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RESEARCH REPORT

(รายงานการวิจัย)

ON

# UTILISATION OF RECYCLED TYRES AND INCINERATOR BOTTOM ASH AS LOW-COST EARTHQUAKE BUFFER

# (การใช้ยางรถยนต์รีไซเคิลและเถ้าเตาเผาขยะเป็นตัวกันชนแรงแผ่นดินไหวราคาถูก)

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(ได้รับการสนับสนุนทุนวิจัยจากมหาวิทยาลัยเทคโนโลยีราชมงคลศรีวิชัย งบประมาณแผ่นดิน พ.ศ. 2559)


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# คำนำ

งานวิจัยนี้ศึกษาความเป็นไปได้ของการใช้ส่วนผสมระหว่างเถ้าเตาเผาขยะและยางรถยนต์ใช้แล้วย่อยเพื่อเป็นวัสดุดินฐานราก โดยมีวัตถุประสงค์เพื่อลดแรงสั่นสะเทือนจากเหตุการณ์แผ่นดินไหวที่จะส่งถ่ายต่อไปยังโครงสร้างส่วนบน การศึกษาทำได้โดยการเตรียมชั้นดินจำลองในกระบะเหล็ก ประกอบด้วยชั้นดินทรายอยู่ด้านล่าง และชั้นบน (จนถึงผิวดิน) คือส่วนผสมเถ้าฯ และยางฯ ที่มีสัดส่วนต่างๆ กัน จากนั้นจึงติดตั้งบ้านพักอาศัยจำลองสองหลัง ประกอบด้วยบ้านหนึ่งชั้นและสองชั้น ที่ระดับใต้ดินได้ฝังตัวจุดระเบิดสำหรับการสร้างแรงสั่นสะเทือน นอกจากนั้นยังได้ติดตั้งเซ็นเซอร์วัดความเร่ง (Accelerometer) จำนวน 3 ตัว ที่ผิวดิน บริเวณหลังคาของบ้านชั้นเดียวและสองชั้น เพื่อวัดแรงสั่นสะเทือนที่เกิดขึ้นทั้งบนพื้นดินและตัวบ้าน การทดสอบกระทำโดยสภาพชั้นดินทรายมีสองสถานะคือแห้งและอิ่มตัว ผลการศึกษาเบื้องต้นแสดงให้เห็นว่า กรณีชั้นดินทรายแห้ง การเพิ่มขึ้นของปริมาณยางฯ จะทำให้แรงสั่นสะเทือนในชั้นดินมีค่าเพิ่มขึ้น หรืออีกนัยหนึ่งทำให้เกิดการขยายตัวของคลื่นสั่นสะเทือน (Amplification) แต่สำหรับกรณีชั้นดินทรายอิ่มตัว กลับพบว่าการเพิ่มปริมาณยางฯ กลับส่งผลให้แรงสั่นสะเทือนในพื้นดินลดลง ผลการศึกษานี้อาจแสดงถึงความเป็นไปได้ในการใช้ส่วนผสมดังกล่าวสำหรับเป็นดินฐานรากในเขตพื้นที่แผ่นดินไหว ซึ่งอาจช่วยลดความเสียหายของโครงสร้างส่วนบนลงได้

นักวิจัยได้เลือกภาษาอังกฤษสำหรับการเขียนรายงานวิจัยฉบับนี้ เนื่องจากวัตถุประสงค์หลักอีกอย่างหนึ่งของโครงการวิจัย คือ การนำผลงานวิจัยออกไปเผยแพร่ในระดับนานาชาติ ซึ่งหมายความว่าต้องใช้ภาษาอังกฤษเป็นภาษาหลัก ดังนั้นการเขียนรายงานวิจัยเป็นภาษาอังกฤษจะทำให้สามารถนำผลการวิจัยออกไปเผยแพร่ในระดับนานาขาติได้ทันทีไม่ต้องมีการเขียนใหม่เป็นครั้งที่สอง หรืออาจมีการปรับปรุงเพียงเล็กน้อยเมื่อมีข้อมูลใหม่เพิ่มเติมเข้ามา

อนึ่ง เนื่องจากภาษาอังกฤษไม่ใช่ภาษาแม่ของนักวิจัย ดังนั้นข้อผิดพลาดทางด้านภาษา เช่น หลักไวยกรณ์ต่างๆ อาจเกิดขึ้นได้ กรณีที่มีข้อผิดพลาดใดๆ ที่เกี่ยวข้องกับหลักการใช้ภาษาอังกฤษ ผู้วิจัยขอน้อมรับไว้แต่เพียงผู้เดียว

งานวิจัยครั้งนี้สำเร็จลงได้ตามแผนงานวิจัย ก็เนื่องจากว่าได้รับความช่วยเหลือจากหลายฝ่าย โดยเฉพาะในส่วนของงบประมาณโครงการ ซึ่งได้รับการสนับสนุนจากมหาวิทยาลัยเทคโนโลยีราชมงคลศรีวิชัย งบประมาณแผ่นดิน พ.ศ. 2559 ซึ่งผู้วิจัยขอกราบขอบพระคุณมา ณ ที่นี้ เป็นอย่างสูง

# ABSTRACT

In the past solid wastes were simply dumped in open areas. Then, landfills were utilised. Nonetheless, the wastes have been growing to the point that burying is unpractical. Hence, incinerators have been employed. This leaves another waste called incinerator ash that also requires treatment. Since the invention of a motor car decades ago the number of car sales is still going strong. This, as well, results in the huge amount of discarded tyres required to be properly managed. This study attempted to make use of those two wastes as foundation soil to buffer the ground vibration transmitted to superstructures. It was done by first constructing a 50 cm thick sand layer in a 120 cm diameter steel chamber. During the construction an explosive detonator was installed at 10 cm from the bottom. Overlying the sand was a 25 cm thick compound incinerator bottom ash-tyre chip (IBA-TC) having the by-weight IBA to TC ratios of 100:0, 95:5, 90:10: 75:25, 40:60, and 0:100. A total of three accelerometers were installed: one on the ground (G1) and the other two over the roofs of one- and two-storey houses (G2 and G3, respectively). Note that the sand was prepared to be two states: dry (DS) and saturated (SS). After the set-up completed the detonator was ignited; the ground acceleration as well as the accelerations induced on the houses were monitored and recorded. The results showed that, for the DS the acceleration is virtually increased with increasing TC. This, however, was contrary to that of the SS as the ground acceleration gradually decreases with the increase of TC. Furthermore, it was found that the percentage reductions for G2 and G3 with respect to G1 for the case of SS are quite higher than those for the case of DS. These findings suggest that both wastes may be employed as foundation soil to buffer the vibration transmitted to superstructures.

**Keywords**: Incinerator bottom ash; Tyre chips; Earthquake; Seismic isolator

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# NOTATION

| | |
|---|---|
| $C_g$ | Coefficient of curvature |
| $C_u$ | Coefficient of uniformity |
| $D_{10}$ | Maximum particle size that has 10% of mass that is smaller |
| $D_{30}$ | Maximum particle size that has 30% of mass that is smaller |
| $D_{50}$ | Average particle size |
| $D_{60}$ | Maximum particle size that has 60% of mass that is smaller |
| D-A0 | Dry, IBA = 0, Tyre = 100 |
| D-A40 | Dry, IBA = 40, Tyre = 60 |
| D-A75 | Dry, IBA = 75, Tyre = 25 |
| D-A90 | Dry, IBA = 90, Tyre = 10 |
| D-A95 | Dry, IBA = 95, Tyre = 5 |
| D-A100 | Dry, IBA = 100, Tyre = 0 |
| W-A0 | Wet, IBA = 0, Tyre = 100 |
| W-A40 | Wet, IBA = 40, Tyre = 60 |
| W-A75 | Wet, IBA = 75, Tyre = 25 |
| W-A90 | Wet, IBA = 90, Tyre = 10 |
| W-A95 | Wet, IBA = 95, Tyre = 5 |
| W-A100 | Wet, IBA = 100, Tyre = 0 |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Research context

Planet earth has been continuously changing in terms of physical due to many reasons. The earth's crust is actually quite thin compared with the diameter of the earth. At the depth below the crust is molten rock in which it is flowing all the time. One of the most important aspects of the crust is that it comprises several plates interconnected. It should be noted that the continuous movement of the molten rock has been called convection. The flowing of the molten rock is one of the causes for volcano activities along the boundary between plates. In addition, it also continuously drives the plates thereby causing them to move either against each other or away from other plates. This movement is one of the causes triggering major earthquakes. Note that each year around 10,000 people die from the earthquake (Elnashai and Sarno, 2008). Unfortunately, even with current technology and knowledge, we still unable to precisely predict an earthquake incident with respect to where, when, and magnitude.

Even though Thailand is not located along the ring of fire in which major earthquakes frequently occur, it does not mean the country is completely safe from earthquakes and tsunamis. As evident in the 26 December 2004 earthquake that causes huge damage to the western coastline, particularly the loss of lives of both foreigners and Thais. The way of life for some Thais is to reside very close to the tsunami-prone beaches because of their careers and close biding with original land. Furthermore, beautiful beaches are the attraction for both foreign and Thai tourists. Another example recently observes was the 5 May 2014 earthquake in Chiang Rai at which huge damage was created. In addition, the loss of some lives was invaluable.

In facts, every year almost same numbers of earthquake occur. In the past, however, Thailand had no seismic stations to observe and record the incidents. Thus, there have not been records and reports with respect to the earthquake incidents. It should be noted that the earthquake-prone areas in Thailand are mostly located in the North and West. Some parts in the South are also prone to minor earthquakes. Thus, civil engineering design in such areas must take into account for the vibration generated by an earthquake. Otherwise, damage experienced in Chiang Rai would come back to haunt us.

Thailand is increasing facing the environmental problem concerning the accumulated numbers of discarded tyres. For example, disposing huge amount of used tyres in open areas is prone to fire, whether by accidents or by intensions. When this happens, it would be very difficult to cease the fire because they are very good for burning. Then, there would be consequences such as the groundwater may be contaminated when the burnt tyres are brought into underground. The contaminated groundwater then needs over hundreds of years to become clean again. It is therefore essential for Thailand to sensibly consider this problem. For instance, solutions must be sustainable, i.e., they must not create consequent and associated problems, cheap to operate, and conserve the environment.

Therefore, in the future Thailand should have some kinds of regulation or law concerning the management for those industrial wastes in order to prevent probably environmental problems might be created. It should be noted herein that the United States of America and Europe have been imposing the laws concerning these wastes for some times. For example, since 2003 disposing of whole used tyres in the EU have been prohibited. In case of tyres required to be thrown away, they must be undergone some processes first, e.g., be shredded to have smaller size. Nonetheless, this process must be carried out by authorised privates (Khalid and Artamendix, 2004). Note that in the UK in the past discarded tyres were frequently burnt to obtain the heat for producing electricity. This operation of course created the air pollution. Therefore, burning used tyres were completely prohibited.

As population is increasing the wastes generated is also growing. In Thailand, the common practice for municipal waste is just simply dumping and covering. This practice has led to several consequent problems, especially the environmental ones. The obvious one is that ground water located nearby a waste site is very likely to be contaminated. Recently, land for dumping the waste is quite scarce. As a result, there have been attempts to build incinerators. In southern Thailand, there are three of them, located in Phangan, Phuket, and Hatyai. It should be emphasised that the left over from burning wastes is ashes, call incinerator ashes, comprising fly- and bottom- ashes. These ashes, however, still need to be properly managed in order to not generate further associated problems.

This research wanted to utilise discarded tyres and incinerator bottom ashes regarded as solid waste. It could be achieved by first mixing them; and, then employed as earthquake buffer. These mixtures were employed as foundation soil (material) located both underneath and surrounding structures in order to absorb the vibration generated by earthquakes. This would somewhat reduce the vibration transmitted to superstructure thereby softening the damage created. The benefits of the search are that both wastes can be utilised instead of just throwing away. In addition, overall construction would be decreased as the wastes can be obtained with no cost.

## 1.2 Research objectives

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

1) Investigate the properties of recycled tyre chips.
2) Investigate the properties of incinerator bottom ashes.
3) Investigate and experiment the mixtures of recycled tyre chips and incinerator bottom ashes.
4) Investigate the efficiency of compound tyre chips-incinerator bottom ashes in terms of vibration reduction.
5) Propose a mixture between the tyre chips and incinerator bottom ashes that could mostly reduce the vibration generated by earthquakes.

## 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 an earthquake. 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 technique for generating a simulated earthquake. In addition, methods for reducing the vibration caused by earthquake are also studied.
2) Prepare and purchase all materials required, including accelerometers and their associated instruments for measuring and recording the vibration during testing.
3) Design and build a chamber for housing model soil layer as well as model houses. Note that the chamber must be strong enough to withstand the vibration.
4) Perform underground explosion to obtain appropriate vibration levels similar to those generated by earthquakes.
5) Perform seismic tests on the model housed having been installed with accelerometers. The houses are constructed over the mixtures between tyre chips and incinerator bottom ashes.
6) Analyse the data obtained from the experiments; compare the results with other earthquake buffer materials.
7) Prepare a final research report.

## 1.4 Expected outcome

This research project wished to obtain the basic and mechanical properties in terms of vibration resistance of the mixtures between recycled tyre chips and incinerator bottom ashes. Then, propose appropriate mixtures in order to be used as earthquake buffer that is very cheap to obtain.

## 1.5 Layout of report

This report begins with chapter 1 that provides some introductory remarks with respect to the importance for conducting this research project, especially basic earthquake engineering. It also includes the 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 the experiments in terms of providing the methods that other investigators had done.

Chapter 3 simply provides readers concerning materials, methods, and test programmes 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

Of all of the natural disasters, it may be said that the earthquake is one of the most deadly incidents. It should be noted that each year several thousand earthquakes occur. Nonetheless, only about 20 major earthquakes are observed. This phenomenon has continuously been happening since the beginning of the earth. In the past the world's population was incomparable to this current number, i.e., very few. Thus, when an earthquake struck the damage to humans was virtually zero. Nowadays, however, so many people are living in smaller areas. Unfortunately, some of those populated areas are located in seismic-prone zones. Therefore, in the last decades we have constantly experienced with so many injuries and damage when a major earthquake strikes. With current knowledge and technologies, we still cannot predict when an earthquake will strike. This is because the mechanism involving earthquake shaking is very complex.

This chapter reviews and summarises the information related both directly and indirectly to this research, including waste tyres, incinerator bottom ashes, earthquake and its consequences, and seismic isolation techniques. Note that the last one was the main theme of this research.

## 2.2 Waste tyres

Every year around the world enormous amounts of tyres are discarded. This is an ongoing problem concerning the environment. The tyres we have seen are one of the most complex engineering products. They may be grossly classified as the tyres for passenger car tyre, lorry tyre, and off-the-road tyre (OTR). Their main components comprise numerous different rubber compounds, many different types of carbon black, fillers like clay and silica, and chemical and minerals added to allow or accelerate vulcanisation. Recently, they also have several types of fabric for reinforcement and several kinds and sizes of steel wires. Because of those complex compositions it is difficult to recycle them (WRAP, 2006). Table 2.1 displays main components for all three types of tyres. Figure 2.1 shows typical parts of a passenger car tyre.

**Table 2. 1 Compositions for tyres (WRAP, 2006)**

| Ingredient | Passenger Car Tyre | Lorry Tyre | OTR Tyre |
|---|---|---|---|
| Rubber/Elastomers[1] | ∀47% | ∀45% | ∀47% |
| Carbon Black[2] | ∀21.5% | ∀22% | ∀22% |
| Metal | ∀16.5% | ∀25% | ∀12% |
| Textile | ∀5.5% | -- | ∀10% |
| Zinc Oxide | ∀1% | ∀2% | ∀2% |
| Sulphur | ∀1% | ∀1% | ∀1% |
| Additives[3] | ∀7.5% | ∀5% | ∀6% |
| Carbon-based materials, total[4] | ∀74% | ∀67% | ∀76% |

1 Lorry & OTR tyres contain higher proportions of natural rubber than passenger car tyres.
2 Silica replaces part of the carbon black in certain types of tyres
3 Some of the additives include clays, which may be replaced in part in some tyres with recycled rubber crumb from waste tyres
4 These approximate totals would be slightly higher if clays were replaced by recycled crumb rubber from waste tyres

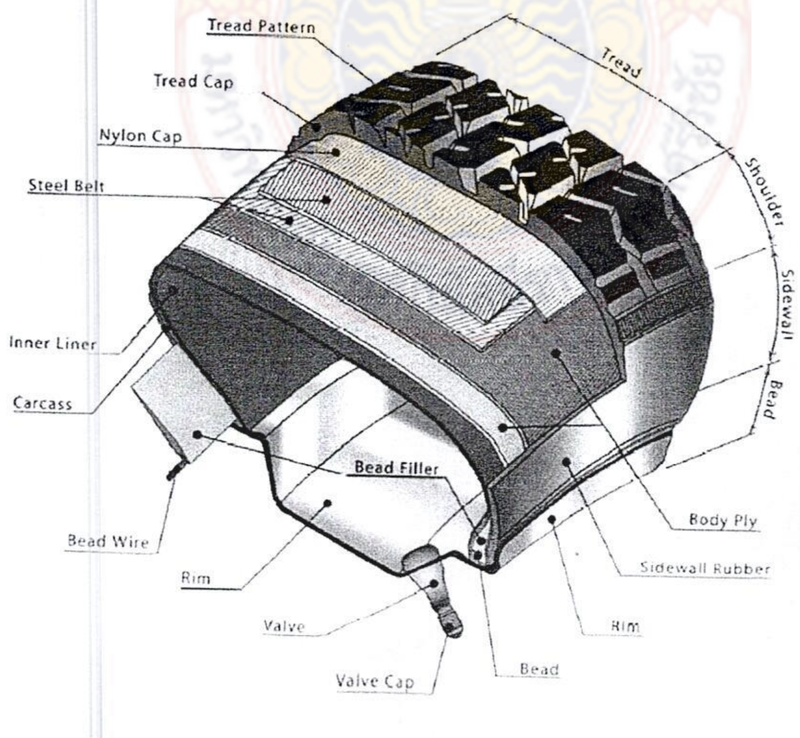


**Figure 2. 1 Typical parts of a passenger car tyre (WRAP, 2006)**

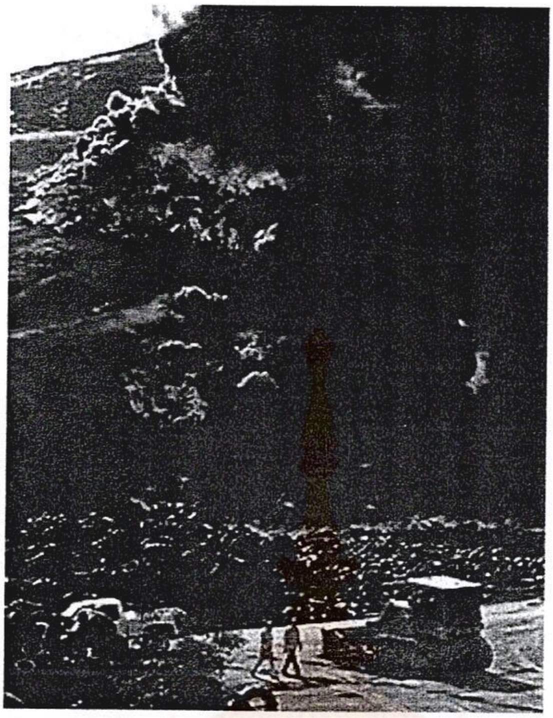

**Figure 2. 2 Tyre fire in Stanislasu Company, California in 1999 (Reschner, 2008)**

As seen in table 2.1 and figure 2.1, attempting to recycle tyres is definitely problematic because it may result in other problems, especially ones concerning the environment. According to Reschner (2008), in developed countries one could generate around 9 kg of scrap tyres a year. In the USA, it has been estimated that 2 to 3 billion scrap tyres are stockpiled throughout the country. These figures may also be similar to her counterparts in Europe. One of the most hazards associated with scrap tyres is large fires, both intentionally and accidently. This is because when a fire has been ignited in a pile of scrap tyres, it would be very difficult to extinguish. In the case of a very large fire occurred in a pile of millions of tyres such as shown in figure 2.2, it would last for several days with the fume being visible for several kilometres. The consequences are that air and soil would be polluted. Thus, the scrap tyres are required to be properly managed.

An interesting numbers with respect to the scrap tyres in Europe during 2006 are summarised and shown in table 2.2. As expected, the majority of the scrap tyres were generated by Germany, UK, France , Italy, and Spain. It can be observed that the recovery disposal comprises three main uses, including material, energy, and landfill. In Europe, the scrap tyres are being recycled for energy recovery, rubber recycling, landfilling, and civil engineering applications.

**Table 2. 2 Scrap tyres statistics for Europe 2006 (Reschner, 2008)**

| Scrap Tyre Generation in 1,000 t/a | | Trade with Used Tyres | | | Recovery Disposal | | |
|---|---|---|---|---|---|---|---|
| | | Sale | Export | Retread | Material | Energy | Landfill* |
| Austria | 55 | - | - | 4 | 16 | 35 | - |
| Belgium and Lux. | 82 | - | 2 | 3 | 28 | 35 | 14 |
| Bulgaria | 10 | - | - | - | - | - | 10 |
| Croatia | 15 | - | - | - | - | - | 15 |
| Cyprus | 5 | - | - | - | - | - | 5 |
| Czech Republic | 80 | - | - | 12 | - | - | 68 |
| Denmark | 45 | 1 | - | 5 | 38 | 1 | - |
| Estonia | 11 | - | - | 2 | 2 | - | 7 |
| Finland | 45 | - | - | 10 | 35 | - | - |
| France | 398 | 20 | 20 | 55 | 157 | 106 | 40 |
| Germany | 585 | 15 | 38 | 60 | 124 | 310 | 38 |
| Greece | 48 | 1 | - | 2 | 5 | 8 | 32 |
| Hungary | 46 | - | - | 5 | 18 | 16 | 7 |
| Ireland | 40 | 1 | 1 | 1 | 3 | - | 34 |
| Italy | 380 | 30 | 50 | 50 | 83 | 148 | 19 |
| Latvia | 9 | - | - | 2 | - | - | 7 |
| Lithuania | 9 | - | - | 2 | - | - | 7 |
| Malta | 1 | - | - | - | - | - | 1 |
| Netherlands (car tires only) | 47 | - | 13 | - | 13 | 21 | - |
| Norway | 47 | - | 1 | 7 | 23 | 16 | - |
| Poland | 146 | 1 | 1 | 21 | 10 | 56 | 57 |
| Portugal | 92 | 1 | 15 | 16 | 26 | 34 | - |
| Romania | 50 | - | - | 5 | 10 | 10 | 25 |
| Slovakia | 20 | - | - | - | 5 | 2 | 13 |
| Slovenia | 23 | - | - | 4 | - | - | 19 |
| Spain | 305 | 10 | 20 | 37 | 42 | 52 | 144 |
| Sweden | 90 | 1 | 7 | 16 | 32 | 34 | - |
| Switzerland | 54 | 1 | 13 | 7 | - | 25 | 8 |
| U.K. | 475 | 32 | 34 | 55 | 212 | 72 | 70 |
| Total: | 3,213 | 114 | 215 | 381 | 882 | 981 | 640 |

Source: European Tyre and Rubber Manufacturers Association 2006. Summary by Kurt Reschner
*) This figure also includes unknown means or disposal

The scrap tyres have been burnt to obtain energy for producing cement kilns. Other applications include paper mills and power plants. However, since this type of recycling causes consequent problems such as air and ground pollutions, it has been prohibited in many countries. It should be noted herein that this application has been termed as the use of tyre derived fuel (TDF) (Reschner, 2008).

It is worthwhile to mention that recycling means the re-use of a material for its originally intended purpose, e.g., old plastic bags can be reproduced as new ones. In the case of scrap tyres, however, recycling would mean the use of discarded tyres as a compounding ingredient for new tyres. In a broader sense, however, tyre recycling is referred to the process of grinding scrap tyres to obtain crumb rubber with the removal of steel belt and wires. Note that this procedure has been highly popular in the USA (Reschner, 2008).

In recent times the scrap tyres have increasingly been dumped in landfills. This is mainly because by this method the tyres need not to be recycled before the application. However, the EU Landfill Directive has banned this operation since 2003 (Reschner, 2008). In the USA, because of huge amounts being stockpiles, the discarded tyres have been employed in civil engineering work for many years, including (1) as lightweight fill for embankments and retaining walls, (2) as leachate drainage material at municipal solid waste landfills, (3) as alterative daily cover at municipal solid waste landfilles, and (4) as insulating layer roads and behind retaining walls (Reschner, 2008).

When car tyres are finally discarded, they are normally shredded to be smaller sizes thereby easier to manage. However, around the world the shredding machines are different, resulting in the recycled tyres having different shapes and sizes. It is therefore essential to have a standard for classifying those recycled tyres, as shown in table 2.3. In the case of ASTM, they are classified as granulated, ground rubber, chip, shred, and rough shred with respect to the sizes of 425 μm-12 mm, 425 μm-2 mm, 12-50 mm, 50-305 mm, and 50x50x50 < X < 762x50x100 mm. Note that the table is very useful in terms of specifying recycled tyres for a particular project. For example, a drainage project may look at the tyre chips instead of tyre shreds.

Edeskär (2006) reported the utilisation of scrap tyres for civil engineering work. He also reported the consequences of using them to the environment. He summarised that the discarded tyres can be employed for: lightweight fill (see figure 2.3), thermal insulation (see figure 2.4), drainage layer in road embankments (see figure 2.5), and trotting track (see figure 2.6).

**Table 2. 3 Terms for recycle tyres having different sizes (CEN, 2004; ASTM, 1988; Edeskär, 2006)**

| prEN 14243:2004 (Europe) | | ASTM D 6270-98 (USA) | |
|---|---|---|---|
| Designation | Size | Designation | Size |
| Fine powder | <500 μm | Granulated | 425 μm–12 mm |
| Powder | <1 mm | Ground rubber | 425 μm–2 mm |
| Granulate | 1–10 mm | Chip | 12–50 mm |
| Chip | 10– 50 mm | Shred | 50–305 mm |
| Shred | 50–300 mm | Rough shred | 50×50×50 < X < 762×50×100 |

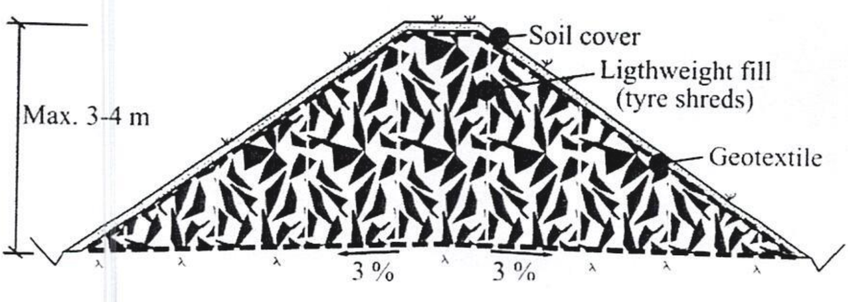


**Figure 2. 3 Tyre shreds employed as fill in road embankment (Edeskär, 2006)**

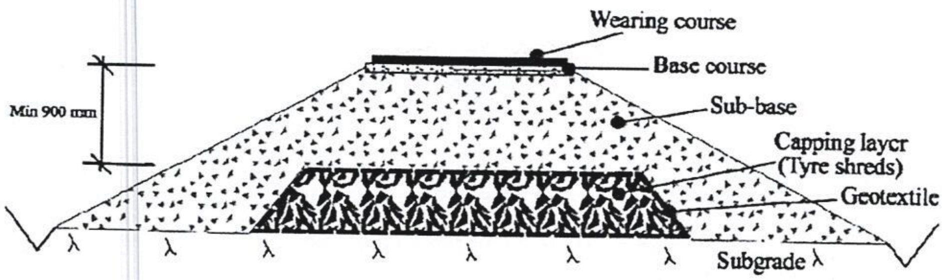


**Figure 2. 4 Tyre shreds employed as thermal insulation in road embankment (Edeskär, 2006)**

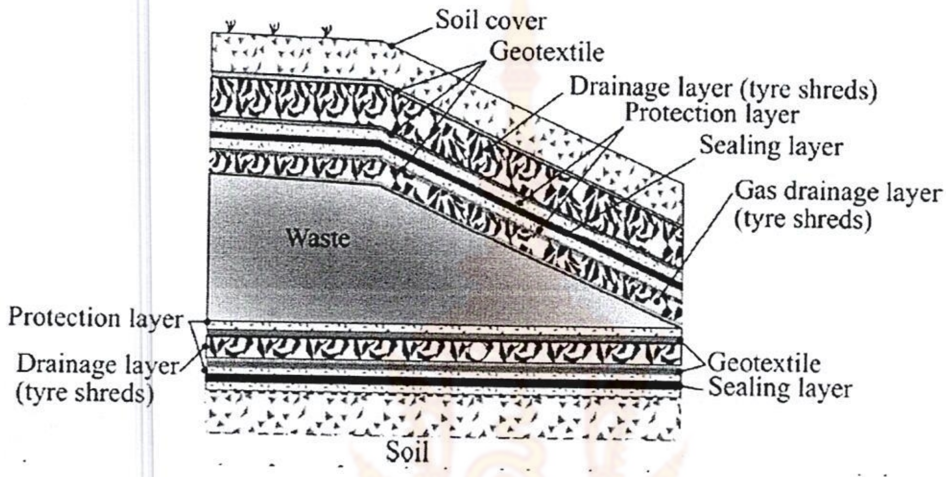


**Figure 2. 5 Tyre shreds employed as drainage layer in road embankment (Edeskär, 2006)**

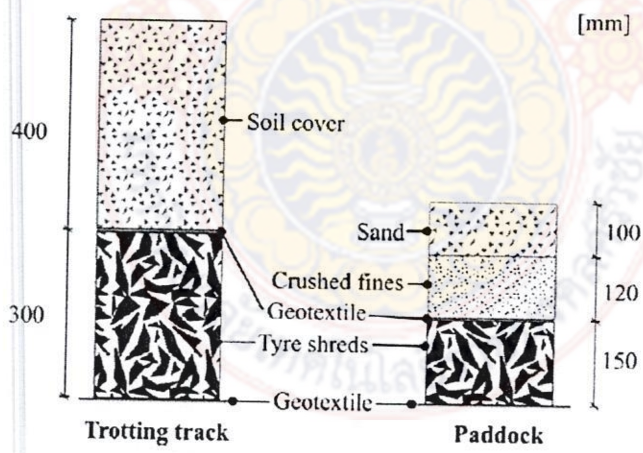


**Figure 2. 6 Tyre shreds employed as trotting track in Nanestad Norway and paddock (Edeskär, 2006)**

## 2.3 Incinerator bottom ashes

Wastes are leftover materials generated from households and industries. With the combination of increasing population and advanced technologies the wastes generated are progressively increased. The waste may be classified as wet- and dry wastes. Sometimes the former is also called fresh waste. It should be noted that the fresh waste generally includes foods and vegetables left from households. For the dry waste, however, it is normally any others that could be ignited. Glasses, metals, and fragrant bricks are also regarded as dry waste. In Thailand, the increasing rate of the waste is about 5.41%, as can be observed from the amounts of wastes during 2010-2012 that is shown and displayed in table 2.4.

**Table 2. 4 Solid wastes during 2010-2011 (PCD, 2012; Boonpan et al., 2013)**

| Areas | Year 2010 | Municipal solid waste (tonnes/day) | | | |
|---|---|---|---|---|---|
| | | Year 2011 | | | Increase/Decrease (%) |
| | | Normal circumstance | Flooding times | Average | |
| Bangkok | 8,766 | 9,126 | 9,790 | 9,237 | +5.37 |
| Pattaya | 324 | 350 | 360 | 352 | +8.64 |
| Municipalities (2,010 areas) | 16,296 | 16,360 | 23,034 | 17,475 | +7.23 |
| Provincial administrative organisations (5,765 areas) | 16,146 | 16,045 | 20,056 | 16,715 | +3.52 |
| Total | 41,532 | 41,881 | 53,240 | 43,779 | +5.41 |

There are several methods for waste extermination. In the past landfilling technique is one of the most employed methods. As the world's population has been dramatically increased in recent time areas required for landfills are quite scarce. This has resulted in the application of incinerators for burning the wastes. For instance, an incinerator having a burning capacity of 250 tonnes per day could eliminate around 8590% of the waste, resulting in about 10% ashes by volume. In terms of weight, however, the ash is about 20% with around 1% of fly ashes. From these figures, it can be seen that some work is still required to manage the ashes. In southern Thailand, three incinerator are being operated, including in Phuket, Phangan, and Hatyai. Note that the one in Hatyai is the latest one. From this trend, it may be concluded that in the future there will be more and more incinerators to be built. This is because it seems the method produces least environmental effects. In addition, the heat generated from burning waste could be employed for generating electricity (Boonan et al., 2013).

Incinerator bottom ashes (IBA) are the waste generated from burning wastes. They have a grey colour, porous particle, rough particle, and quite big size compared with soils. When the ashes just coming out from a burning chamber, they first are cooled by means of water. After that they are stored in order to be transported for further actions. In Thailand, there have not been any serious attempts to make use of the IBA. Nonetheless, when considering their physical properties it is found that they may be employed in road construction because they have a well-graded characteristic and no plasticity. Furthermore, when touched by hands it feels like sand and gravel. Boonpan et al. (2013) employed the Scanning Electron Microscope (SEM) to photograph the IBA obtained from Phuket incinerator; and found that its surface is very rough, angular, and porous, as illustrated in figure 2.7.

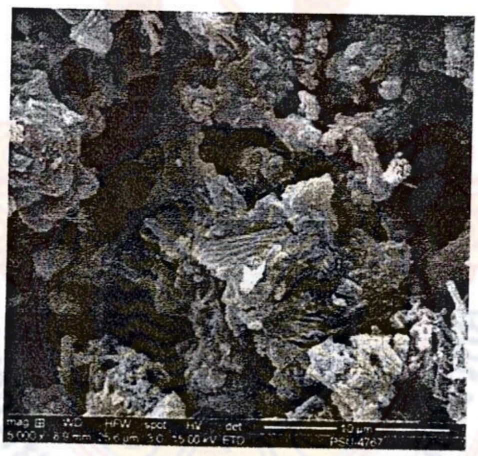

**Figure 2. 7 Details of incinerator bottom ashes by SEM (Boonphan et al., 2013)**

It should be emphasised herein that in other places there have long been studies involving the utilisation of IBA for civil engineering projects. For example, Alhassan and Tanko (2012) collected the IBA from Kano Municipal, Nigeria, to study general properties. They reported that its specific gravity is in the ranges of 1.86-2.37. There was about 5.07-10% of organic materials mixed with. In addition, some silicon and metals were also encountered. The classification test revealed that it has a well-graded particle distribution. According to AASHTO soil classification, it was found that it can be classifies as A-3, at which shows a very good quality in terms of road construction material. Furthermore, the California Bearing Ratio test (CBR) showed that its CBR value is about 70% of which may be suitable for sub-base and even base layer.

EA (2002) investigated and surveyed the materials left from incinerators in England and Wales during 1996-2000. They found that each year there are approximately 28 million tonnes ashes generated from a total of 11 incinerators. They stated that the ashes can be categorially classified as bottom ash and fly ash. It should be noted that both have a potential to damage the environment. In the case of the latter, the obvious problem is that the ashes can easily be blown away in the air. When one takes a breath with such polluted air the ashes might be kept in lungs for good. They also reported that from a total of 23 million tonnes of ashes a total of 2.5 million tonnes are landfilled. Another 2 million tonnes were recycled in the following manners: research and re-burning.

The aforementioned reports clearly indicate that IBA has a high potential for employment. However, several issues must be studied in details. For instance, when it is to be mixed with geomaterials what the mixture will behave. In addition, how to predict its settlement behaviour during and after loaded. This is because this behaviour is the main issue in geotechnical design and construction.

## 2.4 Earthquake

### 2.4.1 Causes of earthquake

The earthquake phenomena are simply the shaking of the ground due to the energy suddenly released form within the earth's crust. Please be noted that, however, the energy may also be generated from the movement of earth's crust, volcano eruption, man-made explosion, and collapse of underground caves. Thus, even though the earthquake has been regarded as natural disaster but its sources are not necessary from the nature. For example, there have been reports showing that some earthquakes were triggered by surcharges, e.g., water weight over the foundation of a dam (Elnashi and Sarno, 2008). When an earthquake strikes one or all of the following would occur:

- Life lines and built environment are partly or completely destroyed causing the difficulty for humans to have a normal life and affect the whole economy.
- Alter the environment as well as geography, e.g., ground elevation is either lower or higher, water way is altered, and land is subsided.
- Human lives are lost, in which is invaluable.

Nowadays, the most accepted theory used to explain the characteristics of earthquake is plate tectonics of which was derived from the theory involving continental drift and seafloor spreading that have long been proposed. Plates are enormously giant rock sheets having an average thickness of about 100 km. They are so formed that create the earth's crust. Under the crust lies molten rock that constantly flows both vertically and horizontally. Please be noted that such flowing of the molten rock has been called as convection. Because the earth's crust is formed from several plates like a jigsaw, the constant movement of molten rock also causes the plates to move somewhat, as illustrated by figure 2.8. These moments then create the friction along the boundaries thereby accumulating the energy within the plates. If the stored energy is greater than the strength of a boundary, that area will break causing the sudden release of the energy. This will result in the vibration, sound, and heat that dissipate and travel through the earth structure as well as the air. From this short description, it may be concluded that the characteristics of a boundary will somewhat influence the occurrence of an earthquake. The boundaries can be classified into three types: (1) divergent of rift zones, (2) convergent of subduction zones, and (3) Transform zones or trans current horizontal slip, as also shown in figure 2.9.

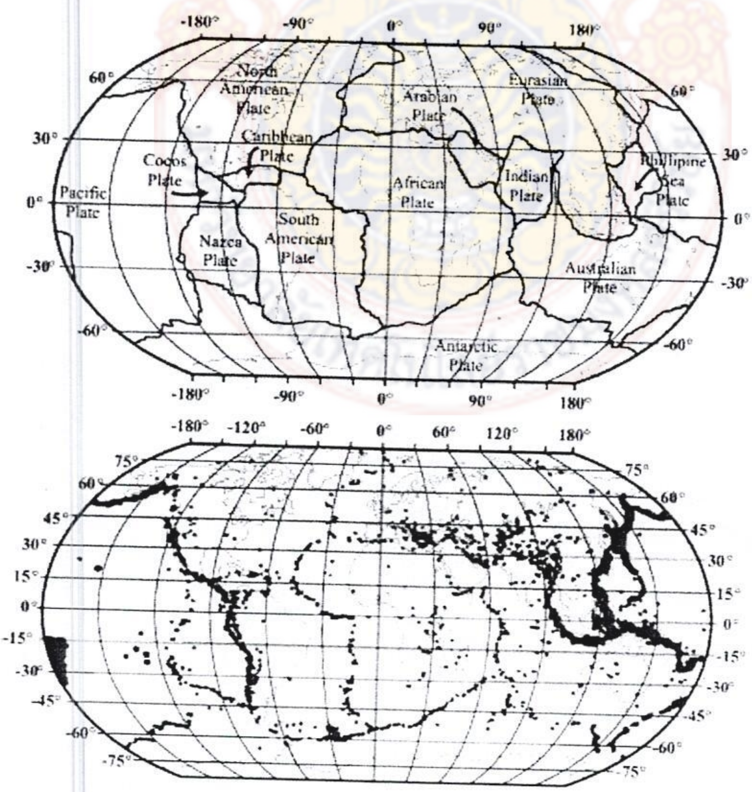


**Figure 2. 8 Plate tectonics (top) distribution of earthquakes around the world (bottom) (Elnashi and Sarno, 2008)**

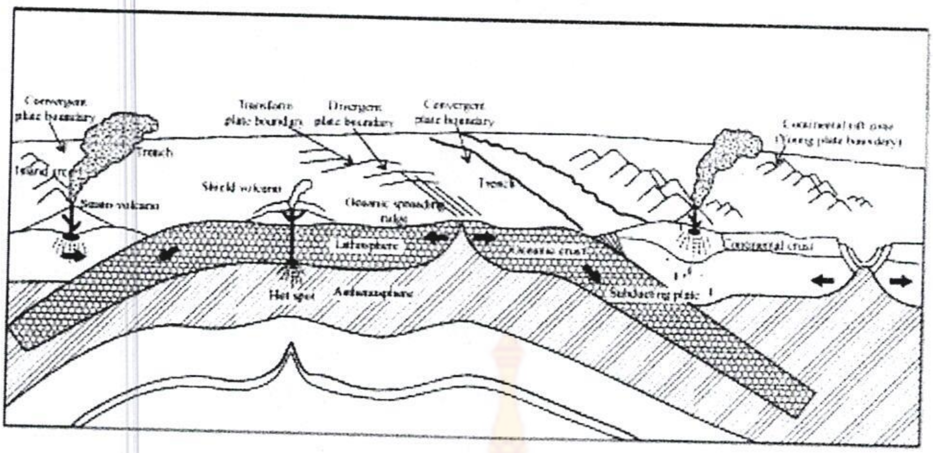

**Figure 2. 9 Section showing types of boundaries (Elnashi and Sarno, 2008)**

### 2.4.2 Earthquake characteristics

Due to the complexity of a fault, in order to describe exact locations of an earthquake caused by the movement of the fault it is essential to define symbols. For example, focus is defined as the origin of an earthquake. In other words, it is the point where earthquake waves originally travel from. It should be noted that the focus is alternately called as hypocentre. Beginning at the focus the earthquake waves travel along and within faults with the velocity of about 2-3 km/s. The depth measured from the surface to the focus has been called as focal depth, or hypocentral depth. A point over the surface projected from is called epicentre. The distance from an observation point (or seismic station, for example) to the epicentre is called epicentral distance. In addition, the distance from an observation point to the focus has been called as focal distance, or hypocentral distance (Kramer, 1996), as schematically depicted in figure 2.10.

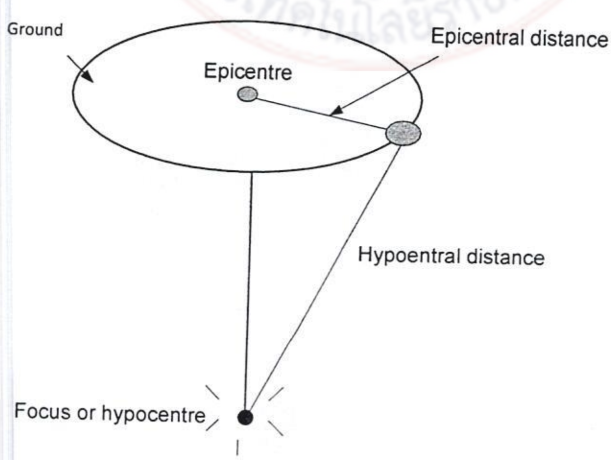


**Figure 2. 10 Symbols explaining terms for earthquake locations (Adapted from Kramer, 1996)**

When stored energy in the earth's crust released there will be waves travelling along the rock and soil forming the crust. The waves are categorised into two groups: (1) body waves and (2) surface waves. It should be noted that the vibration felt on the surface normally is the combination of those two waves.

The body waves comprising (1) longitudinal waves (or primary waves, P-waves) and (2) secondary waves (S-waves) travel inside the earth. These travelling waves generate the compression and extension of the rock, as illustrated by figure 2.11, resulting in the rock to be compressed and extended back and forth, but the shape is still unchanged. It should be noted that this behaviour is very similar to that of the travel of sound waves. Nonetheless, the travelling of the S-waves through rock will create the deformation both horizontally and vertically, causing the shear stress in the rock that the waves passing through. Therefore, the S-waves are sometimes called shear waves. It should be emphasised herein that these waves are the main waves, comparing to other waves, that mostly damage built environment.

The characteristics of the body waves depend on the homogeneity, isotropy, and elasticity of a material the waves travelling passing through. The speeds of P-wave ($v_p$) and S-wave ($v_s$) travelling through a material having a density ($\rho$) and Poisson's ratio ($v$) can be calculated from the following equations

$$v_p = \sqrt{\frac{E(1-v)}{\rho(1+v)(1-2v)}} \quad \textbf{(Eq. 2. 1)}$$

$$v_s = \sqrt{\frac{E}{2\rho(1+v)}} \quad \textbf{(Eq. 2. 2)}$$

and the ratio between $v_s$ and $v_p$ is

$$\frac{v_s}{v_p} = \sqrt{\frac{1-2v}{2(1-v)}} \quad \textbf{(Eq. 2. 3)}$$

When the body waves travelling through the earth's crust they will interfere each other, resulting in the surface waves that travel parallel to the crust. The surface waves comprise (1) love waves (L or LQ) and (2) Rayleigh waves (R or LR), as shown in figure 2.12.

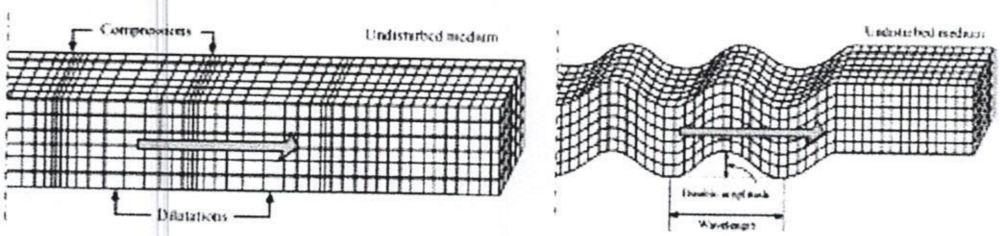


**Figure 2. 11 Paths of body waves (left) and secondary waves (right) (Elnashai, 2008; Bolt, 2004)**

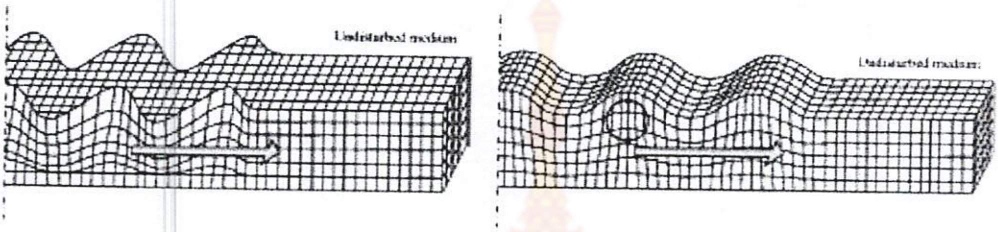


**Figure 2. 12 Paths of surface (love) waves (left) and Rayleigh waves (right) (Elnashai, 2008; Bolt, 2004)**

Nowadays, there are many methods and formulae for providing an earthquake magnitude, depending on how to make use of such number. In the past the level of earthquake vibration was obtained by means of interviewing the people affected by the earthquake. Then, the results were employed to build a contour map indicating vibration levels. Kramer (1996) has summarised the methods for indicating an earthquake magnitude, as shown below

(1) Richer local magnitude

This method was developed by Charles Richter in 1935, based on the principles of Wood-Anderson seismograph. It is most suitable for the so called shallow earthquake at which the focus is not deeper than 600 km. An earthquake magnitude by this method has been regarded as local magnitude. Even though it is widely known to the public, with regard to earthquake engineering it does not appropriate for calculating a magnitude to be used in the earthquake resistant design.

(2) Surface wave magnitude

Because the Richter scale do not differentiate the types of waves generated by earthquakes; the surface wave magnitude was developed to overcome those unclear interpretations. Its principle is that a magnitude must be relevant to a wave type. It is based on the Rayleigh wave during the 20 s period; and, can be calculated by the following equation

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

where $A$ is the maximum ground displacement, and $\Delta$ is epicentre distance.

(3) Body wave magnitude

The magnitude employs the principles of the magnitude of P-waves; it can be calculated from the following equation

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

where $A$ is the magnitude of P-waves having the unit of micrometre (1/1000m), and $T$ is the time (1 cycle period) of P-waves.

(4) Other instrumental magnitude scales

This method is totally different to those previously described. An earthquake magnitude by this method mainly depends on instruments and tools employed for measuring and recoding the vibration causes by earthquakes, normally acceleration versus time records.

(5) Moment magnitude

First and foremost, it should be stressed herein that all those mentioned methods are based on information and observation obtained. Nonetheless, it has been found that the ground vibration due to earthquake shaking does not increase according to the increase of releasing stored energy initiated by an earthquake. In addition, for major earthquakes, it has also been observed that the vibration data obtained from digital instruments is less sensitive to the magnitude of an earthquake, but rather very sensitive to smaller earthquakes. This phenomenon has been termed as saturation. Thus, the moment magnitude was invented in order to overcome the dependency of a magnitude to earthquake shaking levels. This method employs the following equation for estimating an earthquake magnitude

$$M_w = \frac{\log M_o}{1.5} - 10.7 \quad \text{(Eq. 2. 6)}$$

where $M_o$ is Seismic moment, having the unit of dyne-cm.

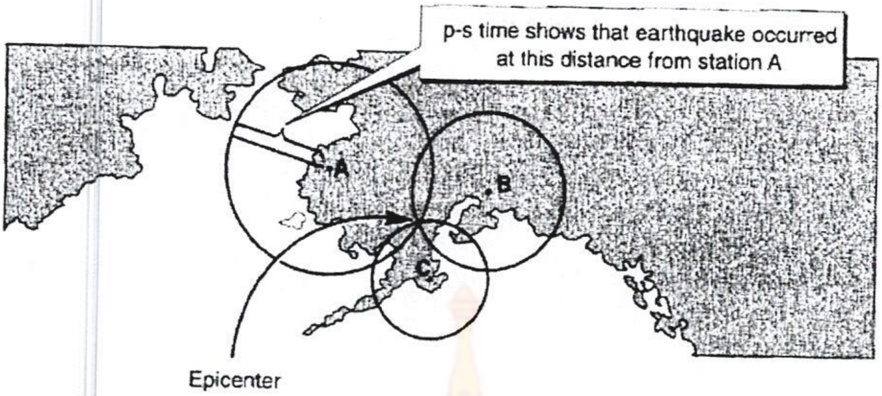


**Figure 2. 13 Locating an earthquake position (Kramer, 1996)**

When there is an earthquake first thing we need to know is where it has happened. To obtain such information the epicentre must be first located. This procedure, however, is somewhat straightforward. Nonetheless, some refinements are required in order to obtain an exact location. Locating an earthquake's position requires the information with respect to both P- and S-waves from at least three seismic stations, as illustrated by figure 2.13.

Because the P-wave speed is faster than the speed of S-wave the former will arrive first on a seismograph showing acceleration versus time. Accordingly, the distance between a seismic station and an earthquake's focus can be calculated from the following equation

$$d = \frac{\Delta t_{p-s}}{\frac{1}{v_s} - \frac{1}{v_p}} \qquad \textbf{(Eq. 2. 7)}$$

where $\Delta t_{p-s}$ is the difference of arrival times between P- and S-waves, $v_p$ is P-wave speed, and $v_s$ is S-wave speed.

Structures must have some parts that have a contact with the ground. Thus, soil is the medium that will transmit the vibration from the earth's crust to superstructures. It is therefore vital to study the characteristics and properties of a soil when encountering earthquake shaking. Those properties are literally called dynamic properties, comprising (Prakash, 1981)

(1) Shear strength that is tested by considering the strain rated during testing.

(2) Dynamic properties such as elastic modulus, shear modulus, and bulk modulus.

(3) Poisson's ration.

(4) Damping ratio.

(5) Parameters concerning with the status changing from solid to liquid such as shear stress ration, dynamic deformation, and change of pore water pressure when loaded.

One of the most important dynamic properties is the shear modulus *G*. It should be noted that the most common device used to obtain such variable is the cyclic simple shear test. The results obtained from the device then can be employed to calculate the shear modulus using the following equation (Dad, 1993)

$$G = \frac{\text{amplitude of cyclic shear stress,}\tau}{\text{amplitude of cyclic shear strain,}\gamma} \quad \text{(Eq. 2. 8)}$$

In the meantime, the damping ration D, which indicates the ability of a material to absorb the energy during being dynamically loaded can be calculated from the following equation (see figure 2.14 for details)

$$D = \frac{1}{2\pi}\left(\frac{\text{area of the hysteresis loop}}{\text{area of triangles } OAB \text{ and } OA'B'}\right) \quad \text{(Eq. 2. 9)}$$

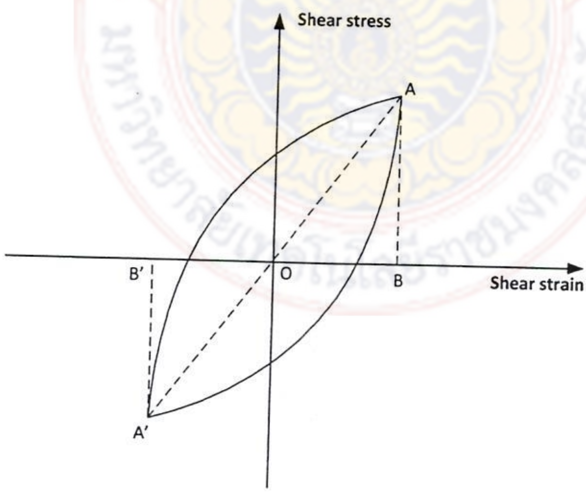


**Figure 2. 14 Determination of damping ration from hysteresis loop (Das, 1993)**

The damages of superstructures when encountering earthquake shaking are because of the vibration transmitted from the ground. Such vibration causes the structures to move back and forth, resulting in the extra inertia forces imposed on the structures. If the design did not include these effects, the structure is very likely to collapse during earthquake shaking.

### 2.4.3 Consequences from earthquakes

## 2.5 Seismic isolation techniques

The earthquake is a kind of natural disasters that cannot be prevented to occur. In addition, with current knowledge and technology we still cannot predict when and where an earthquake will strike. In facts, we could predict where earthquakes will happen by considering maps showing the subduction zones of which has been called as ring of fire. Thus, people can choose where to reside by simply avoiding living in those risky areas. Nonetheless, at the population is increasingly growing some people having no choices at all but have to live in such earthquake-prone areas. This is because the inhabitant area will be constant or even smaller because of the rising of seawater due to climate changes. It should be noted herein that earthquakes happen every single year at constant frequencies. Of all of those there are about 20 major earthquakes strikes annually. Note that the major earthquake is an earthquake having the magnitude of about 6 or higher. The problems arise when a major earthquake strike on a populated area. For instance, damages to both built environment and humans are inevitable. The built environment of course can be repaired or even rebuilt. But the loss of human lives is invaluable.

Therefore, any construction projects to be built on the earthquake-prone area are required to consider the effects of earthquake shaking. The earthquake-resistant design may be classified into two types: (1) superstructure design, and (2) foundation design. For the former, it also has to take into account of types of structures, e.g., bridges, general buildings, tall buildings, earth dams, concrete dams, and retaining walls. This is because each individual structure acts differently during earthquake shaking. In the meantime, for the foundation design, it mainly involves in the improvement of foundation in order to be enough flexible during encountering earthquake shaking. In addition, it also includes the improvement of foundation soil or similar materials. Its main purpose is to reduce the vibration to be transmitted from the ground as much as possible. Notice that techniques employed to reduce the vibration in the ground has been known as seismic isolation.

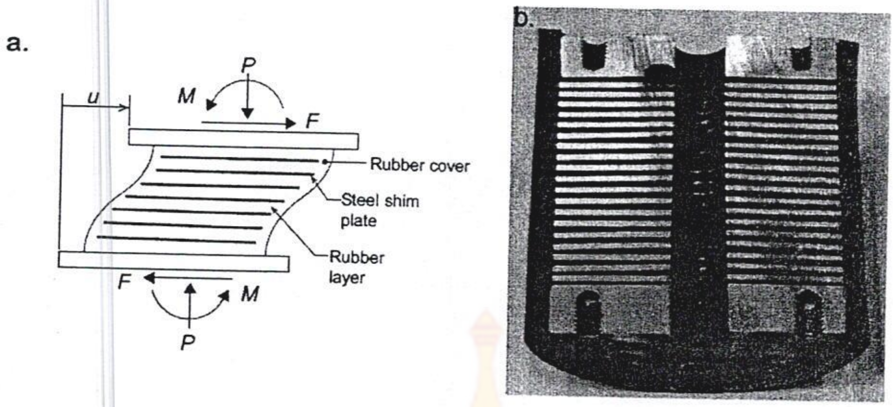


**Figure 2. 15 Horizontal deformation of elastomeric bearing (a) example of elastomeric bearing (b) (Warn and Ryan, 2012)**

The seismic isolation can be categorised into two types: (1) using elastic materials under or around footings, and (2) using foundation soil as seismic isolator. Warn and Ryan (2012) summarised the materials being used as seismic isolation for general buildings as three major types, as shown in the following section

(1) Elastomeric bearings

These bearings are mainly made from polymers, both from nature and artificial. Sometimes, both materials are mixed to obtain a material having desired properties. They are made by stacking layers of rubber sheets having metal sheets inserted between, as illustrated by figure 2.15. This type of bearing can be further classified into two groups: (1) low-damping rubber, and (2) high-damping rubber.

(2) Lead-rubber bearings

These bearings are mainly made from the mixtures between rubber and lead. They are one of the most popular bearings being employed worldwide. They are made by stacking layers of rubber with the insertion of lead bar. During earthquake shaking, the lead bar would plastically deform, resulting in the better energy distribution comparing with the elastomeric bearing.

(3) Sliding bearings

These bearings are mainly used for supporting structural weights. They are placed on sliding plates that are built to have as less friction as possible, resulting in very little resistance to lateral forces. The most popular material used to make these bearing is polytetrafluorethylene (PTEE). There may be stainless steel connected that acts as sliding plates. A friction pendulum is normally applied in order to move the bearing back to original position, as shown in figure 2.16.

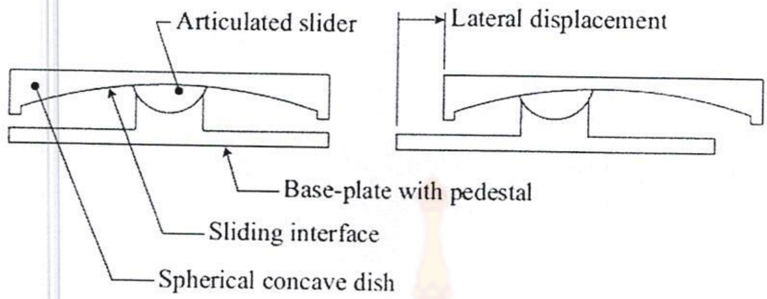


**Figure 2. 16 Bearing with frictional pendulum (Warn and Ryan, 2012)**

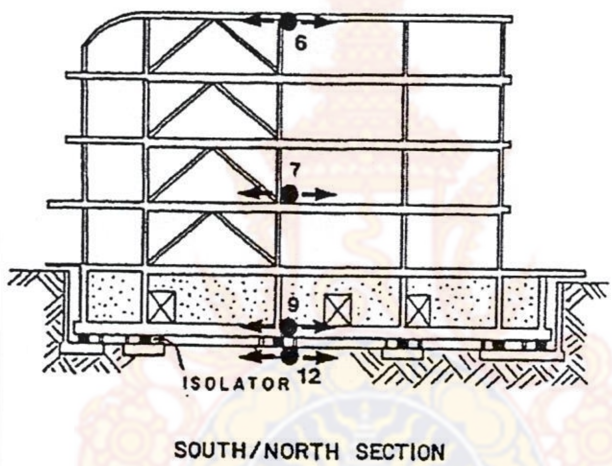


**Figure 2. 17 Section of FCLJC building showing locations of accelerometers at 6, 7, 9, and 12 (Lew and Bowman, 1988)**

The application of those bearings described has been in active for long time. For example, Lew and Bowman (1988) reported the results of bearing applications for construction projects such as FCLJC building shown in figure 2.17. The building is a four storey building built to house several heavy duty machines. This means that there will be vibration all the time during operation. The main structure of the building is the 417 x 110 feet steel frame. It was designed such that it can move up and down up to 16 in. In addition, designers chose to employ the 98 natural rubbers as seismic isolator constructed over the foundations at the underground floor, as illustrated by figure 2.17. In addition, a number of accelerometers were installed at the locations of 6, 7, 9, and 12 in order to monitor and record the vibration during earthquake shaking. After the building had been occupied, several earthquakes occurred. In 1985, an earthquake struck, providing some acceleration records, as shown in figure 2.18. From the figure, it was observed that some vibration was filtered out because of the isolators installed, as evident in figure 2.18.

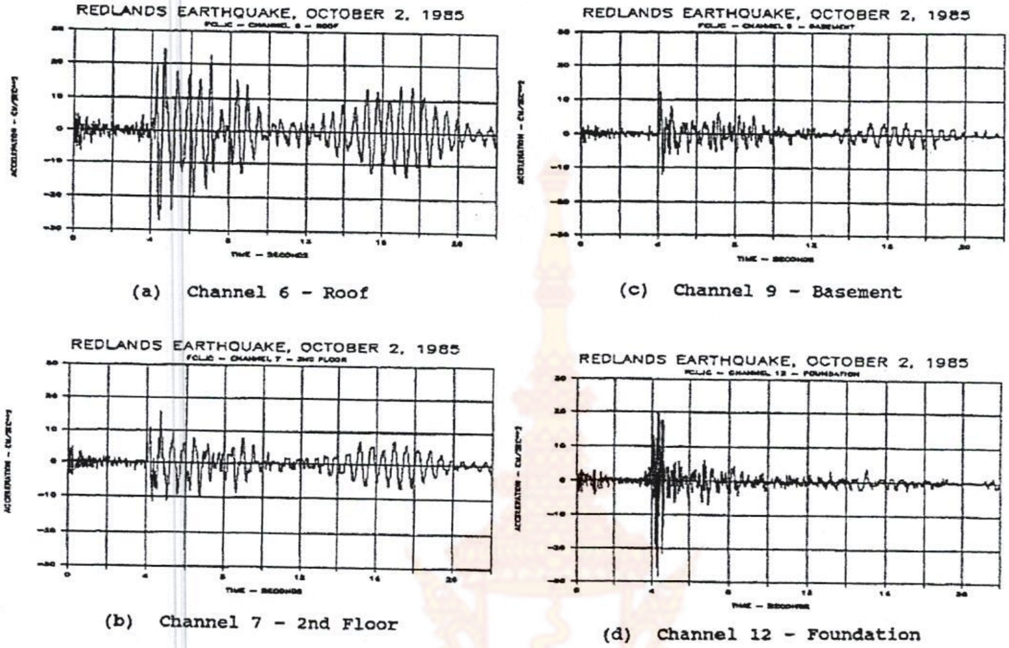


**Figure 2. 18 Acceleration versus time during earthquake shaking due to the Redlands earthquake on 2 October 1985 (Lew and Bowman, 1988)**

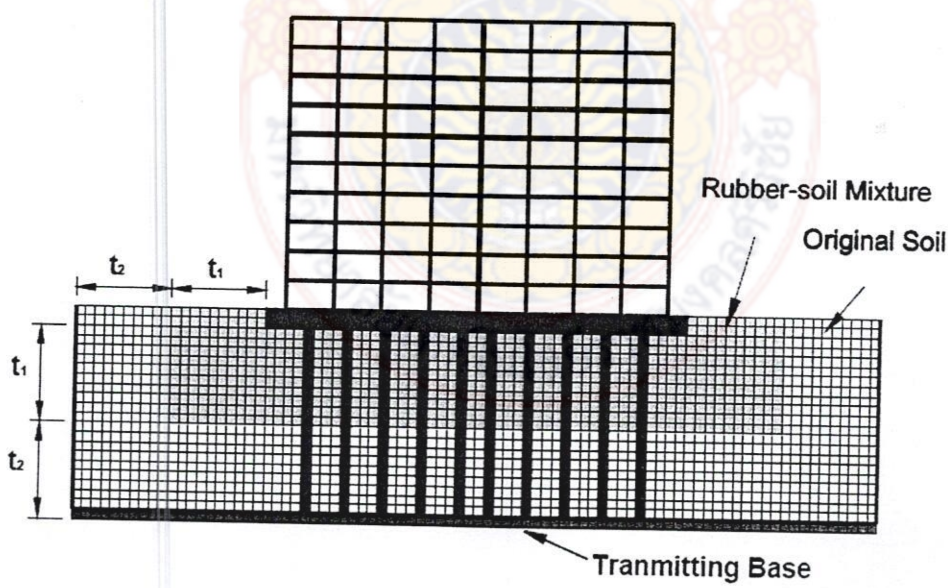


**Figure 2. 19 Finite element meshes for the structural analysis of structure and foundation soil when encountering earthquake (Tsang et al., 2010)**

Nowadays, there are not many researchers study the improvement of foundation soil in order to soften the vibration caused by earthquake shaking. Most of the studies concentrate on the design and improvement of superstructures. This may because the behaviour of superstructures when encountering earthquakes is easier to comprehend. In addition, the construction for the superstructures is also easier.

Tsang et al. (2010) investigated the application of discarded tyres to be mixed with conventional foundation soil to be employed as seismic isolator. They mixed rubber and soil, calling RSM (rubber-soil mixture); and used them as foundation material. A finite element program was employed to study the behaviour of foundations and superstructures in terms of the reduction of the vibration transmitted to the superstructures. The study was carried out by means of parametric study, changing the parameters in order to obtain the best results, as shown in table 2.5.

**Table 2. 5 Parameters for studying the behaviour of foundation soil during earthquake shaking (Tsang et al., 2010)**

| **Input Parameter** | | **Ref.** | |
|---|---|---|---|
| Thickness of RSM $t_1$ (m) | 5 | **10** | 15 |
| Building Width (m) | 20 | **40** | 80 |
| Number of Stories | 5 | **10** | 15 |
| Length of Piles (m) | **0** | 10 | 20 |
| Peak Horizontal Acceleration (g) | 0.72 – 1.78 | | |
| Peak Vertical Acceleration (g) | 0.33 – 1.05 | | |

The results showed that the application of RMS as foundation soil in models result in the decrease of horizontal vibration at the roof around 50-70%. For the horizontal acceleration at the foundation, it was found that the reduction is about 40-60%. In addition, the lateral movement at the first floor is found to be 40-60% lower. However, the thickness of RMS had to be taken into account. For example, when the thickness of RMS was increased from 5 m to 15 m, it was found that the percentage reduction in terms of horizontal acceleration at the roof and foundation is increased from 47% to 73% and from 35% to 65%, respectively, as evident in figure 2.20.

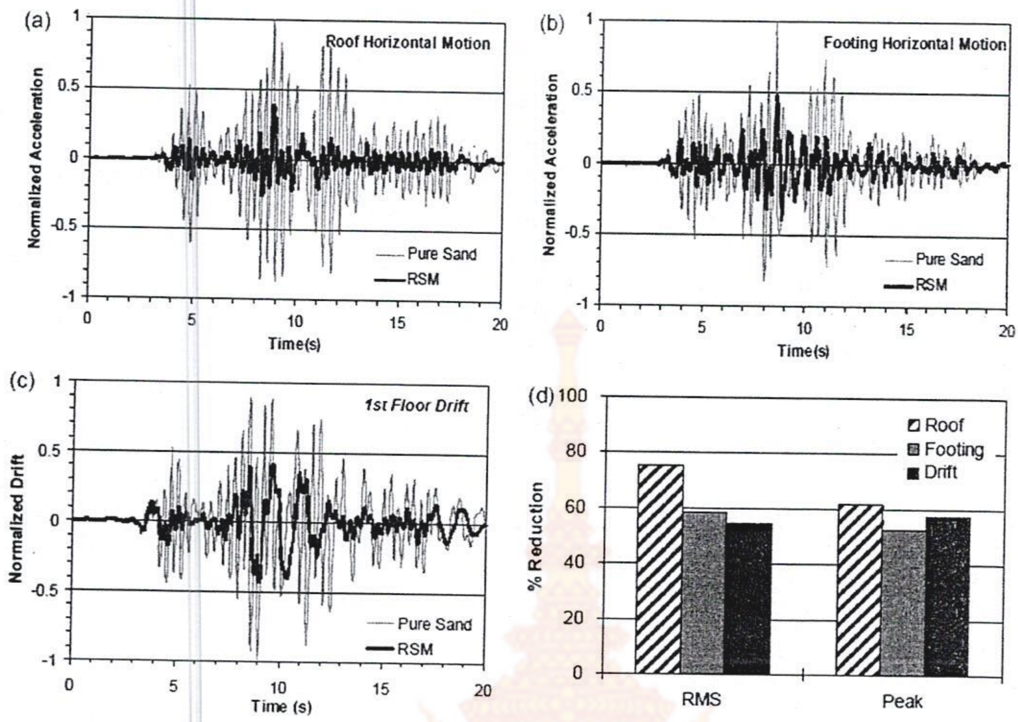


**Figure 2. 20 Displacement and acceleration vs. time behaviour for (a) roof top area (b) foundation (c) first floor (d) percentage decreasing for acceleration and displacement (Tsang et al., 2010)**

# CHAPTER 3

# MATERIALS, TEST PROGRAMMES, AND METHODS

## 3.1 Introduction

This research was concerned with the vibration caused by earthquake shaking that imposes on structures. Note that the shaking is first generated at a locus. Then, it propagates through the earth's crust. During this propagation, the waves may be either amplified or softened, depending on the medium they are travelling through. Eventually, the waves reach the ground surface. If a structure has been built over an affected area, surely the shaking will be somewhat transmitted through. In the case the structure could not resist the level of shaking, damage is inevitable. People know that where is a safe place from earthquake strikes; but, as the population is overgrown the safely inhabitant area, some have no choice but reside over those earthquake-prone areas. Therefore, geologists, geotechnical engineers, and civil engineers have a task to ensure the safety of building a structure over those risky areas.

This research employed two materials: (1) discarded tyres (DT) and (2) incinerator bottom ashes (IBA), as foundation material in order to reduce the shaking transmitted to superstructures. It should be emphasised herein that both materials are regarded as solid waste. In the past they were just dumped in open areas. This practice, however, pose a danger to the environment. In the other words, they are required to be appropriately managed, e.g., dumped in a protected landfill. The foundation material was the mixtures between those two materials having various mixing proportions. Then, model houses were installed over the model foundation prepared from the mixtures. An explosion was buried under the foundation; then, it was detonated to create an artificial earthquake. Accelerometers were installed both over the ground and the housed to monitor the level of shaking. The results were analysed and compared in order to evaluate the effectiveness of the mixtures in terms of seismic isolation. This chapter provides the detailed information with respect to the test materials employed, equipment used, and testing methods carried out in this research.

## 3.2 Test materials

### 3.2.1 Sand

Medium sand was chosen as foundation to support the mixtures between incinerator bottom ashes and tyre chips. It was commercially obtained from Suratthani province, located in Southern Thailand. Figure 3.1 displays the sand employed in this study. The sand was sieved in order to obtain its size distribution characteristics. Table 3.1 displays the results obtained from the conventional sieving test of the sand. Then, the results were plotted and shown in figure 3.2.

It was found that the values of D10, D30, and D60 are 0.30, 0.53, and 1.10 mm, respectively. In addition, the average particle size was about 0.53 mm. This resulted in the coefficient of uniformity (Cu) and the coefficient of gradation (Cg) of 3.67 and 0.85, respectively.

**Figure 3. 1 Photo of the sand**

**Table 3. 1 Sieve analysis result for the sand**

Mass of sample = 500.89 g

| Sieve no | Diam (mm) | Mass retained (g) | % retained | % passing |
|---|---|---|---|---|
| 4 | 4.75 | 0.00 | 0.00 | 100.00 |
| 10 | 2.00 | 104.45 | 20.90 | 79.10 |
| 20 | 0.85 | 169.19 | 33.85 | 45.25 |
| 40 | 0.42 | 120.50 | 24.11 | 21.13 |
| 60 | 0.25 | 80.73 | 16.15 | 4.98 |
| 100 | 0.150 | 20.78 | 4.16 | 0.82 |
| 200 | 0.063 | 4.04 | 0.81 | 0.01 |
| Pan | | 0.07 | 0.01 | 0.00 |
| | $\sum$ = | 499.76 | | |

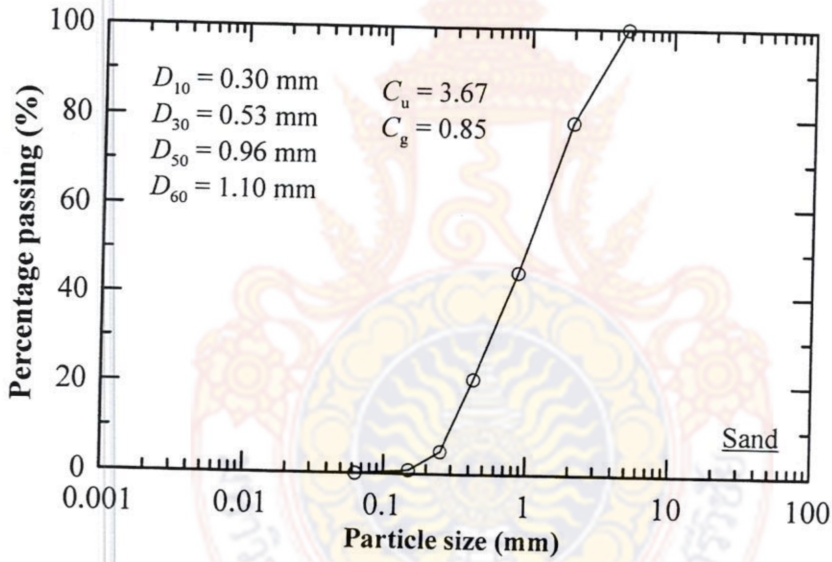


**Figure 3. 2 Particle size distribution curve for the sand**

### 3.2.2 Incinerator bottom ashes

One of the main materials used in this study, incinerator bottom ashes, was obtained from Phuket Municipal Solid Waste Incineration Plant, located in Phuket province, the famous place among tourists. The address of the plant is Rattanakosin Road, Moo 1, Vichit sub district, Mueang District, Phuket Province. It can burn the wastes of around 250 tonnes daily. It comprises a separation building, landfill area, and wastewater treatment zone. Figure 3.3 shows the samples obtained from the plant.

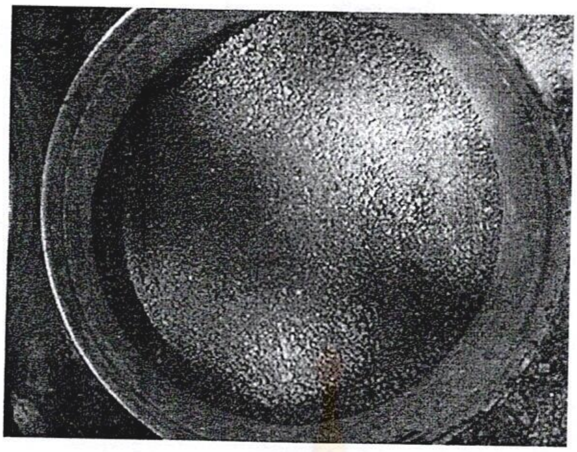

**Figure 3. 3 Photo of the incinerator bottom ash**

The leftover from the burning process includes bottom ash and fly ash. Each year they are generated at the quantities of 24,750 and 3,960 tonnes, respectively. The former normally is landfilled in the allocated areas. For the latter, however, it is kept in a special area that ensuring it will not cause environmental problems. This is because, as its name imply, it can easily be blow away into the air. In the case it has been breathed by either humans or animals, the long-term health problem is foreseen.

Because, it is virtually granular material; it is essential to carry out the particle size analysis in order to compare with the conventional geomaterial. Table 3.2 displays the data obtained from the sieving analysis of the incinerator bottom ash. Meanwhile, figure 3.4 shows the size characteristics of the material.

**Table 3. 2 Sieve analysis result for the incinerator bottom ash**

Mass of sample = 500.17 g

| Sieve no | Diam (mm) | Mass retained (g) | % retained | % passing |
|---|---|---|---|---|
| 4 | 4.75 | 0.00 | 0.00 | 100.00 |
| 10 | 2.00 | 159.01 | 31.99 | 68.01 |
| 20 | 0.85 | 148.40 | 29.86 | 38.15 |
| 40 | 0.42 | 91.59 | 18.43 | 19.73 |
| 60 | 0.25 | 45.87 | 9.23 | 10.50 |
| 100 | 0.150 | 25.35 | 5.10 | 5.40 |
| 200 | 0.063 | 18.06 | 3.63 | 1.76 |
| Pan | | 8.77 | 1.76 | |
| | $\sum$ = | 497.05 | | |

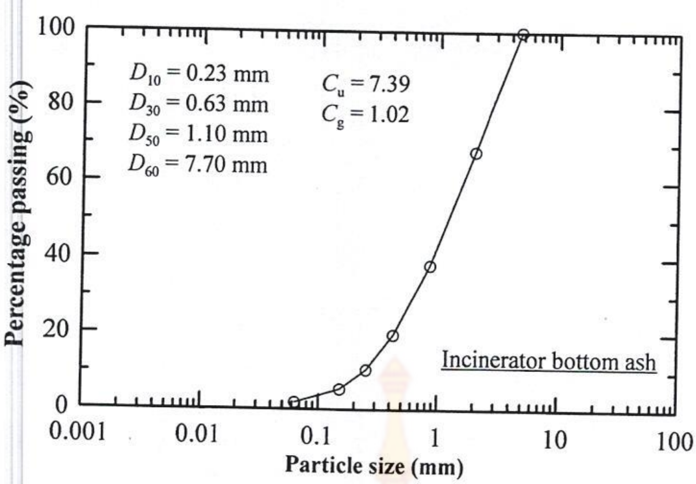


**Figure 3. 4 Particle size distribution curve for the incinerator bottom ash**

The size distribution analysis for the incinerator bottom ash showed that its size characteristics, D10, D30, and D60, are 0.23, 0.63, and 7.70 mm. It can be seen that it was very similar to those of the tested sand, except the D60 that was quite bigger. In addition, its average particle size was about 1.10 mm, which was also similar to that of the sand. In addition, it was found that the coefficients of uniformity and gradation are 7.39 and 1.02, respectively. This indicates that the incinerator bottom ash has a wide range of particle size. In other words, it is very good for being employed as foundation soil.

### 3.2.3 Tyre chips

The tyre chips used in this research was commercially obtained from KKI Recycle, Nakhonpathom. Figure 3.5 shows the samples of the chips used in this study. In order to obtain its physical characteristics a sieve analysis was carried out the same way as done with the sand. Table 3.3 shows the result from the sieve test, including the size and percentage passing for the tyre chips. In addition, the result was plotted and shown in figure 3.2. It was found that the D60, D50, D30, and D10 are 0.60, 0.54, 0.44, and 0.24 mm, respectively (see figure 3.6). These resulted in the coefficients of uniformity and gradation of 2.50 and 1.34, implying it is a kind of poorly-graded material in terms of geotechnical engineering usage. It can be seen overall the tyre chips are quite smaller than the sand. This may later result in the behaviour because as the proportion of a mixture changes, the void ration would also change accordingly. The specific gravity for the tyre chips was found to be 1.02. It can be seen that it is as much twice lower than that of the sand.

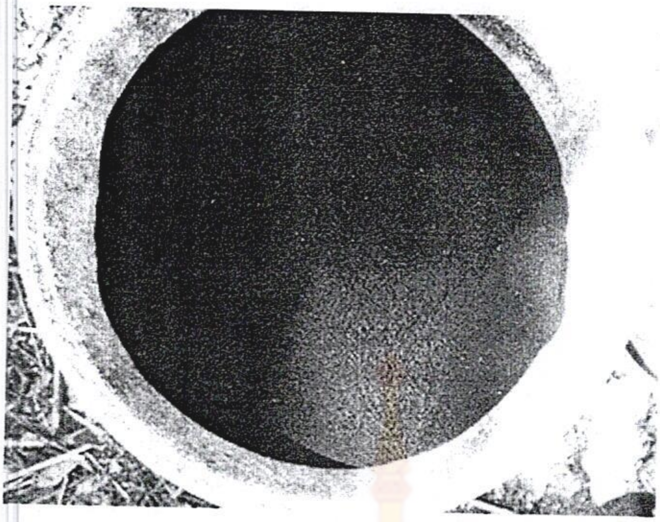

**Figure 3. 5 Photo of the tyre chips**

**Table 3. 3 Sieve analysis result for the tyre chips**

Mass of sample = 500.36 g

| Sieve no | Diam (mm) | Mass retained (g) | % retained | % passing |
|---|---|---|---|---|
| 4 | 4.75 | 0.00 | 0.00 | 100.00 |
| 10 | 2.00 | 0.00 | 0.00 | 100.00 |
| 20 | 0.85 | 51.66 | 10.34 | 89.66 |
| 40 | 0.42 | 319.90 | 64.03 | 25.63 |
| 60 | 0.25 | 78.58 | 15.73 | 9.90 |
| 100 | 0.150 | 33.47 | 6.70 | 3.20 |
| 200 | 0.063 | 11.45 | 2.29 | 0.91 |
| Pan | | 4.56 | 0.91 | 0.00 |
| | $\sum$ = | 499.62 | | |

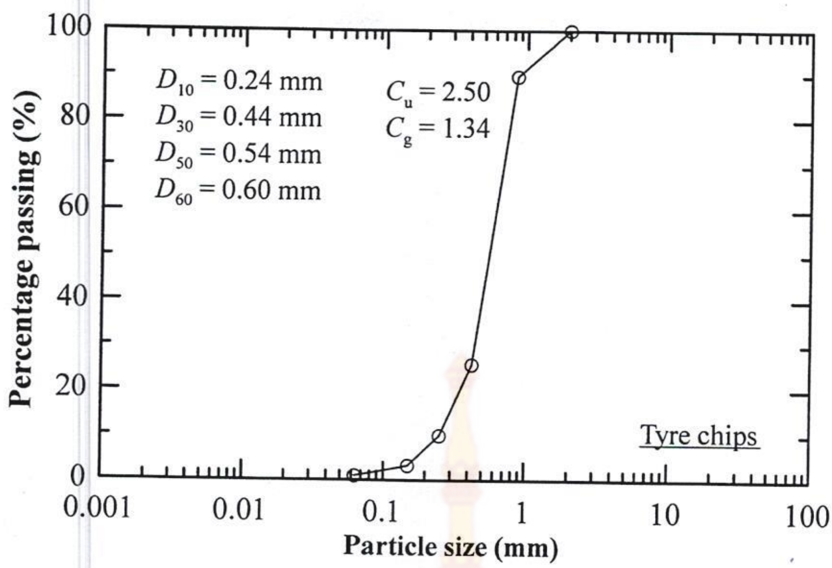


**Figure 3. 6 Particle size distribution curve for the tyre chips**

### 3.2.4 Explosive

Explosive employed in this study was by means of a detonator having 0.16 g of charge. This was because such small amount of explosive is more than enough for producing simulated earthquake vibration in a steel chamber with 120 cm diameter. Figure 3.7 displays the detonator being installed (buried) into the sand layer; figure 3.7 illustrates how to ensure a detonator installed is working.

**Figure 3. 7 Examples of explosive charge used in this study**

**Figure 3. 8 Checking for the continuity of the charge before being employed**

### 3.2.5 Model houses

A total of two model houses, one- and two-storey, were constructed in order to be placed over the foundation soil. They were entirely made from balsa wood having the dimensions of 27.5 by 27.5 cm, corresponding to 8.25 by 8.25 m by the scale of 1:30. They were constructed to have such structural members that are the same as a real house, comprising footings, pillars, columns, beams, slabs, walls, and roofs, as illustrated by figures 3.9 and 3.10. These were done so in the hope that the model houses constructed could mimic the transmitted-vibration behaviour induced in the real house.

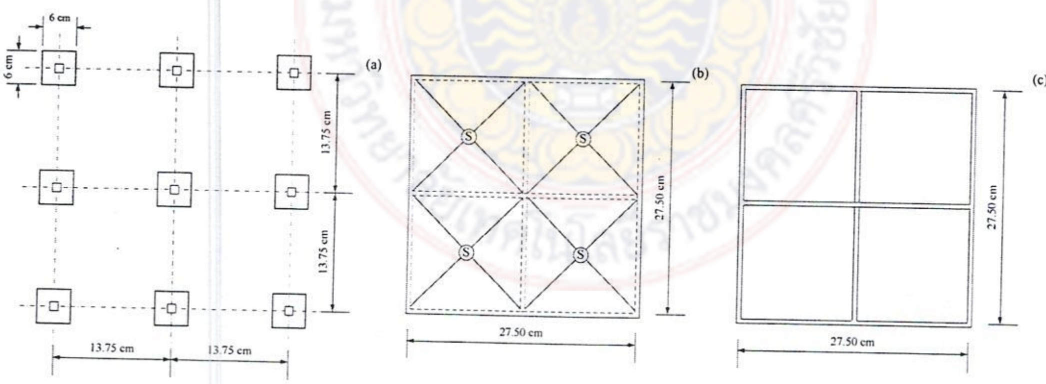


**Figure 3. 9 Foundation plan (a) floor plan (first floor for one-storey house; first and second floors for two-storey house) (b) roof beam plan (c)**

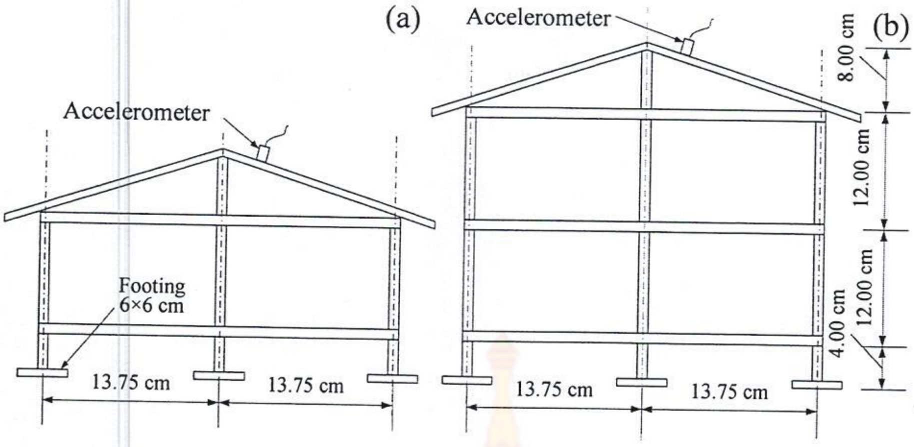


**Figure 3. 10 Elevation drawings for one-storey house (a) two-storey house (b)**

## 3.3 Equipment

### 3.3.1 Sensors

The accelerometer used to measure the acceleration in this project obtained from PCB Piezotronics was the model number 352C33, as shown in figure 3.11 (a). Some of its specifications are as below:

- It is used to measure the acceleration.
- Its sensitivity is 100 mV/g.
- The range of measurement is □ 50 g.
- The range of frequency to be measured is 0.5 to 10,000 Hz.
- It has a connection to a cable connected to a data acquisition system.

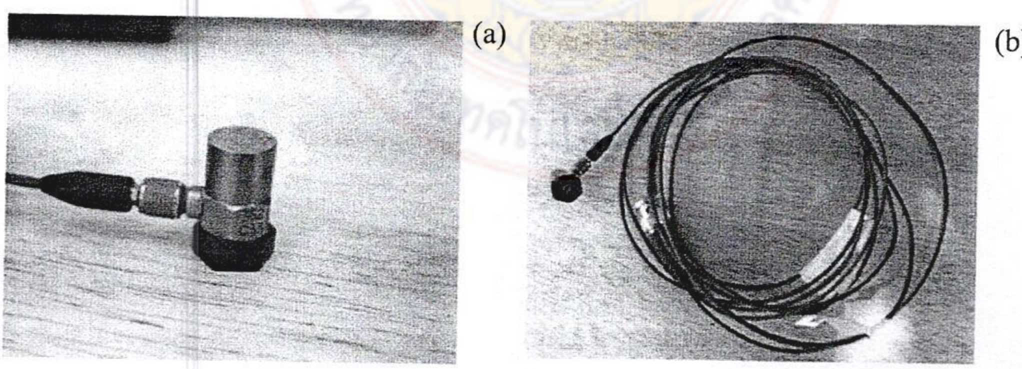


**Figure 3. 11 Accelerometer (a) the accelerometer connected to the coaxial cable**

The coaxial cable is an essential part used to transmit the signal generated during blasting to a data acquisition system, as shown in figure 3.11 (b). Some of its specifications are as below:

- It is used to connect between an accelerometer and a data acquisition system.
- It is 10 – 32 plugs type having a BNC connection model 780986-01, according to National Instrument.

### 3.3.2 Data acquisition system

The data acquisition system employed in this study was obtained from National Instruments. Basically, it comprised a chassis and a module. The former was used as connection between a computer and the latter. The accelerometer was first connected to the latter; then, it was inserted into the chassis connected to the computer having been installed with a special program. The program was used to monitor and record the signals generated during testing. Figures 3.12 (a) and (b) show the chassis and the module, respectively.

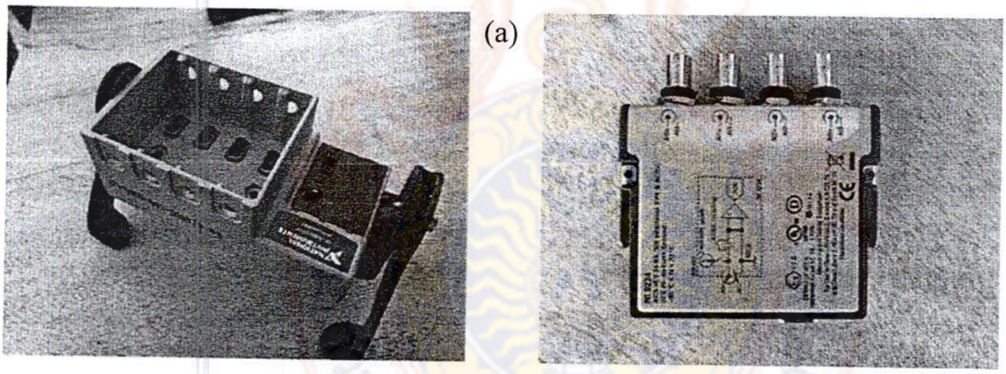
(a) (b)

**Figure 3. 12 NI Compact DAQ chassis (a) NI module for acquiring the acceleration signals**

## 3.4 Testing methods and programmes

### 3.4.1 Testing methods and procedures

In this study, the very first step was to construct a sand layer having the thickness of 50 cm, acting as supporting soil. During the construction, however, a detonator having the charge of 0.16 g was also installed within the sand at 10 cm from the bottom. It should be noted that a steel chamber having the diameter and height of 120 and 75 cm, respectively, was employed to house the model foundation soil because it could withstand the explosion.

Then, overlying the sand layer was the 25 cm thick layer of the mixtures between the IBA and the TC. These materials were meant to be investigated their effectiveness in terms of softening the vibration caused by the explosion transmitted to the model houses. The IBA to TC proportions by weight were 100:0, 95:5, 90:10, 75:25, 40:60, and 0:100.

After the foundation soil was completed, both model houses were installed according the test configuration displayed in figure 3.13. Over the roof of the houses an accelerometer was attached in order to measure the explosive-induced vibration transmitted from the ground. Another accelerometer was also installed on the ground; but, to directly measure the ground vibration. These arrangements would provide data that could be analysed later on in order to evaluate the effectiveness of the mixtures in terms of reducing the vibration transmitted from the ground to the superstructures. In the other words, by comparing the ground acceleration and the accelerations measured on the roofs, either the decrease or the increase of acceleration could be obtained.

It should be noted that all of the accelerometers were connected to a data acquisition system (DAQ) obtained from National Instruments, comprising the cDAQ-9174 chassis and the NI-9234 module. The DAQ was then connected to a computer that has monitoring and recording signal software installed.

When the test set-up described above finished, the detonator was ignited using a car battery directly connected to the detonator's wire. This created an instantaneously extreme impact underground thereby producing the vibration that sent stress waves travelling across the ground; eventually, they were transmitted to the superstructures. In the same time, the accelerometers sensed the vibration, both on the ground and structures. Figures 3.14 and 3.15 display the setting up for this experiment, showing all three accelerometers: (1) G1 installed on the ground, (2) G2 installed over the roof of one-storey house, and (3) G2 installed over the roof of two-storey house.

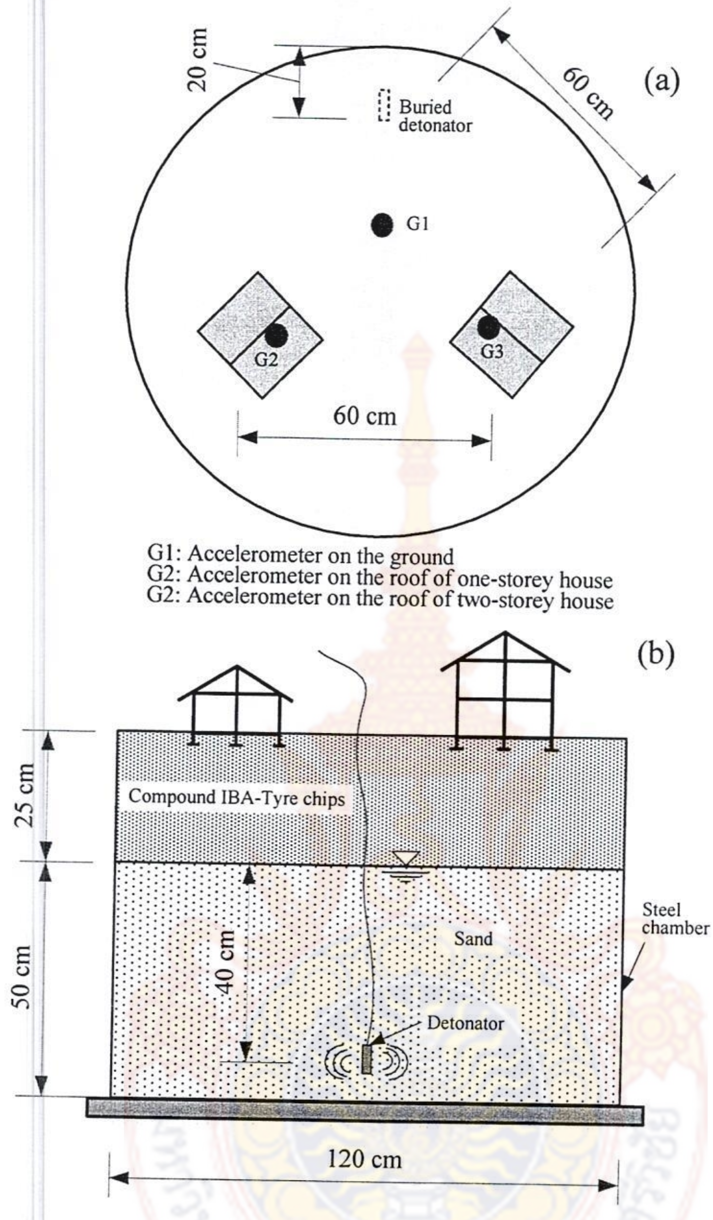


**Figure 3. 13 Test set-up and measurement arrangement: top view (a) sectional view (b)**

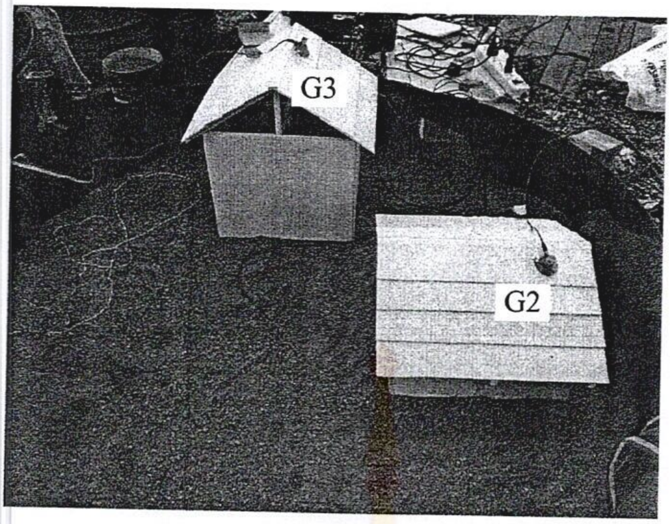


**Figure 3. 14 Installation of one- and two-storey houses**

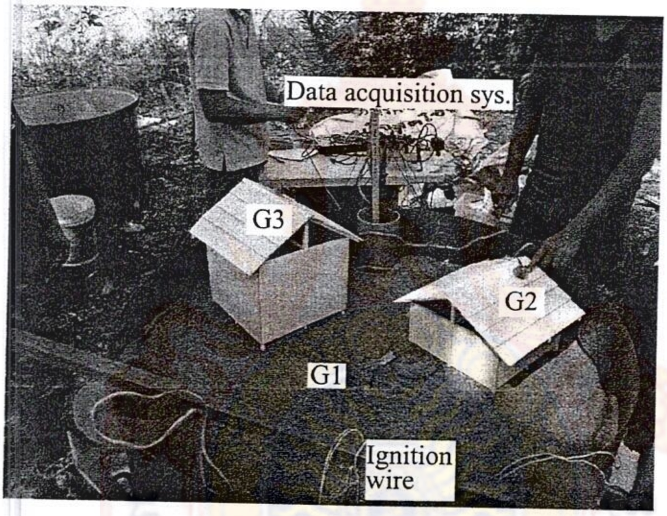


**Figure 3. 15 Accelerometers being installed and connected to the data acquisition system**

### 3.4.2 Testing programmes

It should be noted herein that the presence of the groundwater near the surface is not unusual in most parts of the world. As such, it was also interesting to observe the ground shaking behaviour when saturated. Therefore, the sand layer was prepared such that it had two states, completely dry and saturated. This resulted in a total of 12 different test configurations, as explained in table 3.4.

**Table 3. 4 List of all test configurations**

| Number | Foundation material | Sand layer state | Mixture proportion (%) | |
|---|---|---|---|---|
| | | | IBA | TC |
| 1 | D-A100 | Dry | 100 | 0 |
| 2 | D-A95 | Dry | 95 | 5 |
| 3 | D-A90 | Dry | 90 | 10 |
| 4 | D-A75 | Dry | 75 | 25 |
| 5 | D-A40 | Dry | 40 | 60 |
| 6 | D-A0 | Dry | 0 | 100 |
| 7 | W-A100 | Saturated | 100 | 0 |
| 8 | W-A95 | Saturated | 95 | 5 |
| 9 | W-A90 | Saturated | 90 | 10 |
| 10 | W-A75 | Saturated | 75 | 25 |
| 11 | W-A40 | Saturated | 40 | 60 |
| 12 | W-A0 | Saturated | 0 | 100 |

# CHAPTER 4

# TEST RESULTS AND DISCUSSION

## 4.1 Introduction

The main purpose of this research was to investigate the effectiveness of the mixtures between incinerator bottom ash (IBA) and tyre chips (TC) in terms of buffering the vibration induced by earthquake. It was achieved by first constructing model soil strata comprising sand and the mixtures. Two model houses then were placed over the top of the surface. During the soil strata construction, a detonator was also installed underground. Then, it was ignited in order to generate the vibration similarly to that of the earthquake. A total of three accelerometers were installed: one on the ground, the other two on the roofs of the model houses. This provided the information concerning the vibration induced on the ground and the house, thereby yielding the information for further analysis in terms of earthquake buffering behaviour. The test results are explained below.

## 4.2 Results and discussion

The results obtained from this study were chiefly maximum accelerations measured on the ground and over the roofs of both model houses, designated as G1, G2, and G3, with respect to the values on the ground and over the roofs of one- and two- storey houses, respectively. The testing results for the dry sand were summarised and shown in table 4.1; while table 4.2 displays the results for the saturated sand. Also shown in both tables are the percentage differences of the accelerations for G2 and G3, with respect to G1. Examples of acceleration versus time for the dry sand are illustrated by figures 4.1 to 4.6; while figures 4.7 to 4.12 display some measured accelerations obtained from the saturated sand.

Overall, it was found that the accelerations obtained from the saturated sand are much greater than those obtained from the dry sand. This may be because the pore water acted as the blockage of travelling stress waves thereby increasing the ground vibration. In case of the dry sand, however, the stress waves probably were more freely to travel and radiate within the foundation soil.

Considering the accelerations obtained from G1, it was observed that for the dry sand the maximum acceleration is gradually increased with the increase of TC from 0 to 25%. After that it slightly decreased when the TC was 60%; and, increased again when the TC was 100%. This is quite contrary to the case of saturated sand: the maximum acceleration was progressively decreased with the increase of TC.

The difference between the maximum measured accelerations obtained from the dry- and saturated sands can be clearly seen when considering Figures 7 and 8, corresponding to the mixtures D-A75 and W-A75, respectively. Note that both mixtures had the IBA and TC of 75% and 25%, respectively. In case of the ground acceleration (G1), it was found that the maximum acceleration for W-A75 is almost 29.1 g; while it was only just 5.03 g for D-A75. This clearly confirms that the presence of pore water in the sand layer caused the dramatic increase of ground vibration.

When considering the acceleration induced on both model houses, however, the maximum accelerations obtained from G2s with respect to D-A75 and W-A75 were approximatley 0.81 g and 2.05 g. Comparing these values to their corresponding G1s, it was observed that the transmitted accelerations for D-A75 and W-A75 are 84% and 93% lower. This demonstrates that when the sand saturated, even though the ground acceleration is much greater than that of the dry sand, the vibration transmitted to the house is much lower compared to the ground acceleration.

Figures 13 and 14 display the maximum measured accelerations versus tyre chip contents with respect to the sand layer being dry and saturated, respectively. To be able to analyse the effects of the compound IBA-TC on the acceleration transmitted to the superstructures, the percentage differences of maximum measured accelerations of G2 and G3 with respect to G1 for both sands were plotted and shown in figure 15.

It revealed that the behaviours of both G2 and G3 for the dry sand is quite different to those for the saturated sand. For instance, the maximum measured acceleration induced on the houses was gradually increased with the increase of tyre chip contents, as seen in Figure 9. In addition, it was maximum when the mixture having the TC of 60%. Contrary to the dry sand, the accelerations obtained from G2 and G3 for the saturated sand was gradually decreased with the increase of TC from 0 up to 25%. When the TC was greater, however, the accelerations were virtually constant, as illustrated by Figure 10.

Another point should be noted is that the difference of accelerations between G2 and G3 for the dry sand is quite greater than that for the saturated sand. These findings strengthen the idea that the presence of pore water in the sand layer could: (1) amplify the ground acceleration and (2) soften the acceleration transmitted to the superstructure, as can be clearly seen in figure 15.

**Table 4. 1 Maximum accelerations for the dry conditions**

| Foundation material | Max. measured acceleration (g) | | | Percentage diff. with respect to G1 | |
|---|---|---|---|---|---|
| | G1 | G2 | G3 | G2 | G3 |
| D-A100 | 2.18 | 0.52 | 0.76 | -76 | -65 |
| D-A95 | 2.86 | 0.57 | 0.84 | -80 | -71 |
| D-A90 | 2.98 | 0.55 | 1.09 | -82 | -63 |
| D-A75 | 5.03 | 0.81 | 1.26 | -84 | -75 |
| D-A40 | 3.50 | 0.86 | 1.55 | -76 | -56 |
| D-A0 | 4.99 | 0.84 | 1.15 | -83 | -77 |
| | | | Average | -80 | -68 |

**Table 4. 2 Maximum accelerations for the wet conditions**

| Foundation material | Max. measured acceleration (g) | | | Percentage diff. with respect to G1 | |
|---|---|---|---|---|---|
| | G1 | G2 | G3 | G2 | G3 |
| W-A100 | 50.3 | 6.73 | 7.31 | -87 | -85 |
| W-A95 | 50.3 | 3.76 | 4.30 | -93 | -91 |
| W-A90 | 22.3 | 2.29 | 2.60 | -90 | -88 |
| W-A75 | 29.1 | 2.05 | 2.71 | -93 | -91 |
| W-A40 | 34.8 | 2.89 | 3.07 | -92 | -91 |
| W-A0 | 17.7 | 2.24 | 2.07 | -87 | -88 |
| | | | Average | -90 | -89 |

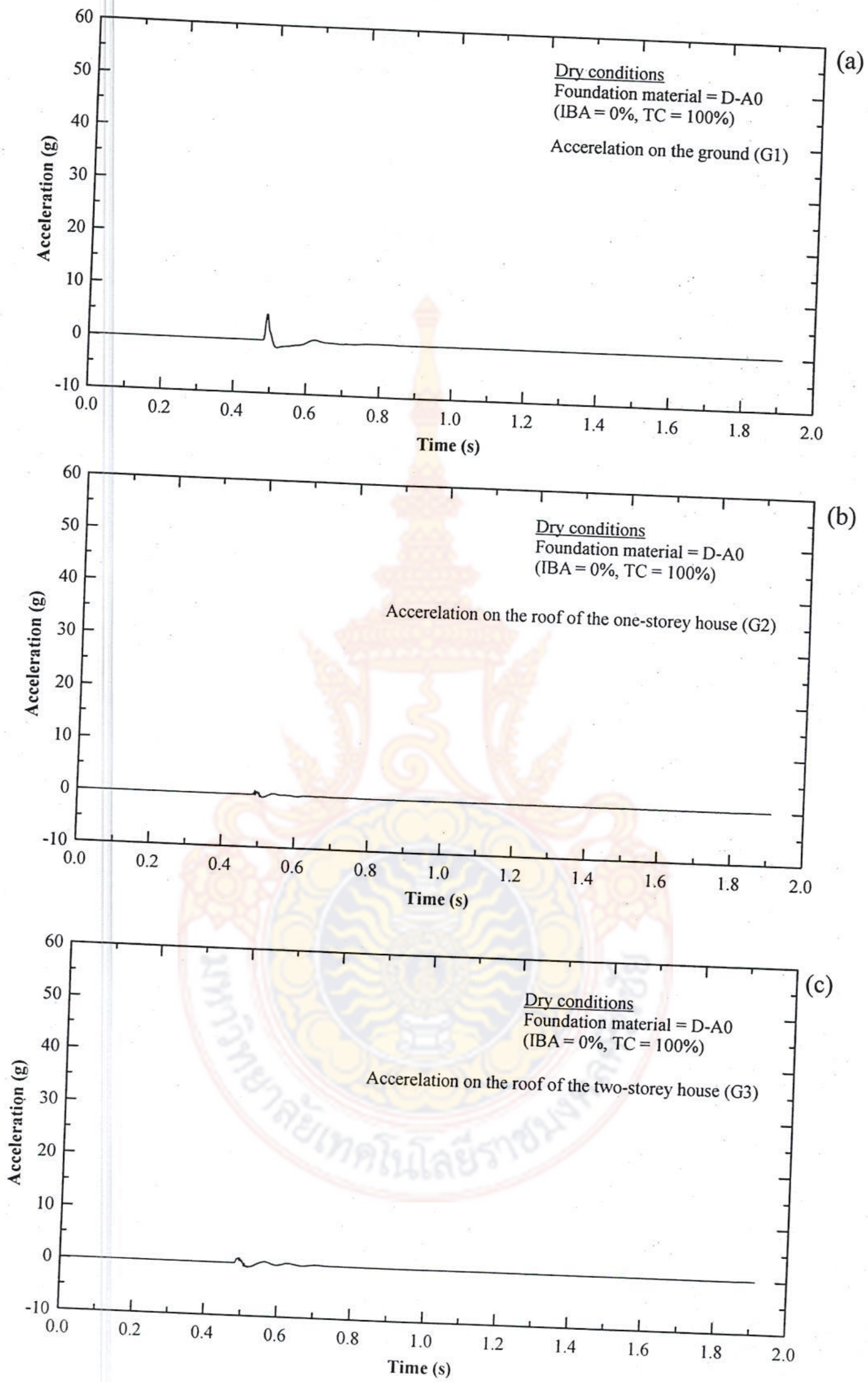


**Figure 4. 1 Acceleration signals for D-A0 (dry conditions): G1 (a) G2 (b) and G3 (c)**

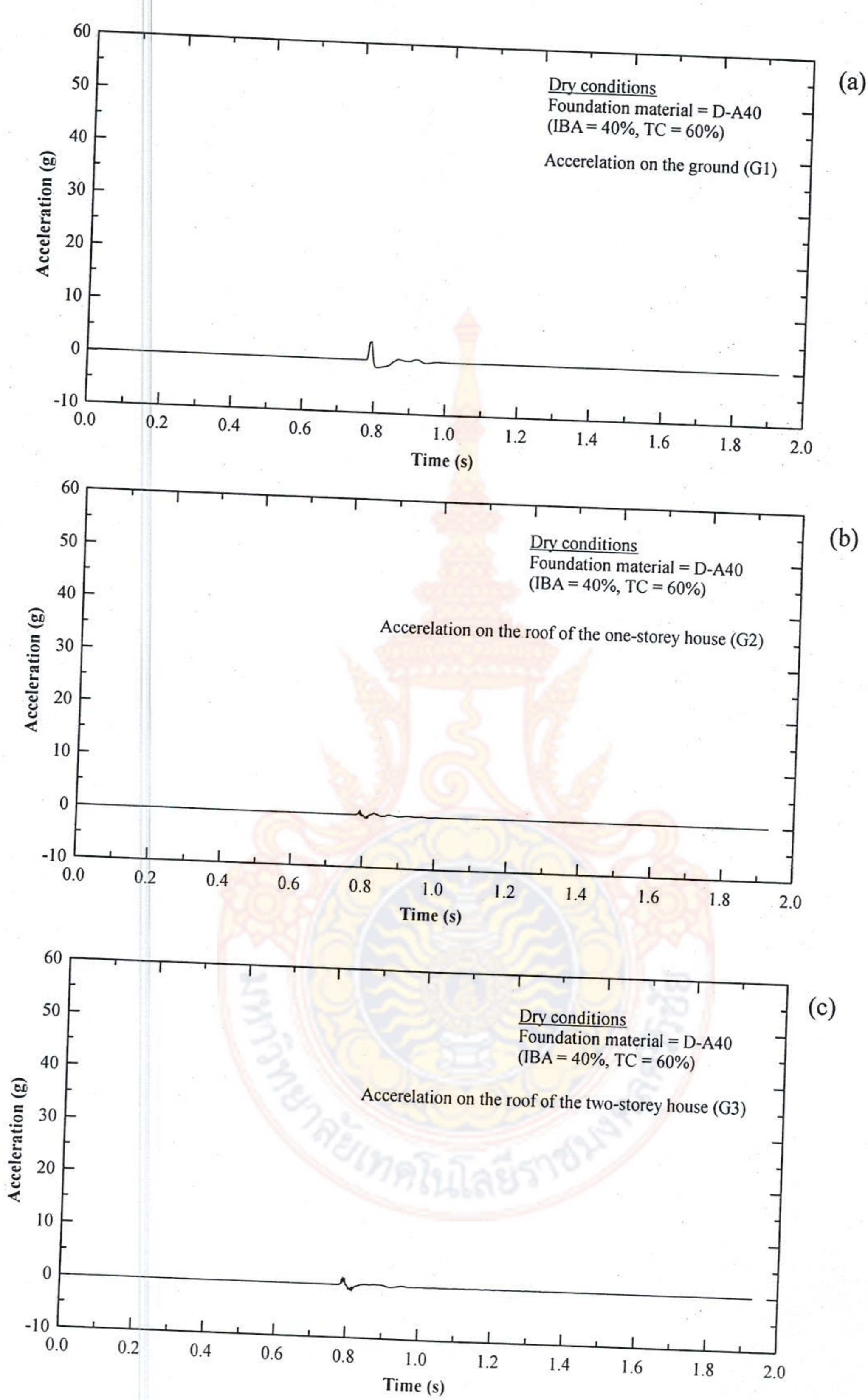


**Figure 4. 2 Acceleration signals for D-A40 (dry conditions): G1 (a) G2 (b) and G3 (c)**

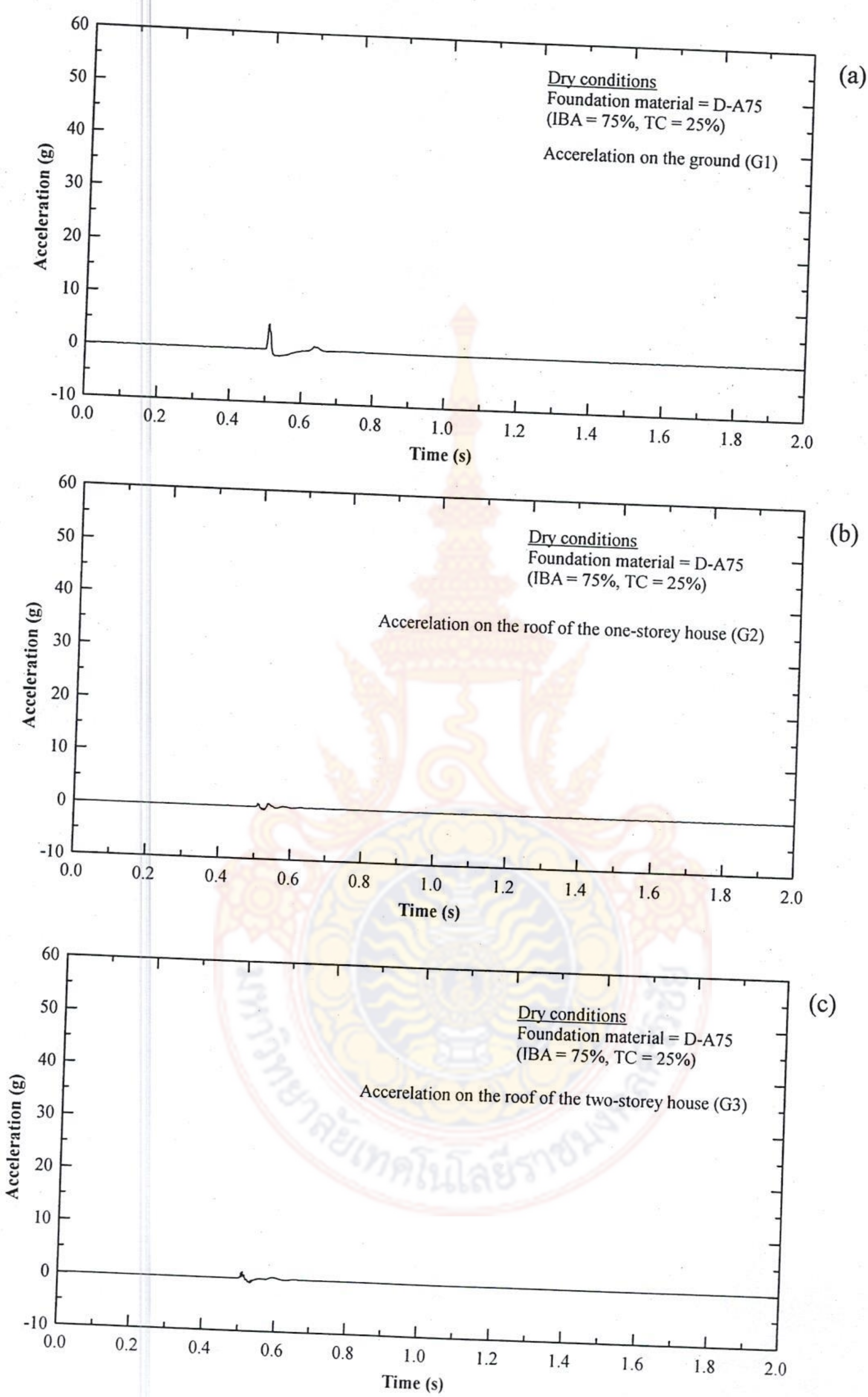


**Figure 4. 3 Acceleration signals for D-A75 (dry conditions): G1 (a) G2 (b) and G3 (c)**

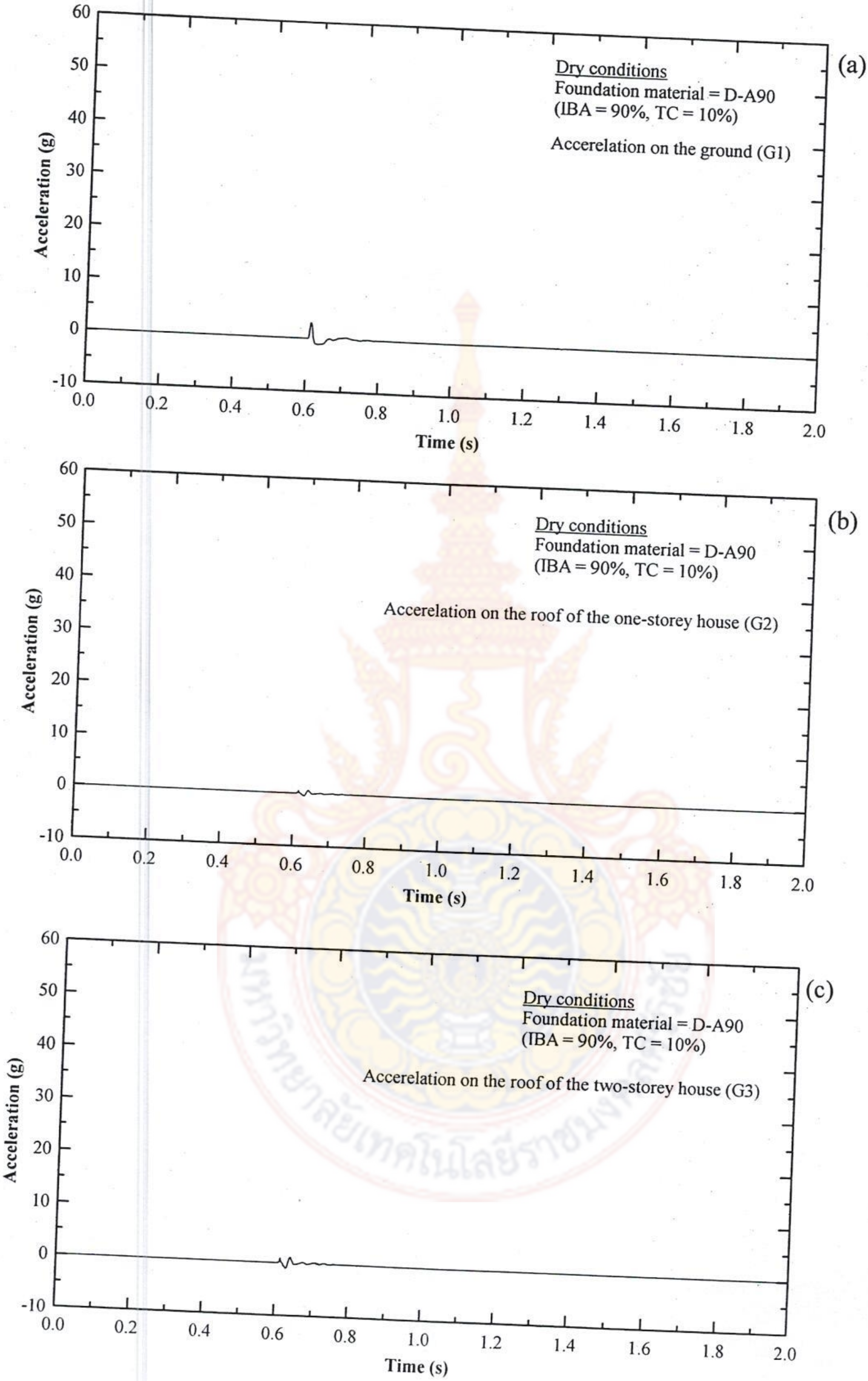


**Figure 4. 4 Acceleration signals for D-A90 (dry conditions): G1 (a) G2 (b) and G3 (c)**

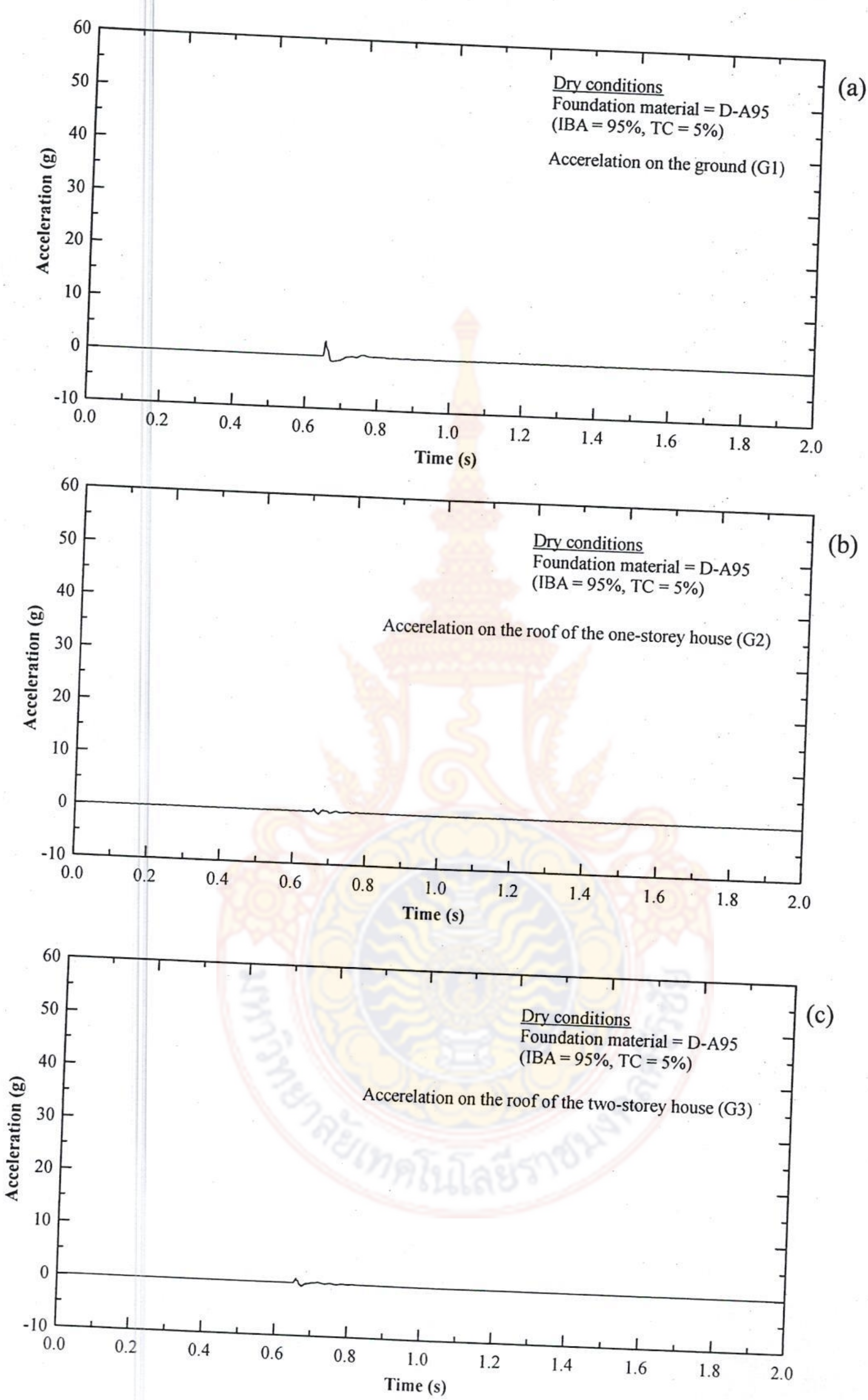


**Figure 4. 5 Acceleration signals for D-A95 (dry conditions): G1 (a) G2 (b) and G3 (c)**

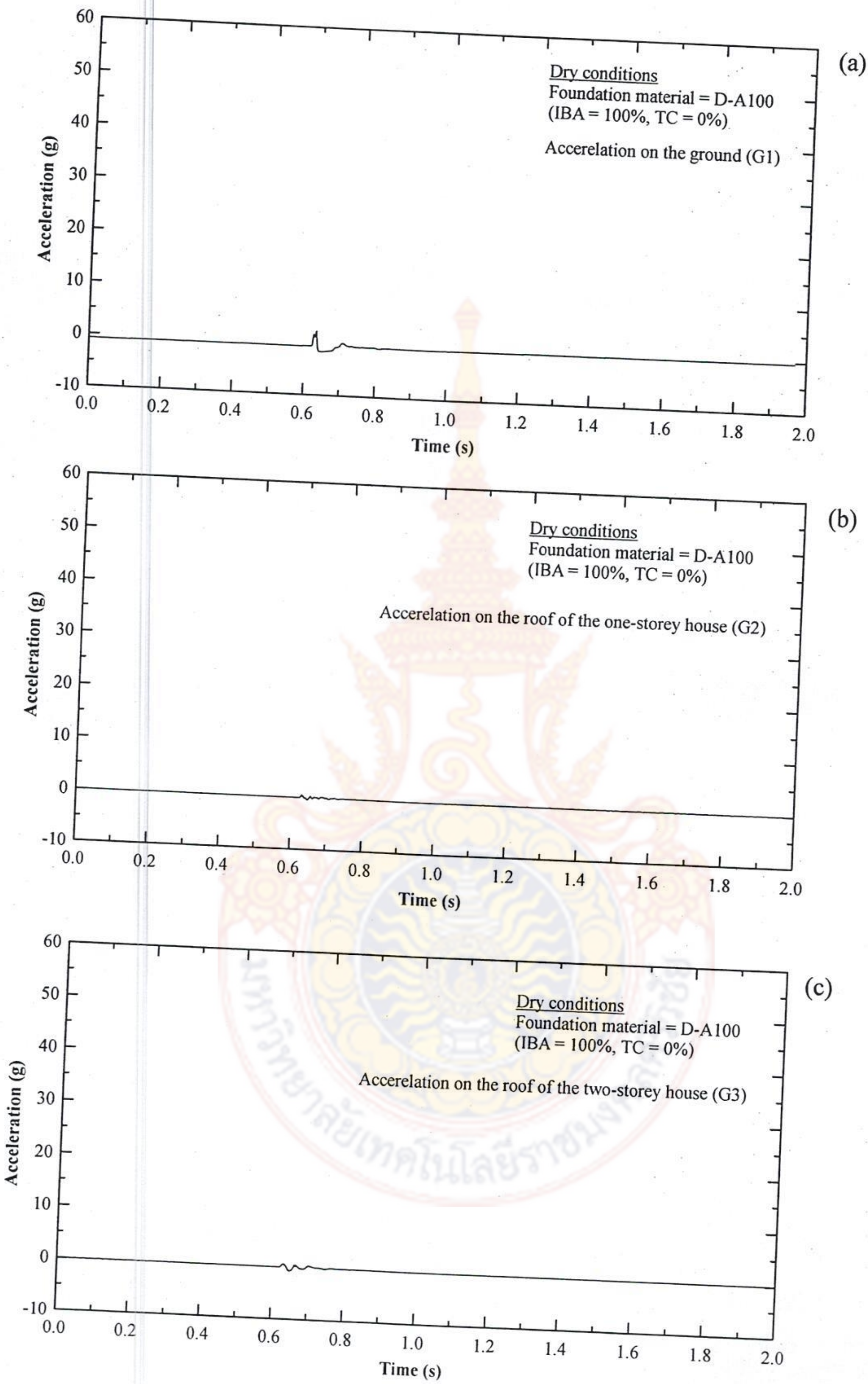


**Figure 4. 6 Acceleration signals for D-A100 (dry conditions): G1 (a) G2 (b) and G3 (c)**

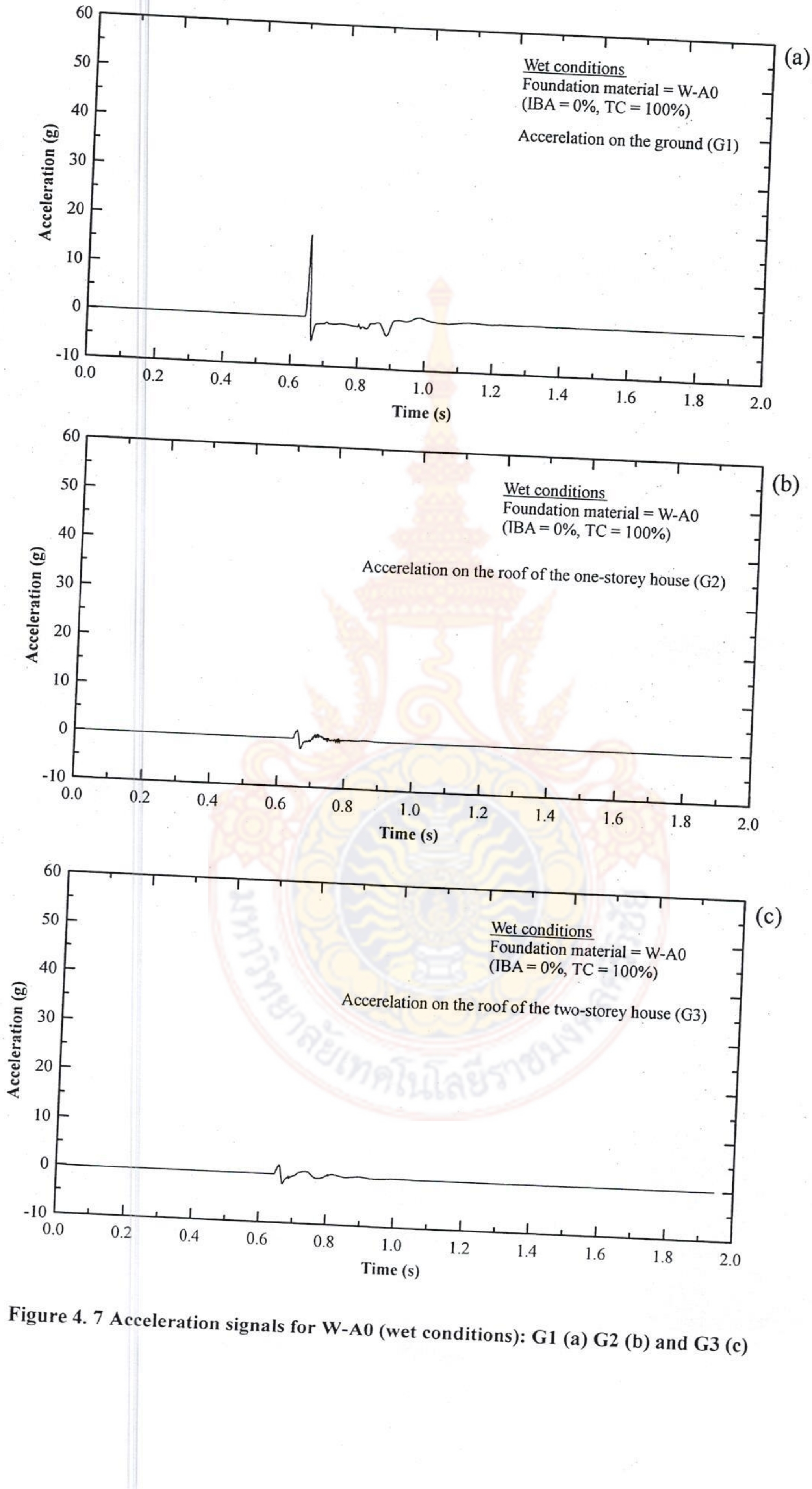


**Figure 4. 7 Acceleration signals for W-A0 (wet conditions): G1 (a) G2 (b) and G3 (c)**

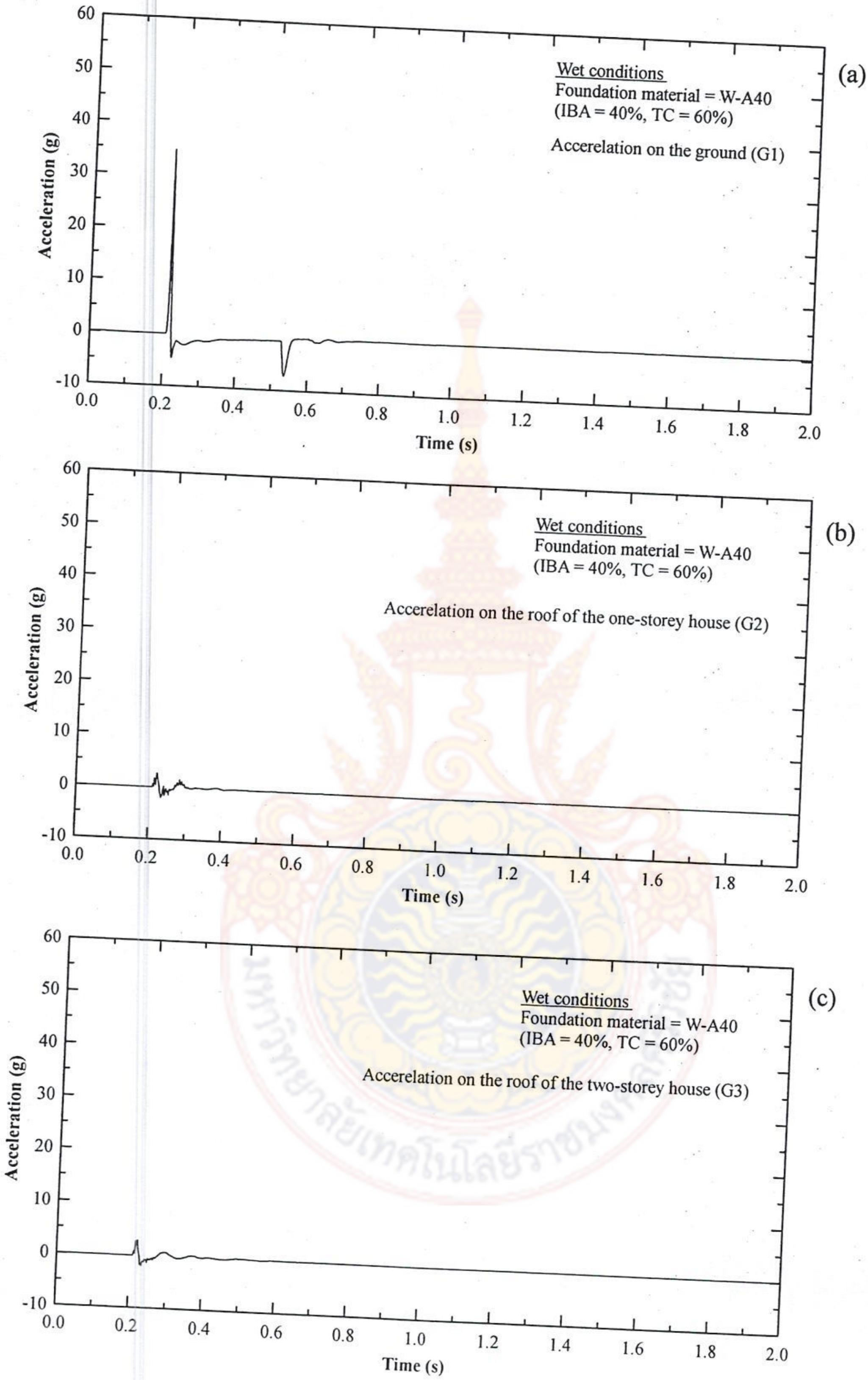


**Figure 4. 8 Acceleration signals for W-A40 (wet conditions): G1 (a) G2 (b) and G3 (c)**

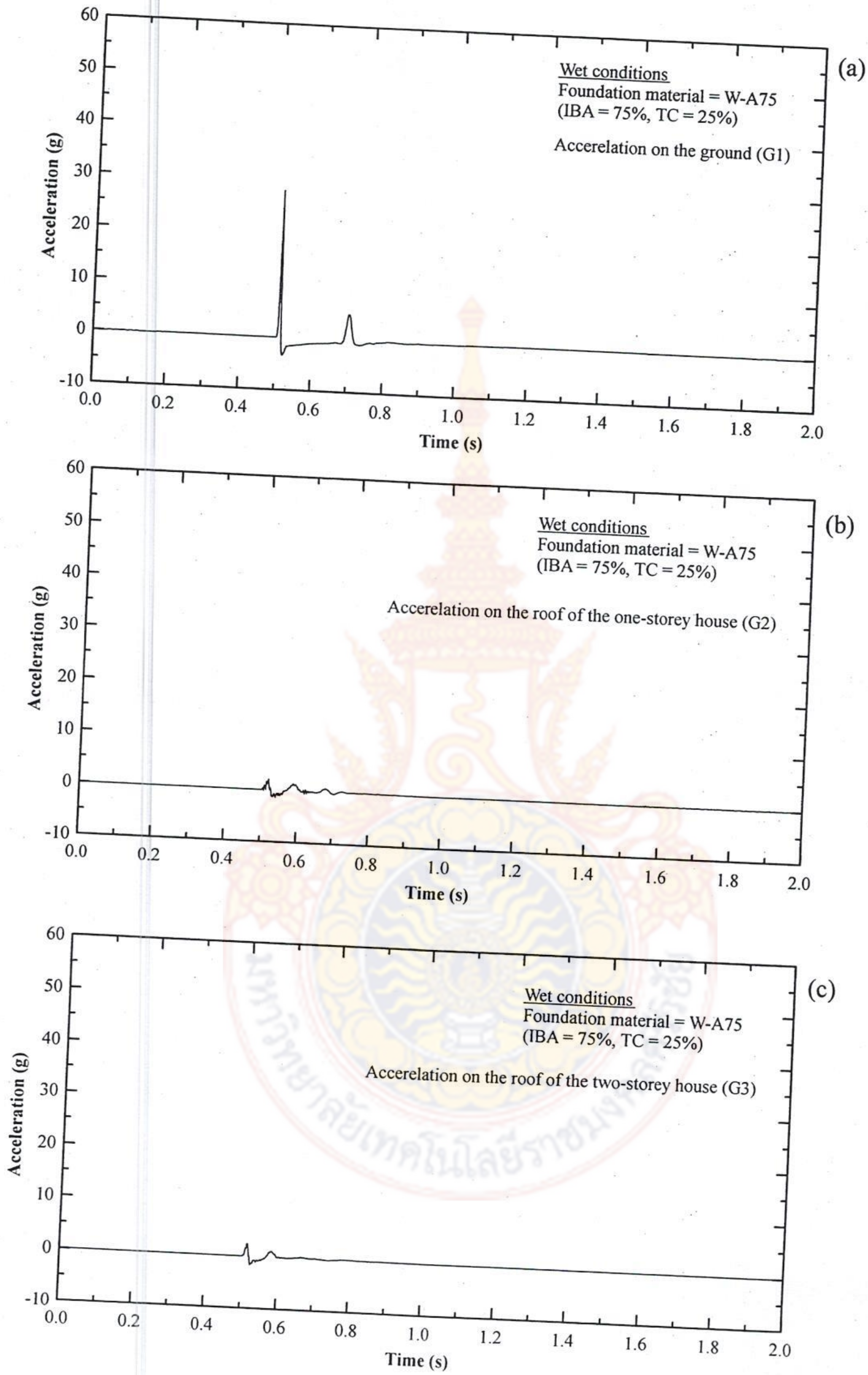


**Figure 4. 9 Acceleration signals for W-A75 (wet conditions): G1 (a) G2 (b) and G3 (c)**

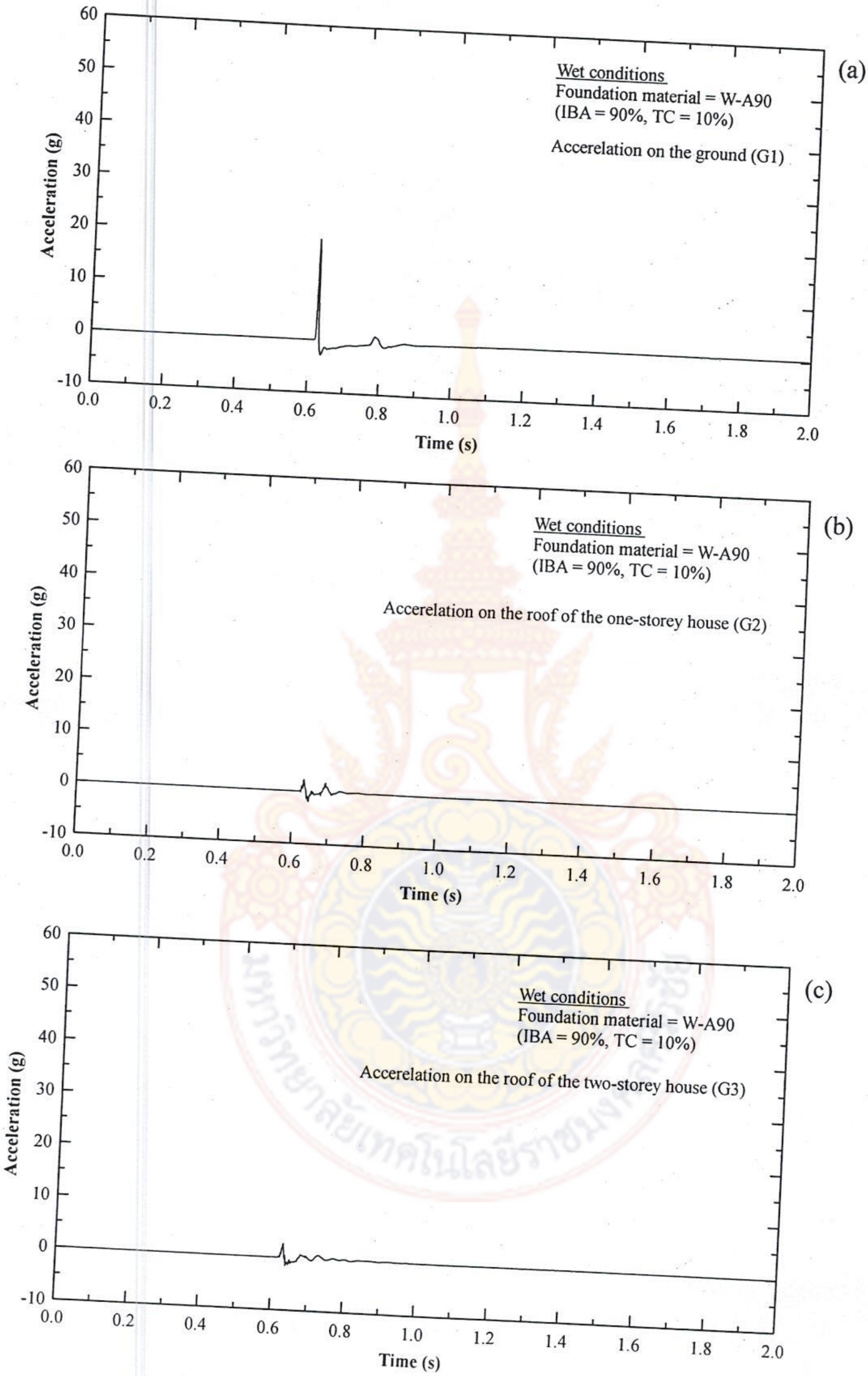


**Figure 4. 10 Acceleration signals for W-A90 (wet conditions): G1 (a) G2 (b) and G3 (c)**

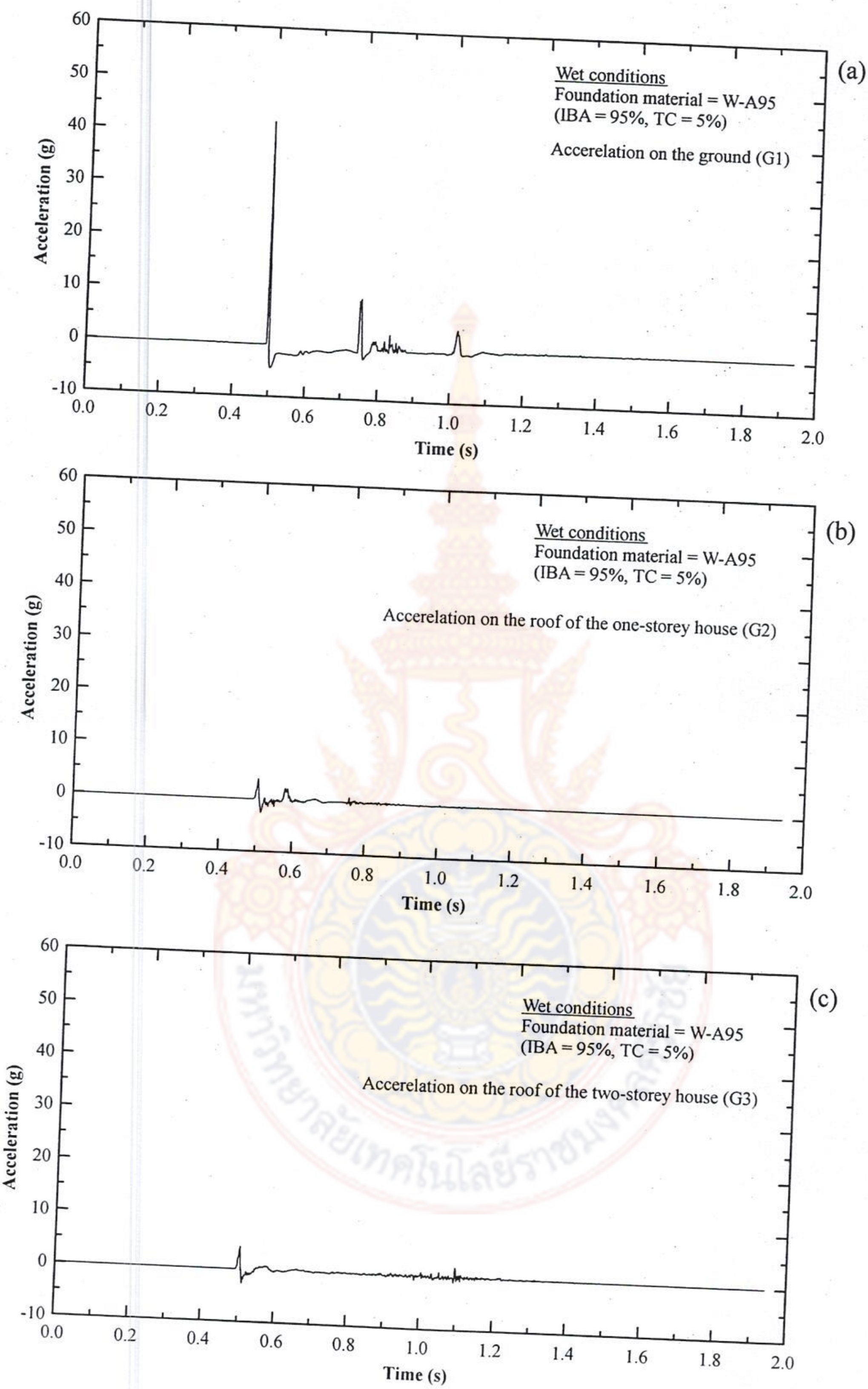


**Figure 4. 11 Acceleration signals for W-A95 (wet conditions): G1 (a) G2 (b) and G3 (c)**

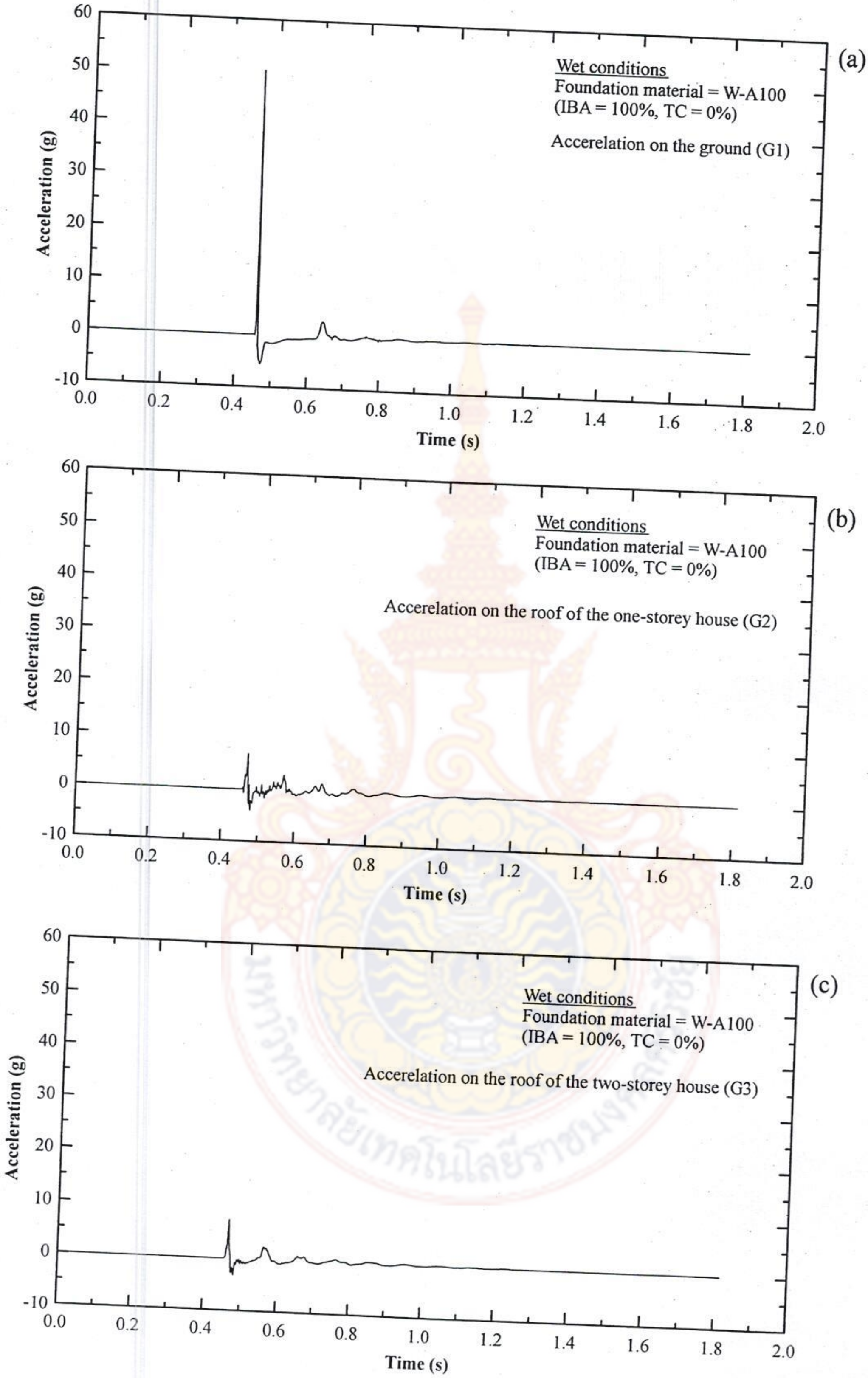


**Figure 4. 12 Acceleration signals for W-A100 (wet conditions): G1 (a) G2 (b) and G3 (c)**

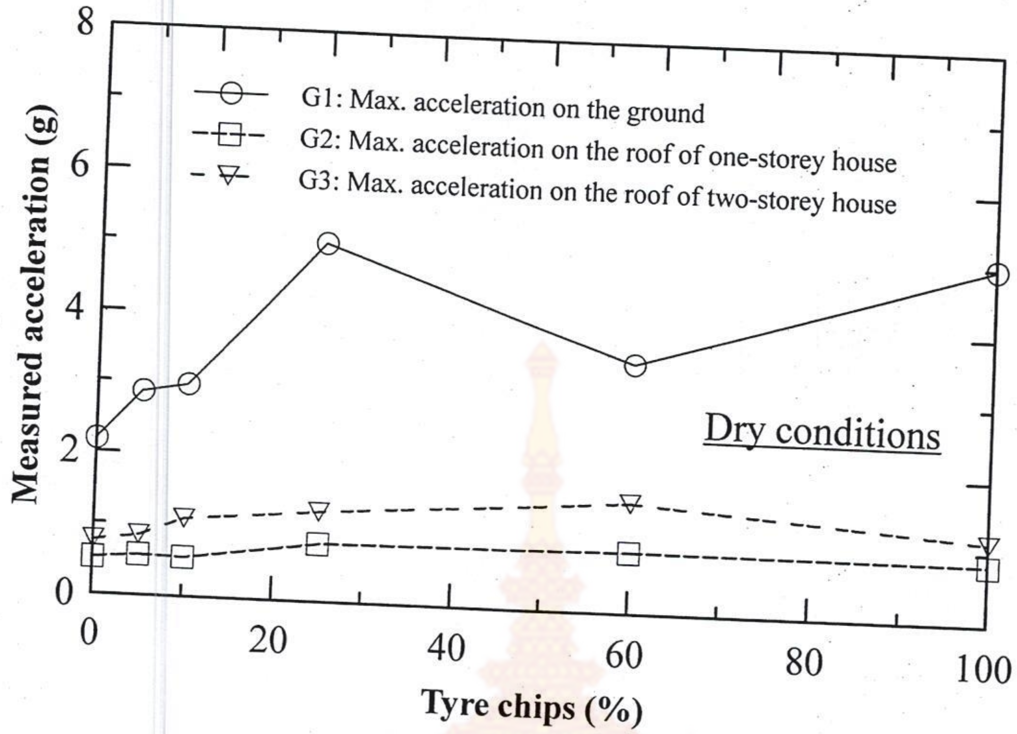


**Figure 4. 13 Maximum measured accelerations versus percentage tyre chips for the dry conditions**

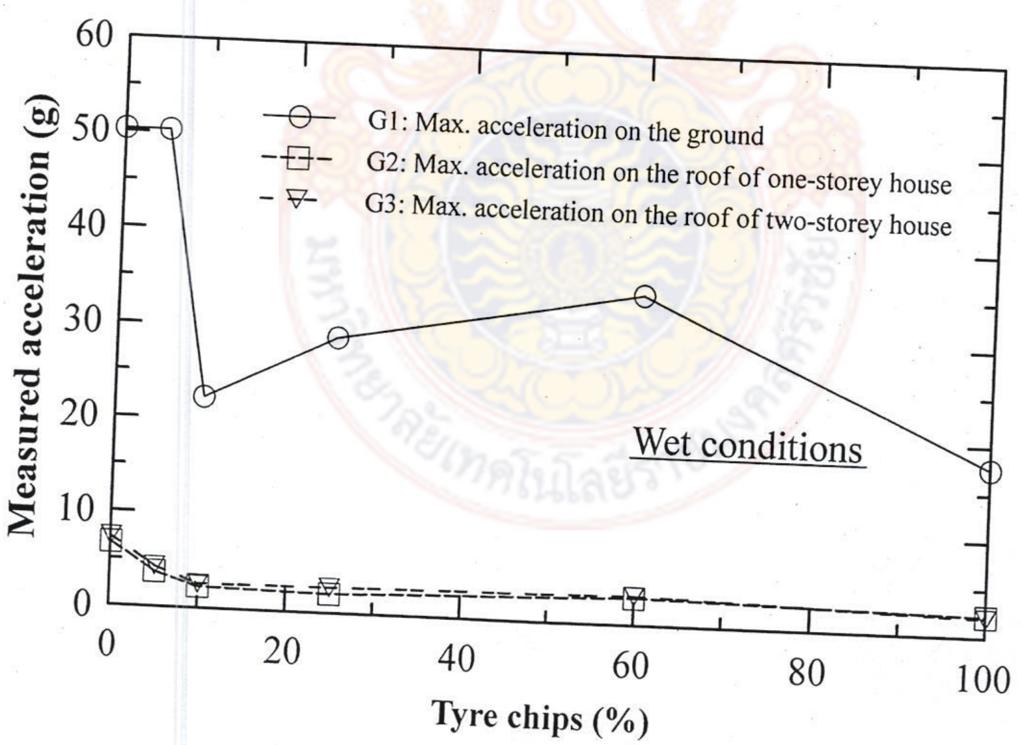


**Figure 4. 14 Maximum measured accelerations versus percentage tyre chips for the wet conditions**

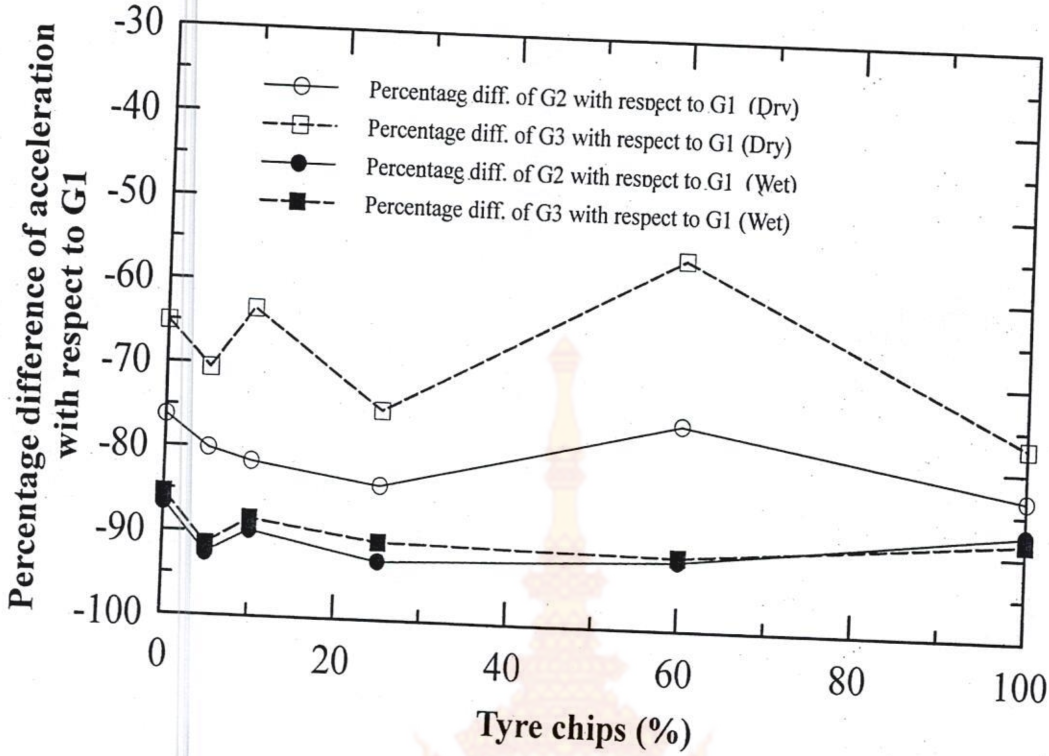


**Figure 4. 15 Percentage differences of max. accelerations of G2 and G3 with respect to G1**

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

When a major earthquake strikes, damage is inevitable. Unfortunately, with current knowledge and technologies we are still unable to predict when an earthquake will occur. In addition, it has been happening since the beginning of the earth.

In this study, incinerator bottom ash was mixed with recycled tyre chips in order to be employed as foundation soil. The main purpose was to investigate their effectiveness in terms of reducing the vibration transmitted from the ground to superstructures. It was achieved by first construction a 50 cm thick sand layer in a steel chamber having the diameter of 120 cm. During the sand layer construction an explosive detonator was installed at 10 cm from the bottom. Then, the compound IBA-TC having varied mixes was placed over the sand. The ratios of IBA to TC were 100:0, 95:5, 90:10, 75:25, 40:60, and 0:100, by weight.

After the completion of the foundation material construction two model houses, one- and two-storey, were placed over the ground. A total of three accelerometers were then installed: one on the ground and the other two over the roof of the two houses. This set-up was followed by the immediate ignition of the explosive already installed thereby generating the vibration under the ground. Eventually, the ground vibration was transmitted to the model houses. In the meantime the accelerations on the ground as well as on the roofs were monitored and recorded for further analysis. It should be emphasised that the sand layer was prepared to be two states, dry and saturated. This was intended for investigating the effects of the presence of pore water in the sand layer on the transmission of acceleration from the ground to superstructures. Based on the experiment conducted, the following conclusions have been drawn:

## 5.2 Ground Vibration

(1) Overall, the ground vibration in the case of dry sand is progressively increased with the gradual increase of TC from 0 to 25%; then, it decreases when the TC is 60%. It increases again when the mixture has no IBA.

(2) For the saturated sand, the ground vibration dramatically decreases when the TC is 10%; then, it gradually increases when the TC contents are from 25 to 60%. However, the ground vibration is dramatically decreased again when the mixture has no IBA.

(3) In the case of dry sand, the vibrations measured on the two-storey house are quite greater than those occurred on the one-storey house. This is not the case for the saturated sand because the accelerations for the both houses are virtually similar.

(4) From the findings, it may be concluded that in the case of water table is near the ground surface employing compound IBA-TC as foundation soil could reduce the vibration transmitted to superstructures. This could benefit many ways. For example, both IBA and TC, regarded as waste, could be used as construction material thereby reducing overall construction cost somewhat as well as preserve the environment.

## 5.3 Recommendation for Future Work

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

(1) Different sizes of tyre chips should be mixed with the IBA in order to observe the vibration buffering behaviour.

(2) Instead of sand layer, clay should be employed to observe the different behaviour.

(3) Different sizes of explosive should be experimented.

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