near the sea in order work as fisherman. Moreover, most of the beaches are very attractive to tourists, both Thais and foreigners, thereby creating lots of jobs for the people living there. For these reasons, it is almost impossible to relocate the people from the beaches that are prone to tsunami.

Any countermeasures for a tsunami must comprise several means. All of them require a large sum of money. It may be said that the best possible solution is a warning system that tell the people what to do when a tsunami strikes. It should be noted that, however, such system must be able to immediately give directions so that the people could react in time.

This research project aimed at finding a solution to prevent and reduce the damage caused by a tsunami to residential buildings. To achieve the aim the project studied the utilisation of discarded electric poles and tyres as underground breakwater. In addition, it also designed a form of one-storey house that could withstand or soften the wave force acting upon the structure.

Apart from preventing the damage to a house, the benefits of this project would be the utilisation of wastes such as discarded electric poles and tyres. This is because the Thai people are gradually becoming richer; thus, acquiring a car is a lot easier. This would results the huge amount of tyres to be discarded in the future. Thus, Thailand must investigate a way to manage such waste. Therefore, making use of discarded tyres would certainly improve the environment.

1.2 Research objectives

The following objectives were set to achieve the aims of this research project:

1) To investigate the characteristics of shoreline in the west coast of Thailand.
2) To study and construct a chamber that could contain a model shoreline and in the same time could simulate a tsunami.
3) To study and design a breakwater using wastes such as discarded electric poles and tyres.
4) To study and design a one-storey house that could reduce the wave forces acting upon its structures.
5) To propose a method and a form of one-storey house that is likely to withstand when a tsunami strikes.

1.3 Research methods

To achieve the aims of the research the first task was to obtain as much information related to this project as possible, especially a technique for simulating a tsunami. The methods for this research project were divided into steps as following:

1) Study and search the literature related to this project for the purpose of gathering information as much as possible. For example, a method for building a system that could simulate a tsunami.
2) Investigate the conditions of shoreline in the region of Pangnga and Phuket for the purpose of obtaining its characteristics such as slope and types of sand.
3) Build a chamber in order to contain a model shoreline as well as create a tsunami.
4) Design and construct a model one-storey house having various forms.
5) Design and build an underwater breakwater.
6) Experiment the capability of the house in terms of resisting the wave forces generated by the simulated tsunami.
7) Analyse the results obtained from 6).
8) Prepare a final research report.

1.4 Expected outcomes

This research is concerned with the damage done to small houses due to tsunamis. It hopes that after the research completed a form of the one-storey house constructed near tsunami-prone areas would be obtained. The form obtained would have the capability to withstand some low to moderate forces generated by a tsunami to reduce the damage might be induced. In addition, the behaviour of a house being hit by the waves would be obtained. This data may be helpful for designing and constructing a structure to undergo similar lateral forces. Furthermore, the results would be utilised to prepare a manuscript for internationally published so that other investigator would give some feedback. This would result in the enhancement of knowledge concerning tsunami forces acting on structure.

1.5 Outline of report

This report begins with chapter 1 giving some introductory remarks with respect to the importance for conducting this research project. It also includes brief methods employed to carry out the experiment and objectives of the research. All of the essential work and research related to this research were reviewed and summarised in our own understanding in chapter 2. This chapter also paves ways for conducting experiments in terms of providing the methods that other investigators had done.

Chapter 3 simply provides readers concerning material, methods, and test programmed to be carried out. The main aim of this chapter is to provide the information as accurate as possible so that others would be able to follow suite. After all of the test programmes done, their results are summarised in chapter 4. Also included in the chapter is discussion at which is one of the most important aspect of conducting research. This is because it would provide some insight knowledge why something happens. Then, it would be further enhanced by others to form a group of new knowledge. Chapter 5 traditionally concludes what this project has done and got. Also, some recommendations are also included so that one might be interested in doing similar work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

According to a widely excepted theory, the earth has been created for approximately 4,500 million years. At the beginning it was like molten rock. After a while in terms of geological time it cooled down, and the earth's crust was formed. Structurally, the planet earth comprises four layers: (1) crust, (2) mantle, (3) outer core, and (4) inner core, with respect to from outermost to innermost. Considering figure 2.1, it can be clearly seen that the crust is extremely thin compared with the overall diameter of the earth of about just over 12,000 km. In addition, it has long been evident that the crust varies between 5 and 80 km, depending on its location. For instance, a crust under the ocean is commonly thinner that those located on the continents.

Unfortunately, the earth's crust is not completely uniform; it actually consists of several plates connected together like a jigsaw, as evident in figure 2.2. It should be noted that those interconnecting plates have been coined plate tectonics. According to the theory describing the continental drift (Elnashai and Sarno, 2008), there are 15 major rigid plates forming the earth's crust. It were the plate boundaries that earthquakes mostly occur. As such, the boundaries have been called as seismic belt. There are three principle types of plate boundaries: (1) divergent or rift zones, (2) convergent or subduction zones, and (3) transform zones or transcurrent horizontal slip. All of the boundary types were schematically shown in figures 2.3 and 2.4.

When an earthquake strikes, we can feel from the shaking of the ground. If a major earthquake happens in populated areas, damage is foreseen. However, there are also other consequences generated by the earthquake. For example, if the earthquake happens under sea, a tsunami may be initiated owing to the movement of a fault.

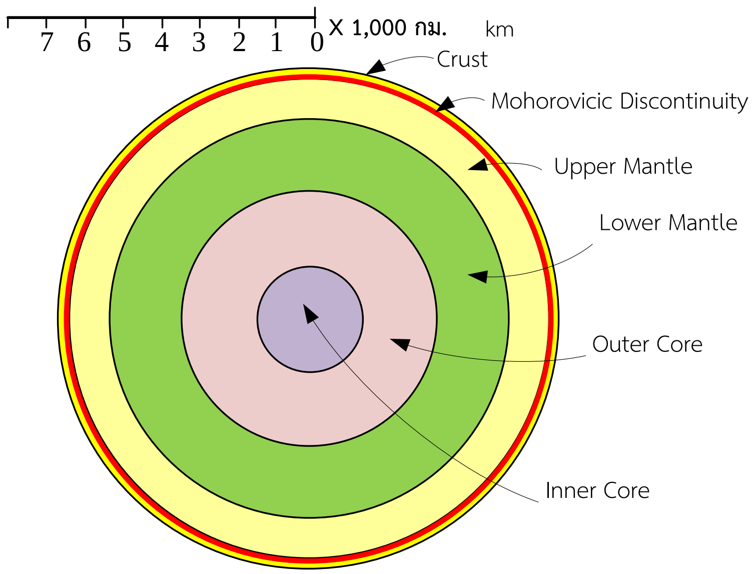

Figure 2. 1 Sections of the structural earth (Whitlow, 1995; Promputthangkoon, 2012)

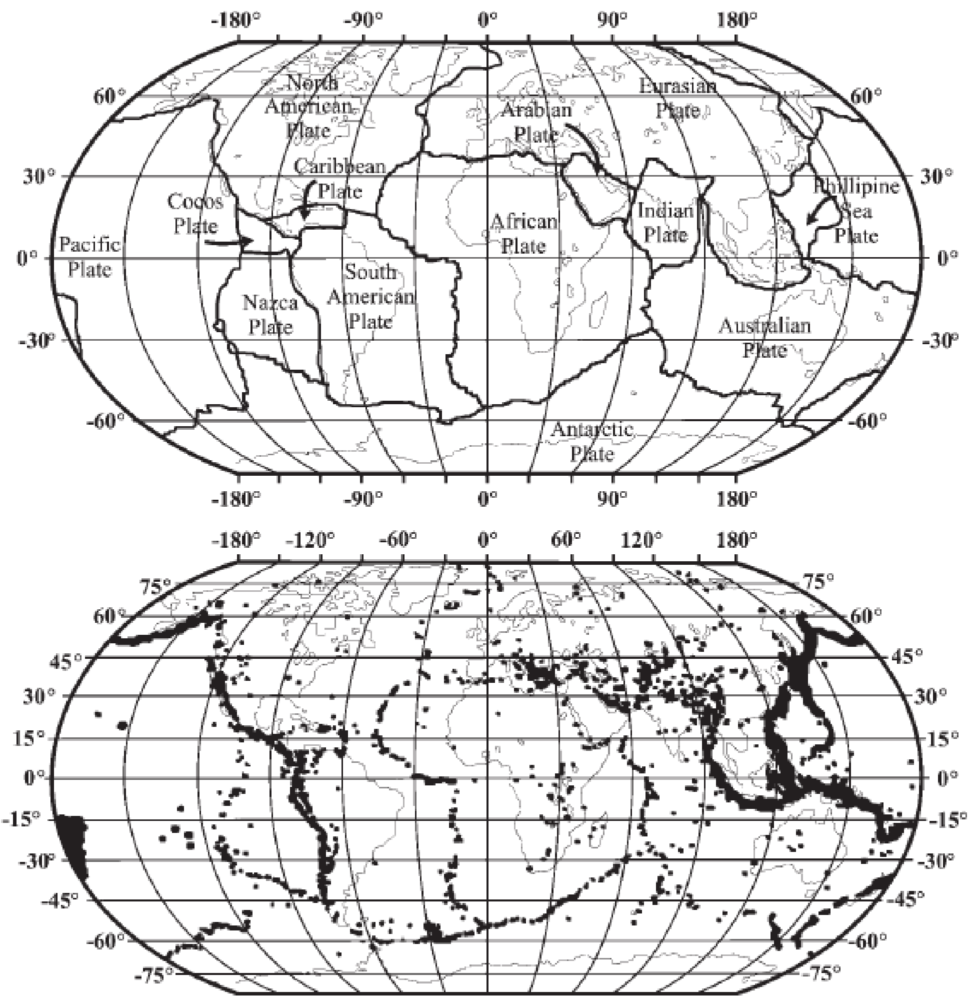

Figure 2. 2 Numbers of plate tectonic (top) and earthquake distribution (bottom) (Elnashai and Sarno, 2008)

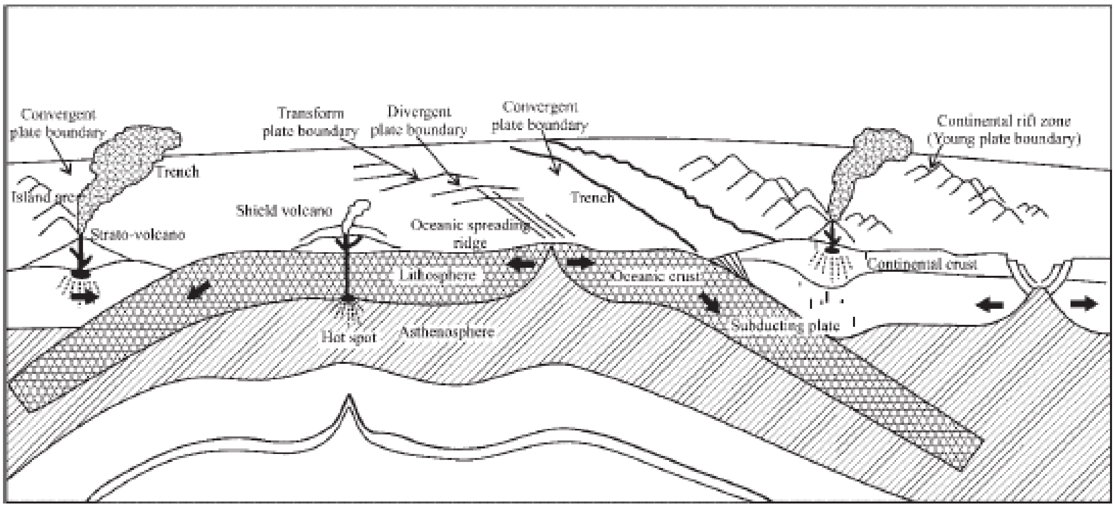

Figure 2. 3 The boundary types of the earth's crust (Elnashai and Sarno, 2008)

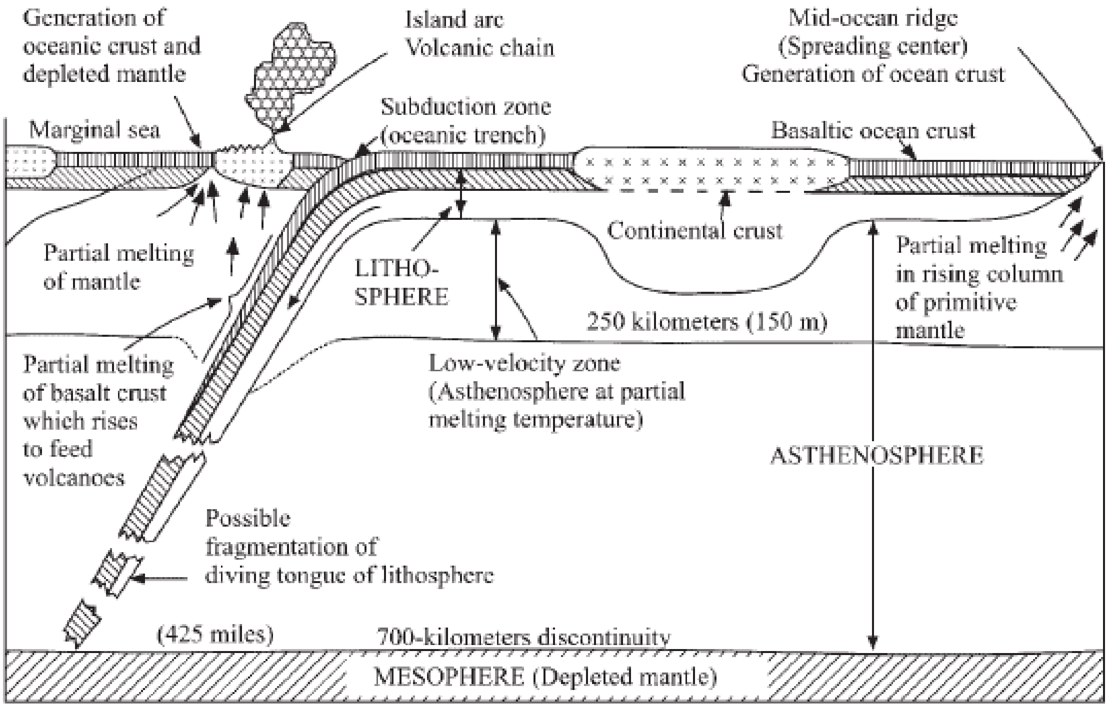

Figure 2. 4 Mechanisms of plate tectonics (Elnashai and Sarno, 2008)

2.2 Earthquake phenomenon

Earthquake is simply ground shaking. Even though it is widely perceived by most In summary, an earthquake may be triggered by one of the following (Bolt, 2004):human activities. For example, in the past some countries secretly experimented with nuclear bombs that were detonated underground. As such, during that period many seismic stations recorded the vibration caused by the underground explosion. They thought that they were some kind of earthquake incidents. Nonetheless, it has been generally acknowledged that the most disastrous earthquake is generated by the consequences of plate tectonics movement.

2.2.1 Sources of earthquake

In summary, an earthquake may be triggered by one of the following (Bolt, 2004):

1) Tectonic earthquake

The most disastrous earthquake in terms of destroying power, the tectonic earthquake is triggered by the consequence of the rapid release of energy accumulated along a geological fault and movement. It should be emphasised herein that this one occurs most frequently. In addition, it causes the most damage than any other kinds of earthquake do. Also, in terms of geological points of view, a seismogram obtained from an earthquake caused by plate tectonic movements can be used to study the earth's structure concerning its compositions and thicknesses. Even though most disastrous, unfortunately, with current knowledge and technologies we still cannot predict when and where it will strikes. This owes to the complexities of the structure of earth's crust and its movement.

2) Volcanic earthquake

It has been widely recognised that the earth is dynamics: it is constantly changing with time in terms of structure. This is because, even though hard at the surface, under the crust is simply molten rock. The magna always flows with respect to the varied temperature. Notice that this flowing has been coined as convection: heat transfer by mass motion of a fluid-like substance when the heated fluid is caused to move away from the source of the heat. The movement also increase the pressure of the molten rock resulting in its eruption to the surface.

The earthquake caused by an extreme volcanic eruption has been recorded since the ancient Greek by philosophers. It was shown that the vibration occurred both before and after explosions. It should be noted that, however, this type of earthquake is closely related to the plate tectonic movement. For example, as the plate tectonics are moving against each other the huge pressure is also being accumulated. Essentially, the pressure would be released through a volcano resulting in an earthquake.

3) Collapse earthquake

Considering its definition and explanation, any ground vibration could be regarded as earthquake. However, it is customary not to adapt the definition for very small to medium vibration. For example, vibration generated by traffic, machinery, and human activities should not be considered as earthquake. It should be noted that quit often we simply call it ground vibration. Nonetheless, in some cases the vibration may be large enough. For example, if a very big rocky mass falls off the cliff, the vibration may be felt for over long distance. This kind of vibration has been called collapse earthquake. The collapse earthquake is normally small- to mid-magnitudes. The causes may also be from the collapse due to underground mining activities.

4) Explosion earthquake

This type of earthquake may be said that it is created by human activities. For instance, underground mining has been regarded as one of the causes. In the past, underground nuclear experiments were the main cause. Please be noted that as the nuclear experiment in the past was highly secret, the vibration generated was thought to be an earthquake.

5) Impact earthquake

This earthquake is triggered by the means of impacting forces acting on earth. For example, a meteorite travelling at high speed impacts on earth would create a major earthquake.

2.2.2 Physics of earthquake

A plate tectonics earthquake is generally generated due to the accumulated energy at a fault is greater than the strength of the fault material. The point at which the energy begins to spread is called focus (foci for plural). If a focus is vertically projected to a point at the surface, such projected point is called epicentre. In Addition, the vertical distance between a focus and epicentre is termed a focal depth. The distance between a seismic station and the epicentre is termed epiccentral distance. These terms are schematically illustrated by figure 2.5. Notice that the seismic station normally employs a seismometer for measuring the ground vibration generated by earthquakes. To precisely locate an epiccentre point, at least three seismic stations are required.

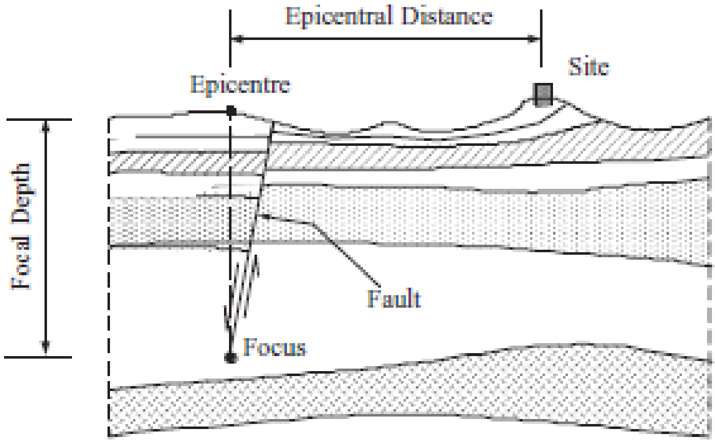

Figure 2. 5 Definitions of an earthquake (Elnashai, 2008)

When an earthquake does strike, there will be several types of stress wave travelling both inside and along the bed rock and soil strata. Those waves have been divided as (1) body waves and (2) surface waves. It should be noted herein that the vibration we experience during earthquake shaking is the mix of those stress waves.

The body wave that travels through the inside of the earth comprises (1) longitudinal waves, or primary waves, p-waves for short and (2) secondary waves, or s-waves. During travelling, the p-wave cause the bed rock to repeatedly compress and expand, as shown in figure 2.6. Please be noted that during the compression and extension, the rock still has the same shape. Thus, it may be said that the behaviour of the wave during travelling similar to those of sound wave. Therefore it would damage structure lightly. On the contrary, the s-wave travels through bed rock both laterally and vertically. These result in the shear stress generated within the medium it passing through. Sometimes, it is also called shear waves. It should be noted herein that it is the s-wave that causes the most damage to structures, compared to other waves.

The characteristics of the body waves greatly depend on the homogenous property, isotropy, and elastic modulus of a medium it passing through. The wave velocities due to p-waves and s-waves that travel through a material having the density ρ and poison's ratio ν can be calculated from the following equations:

$$\boldsymbol{\nu}_{\mathbf{p}} = \sqrt{\frac{\boldsymbol{E}(\mathbf{1}-\boldsymbol{\nu})}{\boldsymbol{\rho}(\mathbf{1}+\boldsymbol{\nu})(\mathbf{1}-\mathbf{2}\boldsymbol{\nu})}} \quad \textbf{Eq. 2. 1}$$

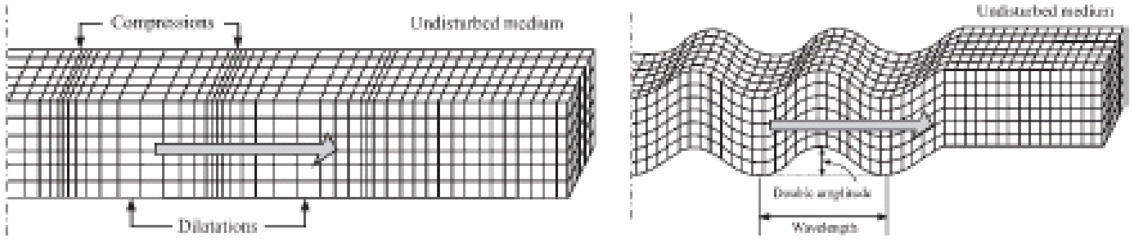

Figure 2. 6 Body wave paths (left) and secondary wave paths (right) (Elnashai, 2008; Bolt, 2004)

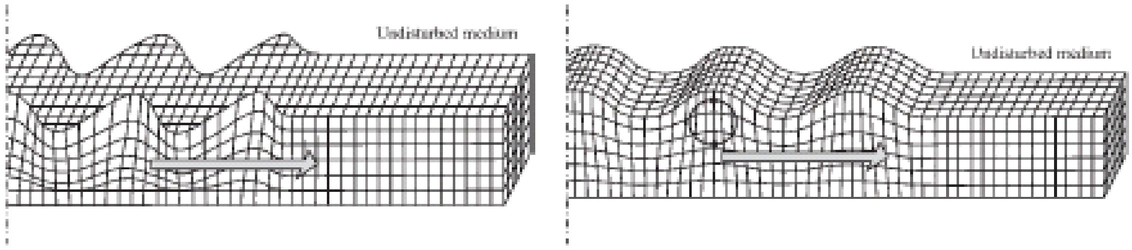

Figure 2. 7 Surface (love) waves (left) and Rayleigh waves (right) (Elnashai, 2008; Bolt, 2004)

$$\boldsymbol{\nu_s = \sqrt{\frac{E}{2\rho(1+\nu)}}} \qquad \textbf{Eq. 2. 2}$$

And, the relationship between ν_p and ν_s may be calculated from:

$$\boldsymbol{\frac{\nu_s}{\nu_p} = \sqrt{\frac{1-2\nu}{2(1-\nu)}}} \qquad \textbf{Eq. 2. 3}$$

For the surface waves, they travel through the earth's crust. Generally, these waves are generated from the interaction among the body waves, resulting in the surface waves travelling parallel to the earth's crust. They comprise (1) love waves, L or LQ and (2) Rayleigh waves, R or LR, as illustrated by figure 2.7.

Nowadays, there are several methods for describing a magnitude of an earthquake. It should be noted that in the past vibration levels were recorded by means of interviewing the people residing at different location affected by the shocks. Then, a map was created to display the levels of earthquake. This kind of map heavily depends on the feeling, not science. The logical and scientific methods for describing an earthquake's magnitude was summarised by Kramer (1996), as explained below:

1) Richter local magnitude

This method was developed by Charles Richter in 1935 by employing the Wood-Anderson seismograph for shallow earthquakes (less than 600 km). The magnitude calculated by this method has been called local magnitude. It should be noted that even though the method has been widely acknowledged by the majority of people; in terms of earthquake, however, it is not appropriated for being used in the design for earthquake resistance.

2) Surface wave magnitude

Because the Richter local magnitude does not differentiate the waves generated by an earthquake, for example surface and body waves, therefore this method was developed based on types of wave. This method employed the Rayleigh wave during the 20 s of vibration, and can be estimated from the following equation:

$$M_s = \log A + 1.66 \log \Delta + 2.0 \qquad \text{Eq. 2. 4}$$

when A is the maximum displacement of the ground and Δ is epicentre distance.

3) Body wave magnitude

This method employs the basis of p-wave magnitude to calculate according to the following equation:

$$m_b = \log A - \log T + 0.01\Delta + 5.9 \qquad \text{Eq. 2. 5}$$

when A is the magnitude of p-wave having the unit of micrometre (1/1000 m) and T is one-cycle period of the wave.

4) Other instrumental magnitude scale

This method is totally different to those already described. A magnitude by this method depends on devices and instruments used to measure the vibration levels during earthquake shaking.

5) <u>Moment magnitude</u>

It should be emphasised herein that all of the methods already described were developed based on data and observation. It has been found that, however, the earthquake magnitude actually does not increase corresponding to the level of energy released. For a major earthquake it was also found that the vibration data obtained from instruments is very slightly sensitive to an earthquake's magnitude. This phenomenon has been called saturation. Therefore this method was developed based on the assumption that a magnitude will not depend on the vibration level, and can be calculated from the following equation:

$$\boldsymbol{M_{\mathrm{w}} = \frac{\log M_{\mathrm{o}}}{1.5} - 10.7} \qquad \textbf{Eq. 2. 6}$$

when M_{o} is seismic moment having the unit of dyne-cm.

Anyhow, a structure must have some parts connected with soil. Therefore, the soil is a medium that transmits the earthquake shaking to the superstructure. Thus, it is vital to study the characteristics and properties of the soil when encountering the earthquake. These properties have been termed dynamic properties (Prakash, 1981) of which comprise:

(1) the shear strength of soil that depends on the rate of strain,
(2) dynamic properties, including elastic modulus, shear modulus, bulk modulus, and cohesive modulus,
(3) Poison's ration,
(4) damping, and
(5) variables with respect to the changes from solid to liquid of soil, for example, shear strain ratio, dynamic deformation, and changing of pore water pressure when loaded.

2.2.3 Consequences of earthquake

When an earthquake initiated, there will certainly be some consequences. First thing we would observe and experience is the ground vibration. It is such ground vibration that triggers several consequences. The most obvious consequence is the shaking of buildings, structures, bridges, and dams. Then, if there are people either inside or nearby those affected structures, injuries and even the loss of human lives are expected. In the current circumstance – every part around the world globally interconnected – economic turmoil is also anticipated. This section provides some examples concerning the consequences when an earthquake strikes so that one could comprehend the overall picture of the incident and its consequences.

1) <u>Effects on the ground</u>

The most obvious thing we feel when an earthquake happens is the ground shaking. If one is standing over the ground he/she will absolutely acknowledge what is going on. As geologist, he wants to know not only how strong the incident has caused but also what the origin of the earthquake is. In addition, the signals he has obtained would be very important in terms of having a good chance to study the inside of the earth. For geotechnical engineers, however, they are solely interested to the characteristics of the ground motions. Because such motions that cause the damage to structure. They have to comprehend those aspects because it is their job to design and construct a structure to withstand such disastrous phenomenon.

When ground vibration signals obtained, one of the most important task for engineers is the estimation of their strength. Hays (1980) summarised that the seismic design parameter for a particular site requires several information, including geological, geophysical, seismological, and geotechnical characteristics. In addition, statistical and deterministic models have to be developed. He also concluded that a total of seven steps should be carried out in order to specify the characteristics of the ground motion needed for earthquake resistant design (also shown in figure 2.8):

1) to determine the seismicity of the region in terms of geography where the application is going to be planned,
2) to identify the region seismtectonic features,
3) to estimate the local seismic attenuation,
4) to estimate the ground shaking parameters, for example, peak acceleration or Modified Mercalli intensity at the site,
5) to define and estimate the ground-motion response spectra for the site,
6) to determine the local amplification effects as well as to modify the design response spectra for the site as necessary, and
7) to estimate the uncertainty in the ground-motion design values.

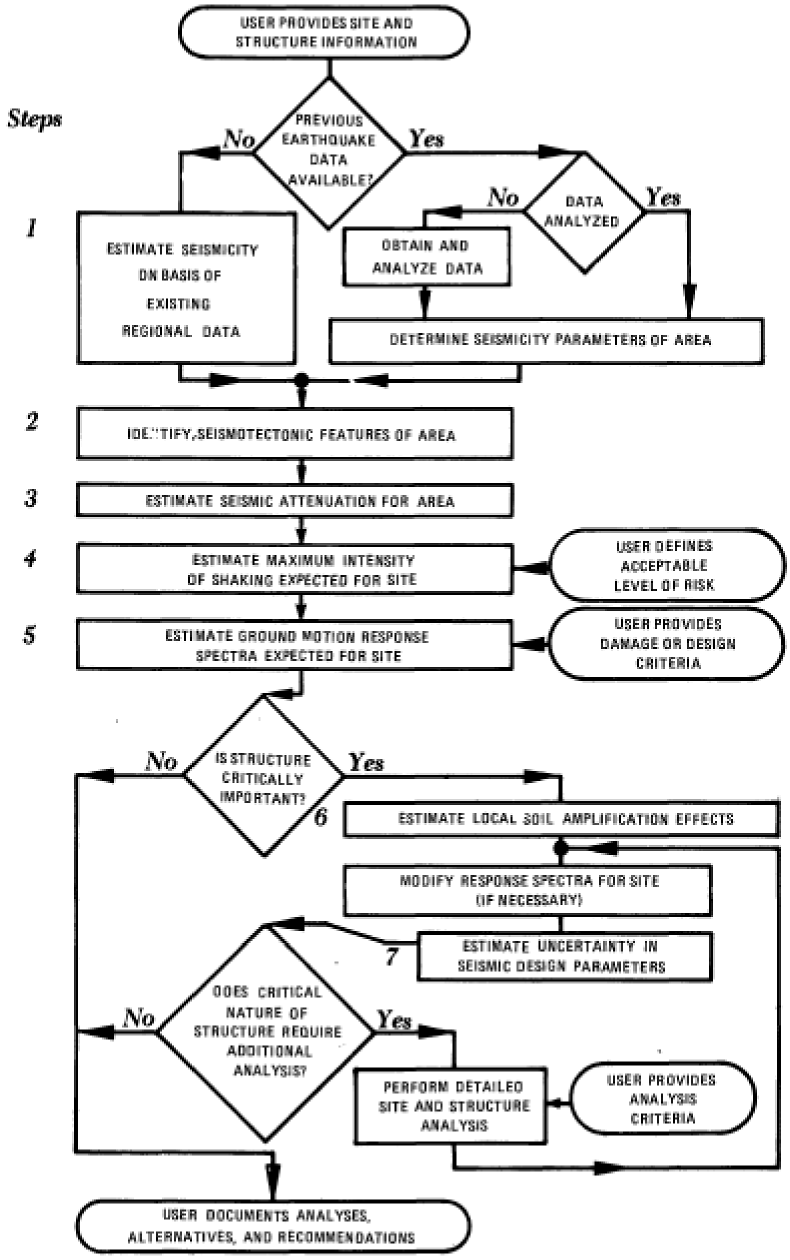

Figure 2. 8 Steps of estimating ground motions due to earthquake for earthquake resistant design (Hays, 1980)

There are two main methods for designing a structure to resist earthquake load: (1) equivalent static load, and (2) dynamic analysis method. The former has been widely employed for general earthquake design (Jardaneh, 2004). However, to be able to do that soil properties must be available. The other parameters required include an earthquake magnitude, predominant period, maximum acceleration and corresponding duration. Jardaneh (2004) presented the evaluation of those parameters by means of studying the past earthquake occurred in Palestine, and the utilisation of computer software called SHAKE (Idriss and Sun, 1992).

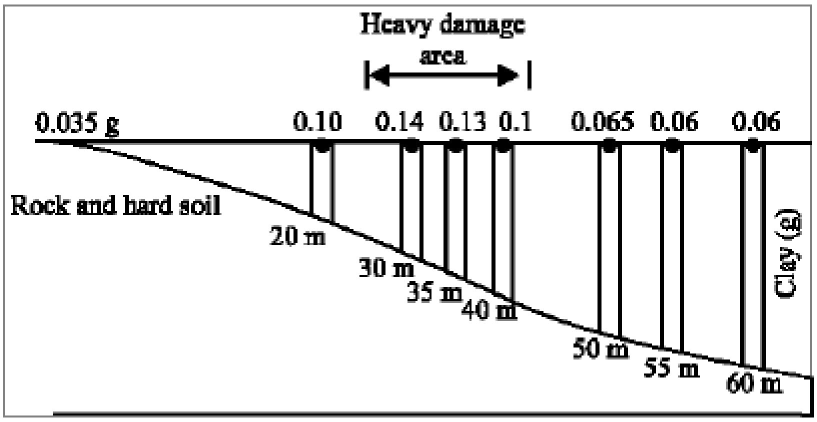

Figure 2. 9 Distribution characteristics of peak ground acceleration at surface for a typical soil profile (Jardaneh, 2004)

Jardaneh (2004) summarised that to obtain the ground surface response spectra three steps are required: (1) selection of earthquake motion, including design earthquakes for the region interested (2) evaluation of soil stratum conditions and their properties, and (3) calculation of response spectra. It should be noted herein that earthquake response spectra at the ground surface is highly affected by earthquake source conditions, including source-to-site transmission path properties and site conditions, rock properties beneath the site, and local soil conditions. These were demonstrated in figure 2.9 showing parts of Mexico City in the 1985 Mexico earthquake. From the figure, it can be seen that at the depth of 30 to 40 m the ground acceleration is significantly amplified. When the depth was 50 m and over, however, the acceleration was much lower than that of the original signal.

Figures 2.10 to 2.12 display the relationships between length of surface rupture (km) and earthquake magnitude, distance from fault and bedrock acceleration, and epicentral distance and predominant period, respectively. Those figures were employed by Jardaneh for developing the parameters needed for earthquake resistant design. There were two faults utilised in this study, namely Dead Sea and Al-Kamel faults. Their characteristics corresponding to earthquake shaking are summarised in table 2.1.

Next, Jardenah created an idealised soil profile concerning the local conditions for both faults, as illustrated by figure 2.13. With all of the information gathered, including earthquake characteristics and soil profile, the shear wave velocity V_S was formulated, as shown in the following equation

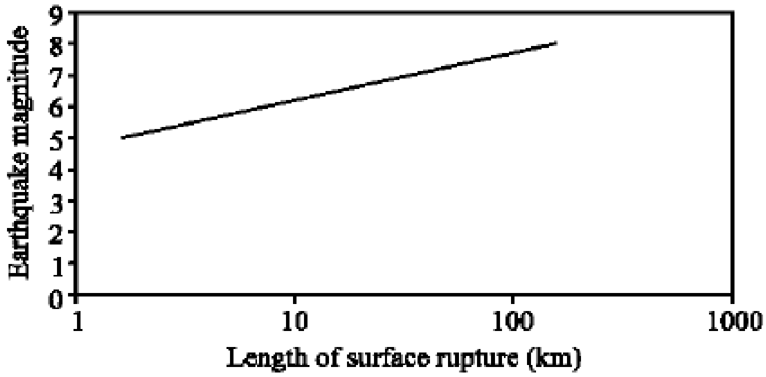

Figure 2. 10 Relationship between earthquake magnitude and the length of surface rupture (Jardaneh, 2004)

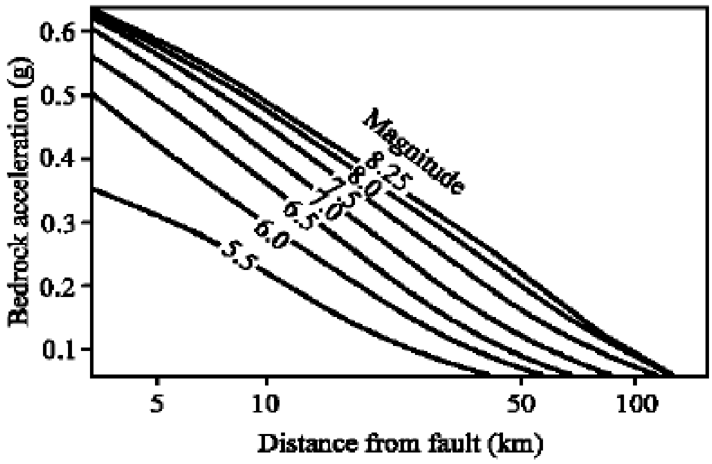

Figure 2. 11 Relationship between bedrock acceleration and distance from the faults (Jardaneh, 2004)

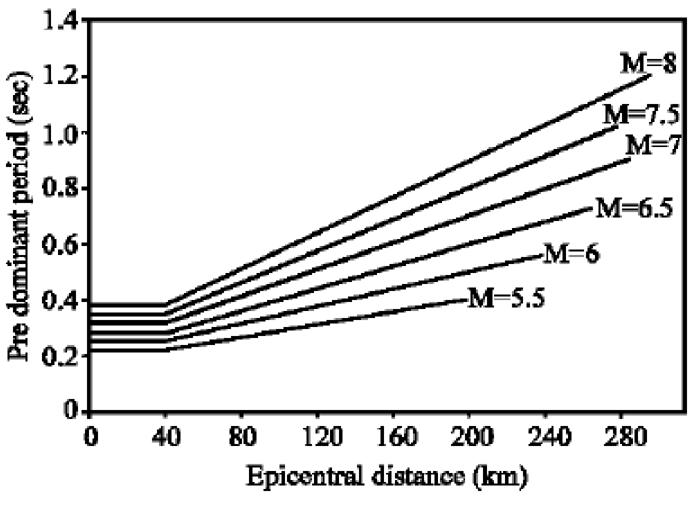

Figure 2. 12 Relationship between predominant period and distance from the faults (Jardaneh, 2004)

Table 2. 1 Earthquake characteristics at the bedrock (Jardaneh, 2004)

Fault name	Earthquake magnitude	Duration (s)	Maximum acceleration (g)	Predominant period (s)
Dead Sea	7.4	45-00	0.16	0.37
Al-Karmel	7.2	45-50	0.30	0.33

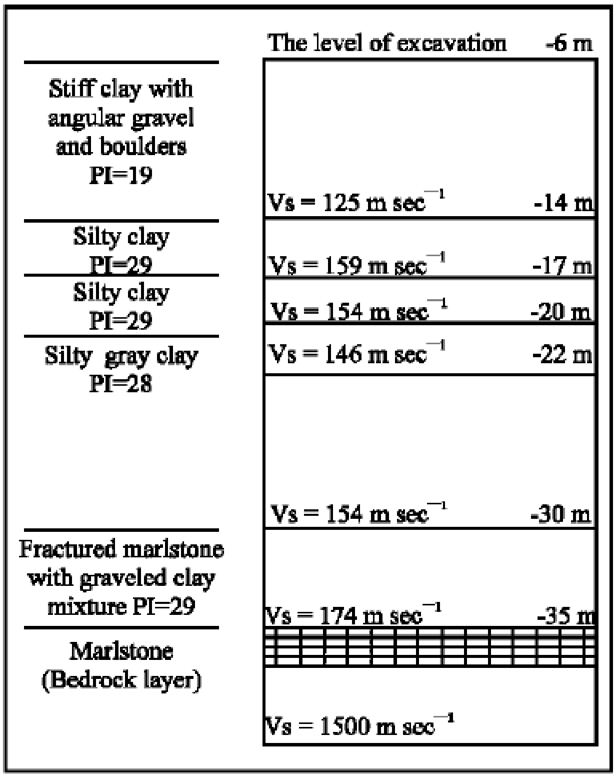

Figure 2. 13 Soil profile for the analysis (Jardaneh, 2004)

$$V_s = \sqrt{\frac{9.81E}{2\gamma(1+\upsilon)}} \qquad \textbf{Eq. 2. 7}$$

where V_s is shear wave velocity (m/s), E is elastic modulus (kN/m^2), is Poisson's ratio, and γ is soil unit weight (kN/m^3). After all of those information obtained and steps done, a computer program such as SHAKE can be employed to analyse and generate the response acceleration spectrum, as shown in figures 2.14 and 2.15, for further earthquake analysis and design.

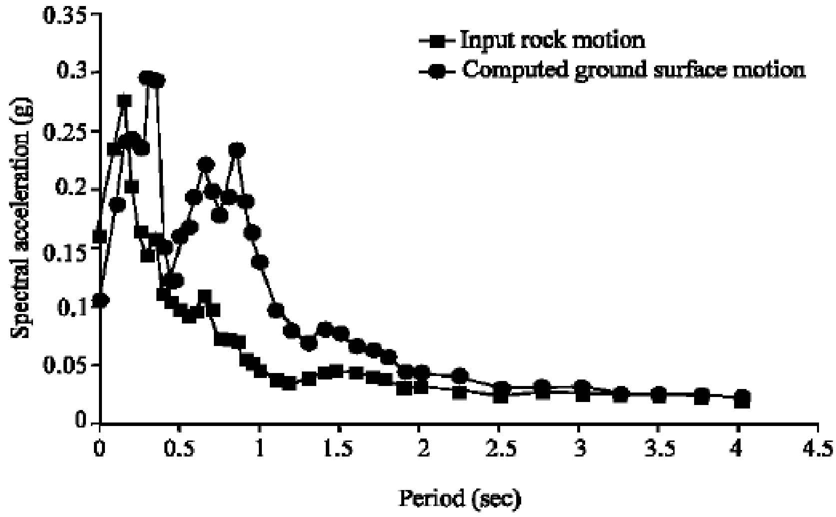

Figure 2. 14 Response spectral acceleration for ground surface motion compared with rock motion for the Dead Sea Fault (Jardaneh, 2004)

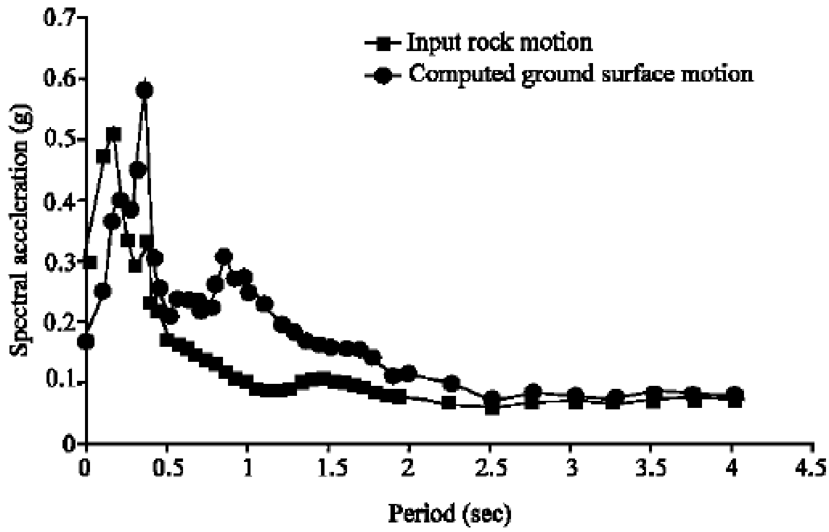

Figure 2. 15 Response spectral acceleration for ground surface motion compared with rock motion for the Al-Karmel Fault (Jardaneh, 2004)

2) <u>Effects on superstructures</u>

The transmission of both surface and body waves generated by an earthquake through the ground causing it to vibrate. If a structure built over such ground there will certainly be some shaking transmitted to the structure. This results in the structure to vibrate thereby creating some inertia. It is such inertia force that affects the behaviour of the structure when encountering an earthquake. In addition, it should be emphasised herein that those extra force must be included in the analysis and design of a structure to be constructed in an earthquake-prone area. Notice that the inertia force generated by an earthquake has been called as seismic force.

Buildings and structures are generally fixed to the ground, as shown in figure 2.8; thus, as the base moves due to earthquake shaking its structural components also move and vibrate. The problem arises because their movement is almost impossible to predict in terms of both magnitude and direction. As shown in figure 2.8, when the structural components vibrate seismic forces are generated. It should be noted that the earthquake loads are dynamic in nature. However, ones may employ the following equation to estimate an extra load crated by an earthquake

$$\boldsymbol{F} = (\boldsymbol{S})(\boldsymbol{F_s})(\boldsymbol{I})(\boldsymbol{C})(\boldsymbol{W}) \qquad \textbf{Eq. 2. 8}$$

where F is seismic load, $(S), (F_s), (I), (C), (W)$ are factors affecting the seismic load (can be found in IEAA, 2004). The factor S depends upon the ground density of an earthquake. For the factor F_s, its value depends upon the ration fundamental elastic period of vibration of a structure in the direction under consideration and the characteristic site period. The occupancy importance of hazard factor I depends upon the usage of a building. While the factors C and W depend on the stiffness an damping of a structure, and the total weight of a superstructure, respectively.

Because the horizontal seismic forces are reversible in direction, structural elements such as walls, beams, and columns that normally carry only vertical loads now have to carry extra horizontal loads, as illustrated by figure 2.16. Thus, it follows that the design must consider the strength both being tension and compression. In order to successfully design a structure to withstand an earthquake, its failure mechanism must first be appreciated. Figure 2.17 schematically illustrates the failure characteristics of a free standing wall. It can be seen that when the transverse earthquake acting the wall tends to be overturned. Because the overall strength of a wall depends very much on just mortar, therefore the wall will definitely break and fail. In the case of wall enclosure but without roof, as displayed in figure 2.18, it can be seen that for the X direction of force walls B act as shear wall, besides already taking their own weight. In addition, they also provide some resistance against the wall A as well. Figures 2.19 and 2.20 show a roof sitting on vertical walls. If the strength of the roof is enough, it would transfer some inertia to the walls thereby creating the diaphragm behaviour.

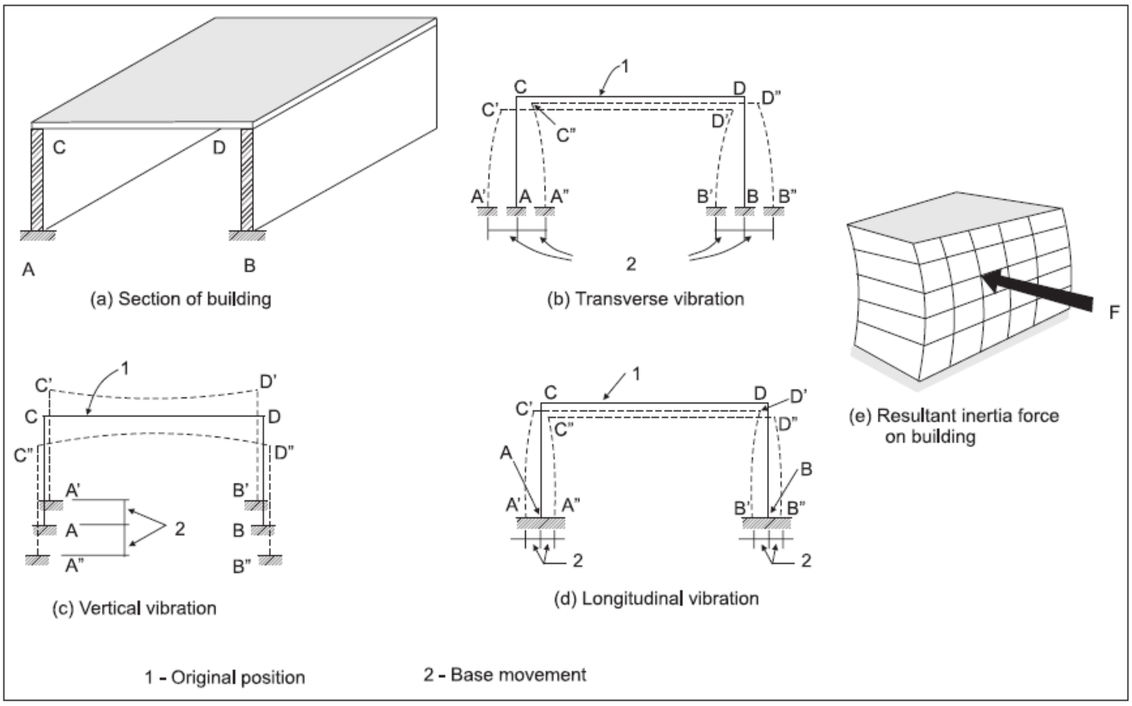

Figure 2. 16 Seismic vibration of structures and resultant seismic force (IAEE, 2004)

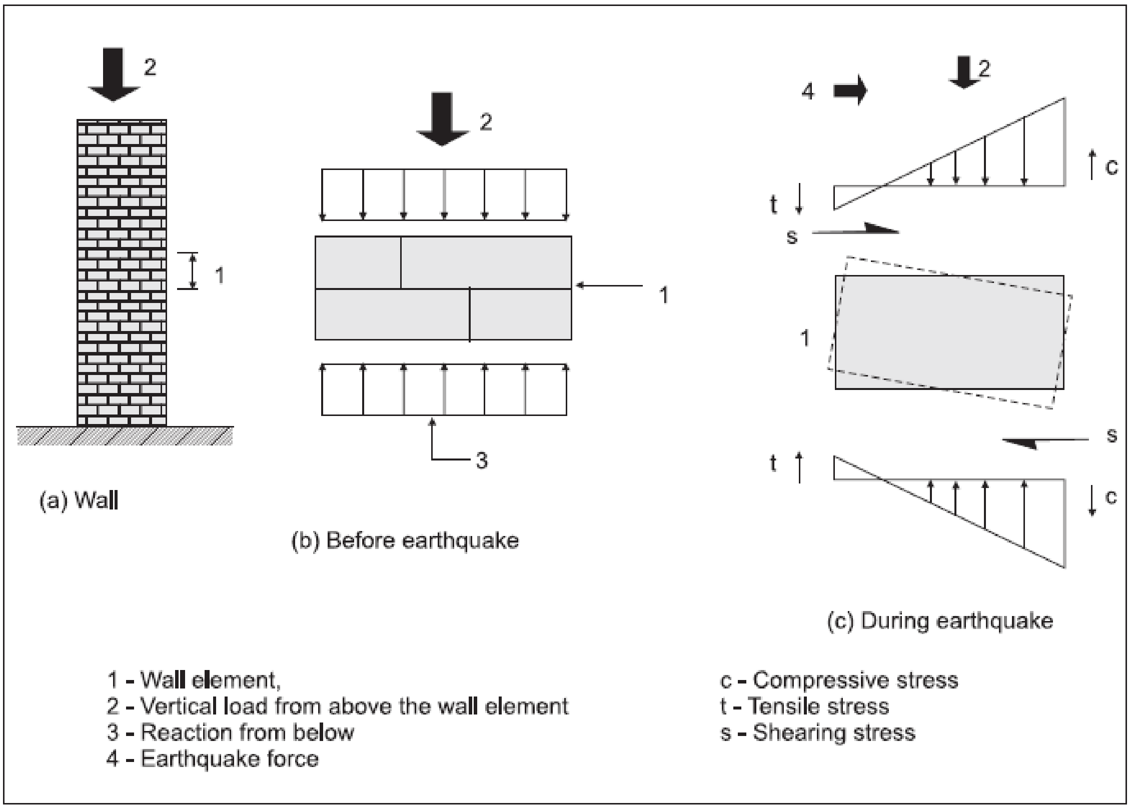

Figure 2. 17 Stress conditions for a wall during earthquake shaking (IAEE, 2004)

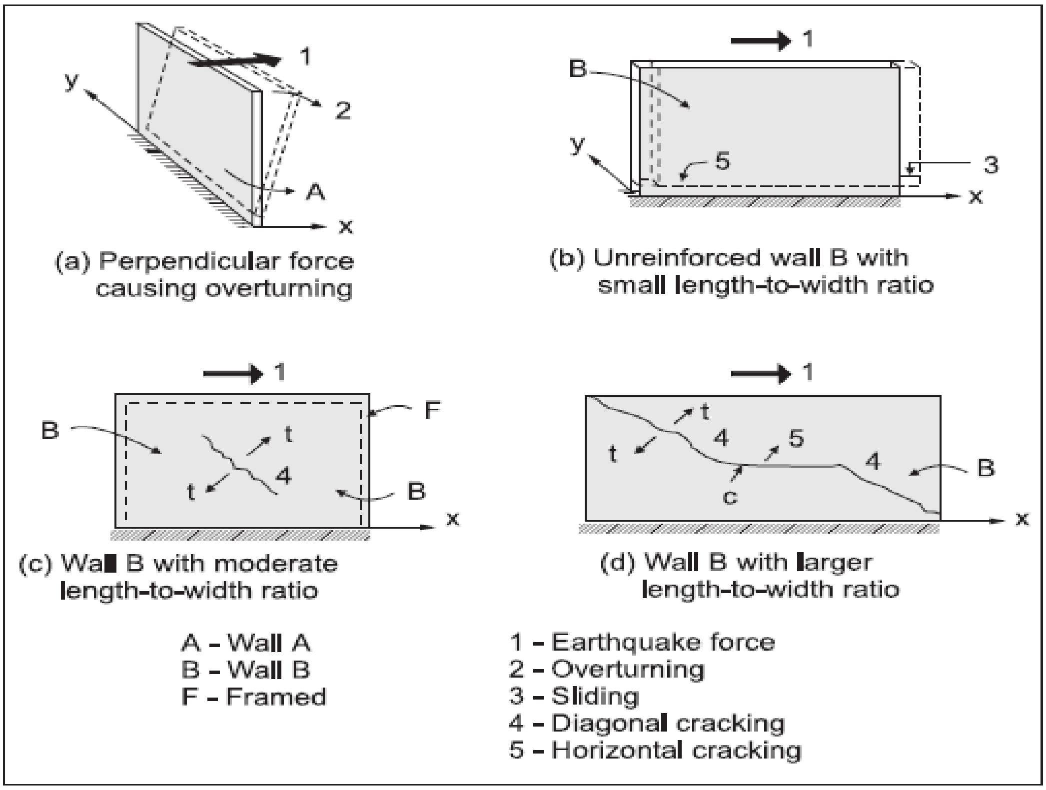

Figure 2. 18 Failure characteristics of free standing walls (IAEE, 2004)

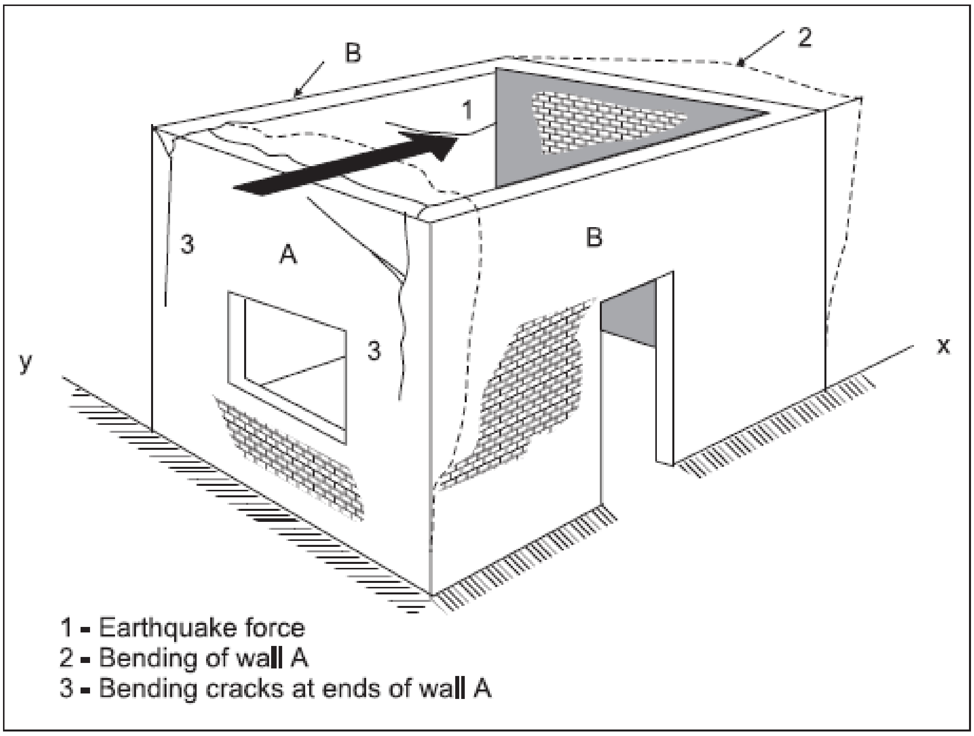

Figure 2. 19 Failure mechanism of wall enclosure without roof (IAEE, 2004)

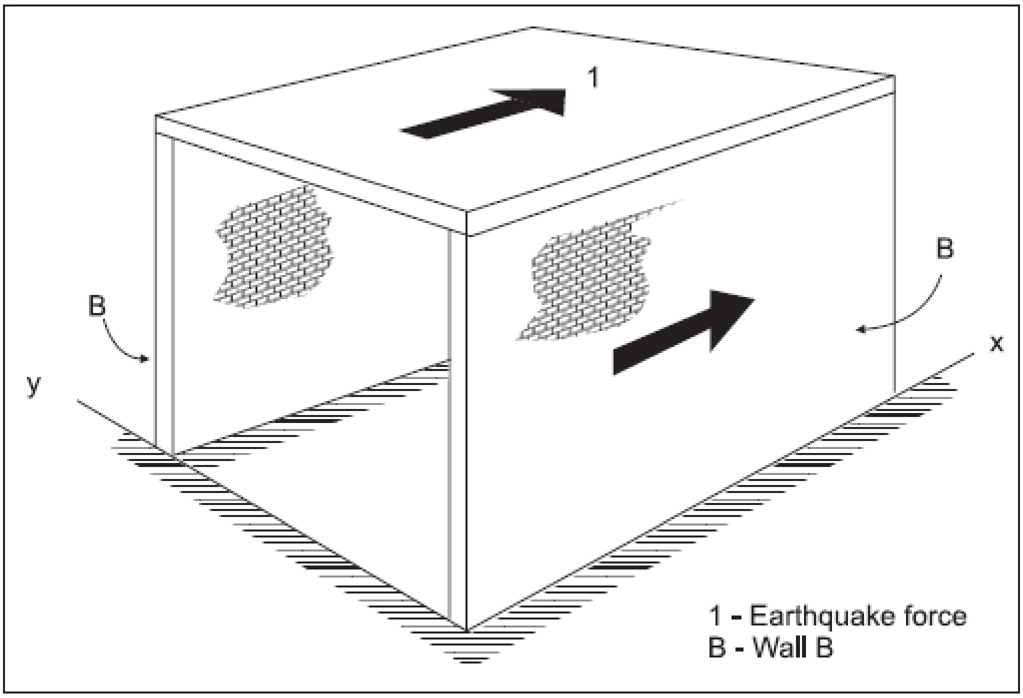

Figure 2. 20 Seismic forces on two walls with roof (IAEE, 2004)

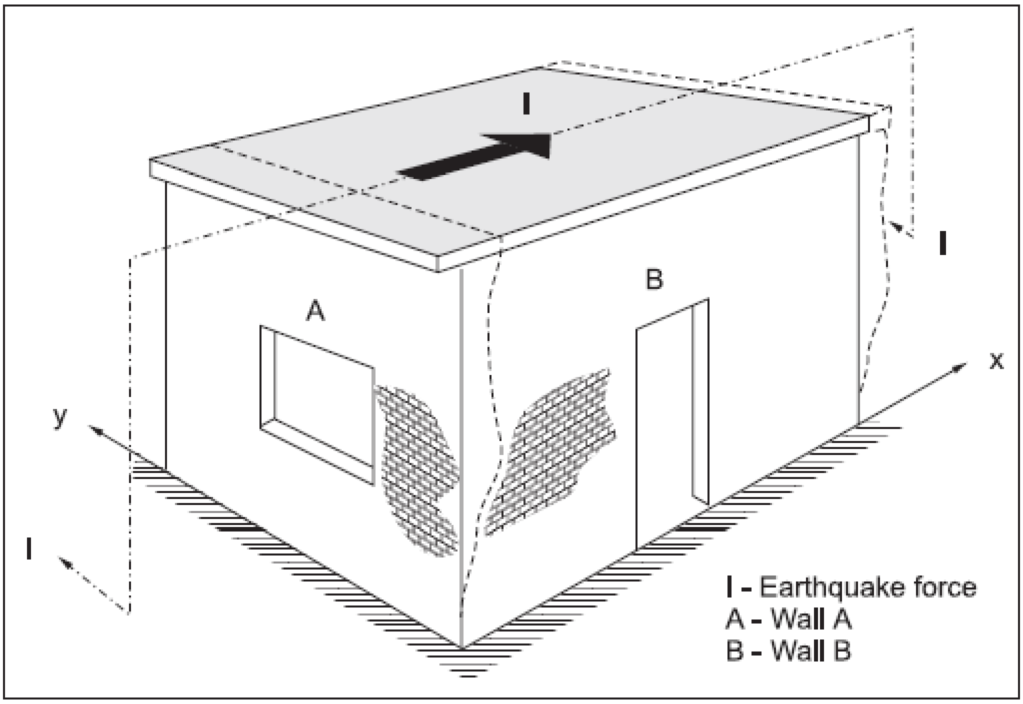

Figure 2. 21 Roof and wall enclosure (IAEE, 2004)

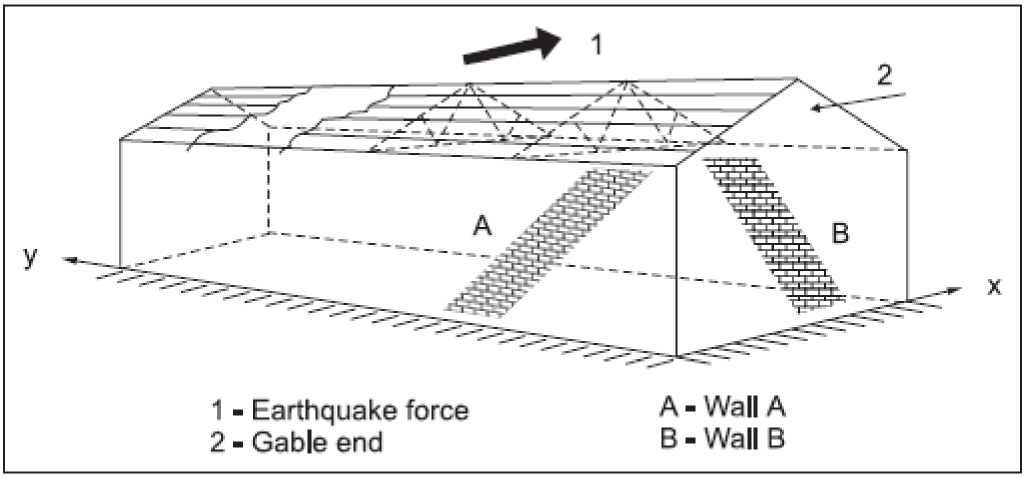

Figure 2. 22 Long building with roof truss structures (IAEE, 2004)

Considering a complete enclosure with a roof subjected to earthquake shaking as shown in figure 2.22, if the roof is rigid and behaves as horizontal diaphragm, its inertia will be distributed to the four walls with respect to their stiffness. It should be noted that, however, that behaviour would occurred only if the roof and the floor are enough rigid. It has long been acknowledged that the shear wall is the main lateral earthquake resistant elements in several buildings. For example, figure 2.23 displays the piers between the openings are more flexible than some portions of the wall below or above the openings.

Earthquakes come with different magnitudes. The magnitude of an individual earthquake depends on several factors, including earthquake types, depths of foci, distance between the source and buildings etc. However, in terms of earthquake resistant design a system to classify the levels of damage generated by the earthquake must be provided. This classification system then is employed for choosing appropriate parameters to suite the design with respect to, for example, earthquake magnitude. Around the world, because of differences in geography, political conditions, and economy, there have been several systems.

IEAA (2004) provides a very useful table for engineers to classify the levels of damage done by an earthquake, as shown in table 2. The table simply categorises the damages into six levels, ranging from 0, I, II, III, IV, and V. It can be observed that the categories responses to the damage level from zero to IV corresponding from to the least to the maximum. Notice that this system is very easy to grasp when being employed.

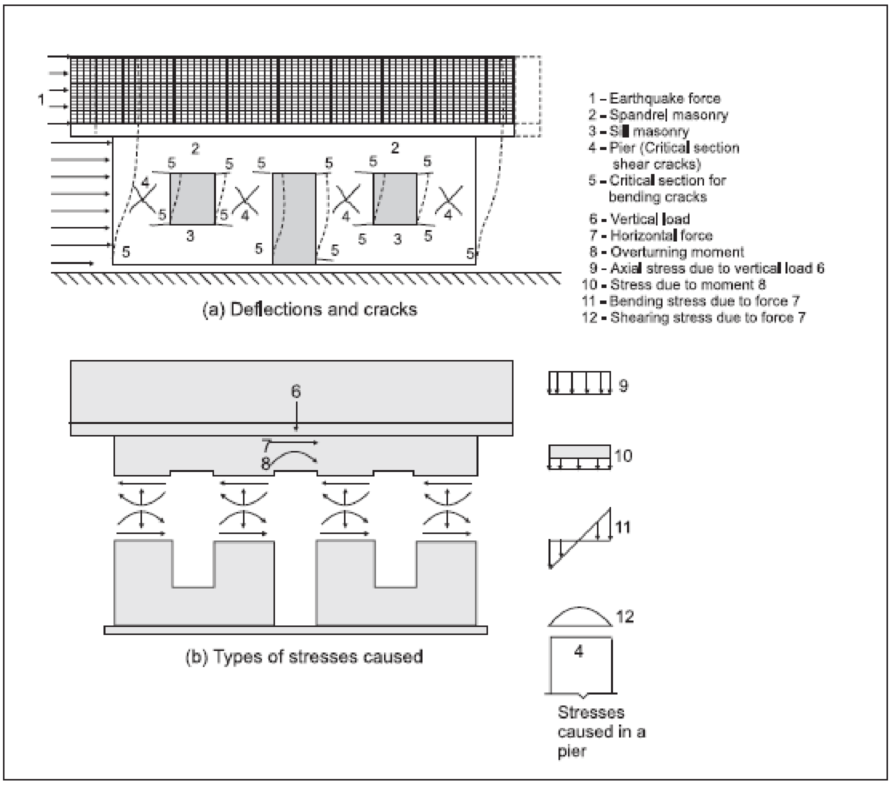

Figure 2. 23 Deformation of a shear wall having openings (IAEE, 2004)

Table 2. 2 Categories of damage caused by an earthquake (IAEE, 2004)

	Damage category	*Extent of damage in general*	*Suggested post- earthquake actions*
0	No damage	No damage	No action required
I	Slighty non-structural damage	Thin cracks in plaster, falling of plaster bits in limited parts.	Building need not be vacated. Only architectural repairs needed.
II	Slight Structural Damage	Small cracks in walls, failing of plaster in large bits over large areas; damage to non-structural parts like chimneys, projecting cornices, etc. The load carrying capacity of the structure is not reduced appreciably.	Building need not be vacated. Architectural repairs required to achieve durability.
III	Moderate structural damage	Large and deep cracks in walls; widespread cracking of walls, columns, piers and tilting or failing of chimneys. The load carrying capacity of the structure is partially reduced.	Building needs to be vacated, to be reoccupied after restoration and strengthening. Structural restoration and seismic strengthening are necessary after which architec tural treatment may be carried out.
IV	Severe structural damage	Gaps occur in walls; inner and outer walls collapse; failure of ties to separate parts of buildings. Approx. 50 % of the main structural elements fail. The building takes dangerous state.	Building has to be vacated. Either the building has to be demolished or extensive restoration and strengthening work has to be carried out before reoccupation.
V	Collapse	A large part or whole of the building collapses.	Clearing the site and reconstruction.

3) Damage of underground structures

Underground structures have been built by humans for a very long time. These include underground water systems, tunnels, and buried pipes. In recent years, almost every major city around the world has an underground train system. Generally, the system is constructed in the stiff clay. In addition, as the major city is very densely populated most utility systems such as water supply and sewer pipes have been lowered to underground. If these underground structures to be installed in earthquake-prone areas, countermeasures of course are required.

It may be said that the most important underground structure is tunnels for underground train. This is because they are involved with many people during working. For example, if an earthquake unexpectedly strikes during a peak hour whereby many people packed in a train, the tunnel must be strong enough to withstand such seismic force. Otherwise, catastrophe is foreseen. Figure 2.24 displays examples of large tunnels built for the underground train. It should be noted that the large-diameter tunnels are linear underground structures: their lengths are much greater than the cross-sectional dimension (Hashash et. al., 2001).

These structures have been classified as (1) bored or mine tunnels, (2) cut-and-cover tunnels, and (3) immersed tube tunnels (Power et. al., 1996). Notice that these big tunnels are mostly constructed for being metro structures, highway tunnels, and large water and sewage transportation ducts. The analysis and design for the underground structures has to be done with the inclusion of the following aspects (Hashash et. al., 2001):

(1) Generally, at the same level of vibration underground structures are less damage than those of superstructures.
(2) The deeper the underground structure the lesser the damage may occur. For example, a tunnel constructed at 30 m deep is safer one constructed above 30 m.
(3) Underground structure constructed in soil may be more damage than those of openings constructed over solid rocks.
(4) Between the lined and grouted tunnel and unlined tunnel, the former is safer when encountering earthquake. In addition, the factor of safety can be significantly improved if the soil surrounding the tunnel is stabilised.

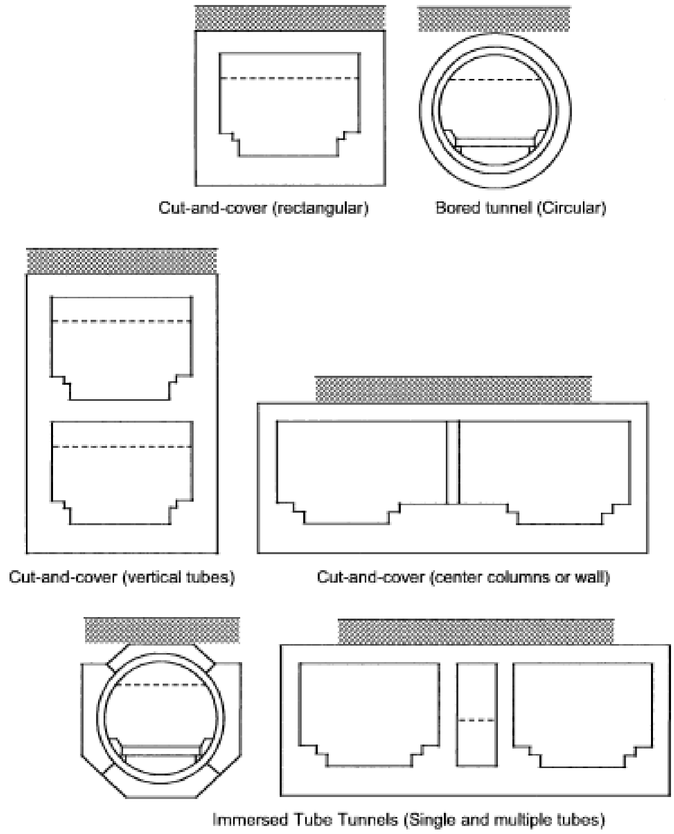

Figure 2. 24 Examples of cross-sectional of tunnels (Power et. al., 1996; Hashash et. al., 2001)

(5) Tunnels having symmetrically loaded are safer than those having unsymmetrical load applied.

(6) Normally, damage is related to ground peak acceleration and velocity based on the magnitude and epicentral distance of the affected earthquake.

(7) Amongst the other factors, the duration of strong-motion shaking is the most important. This is because it may cause fatigue failure thereby large deformation created.

(8) It should be beared in mind that high frequency motions may explain the local spalling of rock or concrete along planes of weakness. In addition, these frequencies may be anticipated mainly at small distances from the causative fault.

(9) Ground motion may be amplified upon incidence with a tunnel in the case the wavelengths are between one and four times the tunnel diameter.

(10) If a tunnel constructed along a slope the damage at and near tunnel portals may be significant.

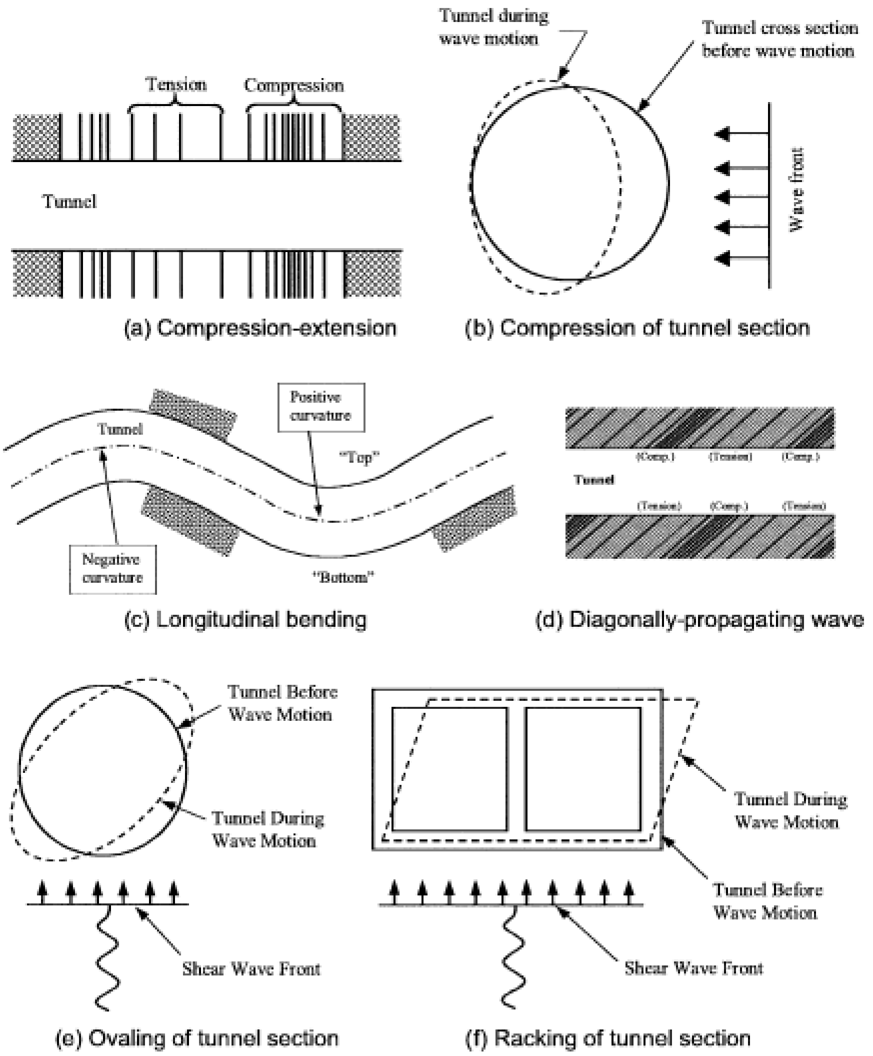

Figure 2. 25 Deformation models for tunnels during earthquake shaking (Owen and Scholl, 1981; Hashash et. al., 2001)

In order to simplify the analysis and design of a tunnel, its behaviour may be approximated to that of and elastic beam subject to deformations imposed by the surrounding ground, as shown in figure 2.25. There are three types of deformation that may express the response of underground structures to seismic motions: (1) axial compression and extension, (2) longitudinal bending, and (3) ovaling/racking. The details can be found in Hashash et. al. (2001).

4) <u>Loss of human lives</u>

It should be emphasised that the planet earth is dynamic. It is structurally changing all the time because of its internal structure. The earthquake has been with the planet since the early time of the earth; and, it is still going on till the collapse of the sun. During last century we have seen a dramatically increase of world population.

Since in the past, we have acknowledged that what places are safe from the earthquake. However, because of there are too many people but few inhabitant places, they have to reside in earthquake-prone areas. As a result, when an earthquake strikes one of the most important news is how many people dies. Thus, as an engineer, one must comprehend the incident thereby providing best solutions for the people.

5) Economic loss

Apart from the loss of human lives, the other obvious loss is the cost for reconstruction. In the case of transportation networks damaged, there will be also economic loss. For instance, several commercial activities will be interrupted if people cannot travel to see each other. The magnitude of the loss depends upon many factors such as population density, economic size, and type of goods. Economists have been continuously attempted to forecast this kind of loss. However, the world economy, both globally and locally, is changing all the time. As such a model for a particular period may not be true for a decade later.

6) Other issues

During and after earthquake shaking, apart from the loss of lives and infrastructures, there may also be unrest in an affected area. This normally involves policy makers, local communities, and central governments. It is therefore necessary for an earthquake-prone country to have a plan for dealing with this natural disaster.

2.3 Occurrence of tsunami and its consequences

Tsunamis are simply giant waves. In theory, anything that could initiate waves as big as tsunami can be called a tsunami. However, volcanic eruption and earthquake shaking are the most incidents that generate the tsunami. In the case of the former, both under-the-sea volcanic eruption and normal volcanic eruption have been observed to initiate the tsunami. It should be noted that, however, it is the undersea activity that is the most disastrous. When an earthquake strikes, the vibration may be transmitted through the body of ocean water. This would result in giant ocean waves. Sometimes, faults under the sea that rapidly move just before the release of accumulated strain energy also creates the tsunami. The incident would be more severe if the movement is dip-slip, as experienced in the 2004 Indian Ocean tsunami.

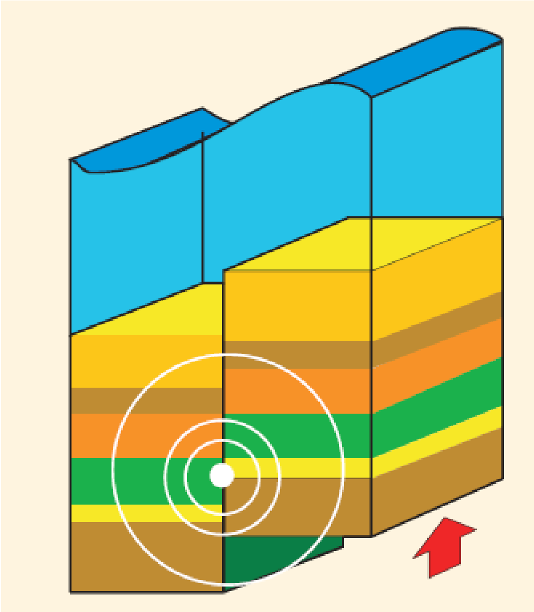

Figure 2. 26 Tsunami generated by sudden movement of sea floor (Maijde, nd.)

As the gigantic waves travelling onwards a shoreline, their wave lengths would be progressively reduced while their amplitudes increase accordingly. If there are structures very close to the beach, those tsunamis may damage them, depending on the height and velocity of the waves during being onshore.

As mentioned before, anything that could move the very large body of water can cause a tsunami. Generally, these include earthquakes, landslides, volcanic eruptions, explosions, and maybe impact from cosmic bodies, as shown in figure 2.26 (Maijde, nd.). In the case of earthquakes, especially under the sea, a tsunami is initiated when the sea floor abruptly deforms and almost vertically displaces the overlying water. This result in the entire water column is disturbed by the uplift of subsidence of the sea floor. Then, waves are formed due to the displaced water mass attempts to regain the equilibrium conditions. These waves would affect the whole column of water between the sea surface and sea floor as they are moving, from the area of origin in the middle of the sea, towards the coast.

More specifically, a tsunami is generally a shallow water wave. It should be noted that a shallow wave is the wave whose wave length is much longer than the depth of the water the wave is travelling through. For example, a wave that has the wavelengths of greater than 100 km while travelling through 5 -7 km deep water. In addition, the rate at which the wave loses its energy is inversely related to its wave length, tsunamis not only propagate at high speed, they can also travel great, transoceanic distances with limited energy loss (Maijde, nd.). This is clearly explained why the coast of Africa is hit by a tsunami originated over 5000 km away.

It should be noted herein that the behaviour of a tsunami in deep Ocean is quite different to that approaching shore, as illustrated by figure 2.27. For example, the deep-ocean tsunami has very long wavelengths and very low amplitude. In the meantime, the tsunami approaching the shore will slow down in speed and amplitudes will dramatically increase. This is based on the fact that the tsunami’s flux, which quite depends of both its wave speed and wave height, remains almost constant. Therefore, as the speed of tsunami diminishes during travelling into shallower water, its height grows. Because of these facts, the height of a tsunami approaching a shore may be as high as 10-15 m (Maijde, nd.).

Furthermore, the difference between the behaviour of water mass flowing into shore caused by wind-waves and tsunamis should be explained. Figure 2.28 displays the characteristics of water mass travelling towards shore by the wind-waves and tsunami. For the wind wave, the wave length may be as long as just 150 m with the period of up to 10 s. In addition, the wind wave only disturbs the water near the surface. The most significant difference is, however, the speed: the wave speed of tsunami is about 600 – 900 km/hr, while is just 15 – 50 km/hr for the wind wave. That is why the tsunami can destroy anything in front of its path during travelling towards shore.

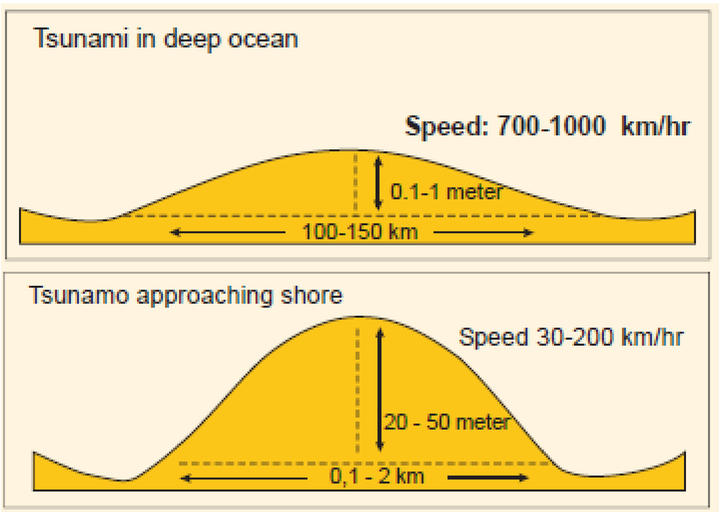

Figure 2. 27 Difference between deep-ocean tsunami and the tsunami approaching shore (Maijde, nd.)

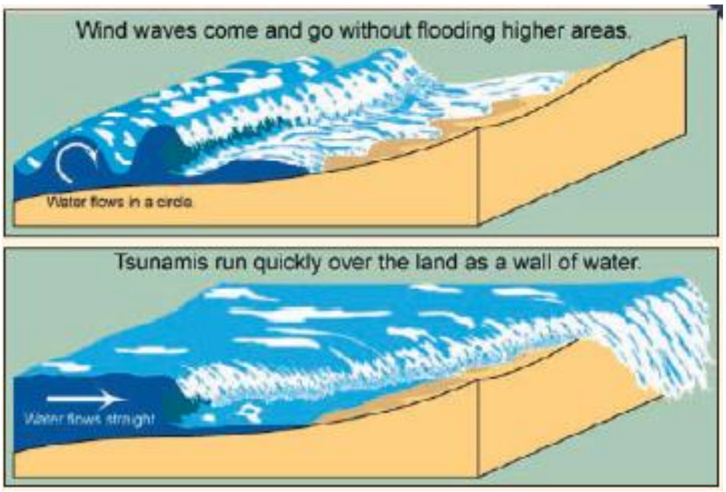

Figure 2. 28 Characteristics of wind-generated waves versus water flowing towards shore by a tsunamic (Maijde, nd.)

Table 2. 3 Damage from the 2004 and 2011 tsunamis (Suppasri et. al., 2012)

Item	2004 tsunami	2011 tsunami
Earthquake magnitude	9.3	9
Size of rupture (km^2)	1,000*150	500*200
Max. tsunami height (m)	50.9	40.5
No. of death	230,000	20,000
No. of affected country	15	Mostly in Japan

The tsunami has long been one of the most natural disasters that affecting both humans and built environments. Most recently tsunamis, the 2004 Indian Ocean and 2011 Japan tsunamis, have been regarded as ones of the most disastrous tsunami. For the former, it was reported that the death toll worldwide is approximately 230,000. In addition, the casualties were found from Southeast Asian countries to the countries along the Indian Ocean, and also as far as the coast of Africa. For the 2011 tsunami, even though the casualties were much fewer than those reported in the 2004 tsunami, but 20,000 people are of course a very huge loss, as shown in table 2.3. Furthermore, the consequence of the 2011 tsunami is still evident today. For instance, people are not allowed to reside around the affected area because of the failure of the nuclear power plant. It may be said that the economic loss from the 2011 tsunami is as high as the loss of human lives.

2.4 Design of structures to withstand wave forces

To be able to design a structure to withstand the forces generated by a tsunami, one must comprehend the characteristics of the following forces: hydrostatic forces, buoyant forces, hydrodynamic forces, surge forces, impact forces, and breaking wave forces (Yeh, 2006). In most cases, however, the breaking wave force is not considered as the force to act on a structure built on land.

According to the summary given by Yeh (2006), the hydrostatic force acting on a panel F_h (not on a building) can be estimated from the following equation

$$\boldsymbol{F_h = p_c A_w = \rho g \left(h_{max} - \frac{h_w}{2}\right) b h_w}$$ **Eq. 2. 9**

where p_c is the hydrostatic pressure at the centroid of the wetted portion of a wall panel, A_w is the wetted area of the panel, h_{max} is the maximum water height above the base of the wall, b is the width of the wall panel, and $h_w$is the height of the wall panel. Please be noted that the eq.2.9 is for $h_{max} > h_w$, otherwise $h_{max} \to h_w$.

For the buoyant force – a force acting on a structure subject to either partial of full submergence -, it will act vertically through the centre of mass of the displaced volume, and can be calculated from the equation

$$\boldsymbol{F_b = \rho g V}$$ **Eq. 2. 10**

where F_b is buoyant force, ρ is density of liquid (normally water), and $V$is the volume of water displaced by submerged mass. It should be noted that the buoyant force is of more concerned with wood frame buildings that are empty above-ground and below-ground tanks. This is because their own weights are relatively small compared with their buoyant force thereby being lifted easily.

The hydrodynamic force occurs when water flowing around a structure (a building). It can be calculated from the following equation

$$\boldsymbol{F_D = \frac{1}{2} \rho C_d A u^2}$$ **Eq. 2. 11**

where F_D is buoyant force, C_d is drag coefficient (see table 2.4) , A is the affected area, and $u^2$is a parameter (see Yeh, 2006).

Table 2. 4 Drag coefficients Cd (Yeh, 2006)

Width to Depth Ratio (w/ds or w/h)	Drag Coefficient Cd
From 1 - 12	1.25
13 - 20	1.3
21 - 32	1.4
33 - 40	1.5
41 - 80	1.75
81 - 120	1.8
> 120	2

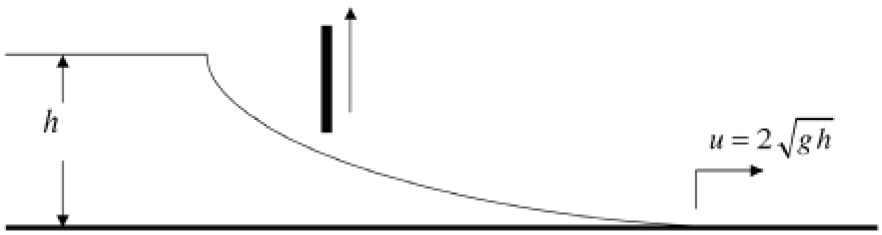

Figure 2. 29 Characteristics of surge water (Yeh, 2006)

Surge force is generated when the leading edge of a surge of water impinging on a structure, and can be calculated from the following equation

$$F_s = 4.5\rho g h^2 b \qquad \textbf{Eq. 2. 12}$$

where F_S is the surge force, and h is the height of the surge water. Note that Japan employ the number 3 instead of 4.5 shown in eq.2.12.

Impact force is simply the impact cause by the water mass flowing into a structure, and can be calculated from the following equation

$$F_I = m\frac{du}{dt} = m\frac{u_I}{\Delta t} \qquad \textbf{Eq. 2. 13}$$

where F_I is the impact force, and $\frac{du}{dt}$ is rate of change of velocity.

CHAPTER 3

MATERIALS, TEST PROGRAMMES, AND METHODS

3.1 Introduction

The 2004 Indian Ocean tsunami has been widely regarded as one of the deadliest natural disasters in recent time. Approximately 230,000 people died because of the incident both directly and indirectly. For instance, the large sum of death tolls were caused by huge water mass flowing towards buildings and structures where people being inside, resulting in drowning without any warnings. In addition, there were some deaths after the tsunami have passed for some times because of illness and diseases. Nonetheless, that figures have not been evaluated.

This research is concerned with the design and construction of houses, especially one-storey houses, being constructed very close to the beach. The assumption is that some parts of a house could be altered and constructed in order to reduce the forces generated by the tsunami flowing acting upon the structures. Thought it was not intended to totally prevent a house from any damage, but rather to reduce the damage as much as possible. For instance, some parts such as doors, windows, and roofs may be damaged during tsunami, but the main structural elements such as walls, beams, and column must be intact. This section gives explanation with respect to materials, equipment, methods, and programmes carried out.

3.2 Test Materials

3.2.1 Tested sand

The river sand from Karnchanadit, Suratthani was chosen to be used as shoreline slope for housing model houses. It had a specific gravity of 2.65 of which is in a range of typical value for this type of sand. The physical characteristics of the sand were obtained by conducting a sieving analysis. This resulted in the size distribution curve, as shown in Figure 3.1. Further analysis revealed that the sand comprises various sizes. In addition, it was found that the coefficient of uniformity, Cu is 3.66 and the coefficient of gradation, Cg is 0.84. According to the unified soil classification system, the soil was classified as SP, meaning it is sand having poorly grading characteristic.

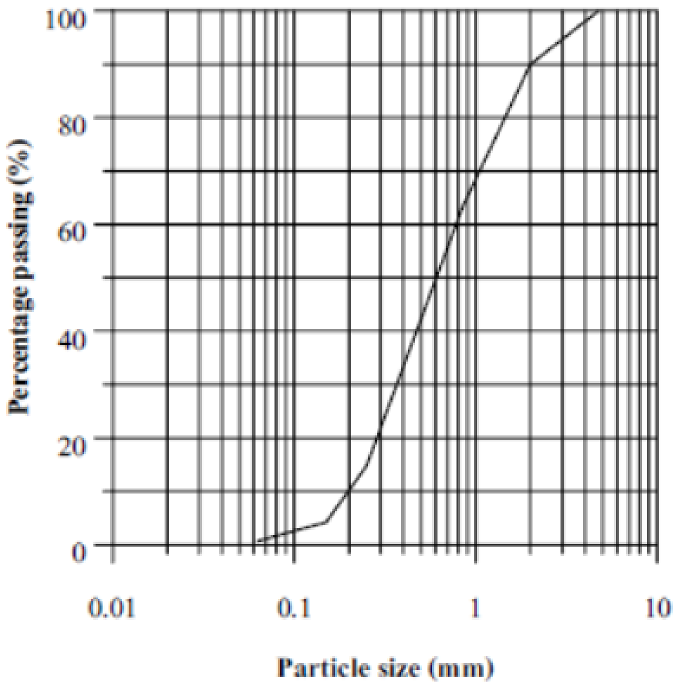

Figure 3. 1 Grain size distribution of the test sand (Promputthangkoon and Karnchanachetanee, 2014)

3.2.2 Model houses

There were two types of one-storey house in this research: (1) normal wall, and (2) hollowed wall, as graphically shown in figures 3.2 and 3.3, respectively. They were modelled using the scale of about 1:25. The main material employed for making a house was balsa wood. Figures 3.4 and 3.5 display the real model house constructed with respect to the normal- and hollowed walls. From the pictures it can be observed and compared their sizes by comparing with a measurement tape in the figure. In addition, both houses were designed to have a changeable length of foundation post between 1 and 2 m in order to observe the behaviour of water flowing towards the houses.

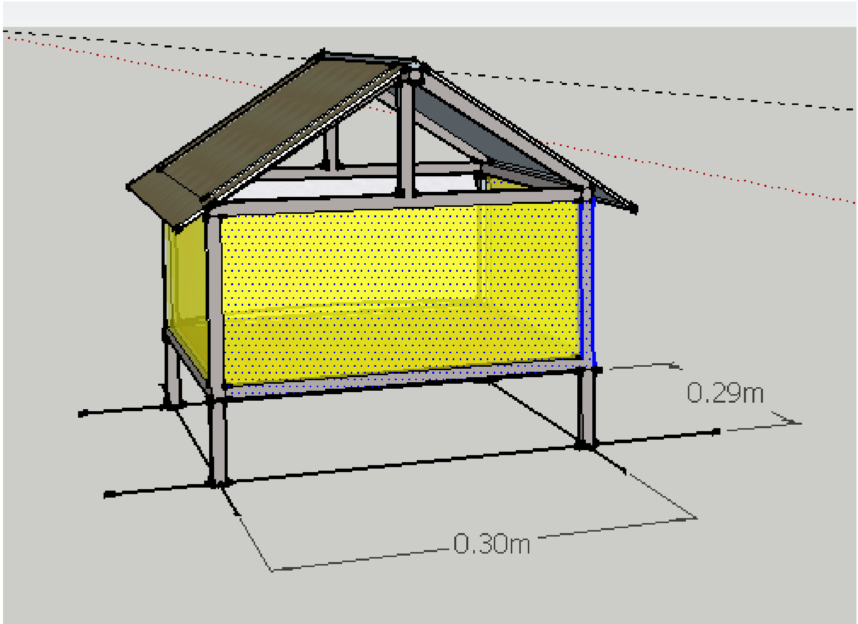

Figure 3. 2 Graphically model house having plane front wall

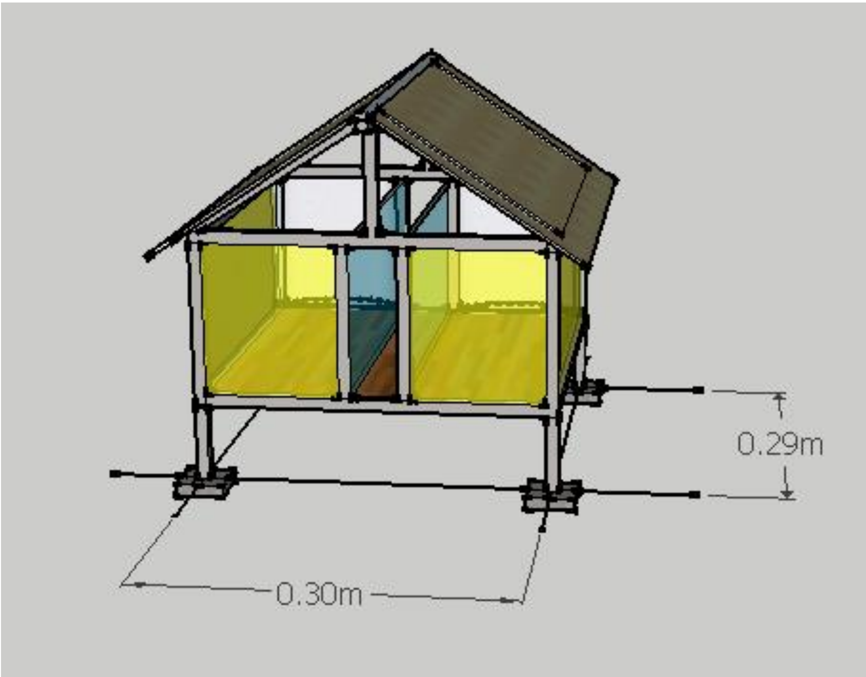

Figure 3. 3 Graphically model house having hollowed wall

Figure 3. 4 Model house having plane front wall

Figure 3. 5 Model house having hollowed wall

Figures 3.6 and 3.7 displays the model houses having plane and curve walls made from a very thin zinc sheet installed during testing process. It should be noted that behind the walls there are two stain gauges installed. In the meantime, figures 3.8 and 3.9 show the configurations of the hollowed houses having plane and curve walls, respectively. It should be emphasised herein that all of the house forms were attached with the foundation posts having the length of 1 and 2 m. For the 1 m length foundation post, during testing a house was installed so that the floor is at the level of the ground. For the 2 m length post, however, the floor was around 1 m over the ground.

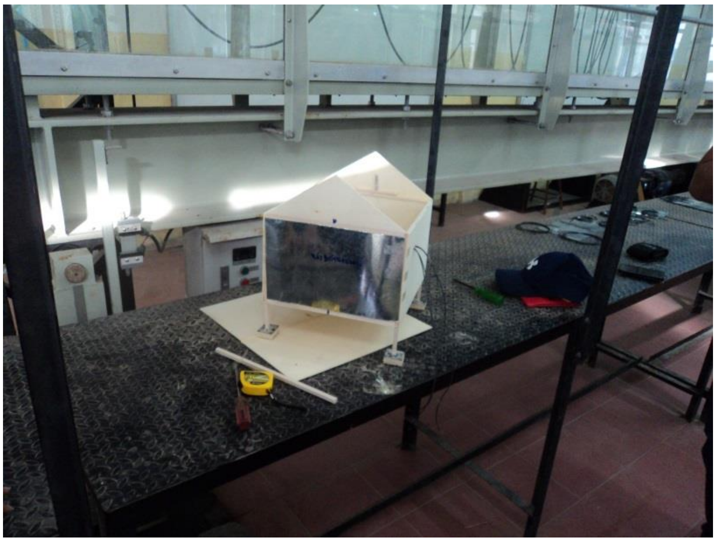

Figure 3. 6 Model house with plane wall being installed for tsunami test

Figure 3. 7 Model house with curved wall being installed for tsunami test

Figure 3. 8 Model house having hollowed wall and being installed for tsunamic test

Figure 3. 9 Model house having hollowed- and curved wall being installed for tsunamic test

3.3 Equipment

3.3.1 Chamber

In order to house a beach and model house a steel chamber was designed and built, as shown in figure 3.10. The overall dimensions were 3.30 m by 0.50 m, approximately. Its height was about 1.40 m. To be able to observe the wave behaviour a tranparent plastic sheet was employed as the walls of the chamber.

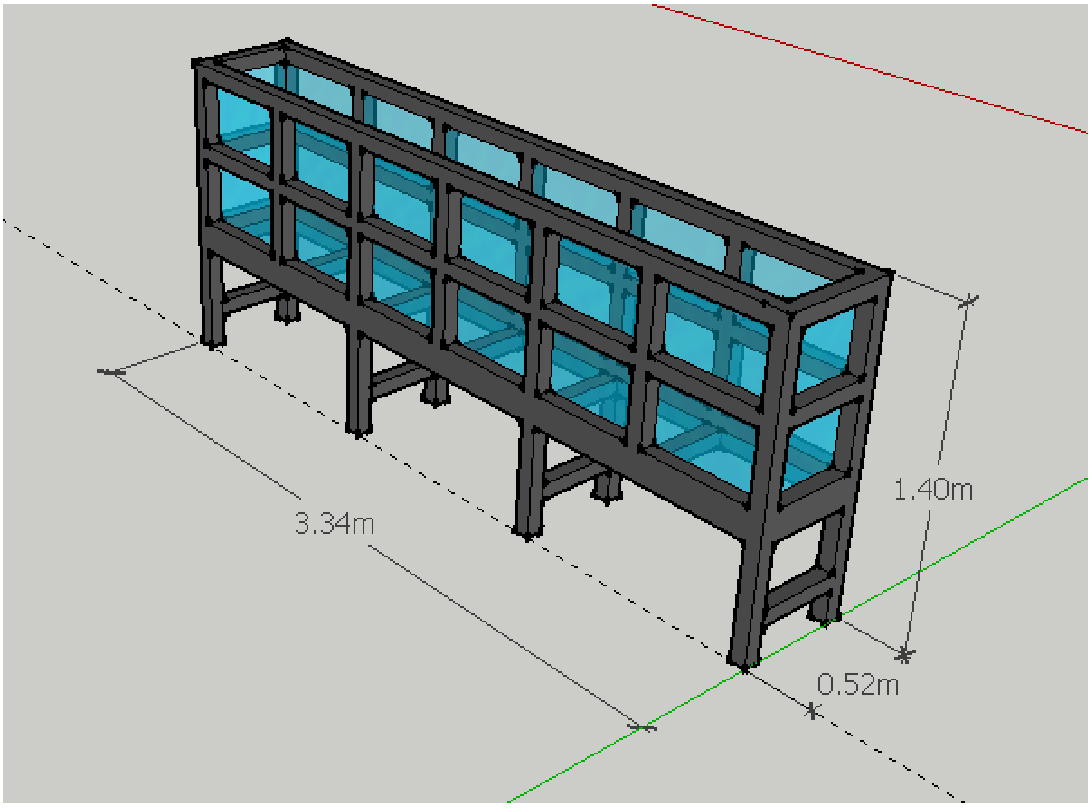

Figure 3. 10 Graphically model chamber for housing model beach and houses for tsunamic test

3.3.2 System for generating simulated tsunami

One of the most important aspects of this research was a system for generating tsunami. It should be noted that the tsunami travel very fast comparing the other waves such as tidal waves and waves generated by wind. As such, this research designed a weight system that could be instantaneously dropped into the water. This would result in waves that could travel quite fast when flowing into shoreline. The system is illustrated by figure 3.11. Basically, it comprised a steel frame connected with a mechanical winch. The weight was simply an in-house cast concrete having the weight of around 60 kg. This was many times experimented, however, in order to obtain a right weight. For instance, if it was too light the waves would be small and travel at speeds lower than required. In contrast, if the weight was too heavy, during dropping the chamber might be damage. It should also be noted that there are several systems that could generate the tsunami, depending on the objectives and budget for a project.

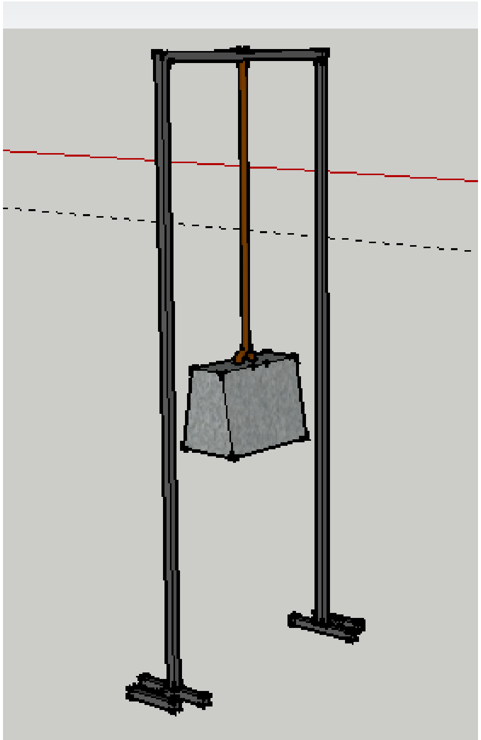

Figure 3. 11 Mechanism for simulating tsunamis

3.3.3 Data acquisition system

(1) Strain gauge

According to the Hooke's law, for most of the engineering material, there is a proportional relationship between stress and strain as long as the material is still being in the range of elasticity. The stress level at which is the limited value for the elastic range is called as proportional limit. This description is schematically explained in figure 3.12.

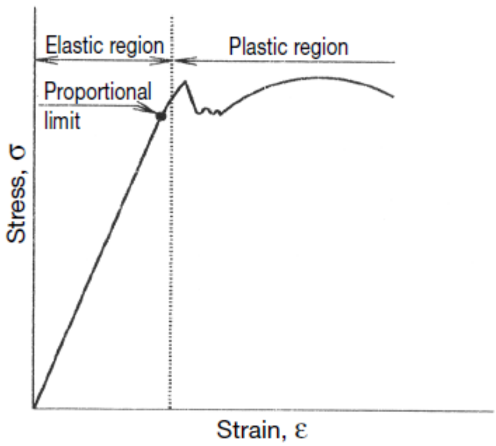

Figure 3. 12 Typical stress-strain curve (Kyowa, nd.)

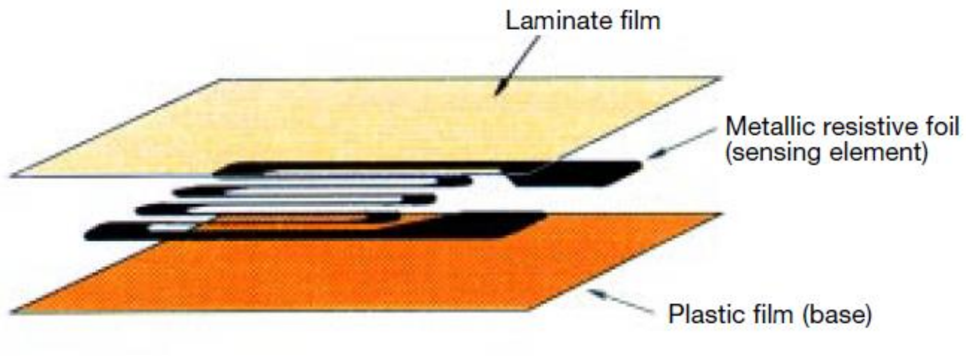

Figure 3. 13 Typical strain gauge (Kyowa, nd.)

It should be noted that the stress-strain relation for an engineering material is of utmost interest because it is employed to design components made from such material. In addition, to obtain that data laboratory tests are most widely employed. Sometimes, measurement of the stress is difficult and cumbersome, strain measurement then is carried out instead. Also note that the strain is unitless quantity; it is simply the ratio of elongation (both compression and extension) to an initial length. However, this explanation is only true for axial strain. There are more types of strain such as shear strain and volumetric strain.

Scientists have developed a sensor called strain gauge, as shown in figure 3.13. It can be said that the invention of strain gauges is one of the most important innovation in terms of engineering design. In other words, without them, engineers may not be able to design and build devices, machines, and equipment as fast as they have been. There are several types of strain gauge available nowadays. Typically, however, it comprises a metallic resistive foil (sensing element) sandwiched by a layer of laminate film and plastic film.

According to Kyowa (nd.), to measure the strain of a material, first tightly bond a strain gauge to the material so that the sensing element may elongate or contract with respect to the strain borne by the measuring object. Note that when bearing mechanical elongation of contraction, most metals undergo a change in electric resistance. As such, the strain gauge applies these principles to the measurement of strain using the resistance change. In general, the sensing element of the strain gauge is made of a copper-nickel alloy foil. In addition, the alloy foil has a rate of resistant change that is proportion to strain with a certain constant.

Similarly to the Hooke's law, the following equation is developed

$$\frac{\Delta R}{R} = K\varepsilon \qquad \textbf{Eq. 3. 1}$$

where R is the original resistance of a strain gauge (ohm, Ω), ΔR is elongation- or contraction-initiated resistance change (ohm, Ω), K is proportional constant (normally called gauge factor, GF), and ε is strain. It should be noted that the gauge factor depends on metallic materials. Normally, the copper-nickel alloy has a gauge factor of about 2.

To measure the strain using strain gauges, the Wheatstone bridge, an electric circuit, is employed because it is suitable for detection of very small changes in electric resistance. Its general configuration is illustrated by figure 3.14. From the figure, suppose $R1 = R2 = R3 = R4$ or $R1 \times R3 = R2 \times R4$, then, whatever voltage is applied to the input results in the output e of zero. Such a bridge status has been called "balanced". However, when the bridge loses the balance, it outputs a voltage corresponding to the resistance change. Figure 3.15 shows a stain gauge connected in place of $R1$in the circuit. If the gauge bears strain and initiates a resistance change ΔR, the bridge outputs a corresponding voltage e, as shown in the following equation

$$e = \frac{1}{4}\frac{\Delta R}{R}E \qquad \textbf{Eq. 3. 2}$$

or can be formulated as

$$e = \frac{1}{4}K\varepsilon E \qquad \textbf{Eq. 3. 3}$$

since values other than ε are also known as values, strain ε, can be determined by taking a measurement of the bridge output voltage (Kyowa, nd.). It should be noted herein that the strain gauge can be configured many ways, depending on measurement types. For example, it may be configured for measuring bending, axial strain, and torsional strain. It should be noted that any strain gauge manufactured is required to have been calibrated in order to obtain some properties such as gain factor. Figure 3.16 shows a typical calibration graph for a strain gauge.

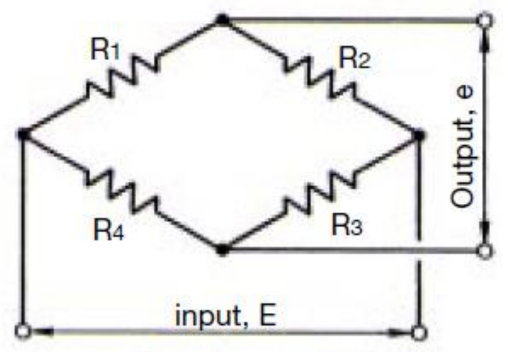

Figure 3. 14 Typical configured circuit of a strain gauge (Kyowa, nd.)

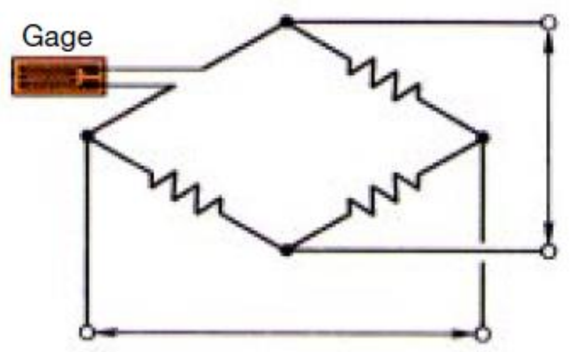

Figure 3. 15 A strain gauge connected to a bridge circuit (Kyowa, nd.)

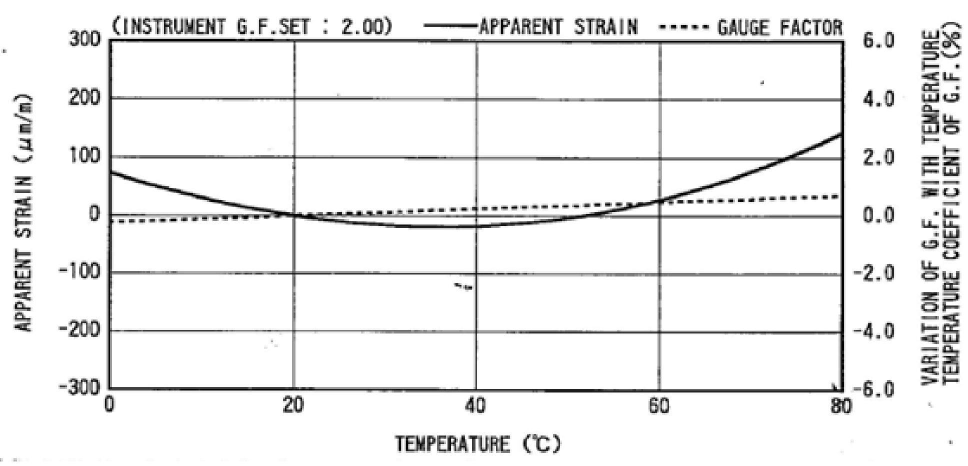

Figure 3. 16 Typical calibration curve of a strain gauge

Generally, research and study that require the application of strain gauges need to obtain a strain gauge first. However, as the nature of engineering research is very varied project by project. As such, the strain gauge mostly is in-house installed. This project employed normal tools and equipment to install and attach the strain gauges, including soldier kits and wires, as shown in figure 3.17. The strain gauges employed were from RS Thailand and Kyowa, as shown in figures 3.18 and 3.19, respectively. Soldering a strain gauge requires high temperature. As a result, it does not mean every installation will be successful. Therefore, after the soldering process an installed strain gauge must be tested to ensure it will response with the stress applied. Otherwise, it would be wasteful if it has been discovered that the whole experiment produces zero data.

Figure 3. 17 Tools and equipment used to prepare the strain gauge

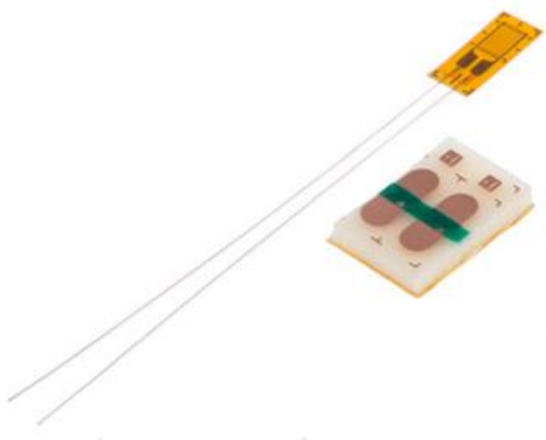

Figure 3. 18 RS 632-146 strain gauge having the gauge length of 2.5 mm

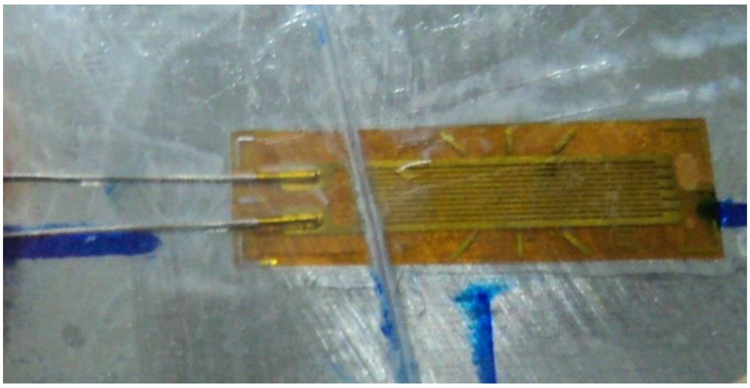

Figure 3. 19 A strain gauge firmly attached to a model wall for tsunami test

Figure 3. 20 Data acquisition system employed to determine the workability of strain gauges installed before being employed for tsunami test

(2) Analogue to digital acquisition device

The electrical signal generated by a strain gauge requires an electronic device that can interpret the signal. In this research an analogue to digital acquisition was NI 9235. Basically, it is a quarter-bridge stain gauge module manufactured by National Instruments. It was chosen because it is very to set up and run. A total number of channels was eight, which was more than enough for this research. One of the most important aspect was that it was built with the analogue input resolution of 24 bits, meaning it can measure the signals at very fast speed. The module is illustrated by figure 3.21.

Figure 3. 21 NI 9235 quarter-bridge stain gauge module

(3) Monitoring and recording device

The NI 9235 module was required to connect with an NI chassis. The chassis acts as a medium between the module and a computer. Ni cDAQ 9174 USB chassis was chosen for this research because it was compatible with the NI 9235. It was chosen because it provides the plug-and-play simplicity of USB to sensors, in this case strain gauge, on the benchtop, in the field, and on many other NI modules. It comprises four slots, meaning at least four different types of sensor can be measured at the same time. Figure 3.22 shows the USB chassis employed in this research.

Figure 3. 22 NI cDAQ 9174 USE 4 slots chassis

3.4 Methods and programmes

To achieve the purpose of this research three steps were required to be done: (1) designing and building of equipment for simulating tsunami, including chamber, drop weight, model houses with strain gauges installed, (2) experimenting with tsunami flooding towards the model house in order to obtain the strain caused by tsunami, and (3) analysing the strain data obtained with the conjunction of tsunami observed.

3.4.1 Test procedures

The testing procedures are as follow:

1) Designed and built a steel frame for housing a model beach and house. The design was based on the assumptions the side walls should be transparent in order to observe the behaviour of tsunami during in the sea and after on shore.
2) Designed and built a dropping weight system based on the assumption that it must be heavy enough to generate big waves. However, it would not damage the chamber because its side walls were made of transparent plastic (acrylic sheet).
3) Designed and built one-storey model houses using the 1:25 scale. There were two forms of houses, normal wall and hollowed wall. In addition, each one had two different types of wall, including plane and curve walls. Every single wall had two strain gauges installed; each was located along the vertical line at the distance of about 2.5 cm from the centre. The intention of employing two strain gauges was to average the strain obtain. This is because the strain gauge simply measure electrical signal. Then the signal is converted to strain. Thus, employing two strain gauges would benefit in terms of ensuring the data obtained.
4) For each configuration, the test was carried by lifting the drop weight to 10 cm above the water level; then, it was instantaneously freely dropped into the water to generate simulated tsunami. When the wave was calm another drop was carried out. During testing a video was also taken in order to further analyse the behaviour of the waves during in the sea and after being on shore.

5) An underwater breakwater was also installed for every configuration to observe its benefit in terms of wave force reduction. The breakwater was simply a pole inserting into a donut object. In reality, the pole would be discarded electric poles; while the donut object would be discarded tyres of which is progressively problematic in Thailand. Figure 3.23 graphically displays the whole test system. While figure 3.24 shows the underwater breakwater being installed during testing.

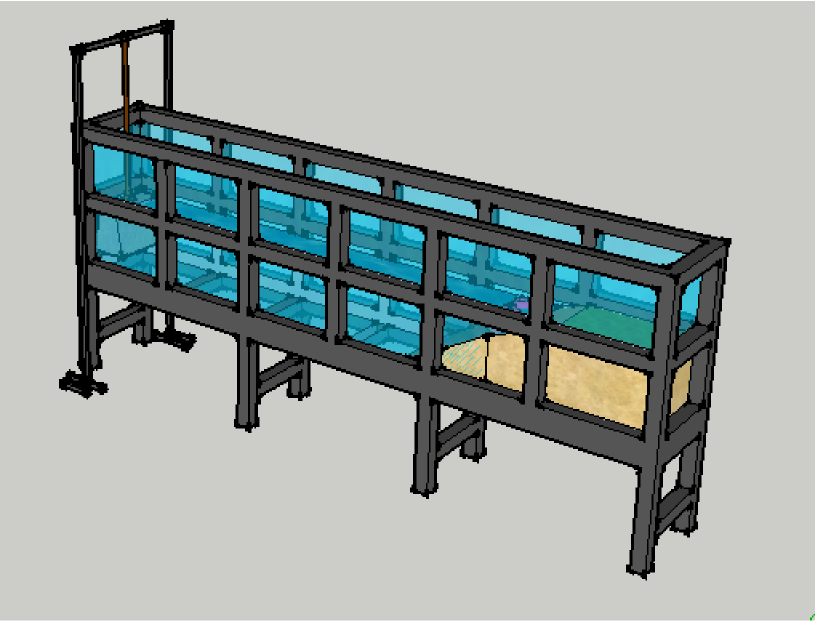

Figure 3. 23 Whole system for tsunami test

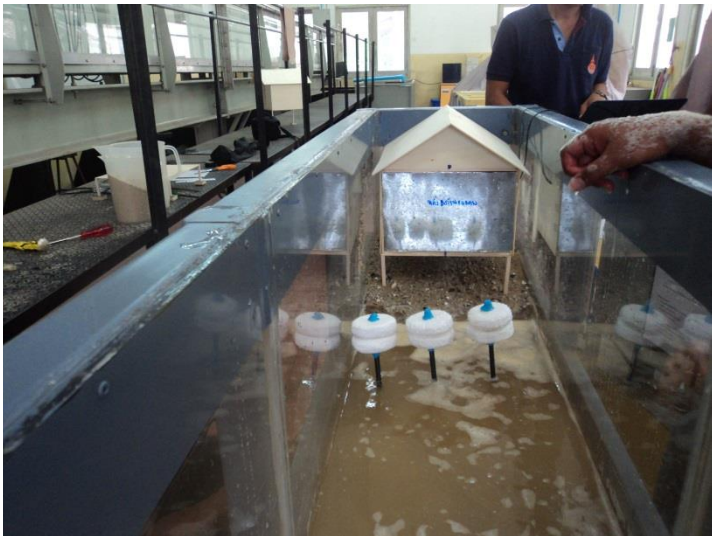

Figure 3. 24 Installation of break water to reduce the wave forces generated by simulated tsunami

3.4.2 Test programme

With the two forms of houses, two types of walls, two levels of ground slab, and with and without breakwater system, this resulted in a total of 16 configured tests, as shown in table 3.1.

Table 3. 1 List of test configurations

No.	House form	Slab level	Wall shape	Break water system	Symbol
1	Normal wall	On ground	Plane	No	NOPN_X1
2				Yes	NOPY_X1
3			Curve	No	NOCN_X1
4				Yes	NOCY_X1
5		1 m over the ground	Plane	No	N1PN_X1
6				Yes	N1PY_X1
7			Curve	No	N1CN_X1
8				Yes	N1CY_X1
9	Hollowed wall	On ground	Plane	No	HOPN_X1
10				Yes	HOPY_X1
11			Curve	No	HOCN_X1
12				Yes	HOCY_X1
13		1 m over the ground	Plane	No	H1PN_X1
14				Yes	H1PY_X1
15			Curve	No	H1CN_X1
16				Yes	H1CY_X1

CHAPTER 4

TEST RESULTS AND DISCUSSION

4.1 Introduction

Houses constructed very close to beaches that are prone to tsunamis are very likely to damage if flooded by very strong waves. In the case of Thailand, because of everyday life and tourism, some people tend to reside in such risky areas. This research was concerned with the alteration of wall form for one-storey house in order to reduce the wave forces generated by tsunamis. The assumption was that a wall form if properly designed and built could somewhat reduce the impact forces generated by tsunamis.

To prove the assumption a system was designed and built to simulate a tsunami in a small scale. A chamber was also constructed to accommodate a simulated shore and model house. Two types of house were modelled, including normal- and hollowed front walls. Then, both houses were modelled having two different types of wall, (1) plane wall and (2) curve wall. Each panel was instrumented by attaching two strain gauges to measure the strain during the waves flooding towards the shore and house. The waves were initiated by dropping a dead weight of about 60 kg made entirely form concrete into the model sea. A total of 16 configurations were tested and observed. During testing a video camera was also employed to record the behavior of the waves during travelling towards the shore and house. In addition, an underwater breakwater was also designed and installed to observe its effectiveness in terms of reducing the wave forces.

For the house having normal wall, only one panel was constructed. However, for the hollow wall, two panels were constructed, leaving a hollowed hole at the middle of the house. This resulted in the each configuration of the normal wall house having two strain gauges installed; while there were a total of four strain gauges installed for the hollow wall house.

4.2 Strain caused by simulated tsunamis

One and foremost quantity measured in this research was the strain caused by the reflection of a wall during being flooded by simulated tsunamis. For the normal wall house having the slab sitting on the ground, the results are shown in figures 4.1 to 4.4 with respect to the test configurations of NOPN_X1, NIPY_X1, NOCN_X1, and NOCY_X1. For the same type of house but the slab was raised around 1 m over the ground, the results are shown in figures 4.5 to 4.8 with respect to the test configurations of N1PN_X1, N1PY_X1, N1CN_X1, and N1CY_X1.

In the case of the hollow wall house having the slab on ground, the results are shown in figures 4.9 to 4.12 with respect to the test configurations of HOPN_X1, HOPY_X1, HOCN_X1, and HOCY_X1. However, for the case of the slab was raised to 1 m over the ground, the results are shown in figures 4.13 to 4.16 with respect to the test configurations of H1PN_X1, H1PY_X1, H1CN_X1, and H1CY_X1. All of results were plotted and shown by means of strain versus time. From the graph then the stain and maximum strain could be easily observed. In addition, the maximum strains for all test configurations are summarised and shown in table 4.1.

For the test number NOPN_X1, it can be seen that the maximum strain is approximately 0.118. However, this is the maximum value for the strain gauge; the possible maximum value might be greater. It should also be noted that the bottom strain gauge yield nothing. This may be because the wave may flow over the top of the strain gauge thereby nothing was generated. When the underwater breakwater was installed, the test number NOPY_X1 having the test configuration same as NOPN_X1 except the breakwater, it was observed that the maximum strain is very similar. However, the strain after the second wave was quite lower (see figure 4.2 versus figure 4.1). This clearly suggests the influence of the underwater breakwater in terms of reducing the wave forces flooding towards the wall.

For the normal wall house but with curve wall and no breakwater, it was found that the average strain is relatively lower compared with those of NOPN_X1 and NOPY_X1. This indicates that the wall curve could reduce the wave forces acting on a wall during a tsunami (see figure 4.3 for clarification). Furthermore, when the underwater breakwater was added to, the average strain was just about 0.06, indicating the effectiveness of the underwater breakwater (see figure 4.4 and compare with figure 4.3).

For the normal wall house having plane wall but the slab was raised to 1 m above the ground (test number N1PN_X1), it was found that the strain is just around 0.06. During testing, however, it was observed that the waves rarely make contact with the wall. Unsurprisingly, this was because of raising the slab to 1 m over the ground. It should be noted that, however, in such case the waves may be able to get over the ground under a house thereby eroding the soil. If the erosion is very severe, a house may be collapse due to the damage of the foundation resulting from the foundation soil eroded. Furthermore, in the case of the same configuration but having the underwater breakwater installed (test number N1PY_X1, see figure 4.6), no strain was generated. This was because the waves could not make to have a contact with the wall owing to the raising of the slap as well as the installation of the underwater breakwater.

For the normal wall houses having the slab raised to 1 m above the ground with and without underwater breakwater (figures 4.7 and 4.8, respectively), it can be seen that no strain generated. Please be noted that during testing it was observed that the waves could not make to have a contact with the walls thereby zero strain observed. This was one of the flaws of this research though. In facts, the dropping weight should be dropped at a higher height. However, such action may damage the chamber thereby the drop height was restricted to only 10 cm. Nonetheless, it shows that these configurations could reduce the wave forces generated by a tsunami.

For the figures 4.9 to 4.16 representing the results for all of the hollow houses, it was observed that overall the strain is much lower than those observed from the normal house that has been shown and discussed. In the case of the hollow house having plane walls and on-ground slab, it was found that the maximum strain for the house without underwater breakwater (figure 4.9, test number HOPN_X1), is about 0.06. For the same configuration but with underwater breakwater, however, the maximum strain was just about 0.05 (see figure 4.10), indicating the effect of the installation of underwater breakwater.

For the hollow house with curve wall but without underwater breakwater (test number HOCN_X1, see figure 4.11), it was found that the maximum stain is about 0.05.

However, when the underwater breakwater was installed (test number HOCY_X1, shown in figure 4.12), the strain generated was just 0.045, of which is slightly lower. When the hollow house with plane walls having slab raised to 1 m over the ground (see figure 4.13, test number H1PN_X1), it was observed that the maximum strain is about 0.06, of which is similar to those observed in the test number HOCN_X1. However, when the underwater breakwater was added, no strain was generated, indicating the effectiveness of the underwater breakwater in terms of reducing the severing of the wave forces. For the hollow house with curve walls having slab raised to 1 m over the ground, both test numbers H1CN_X1 and H1CY_X1 showed no sign of strain. This, again, emphasises the effects of the alteration of house forms and the installation of underwater breakwater for reducing the wave forces generated by tsunami.

The test results obtained from this research, even though some flaws occurred, suggest that with the right configurations of a structure we could minimise the damage that may be occurred during a tsunami. In addition, an underwater breakwater system also showed that it is somewhat useful for this matter.

Table 4. 1 Summary of the maximum strain for each test

No.	Symbol	Maximum strain	Note
1	NOPN_X1	0.118	Maximum value for the gauge
2	NOPY_X1	0.118	0.065 for second wave
3	NOCN_X1	0.118	Only 0.1 for the other one
4	NOCY_X1	0.075	
5	N1PN_X1	0.070	
6	N1PY_X1	0.000	Waves did not reach the wall
7	N1CN_X1	0.000	
8	N1CY_X1	0.000	Waves did not reach the wall
9	HOPN_X1	0.060	
10	HOPY_X1	0.060	
11	HOCN_X1	0.000	
12	HOCY_X1	0.000	
13	H1PN_X1	0.080	
14	H1PY_X1	0.000	Waves did not reach the wall
15	H1CN_X1	0.000	
16	H1CY_X1	0.000	

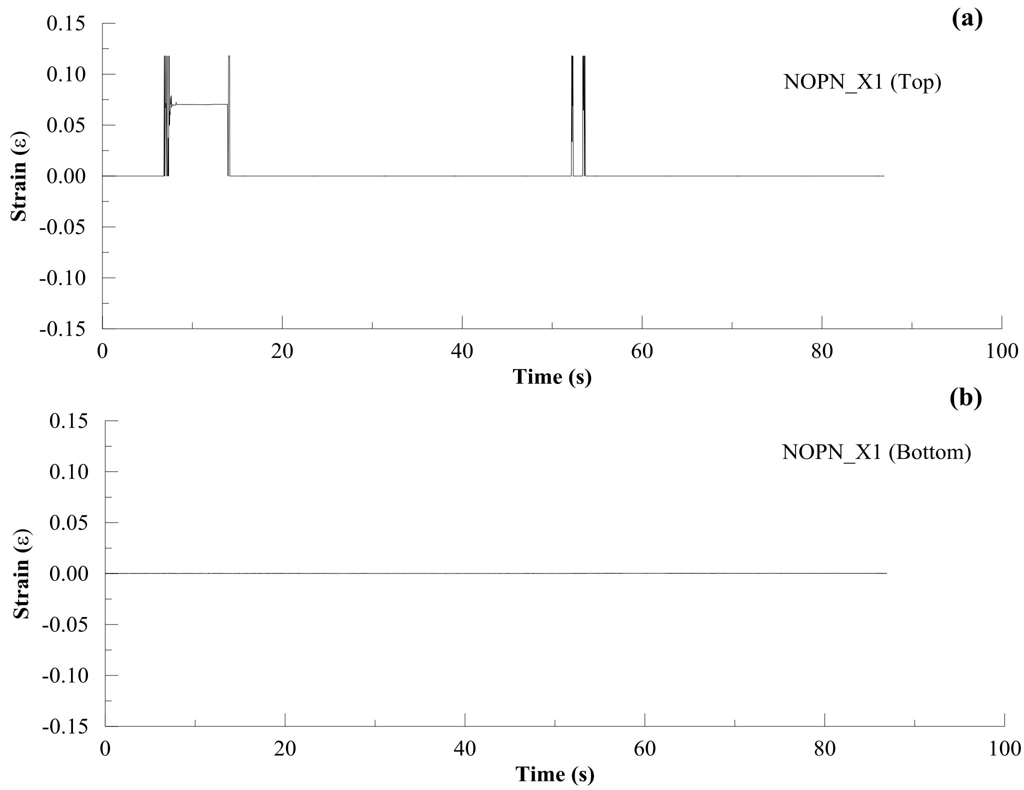

Figure 4. 1 Strain vs. time due to wave forces for test no. NOPN_X1, top strain gauge (a), bottom strain gauge (b)

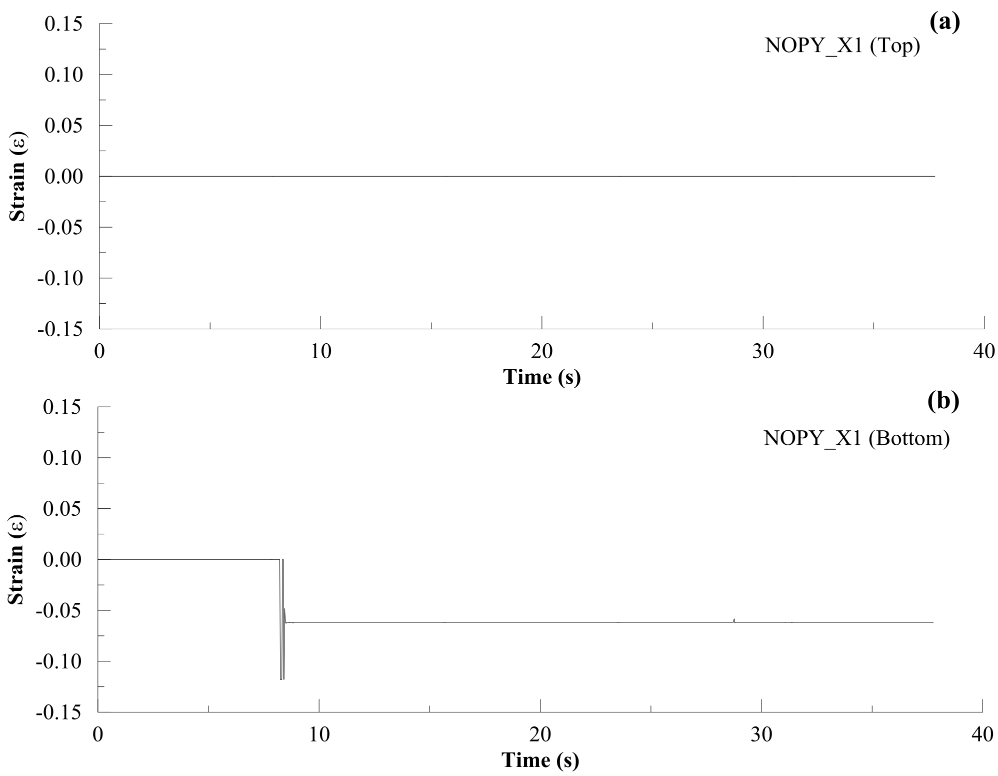

Figure 4. 2 Strain vs. time due to wave forces for test no. NOPY_X1, top strain gauge (a), bottom strain gauge (b)

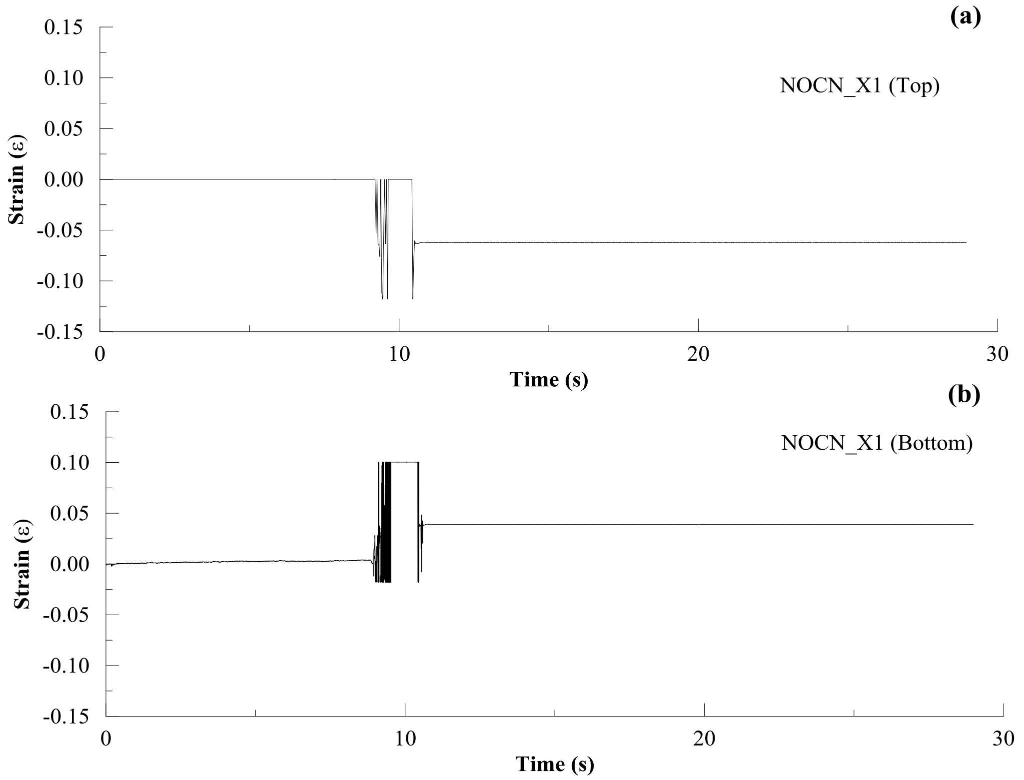

Figure 4. 3 Strain vs. time due to wave forces for test no. NOCN_X1, top strain gauge (a), bottom strain gauge (b)

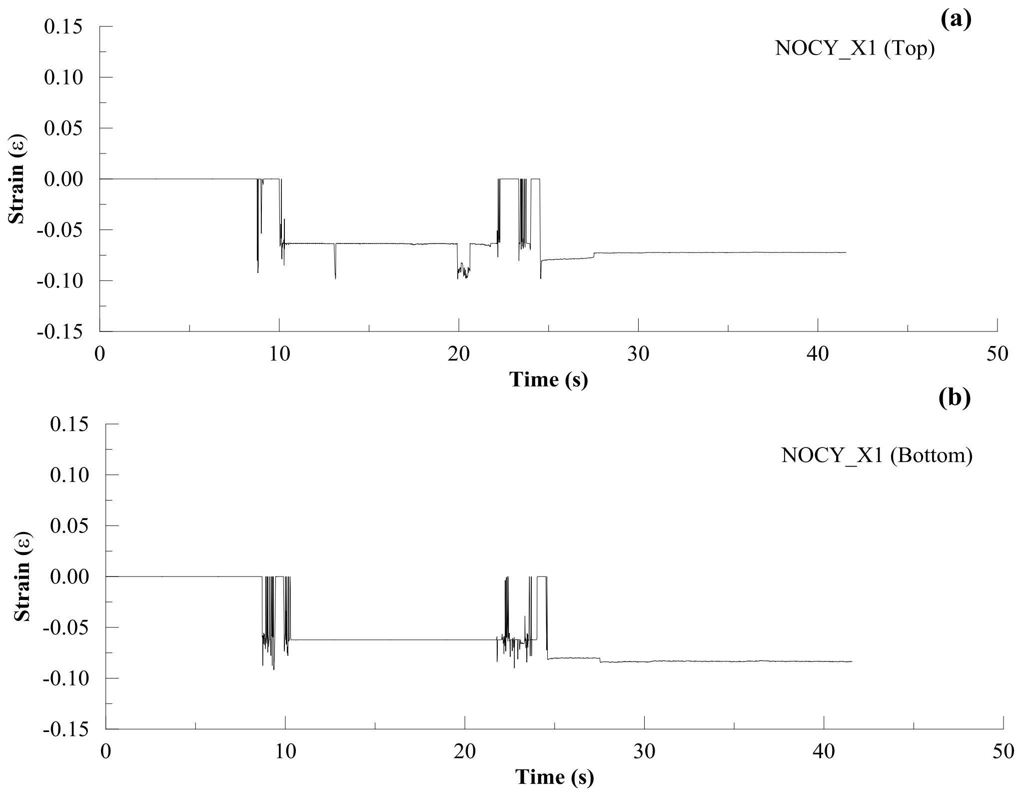

Figure 4. 4 Strain vs. time due to wave forces for test no. NOCY_X1, top strain gauge (a), bottom strain gauge (b)

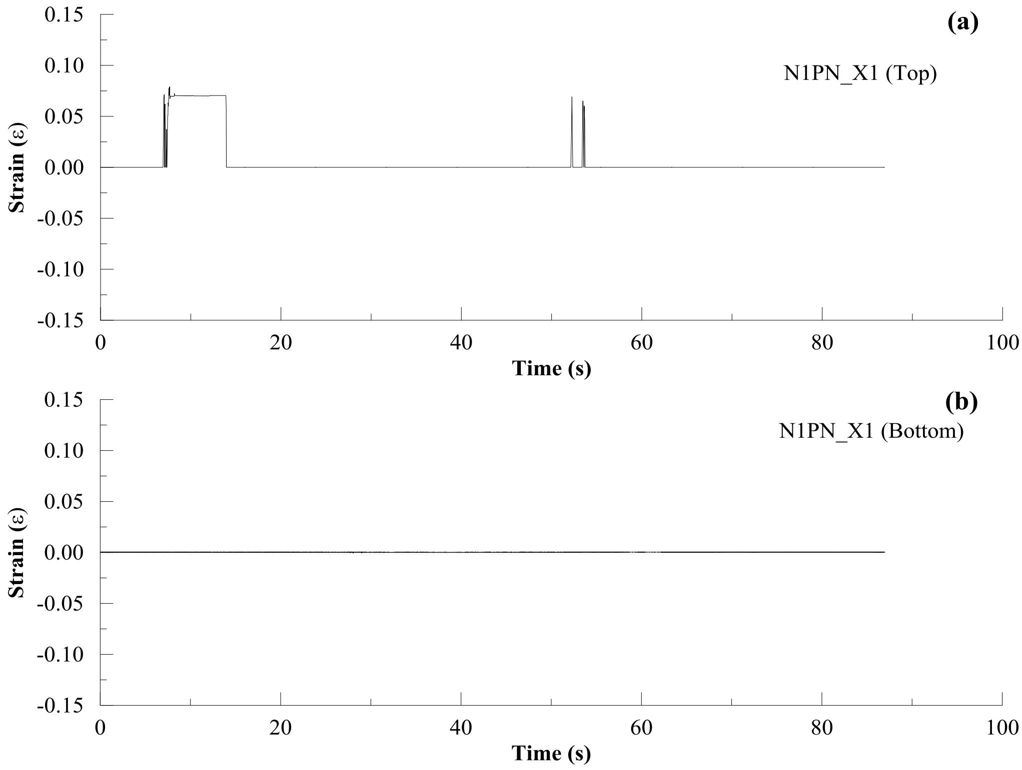

Figure 4. 5 Strain vs. time due to wave forces for test no. N1PN_X1, top strain gauge (a), bottom strain gauge (b)

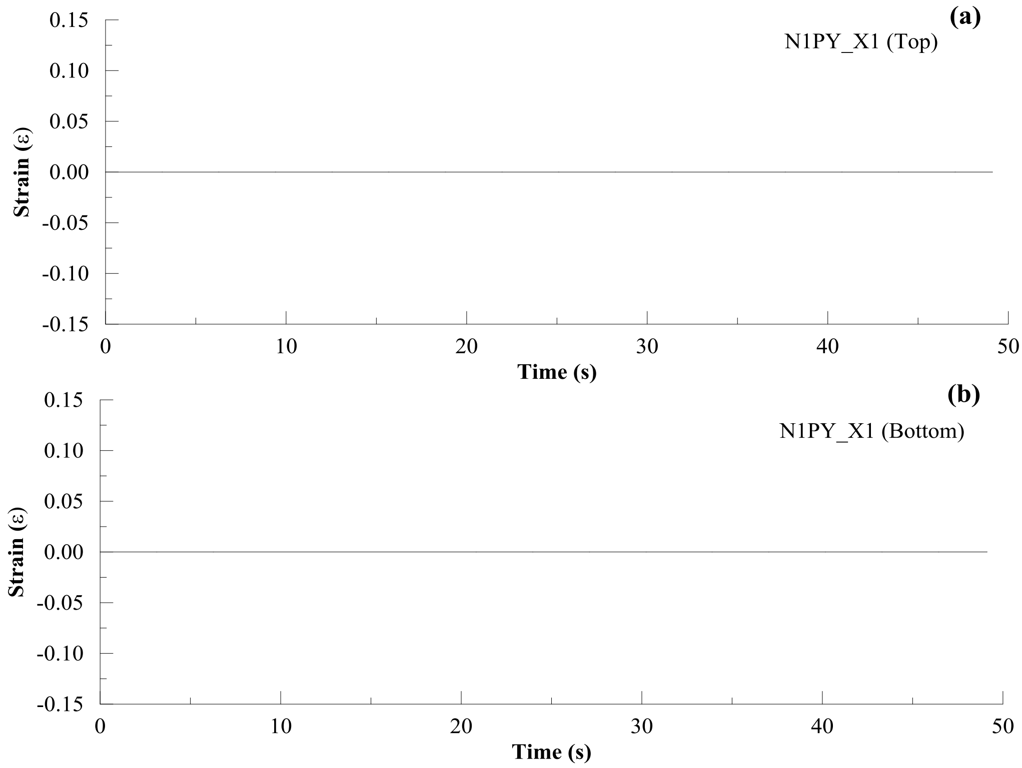

Figure 4. 6 Strain vs. time due to wave forces for test no. N1PY_X1, top strain gauge (a), bottom strain gauge (b)

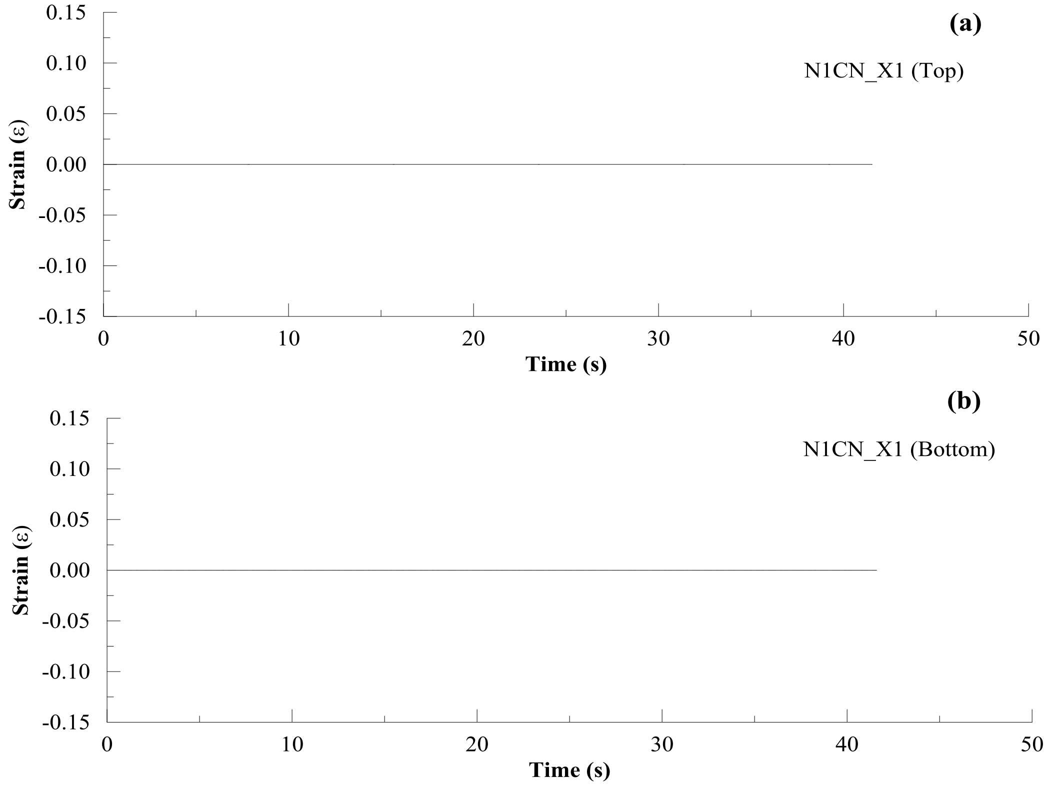

Figure 4. 7 Strain vs. time due to wave forces for test no. N1CN_X1, top strain gauge (a), bottom strain gauge (b)

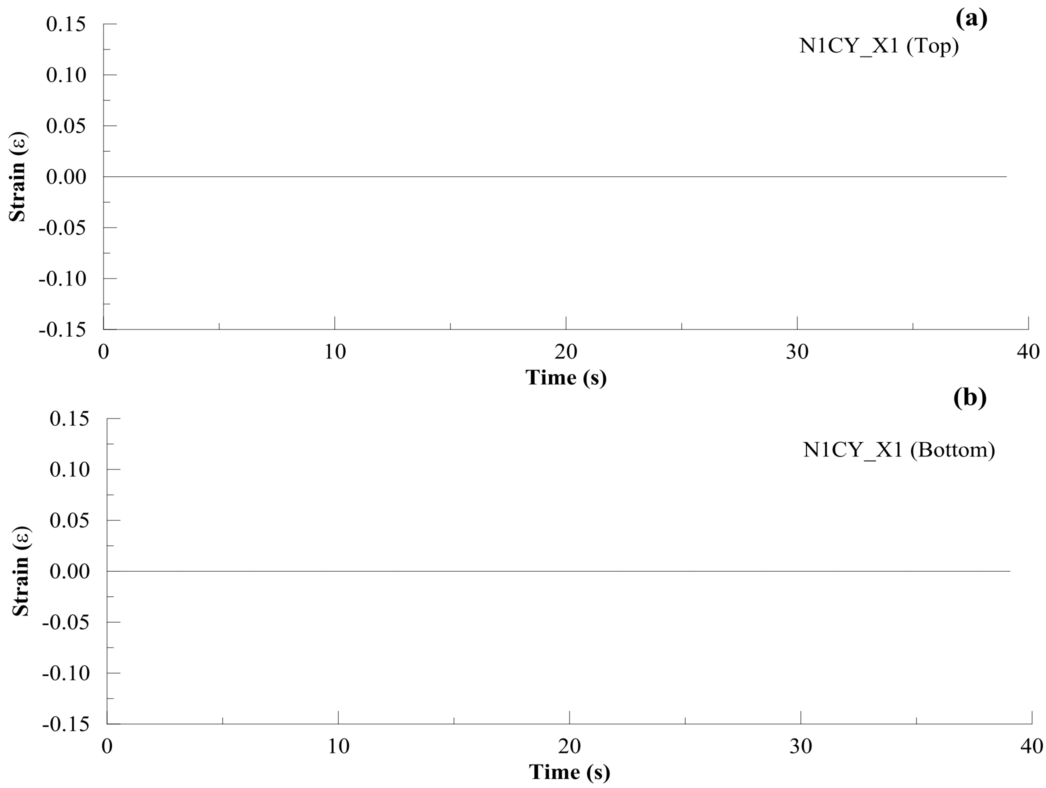

Figure 4. 8 Strain vs. time due to wave forces for test no. N1CY_X1, top strain gauge (a), bottom strain gauge (b)

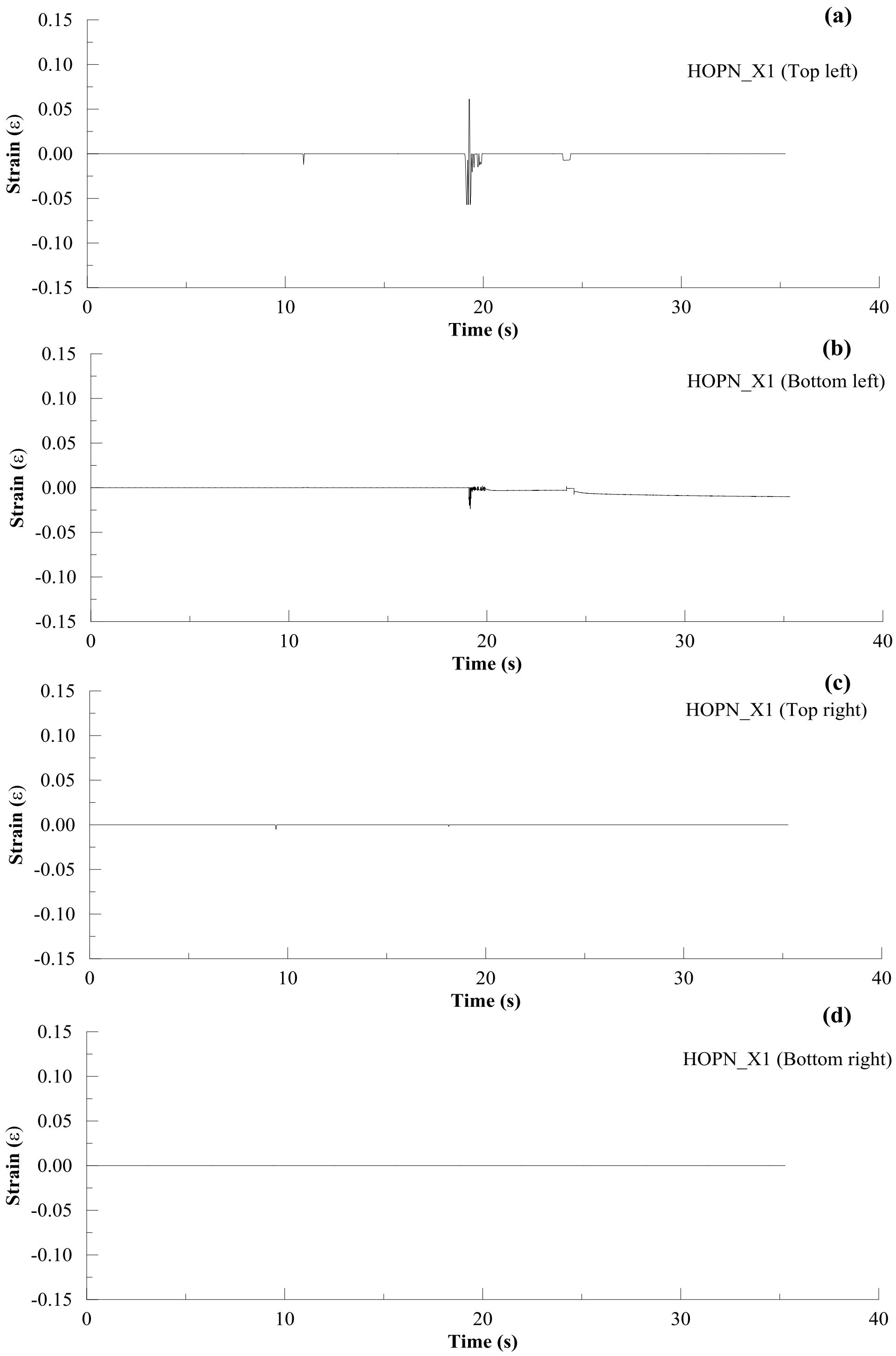

Figure 4. 9 Strain vs. time due to wave forces for test no. HOPN_X1, top left strain gauge (a), bottom left strain gauge (b), top right strain gauge (c), bottom right strain gauge (d)

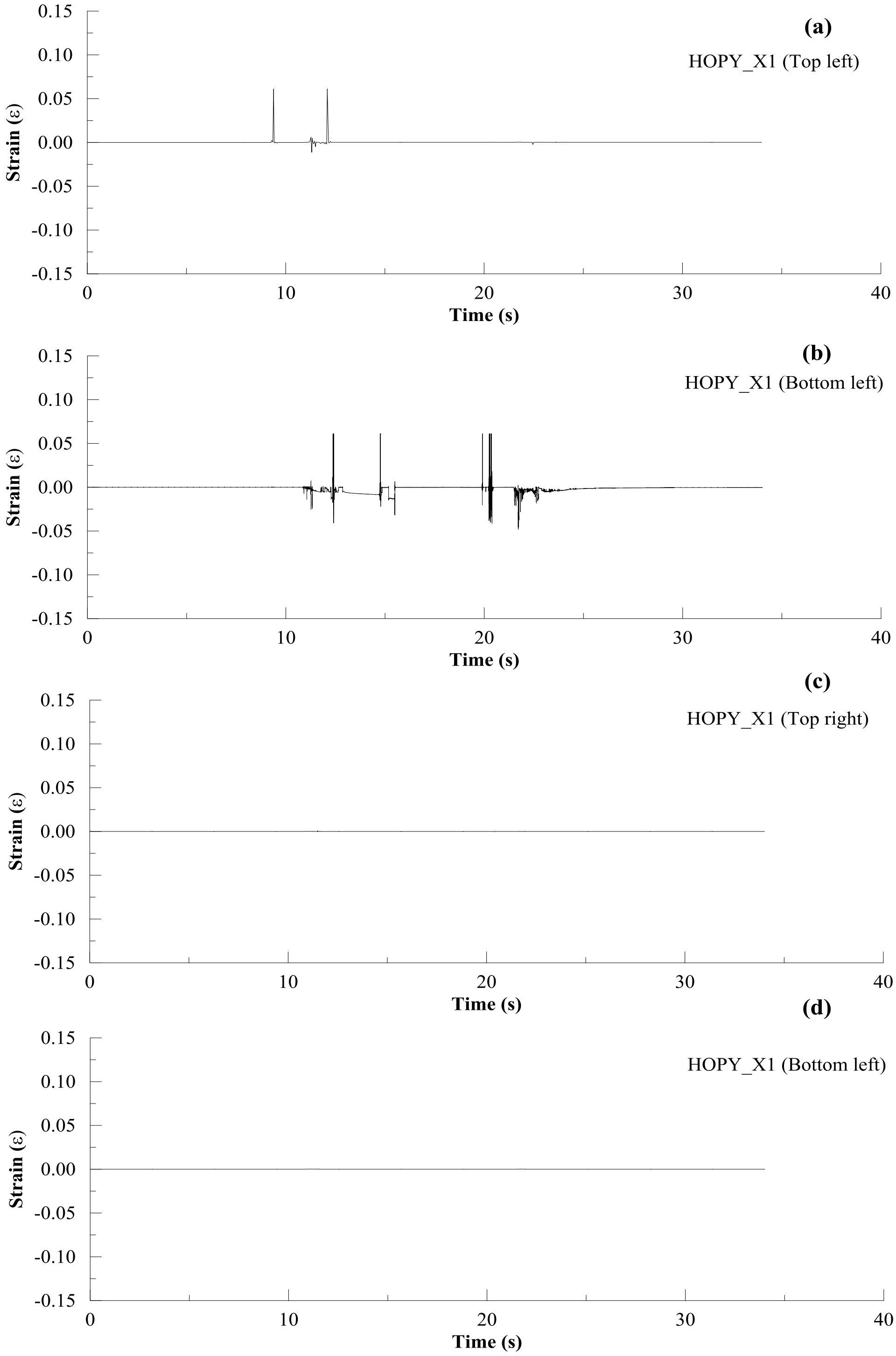

Figure 4. 10 Strain vs. time due to wave forces for test no. HOPY_X1, top left strain gauge (a), bottom left strain gauge (b), top right strain gauge (c), bottom right strain gauge (d)

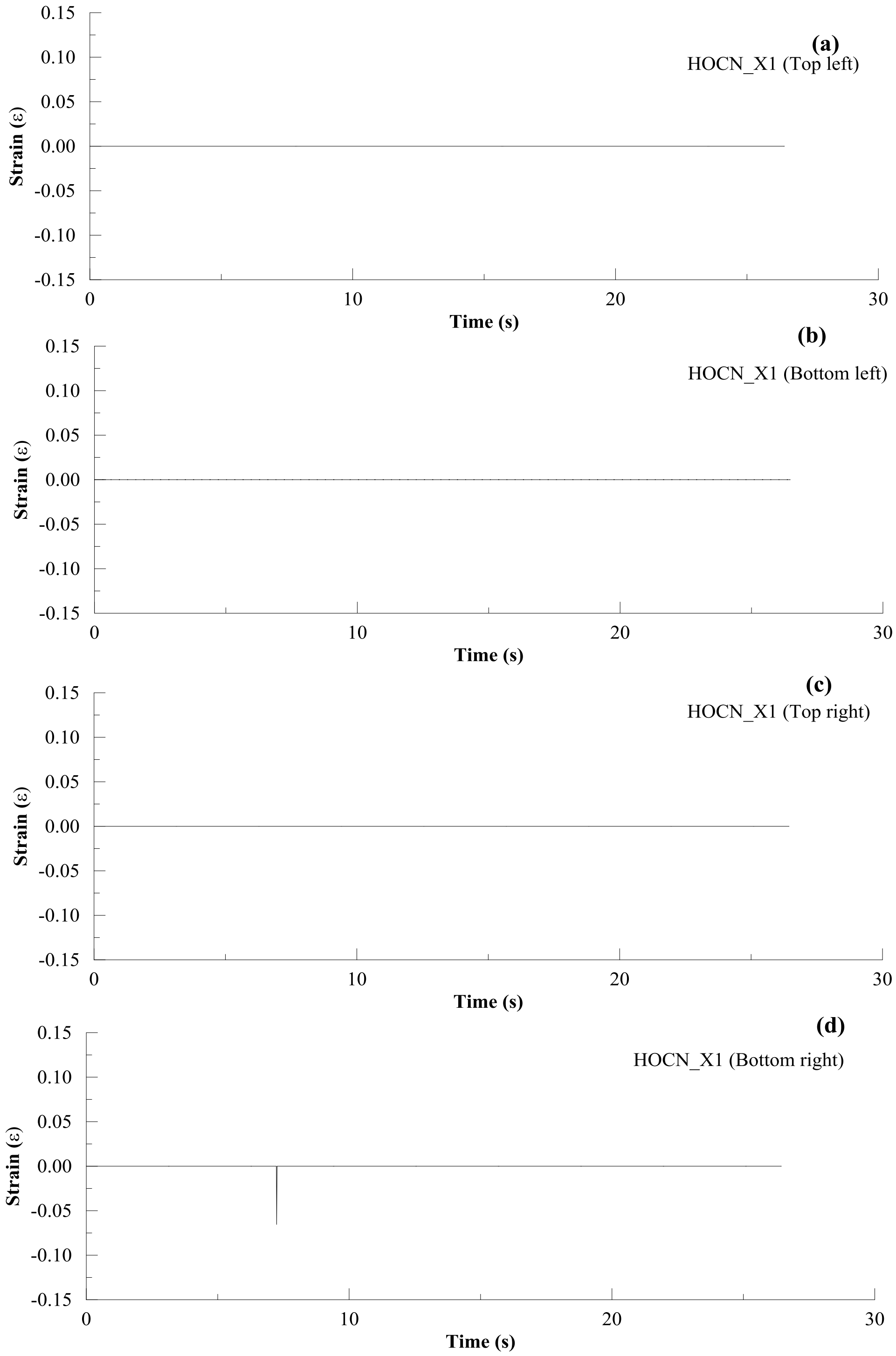

Figure 4. 11 Strain vs. time due to wave forces for test no. HOCN_X1, top left strain gauge (a), bottom left strain gauge (b), top right strain gauge (c), bottom right strain gauge (d)

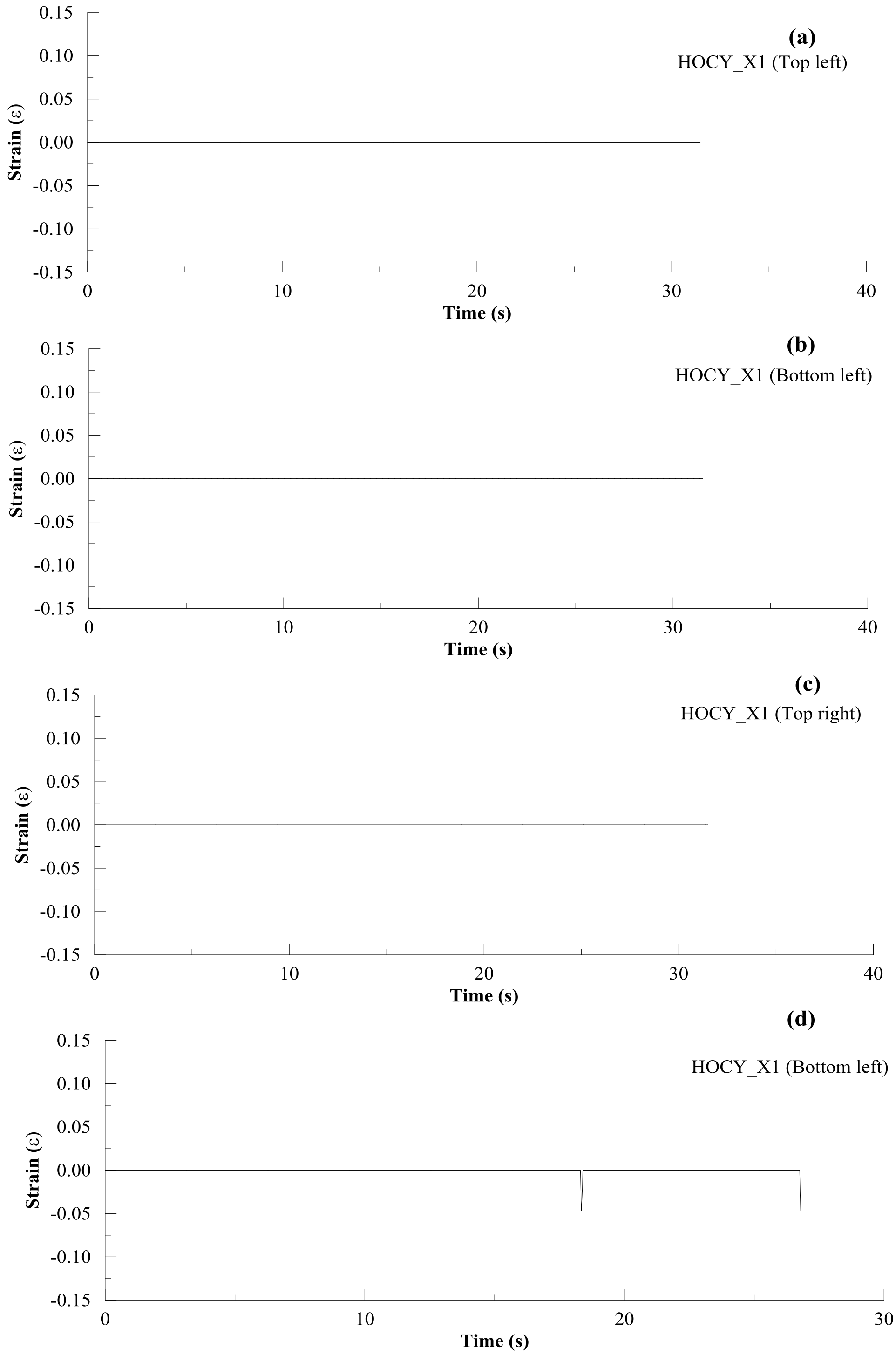

Figure 4. 12 Strain vs. time due to wave forces for test no. HOCY_X1, top left strain gauge (a), bottom left strain gauge (b), top right strain gauge (c), bottom right strain gauge (d)

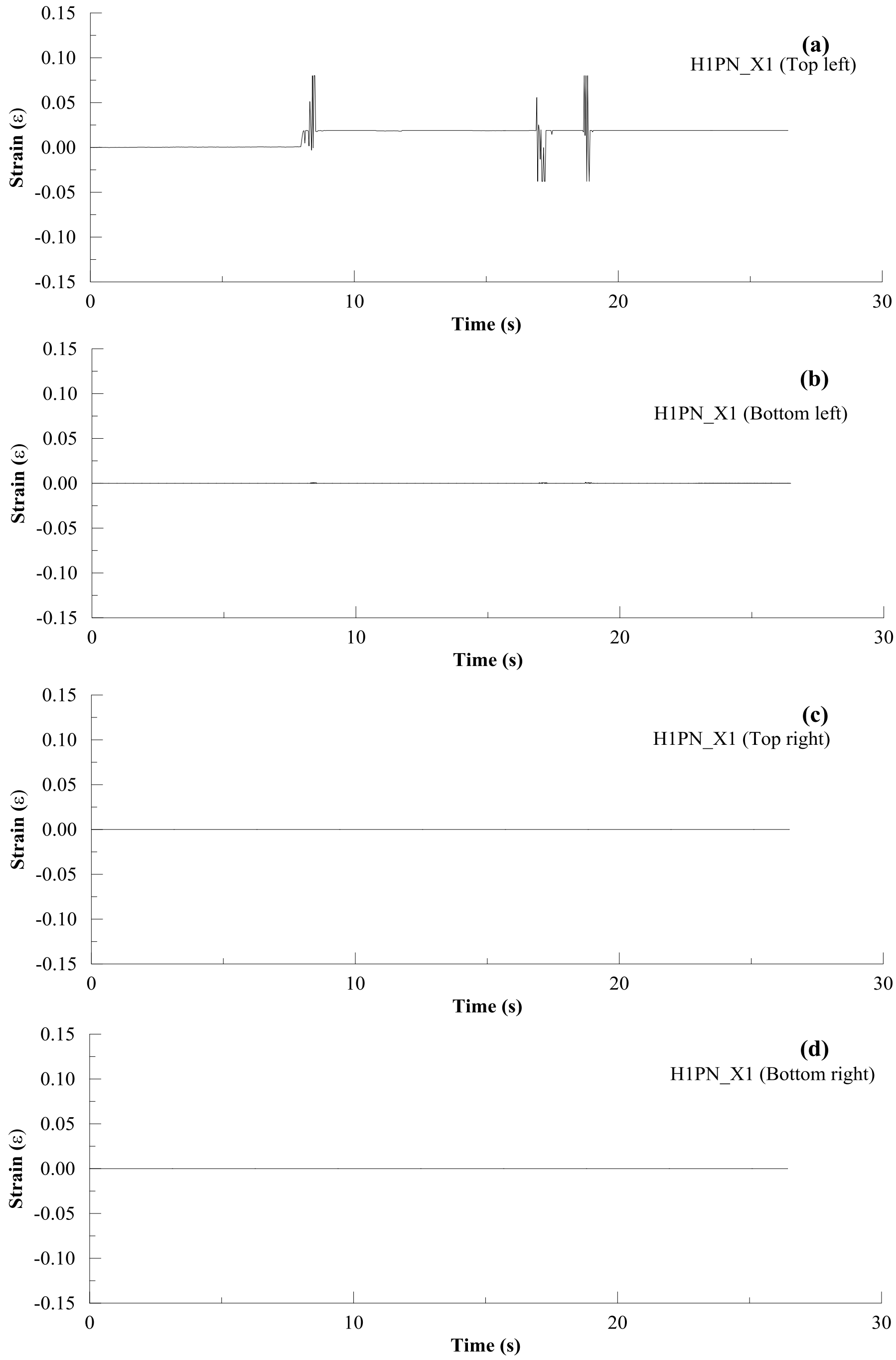

Figure 4. 13 Strain vs. time due to wave forces for test no. H1PN_X1, top left strain gauge (a), bottom left strain gauge (b), top right strain gauge (c), bottom right strain gauge (d)

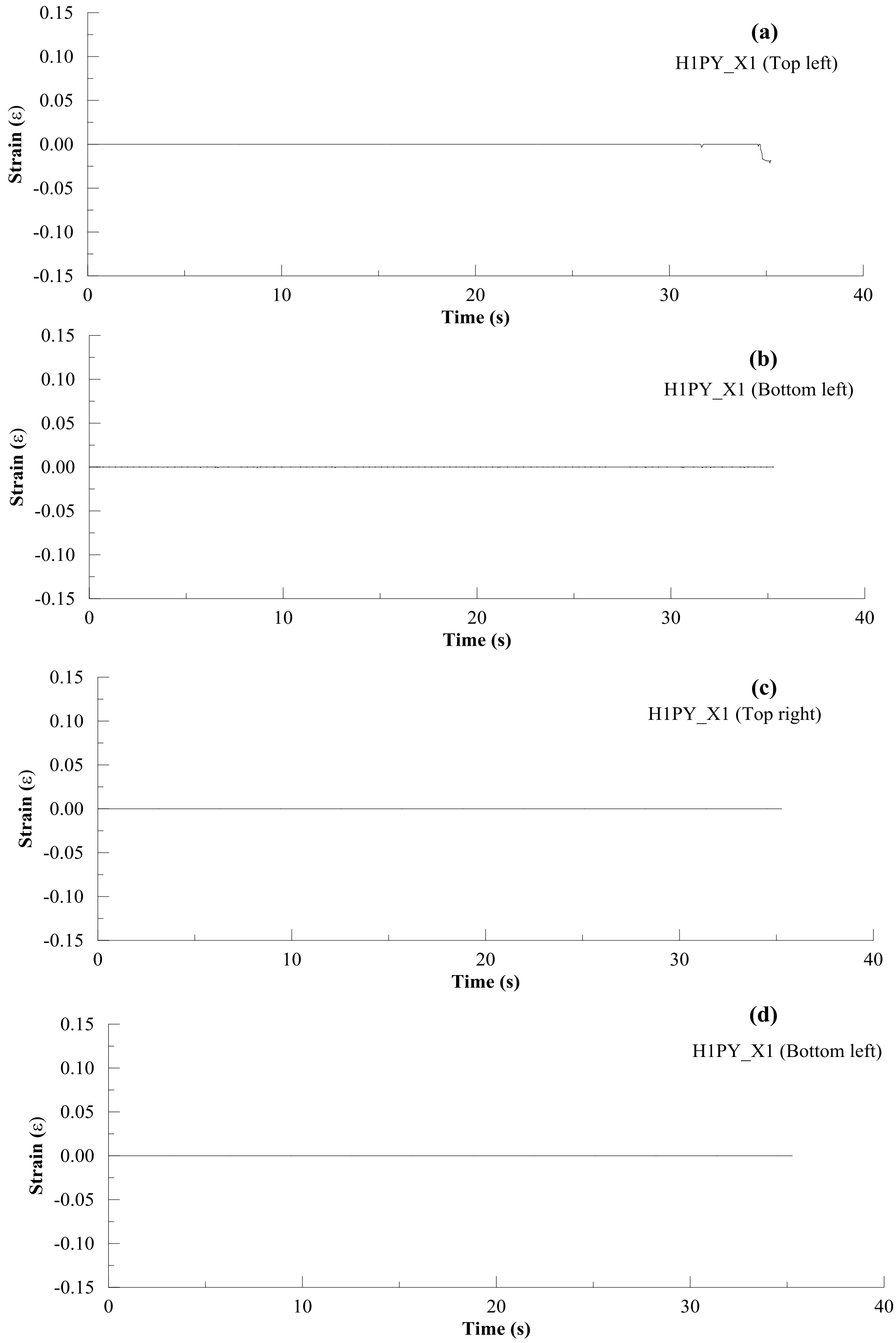

Figure 4. 14 Strain vs. time due to wave forces for test no. H1PY_X1, top left strain gauge (a), bottom left strain gauge (b), top right strain gauge (c), bottom right strain gauge (d)

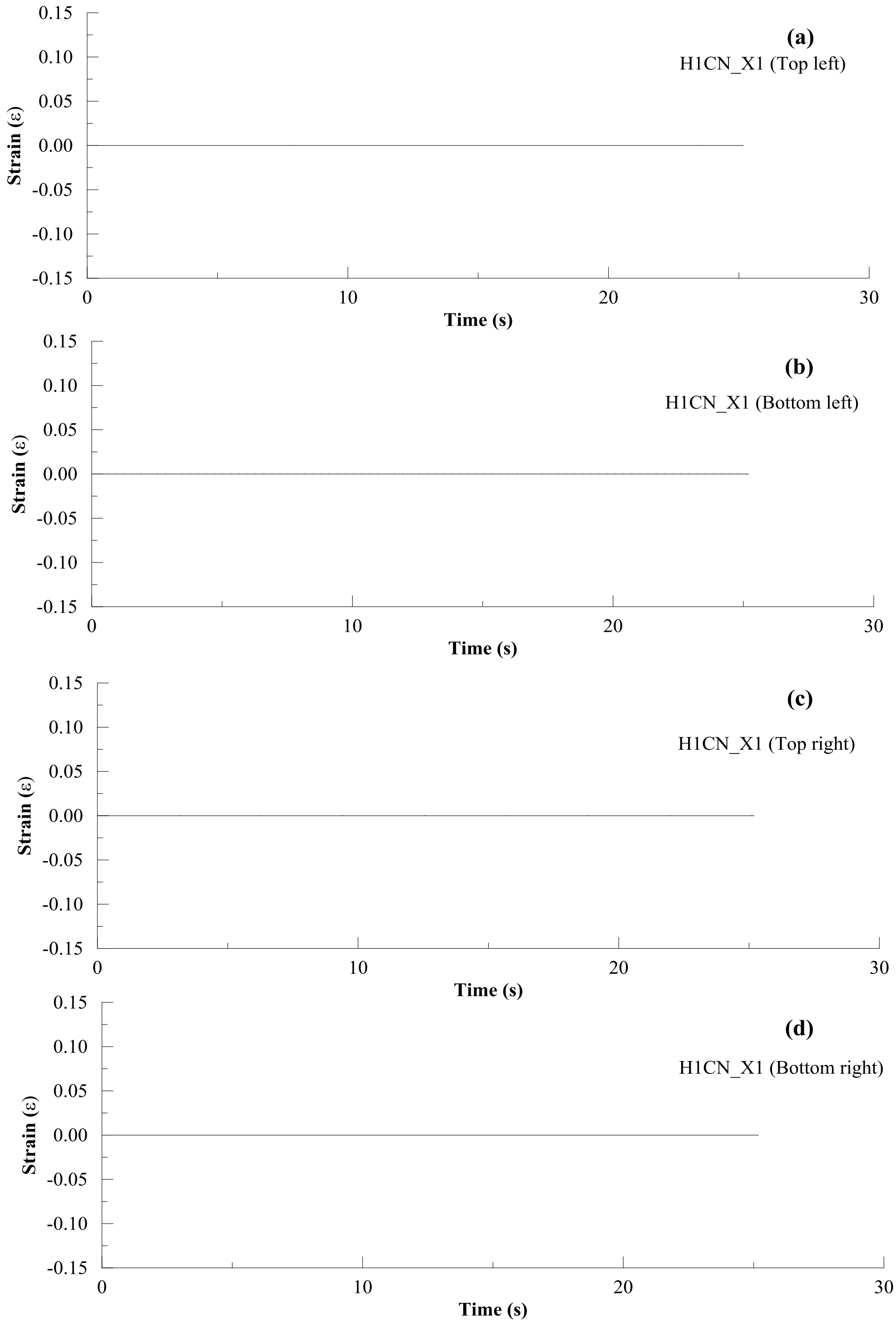

Figure 4. 15 Strain vs. time due to wave forces for test no. H1CN_X1, top left strain gauge (a), bottom left strain gauge (b), top right strain gauge (c), bottom right strain gauge (d)

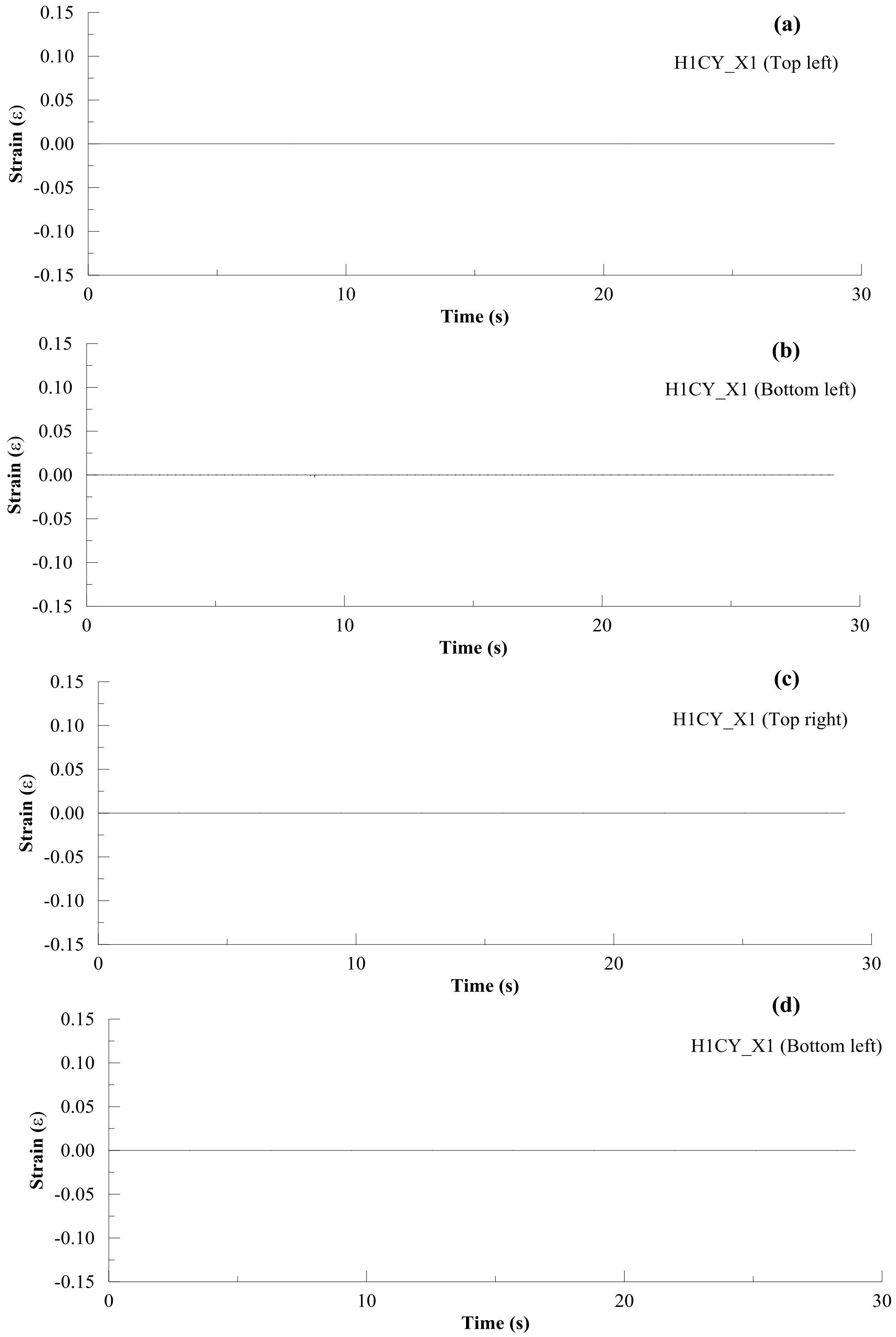

Figure 4. 16 Strain vs. time due to wave forces for test no. H1CY_X1, top left strain gauge (a), bottom left strain gauge (b), top right strain gauge (c), bottom right strain gauge (d)

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this research, a system was designed and built to simulate the tsunami. It comprised a steel chamber for housing simulated beach and sea and a steel frame connecting with a drop weight made from concrete. Model houses having different wall forms were built and installed to withstand the simulated tsunami. At the house wall strain gauges were installed in order to measure the strain generated due to the deflection of the wall during being impacted by the wave forces. A data acquisition system was also employed to measure and record the signals for further analysis. In addition, digital video camera was utilised to record the behaviour of the waves during being in the sea and hitting the walls.

This research attempted to find a form of one-storey house being constructed on beaches that are prone to tsunami. The aim was to minimise the impact caused by a tsunami so that the main structure of a house remains intact, even other minor structures destroyed. Based on reviewing the literature indirectly or directly related to this research and the test results, the following conclusions have been drawn.

(1) The highest strain was observed on the normal wall house having plane walls and being on the ground.

(2) When the house has a hollow in the middle, with the slab being raised to 1 m above the ground and having curve walls, it was found that the strain is zero. This owes to two facts: (1) the slab was raised so the waves could not reach the wall, and (2) even some waves reached the walls but the impact was minimal thereby not enough energy to bend the wall.

(3) Comparing with the same house forms, the one that had curve walls generated less strain that the one that had plane walls.

(4) Comparing between the normal wall and hollow house, it was found that the latter generates much lower stain levels.

(5) Comparing between the same house forms, it was found that the one that its slab was raised to 1 m above the ground generates less strain.

(6) Overall, the best performance in terms of reducing the wave forces was the hollow wall house with curve walls and its slab was raised to 1 m above the ground. From this conclusion, its form may be employed for future construction of a house to be constructed on a beach that is prone to the tsunami.

5.2 Recommendation for Future Work

Based on the experiences, test results, and analyses, the following recommendations have been drawn.

(1) Different types of soil should be used to model a beach in order to observe the erosion behaviour during being hit by a tsunami.

(2) Different types of dropping weight (or other system having similar purpose) should be further studied in order to obtain a tsunami that is very similar the real one.

(3) Other forms of house should also be studied. For example, a house having multi-curve walls at the front. In addition, the multi-curve walls should also be altered to have different radii and width.

(4) Other instruments or sensors should be employed to collect more data. For example, a sensor capable of indicating a wave height should be installed. This data could be very useful for synchronising with the strain measured. It would provide a more details with respect to the tsunami being flooded towards a structure.

5.3 Output of This Research

Some parts of this research is being submitted to a national conference organised by Kasetsart University, Kampaengsaen Campus. It will be presented and published during 8 – 9 December, 2016.

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