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COMPARATIVE STUDY OF DROP-HAMMER PILE-DRIVING PROCESSES IN INDONESIA, MALAYSIA AND THAILAND

Mr. Arief Setiawan Budi Nugroho

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By : Mr. Arief Setiawan Budi Nugroho

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Thesis Advisor : Associate Professor Tanit Tongthong, Ph.D.

Accepted by the Faculty of Engineering, Chulalongkorn University in Partial Fulfillment of Requirements for Master's Degree

…..………………………………………Dean of the Faculty of Engineering
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…………………………………………….Member
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(Associate Professor Wisanu Subsompon, Ph.D.)

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การตอกเสาเข็มเป็นกิจกรรมหนึ่งที่มักจะพบเห็นในโครงการก่อสร้างโดยทั่วๆ ไป โดยเฉพาะในประเทศที่กำลังพัฒนาการตอกเสาเข็มโดยใช้ปั้นจั่นตอกเสาเข็มมักจะเป็นวิธีที่นิยมใช้ในโครงการก่อสร้างขนาดเล็ก อย่างไรก็ตามในประเทศในภูมิภาคเอเชียตะวันออกเฉียงใต้การตอกเสาเข็มมีทั้งความเหมือนและความแตกต่างในเรื่องของเครื่องจักร วัสดุเสาเข็มที่ใช้ และกระบวนการ งานวิจัยนี้จึงมีวัตถุประสงค์ในการสำรวจกระบวนการตอกเสาเข็มในประเทศอินโดนีเซีย ประเทศมาเลเซีย และประเทศไทย เพื่อที่จะเปรียบเทียบการตอกเสาเข็มในโครงการก่อสร้างขนาดเล็ก โดยมุ่งหวังให้เกิดการถ่ายโอนเทคโนโลยี่เพื่อปรับปรุงการทำงาน การศึกษาเริ่มจากการศึกษาเบื้องต้นของกระบวนการตอกเสาเข็มในประเทศไทยและอินโดนีเซีย หลังจากนั้นจึงทำการเก็บข้อมูลโดยละเอียดโดยการสัมภาษณ์และการเก็บข้อมูลการทำงานที่โครงการก่อสร้างในสามประเทศรวมทั้งลักษณะปั้นจั่นที่ใช้ในการตอกเสาเข็ม รูปแบบเสาเข็มที่ใช้ กระบวนการทำงาน และระยะเวลาการทำงานตั้งแต่การติดตั้งเสาเข็ม การตอกเสาเข็ม การเชื่อมต่อเสาเข็มและการเคลื่อนย้ายเสาเข็ม จากนั้นทำการวิเคราะห์ความสามารถในการทำงานของเครื่องจักรแต่ละชนิดในแต่ละขั้นตอนการทำงาน การจำลองสถานการณ์การทำงานได้จัดทำขึ้นเพื่อเปรียบเทียบสมรรถนะในการทำงานของเครื่องจักรแต่ละประเภทในสภาพงานเดียวกัน จากผลการสำรวจพบว่าการตอกเสาเข็มโดยใช้ปั้นจั่นตอกเสาเข็มเป็นวิธีที่นิยมใช้ในโครงการขนาดเล็กในทั้งสามประเทศ ขั้นตอนหลักในการทำงานมีลักษณะคล้ายคลึงกันแต่ลักษณะของเครื่องจักร และกลไกการทำงานมีความแตกต่าง โครงสร้างของปั้นจั่นตอกเสาเข็มในประเทศไทยและมาเลเซียจะมีลักษณะเป็นโครงสร้างเหล็กถักในขณะที่ในประเทศอินโดนีเซียมีลักษณะเป็นโครงเหล็กสามขาประกอบกัน สำหรับฐานการรับรองน้ำหนักของปั้นจั่นตอกเสาเข็มในประเทศไทยใช้เหล็กรูปรางรถไฟในขณะที่ในประเทศมาเลเซียและอินโดนีเซียใช้เหล็กท่อกลม จากลักษณะที่แตกต่างทำให้ระยะเวลาที่ใช้ในการทำงานแตกต่างกันตั้งแต่การติดตั้ง การเคลื่อนย้าย และการถอดประกอบ สำหรับเสาเข็มที่ใช้นั้นในประเทศอินโดนีเซียจะนิยมใช้เสาเข็มที่มีหน้าตัดรูปสามเหลี่ยม ในประเทศไทยนิยมใช้เสาเข็มที่มีหน้าตัดรูปตัวไอ และประเทศมาเลเซียนิยมใช้เสาเข็มที่มีหน้าตัดรูปสี่เหลี่ยมจตุรัส จากการวิเคราะห์พบว่าปั้นจั่นตอกเสาเข็มในประเทศไทยจะให้พลังงานในการตอกเสาเข็มสูงกว่าแต่การเคลื่อนย้ายทำได้ลำบากเนื่องจากการใช้รางรถไฟเป็นฐาน สำหรับปั้นจั่นตอกเสาเข็มในประเทศอินโดนีเซียและมาเลเซียจะให้พลังงานในการตอกน้อยเนื่องจากลูกตุ้มมีน้ำหนักน้อย แต่การเคลื่อนย้ายจะทำได้สะดวกรวดเร็วกว่าเนื่องจากใช้ท่อเหล็กเป็นฐานและมีกลไกการเคลื่อนย้ายที่ง่ายกว่า ข้อแนะนำจากการวิจัยคือการใช้ประโยชน์จากข้อดีของการทำงานในแต่ละประเทศ อย่างไรก็ตามจะต้องมีการทดลองทำจริงและทดสอบในสภาพการทำงานจริงต่อไป ข้อจำกัดในงานวิจัยนี้ที่เป็นประเด็นสำคัญคือ ข้อมูลมีจำนวนน้อย และการเลือกเครื่องจักรที่ใช้ในการเปรียบเทียบมีสภาพที่แตกต่างกัน เช่นปั้นจั่นในประเทศไทยมีขนาดใหญ่กว่า จึงได้ผลในภาพรวมมากกว่าการเปรียบเทียบโดยตรงระหว่างเครื่องจักร

ภาควิชา วิศวกรรมโยธา ลายมือชื่อนิสิต..

สาขาวิชา วิศวกรรมโยธา ลายมือชื่ออาจารย์ที่ปรึกษา..

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KEY WORD : PILING / PILE-DRIVING / DROP-HAMMER / DRIVEN-PILE

ARIEF SETIAWAN BUDI NUGROHO: THESIS TITLE. COMPARATIVE STUDY OF DROP-HAMMER PILE-DRIVING PROCESSES IN INDONESIA, MALAYSIA AND THAILAND. THESIS ADVISOR: ASSOC. PROF. DR. TANIT TONGTHONG, 104 pp. ISBN 974-53-1415-3

Pile-driving is one of the common processes usually found in many construction projects. In the developing countries, a drop-hammer pile-driving method is widely employed in small construction projects. However, there are some similarities and differences in this common process in terms of machines, materials, and procedures, used in the South-East Asian countries. This research then aims to explore the pile-driving processes in Indonesia, Malaysia and Thailand to compare pile-driving works in small construction projects for an operation improvement via the technology transfer. The study starts from the preliminary site investigation on pile-driving processes in Thailand and Indonesia. Next, the data are collected by interviewing the site engineers, observing and capturing actual processes in three countries, Indonesia, Malaysia and Thailand. Factors influencing operation of pile-driving works such as types of machines and pile shapes are investigated. Data representing work mechanisms of the machines are captured as well as cycle times of each process. The cycle times include four minor processes, setting a pile, driving a pile, welding a joint of two connected piles, and the machine movement. Based on the cycle times, statistical analysis is done to identify the performances of each machine in each process. Simulation analysis is then performed to find the overall performance of these machines. From the exploration, it is found that drop-hammers are the common pile-driving machines use in small construction projects in the observed countries. Their series of processes are similar but their machine components and operation mechanisms are different. Structures of drop-hammers found in Indonesia are made in forms of simple space frames whereas structures of drop-hammers found in Malaysia and Thailand are made in forms of space trusses. In the case of machine supports, steel rails are equipped in the drop-hammers in Thailand while steel pipes are equipped in the drop-hammers in Indonesia and Malaysia. According to the differences, these machines require different times for installation, movement and dismantling. In the case of piles, triangle-shape, square-shape, and I-shape are the popular pile-shapes used in Indonesia, Malaysia and Thailand, respectively. The analysis presents that drop-hammers found in Indonesia and Malaysia utilize mechanisms that provide an ease in moving the machines but with lower weight of rams, they produce lower driving energy. On the other hand, drop-hammers found in Thailand provide high driving energy due to their heavy rams but require longer time in machine movement. Combination of the advantages of the drop-hammers is recommended for performance improvement. However, the real experiment is needed to be conducted in the similar conditions. The major limitations in this research are that (a) there are few numbers of data in some processes and, (b) the machines used to compare the performance are selected and their characteristics are not exactly the same. For example, the machines in Thailand are larger than the others.

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Finally, to all readers, due to my intention to present this research pervasively, please accept my sincere apologies for my English usage in this research and any misunderstanding, which may arise from English language.

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CHAPTER I
INTRODUCTION

1.1. Overview

Efficiency and effectiveness are important issues in construction work. Contractors, engineers and suppliers, as the construction participants, are expected to keep improving construction methods in order to achieve more effective and efficient work. Some of the goals of the construction method improvement are to minimize waste and reduce work duration.

In terms of efficiency and effectiveness, productivity becomes another part which directly influences the duration and the cost of the work. There are several meanings of productivity. In nationally developed statistics, it is commonly stated as a constant in place value divided by inputs, such as worker-hours (Oglesby, et al, 1989). For the owner of an existing plant or other property or equipment, it may be the cost per unit of output produced by the facility. For the contractor, a rough measure of the amount or percentage costing less (or more) than the payment from the owner. Basically, all these approaches attempt to measure the effectiveness of management skills, workers, and equipment. Tools are employed in support of work-face activities to produce a finished building, plant structure, or other fixed facility at the lowest feasible cost.

In construction, productivity problems, for instance, can be found in pile-driving work. Pile-driving is one of the common types of foundation widely used in construction projects, and it can be a critical activity since delay of this work may delay project completion. In most construction contracts, delay of the work should be compensated with an amount of punishment per day of delay (FIDIC, 1999). Since pile-driving work is the first activity in construction, good planning is crucial. However, this work often faces productivity problems because of uncertainties that may occur during operations. For these reasons, a good plan should be adopted that covers not only thorough soil investigation but also selection of the appropriate pile-driving equipment.

In small construction projects, pile-driving usually involves a simple process. The pile-driving machine is usually a simple machine and the piles are usually small and light. Although in some areas large and heavy piles are possible as well. Productivity problems in this type of project usually occur due to inappropriate selection of pile-driving equipment. To compensate low machine productivity, a good plan and strategy should be implemented to obtain proper work performance. This is generally done by adjusting the number of piles to be driven, the kind of equipment and pile properties, such as shape, length and material component. However, this method aims of shortening the duration and minimizing pile-driving operation costs. To avoid any financial loss caused by these problems, the knowledge and experience of the engineers and contractors in handling pile-driving are very important.

This research aims to discover a better operation for pile-driving through a comparative study of the processes in Indonesia, Malaysia and Thailand. Hence, several types of machines, pile shapes and methods in the observed countries is examined.

1.2. Problem Statement

As developing countries in South-East Asia, Thailand, Indonesia and Malaysia have some similarities. With large populations, each has high potential in human resources. Furthermore, the similarity of seasons, such as rainy and dry season, contributes positive factors towards constructions.

In the matters of pile-driving, Thailand, Indonesia and Malaysia face similar problems. Although there are many kinds of modern equipment which promise higher productivity, utilization of conventional pile-driving machines is still an option, especially, in small construction projects. With low labor costs, the operation cost of utilizing conventional equipment is relatively less than that of utilizing modern machines.

However, there are some differences in pile-driving work in small construction projects in Thailand, Indonesia and Malaysia. In Indonesia, piles can be driven by pile-pushing-machine machines or drop-hammers, whereas, in Thailand and Malaysia drop-hammer machines are widely employed. Other differences include the characteristics of pile-driving machines and types of piles.

Another part of the pile-driving system where differences and similarities exist is in the pile shapes. In areas where bearing resistance is more dominant than friction, piles need to be installed until their tips reach very hard soil to obtain the required soil resistance capacity. In these areas, circle spun piles are commonly used in these three countries. However, in areas where friction resistance is more dominant than bearing, Indonesia, Thailand, and Malaysia have some different ways to create the pile-shape in order to achieve the effective and efficient resistance.

With all the similarities and differences of pile-driving works which exist in Thailand, Indonesia and Malaysia, the basic problem is still at the low machine productivity. At the beginning of a project, site congestion which may affect low work productivity (Thomas, et al, 2003), is often caused by employing many unproductive piling equipment. Thus, the effect of unproductive pile-driving equipment may have an impact on the performance of construction projects. Therefore, studying pile-driving problems and enhancing its productivity becomes very crucial.

1.3. Objectives

The objective of this research is to perform a comparative study of pile-driving processes using drop-hammer machines in some South-East Asian countries; Thailand, Indonesia and Malaysia. The supporting goals are as follows:

1. To discover the similarities and differences of the drop-hammer pile-driving processes used in small construction projects in Indonesia, Malaysia and Thailand.
2. To suggest a better operation developed through the technology transfer.

1.4. Scopes of The Research

To study pile-driving processes, there are several data to be collected. As performance of pile-driving machines is influenced by many factors, precise estimates of pile-driving productivity are very difficult to identify. Some of the influencing factors determining pile-driving machines performances are types of driving machines, pile properties, conditions of the construction sites, and soil characteristics.

Due to the above, some constraints will be considered as limitation of this research.

1. Case studies are taken only in some cities in the three observed countries; Indonesia, Malaysia and Thailand.
2. Exploration is focused on discovering similarities and differences of pile-driving operation in those observed countries.
3. The machines used to be observed and compared in this research are:
   a) Indonesia : 10 m high machine with 1.7 tons of ram
   b) Malaysia : 10 m high machine with 1.2 tons of ram
   c) Thailand : 18 m high machine with 5 tons of ram
4. Effectiveness of pile-shapes is analyzed to the piles which are frequently used in small construction in the three observed countries.
5. Other factors are assumed the same in all observed pile-driving projects, such as:
   a) Skill of labors
   b) Electric power for welding
   c) Difficulty level of construction sites
   d) 100% driving-energy efficiency and no energy lost caused by machine components.

1.5. Research Contributions

1. Exchange knowledge of construction management and technology between the three observed countries, Thailand, Indonesia and Malaysia, especially, in terms of pile-driving works for small constructions.
2. Provide guidelines for construction participants to plan better pile-driving works.
3. Offer new concept which may contribute to enhance the productivity of present pile-driving equipment.

CHAPTER II
LITERATURE REVIEW

This chapter presents literature review of related research. Several literatures are searched from several media such as internet and library.

The review literature in this chapter includes, first, discussing several kinds of pile-driving machines such as drop-hammer, diesel hammer, and double acting hammer. Second, Classification of piles in a brief review of the behavior of piles when resist external load is presented. Next, the previous research about pile-driving productivity is reviewed. Last, the analysis theory of soil resistance capacity in pile-driving system is presented.

2.1. Driving Machines

There are many kinds of pile-driving equipment. Among of them, a drop-hammer machine is the basic driving equipment (Thomlinson, 1977). The simplicity in operation makes this machine become practically used in some construction projects. It is also cheaper in operation and maintenance.

The work mechanism of drop-hammer is guided by lugs or jaws sliding in the leaders and actuated by the lifting rope. The drop-hammer consists of a solid mass or assemblies of forged steel. The striking speed is slower in the case of single or double acting hammers. When drop-hammers are used to drive concrete piles there is a risk of damage to the pile if an excessively high drop of the hammer is adopted when the driving becomes difficult (Thomlinson, 1977).

There has been a revival of interest in the simple drop-hammer because of its facility to be operated inside a sound-proofed box, so complying with noise abatement regulations. Drop-hammers are not used efficiently when operated from a pontoon-mounted piling frame working in open waters, since the height of the drop cannot be controlled when the pontoon is rising and falling on the waves. However they can be used effectively in sheltered waters (Thomlinson, 1977).

Different from the modern pile-driving machine which its performance relies on the complexity of the machine, the performance of drop-hammer relies on the skill of the operator and labors to handle its operation. The more skilful the operator and labors is, the more productive the work will be achieved.

The second type of piling hammer is Single-acting hammer. Single-acting hammer is operated by steam or compressed air, which lift the ram and then allows it to fall by gravity. The single acting hammer is best suited for driving timber or precast concrete piles since the drop of each blow of the hammer is limited in height and is individually controlled by the operator. The single acting hammer is also suitable for driving all types of pile in stiff to hard clay, where a heavy blow with a small drop is more efficient and less damaging to the pile than a large number of lighter blows (Thomlinson, 1977).

Similar to the single acting hammer where the power for lifting up the hammer is produced by steam or air power, the third kind of piling hammer is double acting hammer. Double acting (or differential acting) hammers are steam or air operated both on the upstroke and down-stroke, and are designed to impart a rapid succession of small-stroke blows to the pile. The double acting hammer exhausts the steam or air on both the up and down strokes. In the case of the differential-acting hammer, however, the cylinder is under equal pressure above and below the piston and is exhausted only on the upward stroke. The downward force is a combination of the weight of the ram and the difference in total force above and below the piston, the force being less below the piston because of the area occupied by the piston rod. These hammers are most effective in granular soils where they keep the ground 'live' and shake the pile into the ground, but they are not so effective in clays (Thomlinson, 1977). Double acting hammers have their main use in driving sheet piles and are used for bearing piles in preference to diesel hammers. However, unlike the diesel hammer they can operate under water and by the way the steam or air supply for both single acting and double-acting hammers should be at least 125% of the nominal consumption stated by the hammer manufacturer.

The forth kind of Hammer machine is Diesel Hammer. A diesel pile-driving hammer is a self-contained driving unit that does not require external source energy such as a steam boiler or an air compressor. In this respect, it is simpler and more easily moved from one location to another than a steam hammer (Peurifoy, et al, 2002). A complete unit consists of a vertical cylinder, a piston or ram, an anvil, fuel- and lubricating oil tanks, a fuel pump, injector and a mechanical lubricator.

The mechanism of energy generation of diesel hammer is illustrated in Figure 2.1. After a hammer is placed on top of pile, the combination piston and ram are lifted on the upper end of the stroke and released to start the unit operating (Peurifoy, et al, 2002). As the ram is near the end of the down-stroke, it activities a fuel pump that injects the fuel into the combustion chamber between the ram and the anvil. The continued down-stroke of the ram compresses the air and the fuel to ignition heat. The resulting explosion drives the pile downward and the ram upward to repeat its stroke.

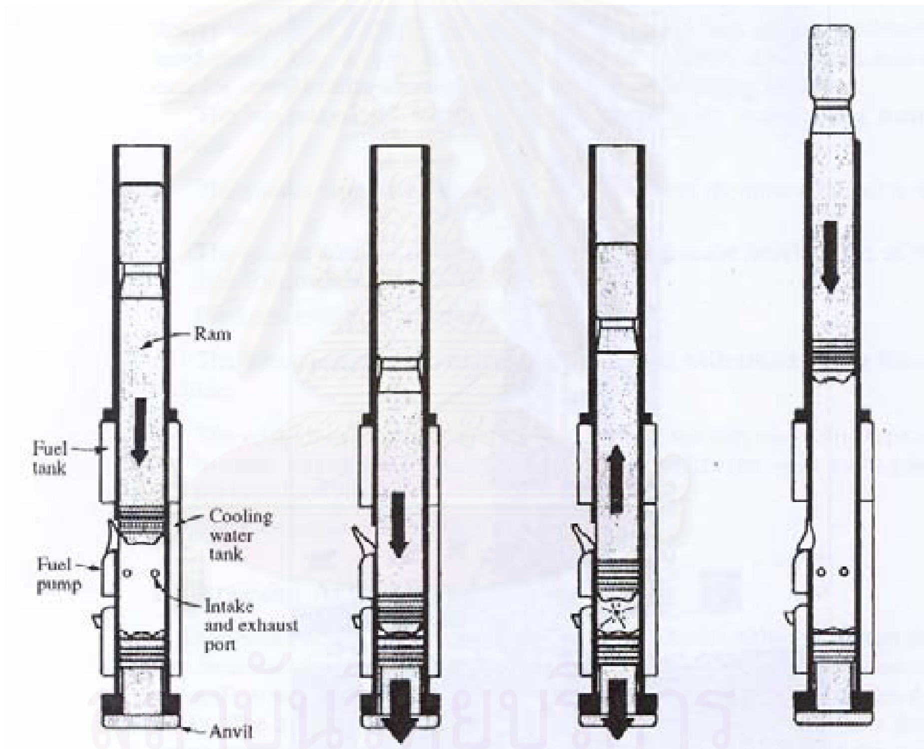


Figure 2.1 The operations of diesel hammer (Peurifoy, et al, 2002)

2.2. Classification and Selection of Piles

The British Standard Code of Practice for Foundation (quoted in Thomlinson, 1977), classifies type of piles in three categories. These are as follows.

1) Displacement (or large displacement) pile

It comprises solid-section plows or hollow-section piles with a closed end, which are driven or jacked into the ground and thus displace the soil. All types of driven and cast in situ piles come into this category.

2) Small displacement pile

It is also driven or jacked into the ground but have relatively small cross section area. They include rolled steel H- or I-sections, and pipe or box sections driven with an open end such that the soil enters the hollow section. Screw piles that have a small-diameter shaft and a larger helical blade are also classed as small-displacement piles.

3) Non-displacement pile

It is formed by first removing the soil by boring using a wide range of drilling techniques. Concrete may be placed into an unlined or lined hole, or the lining may be withdrawn as the concrete is placed. Preformed element of timber, concrete, or steel may be placed in drilled holes.

The selection of the appropriate type of pile from any of the above categories depends on the following three principal factors; the location and type of structure, the ground conditions and the durability (Thomlinson, 1977).

Other factors influencing the choice of one or another type of pile in each main classification in which the various types of pile are described in detail. Having selected a certain type or types of piles as being suitable for the location and type of structure, for the ground conditions at the site, and for the requirement of durability, the final choice is then made on the basis of cost. However, the total cost of a piled foundation is not simply the quoted price per meter run of piling or even the more accurate comparison of cost per pile per KN of working load carried. The most important consideration is the overall cost of the foundation work including the main contractor’s costs and overheads.

2.2.1. Precast concrete pile

The current trend of increasing efficiency and productivity in the management of construction activities has placed considerable emphasis on the use of precast members where off-site manufacture, under controlled conditions, and uncoupled from site processes and delays, can provide a constant supply of precast elements

(Chan et al, 2000). The use of precast elements is more crucial at locations where heavy rains can cause serious delays due to a difficult working environment. This is particularly evidence for foundation works in soft or slimy soils where heavy rainfall can cause the sides of the excavation to fail and thus requires further time and effort to rectify the excavation.

Precast concrete piles have their principal use in marine and river structures, i.e. in situation where the use of driven-and-cast-in-situ piles is impracticable or uneconomical (Thomlinson, 1977). For land structures precast concrete piles are frequently more costly than driven-and-cast-in-situ type for two main reasons.

1) Reinforcement must be provided in the precast concrete pile to withstand the bending and tensile stresses which occur during handling and driving. Once the pile is in the ground, and if mainly compressive loads are carried, the majority of this steel is redundant.
2) The precast concrete pile is not readily cited down or extended to suit variations in the level of the bearing stratum to which the piles are driven.

However, there are many situations for land structures where the precast concrete pile can be the more economical. Where large numbers of piles are to be installed in easy driving conditions the saving cost due to the rapidity or driving achieved may out-weight the cost of the heavier reinforcing steel necessary (Thomlinson, 1977). Reinforcing may be needed in any case to resist bending stresses due to lateral loads or tensile stresses from uplift loads. Where high-capacity to be driven to a hard stratum savings in the overall quantity of concrete compared with cast-in-situ piles can be achieved since higher working stresses can be used. Where piles are to be driven into sulphate-bearing ground or into aggressive industrial waste materials, the provision of sound high-quality dense concrete is ensured. The problem of varying the length of the pile can be overcome by adopting a jointed type.

2.2.2. Pre-stressed concrete pile

From the above remarks it can be seen that there is still quite a wide range of employment for the precast concrete pile, particularly for projects where the costs of establishing a precast yard can be spread over a large number of piles. The piles can be designed and manufactured in ordinary reinforced concrete, or in the forms of pretensioned or post-tensioned prestressed concrete members. The ordinary reinforced concrete pile is likely to be preferred for a project requiring a fairly small number of piles, where the cost of establishing a production line for prestressing work on site is not justifiable and where the site is too far from an established factory to allow the economical transportation of prestressed units from the factory to the site (Thomlinson, 1977). In countries where the precast concrete pile is used widely, the ordinary reinforced concrete pile is preferred to the prestressed design in almost all circumstances.

2.3. Pile-driving Work in Thailand

The previous research which discusses pile-driving productivity was done by Chantararath in 1984. The research examined the progress characteristic of pile-driving work in construction in Thailand.

Chantararath (1984) reveals that the most important factor in selection of hammer type is the capacity of driving and efficiency of working to economize the cost. However, since pile-driving work is influenced by many factors affecting delay, usually pile-driving rig can not work with its full capacity. In fact, unproductive time of piling work may reach as high as 50% of the productive time, or even more.

Chantararath (1984) also cites that the time to install each pile depends on the cross section and length of pile, characteristic of site and soil properties. However, using drop-hammer, in Thailand, normally installation time of each pile takes about 1.5 hours for large pile and 1hour for small pile with the production rate is about 6 to 7 piles per day at medium stiff soil and 3 to 4 piles per day at a very stiff soil condition. If assembling and dismantling duration are taking into a count, total the time consumed must be added by 8 days which is 6 days for assembling and 2 days for dismantling.

Finally Chantararath (1984) points out that the factors affecting delay of piling work are usually not caused by the high technical problem, but they are triggered by the poor condition of equipment, site, manpower and management.

2.4. Basic Theory

2.4.1. Static Pile Capacity

(Bowles, 1997), All static pile capacities can be computed by the following equations:

$$\left.\begin{aligned} P_u &= P_{pu} + \sum P_{si} \\ &= P_{pu} + \sum P_{si,u} \end{aligned}\right\} \quad \text{(compression)} \qquad (2.1)$$

$$T_u = \sum P_{si,u} + W_p \quad \text{(tension)} \qquad (2.2)$$

Where :

P_u	=	ultimate maximum pile capacity in compression-usually defined as that load producing a large penetration rate in a load test.
T_u	=	ultimate pullout capacity
P_{pu}	=	ultimate pile tip capacity – seldom occurs simultaneously with ultimate skin resistance capacity $\sum P_{si,u}$; neglect for "floating" piles (which depend only on skin resistance).
P_p	=	tip capacity that develops simultaneously with $\sum P_{si,u}$; neglect for "floating" piles.
$\sum P_{si}$	=	skin resistance developing with ultimate tip resistance P_{pu}; neglect for point bearing piles
$\sum P_{si,u}$	=	ultimate skin resistance developing simultaneously with some tip capacity P_p.
W_p	=	weight of pile being pulled
$\sum$	=	summation process over *i* soil layers making up the soil profile over length of pole shaft embedment

The allowable pile capacity P_a or T_a is obtained from applying a suitable SF in the contribution parts as

$$P_a = \frac{P_{pi}}{SF_p} + \frac{\sum P_{si}}{SF_s} \qquad (2.3)$$

or using a single value SF (most common practice) to obtain

$$P_a = \frac{P_u}{SF} \quad \text{or} \quad T_a = \frac{T_u}{SF} \tag{2.4}$$

2.4.2. Dynamic Formula

Dynamic formulas have been widely used to predict pile capacity. Some means is needed in the field to determine when a pile has reached a satisfactory bearing value other than by simply driving it to some predetermined depth (Bowles, 1997). Driving the pile to the predetermined depth may or may not obtain the required bearing value because of normal soil variations both laterally and vertically.

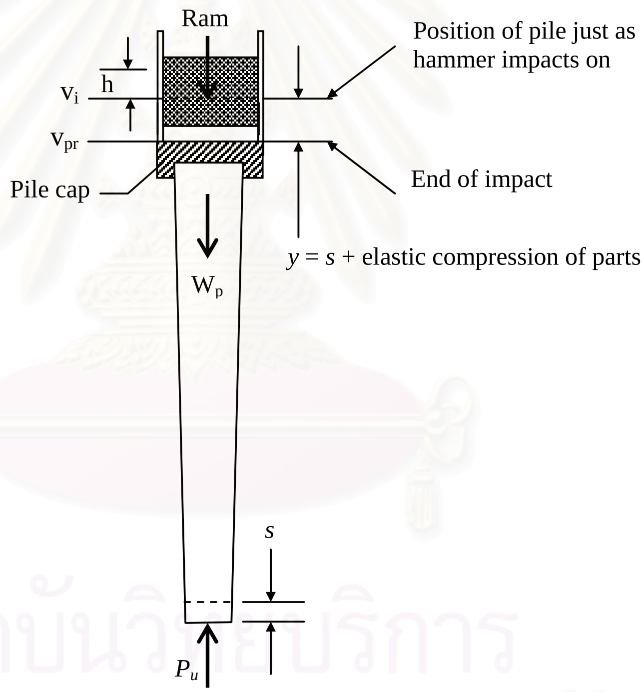


Figure 2.2 Force mechanisms during driving processes (Bowles, 1997)

Where:

k1 = elastic compression of capblock and pile cap and is a form of Pu.L/AE (L)

k2 = elastic compression of pile and is of a form Pu.L/A.E (L)

k3 = elastic compression of soil, also termed quake for wave equation analysis (L)

n = coefficient of restitution

s = amount of point penetration per blow (L)

Wp = weight of pile including weight of pile cap, all or part of the soil "plug", driving shoe, and capblock (also includes anvil for double-acting steam hammers) (F)

Wr = weight of ram (for double acting hammer include weight of casing) (F)

It is generally accepted that the dynamic formulas do not provide very reliable predictions. Predictions tend to improve by using a load test in conjunction with the equation to adjust the input variables. Predictions by persons with experience in a given area, using certain equipment, with a good knowledge of the input variables of weight, etc., are often considerably better than many of the predictions found in the literature (Bowles, 1997).

Most of the dynamic pile formula, termed the *rational pile formulas*, currently used are based on impulse-momentum principles. The derivation refers to Figure 2.2.

Hiley (quoted in Bowles, 1997) present an equation for P_u as:

$$Pu = \left[\frac{e_h.W_r.h}{s+\frac{1}{2}(k_1+k_2+k_3)}\right].\left[\frac{W_r+n^2.W_p}{W_r+W_p}\right] \tag{2.5}$$

Chellis (quoted in Bowles, 1997), suggested the following form of the Hiley equation:

$$Pu = \left[\frac{e_h.E_h}{s+\frac{1}{2}(k_1+k_2+k_3)}\right].\left[\frac{W+n^2.W_p}{W+W_p}\right] \tag{2.6}$$

According to Chellis(quoted in Bowles, 1997), the manufacture's energy rating of E_h is based on an equivalent hammer weight term *W* and height of ram fall *h* as follows:

$$Eh = W.h = (Wr + \text{weight of casing}) . h \tag{2.7}$$

Inspection of the derivation of the Hiley equation indicates the energy loss fraction should be modified to *W* as shown in Equation (2.6) also.

A careful inspection of the Hiley equation, together with a separation of term, results in

Energy in = work +impact loss + cap loss + pile loss + soil loss

$$e_h.W_r h = P_u.s + e_h.W.h\frac{W_p\left(1-n^2\right)}{W_r + W_p} + P_u k_1 + P_u k_2 + P_u k_3 \qquad (2.8)$$

Best results from the dynamic formula as a pile capacity prediction tool are obtained when a careful and separate assessment is made of the several loss factors (Bowles,1996).

2.5. Conclusion

Some related literatures are presented in this chapter. The operation concepts of some pile-driving equipment which provide the basic of the pile-driving processes are discussed.

In the second part of this chapter, various types of driven pile are presented. Based on literatures, considerations of how to select the appropriate pile is also explained.

As the important foundation of this research, a previous similar research done in Thailand is described. This research provides information which relate to productivity of pile-driving work in Thailand.

Finally, some theories of pile resistance capacity is presented. The basic theory is derived from the principle of the dynamic and static pile resistance. The theory convinces the concept that pile resistance capacity depends on the energy produced by the hammer blows minus some losses such as loss caused by impact, cap, pile and soil, etc.

CHAPTER III
RESEARCH METHODOLOGY

This chapter discusses the methodology of the research. First, the preliminary site investigation is explained. Second, a brief review of related literature is included. Data collection and statistical analysis are also explained. Then, the comparisons of performance of each observed machine are described. The method of simulation used to calculate the overall performance of pile-driving work is presented.

The overall steps of the research methodology are shown in the Figure 3.1.

3.1. Preliminary Site Investigation

Site investigation is the first step of this research. Its purpose is to find general knowledge of pile-driving works in real construction projects; thus, the real problems of pile-driving works can be recognized. Further, by recognizing the real pile-driving problems, it is expected that a strategy of collecting detailed data can be arranged properly.

Preliminary site investigation was accomplished within October 2003 to March 2004 by visiting pile-driving projects in two observed countries, Indonesia and Thailand.

3.1.1. Exploration of driving equipment

The first purpose of doing preliminary site investigation is to explore common pile-driving equipment used in small construction in the initially observed countries, Indonesia and Thailand.

Machine exploration is focused on observing the equipment properties such as hammer weight, equipment height, machine structure, and other machine's components. Next, these machine properties will be analyzed to identify their effect to machine's performance.

The exploration outcomes are discussed in detail in Chapter 4.

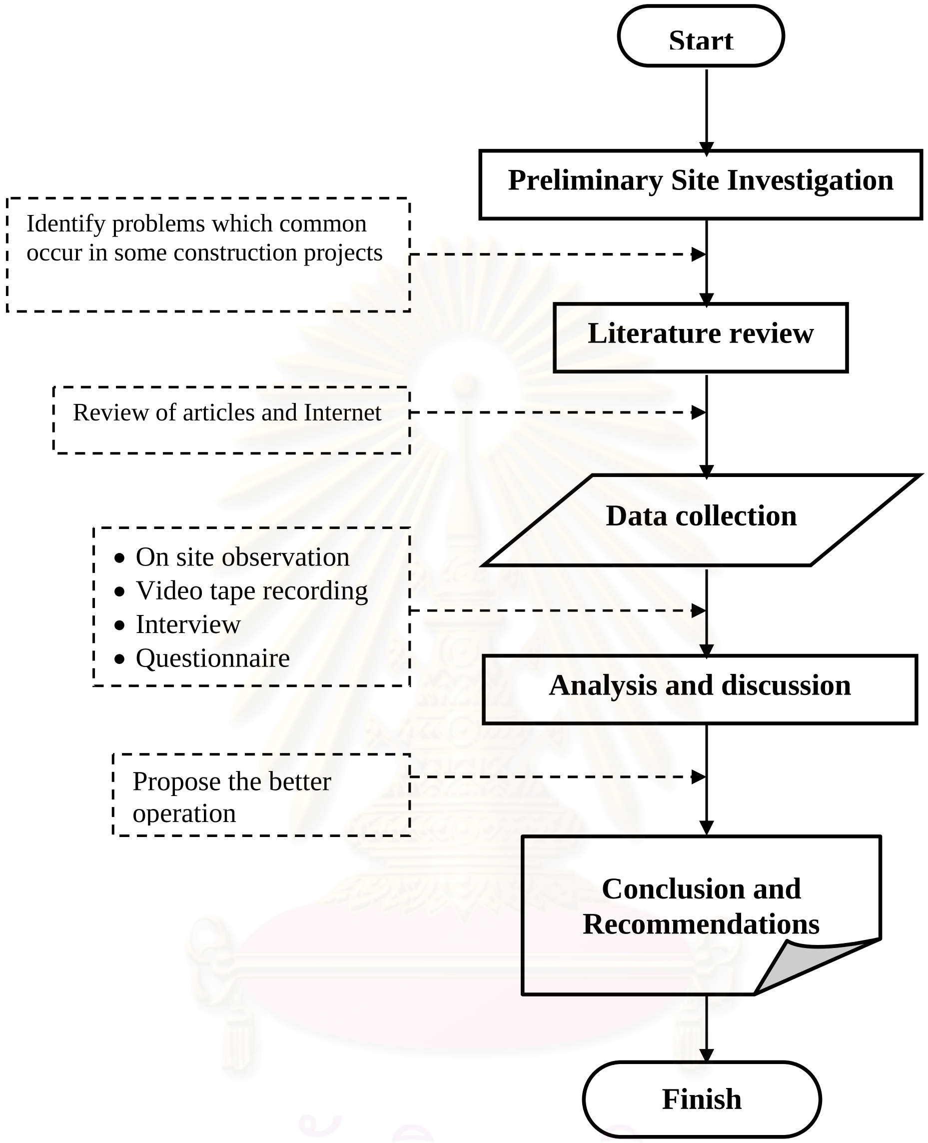


Figure 3.1 Flow Chart of Research Methodology

3.1.2. Exploration of the driving processes

One of the influencing factors determining productivity of pile-driving work is equipment performance. Since pile-driving equipment commonly used in small construction are conventional pile-driving machines such as drop-hammers and pile-pushing machines, where their operations mostly rely on the skill of the labor and machine mechanisms, understanding the process of different pile-driving equipment is necessary. Through this understanding, machines performance may be analyzed, and furthermore, advantages and drawbacks of each machine can be recognized and better operations can be projected.

3.1.3. Exploration of problems

In pile-driving works, there are various problems from one construction site to another. Since productivity of these works can not simply be determined through the types of the machines but also requires other variables such as soil characteristic, pile properties, labor skill, etc., thus, productivity analysis becomes very difficult to be compared.

In the stage of preliminary site investigation, problems, which may affect the pile-driving productivity, are classified. Next, this information is used to set the research scopes so analysis can be considered within the problems only.

3.1.4. Exploration of pile-shape

The other exploration activity conducted in the stage of preliminary site investigation is discovering the common pile-shapes. In pile-driving, selecting pile-shapes is important. Pile-shape can influence the pile resistance capacity. In static loading, piles' resistance is provided by tip and friction resistances. Tip resistance depends on the pile tip area while friction resistance depends on the pile skin area (Bowels, 1997). Thus, different pile-shapes may provide same tip area but different skin area, in which may produce different pile resistance capacity. At the same tip area, the shapes which have wider skin area will provide more resistance capacity than the narrower.

However, during driving, friction resistance can not be taken into account (Bowels, 1997). Skin friction will not affect driving energy needed. The amount of driving energy is only influenced by the tip pile resistance.

Discovering the common pile-shapes is focused on finding the effective pile shapes. This variable is considered as the friction area provided by each pile-shape divided by its tip area. In detail, this matter is explained in the next part of this chapter, whereas, the analysis is presented in Chapter 5.

3.2. Reviewing Related Literatures

In order to determine research fundamentals, previous journals, text books and other literature are reviewed. However, there was only one related research which studied pile-driving techniques in South-east Asia. This research was done by Chantararatn in 1984 titled “*Process Characteristic of Piling Work in Construction*”.

Other information related to this research is mostly based on text book theories.

3.3. Data Collection

Data are collected from three countries in South-east Asia; Indonesia, Malaysia and Thailand. However, as the main objective of this research is to find the similarities and differences of pile-driving works and the time limit, exploration was done only in some parts of the countries. For Indonesia, observation was done in Yogyakarta and Semarang, while for Malaysia, it was done in Langkawi and Perak, whereas for Thailand, it was done only in Bangkok. To find the general information, at least two pile-driving projects are investigated for each country, whereas, for the quantitative data (cycle times), they are recorded from a pile-driving project in each country.

There are four methods used in data collection; video tape recording, picture capturing, interview and on site observation.

3.3.1. Video tape recording

The idea of using video-tape recording is stressed to record the sequence of pile-driving processes. As the features of the video-tape that can be rewind and replay, this method can also be used to recognize the problems which mostly occur during pile-driving work.

3.3.2. Picture capturing

Some important activity stages in pile-driving processes are documented by capturing them with digital camera photographs. Since resolution of digital camera photographs is better than that of video-tape, this method is focused on capturing the details of the important parts of the observed equipment.

3.3.3. Interview

Not all data and information can be obtained and measured in the construction site directly. Some technical information such as hammer weight and equipment height can be obtained through interviews with engineers. This method is also used to seek technical knowledge from the site engineers. For instance, questioning on the general problems that most frequently occur during pile-driving work. This information is very important for considering the research scopes and minimizing uncertainties.

3.3.4. On site observation

On site observation is one of the data collection methods conducted by direct observations at construction sites. These observations focus on recording the cycle time of the pile-driving stages and other information which can be directly acquired at the construction sites such as number of workers involved and soil condition.

3.3.4.1. Process of cycle time

To distinguish the different performance of the observed machines, cycle times of pile-driving activities are recorded. The data is in the forms of duration of each activity in pile-driving works. To recognize the process which most influences the performance of the observed pile-driving equipment, cycle times are recorded for four activities in pile-driving process. These activities are setting, driving, welding, and moving stage. Detailed explanations of these activities are given in the next part of this Chapter, Section 3.4.3.

3.3.4.2. Number of workers

As conventional equipment, performance of the observed pile-driving machines is very dependent on labor skill. The more skilful is the workers, the higher the pile-driving productivity is expected to be.

Data of the number of workers involved in each observed pile-driving process is used to analyze the labor participation in operating each pile-driving machine. The analysis method of the labor productivity is also explained in Section 3.4.3.

3.3.5. Availability of various piles

Selecting piles is one of the important stages influencing the efficiency and the effectiveness of pile-driving work. Pile tip area multiplied by soil bearing capacity contributes to pile bearing resistance, whereas, the result of pile perimeter and length multiplied by the cumulative of soil friction capacity provides pile friction resistance. As resistance capacity of piles depends on the tip area and the friction area, selecting the proper pile shapes may offer more effective pile resistance. Thus, exploring the availability of various pile-shapes in each observed countries, Thailand, Indonesia and Malaysia, is necessary.

Type of piles does not only affect the effective pile resistance but also influence the productivity of a pile-driving machine. In the same construction site, utilizing the same pile-shape but different pile dimensions will vary the pile-driving productivity, or utilizing the same pile shape and dimensions but in different construction fields will also yield different results.

The data of pile collected are in the forms of:

1) Pile shape
2) Pile dimension (lengths and section properties of piles)
3) Other components of piles, such as pile shoe and toe.

3.4. Basic of Analysis

3.4.1. Basic concept of the analysis of the driving time

The simple equation for drop-hammer (Peurifoy, 2002):

$$R = \frac{2.W.H}{S + 1.0} \tag{3.1}$$

where :

R = safe load on a pile in pounds

W = weight of a falling mass in pounds

H = height of free fall for mass W in feet

S = average penetration per blow for last 5 or 10 blows in inches.

If Equation (3.1) combines with Equation (2.3) (previous equation in Chapter 2) which considers safety factor, it becomes

$$S + 1.0 = \frac{2.W.H}{P_{pa} + \sum P_{si,a}} \tag{3.2}$$

However, according to the dynamic formula, the total force resisted by the soil during driving process is only affected by the tip soil capacity, so Equation (3.2) becomes

$$S + 1.0 = \frac{2.W.H}{P_{pa}} \tag{3.3}$$

By considering S+1, the total depth of penetration and rebounding of the machine ram, as S_d (depth of penetration), then divide two parts of equation with time (t), it becomes

$$\frac{S_d}{t} = \frac{2.W.H/t}{P_{pa}} \tag{3.4}$$

S_d/t is considered as the penetration speed (V_p) and WH/t as Energy productivity of the driving machine (E_p), the new equation for the amount of energy produced per time per one cycle becomes

$$V_p = \frac{2.E_p}{P_{pa}} \tag{3.5}$$

Based on equation (3.5), it is known that penetration speed of pile-driving operation depends on blows energy rate and the soil bearing capacity.

According to physics theory, "*amount of energy after and before reaction is the same*", thus, in the pile-driving mechanism, the amount of energy produced by a falling hammer must be equal to the driving energy. Figure 3.2 illustrates the derivation of force equality during the driving process.

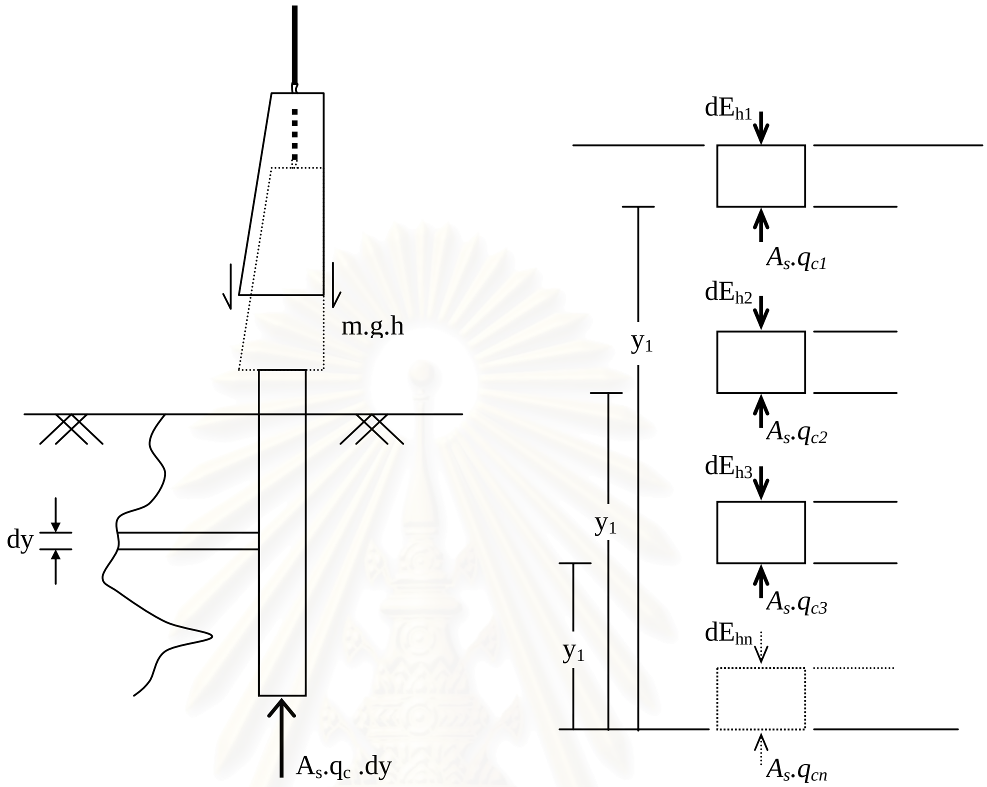


Figure 3.2 Force equality of driving process

Action energy = reaction energy

Hammer's potential energy = soil's resistance energy

$$m.g.h = F \times s \tag{3.6}$$

where:

- m = weight of hammer
- g = coefficient of gravity
- h = height of stroke
- F = soil resistance capacity
- s = displacement

In the process of driving the pile, due to moveable condition of the pile, the soil friction capacity is neglected (Bowles, 1997). If equation (3.6) is continued, it becomes

$$n.\ m\ .\ g\ .\ h = A\int q_c.dy \tag{3.7}$$

where:

n = total number of blow

q_c = the soil tip resistance in which is in the function of y.

Equation (3.7) shows the equality of the total amount of energy. The work needed to accomplish placing a pile into the ground is equal to the amount of soil bearing capacity multiplied by the pile tip area as long as the total dept of penetration. If the blow rate of the hammer (*f*), the number of blows per time unit, is recognized, thus the driving duration (*t*) can also be estimated.

$$n = f \, . \, t \tag{3.8}$$

where:

n = number of required blows

f = blows rate

t = driving duration

If n in equation (3.7) is substituted by the equation (3.8), it becomes

$$f \, . \, t. \, m \, . \, g \, . \, h \; = \; A.\int q_c.y \tag{3.9}$$

or

$$t = \frac{A.\int q_c.dy}{f.m.g.h} \tag{3.10}$$

Equation (3.8) states that the duration of driving a pile is equal to the summation of the soil resistance, the numerator of Equation (3.10), divided by driving energy (*m.g.h*) and blow rate (*f*).

3.4.2. Statistical analysis

Statistical analysis is used to calculate the data acquired from the recording cycle time of pile-driving processes. The parameters taken into account in this analysis consist of number of data, mean, and the standard deviation. These parameters are also used as the input of the simulation in Chapter 6.

The average value of the recorded data is calculated as (Washington, et al, 2003):

$$\bar{x} = \frac{\sum_{i}^{n} x_i}{n} \tag{3.10}$$

Where: $\bar{x}$ = the average value of the entire data

x_i = value of data x at series i

n = number of data

The standard deviation is a measure of how widely values are dispersed from the average value (the mean). The standard deviations of the data in this research assumes that the data are sample of the population and calculated using the "*unbiased*" or "*n-1*" method. The standard deviation uses the following formula (Washington, et al, 2003):

$$\sigma = \sqrt{\frac{\sum_{i}^{n}(x_i - \bar{x})^2}{n-1}} \qquad (3.11)$$

Where: σ = standard deviation

$\bar{x}$ = the average value of the entire data

x_i = value of data x at series i

n = number of data

3.4.3. Machine performance and labor participation

Productivity analysis focuses on analyzing the performance of the observed pile-driving machines and their labor participation in every stage of pile-driving work. As the general meaning of productivity, *output divided by input* (Peurifoy, et al, 2002), labor participation in this research is calculated as the performance of each stage (output) divided by the number of workers (input). Performance of the pile-driving work is divided into 4 stages; driving, setting, welding and moving.

3.4.3.1. Driving process

Performance of the machine in producing driving energy is defined as the average amount of energy produced by lifting and dropping the ram for 10 cycles. Productivity of driving energy is formulated as:

$$E = \frac{10.W_h.h}{\sum_{i=1}^{10} t_{Ei}} \qquad (3.12)$$

which:

E = driving energy rate (kg.m/sec)

h = height of stroke (m)

W_h = weight of hammer (kg)

t_{Ei} = duration of producing the-i blow (sec)

Regarding Equation (3.9), this data is used to estimate the driving time of the observed drop-hammers when they are employed at different construction sites and/or different soil properties.

While labor participation in driving stage is formulated as:

$$L_d = \frac{E}{N_l} \qquad (3.13)$$

which:

L_d = labor participation in driving stage (kg.m / person.sec)

E = driving energy rate (kg.m/sec)

N_l = number of labor (person)

3.4.3.2. Movement process

This is used to determine the ability of equipment to move sideward or backward/forward. Movement ability is illustrated as the duration taken to move the driving machine per meter of shifting. Movement ability in this research also can be described as the movement speed of pile-driving machines, but in the reversed unit. Its equation is described as follows:

$$V = \frac{t_m}{S} \qquad (3.14)$$

which:

V = movement speed (time*/m)

t_m = movement duration (time*)

S = distance (m)

* time is in (hh:mm:ss)

While labor productivity in the movement stage is formulated as:

$$L_m = \frac{1}{V.N_l} \qquad (3.15)$$

which:

L_m = labor participation in movement stage (m/person.time*)

V = movement speed (time*/m)

N_l = number of labor (person)

* time is in (hh:mm:ss)

3.4.3.3. Setting process

Setting becomes another factor that affects the cycle time of the whole pile-driving process. Analyzing the setting speed is used to recognize the effect of different pile weights toward the duration of setting. Setting time covers from the time that a pile is taken from the yard until the moment that this pile is ready to be driven into the ground.

The indicator of setting performance is presented as:

$$S = \frac{t_s}{W_P} \qquad (3.16)$$

which:

S = setting speed (time*/kg)

W_p = weight of one piece of pile (kg)

t_s = setting duration (time*)

* time is in (hh:mm:ss)

While labor productivity in the setting stage is formulated as:

$$L_s = \frac{1}{S.N_l} \qquad (3.17)$$

Which:

L_s = labor participation in setting stage (kg / person.time*)

S = setting speed (time*/kg)

N_l = number of labor (person)

* time is in (hh:mm:ss)

3.4.3.4. Welding process

In the series of pile-driving processes, welding becomes an independent activity. Given that this activity is accomplished by welders utilizing welding tools, welding is not influenced by the type of pile-driving machines. Welding is mainly influenced by skill of the welders and the welding electric power generating the heat.

In this research, it is assumed that welders' skill and welding electric power are the same in all observed pile-driving projects. Thus, welding performance is only determined by the duration of welding divided by the welding length. Therefore, the indicator of welding ability is presented as:

$$W = \frac{t_w}{L_w} \tag{3.18}$$

which :

W = welding speed (time*/cm)

L_w = welding length (cm)

t_w = welding duration (time*)

* time is in (hh:mm:ss)

While labor participation in the welding stage is formulated as:

$$L_w = \frac{1}{W.N_l} \tag{3.19}$$

which:

L_w = labor participation in welding stage (cm / person.time*)

W = welding speed (time*/cm)

N_l = number of labor (person)

* time is in (hh:mm:ss)

3.5. Equipment Performance

Since there are many factors influencing pile-driving productivity, estimating the duration of pile-driving work is not simple. Chantararath (1984) described that productivity of pile-driving work is influenced by:

1) Driving energy of the equipment.
2) Efficiency factor of the equipment
3) Soil properties
4) Pile properties
5) Foundation layout
6) Difficulty level of the sites.
7) Number and skill of the labor.

Hence, productivity of pile-driving machine can not be determined only from one machine's superiority. A pile-driving machine which can provide larger driving energy is not always more productive than another pile-driving machine which may provide less driving energy but can perform faster movement. Thus, comparing the overall performance of pile-driving machines must consider the overall stages of the pile-driving work.

In order to compare the overall performances of all observed pile-driving equipment, computation is done by analyzing the total cycle time of the whole pile-driving process. Total cycle time is the total duration consumed by a pile-driving machine to finish one cycle of the driving process. Total cycle is formulated as:

$$T = t_s + t_d + t_m \ (+\ t_w) \tag{3.20}$$

Which:

T = total cycle time (time*)

t_s = setting duration (time*)

t_d = driving duration (time*)

t_m = movement duration (time*)

t_w = welding duration (time*), this process may be necessary or unnecessary

* time is in (hh:mm:ss)

In conclusion, the total cycle time of the observed pile-driving machines will be compared to discover the most effective machines at an assumed condition.

3.6. Simulation

Pile-driving productivity is influenced by many factors. Among of these, site is one of the factors which affect the driving duration. The same equipment used at different construction sites will produce different driving time. However, bring different pile-driving equipment to be tested at the same site to compare their performance in driving piles is impossible. Instead of testing the real equipment, simulation analysis is employed.

3.6.1. Deterministic simulation

The first assumption used in the simulation in this research is the deterministic analysis. Because the basic factor that most affects pile-driving productivity is location, two determined foundation layout models are established in the simulation to accommodate this problem. In the simulation, it is assumed that conditions of the construction site are the same and the soil resistance is determined. For soil resistance, it is assumed that penetrating one set of piles needs 1,700 tons.m of driving energy. This amount is the average amount of driving energy used to drive one set of piles in the U.M.Y Project in Indonesia.

3.6.2. Stochastic simulation

Productivity of any pile-driving equipment can not always be the same. For instance, if there are 10 movement activities to be performed, it is impossible that between one movement and another, the same machine can perform the same movement speed.

The stochastic analysis is established to determine the performance of each activity in pile-driving process in the simulation. In the stochastic analysis, the performances of each pile-driving activity are determined by the value of the random number generated by MS-Excel. Among all activities in pile-driving process, stochastic analysis is performed for the stages of:

1. moving
2. setting
3. driving
4. welding

Simulation is done based on Monte Carlo Simulation (Ostwald, 2004). Assuming that all data are distributed normal, thus, the probability of each activity of pile-driving process will follow the cumulative distribution function (Hayter, 2002)

$$\Phi(x) = \int_{-\infty}^{x} \phi(x)dx \tag{3.21}$$

and

$$\phi(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2 / 2\sigma^2} \tag{3.22}$$

so that

$$x = \Phi(x)^{-1} \tag{3.23}$$

which :

σ = value of the standard deviation of the data

μ = mean of the data (the average of each activity performance)

x = the generated performance

$\Phi(x)$ = value of the cumulative distribution function (in the simulation, this value is random number generated by MsExcel)

In the simulation, value of x is calculated by using the NORMINV, MS-Excel formula facility. NORMINV returns the inverse of the normal cumulative distribution for the specified mean and standard deviation.

3.7. Conclusion

This chapter presents the research methodology which is generally divided into four steps. This research begins by doing preliminary investigation of pile-driving work in Thailand and Indonesia. This first step focuses on acquiring the information of the pile-driving work in two of the three observed countries.

After preliminary information, next comes the review of some related literature.

Next, the methods of data collection are presented. The data collection focuses on acquiring the supporting information which can be used to compare the process of each pile-driving machine discovered in the observed countries. The recorded data focuses on understanding the stages of pile-driving processes so that comparative analysis of the performances of the observed pile-driving machines can be done.

Finally, the analysis methods used to compare the piling systems in the observed countries are discussed. Two major analyses, the performance and the labor contribution, are established based on the related theory. The utilization of deterministic and stochastic simulations is explained as they are used to compare the machine performances.

CHAPTER IV
RESEARCH OUTCOMES

The existence of conventional pile-driving equipment and its practical operation have been observed in Thailand, Indonesia and Malaysia. The investigation is focused on simple pile-driving machines, such as drop-hammers and pile-pushing machines, in small construction projects.

This chapter discusses the observation result of utilizing conventional pile-driving equipment, drop-hammers and pile-pushing machines, and popular pile shapes in Indonesia, Malaysia and Thailand. Operation procedures and features of both types of machines as well as properties of those piles are discussed.

4.1. Pile-Driving Equipment in South-East Asian Countries

In some areas with low soil support capacity, foundation becomes a problem to be solved. In these areas where the high soil resistance is in the deep level stratum, the use of direct foundation is necessary but costly. Since the buildings need to be built on enough ground support capacity, the need of driven piles becomes crucial. However, driving methods raise other problems. Utilizing sophisticated pile-driving equipment such as diesel hammer, hydraulic hammer, etc., which may provide quick operation, is not suitable due to the operation cost. On the other hand, simple pile-driving equipment seems to be promising.

From observation, it is found that the use of driven piles for foundations do not have the same popularity in all observed countries. In Thailand, due to the soil characteristics, piling system is very commonly used in many construction projects. Not only large construction but also small construction projects in this country use piling for foundation system. On the other hand, in Indonesia and Malaysia, piling system is mostly used in large-scale construction projects.

There are two kinds of simple pile-driving machines discovered in this research, drop-hammer and pile-pushing machine. As their names imply, both machines utilize different methods to penetrate piles into the ground. Drop-hammers penetrate piles by dropping the hammer onto the pile cap while pile-pushing machines install piles by using counter weight to press piles into the ground.

In Thailand, Indonesia and Malaysia, drop-hammers are more popular than pile-pushing machines. The practice of drop-hammers utilization can be found in some construction projects in these countries, whereas, pile-pushing machines only exist in Indonesia. In fact, among of these machines, in contractors' and engineers' points of view, drop-hammers are more preferable in which it can produce higher productivity than the pushing one.

On the other hand, with its simple operation, as a result of the hammer impact, using drop-hammer is noisy. Drop-hammers disturb the surrounding community and also produce vibration which may damage the surrounding buildings structures. Hence, drop-hammers are usually used in rural areas meanwhile pushing machine is mostly used in urban areas. In the urban areas, where construction projects are often located in surrounding existing buildings or people residences, utilizing drop-hammers will provoke many complaints. Thus, instead of using drop-hammers, in Indonesia, pile-pushing machines are used.

In terms of cost of pile-driving work, there are many factors that must be considered. One of these factors is type of pile-driving machines. Types of machines affect operational costs which occur during utilizing the machine. This cost consists of labor and fuel cost. However, costs of pile-driving works include maintenance and delivery costs. Usually, for the simple equipment, the less operational and maintenance cost is needed. On the other hand, labor cost for simple equipment may be higher than that of sophisticated machines.

Because of their simple operation and maintenance, drop-hammer and pile-pushing machines offer low performance cost. In general, when all costs of pile-driving work are considered, the performance cost of a drop-hammer or pile-pushing machine is still lower than the performance cost of a sophisticated machine (resources: interview, 2005). Performance of this equipment relies more on worker's and machine-operator's skill than the machine's sophistication. However, as long as labor salary is not too high, like in South-East Asian region, utilizing this equipment seems to be interesting. Based on this reason, although simple pile-driving machines promise low productivity, employing drop-hammers or pile-pushing machines is still preferred, especially for small construction projects.

4.1.1. Drop-hammer machine

As mentioned earlier, in South-east Asian countries, there is a similar reason why the drop-hammer is still preferred for pile-driving work. Its cheap operation and maintenance cost are more important considerations than its productivity. Thus, although it constitutes simple pile-driving equipment, drop-hammers still become a choice among other pile-driving equipment.

In Thailand, Indonesia and Malaysia, drop-hammers are widely used in several pile-driving projects, especially for small construction. Compared with other sophisticated pile-driving machines such as hydraulic or diesel hammers, drop-hammers are less productive. However, the economical cost of pile-driving work does not depend on only the driving speed or productivity of installing the piles but also the total cost to perform it. Thus, in small construction project, employing sophisticated pile-driving machine which requires higher cost is not efficient. Moreover if there are a few piles to be driven, the duration to complete pile-driving work produced by employing sophisticated pile-driving machine and drop-hammer is not significant. Hence, due to the several reasons, drop-hammer becomes a choice when the time constraint of accomplishing pile-driving work is relatively long or there is a few numbers of piles to be driven.

Among the three observed countries; Thailand, Indonesia and Malaysia, Thailand is the country where drop-hammers are very widely used in many pile-driving works in several construction projects. In Thailand, drop-hammer can be found not only in rural areas but also in urban areas. Since the soil properties of some parts of Thailand, such as Bangkok and its surrounding areas, constitutes of clay, the use of shallow foundation, such as foot-plate foundation, is not practical. Most buildings, bridges and other construction projects, from small to the large construction, use piling system as the foundation system.

In order to optimize its efficiency and effectiveness, in Thailand, drop-hammers are built in various sizes. According to the size of the driving-hammer, Thai drop-hammers are available in 1.2 tons up to 12 tons of hammer weight, whereas, the height of the structures ranges from 9 m to 30 m, approximately. The smallest drop-hammer machine with a 1.2-ton driving-hammer and 9-m equipment-height, is used to install small piles such as piles for fences or walls, whereas, the heavy hammer and tall rig is used to install large and long piles. For instance, at the Water Plant Project in Bang Na, Thailand, they used a 12-ton drop-hammer with 30-m high rig. The total length of the piles driven is 31.5 m, driven in two parts, 2 @ 15.75-m.

In Indonesia and Malaysia, not like in Thailand, finding pile-driving work using a drop-hammer is more difficult as not many small construction projects need a piling system. As soil resistance capacity in some parts of Indonesia and Malaysia is strong enough to support the work load of a small construction project, shallow foundation becomes first choice before small piles.

In Malaysia and Indonesia, drop-hammers are available only in a few size variations. Its height is only 10-15 m and the weight of its hammer is about 1.2 to 2.4 tons. This machine is usually used to install small piles with a maximum capacity of 50 tons. Because of its height, this machine can drive piles with a maximum length of 6 m. This limitation means this machine can not be employed in all construction projects.

4.1.1.1. Type of the structure

The structure of drop-hammer in the three observed countries varies between one and another. The drop-hammers in Thailand are made in the form of space-frames. The size of these structures depends on the size of the main machines which controls their overall operation. The more powerful the machines, usually, the larger and higher are their structures. The height of a drop-hammer in Thailand can reach 24 m and operate a 12-ton driving ram.

The structures of drop-hammers in Thailand are built by arranging several profiles L steel bar together until they form a rigid space frame. The bottom of the structures is also wider than the top. The bottom is used to hold the main machine and the welding generator while the upper part acts to support the hoist. At the front, the ram leader is attached.

The drawback of this kind of structures is on the length of their installation time. For the small structure, about 10-m high, the time needed to build the structure is about 1 day, while the medium size, 18-m high, the installation time is 3 days. For the biggest machines, approximately 24 meters tall, the installation time can reach up to 1 week. This matter constitutes a serious problem when there are only a few piles to be driven. The less the numbers of pile means the shorter the time of installing the entire piles. This implies that the percentage of unproductive time and cost caused by structure installation becomes very high. A sample of a structure of drop-hammer in Thailand is shown in Figure 4.1 (c).

In Indonesia, drop-hammer machines are built as simple space frames which consist of three frame members, the leader, which supports the hammer, and the other two to support the leader.

Like drop-hammers in Thailand, the bottom of the structures of drop-hammers in Indonesian is used to hold the main machines, which control equipment performance. However, different from drop-hammers in Thailand, the hoists, used to hang the machine’s ropes, are put on the top of the main leaders.

Since the size of the bottom of the structures is not as big as drop-hammer in Thailand, structures of drop-hammers in Indonesia can not hold the electric welding generator. During operation, the welding generators are moved to the drop-hammers. This means moving the welding generators to new positions where the drop-hammers are set. This, thus, increases the percentage of unproductive time and cost as well. Figure 4.1 (a) shows a sample of a structure of a drop-hammer in Indonesia.

The last drop-hammer observed is the Malaysian drop-hammers. Considering their form, the structures of Malaysian drop-hammers are similar to drop-hammers in Thailand. They are made in the form of space frames but smaller in size. The difference is the installation and dismantling methods. In its operation, drop-hammers in Malaysia do not need to be installed and dismantled. As they are brought to the construction side already assembled.

(a) (b) (c)

Figure 4.1 The figure of the structure of drop-hammer in (a) Indonesia, (b) Malaysia and (c) Thailand

In terms of structure size, the Malaysian drop-hammer is the same height as the Indonesian drop-hammer but narrower at the bottom. It is approximately 10 meters high. Similar to the Indonesian drop-hammer, because of its small size, the Malaysian drop-hammer does not carry its electric welding generator.

One drawback of the Malaysian drop-hammer is its pile-setting capability. Because of its narrow bottom, this equipment can not be used to pull piles from far a distance, which means longer rolling movement works. In fact, this condition may cause the structure to collapse.

4.1.1.2. Ram

Driving energy of all pile-driving equipment, except the pile-pushing machine, is produced by the hammer blow. Accordingly, the heavier the weight of the ram, the larger the driving energy produced. Likewise, the higher the falling stroke, the larger the driving energy produced. It can be formulated that the driving energy of a drop-hammer is equal to the weight of the hammer multiplied by the height of the falling stroke.

$$E_d = W_h \cdot h$$

Which:

E_d = driving energy (kg.m)

W_h = weight of the hammer (kg)

h = height of the stroke (m)

In terms of properties of the driving hammers, there are similarities and differences between the ram of drop-hammer machines in Thailand, Indonesia and Malaysia. The Thai ram is similar to that of the Malaysian drop-hammer. Both drop-hammers have a square ram. Meanwhile, the ram of Indonesian drop-hammer is cylindrical. Figure 4.2 shows the rams of the drop-hammers in these three countries.

In terms of weight, the ram weight of the Indonesian drop-hammers is similar to that of Malaysia. They are less than 2.5 tons. According to the exploration results, the ram weights of Indonesian drop-hammers are between 1.2 tons up to 2.4 tons, while the rams of Malaysian drop-hammers are 1.2 tons only. Equipped with a light driving-hammer, Malaysian and Indonesian drop-hammers can be used only to perform light pile-driving work. Usually they are used to drive small piles with a maximum section area of up to 500 cm^2 and maximum pile length of 24 m. They will not be used to penetrate piles designed to resist more than 50 tons of static load.

Different from Indonesian and Malaysian drop-hammers, Thai drop-hammers are equipped with a 1.2-ton up to 12-ton driving hammer. For this reason, Thai drop-hammers can be used to perform pile-driving work for light and hard driving.

Varying ram weight will affect the production of energy. Although the machine power to operate the ram will vary, in fact, in normal operation, a heavier ram will slow down the ram-lifting speed. However, since the amount of driving energy comes from the multiplication between the ram weight and the falling height, the heavier ram still provides a larger driving energy. The comparison of this analysis is discussed in chapter 5.

(a) **(b)** **(c)**

Figure 4.2 The rams of drop-hammer in
(a) Thailand, (b) Indonesia, and (c) Malaysia

4.1.1.3. Support

During pile-driving, the drop-hammers must be secure so it will not move because of any disturbances. Equipment also has to be kept on the right and steady alignment.

Based on this rule, a drop-hammer is usually equipped with supports. A support is one of the important components of drop-hammers. As a drop-hammer needs to be placed on a stable base, the existence of a proper shaped support becomes vital. In fact, in addition to spreading the drop-hammer weight to the soil surface, a support can also perform as a movement route of the machine. However, because of different equipment weight, the size and shape of the drop-hammer's support may vary as well.

Figure 4.3 A support of Thai drop-hammer

Figure 4.4 A support of Indonesian drop-hammer

In Thailand, the drop-hammer's support is provided in the form of a steel rail. Usually it is 6 m in length but the section size is dependent on the weight of the drop-hammer it must support. The heavier the equipment, the larger the support is. The support of a Thai drop-hammer is shown in Figure 4.3.

In Indonesia, a drop-hammer's support is made in the form of a steel pipe. The main aim of using this support shape is as well as to support the equipment, because of its round shape, it can also be employed as movement equipment. The support makes it so the equipment can be moved forward or backward easily by rolling the support forward or backward, respectively. To achieve faster movement, a rolling mechanism can be employed by putting the machine's rope around the support surface and then pulling the rope with the machine power. This mechanism will be explained in the next part of this chapter. Figure 4.4 shows the shape of the support of an Indonesian drop-hammer.

(a) The steel pipe and wheel

(b) The dowel

Figure 4.5 Support and dowel of Malaysian drop-hammer

The Malaysian drop-hammers use the same support as the Indonesian. The steel pipe support supporting a Malaysian drop-hammer is put below steel wheels. Like it can support the machine, as well as be used to move the equipment forward or backward, while the steel wheel is used to move the drop-hammer sideward, while providing ease of sideward movement; the steel wheel can cause instability to the machine. To solve this problem, the operator and helpers attach a steel dowel to hold the machine in place. A Malaysian drop-hammer support is shown in Figure 4.5 (a) while the steel dowel is shown in Figure 4.5 (b).

4.1.1.4. Jack of the machines

The next drop-hammer component is the jack. The jack is used to lift the machine when movement needs to be done. Some drop-hammers in Indonesia use a manual jack like drop-hammers in Thailand, but some others use threaded bolts which placed at the four sides of the equipment.

Different from Indonesian and Thai drop-hammers, Malaysian drop-hammers do not need any tools to jack up the machine. Jacking is done by using a wood shaft put under the equipment at one end while the other end is pushed downward by man power.

The Thai drop-hammer jack is shown in Figure 4.6, while that of Indonesia is shown in Figure 4.7 and Malaysia in Figure 4.8.

Figure 4.6 The jack of Thai drop-hammer

Figure 4.7 The jack of Indonesian drop-hammer

Figure 4.8 The jacking mechanism of Malaysian drop-hammer

4.1.1.5.   Operation procedure

In order to reach desired productivity, understanding the operating procedure of pile-driving work is required. The operating procedure is one of the influencing factors which has to be taken into account to estimate productivity. Among all types of drop-hammers, their operating procedure is similar. This procedure is shown in the flow chart in Figure 4.9.

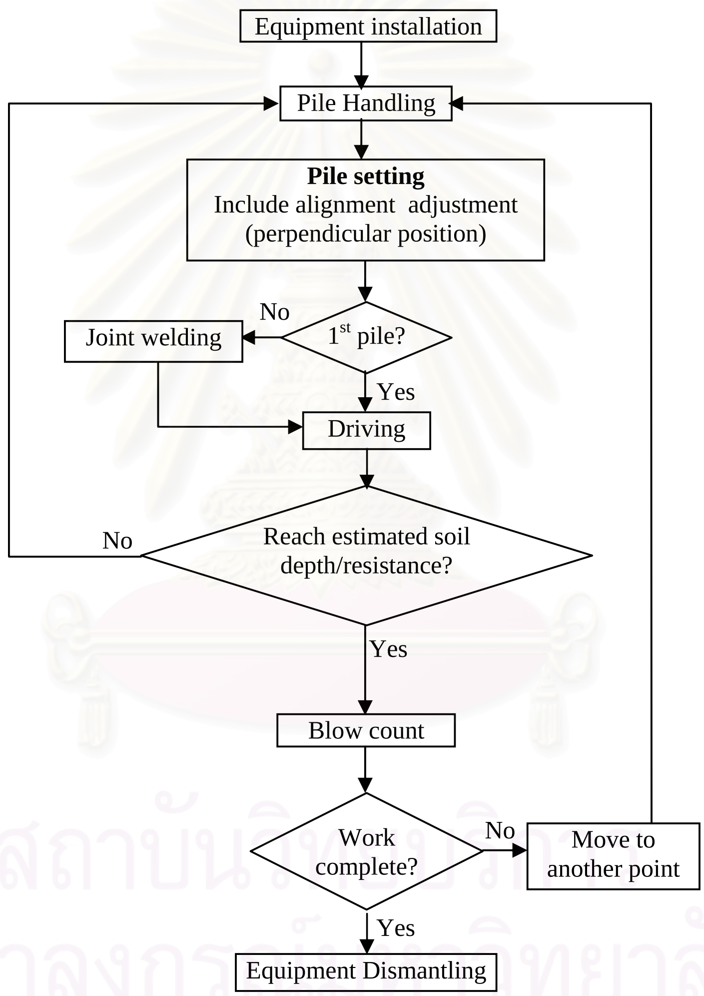


Figure 4.9 Operating procedure of pile-driving work using a drop-hammer

To begin, drop-hammers are brought in pieces to the construction site. The first task that has to be quickly accomplished is assembling the equipment. Once the equipment is ready, pile-driving can commence. Pile installation is started by taking the pile, aligning it perpendicular to the required driving point. After the pile is in its vertical position at the specified point, the first hammer blow can commence. Once the first pile has been installed, the driving activity is continued at the next pile.

Labor used in the driving stage includes one operator and some helpers. The operator must control the stroke height of the hammer. Once the rope pulls the hammer to the required height, the operator has to release the pedal so the hammer falls on the head of the pile at the desired driving energy. While driving, helpers are assigned to record the number of blows and monitor the depth of penetration.

The next process is joining piles, if needed. The joining activity consists of setting the subsequent pile and welding. Some designers, to reduce cycle time, consider substituting joining activity by providing longer piles. However, longer piles mean heavier piles which further extends the piles' setting time.

When the piles reach the expected depth or required soil resistance, the blow count must be done to identify pile load capacity. Blow count is a measurement of the depth of penetration every 10 hammer blows. There are two aims of blow-count; 1) to analyze the bearing capacity of the pile, and 2) to predict the type of soil stratum that has been reached. In some areas where pile resistance is mostly supported by friction instead of bearing, stopping driving piles when the hard soil stratum is reached is almost impossible. In this case, driving piles will be stopped when piles have reached the required soil stratum.

Pile installation is continued until all the piles are installed, after which equipment is dismantled and removed.

4.1.1.6. Movement mechanism

For drop-hammers, movement is an important activity in the process that affects productivity since drop-hammers need to be shifted from one driving point to another to complete the project successfully. According to the direction usually performed, movement can be divided into two types, i.e., sideward movement and forward/backward movement. Practically, these two kinds of movement produce a very significant difference in terms of time duration. This is caused by the different moving mechanisms.

Sideward movement

Side movement is the most frequent shifting method used to move drop-hammers and pushing machines from one driving point to another. Compared with other movement directions, shifting drop-hammers sideward is easier. Mechanism of sideward movement of drop-hammers is shown in Figure 4.10.

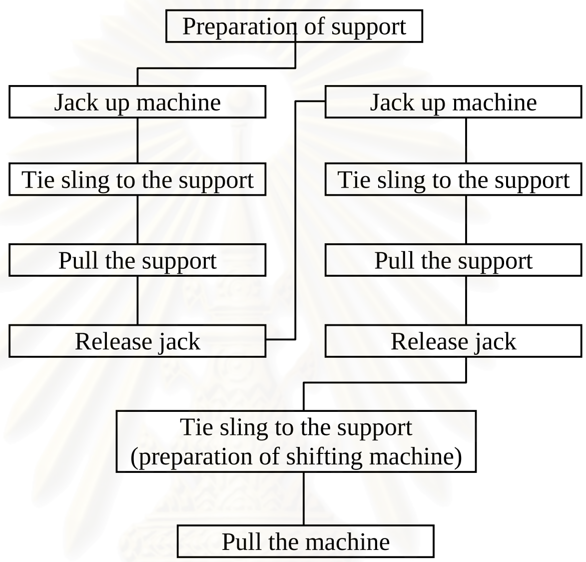


Figure 4.10 Mechanism of sideward movement

Figure 4.11 Mechanism of shifting an support using an attached hoist at Indonesian drop-hammer

Figure 4.12 Mechanism of shifting an support using a moveable hoist at Thai drop-hammer

In spite of having different types of support, the side movement mechanisms of the Thai and Malaysian drop-hammers are similar. Side movement is done by shifting this equipment on their support. In order to reduce the friction resistance on the surface of the supports and obtain easier shifting, side movement is started by jacking up the drop-hammer before shifting it on its supports. After the support is in the right position, the jack is released and the drop-hammer can be shifted.

Figure 4.13 Mechanism of shifting an support which relies on man power at Malaysian drop-hammer

Backward/forward movement

Since support forms are different, the mechanisms of forward and backward movement of drop-hammers in Indonesia and Thailand are different. On one hand, exploiting the circular form of its support, Indonesian drop-hammer move forward and backward by rolling its supports. On the other hand, Thai drop-hammers need to follow similar steps to their sideward movement but the speed of their forward movement is much slower than their sideward movement. This is because their supports need to be moved gradually and jacked up repeatedly.

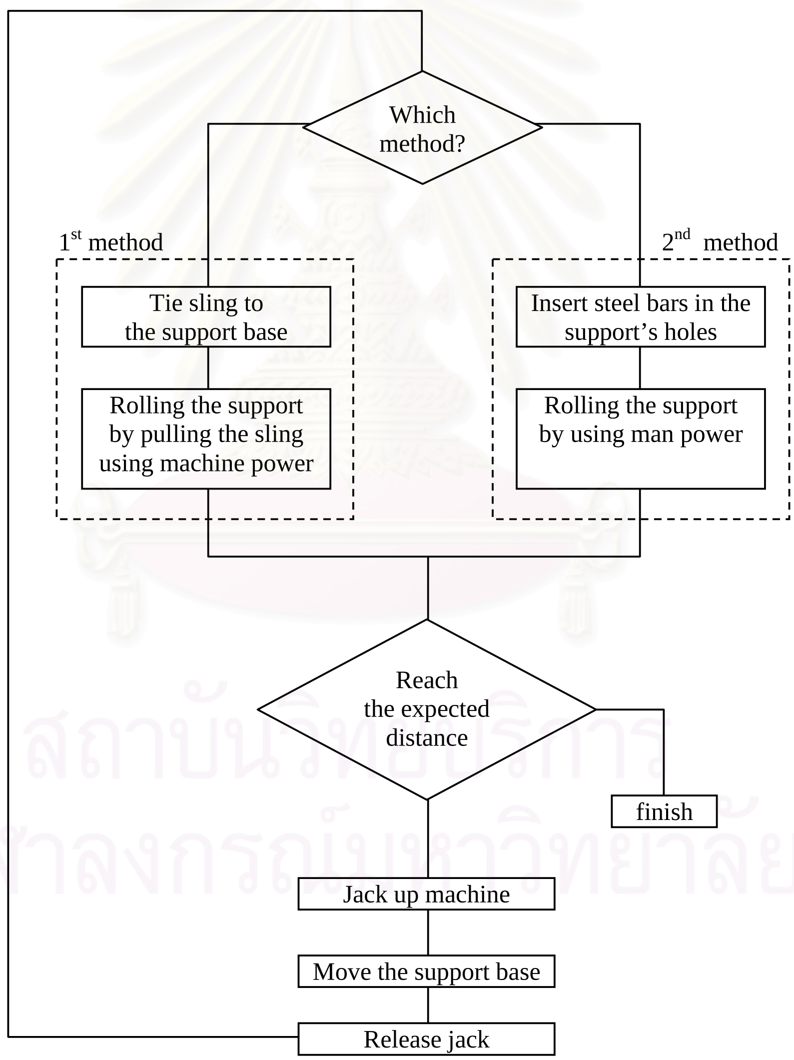


Figure 4.14 Flow chart of the method of backward/forward movement of Indonesian drop-hammer

The rolling method of Malaysian drop-hammers may be conducted using either man power while Indonesian drop-hammers may be conducted either using man or machine power. Figure 4.15 and 4.16 depict one method of rolling the support through man power for a Malaysian and Indonesian drop-hammer, respectively. In the case of man power, the rolling method requires about 3 to 4 persons. After inserting steel bars in the support holes at all four sides, workers rotate the support to the desired direction simultaneously. When machine power is utilized, the machine rope is twisted on the front support and its end is hooked to a support base. The support will rotate when the rope is pulled. Compared with forward/backward movements of Thai drop-hammers, the steel pipe provides faster movement for Indonesian and Malaysian drop-hammers.

The mechanism of backward/forward movement of the Indonesian drop-hammer is shown in Figure 4.14.

Figure 4.15 Mechanism of backward movement of Malaysian drop-hammer

Figure 4.16 Mechanism of backward movement of Indonesian drop-hammer

4.1.2. Pile-pushing machines

The pile-pushing machine is another popular pile-driving equipment in Indonesia. This equipment has a different procedure for penetrating piles into the ground. Instead of hammering piles, the pile-pushing machines employs pushing mechanism to install the piles. The pushing power is generated by the dead load of the equipment plus its counterweight. Equipped with hydraulic power, this equipment forwards its weight to push the pile into the ground.

The advantage of this method is pile-pushing machines do not generate vibration. Thus, driving piles using these machines will not harm the surrounding buildings or disturb the adjoining community.

Compared with other pile-driving equipment, pile-pushing machines have another feature, they can reduce noise pollution. The loud noise resulting from the impact of ram and pile's head is eliminated.

The negative side of using a pile-pushing machine is its productivity. Because of their heavy weight and operation mechanism, pile-pushing machines are difficult to move. This makes pile-pushing a contractor's last choice for pile-driving. Usually, as long as noise and vibration are tolerated, pile-driving work is performed using drop-hammers. Even in Thailand, most pile-driving works employ drop-hammers. In some areas in Indonesia, utilizing any pile-driving equipment, which generates noise and vibration, is not allowed.

In general, pile-pushing machines comprise five components. The first is the main structure which carries the hydraulic machine and all the whole equipment. The second is the counter weight, which is used to generate the power of the pushing mechanism. The third is the support, used as the support and route of the machine's movement. The fourth includes the wheels used as moving tools, and the last one is the support's base, which is needed to support the machine in special site conditions.

4.1.2.1. Type of structure

The main structure of a pile-pushing machine is shown in Figure 4.17. It is similar to Indonesian drop-hammers and is composed of the main leader and two stiff poles. The difference is the function and profile of the main leader. Unlike the main leaders of Indonesian drop-hammers, which are used to attach the driving hammer, the main leader of a pile-phusing machine is used to hold the hydraulic pushing bar. These leaders consist of two I-profile steel with two hidraulic pushing bars. The main leader of a pile-pushing machine is also used to keep the pile in vertical alignment while it is penetrated into the ground.

Figure 4.17 Indonesian pile-pushing machines

4.1.2.2. Counter weight

As the operation of a pile-pushing machine is done by pushing the piles instead of giving a blow with a heavy hammer, this mechanism requires a very heavy load, to force piles into the ground. This is achieved if the pushing force is larger than the soil resistance transferred to the pile. The minimum load should be equal to the maximum soil resistance under the pile.

As the pushing mechanism needs a very large force to push the piles, pile-pushing machines are equipped with a counter weight which is made by piling concrete blocks onto the machine. Each concrete-block is lifted gradually by a machine crane. When the necessary number of concrete-blocks is achieved, wires are used to tie them together and keep them in position.

As the penetration point of the pile-pushing machine is concentrated at the front, the counter-weight is also positioned at the front of the machine, close to where the hydraulic-pushing bar is laid. By positioning the counter weight at this point, forwarding equal to the counter-weight's load acting as the pushing power may be achieved.

Figure 4.18 A piece of counter weight of Indonesian pushing-machine

4.1.2.3. Support

Like Indonesian drop-hammers, pile-pushing supports are made of steel in the form of a square hollow box. Conversely, unlike Indonesian drop-hammers' supports which are steel pipe, the pile-pushing machine supports are made of very thick square steel plates and, therefore, can not be used as movement tools as with an Indonesian drop-hammer.

One of the reasons why the pile-pushing machine uses a modified steel support is because of its great weight up to 70 tons, placed on the very rigid and strong support. Utilizing pipe support, small section inertia is almost impossible.

Figure 4.19 shows the modified square support of a pile-pushing machine which is laid on a timber base and under the equipment's wheels.

Figure 4.19 A support, a wheel and a wire rope of a pile-pushing machine

4.1.2.4. Wheels

Because of the weight of the pile-pushing machine, it is very difficult to be shifted. With a dead-load weight of approximately 20 tons and, moreover, the added counter-weight of up to 50 tons, this equipment requires a big power to move it. To accommodate movement, the pile-pushing machine is equipped with steel wheels.

Hydraulic power is used to pull this machine in the desired direction. Wire is tied to one of the front support's ends. When the wire is pulled by the machine's hydraulic power, the machine's wheels roll. The supports which are laid under the wheels function as the movement track.

Figure 4.19 shows a steel wheel of a pile-pushing machine when it is used to move a pile-pushing machine on its support.

4.1.2.5. Support base

The support base is used to support the support as well as keep the support in horizontal alignment. In general, a pile-pushing machine uses timber for its support. However, in some special field conditions, a steel plate can be utilized.

When pile-pushing machines must be located on soft soil or near a hole, there is a risk of quick soil settlement occurring. Quick soil settlement may occur as the soil has to support the heavy load of the pile-pushing machine. This can be a hazard as unbalanced soil settlement under the equipment may affect the incline of the pile-pushing machine and, possibly, the equipment will collapse while releasing the counterweight from its position. The counter weight may then fall and hit workers handling the equipment, which can result in death.

Figure 4.20 A bended support base of a pile-pushing machine after used near a hole

In an effort to reduce the risk caused by improper soil support, a special support base usually employed. This component is made from a rigid steel plate with enough thickness. The main task of this support base is to distribute the heavy load of the pile-pushing machine on to the soil. If direct soil settlement can not be avoided, the support base is expected to keep the settlement in balance to reduce the hazard.

Figure 4.20 shows a bended steel plate which was just used as an support base for a pile-pushing machine. The location of support base was above a septic tank.

4.1.2.6. Hydraulic jack

Like a drop-hammer, the pile-pushing machine is also equipped with jacking tools. The function of the jacking tools of pile-pushing machine is similar to the Indonesian drop-hammers which are used when movement mechanism is needed.

Unlike the jacking tools of the Indonesian drop-hammer, a manual jack or threaded bolt set at the four sides of the equipment, the pile-pushing machine uses hydraulic power to jack up the machine before sideward movement. At the bottom of each jack, a circular steel plate is laid. This plate distributes the load over the jack's base. Between the jack-bar and the jack support, the circular steel plate is connected by a hinge mechanism so it can be rotated in any direction to find the proper base support.

Figure 4.19 shows two hydraulic jacks of a pile-pushing machine with their circular steel base.

Figure 4.21 Jack equipment of pushing-machine which use hydraulic power

4.2. Pile Properties

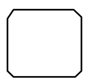
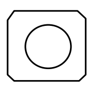
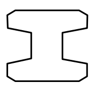
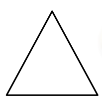
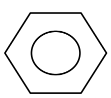
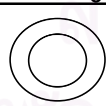
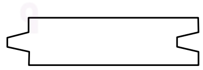
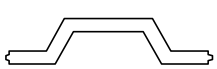
As one of the factors influencing pile-driving productivity is pile, the main concern in designing a pile is to find the optimal dimension which can resist larger load with the same material composition.

Observation of available pile-shapes was done in three observed countries. The types of pile found in construction were recorded and brochures of precast pile products of some pile manufacturing companies have been collected. Other data was gained for the observed countries by browsing the Internet.

4.2.1. Available pile

From the observation, there are different popular pile shapes used in the three observed countries. The popular pile shape used in small construction in Thailand is the I-shape, in Indonesia the triangle-shape and in Malaysia a rectangular shape. Unlike the I-shape and triangle-shape, found only in Thailand and Indonesia, respectively, the rectangular pile commonly used in Malaysia, is also found in Thailand and Indonesia.

Table 4.1 The various pile-shapes available in three observed countries

SHAPE	THAILAND	INDONESIA	MALAYSIA
 Rectangular	√ prestressed	√ reinforced, prestressed	√ reinforced, prestressed
 Hollow rectangular	√ prestressed	–	–
 I-shape	√ prestressed	–	–
 Triangle	–	√ reinforced, prestressed	– reinforced, prestressed
 Hollow hexagonal	√ prestressed	–	–
 Spun pile	√ prestressed	√ prestressed	√ prestressed
 Sheet pile	√ prestressed	√ prestressed	√ prestressed
 Corrugated sheet pile	– prestressed	√ prestressed	√ prestressed

The popularity of I-shape in Thailand and triangle-shape in Indonesia is because their effective shapes which contain the same volume of material composition provide a wider skin friction area.

The rectangular shape, less popular in Indonesia and Thailand, provides less skin friction area but offers a larger inertia and wider tip area. For this reason, in Thailand and Indonesia, rectangular shapes are preferred for pile-driving which requires long piles driven deep into the soil stratum and when bearing capacity is more important than friction resistance.

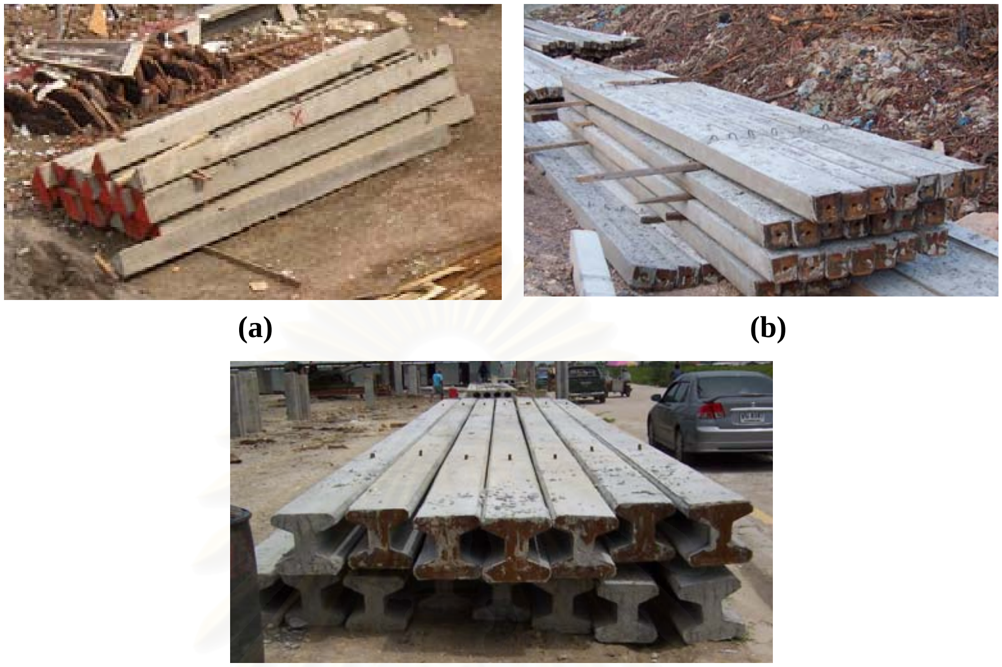
The other shape commonly used in Thailand is hexagonal. Small in size, the hexagonal-shape pile is used only for wall or fence foundations. This pile is usually made in 6-meter lengths and driven in using a back-hoe or man power with simple equipment.

Table 4.1 shows the various piles available in the three observed countries. As shown; rectangular, hollow rectangular, I-shape and triangle piles are usually used in small to medium construction projects, while hollow hexagonal piles are only used to support light construction, spun piles are frequently used for big construction projects, and ordinary and corrugated sheet piles are generally used for a permanent structure.

4.2.2. Pile cap and toe

Because of the hard force generated by the impact of the driving process, piles can be damaged before reaching the expected soil stratum. Damage mostly occurs at either the top or the toe of the pile. At the top, piles can be damaged by the impact of the dropping hammer onto the pile’s cap, whereas at the toe, piles are damaged by the impact between the pile’s toe and hard earth layer, such as hard rock or gravely soil.

To avoid unexpected damage which may occur during the driving process, certain sections of the pile need to be strengthened. Figure 4.22 shows the protection component of three observed precast piles; Indonesian triangle, Malaysian rectangular and Thai I-shape. For Indonesian and Malaysian precast piles, steel caps are attached at the top and the toe of the piles as they protect them from the damaging impact of the hammer at the top of the piles or between the pile’s toe and hard earth layer. Thai precast piles usually have a steel cap attached only at the top of the pile as Thai soil is usually not hard rock or gravely. Thus, damage to the pile’s toe rarely occurs.



(a) (b)

(c)

Figure 4.22 Protection component of (a) Indonesian, (b) Malaysian, and (c) Thai precast piles

4.2.3. Join and welding

One of the disadvantages of adjusting the lengths of precast concrete piles is the need of casting additional lengths to accommodate variations in the depth to a hard bearing stratum. This drawback is usually overcome by employing piles that are joined.

Among the three common piles used in the three observed countries, all employ the same connecting system, welding, when pile extension is required. Welding is usually done with electric power generated by a moveable diesel generator. Figure 4.23 shows two examples of the welding process for Indonesian Triangle piles (a) and Thai I-shape piles (b).

In Malaysia, joints are also made by adding steel rebar as an anchor. This not only strengthens resistance to sliding, but it also can make the setting process easier. Figure 4.23 shows the ‘male’ (c) steel rebar anchor, and ‘female’ (d) special pile cap of a Malaysian rectangular precast pile. Still, the existence of the male and female connection does not eliminate the welding to join two separated piles.

(a)

(b)

(c)

(d)

(e)

Figure 4.23 Joining system of Thai I-shape piles (a) and Indonesian triangle piles (b), and steel rebar anchor (c), special pile's cap (d), and its connection process (e) of Malaysian rectangular pile.

4.3. Conclusion

This chapter discussed the exploration of pile-driving work in three South-East Asian countries, Indonesia, Thailand and Malaysia. From the observation, it is found that the common pile-driving equipment used in small construction projects in each observed country is different. At least two kinds of pile-driving machines have been discovered in the observation. They are a drop-hammer and pile-pushing machine. The drop-hammer is found in all observed countries but with different equipment properties, whereas, the pile-pushing machine is found only in Indonesia.

The specifications and properties of each machine are explained at the beginning of this chapter as is their operation mechanism. Some figures showing the components of each machine are also provided as a flow charts that explain the operation mechanism of each machine.

Finally, this chapter provides the results of the pile exploration. All types of piles discovered in this research are provided in a table. Some pile properties such as pile toe and shoe and pile connection systems are also presented. In fact, like the equipment, the common piles used in small construction in each observed country are different. The I-shape is more common in Thailand while the triangle pile-shape is more popular in Indonesia and rectangular pile-shape well-liked in Malaysia.

CHAPTER V
ANALYSIS AND DISCUSSION

In common understanding, productivity of pile-driving work is meant as the number of piles that can be installed per day (Chantararath, 1984). This definition means that the more piles that can be driven, the more productive the machine. However, the capability of pile-driving equipment to complete penetrating piles is influenced by internal and external factors. In this research, the internal factors are determined as the machine capability and skill of the operator and helpers whereas the external factors are the piles, soil properties, and level of difficulty of the construction site.

There are four important stages which determine performance of pile-driving machines. As mentioned in Section 3.3.4.1, these factors are setting, driving, welding and moving. This chapter discusses the performance of the three drop-hammers and their labor participations at the four pile-driving stages. First, statistical analysis is done toward those four stages using formula presented in Section 3.4.2. Second, labor productivity in each stage is calculated. Third, the effectiveness of three selected pile shapes; triangle, rectangular and I-shape, is analyzed. Finally, safety analysis is discussed.

5.1. Work Performances and Labor Participations

In this research, performance of the three observed drop-hammers is determined as the ability of these machines to complete the installation process in specified time unit. There are many factors that contribute to determine performance of pile-driving machines. Three of them are the machine sophistication, piles specification and numbers and skill of the workers.

There are three kinds of machines and three kinds of piles have been observed in this research; two 10-m drop-hammers in Indonesia and Malaysia and an 18-m drop-hammer in Thailand. In the analysis, these three machines are mentioned as Machine-A, Machine-B and Machine-C, respectively, as presented in Table 5.1.

According to the Table 5.1, machine-A is the 1.7 tons drop-hammer which is discovered in Indonesia, while machine-B is the 1.2 tons drop-hammer discovered in Malaysia, whereas, machine-C is the 5 tons drop-hammers discovered in Thailand.

Table 5.1 Machines specifications

Machine	**Machine-A**[1)]	**Machine-B**[1)]	**Machine-C**[2)]
Type	Drop-hammer	Drop-hammer	Drop-hammer
Discovery location	Indonesia	Malaysia	Thailand
Number of labor (person)	3	2	4
Width (m)	2	3	2
Length (m)	4	5	2
Height (m)	10	10	18
Weight of ram (Ton)	1.7	1.2	5.0
Estimated equipment weight (Ton)	3.3	2.5	13.0

1) Small pile-driving equipment
2) Medium pile-driving equipment

Table 5.2 Piles specifications

Pile	**Pile-A**		**Pile-B**	**Pile-C**
Length (m)	**3**	**6**	**6**	**12**
Discovery location	Indonesia	Indonesia	Malaysia	Thailand
Shape	Triangle	Triangle	Square	I-shape
Side dimension (cm x cm)	28x28	28x28	15x15	35x35
Unit weight (kg/m^3)	83	83	49.5	175
weight (kg)	249	498	297	2100

Analogous to the machines, piles are grouped based on their shapes. Table 5.2 shows the specification of three observed piles; Pile-A, Pile-B and Pile-C as triangle pile in Indonesia, square pile in Malaysia and I-shape pile in Thailand, respectively. Pile-A consists of two kinds of triangle piles 3 meter and 6 meter.

As presented in Chapter 3, labor participation and machine performance are distinguished in four processes; driving, moving, setting and welding process. Labor participation is illustrated as the contribution of the provided workers toward the speed of each of those performances, while machine performance is defined as the ability of the machine to perform each of those four processes. Work performances and labor participations analysis in this chapter follow those four processes.

5.1.1. Driving processes

Blows energy represents the rate of pile-driving machine in producing driving energy to penetrate piles into the ground. Driving energy is produced by a ram falling onto a pile head. The amount of driving energy depends on the weight of the ram and the height of the stroke.

Table 5.3 The analysis of driving energy

Machine			**Machine-A**[1]	**Machine-B**[1]	**Machine-C**[2]
No of data			98	94	79
Height of stroke		(m)	1.0	1.0	0.6
Weight of ram		(kg)	1700	1200	5000
Number of labor		(person)	3	2	4
Driving time	Average	(sec/10blows)	**18.53**	**20.07**	**22.56**
	SD[3]	(sec/10blows)	2.08	1.30	1.85
	Minimum	(sec/10blows)	13.57	17.81	19.68
Rate of driving energy	Average	(kg.m/sec)	**3149.89**	**2407.90**	**6769.49**
	SD[3]	(kg.m/sec)	**352.68**	**156.24**	**553.56**
	Minimum	(kg.m/sec)	2307.41	2136.72	5905.2
Average of labor participation		(kg.m/man.sec)	**229.37**	**269.11**	**443.16**

[1] Small pile-driving equipment (see Table 5.1)
[2] Medium pile-driving equipment (see Table 5.1)
[3] Standard deviation

The analysis results for rate of driving energy for each drop-hammer in the three observed countries are presented in Table 5.3 and Figure 5.1. All of the equations used to do analysis are based on equation in Section 3.4.3.1.

Figure 5.1 shows that among the three drop-hammers, machine-A, machine B and machine-C, the largest driving energy productivity is yielded by machine-C with 5 tons ram, while the smallest one is produced by machine-B with 1.2 tons ram. However, according to Table 5.3, machine-C with 5 tons ram, the heaviest, has the slowest blows speed while the fastest is yielded by machine-A. In fact, the heavier the ram, the larger the driving energy generated, but the slower the blows speed.

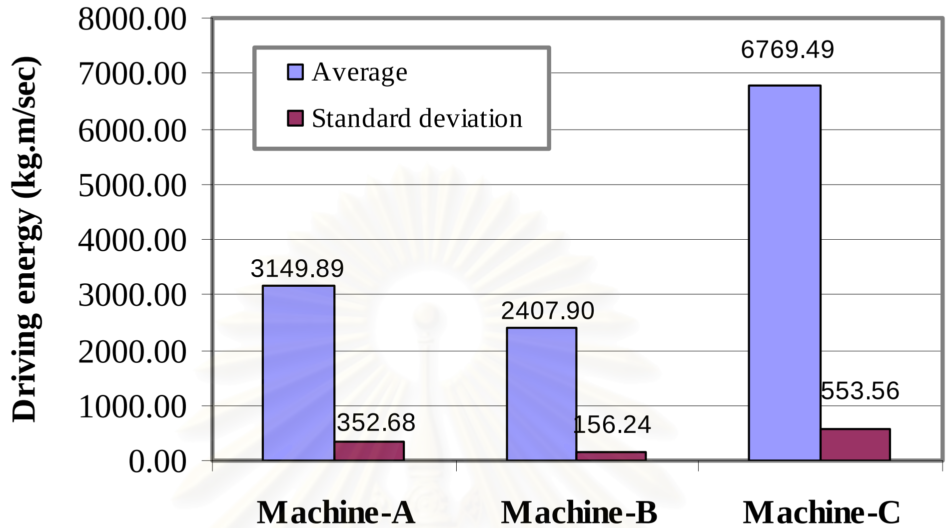


Figure 5.1 Bar-chart of rate of driving energy

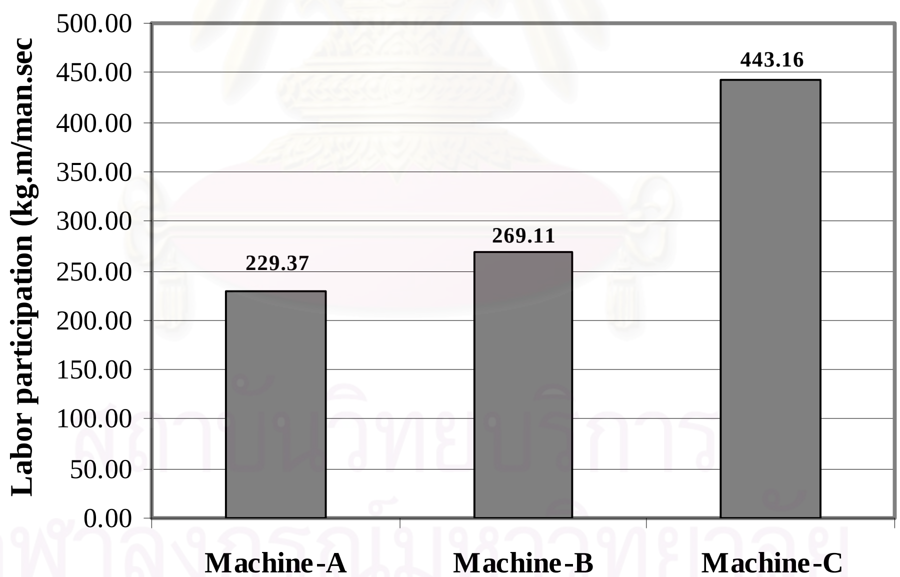


Figure 5.2 Bar-chart of average of labor participation in driving processes

From Table 5.3, it is shown that, at driving stages, labor in each machine provides different contribution. Each worker at machine-C contributes 443.16 (kg).(meter) of driving energy per second, while each at machine-A provides 229.37

(kg).(meter) of driving energy per second, and at machine-B, each worker supplies 269.11 (kg).(meter) of driving energy per second.

5.1.2. Movement processes

As discussed in Chapter 3 in this research, movement speed or movement ability means the distance reached per unit of time. However, based on the unity, movement speed is determined as the need of time to move the equipment per one meter of shift. In this analysis, movement speed is distinguished as sideward and forward/backward movement.

5.1.2.1. Sideward movement

The analysis of the speed of sideward movements of the three observed drop-hammers, Machine-A, machine-B and machine-C, and their labor participation are provided in Table 5.4. Number of sideward movements for machine-A, machine-B and machine-C are 7, 16 and 10 respectively. The analyses are done based on equations in Section 3.4.3.2.

Table 5.4 The analysis of speeds of sideward movement

Machine			**Machine-A**[1)]	**Machine-B**[1)]	**Machine-C**[2)]
No of movement			7	16	10
Number of labor		(person)	4	2	3
movement speed	Average	(time*/m)	**0:02:06**	**0:02:48**	**0:06:44**
	SD[3)]	(time*/m)	**0:00:36**	**0:01:48**	**0:02:50**
	Minimum	(time*/m)	0:01:12	0:00:50	0:03:28
Average of labor participation		(m/man.hr)	**7.14**	**10.71**	**2.97**

[1)] Small pile-driving equipment (see Table 5.1)
[2)] Medium pile-driving equipment (see Table 5.1)
[3)] Standard deviation
* time = (hh:mm:ss)

Figure 5.3 shows the average speed of sideward movement of the three observed drop-hammers; machine-A, machine-B and machine-C. Among these three machines, in average, machine-A can perform the fastest movement at 1 meter in 2 minutes and 6 seconds, followed by machine-B; 1 meter in 2 minutes and 48 seconds, while the slowest is the machine-C at 1 meter in 7 minutes and 27 seconds.

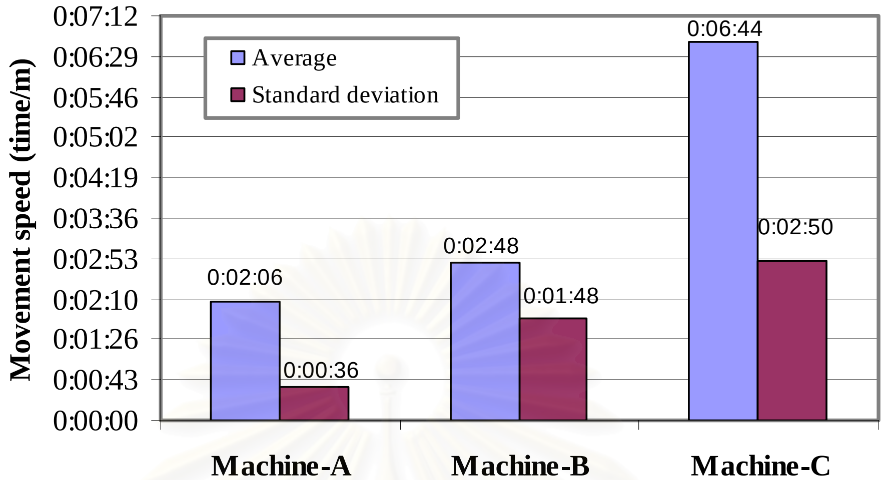


Figure 5.3 Bar chart of speed of sideward movements

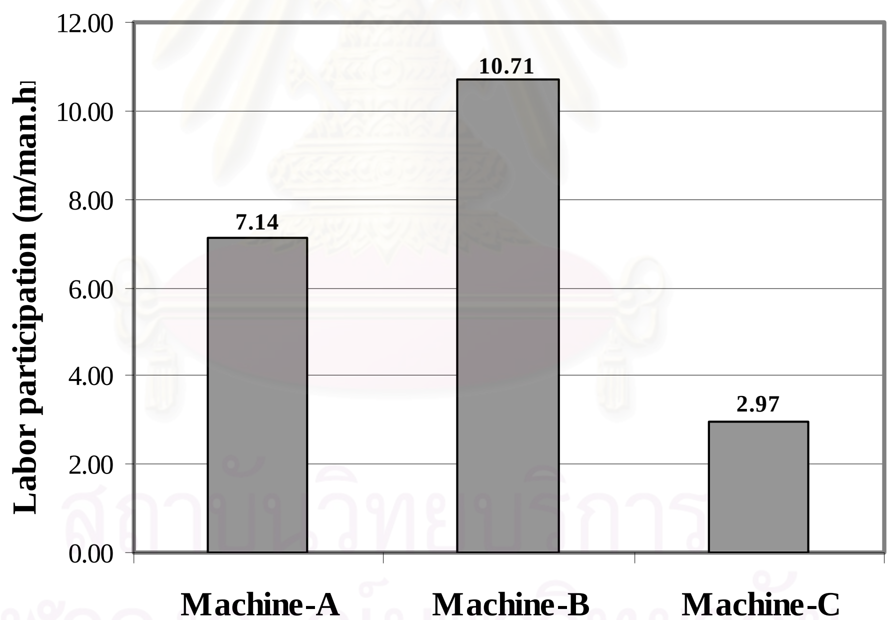


Figure 5.4 Bar-chart of average labor participations in sideward movement process

Figure 5.4 shows the labor participations in sideward movement of those three machines. Every worker of machine-A contribute to do 7.14 meter of sideward movement per hour, at machine-B, every worker contributes 10.71 meter of sideward movement per hour, while workers of machine-C contribute 2.97 meter per hour of sideward movement.

5.1.2.2. Forward/backward movement

The second movement is forward/backward movement. Moving a drop-hammer to this direction constitutes perpendicular movement to the drop-hammer's supports. This movement, further, needs special moving mechanisms and faces difficulties. Hence, this movement is seldom employed. See Chapter 4.

Table 5.5 The analysis of speed of backward movement

Machine		**Machine-A**[1)]	**Machine-B**[1)]	**Machine-C**[2)]
No of movement		2	3	2
Number of labor	(person)	4	2	3
Average of movement speed	(time*/m)	**0:03:52**	**0:05:45**	**0:26:08**
Average of labor participation	(m/man.hr)	**3.88**	**5.22**	**0.77**

1) Small pile-driving equipment (see Table 5.1)
2) Medium pile-driving equipment (see Table 5.1)
* time = (hh:mm:ss)

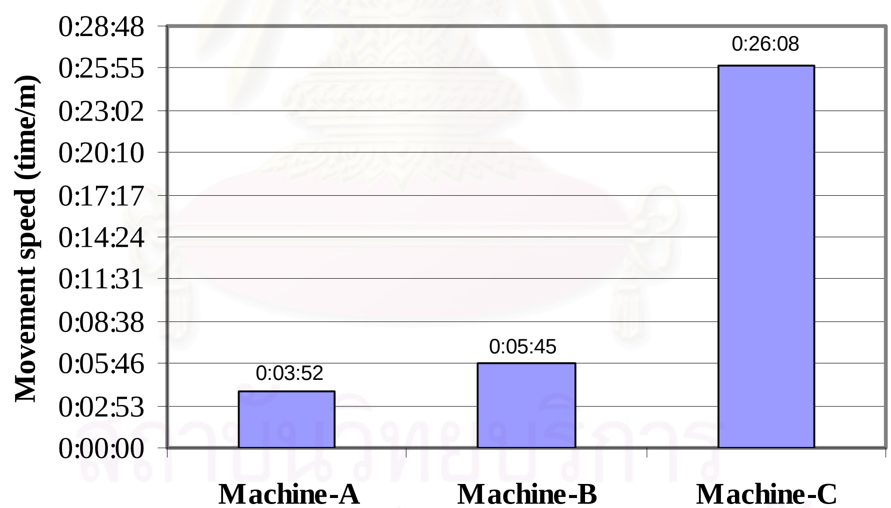


Figure 5.5 Bar chart of average of speed of backward movement

Figure 5.5 shows that, in average, machine-A can perform the fastest forward movement. It takes 3 minutes and 52 seconds for every 1 meter of forward movement. The second fastest machine is machine-B, which takes 5 minutes and 45 seconds for every 1 meter of forward movement. Finally, machine-C is the slowest machine in forward movement. Machine-C takes 26 minutes and 8 second for 1 meter of forward movement. This speed is about 5 times slower than the forward movement speed of machine-B and about 6 times slower than the forward movement speed of machine-A.

The long movement duration of machine-C, 5 tons drop-hammers which discovered in Thailand, is mostly caused by its repetitive and gradual jacking and shifting of its main structure on its support. This mechanism is different from machine-A and machine-B that they do not need any jacking mechanism in their forward/backward movement. See the movement mechanism of the three drop-hammers in Chapter 4.

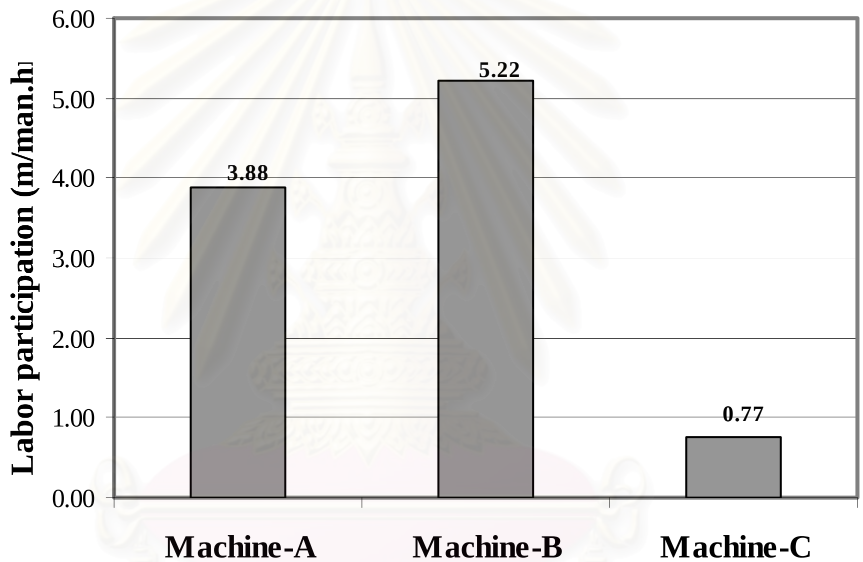


Figure 5.6 Bar-chart of labor participation in processes of backward movement

Figure 5.6 shows the labor participations in backward movement of those three machines. Every worker of machine-A contribute to do 3.88 meters of backward movement per hour, at machine-B, every worker contributes 5.22 meters of backward movement per hour, while workers of machine-C contribute 0.77 meter per hour of backward movement.

5.1.3. Setting processes

As discussed in Section 3.4.3.3, setting ability of pile-driving work is the duration to set a pile from storage area near the machine until it is set in the required position. There are two methods used to analyze the setting process. The first method is considering the effect of pile weight toward the setting time, while the second is considering the effect of pile weight and length.

Table 5.6 provides the data used to analyze the setting process of four kinds of driven-piles; 3 meters of 28x28 triangle pile (3 m pile-A), 6 meters of 28x28 triangle pile (6 m pile-A), 6 meters of 15x15 square pile (pile-B) and 12 meters of 35x35 I-shape pile (pile-C). All of them have different in weight. The detail data including number of setting, pile weight and the analysis result can be found in that table.

Table 5.6 Analysis of setting processes

Pile			**Pile-A**[1]		**Pile-B**[1]	**Pile-C**[2]
Length		(m)	**3**	**6**	**6**	**12**
Number of settings recorded			24	23	41	9
weight		(ton)	249	498	297	2100
Number of labor		(person)	3	3	2	4
Setting time	Average	(time*)	0:02:26	0:03:18	0:01:25	0:11:47
	SD[3]	(time*)	0:00:35	0:01:11	0:00:43	0:05:05
	Minimum	(time*)	0:01:23	0:01:13	0:00:33	0:04:59
Setting speed 1[4]	Average	(time*/ton)	**0:09:46**	**0:06:37**	**0:04:45**	**0:05:37**
	SD[3]	(time*/ton)	**0:02:21**	**0:02:22**	**0:02:23**	**0:02:25**
Setting speed 2[5]	Average	(time*.m/ton)	**0:29:19**	**0:39:43**	**0:28:30**	**1:07:21**
	SD[3]	(time*.m/ton)	**0:07:04**	**0:14:14**	**0:14:20**	**0:29:05**
Labor participation 1[6]		(kg.man/sec)	**0.57**	**0.84**	**1.75**	**0.74**
Labor participation 1[7]		(kg.man/m.sec)	**0.19**	**0.14**	**0.29**	**0.06**

[1] Small pile (see Table 5.2)
[2] Large pile (see Table 5.2)
[3] Standard deviation
[4] Setting speed which considers factor of weight of piles only.
[5] Setting speed which considers factors of weight and length of piles.
[6] Average of labor participation in performance of setting speed 1.
[7] Average of labor participation in performance of setting speed 2.
* time = (hh:mm:ss)

Figure 5.7 shows that, when only piles' weight is considered, in average, among those four piles, pile-B is the easiest pile to be set with its setting rate is 4 minutes and 45 seconds per ton of pile weight. The second and third easiest are pile-C and 6 m pile-A with their setting rates are 5 minutes and 37 seconds and 6 minutes and 37 seconds per ton of pile weight, respectively. Whereas, 3 m pile-A is the most difficult pile to be set. To set pile-A, it takes 9 minutes and 46 seconds per ton of pile weight

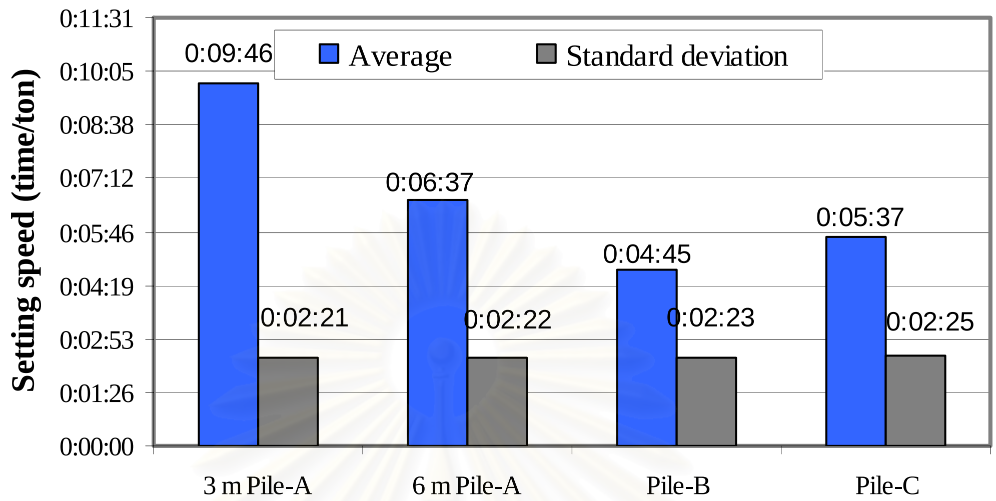


Figure 5.7 The setting speed which considers only the piles' weight. (Setting process-1)

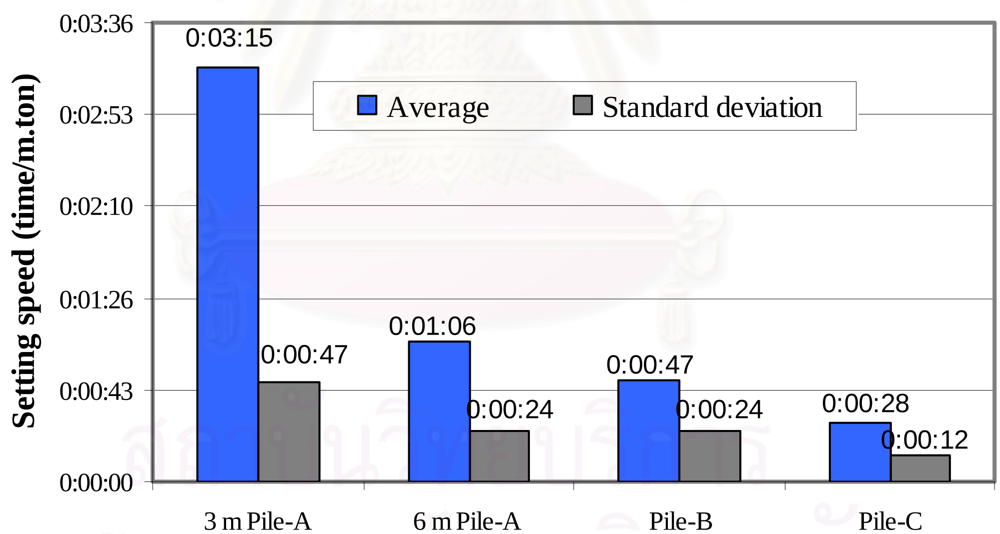


Figure 5.8 The setting speed which considers the piles' weight and length (Setting process-2)

Figure 5.8 shows that, when piles' weight and length are considered, in average, among those four piles, pile-C is the easiest pile to be set with its setting rate is 28 seconds per ton of pile weight per meter of pile length. The second and third easiest are pile-B and 6 m pile-A with their setting rates are 47 seconds, and 1 minutes

6 seconds per ton of pile weight per meter of pile length, respectively. Whereas, 3 m pile-A is still the most difficult pile to be set. To set pile-A, it takes 3 minutes 15 seconds per ton of pile weight per meter of pile length.

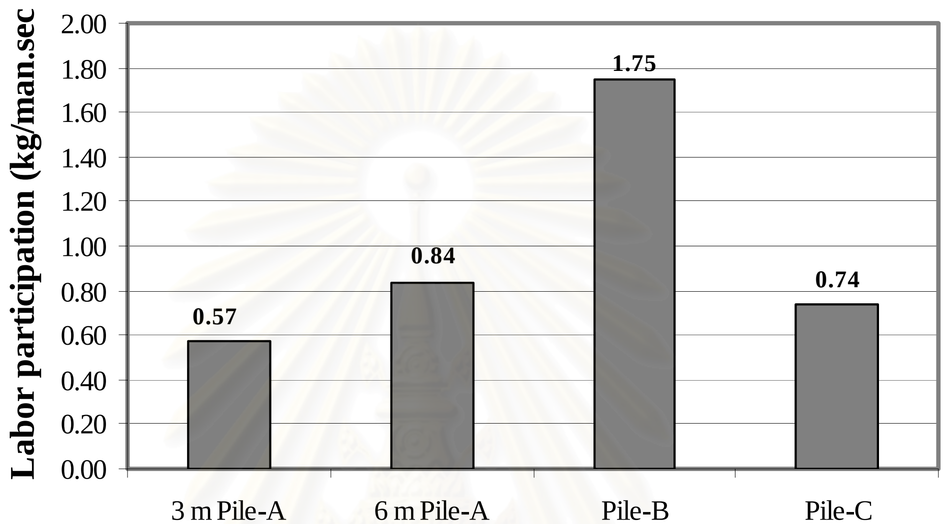


Figure 5.9 Average of labor participation in setting process (1)

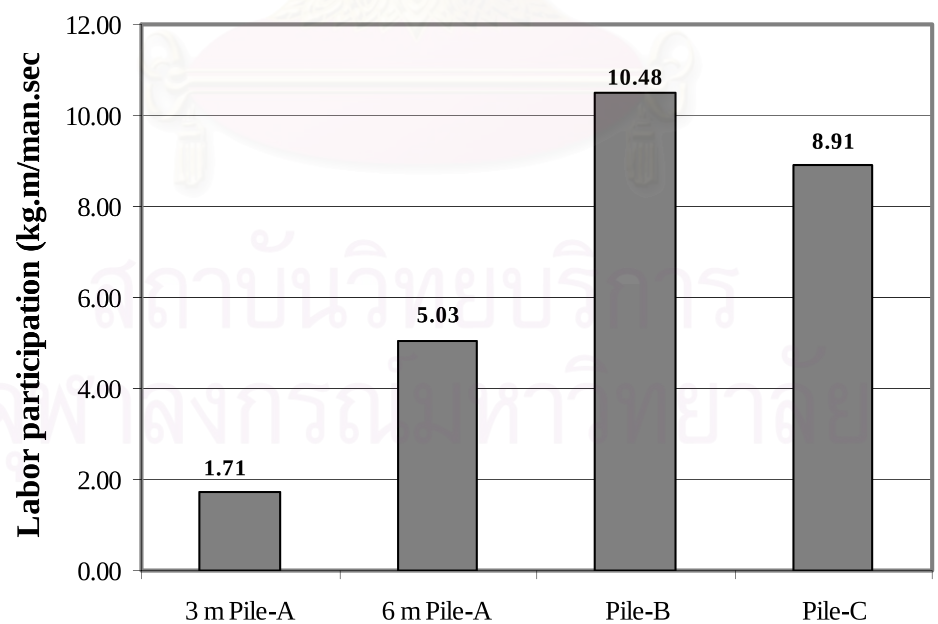


Figure 5.10 Average of labor participation in setting process (2)

Figure 5.9 shows the average of labor participation in setting process-1, when only piles' weight is considered. To set 3m pile-A, every worker contributes 0.57 kg per second, while to 6 m pile-A, pile-B and pile-C every worker contributes 0.84, 1.75 and 0.74 kg per second, respectively.

In Figure 5.10, the average of labor participation in setting process-2, when piles' weight and length are considered, is depicted. To set 3m pile-A, 6m pile-A, pile-B and pile-C, every worker contributes 1.71, 5.03 10.48 and 8.91 kg meter of pile weight and length per second, respectively.

5.1.4. Welding processes

Welding ability is analyzed to three types of pile. The data are provided in Table 5.7. Based on the equation provided in Section 3.4.3.4, welding speed is analyzed as the welding time divided by the welding length (perimeter of pile). Figure 5.11 shows that the average of welding speed for joining a 28x28 triangle-pile is 7 minutes and 36 seconds per meter of welding length, while that for joining a 15x15 square-pile is 4 minutes and 10 seconds per meter welding length, whereas, that for joining a 35x35 I-shape is 10 minutes and 54 seconds per meter welding length.

Table 5.7 Welding duration of various piles

Pile		**Pile-A**[1)]	**Pile-B**[1)]	**Pile-C**[2)]
Number of welding recorded		35	20	4
Number of labor (person)		3	2	4
Welding length (cm)		0.84	0.45**	1.75
Welding time	Average (time*)	0:06:23	0:01:52	0:19:05
	SD[3)] (time*)	0:01:51	0:00:34	0:02:07
	Minimum (time*)	0:04:14	0:00:53	0:16:43
Welding speed	Average (time*/cm)	**0:07:36**	**0:04:10**	**0:10:54**
	SD[3)] (time*/cm)	**0:02:12**	**0:01:15**	**0:01:13**
Labor participation[4)] (cm.man/sec)		**0.07**	**0.20**	**0.04**

1) Small pile (see Table 5.2)
2) Large pile (see Table 5.2)
3) Standard deviation
4) Average of labor participation in welding process.
* time = (hh:mm:ss)
** Welding length of square pile was done at 3 sides of piles only.

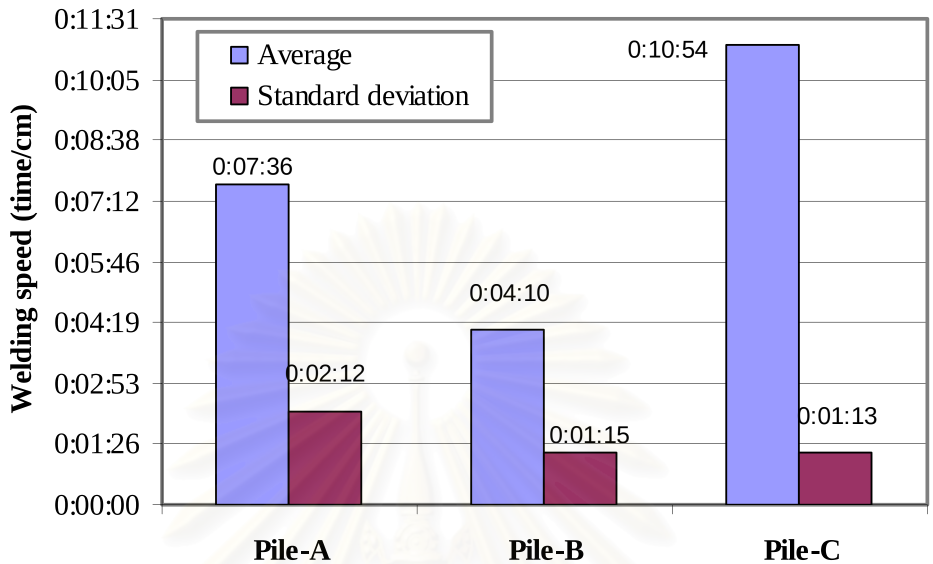


Figure 5.11 Bar chart of average of welding speed

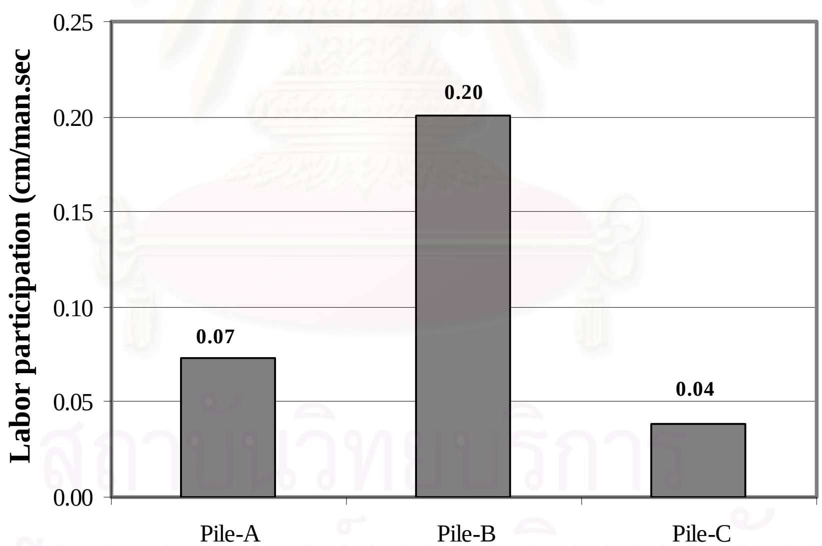


Figure 5.12 Average of labor participation in welding process

Although this assumption may not be absolutely correct, however, the result of welding speed can provide an illustration of the difficulty level of welding of each pile shape. Regarding to that, it can be said that the square pile provides the easiest welding surface followed by the triangle, with the most difficult the I-shape pile.

Labor participation of welding process is shown in Figure 5.12. In average, for welding 28x28 triangular piles, every labor contributes 0.07 cm of welding length per second, while for 15x15 of square piles, every labor contributes 0.20 cm of welding length per second, whereas, for 35x35 I-shape piles, every labor contributes 0.04 cm of welding length per second.

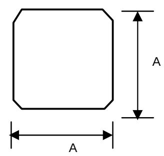
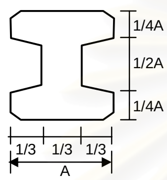
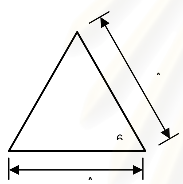
5.2. Pile Effectiveness

According to the analysis method explained in Chapter 3, pile effectiveness is calculated as the capacity of pile to support the vertical load. However, as the capacity of piles depends on soil bearing capacity multiplied by pile tip area plus soil friction capacity multiplied by the pile skin area, thus, pile effectiveness is analyzed as the ratio of the perimeter per the section area of pile.

Many brochures have been collected to identify pile specifications produced by some manufacturing companies in the three observed countries; Indonesia, Thailand and Malaysia. According to the scopes of this research, analysis of pile section effectiveness is only done for piles which commonly used in small construction projects those countries. These piles are the Thai I-shape pile, Indonesian triangle pile and Malaysian rectangular pile.

Table 5.8 shows the pile section's effectiveness of the three types of piles from the three observed countries. It is shown that among the three, the most effective pile section, the biggest ratio of perimeter per section area of pile, is achieved by the I-shape pile with a ratio of 8/A. The triangle pile is the second most effective pile section with a ratio of perimeter per pile-section area of 6.93/A. The last is the rectangular pile which has 4/A a ratio of perimeter per pile-section area.

Table 5.8 Pile-section effectiveness

Section	Section properties	Equation
	Area Perimeter ratio perimeter/area	A^2 $4A$ $\frac{4}{A}$
	Area Perimeter ratio perimeter/area	$\frac{2}{3}A^2$ $\frac{16}{3}A$ $\frac{8}{A}$
	Area Perimeter ratio perimeter/area	$\frac{1}{4}\sqrt{3}A^2$ $3A$ $\frac{12}{\sqrt{3}}A = \frac{6.93}{A}$

5.3.Safety Analysis

As regards the safety factors of the pile-driving work of small construction projects in the three observed countries, there are some matters which should be addressed. Based on observation results, there are three things which are essential to be improved in order to achieve safe pile-driving work; those are, labor uniforms, pile-driving equipment, and the work method.

5.3.1. Labor uniform

In general, all of labor uniforms of pile-driving work in the three observed countries are similar. Workers are not equipped with proper clothing such as helmets and boots, which meet safety requirements. Figure 5.13 (a) shows two workers of an Indonesian drop-hammer who only wear a cap and ordinary shoes. Figure 5.13 (b) shows even more improper clothing worn by an Indonesian worker on a pile-pushing machine. He do not only wear a proper helmet or shoes, but sandals and nothing to protect his body.

Similar with workers of Indonesian drop-hammers, Figure 5.13 (c) and (d) show Thai and Malaysian drop-hammer workers who do not wear a required safety uniform. They only wear a cap and ordinary shoes.

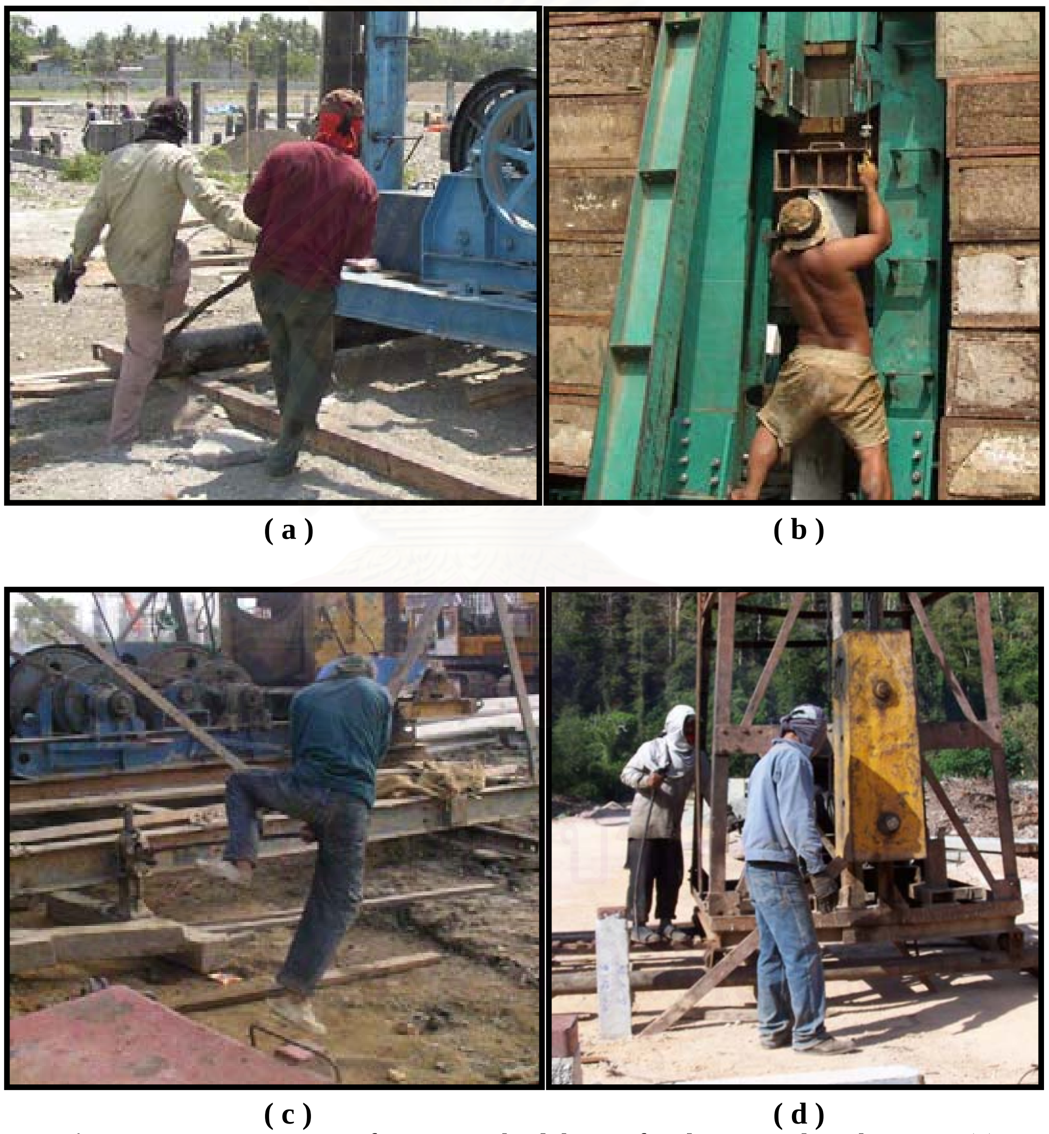
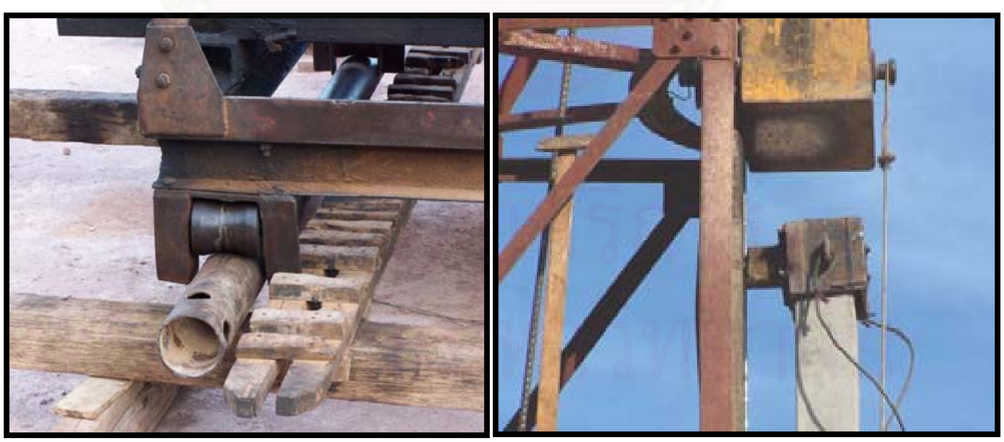


Figure 5.13 Improper uniform worn by labors of Indonesian drop-hammer (a), Indonesian pile-pushing machine (b), Thai drop-hammer (c), and Malaysian drop-hammer (d).

5.3.2. The equipment

From the observation, it is found that the Malaysian drop-hammers are operated with two obvious improper tools which may trigger hazardous work. The first improper tool is an anchor which is only made from wood, as shown in Figure 5.14 (a). In some cases where the machine is not absolutely horizontal, which can be caused by this improper anchor and the existence of the steel wheel, Malaysian drop-hammers are easily relocated without any external pushing force. In fact, this mechanism can trigger an accident when the movement forces the machine's wheel out of its rail, steel pipe. This danger may not be realized by the machine operator as he concentrates on the driving process.

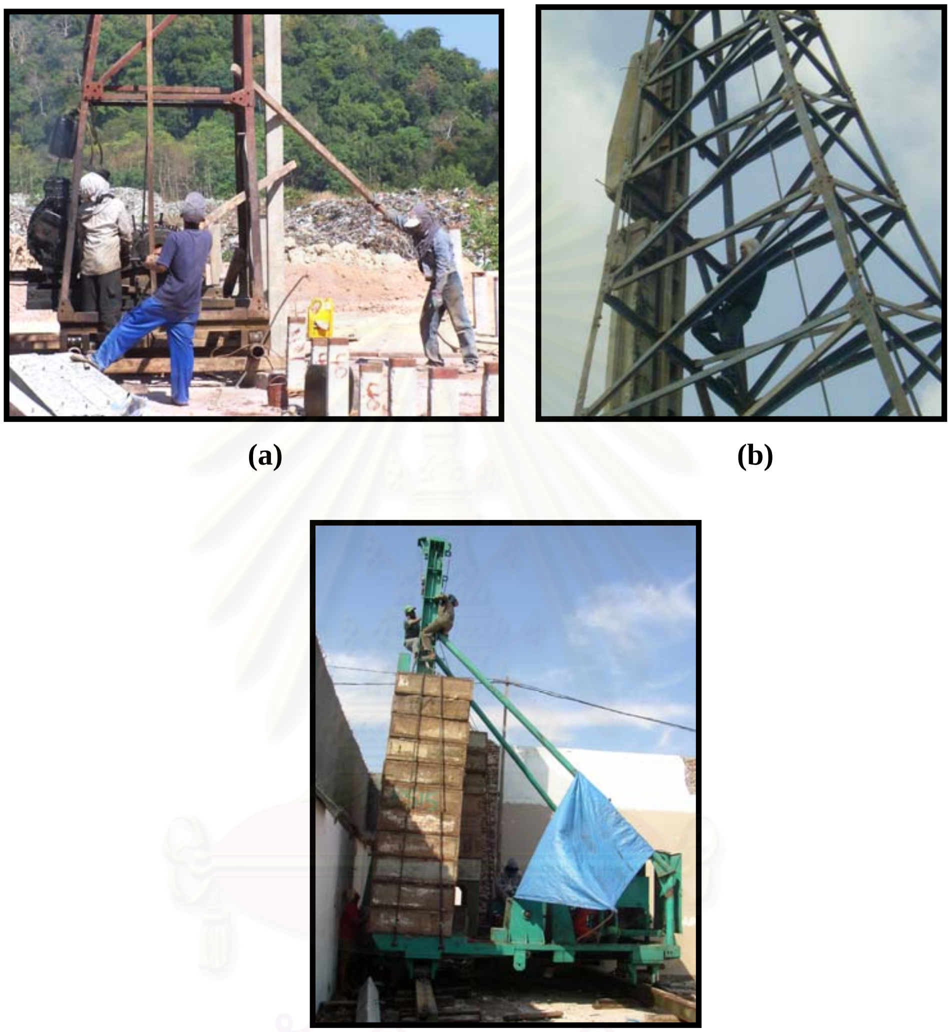
The second improper tool is the pile's cap, as shown in Figure 5.14 (b). The pile's cap of Malaysian drop-hammer is not attached to the leader of the drop-hammer. In fact, at the beginning of the driving process, this improper pile's cap may cause an accident as a pile collapses and falls on workers near the pile. During operation, while driving a pile, one labor must keep pushing the pile into the right position so the driving can be performed and the pile will not fall to the front. See also the Section 5.3.3, Methods of the work, for a detailed explanation.



(a) **(b)**

Figure 5.14 The improper anchor (a) and pile's cap (b) of Malaysian drop-hammer

5.3.3. Methods of the work



(a) (b) (c)

Figure 5.15 Improper work method of Malaysian drop-hammer (a), Thai drop-hammer (b) and Indonesian pile-pushing machine (c).

The third matter of concern in improving the work safety is reducing inappropriate work methods.

As previously cited the driving method of a Malaysian drop-hammer can be hazardous to labor, especially those who work in front of the machine. Figure 5.15 (a) depicts the work method of the Malaysian drop-hammer which requires workers to keep pushing the pile into the right position using a timber, while the pile is driven into the ground. This work method is not only a danger to workers safety but also may harm them as they have to resist the dynamic force generated by the hammer impact and forwarded by the pile being driven.

The second hazardous work method is seen with a Thai drop-hammer, Figure 5.15 (b). As the setting mechanism which is set by hanging the pile's cap on to the driving hammer, before driving process is done, the wire which suspends the pile's cap needs to be released. Usually this job is done by assigning one worker to climb the structure of the drop-hammer. An accident may occur as the worker does not use any safe climbing tools.

The last work method is the work performed with an Indonesian pile-pushing machine Figure 5.15 (c). When penetrating a pile, two workers are assigned to the top of the pile-pushing machine to guide the operator. However, similar with the Thai drop-hammer, an accident may happen as these workers are not given any safe climbing tools.

5.4.Conclusion

Analysis of three kinds of drop-hammers in the three observed countries is presented in this Chapter. Based on the formulas presented in Chapter 3, four main processes of drop-hammer operation are analyzed and compared. From the analysis, it is known that each drop-hammer has different attributes and drawbacks. Generally, the Indonesian and Malaysian drop-hammers are good in movement but inferior in producing driving energy. On the other hand, the Thai drop-hammer is superior in producing driving energy but poor in movement ability.

Different from the analysis of the performance of the drop-hammers, which is calculated as the ability of each machine to produce a process unit per time duration, labor participation in this research is defined as the contribution of the workers in every stage of the pile-driving process. For this definition, the drop-hammer discovered in Malaysian, which requires only two workers, in general, offer higher labor contribution, especially in movement, setting and welding. The drop-hammer found in Thailand, with its much larger driving energy than the other two drop-hammer still provides the higher labor contribution of the driving process, although this drop-hammers require the larger number of workers; four.

In terms of piles, among three popular pile-shapes commonly used in small construction in the three observed countries, the I-shape is the most effective pile-shape as it can provide the widest friction area at the same section area. The triangle is the second most effective pile-shape and the rectangular shape is the third.

In addition, this chapter also provides a safety analysis of the pile-driving work in the three observed countries. Matters concerned with safe construction work are discussed. In fact, the safety problems of pile-driving work in Thailand, Indonesia and Malaysia are similar. These include labor uniforms, inappropriate tools and improper work methods.

CHAPTER VI
SIMULATIONS AND SUGGESTIONS FOR IMPROVEMENT

In this research, improvement operation focuses on reducing the cycle time of pile-driving processes. Among all stages, moving and driving are directly affected by equipment performance, whereas, setting and joining are independent activities that do not depend on equipment performance but on the skill of workers (welders) and welding tools. As discussed in the previous chapter, the major problems when utilizing a drop-hammer are the long duration of movement time and low rate of driving energy.

To reduce the time consumed, the joining stage, or setting and welding activity of piles at the same driving point may be eliminated. This is usually done by extending the length of the piles and be implemented with a high structure which can handle long piles.

Since the number of piles to be driven must follow the foundation lay-out, removing movement activities is virtually impossible. Operation of pile-driving work always starts at one driving point and continues to others ending when all piles have been completely installed.

In Chapter 5, it is analyzed that drop-hammers discovered in Indonesian, Malaysia and Thailand, have different performances at each stage. This chapter provides some comparative analysis which presents useful knowledge of these differences. First, this chapter will provide a simulation model to compare the estimated cycle time of two drop-hammers, drop-hammers which are discovered in Indonesia and Thailand, in two illustrated models. Next, modifying drop-hammer tools, the rail supports and ram, for better operation is also discussed.

6.1. Simulations

To compare the overall performance of each pile-driving machine, simulation is done based on two assumptions, deterministic and stochastic analysis. This simulation focuses on providing an illustration of different applied performances of the machines when they are used under the same field conditions. See Section 3.6 for the simulation method.

6.1.1. Models for simulation

In this simulation, two models of piling-work layout, soil specifications and other influencing factors are assumed. By using the same assumption, it is expected that the simulation results will illustrate a real comparison for performance of each pile-driving machine.

Monte Carlo Simulation is used as the method of simulation. All statistical data, the average and standard deviation of the recorded data, gotten from analysis in Chapter 5 is used as the input. Excel's random number generation is used as the occurrence probability of each activity. The formula of this method has been discussed in the research methodology in Chapter 3.

The illustrative foundation layout is imitated from the real layout of a building project in Indonesia. Based on this real layout, some modifications are made to simplify the simulation. To accommodate the different performance results caused by different a machine's superiority, two layout models are established. The first model is used for all types of drop-hammers while the second is only for Thai drop-hammer.

Figure 6.1 shows the first foundation layout model used to simulate the performance of all pile-driving equipment. The layout shows that piles are designed to support the building's columns. One column needs to be supported with 6 of 28x28 triangular piles, in a group system. Every pile is driven in three pieces, where each piece is 6 meters in length. The distance between each pile group can also be seen.

Limitations of the first model:

1) Pile-driving work has to be accomplished with the same method; 3 piles at every driving point, the same pile size and driving route, as shown in Figure 6.7.
2) Each pile at every driving point needs to be driven with total driving energy of 1,700 (ton).(meter), which is derived from the average number of blows of driving one set of triangle piles in the UMY project in Yogyakarta, or 1000 blows,

3) Monte Carlo Simulation is run 20 times for each pile-driving machine to obtain a reliable result.

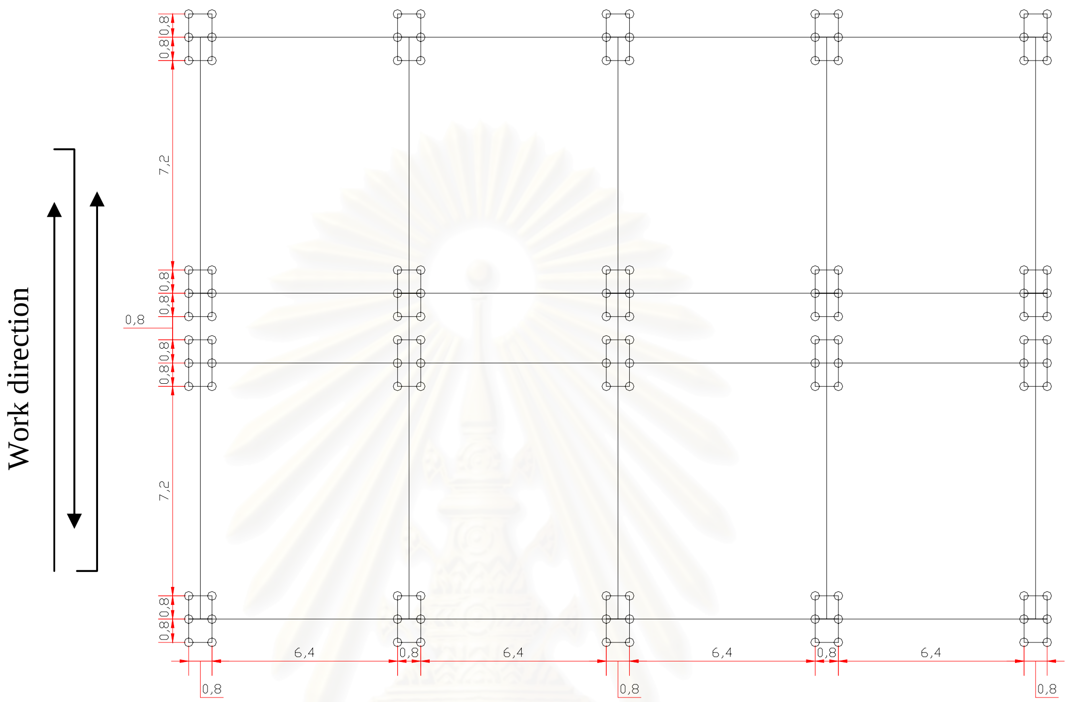


Figure 6.1 The first foundation layout model

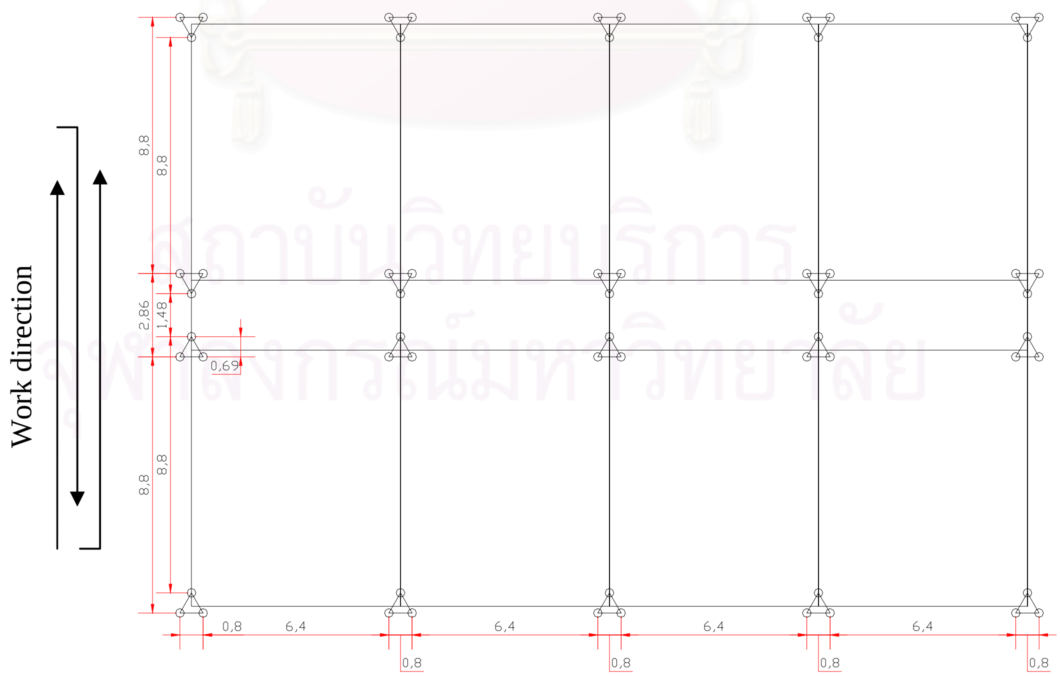


Figure 6.2 The second foundation layout model (for Machine-C only)

In the second model, bigger and longer piles are used, 18 meters 35x35 I-shape piles. By using this pile, the process sequence of the pile-driving work is different. The welding process is eliminated and every pile needs only one setting activity.

Some other assumptions established in the second method are:

1) Since the tip area of 35x35 I-shape piles is approximately twice that of 28x28 triangle piles, the driving energy need becomes twice as much, or 3,400 tons meters.
2) However, a tip area twice the size can provide twice the resistance capacity.

Figure 6.2 shows the 50% number of pile decrease to 60 piles, 35x35 I-shape piles that can support twice the capacity of the 28x28 triangle piles of the first model. The pile group arrangement is changed to a triangle to have the minimum pile numbers in a pile group, three piles (Bowls, 1997).

6.1.2. Result of simulation

6.1.2.1. Total duration of the work performance

The names of the machines; Machine-A, Machine-B and Machine-C, in the simulation refer to Table 5.1 in previous chapter. The simulation results are shown in Figure 6.3. In the results of the first illustrative model, the first three bar charts; Machine-A, Machine-B and Machine-C1, the shortest duration is achieved by the Machine-A while the longest duration is achieved by the Machine-B.

For five composing activities; driving, welding, setting, sideward movement and backward movement, the durations of setting and welding are similar for all types of machines, while the differences are driving and movement activity. According to the statistical analysis done in Section 5.1.3 and 5.1.4, setting and welding are not influenced by the type of machine but by the weight and the perimeter of a pile. This is why the durations of these two activities are similar for all machine types.

In the driving stage, the performance of the Machine-B is very low. This is because this machine is equipped with a light, 1-ton ram. In contrast, the Machine-C has a very heavy, 5-tons ram, which is very fast in terms of driving. However, because of long movement activity, sideward and backward movement, this machine requires quite a long total duration.

When considering the possibility of modifying the foundation design and layout to utilize bigger and longer piles, the Machine-C becomes more effective. This modification eliminates welding time and reduces the setting activity. On the other hand, as the foundation layout is changed to follow the pile group arrangement, this modification increases the duration of side movement. Since the total time increase caused by the sideward movement is still lower than the total time decrease from elimination of welding plus reduction of setting time, the modified pile layout yields a lower total duration than the original pile layout. Figure 6.9 shows that by modifying pile layout, the second model, the Machine-C2 has the shortest cycle time.

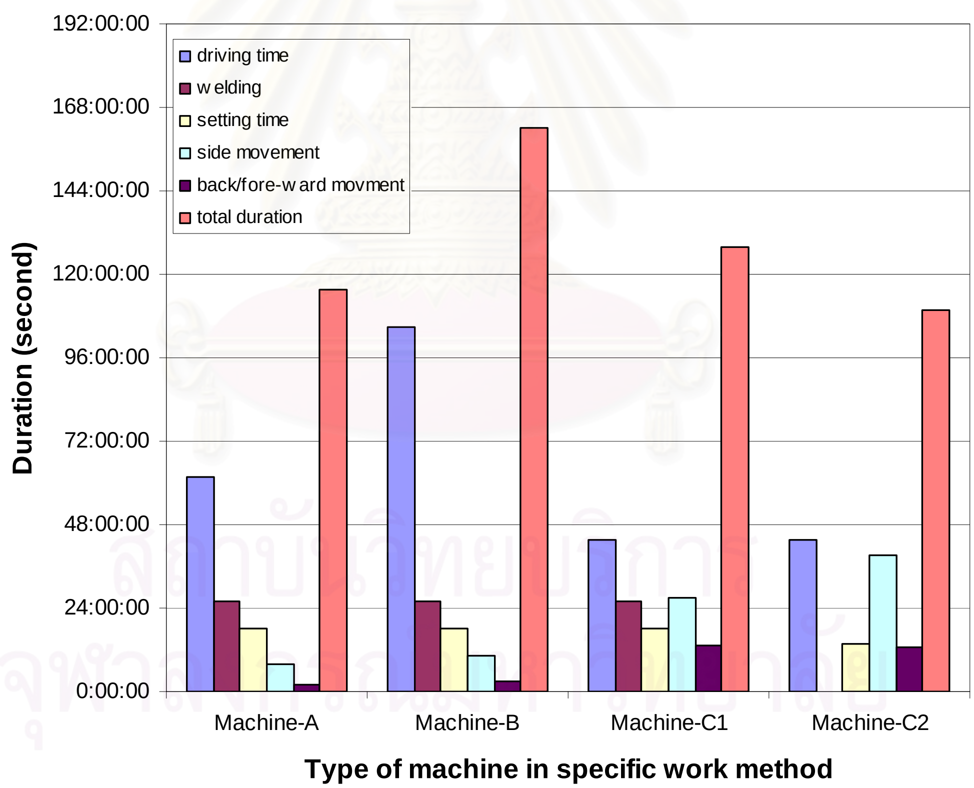


Figure 6.3 Bar-chart of the simulation result of various pile-driving equipment

6.1.2.2. The percentage duration of each process

To comprehend the contribution of each cycle toward total duration of operation, the percentage duration of each process is analyzed. This analysis is used to determine the percentage between productive and unproductive time. Productive time is the time used to produce piles which are successfully installed, while unproductive time is the time which has no effect toward the increment number of installed piles.

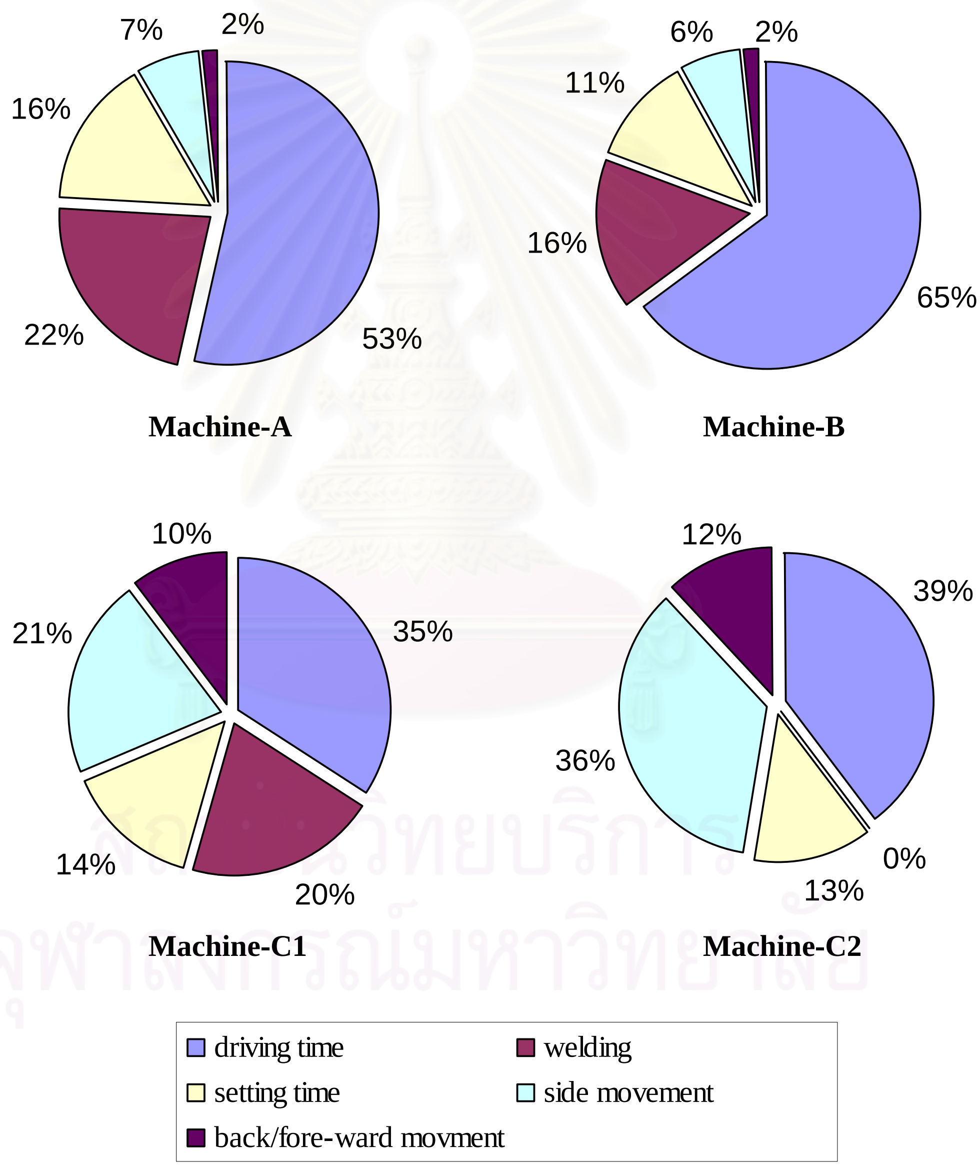


Figure 6.4 The percentage of accomplishing duration of various stages of various pile-driving equipment

Figure 6.4 shows that the Machine-A and Machine-B which use lighter ram, 1.7 tons and 1.2 tons, respectively, use more than 50% of their total cycle time for driving. Another 8-9% is used as movement activity. However, for the same method, the Machine-C, needs less than 40% of its total cycle time for driving, 31% of the total cycle time for movement.

When considering the second method used by the Machine-C, the method which achieves the fastest performance in the illustrative pile-driving work, the cycle time between driving and moving activity becomes more similar. The driving time is about 39% while the moving time is 48%.

6.1.2.3. *Validation*

Table 6.1 The result of the actual and the simulation data

Day	Number of pile driven	Cumulative number of piles driven	Cumulative actual time duration (time)	Cumulative simulation time duration (time)
1	4	4	6:20:00	4:10:40
2	4	8	12:23:00	8:31:23
3	5	13	21:52:00	13:44:13
4	8	21	30:10:00	22:03:45
5	10	31	38:45:00	32:22:16
6	3	34	43:07:00	35:53:51
7	5	39	48:06:00	41:19:06
8	6	45	55:26:00	47:36:03
9	6	51	62:56:00	54:01:19
10	6	57	70:27:00	60:08:01
11	5	62	77:41:00	65:23:43
12	5	67	85:39:00	70:39:41
13	1	68	86:31:00	71:45:01
14	3	71	89:44:00	74:52:26
15	8	79	96:44:00	83:23:59
16	6	85	104:12:00	89:43:44
17	3	88	108:27:00	93:24:48
18	3	91	114:33:00	96:27:51
19	7	98	121:39:00	103:34:51
20	6	104	129:14:00	110:03:26
21	7	111	136:50:00	116:53:04
		Total	136:50:00	116:53:04
		difference	19:56:56	
		%difference	14.58 %	

To validate the simulation methods done in the previous section as well as reliability of data collected, results are presented here. However, as time constraint and some problems could not be solved when actual data were collected, validation of this research can only be done for a sample project; pile-driving work of UMY Project in Yogayakarta, Indonesia, in which the complete data were successfully recorded.

Validation focuses on comparing the actual duration with the duration produced by the simulation. The basics of the simulation used in this validation are similar to the method of the previous simulation which is performed to determine the overall performance of the drop-hammers. Therefore, the difference is the foundation lay out. The layout used in the validation simulation follows the as-built pile-driving layout of the selected project (U.M.Y. Project).

Results of the comparison between the productivity of pile-driving machines generated by the simulation with the productivity of pile-driving machines from the field (actual construction) are presented in Table 6.1, and Figure 6.5. The difference in duration between the simulation and the actual performance is 14.58%. According to the appendices to the data recorded, unproductive time is as much as 10.83 %. This means that the data and the method used in this simulation provide approximately (14.58% - 10.83%) with error value of less than 5%.

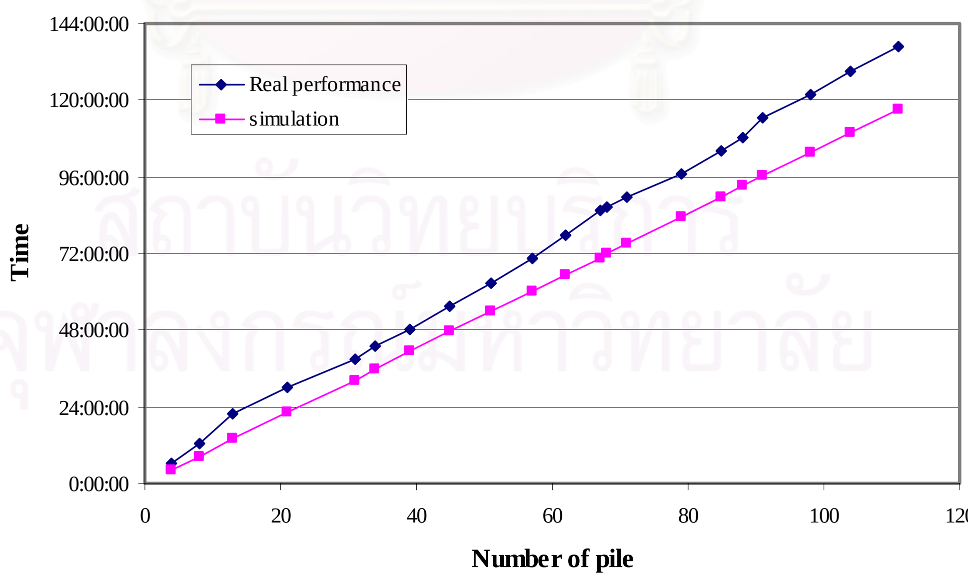


Figure 6.5 The comparative result between computer simulation and the real performance (validation)

6.2. Analysis of the Work Method

Analysis of the work methods is used to understand the percentage of the working and idle time of labor in operating the observed drop-hammers. The method used in this analysis refers to Crew Balance-Chart (Oglesby, 1989). Participations of every worker are plotted in a bar-chart. The total ineffective time (waiting/idle time) is formulated as:

$$\text{Total ineffective time (idle time)} = \frac{\sum_{i=1}^{n} Wt_i}{100 \times n}$$

Which

Wt_i : waiting time of the-i worker

n : number of workers

Analysis of the work method is done based on the percentage of the activities durations in the simulation models as shown in Figure 6.4. Because the operation system of the observed machines are the same, labor participation in each machine operation is the same as well. Helpers and operator work together in setting and moving activities. But, during driving, operator is the only worker who handles the work, while the helpers are idle. On the other hand, a helper is assigned to accomplish welding; the operator and other helpers are idle. The overall labor participations of the previous simulation models are analyzed in the bar charts below.

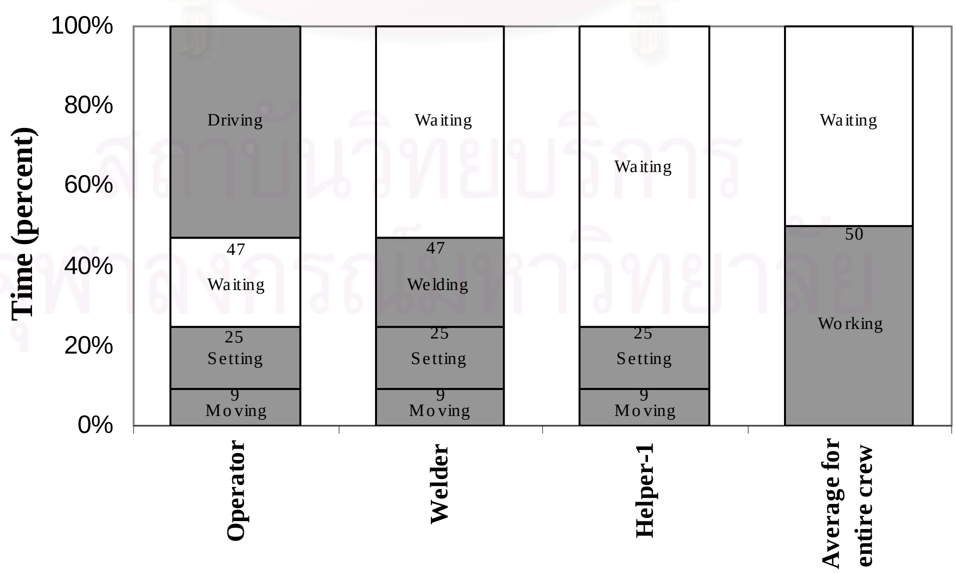


Figure 6.6 Crew Balance-Chart of Machine-A

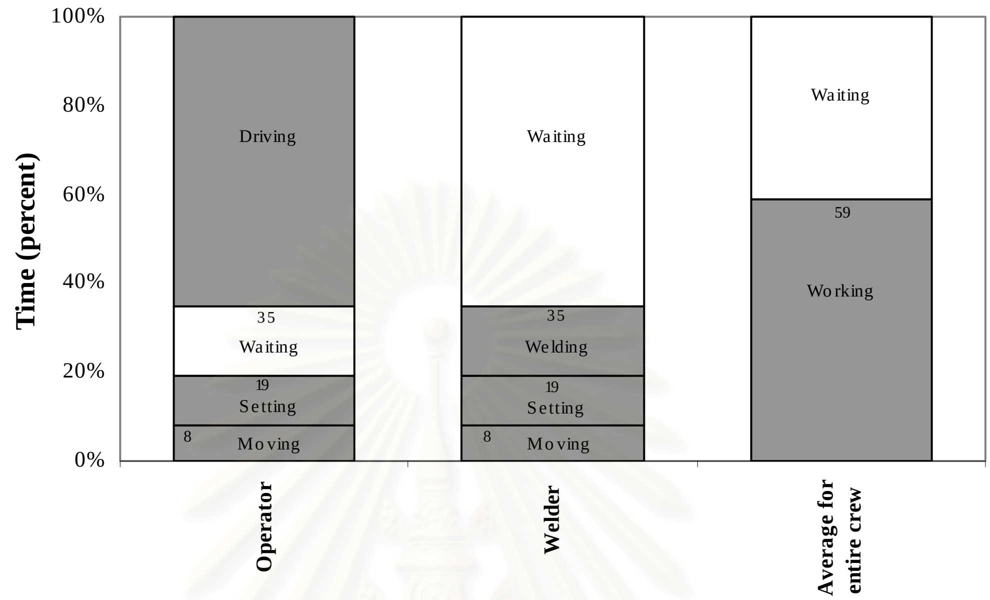


Figure 6.7 Crew Balance-Chart of Machine-B

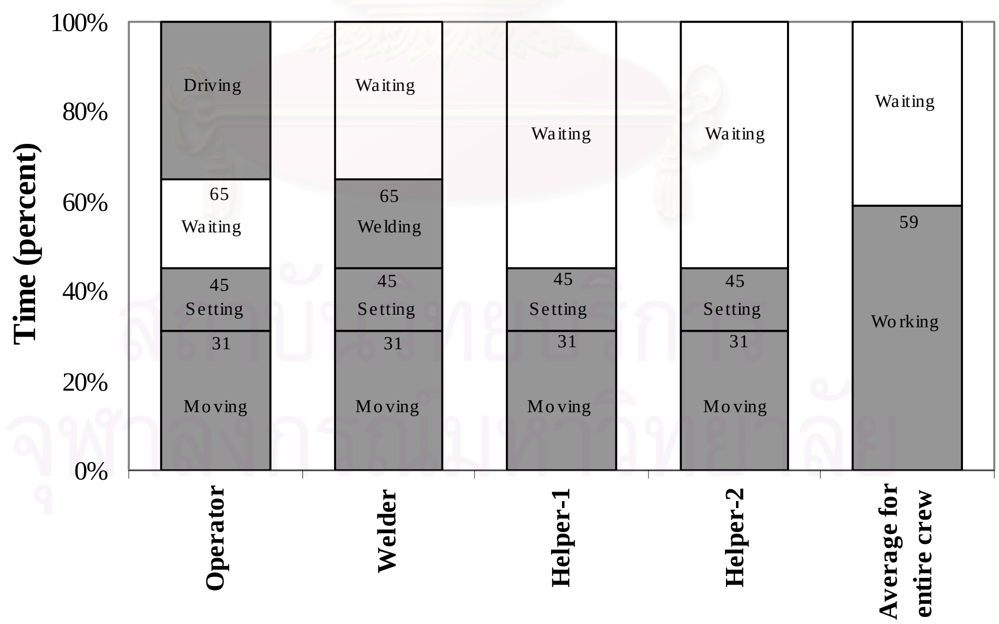


Figure 6.8 Crew Balance-Chart of Machine-C1

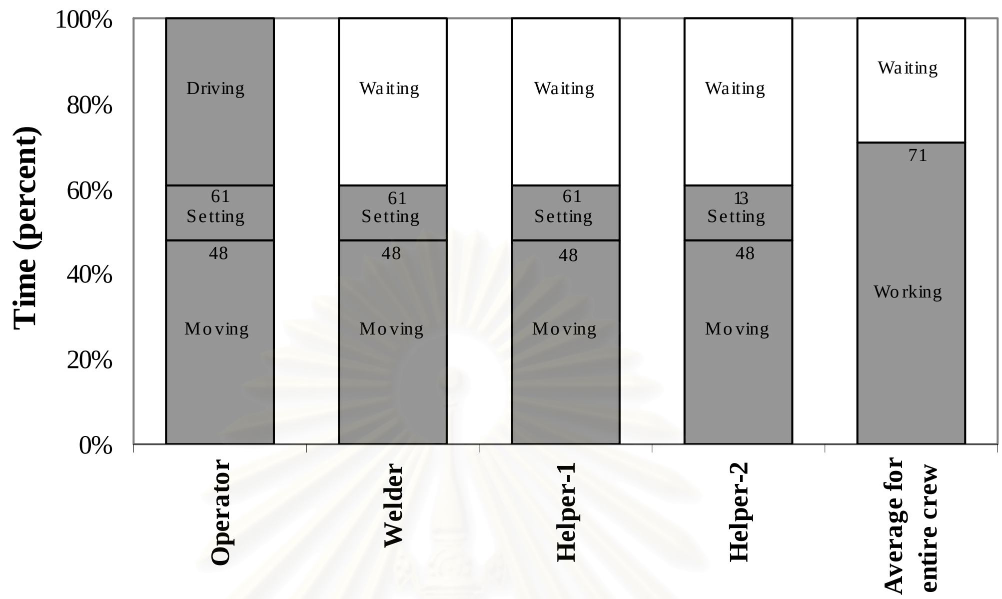


Figure 6.9 Crew Balance-Chart of Machine-C2

Figure 6.6, 6.7, 6.8 and 6.9 show the crew balance charts of machine A, B, C1 and C2, respectively. According to those charts, the work method used by machine C assigned at the second simulation model produces the most productive labor working time. In average, each worker in this work method participates for 71% of the total work duration. Machine-B and machine-C assigned at the first simulation model produce same productive labor working time. Each worker in both work methods participates for 59% of the total work duration. The least productive labor working time is produced by machine-A assigned in the first model, 50%.

6.3. Machine Support

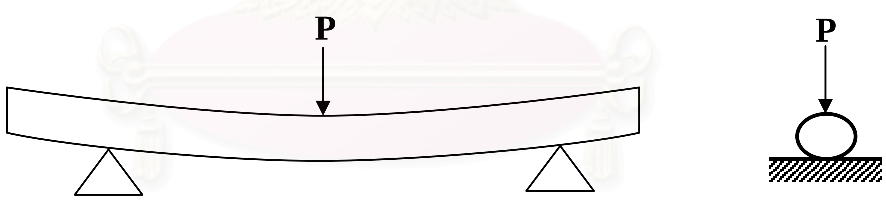
The shape of a machine's support is one of the factors influencing the movement speed of the drop-hammer. For instance, the Indonesian drop-hammer with its circular support made from steel pipe can provide faster movement than the steel rail support of the Thai drop-hammer.

In addition to an equipment base, the support can also act as the machine wheels. As the support is in the form of a steel pipe, moving the pile-driving equipment forward or backward can be done by rotating the support on its base.

(a) (b)

Figure 6.10 Changing steel rail support (a) with steel pipe support (b)

As analyzed and discussed in Chapter 5, if the effect of a machine's weight is neglected, the moving mechanism using a circular support, provides 6-times faster movement than that done by rail support. Based on this, prioritized modification to reduce the movement cycle time may be obtained by changing the steel rail support with a steel pipe support.



(a) (b)

Figure 6.11 Great deflection (a) and Transformation shape of the steel pipe which is caused by a lateral load (b)

In designing the support, however, it is necessary to consider the effect of equipment weight to the strength capacity of the support. As is known, a circular shape is risky from the shape transformation caused by lateral loads. Thus, the steel pipe support must be designed to be not only strong to resist the equipment load but also to resist shape transformation, as shown in Figure 6.11. Rolling the machine may not be done when the support shape is changed to be ellipse. To reduce this risk, reinforcement can be done by adding braces in the pipe as it is shown in Figure 6.10 (b).

6.3.1. Suggestion for support dimension

As discussed at the beginning of Section 6.3, support should be designed to resist the required load. The loads are dead load (equipment load) and live load (pile load). Analysis is focused on designing steel pipe as supports for drop-hammers in Thailand. The analysis is done by SAP2000 version 8.08 (CSI, 2002). In the model, there are two steel pipes are prepared as the supports with diameter and thickness of 7.0 inches and 0.4 inches, respectively. Structure model of the analysis is depicted in Figure 6.12.

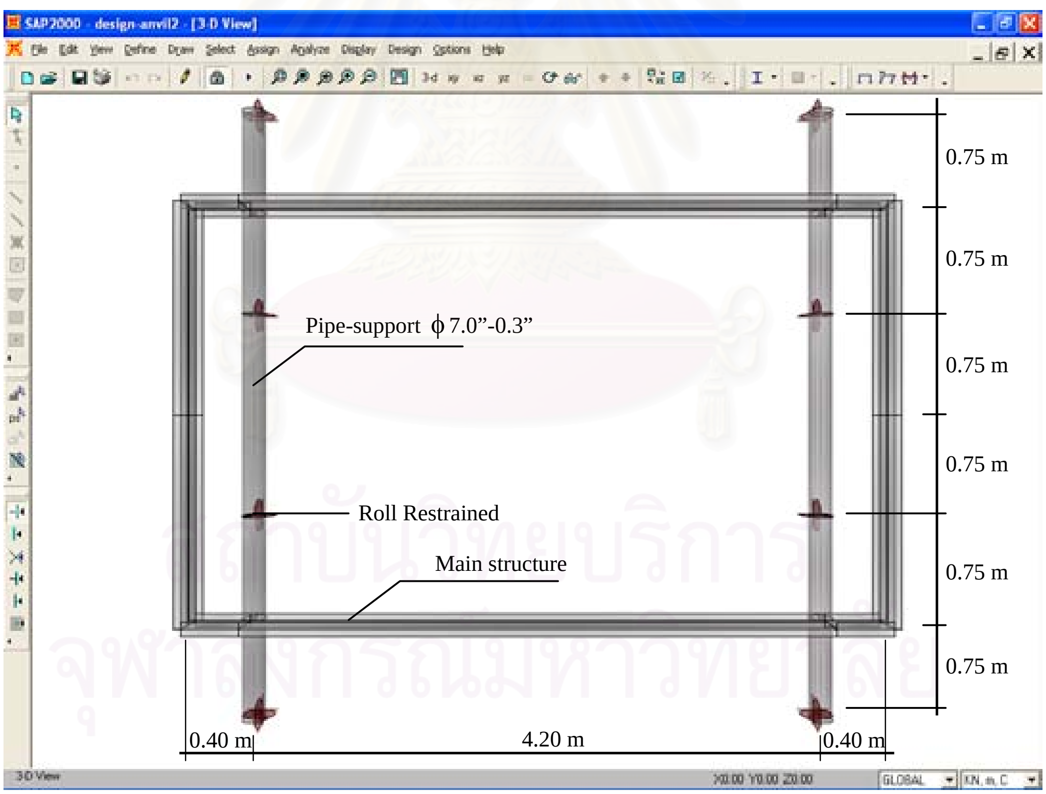


Figure 6.12 Layout of the structure model

Bottom structure is modeled as four I-steel profiles form rectangular-shape 3 meters times 5 meters. Under this structure, two steel pipes are laid. Two steel pipes are laid at the front and the back of the equipment in a row with the 3 meters sides. Detail dimension can be seen in figure 6.12.

Figure 6.13 shows loads of the model. According to the interview to piling engineers, the main structure of 5 tons Thai drop-hammers weights 6 tons while the machine weights 2 tons. Thus, the total equipment weight become

Total weight = weight of ram + weight of structure + weight of machine
= 5 tons + 6 tons + 2 tons
= 13 tons

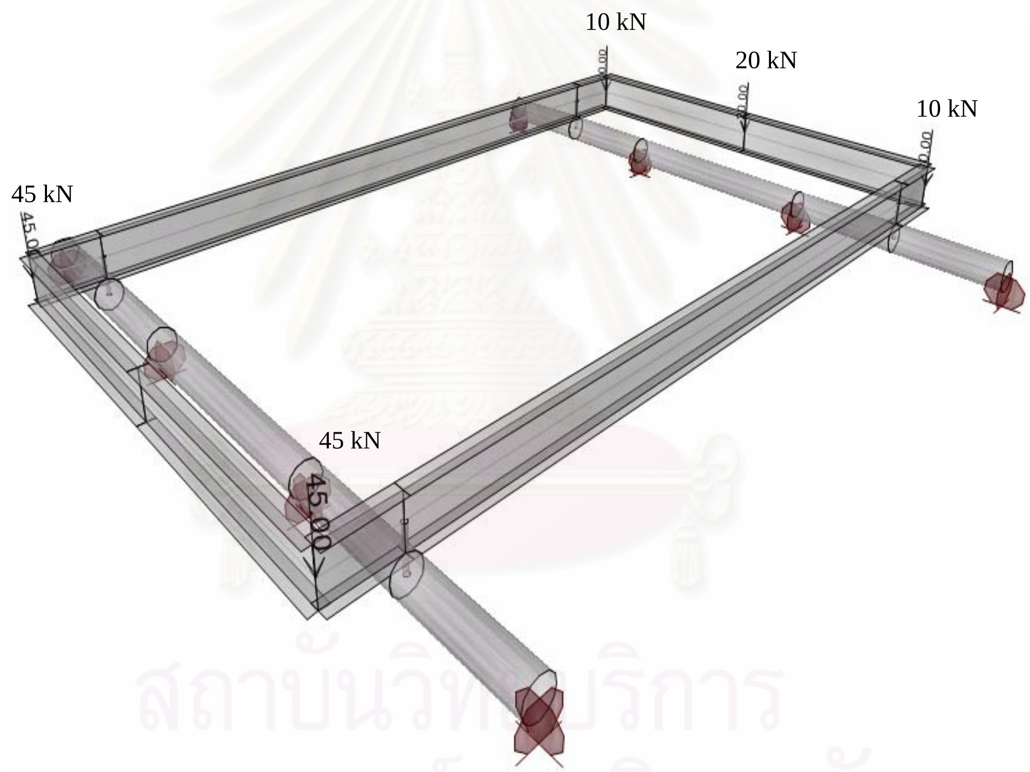


Figure 6.13 Input load in the model

As the main structures of drop-hammers in Thailand form pyramid space truss which upright at the front but oblique at the back side, the distribution load from the weight of the drop-hammer main structure is assumed not equal at the four corners of the bottom structure. Two parts are distributed to two corners at the front (2 tons or 20 kN each) and one part is distributed to two other corners at the back (1 ton or 10 kN each). With same load analysis, ram weight is distributed equally at two corners at the front of the main structure, 2.5 tons or 25 kN each, while machine weight is located on the mid of the back side of the main structure. The analysis of the total load distributions is as follow:

At each of the front corners	= 1/3 of structure weight + ½ of ram
	= 2.0 tons + 2.5 tons
	= 4.5 tons = 45 kN
At each of the back corners	= 1/6 of structure weight
	= 1 ton = 10 kN
At the middle of the back side	= machine weight
	= 2 tons = 20 kN

The detail of the load distribution in the model is shown in Figure 6.13.

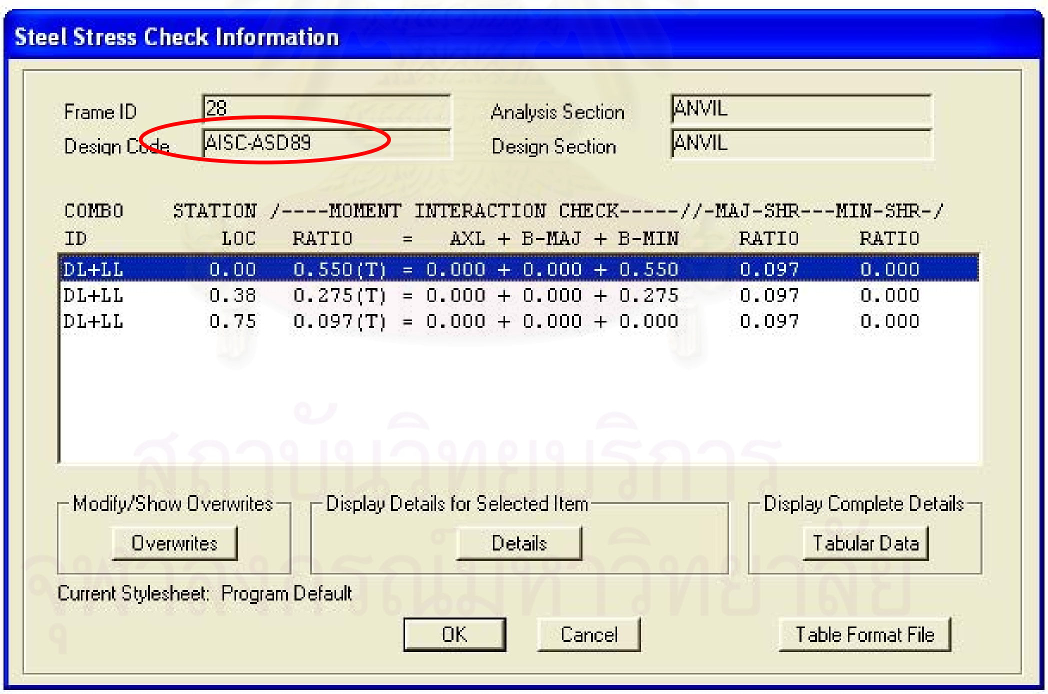


Figure 6.14 The analysis result of the proposed support

Design of the support in this model is calculated based on code of AISC-ASD89, see design code at the top left corner of SAP2000 user interface, Figure 6.14.

The design result shows that steel pipe with diameter and thickness of 7 inches and 0.3 inch, respectively, is strong enough to resist the dead-load and live-load from the equipment with the maximum stress of 0.55 % of the maximum allowable stress. This occur at frame number 28.

In terms of deflection, Figure 6.15 shows the deflection which may occur when ϕ7.0”-0.3” steel pipe is assigned to be the support of 5 tons Thai drop-hammers. The maximum deflection is 0.00131 meter or 1.3 millimeters at joint 21.

According to this analysis model, it can be said that ϕ7”-0.3” steel pipe is string enough to be supports of 5 tons Thai drop-hammers.

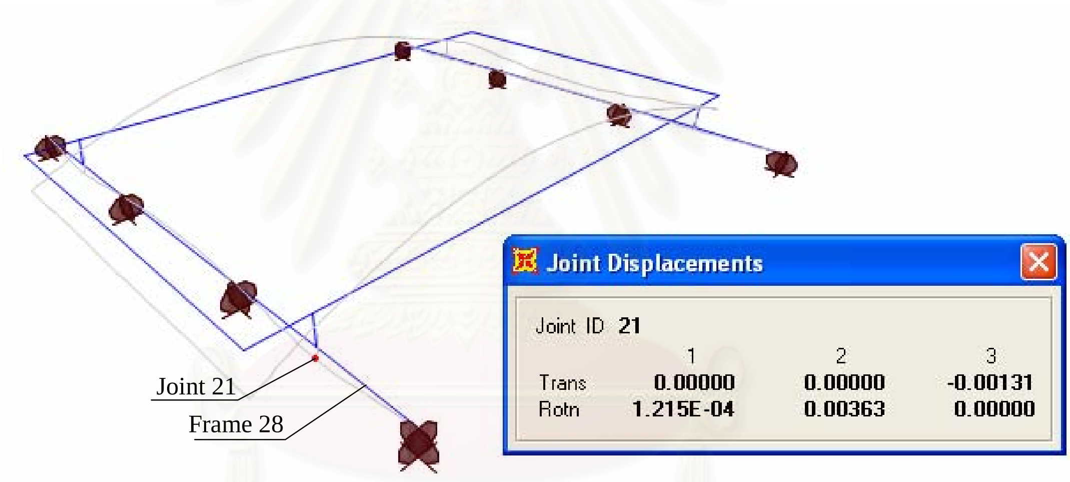


Figure 6.15 Deflection of the proposed support

6.4. Hammer Weight

As the hammer is one of the main tools in pile-driving equipment, it has a required weight ratio toward the pile weight (Bowls, 1997). A hammer that is too light will not be able to drive a big pile. Despite the increase in driving energy, as the height of the stroke can be made higher, the impact energy may still not penetrate the pile, and may even damage the pile cap (Thomlinson, 1967).

One of the wise ways to improve driving energy is by providing the appropriate hammer weight with the allowable height stroke. However, when the weight of the ram is changed to be heavier, other problems may araise. The heavier ram may need more energy to lift it. In addition, a heavier ram may make a structure unsuitable as the heavier load must be supported or the machine could collapse.

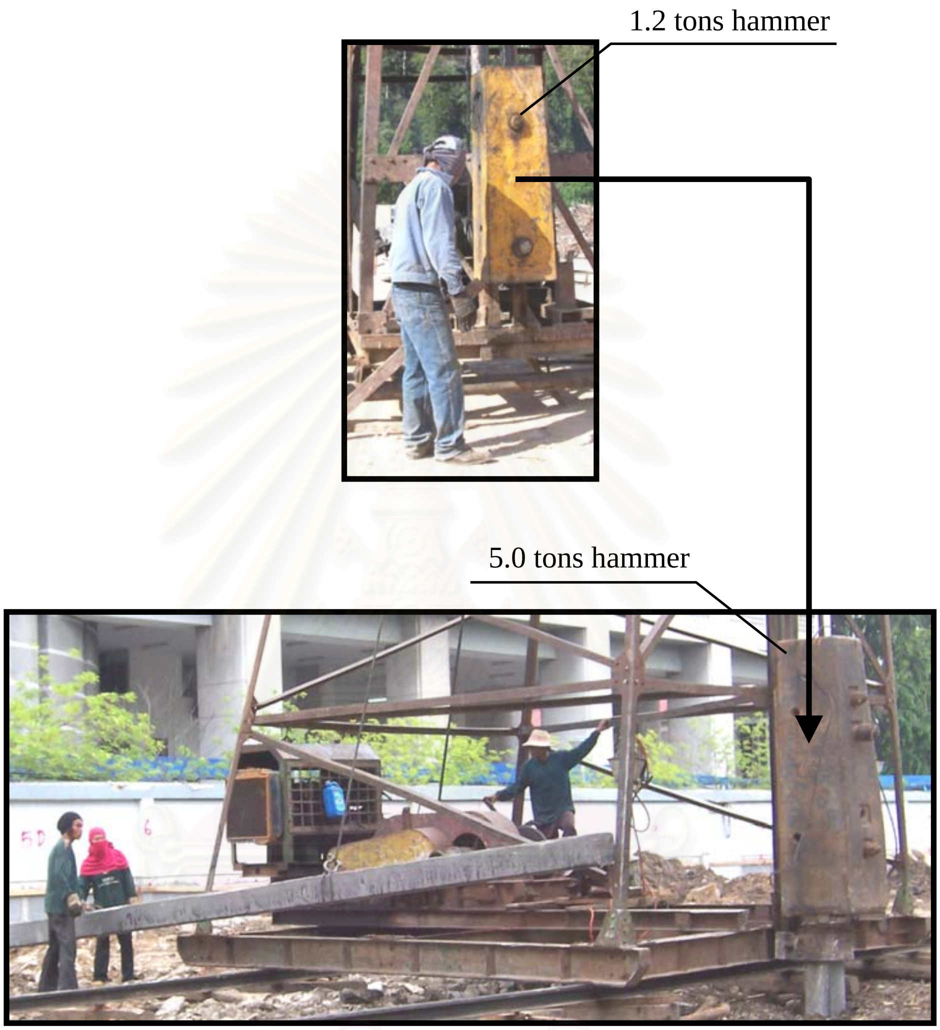


Figure 6.16 Possibility of changing the light ram with the heavier one

As presented in the analysis in Section 3.4 and 3.4.4, driving energy will affect driving duration, and according to the simulation discussed in Section 6.2.2.1, driving time can reach approximately 50% of the total duration of the work performance when the equipment uses a light hammer. Thus, changing the light ram to a heavier one needs to be considered. Still, this can be tried to improve the performance of Indonesian and Malaysian drop-hammers.

6.5. Conclusion

This chapter provides the comparison of drop-hammer equipment used in Thailand, Indonesia and Malaysia. As each drop-hammer has its superiorities and drawbacks, the comparison focused on discovering the appropriate utilization of drop-hammers. Analyses are done through deterministic and stochastic simulation. In the first analysis, the effect of different work conditions toward different performance of each drop-hammer is provided.

In the second part, a simulation model is provided to determine the general performance of machines when they are used to perform pile-driving work in determined (same) conditions.

Finally, proposed improvements are presented. As the main influencing factors of equipment performance are on the ability to produce driving energy and movement speed, equipment improvement is proposed for driving and moving tools. The Thai drop-hammer should be improved in movement while Indonesian and Malaysian drop-hammers must be improved in driving energy. These may be done by using steel pipe as the support to improve movement speed while driving energy may be increased with a heavier ram. According to the proposed design, 5 tons drop-hammers in Thailand may be supported by steel pipe support with diameter and thickness of 7” and 0.3”, respectively.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

The use of drop-hammers as pile-driving equipment has been known for a long time. As the load of high-rise buildings continues into the ground, in some areas with low ground support capacity, driven piles is very popular. Along with the need of high-rise-buildings as a solution of high land prices, pile-driving with drop-hammers has become an alternative among several systems. Even, in small construction projects, drop-hammers are still more popular than modern pile-driving machines.

However, in terms of speed and performance, drop-hammers are relatively low. With the ability to produce energy less than 30 blows per minute and with slow movement, drop-hammers produce very low productivity.

Since the productivity of a pile-driving machine is not influenced only by energy productivity, but are also affected by other aspects, such as soil conditions of the construction site, foundation layout, numbers of workers, and size and shape of pile, improving pile-driving productivity must be concerned with these factors as well.

This research has looked at pile-driving machines in three South-east Asian countries; Thailand, Indonesia, and Malaysia. The different performance of each observed pile-driving machine has also been discussed previously.

This chapter concludes the overall discussion which has been comprehensively presented in previous chapters and ends by providing some constructive recommendations.

7.1. Performances of Observed Drop-hammers

Understanding the strength and weakness of pile-driving systems is necessary to find a better operation. Some analysis that compares performance of each observed drop-hammer has been presented in Chapter 4, 5 and 6, previously. Based on this analysis, the overall performance of the drop-hammers in three observed countries can be determined and concluded.

Table 7.1 shows the machines conclusion. It is presented that the observed drop-hammers in Indonesia and Malaysia, small pile-driving machines with 10-m height and 5-ton ram, are superior in terms of movement but inferior in producing driving energy. These machines are recommended to use a heavier ram to improve their performance. On the other hand, the observed drop-hammer in Thailand, a large machine with 18-m height and 5-ton ram, is strength in producing energy but weak in moving. To solve its movement problem and improve its performance, utilizing steel pipes as the support and movement tools of this equipment are recommended.

Table 7.1 Conclusions of the observed machines in this research

Specification/Performance	**Indonesia**	**Malaysia**	**Thailand**
Machine	Small drop-hammer	Small drop-hammer	Large drop-hammer
Discovery location	Yogyakarta	Langkawi	Bangkok
Main structure	Simple space frame	Small space truss	Large space truss
Width	2 m	3 m	2 m
Length	4 m	5 m	2 m
Height	10 m	10 m	18 m
Assembling time	1 day	Not necessary	3 days
Dismantling time	4 hours	Not necessary	1 days
Ram weight	1.7 Tons	1.5 Tons	5 Tons
Estimated equipment weight	3.3 Tons	2.5 Tons	13 Tons
Number of labor	1 operator, 1 welder, 1 helper	1 operator, 1 welder	1 operator, 1 welder, 2 helpers
Machine support	Steel pipe	Steel pipe	Steel rail
Wheel	Not necessary	Steel wheel	Not necessary
Supporting tools	Screw system jack	Manual jack, anchor steel bar, wood movement lock	Mechanic jack
Sideward movement mechanism	Shifting the equipment on its support	Rolling the wheels on the equipment support	Shifting the equipment on its support
Backward movement mechanism	Rolling the supports (steel pipes) on their bases	Rolling the supports (steel pipes) on their bases	Moving the equipment on its support gradually
Feature	Relatively fast in movement	Relatively fast in movement	Large in producing driving energy
Problems	Low in producing driving energy	Low in producing driving energy	Slow in movement, long dismantling and assembling time
Recommended improvement	***Utilizing heavier ram***	***Utilizing heavier ram***	***Utilizing steel pipes as machine's supports***

7.1.1. *Advantages and drawbacks*

From the two drop-hammer machines and one pile-pushing machine have been observed, each machine has its own strengths and weaknesses. The overall advantages and disadvantages of each machine can be listed as follows:

Thai drop-hammer

Advantage : large to produce driving energy which can also be used to perform hard driving.

Drawback : slow in movement stage which is not appropriate for performing pile-driving work with long movement but easy driving.

Indonesian and Malaysian drop-hammer

Advantage : fast in sideward and forward/backward movement which is very good to perform pile-driving work with long distance of movement.

Drawback : small in producing driving energy which limits the utilization of these drop-hammers to small piles only.

Pile-pushing machine

Advantage : low vibration and noise which is very good for performing pile-driving work in urban or residential areas.

Drawback : relatively lower productivity but higher operation cost as it has slow movement and penetration speed and also needs other supporting equipment, a crane.

7.1.2. Considerations in selecting equipment

Some considerations which need to be followed when the appropriate productivity is expected to be achieved are:

1. Selection of the proper equipment. Utilizing large drop-hammers with heavy ram when the pile-driving work must handle large piles and or require hard driving. Oppositely, for some soil properties where good soil stratum is in shallow depth

and small piles can be alternatively used, utilization of light machines that may provide faster movement should be considered.

2. Minimization of backward movement. Efforts to minimize backward movement need to be done to maximize productive time, for example time for installing a pile.
3. Appropriate moving route. Installation of pile groups must be analyzed first to determine the best moving route for the equipment.
4. Utilization of pile-pushing machine for special sites. Utilizing pile-pushing machines must be considered when there is possibility of damaging surrounding buildings and disturbing the nearby environment.

7.2. Improvement of Operation

7.2.1. Pile-driving equipment

As the drawbacks of most drop-hammers are movement and energy production, the possibility of combining a drop-hammer's strengths seems to be a promising improvement. Creating new drop-hammers which equipped with heavy ram as used by drop-hammers in Thailand, and with steel pipe support as used by drop-hammers in Indonesian or Malaysian, may provide a better result.

Furthermore, designing the main structure of the equipment must be considered as well. A new drop-hammer structure can also influence the effectiveness of assembling and dismantling. At present, small space truss used by Malaysian drop-hammers provides the best solution. However, since the Malaysian drop-hammers are small and not so heavy, they offer the possibility of transporting the machine without passing the assembling and dismantling processes. This structure type might not be able to support heavy ram. As a second choice, the Indonesian drop-hammer may be an alternative.

When a new imagined drop-hammer can be realized, It will provide large energy with very fast movement not only in a sideward direction but also backward or forward. This hopefully may become a useful innovation to solve low productivity of pile-driving work, especially the small pile-driving work. However the actual development and testing are required to experiment.

7.2.2. Pile shape

Since the support capacity of a piling system depends on the end-bearing and friction resistance, selecting the type and shape of a pile to achieve optimum soil resistance becomes very important. Among available pile shapes in the three observed countries, Thailand, Indonesia and Malaysia, the pile shapes are not the same. However, the I-shape which is popular in Thailand, promises the largest soil resistance capacity, as at the same section area, the I-shape provides a larger perimeter. Hence, I-shape piles are good in cohesive soil. However, in cohesiveless soil, utilizing I-shape pile is not wrong. As the friction resistance does not work during driving (Bowls, 1997), having large friction area will not slow down the speed of penetration. Oppositely, an additional friction area will provide extra support capacity for the pile which will further enhance the safety factor of the foundation.

7.3. Future Research and Recommendation

The major limitations in this research are that (a) there are few numbers of data in some processes and, (b) the machines used to compare the performance are selected and their characteristics are not exactly the same. For example, the machines in Thailand are larger than the others. As few data are available in this research because of the period of data collection and other difficulties, the analysis may provide the overview of machine and practices. Advance research is recommended to perform the analysis based on more numbers of data in each process. The research should focuses on developing a prototype of the proposed equipment.

The main goal is to provide a machine which is beneficial for pile-driving work construction.

Finally, a pile-driving-productivity in this research does not cover cost, such as fabrication and pile production cost, operation and maintenance cost of the equipment as well as machine and pile transportation cost, the productive result recommended by this research may not yield the economic cost. Considering cost variables may be another interesting research.

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APPENDICES

RECORDS OF DATA

Location : Yogyakarta INDONESIA
Machine : Drop Hammer 1.7 ton
Falling height : 1 m
Anvil : Steel Pipe
Pile : 2-5 pieces of 6m or 3m long of triangle pile (280x280)
Man Power : 1 Operator, 2 Helper

Time	Duration	Activity	Distance (m)	Blow frequency (10x / s)
The First DAY				
10:31:08	0:15:06	driving 2		17.773
10:46:14	0:01:54	setting 3		19.869
10:48:08	0:05:04	welding		20.667
10:53:12	0:10:00	driving 3		17.833
11:03:12	0:02:22	setting 4		21.373
11:05:34	0:04:34	welding		21.101
11:10:08	0:15:06	driving 4		19.195
11:25:14	0:01:22	side movement	0.8	21.050
11:26:36	0:03:46	setting 1		21.835
11:30:22	0:06:11	driving 1		14.169
11:36:33	0:04:25	taking pile		18.950
11:40:58	0:02:10	setting 2		17.133
11:43:08	0:04:57	welding		20.095
11:48:05	-	brake/nothing		19.975
TAKE A BREAK				
13:03:10	0:17:30	driving 2		18.009
13:20:40	0:02:16	setting 3		18.646
13:22:56	0:04:14	welding		21.673
13:27:10	0:06:54	driving 3		19.435
13:34:04	0:02:06	setting 4		20.016
13:36:10	0:04:26	welding		20.953
13:40:36	0:10:56	driving 4		13.573
13:51:32	0:18:42	side movement	7.2	14.095
14:10:14	0:01:00	nothing		17.856
14:11:14	0:03:32	taking pile		22.209
14:14:46	0:03:54	setting 1		18.696
14:18:40	0:01:34	driving 1		22.273
14:20:14	0:07:56	setting perpendicular machine		18.633
14:28:10	0:03:21	setting 2		20.418
14:31:31	0:06:54	welding		21.692
14:38:25	0:25:07	driving 2		20.723
15:03:32	0:03:30	setting 3		20.280
15:07:02	0:06:53	welding		21.092
15:13:55	0:07:26	driving 3		15.216
15:21:21	0:02:15	setting 4		16.523
15:23:36	0:07:22	welding		18.973
15:30:58	0:11:30	driving 4		17.210
15:42:28	0:02:20	side movement	0.8	17.238
15:44:48	0:01:09	nothing		20.238
15:45:57	0:06:38	setting 1		17.243
15:52:35	0:04:16	nothing		19.546
15:56:51	0:05:50	driving 1		21.544
16:02:41	0:04:43	setting 2		17.866
16:07:24	0:06:09	welding		19.084
16:13:33	0:11:57	driving 2		20.252
16:25:30	0:02:36	setting 3		18.507

Location : Yogyakarta INDONESIA
Machine : Drop Hammer 1.7 ton
Falling height : 1 m
Anvil : Steel Pipe
Pile : 2-5 pieces of 6m or 3m long of triangle pile (280x280)
Man Power : 1 Operator, 2 Helper

Time	Duration	Activity	Distance (m)	Blow frequency (10x / s)
16:28:06	0:04:36	welding		15.387
16:32:42	0:06:01	driving 3		18.267
16:38:43	0:02:02	setting 4		18.858
16:40:45	0:05:35	welding		16.818
16:46:20	0:10:02	driving 4		17.801
16:56:22	-	finish		19.929
The second DAY				
13:07:33	0:03:11	backward movement	0.8	18.826
13:10:44	0:01:04	nothing/stop movement		19.200
13:11:48	0:02:12	taking pile		20.529
13:14:00	0:01:13	setting 1		16.126
13:15:13	0:05:11	driving 1		17.164
13:20:24	0:01:19	taking pile		20.432
13:21:43	0:03:15	setting 2		18.013
13:24:58	0:09:41	welding		18.392
13:34:39	0:10:31	driving 2		20.266
13:45:10	0:01:23	setting 3		17.935
13:46:33	0:04:50	welding		19.518
13:51:23	0:05:19	driving 3		21.327
13:56:42	0:02:06	setting 4		15.156
13:58:48	0:04:22	welding		19.098
14:03:10	0:09:16	driving 4		18.895
14:12:26	0:01:54	side movement	0.8	21.706
14:14:20	0:00:47	taking pile		18.660
14:15:07	0:02:39	setting 1		20.778
14:17:46	0:02:09	setting perpendicular machine		17.727
14:19:55	0:05:15	driving 1		19.453
14:25:10	0:03:25	setting 2		14.741
14:28:35	0:04:59	welding		14.963
14:33:34	0:10:50	driving 2		17.238
14:44:24	0:02:24	setting 3		16.200
14:46:48	0:06:20	welding		17.390
14:53:08	0:06:00	driving 3		19.758
14:59:08	0:01:48	setting 4		16.836
15:00:56	0:04:46	welding		18.480
15:05:42	0:10:20	driving 4		16.956
15:16:02	0:13:31	backward movement	3.6	19.006
15:29:33	0:02:25	taking pile		20.460
15:31:58	0:01:10	setting perpendicular machine		14.644
15:33:08	0:01:55	setting 1		17.053
15:35:03	0:10:15	driving 1		15.120
15:45:18	0:01:36	taking pile		17.118
15:46:54	0:04:44	setting 2		19.310
15:51:38	0:07:00	welding		15.147
15:58:38	0:23:11	driving 2		16.126
16:21:49	0:02:14	setting 3		16.786
16:24:03	0:08:42	welding		19.707
16:32:45	0:06:54	driving 3		15.563
16:39:39	0:03:25	setting 4		17.243

Location : Yogyakarta INDONESIA
Machine : Drop Hammer 1.7 ton
Falling height : 1 m
Anvil : Steel Pipe
Pile : 2-5 pieces of 6m or 3m long of triangle pile (280x280)
Man Power : 1 Operator, 2 Helper

Time	Duration	Activity	Distance (m)	Blow frequency (10x / s)
16:43:04	0:04:46	welding		17.792
16:47:50	0:12:50	driving 4		14.972
17:00:40	0:01:18	side movement	0.8	18.360
17:01:58	0:00:51	taking pile		20.063
17:02:49	0:02:55	setting 1		17.976
17:05:44	-	driving 1		19.103
The third DAY				
8:16:18	0:02:15	setting 4		19.052
8:18:33	0:06:35	welding		18.955
8:25:08	0:29:02	driving 4		18.955
		side movement		16.712
8:54:10	0:01:59	taking pile		16.661
8:56:09	0:03:11	setting 1		20.580
8:59:20	0:05:59	driving 1		19.975
9:05:19	0:02:29	taking pile		17.441
9:07:48	0:02:27	nothing		19.190
9:10:15	0:04:39	setting 2		18.950
9:14:54	0:05:18	welding		17.736
9:20:12	0:11:59	driving 2		17.372
9:32:11	0:02:17	setting 3		20.432
9:34:28	0:07:32	welding		14.880
9:42:00	0:06:31	driving 3		18.203
9:48:31	0:02:22	setting 4		18.738
9:50:53	0:08:27	welding		20.450
9:59:20	0:10:51	driving 4		20.353
10:10:11	0:00:58	side movement	0.8	
10:11:09	0:01:13	taking pile		
10:12:22	0:02:31	setting 1		
10:14:53	0:05:44	driving 1		
10:20:37	0:01:33	taking pile		
10:22:10	0:03:02	setting 2		
10:25:12	0:07:13	welding		
10:32:25	0:09:22	driving 2		
10:41:47	0:02:29	setting 3		
10:44:16	0:05:02	welding		
10:49:18	0:06:19	driving 3		
10:55:37	0:02:28	setting 4		
10:58:05	0:08:56	welding		
11:07:01	0:10:57	driving 4		
11:17:58	0:26:16	side 3m & forward/rotation 3m	90	
11:44:14	0:02:45	taking pile		
11:46:59	-	break		
TAKE A BREAK				
13:03:17	0:01:20	turn on machine		
13:04:37	0:01:49	setting 1		
13:06:26	0:08:38	driving 1		
13:15:04	0:02:26	setting 2		
13:17:30	0:11:05	welding		
13:28:35	0:19:40	driving 2		
13:48:15	0:02:44	machine brake down		

Location : Yogyakarta INDONESIA
Machine : Drop Hammer 1.7 ton
Falling height : 1 m
Anvil : Steel Pipe
Pile : 2-5 pieces of 6m or 3m long of triangle pile (280x280)
Man Power : 1 Operator, 2 Helper

Time	Duration	Activity	Distance (m)	Blow frequency (10x / s)
13:50:59	0:03:46	setting 3		
13:54:45	0:05:30	welding		
14:00:15	0:09:25	driving 3		
14:09:40	0:01:36	taking pile		
14:11:16	0:02:12	setting 4		
14:13:28	0:06:33	welding		
14:20:01	0:17:24	driving 4		
14:37:25	0:02:39	backward 0.6m & sideward 1.2m		
14:40:04	0:01:43	taking pile		
14:41:47	0:03:27	setting 1		
14:45:14	0:09:23	driving 1		
14:54:37	0:02:52	setting 2		
14:57:29	0:09:38	welding		
15:07:07	0:11:38	driving 2		
15:18:45	0:03:49	machine brake down		
15:22:34	0:07:47	driving 2		
15:30:21	0:01:24	taking pile		
15:31:45	0:03:40	setting 3		
15:35:25	0:05:30	welding		
15:40:55	0:07:55	driving 3		
15:48:50	0:02:10	setting 4		
15:51:00	0:05:18	welding		
15:56:18	0:09:04	driving 4		
16:05:22	0:02:43	side movement	1.2	
16:08:05	0:02:49	taking pile		
16:10:54	0:04:19	setting 1		
16:15:13	0:06:11	driving 1		
16:21:24	0:02:55	setting 2		
16:24:19	0:09:52	welding		
16:34:11	0:16:09	driving 2		
16:50:20	0:01:46	taking pile		
16:52:06	0:02:23	setting 3		
16:54:29	0:05:00	welding		
16:59:29	-	stop working		

GROUPING AND STATISTICAL ANALYSIS

Location : Yogyakarta INDONESIA
Machine : Drop Hammer 1.7 ton
Falling height : 1 m
Anvil : Steel Pipe
Pile : 2-5 pieces of 6m or 3m long of triangle pile (280x280)
Man Power : 1 Operator, 2 Helper

time	duration	activity	distance (m)	movement speed (time/m)
11:25:14	0:01:22	side movement	0.8	0:01:43
13:51:32	0:18:42	side movement	7.2	0:02:36
15:42:28	0:02:20	side movement	0.8	0:02:55
14:12:26	0:01:54	side movement	0.8	0:02:22
17:00:40	0:01:18	side movement	0.8	0:01:37
10:10:11	0:00:58	side movement	0.8	0:01:12
16:05:22	0:02:43	side movement	1.2	0:02:16
			average	**0:02:06**
			Standard deviation	**0:00:36**
			minimum	**0:01:12**
13:07:33	0:03:11	backward movement	0.8	0:03:59
15:16:02	0:13:31	backward movement	3.6	0:03:45
			average	**0:03:52**
			Standard deviation	**0:00:10**
			minimum	**0:03:45**

time	duration	activity	pile's length (m)
11:26:36	0:03:46	setting 1	6
14:14:46	0:03:54	setting 1	6
15:45:57	0:06:38	setting 1	6
13:14:00	0:01:13	setting 1	6
14:15:07	0:02:39	setting 1	6
15:33:08	0:01:55	setting 1	6
17:02:49	0:02:55	setting 1	6
8:56:09	0:03:11	setting 1	6
10:12:22	0:02:31	setting 1	6
13:04:37	0:01:49	setting 1	6
14:41:47	0:03:27	setting 1	6
16:10:54	0:04:19	setting 1	6
11:40:58	0:02:10	setting 2	6
14:28:10	0:03:21	setting 2	6
16:02:41	0:04:43	setting 2	6
13:21:43	0:03:15	setting 2	6
14:25:10	0:03:25	setting 2	6
15:46:54	0:04:44	setting 2	6
9:10:15	0:04:39	setting 2	6
10:22:10	0:03:02	setting 2	6
13:15:04	0:02:26	setting 2	6
14:54:37	0:02:52	setting 2	6
16:21:24	0:02:55	setting 2	6
	0:03:18	**average**	
	0:01:11	**Standard deviation**	
	0:01:13	**minimum**	

Location : Yogyakarta INDONESIA
Machine : Drop Hammer 1.7 ton
Falling height : 1 m
Anvil : Steel Pipe
Pile : 2-5 pieces of 6m or 3m long of triangle pile (280x280)
Man Power : 1 Operator, 2 Helper

time	duration	activity	pile's length (m)
10:46:14	0:01:54	setting 3	3
13:20:40	0:02:16	setting 3	3
15:03:32	0:03:30	setting 3	3
16:25:30	0:02:36	setting 3	3
13:45:10	0:01:23	setting 3	3
14:44:24	0:02:24	setting 3	3
16:21:49	0:02:14	setting 3	3
9:32:11	0:02:17	setting 3	3
10:41:47	0:02:29	setting 3	3
13:50:59	0:03:46	setting 3	3
15:31:45	0:03:40	setting 3	3
16:52:06	0:02:23	setting 3	3
11:03:12	0:02:22	setting 4	3
13:34:04	0:02:06	setting 4	3
15:21:21	0:02:15	setting 4	3
16:38:43	0:02:02	setting 4	3
13:56:42	0:02:06	setting 4	3
14:59:08	0:01:48	setting 4	3
16:39:39	0:03:25	setting 4	3
8:16:18	0:02:15	setting 4	3
9:48:31	0:02:22	setting 4	3
10:55:37	0:02:28	setting 4	3
14:11:16	0:02:12	setting 4	3
15:48:50	0:02:10	setting 4	3
	0:02:26	**average**	
	0:00:35	**Standard deviation**	
	0:01:23	**minimum**	

time	duration	activity	Welding	
			Length (m)	Speed (time/m)
10:48:08	0:05:04	welding	0.84	0:06:02
11:05:34	0:04:34	welding	0.84	0:05:26
11:43:08	0:04:57	welding	0.84	0:05:54
13:22:56	0:04:14	welding	0.84	0:05:02
13:36:10	0:04:26	welding	0.84	0:05:17
14:31:31	0:06:54	welding	0.84	0:08:13
15:07:02	0:06:53	welding	0.84	0:08:12
15:23:36	0:07:22	welding	0.84	0:08:46
16:07:24	0:06:09	welding	0.84	0:07:19
16:28:06	0:04:36	welding	0.84	0:05:29
16:40:45	0:05:35	welding	0.84	0:06:39
13:24:58	0:09:41	welding	0.84	0:11:32
13:46:33	0:04:50	welding	0.84	0:05:45
13:58:48	0:04:22	welding	0.84	0:05:12
14:28:35	0:04:59	welding	0.84	0:05:56
14:46:48	0:06:20	welding	0.84	0:07:32
15:00:56	0:04:46	welding	0.84	0:05:40
15:51:38	0:07:00	welding	0.84	0:08:20
16:24:03	0:08:42	welding	0.84	0:10:21
16:43:04	0:04:46	welding	0.84	0:05:40
8:18:33	0:06:35	welding	0.84	0:07:50
9:14:54	0:05:18	welding	0.84	0:06:19

Location : Yogyakarta INDONESIA
Machine : Drop Hammer 1.7 ton
Falling height : 1 m
Anvil : Steel Pipe
Pile : 2-5 pieces of 6m or 3m long of triangle pile (280x280)
Man Power : 1 Operator, 2 Helper

time	duration	activity	Welding	
			Length (m)	Speed (time/m)
9:34:28	0:07:32	welding	0.84	0:08:58
9:50:53	0:08:27	welding	0.84	0:10:04
10:25:12	0:07:13	welding	0.84	0:08:35
10:44:16	0:05:02	welding	0.84	0:06:00
10:58:05	0:08:56	welding	0.84	0:10:38
13:17:30	0:11:05	welding	0.84	0:13:12
13:54:45	0:05:30	welding	0.84	0:06:33
14:13:28	0:06:33	welding	0.84	0:07:48
14:57:29	0:09:38	welding	0.84	0:11:28
15:35:25	0:05:30	welding	0.84	0:06:33
15:51:00	0:05:18	welding	0.84	0:06:19
16:24:19	0:09:52	welding	0.84	0:11:45
16:54:29	0:05:00	welding	0.84	0:05:57
	0:06:23		**average**	**0:07:36**
	0:01:51		**Standard deviation**	**0:02:12**
	0:04:14		**minimum**	**0:05:02**

Location : Yogyakarta INDONESIA
Machine : Drop Hammer 1.7 ton
Falling height : 1 m
Anvil : Steel Pipe
Pile : 2-5 pieces of 6m or 3m long of triangle pile (280x280)
Man Power : 1 Operator, 2 Helper

Time	Duration	Activity
11:30:22	0:06:11	driving 1
14:18:40	0:01:34	driving 1
15:56:51	0:05:50	driving 1
13:15:13	0:05:11	driving 1
14:19:55	0:05:15	driving 1
15:35:03	0:10:15	driving 1
8:59:20	0:05:59	driving 1
10:14:53	0:05:44	driving 1
13:06:26	0:08:38	driving 1
14:45:14	0:09:23	driving 1
16:15:13	0:06:11	driving 1
10:31:08	0:15:06	driving 2
13:03:10	0:17:30	driving 2
14:38:25	0:25:07	driving 2
16:13:33	0:11:57	driving 2
13:34:39	0:10:31	driving 2
14:33:34	0:10:50	driving 2
15:58:38	0:23:11	driving 2
9:20:12	0:11:59	driving 2
10:32:25	0:09:22	driving 2
13:28:35	0:19:40	driving 2
15:07:07	0:11:38	driving 2
15:22:34	0:07:47	driving 2
16:34:11	0:16:09	driving 2
10:53:12	0:10:00	driving 3
13:27:10	0:06:54	driving 3
15:13:55	0:07:26	driving 3
16:32:42	0:06:01	driving 3
13:51:23	0:05:19	driving 3
14:53:08	0:06:00	driving 3
16:32:45	0:06:54	driving 3
9:42:00	0:06:31	driving 3
10:49:18	0:06:19	driving 3
14:00:15	0:09:25	driving 3
15:40:55	0:07:55	driving 3
11:10:08	0:15:06	driving 4
13:40:36	0:10:56	driving 4
15:30:58	0:11:30	driving 4
16:46:20	0:10:02	driving 4
14:03:10	0:09:16	driving 4
15:05:42	0:10:20	driving 4
16:47:50	0:12:50	driving 4
9:59:20	0:10:51	driving 4
11:07:01	0:10:57	driving 4
14:20:01	0:17:24	driving 4
15:56:18	0:09:04	driving 4

Location : Yogyakarta INDONESIA
Machine : Drop Hammer 1.7 ton
Falling height : 1 m
Anvil : Steel Pipe
Pile : 2-5 pieces of 6m or 3m long of triangle pile (280x280)
Man Power : 1 Operator, 2 Helper

Non Productive Activity		
Time	**Duration**	**Activity**
14:37:25	0:02:39	backward 0.6m & sideward 1.2m
11:17:58	0:26:16	side 3m & forward/rotation 3m
13:48:15	0:02:44	machine brake down
15:18:45	0:03:49	machine brake down
14:10:14	0:01:00	nothing
15:44:48	0:01:09	nothing
15:52:35	0:04:16	nothing
9:07:48	0:02:27	nothing
13:10:44	0:01:04	nothing
14:20:14	0:07:56	setting perpendicular machine
14:17:46	0:02:09	setting perpendicular machine
15:31:58	0:01:10	setting perpendicular machine
13:03:17	0:01:20	turn on machine
11:36:33	0:04:25	taking pile
14:11:14	0:03:32	taking pile
13:11:48	0:02:12	taking pile
13:20:24	0:01:19	taking pile
14:14:20	0:00:47	taking pile
15:29:33	0:02:25	taking pile
15:45:18	0:01:36	taking pile
17:01:58	0:00:51	taking pile
8:54:10	0:01:59	taking pile
9:05:19	0:02:29	taking pile
10:11:09	0:01:13	taking pile
10:20:37	0:01:33	taking pile
11:44:14	0:02:45	taking pile
14:09:40	0:01:36	taking pile
14:40:04	0:01:43	taking pile
15:30:21	0:01:24	taking pile
16:08:05	0:02:49	taking pile
16:50:20	0:01:46	taking pile
	1:34:23	**Total**
	10.83%	**Percentage**

Location : Yogyakarta INDONESIA
Machine : Drop Hammer 1.7 ton
Falling height : 1 m
Anvil : Steel Pipe
Pile : 2-5 pieces of 6m or 3m long of triangle pile (280x280)
Man Power : 1 Operator, 2 Helper

Driving energy productivity					
bowl frequency 10x / scnd	**Driving energy (kg.m/s)**	**bowl frequency 10x / scnd**	**Driving energy (kg.m/s)**	**bowl frequency 10x / scnd**	**Driving energy (kg.m/s)**
14.17	2408.73	18.51	3146.19	20.67	3513.39
15.22	2586.72	18.90	3212.15	21.10	3587.17
16.13	2741.42	17.73	3013.59	21.84	3711.95
15.16	2576.52	19.87	3377.73	18.95	3221.50
14.74	2505.97	21.37	3633.41	19.98	3395.75
14.64	2489.48	21.05	3578.50	21.67	3684.41
15.56	2645.71	20.10	3416.15	20.95	3562.01
17.77	3021.41	18.65	3169.82	17.86	3035.52
17.13	2912.61	20.02	3402.72	22.27	3786.41
22.21	3775.53	14.10	2396.15	21.69	3687.64
17.21	2925.70	18.70	3178.32	21.09	3585.64
15.39	2615.79	20.42	3471.06	18.97	3225.41
17.16	2917.88	20.28	3447.60	20.24	3440.46
16.20	2754.00	16.52	2808.91	21.54	3662.48
15.12	2570.40	17.24	2930.46	20.25	3442.84
14.97	2545.24	19.55	3322.82	18.86	3205.86
17.83	3031.61	19.08	3244.28	19.93	3387.93
18.01	3061.53	18.27	3105.39	20.53	3489.93
18.63	3167.61	17.80	3026.17	18.01	3062.21
17.24	2931.31	19.20	3264.00	20.27	3445.22
16.82	2859.06	20.43	3473.44	21.33	3625.59
18.39	3126.64	19.52	3318.06	19.10	3246.66
18.66	3172.20	20.78	3532.26	21.71	3690.02
15.15	2574.99	14.96	2543.71	19.45	3307.01
19.20	3263.15	17.39	2956.30	17.24	2930.46
19.44	3303.95	19.01	3231.02	19.76	3358.86
20.72	3522.91	17.05	2899.01	20.46	3478.20
17.87	3037.22	17.12	2910.06	19.31	3282.70
18.83	3200.42	16.13	2741.42	17.79	3024.64
17.94	3048.95	19.71	3350.19	20.06	3410.71
16.96	2882.52	17.24	2931.31	18.96	3222.35
16.79	2853.62	18.36	3121.20		
19.10	3247.51	19.05	3238.84		
13.57	2307.41				
			average	**18.53**	**3149.89**
			Standard deviation	**2.07**	**352.68**
			minimum	**13.57**	**2307.41**

RECORDS OF DATA

Location : Langkawi MALAYSIA
Machine : Drop Hammer 1.2 ton
Falling height : 1 m
Anvil : Steel Pipe
Pile : 2 pieces of 6m long of square pile (150x150)
Man Power : 1 Operator, 1 Helper

Time	Duration	Activity	Distance (m)	Blow frequency (10x / s)
The First DAY				
9:10:30	0:02:00	setting1		21.844
9:12:30	0:01:25	driving1		21.512
9:13:55	0:01:32	setting2		20.796
9:15:27	0:02:03	ready welding		21.263
9:17:30	0:02:00	welding		21.927
9:19:30	0:07:00	driving2		22.776
9:26:30	0:02:05	moving side	1.5	22.740
9:28:35	0:01:35	setting1		23.220
9:30:10	0:01:55	driving1		23.132
9:32:05	0:01:25	moving anvil		23.326
9:33:30	0:00:20	driving1 continue		22.343
9:33:50	0:01:25	setting2		22.306
9:35:15	0:00:25	ready welding		21.216
9:35:40	0:01:20	welding		21.881
9:37:00	0:01:40	no activity		22.107
9:38:40	0:07:05	driving2		20.553
9:45:45	0:05:59	moving side	1.5	21.180
9:51:44	0:03:46	taking		19.061
9:55:30	0:00:40	setting1		19.541
9:56:10	0:02:30	driving1		20.598
9:58:40	0:01:07	setting2		19.892
9:59:47	0:00:53	ready welding		21.336
10:00:40	0:01:11	welding		19.500
10:01:51	0:08:29	driving2		19.606
10:10:20	0:02:40	moving side	1.5	19.056
10:13:00	0:01:55	setting1		18.507
10:14:55	0:06:55	driving1		18.664
10:21:50	0:02:00	setting2		18.720
10:23:50	0:00:25	ready welding		19.172
10:24:15	0:01:33	welding		18.830
10:25:48	0:14:24	driving2		19.135
10:40:12	0:02:03	moving anvil		18.572
10:42:15	0:01:25	driving2 continue		19.232
10:43:40	0:03:10	moving side	1.5	18.816
10:46:50	-	brake		18.992
BREAK				
14:47:00	0:05:10	moving backward (adjust anvil)		18.886
14:52:10	0:01:40	setting1		18.203
14:53:50	0:04:15	driving1		18.023
14:58:05	0:00:36	setting2		18.170
14:58:41	0:01:14	ready welding		17.963
14:59:55	0:01:25	welding		18.401
15:01:20	0:12:25	driving2		18.909
15:13:45	0:14:00	moving backward	3	19.075
15:27:45	-	break		19.167
BREAK				

Location : Langkawi MALAYSIA
Machine : Drop Hammer 1.2 ton
Falling height : 1 m
Anvil : Steel Pipe
Pile : 2 pieces of 6m long of square pile (150x150)
Man Power : 1 Operator, 1 Helper

Time	Duration	Activity	Distance (m)	Blow frequency (10x / s)
16:39:35	0:01:05	setting1		20.040
16:40:40	0:04:20	driving1		19.726
16:45:00	0:01:10	setting2		19.666
16:46:10	0:00:40	ready welding		18.627
16:46:50	0:01:30	welding		18.936
16:48:20	0:09:20	driving2		19.896
16:57:40	0:01:15	moving side	1.5	19.620
16:58:55	0:01:30	taking		19.735
17:00:25	0:01:25	setting1		19.343
17:01:50	0:04:00	driving1		19.827
17:05:50	0:00:43	setting2		20.132
17:06:33	0:00:27	ready welding		20.630
17:07:00	0:01:40	welding		19.564
17:08:40	0:09:30	driving2		19.716
17:18:10	0:03:00	moving side	1.5	19.813
17:21:10	0:01:57	setting1		19.993
17:23:07	0:02:28	driving1		20.796
17:25:35	0:01:08	setting2		20.935
17:26:43	0:00:37	ready welding		21.558
17:27:20	0:01:40	welding		21.743
17:29:00	0:07:33	driving2		19.518
17:36:33	0:01:11	moving side (adjust anvil)	1.5	19.361
17:37:44	0:01:02	driving2 (continued)		18.269
17:38:46	0:06:34	moving side	1.5	19.587
17:45:20	0:01:18	setting1		19.744
17:46:38	0:03:27	driving1		19.721
17:50:05	0:00:56	setting2		19.610
17:51:01	0:00:39	ready welding		19.430
17:51:40	0:02:10	welding		20.446
17:53:50	0:07:15	driving2		20.589
18:01:05	0:00:45	nothing		21.396
18:01:50	0:01:03	driving2 continue		20.538
18:02:53	0:04:57	moving side	1.5	20.413
18:07:50	0:01:30	setting1		19.629
18:09:20	0:01:55	driving1		18.756
18:11:15	0:00:57	setting2		19.573
18:12:12	0:00:33	ready welding		19.181
18:12:45	-	welding		19.250
The Second DAY				
11:08:00	0:01:30	moving side (+2.5minute)	1.5	19.333
11:09:30	0:01:47	setting1		19.929
11:11:17	0:01:53	driving1		20.529
11:13:10	0:01:31	setting2		20.441
11:14:41	0:02:47	ready welding		20.353
11:17:28	0:03:02	welding		17.806
11:20:30	0:14:00	driving2		18.687
11:34:30	0:16:00	moving bacward	3	21.876
11:50:30	0:00:30	taking		21.355
11:51:00	0:01:20	setting1		21.535
11:52:20	0:01:55	driving1		21.166
11:54:15	0:01:15	setting2		19.721
11:55:30	0:00:47	ready welding		

Location : Langkawi MALAYSIA
Machine : Drop Hammer 1.2 ton
Falling height : 1 m
Anvil : Steel Pipe
Pile : 2 pieces of 6m long of square pile (150x150)
Man Power : 1 Operator, 1 Helper

Time	Duration	Activity	Distance (m)	Blow frequency (10x / s)
11:56:17	0:02:00	welding		
11:58:17	0:09:28	driving2		
12:07:45	0:02:10	taking		
12:09:55	0:01:45	moving side	1.5	
12:11:40	0:01:45	setting1		
12:13:25	0:02:01	driving1		
12:15:26	0:00:59	setting2		
12:16:25	0:00:38	ready welding		
12:17:03	0:02:17	welding		
12:19:20	0:09:30	driving2		
12:28:50	#VALUE!	brake		
		BRAKE		
13:58:35	0:01:30	moving side	1.5	
14:00:05	0:01:07	setting1		
14:01:12	0:01:38	driving1		
14:02:50	0:00:54	setting2		
14:03:44	0:00:56	ready welding		
14:04:40	0:02:05	welding		
14:06:45	0:09:15	driving2		
14:16:00	0:01:42	moving side (not finished)	1.5	
14:17:42	0:05:08	taking		
14:22:50	0:07:30	moving side (continued)	1.5	
14:30:20	0:01:30	setting1		
14:31:50	0:03:05	driving1		
14:34:55	0:00:55	taking		
14:35:50	0:00:33	setting2		
14:36:23	0:00:57	ready welding		
14:37:20	0:02:05	welding		
14:39:25	0:09:08	driving2		
14:48:33	0:00:47	taking		
14:49:20	0:01:50	moving side	1.5	
14:51:10	0:01:25	setting1		
14:52:35	0:04:20	driving1		
14:56:55	0:01:10	setting2		
14:58:05	0:00:45	ready welding		
14:58:50	0:01:40	welding		
15:00:30	0:07:40	driving2		
15:08:10	0:01:55	moving side	1.5	
15:10:05	0:01:09	driving2 continue		
15:11:14	0:01:21	taking		
15:12:35	0:03:12	moving side	1.5	
15:15:47	0:01:39	setting1		
15:17:26	0:04:31	driving1		
15:21:57	0:01:23	setting2		
15:23:20	0:00:40	ready welding		
15:24:00	0:02:45	welding		
15:26:45	0:14:37	driving2		
15:41:22	0:16:38	moving backward (3m)	3	
15:58:00	0:32:00	brake		
16:30:00	0:03:06	moving side (adjust anvil) useless		
16:33:06	0:01:04	taking		
16:34:10	0:01:30	setting1		
16:35:40	0:04:39	driving1		

Location : Langkawi MALAYSIA
Machine : Drop Hammer 1.2 ton
Falling height : 1 m
Anvil : Steel Pipe
Pile : 2 pieces of 6m long of square pile (150x150)
Man Power : 1 Operator, 1 Helper

Time	Duration	Activity	Distance (m)	Blow frequency (10x / s)
16:40:19	0:00:56	setting2		
16:41:15	0:00:43	ready welding		
16:41:58	0:02:52	welding		
16:44:50	-	driving2		
		BRAKE		
17:01:52	0:05:15	driving1		
17:07:07	0:01:33	setting2		
17:08:40	0:00:54	ready welding		
17:09:34	0:01:56	welding		
17:11:30	0:11:50	driving2		
17:23:20	0:01:25	moving side	1.5	
17:24:45	0:01:05	setting1		
17:25:50	0:03:06	driving1		
17:28:56	0:02:19	taking		
17:31:15	0:05:09	setting2		
17:36:24	0:00:36	ready welding		
17:37:00	0:01:22	welding		
17:38:22	0:07:20	driving2		
17:45:42	0:00:48	moving side (adjust anvil)	1.5	
17:46:30	0:01:25	driving2 continue		
17:47:55	0:07:25	moving side	1.5	
17:55:20	0:01:42	setting1		
17:57:02	0:02:18	driving1		
17:59:20	0:01:17	taking		
18:00:37	0:00:58	setting2		
18:01:35	0:01:27	ready welding		
18:03:02	0:00:53	welding		
18:03:55	0:08:27	driving2		
18:12:22	0:00:33	moving side (not finished) useless		
18:12:55	0:00:15	driving2 continue		
18:13:10	-	moving side (continued) useless		

GROUPING AND STATISTICAL ANALYSIS

Location : Langkawi MALAYSIA
Machine : Drop Hammer 1.2 ton
Falling height : 1 m
Anvil : Steel Pipe
Pile : 2 pieces of 6m long of square pile (150x150)
Man Power : 1 Operator, 1 Helper

Time	Duration	Activity	Distance (m)	Movement speed (time/m)
9:32:05	0:07:24	moving side	1.5	0:04:56
10:40:12	0:05:13	moving side	1.5	0:03:29
16:57:40	0:01:15	moving side	1.5	0:00:50
17:18:10	0:03:00	moving side	1.5	0:02:00
17:36:33	0:07:45	moving side	1.5	0:05:10
18:02:53	0:04:57	moving side	1.5	0:03:18
12:09:55	0:01:45	moving side	1.5	0:01:10
13:58:35	0:01:30	moving side	1.5	0:01:00
14:16:00	0:09:12	moving side	1.5	0:06:08
14:49:20	0:01:50	moving side	1.5	0:01:13
15:08:10	0:05:07	moving side	1.5	0:03:25
17:23:20	0:01:25	moving side	1.5	0:00:57
17:45:42	0:08:13	moving side	1.5	0:05:29
11:08:00	0:04:00	moving side (+2.5minute)	1.5	0:02:40
9:26:30	0:02:05	moving side (3m)	1.5	0:01:23
10:10:20	0:02:40	moving side (3m)	1.5	0:01:47
			Average	**0:02:48**
			Standard Deviation	**0:01:48**
			Minimum	**0:00:50**
14:47:00	0:19:10	moving backward	3	0:06:23
15:41:22	0:16:38	moving backward	3	0:05:33
11:34:30	0:16:00	moving backward	3	0:05:20
			Average	**0:05:45**
			Standard Deviation	**0:00:34**
			Minimum	**0:05:20**

time	duration	activity	pile's length (m)
9:10:30	0:02:00	setting1	6
9:28:35	0:01:35	setting1	6
9:55:30	0:00:40	setting1	6
10:13:00	0:01:55	setting1	6
14:52:10	0:01:40	setting1	6
16:39:35	0:01:05	setting1	6
17:00:25	0:01:25	setting1	6
17:21:10	0:01:57	setting1	6
17:45:20	0:01:18	setting1	6
18:07:50	0:01:30	setting1	6
11:09:30	0:01:47	setting1	6
11:51:00	0:01:20	setting1	6
12:11:40	0:01:45	setting1	6
14:00:05	0:01:07	setting1	6
14:30:20	0:01:30	setting1	6
14:51:10	0:01:25	setting1	6
15:15:47	0:01:39	setting1	6
16:34:10	0:01:30	setting1	6
17:24:45	0:01:05	setting1	6
17:55:20	0:01:42	setting1	6
9:13:55	0:01:32	setting2	6

Location : Langkawi MALAYSIA
Machine : Drop Hammer 1.2 ton
Falling height : 1 m
Anvil : Steel Pipe
Pile : 2 pieces of 6m long of square pile (150x150)
Man Power : 1 Operator, 1 Helper

time	duration	activity	pile's length (m)
9:33:50	0:01:25	setting2	6
9:58:40	0:01:07	setting2	6
10:21:50	0:02:00	setting2	6
14:58:05	0:00:36	setting2	6
16:45:00	0:01:10	setting2	6
17:05:50	0:00:43	setting2	6
17:25:35	0:01:08	setting2	6
17:50:05	0:00:56	setting2	6
18:11:15	0:00:57	setting2	6
11:13:10	0:01:31	setting2	6
11:54:15	0:01:15	setting2	6
12:15:26	0:00:59	setting2	6
14:02:50	0:00:54	setting2	6
14:35:50	0:00:33	setting2	6
14:56:55	0:01:10	setting2	6
15:21:57	0:01:23	setting2	6
16:40:19	0:00:56	setting2	6
17:07:07	0:01:33	setting2	6
17:31:15	0:05:09	setting2	6
18:00:37	0:00:58	setting2	6
	0:01:25	**Average**	
	0:00:43	**Standard Deviation**	
	0:00:33	**Minimum**	

time	duration	activity	Welding	
			Length (m)	Speed (time/m)
9:17:30	0:02:00	welding	0.45	0:04:27
9:35:40	0:01:20	welding	0.45	0:02:58
10:00:40	0:01:11	welding	0.45	0:02:38
10:24:15	0:01:33	welding	0.45	0:03:27
14:59:55	0:01:25	welding	0.45	0:03:09
16:46:50	0:01:30	welding	0.45	0:03:20
17:07:00	0:01:40	welding	0.45	0:03:42
17:27:20	0:01:40	welding	0.45	0:03:42
17:51:40	0:02:10	welding	0.45	0:04:49
11:17:28	0:03:02	welding	0.45	0:06:44
11:56:17	0:02:00	welding	0.45	0:04:27
12:17:03	0:02:17	welding	0.45	0:05:04
14:04:40	0:02:05	welding	0.45	0:04:38
14:37:20	0:02:05	welding	0.45	0:04:38
14:58:50	0:01:40	welding	0.45	0:03:42
15:24:00	0:02:45	welding	0.45	0:06:07
16:41:58	0:02:52	welding	0.45	0:06:22
17:09:34	0:01:56	welding	0.45	0:04:18
17:37:00	0:01:22	welding	0.45	0:03:02
18:03:02	0:00:53	welding	0.45	0:01:58
	0:01:52		**Average**	**0:04:10**
	0:00:34		**Standard Deviation**	**0:01:15**
	0:00:53		**Minimum**	**0:01:58**

Location : Langkawi MALAYSIA
Machine : Drop Hammer 1.2 ton
Falling height : 1 m
Anvil : Steel Pipe
Pile : 2 pieces of 6m long of square pile (150x150)
Man Power : 1 Operator, 1 Helper

Time	Duration	Activity
9:12:30	0:01:25	driving1
9:30:10	0:02:15	driving1
9:56:10	0:02:30	driving1
10:14:55	0:06:55	driving1
14:53:50	0:04:15	driving1
16:40:40	0:04:20	driving1
17:01:50	0:04:00	driving1
17:23:07	0:02:28	driving1
17:46:38	0:03:27	driving1
18:09:20	0:01:55	driving1
11:11:17	0:01:53	driving1
11:52:20	0:01:55	driving1
12:13:25	0:02:01	driving1
14:01:12	0:01:38	driving1
14:31:50	0:03:05	driving1
14:52:35	0:04:20	driving1
15:17:26	0:04:31	driving1
16:35:40	0:04:39	driving1
17:01:52	0:05:15	driving1
17:25:50	0:03:06	driving1
17:57:02	0:02:18	driving1
9:19:30	0:07:00	driving2
9:38:40	0:07:05	driving2
10:01:51	0:08:29	driving2
10:25:48	0:15:49	driving2
15:01:20	0:12:25	driving2
16:48:20	0:09:20	driving2
17:08:40	0:09:30	driving2
17:29:00	0:08:35	driving2
17:53:50	0:08:18	driving2
11:20:30	0:14:00	driving2
11:58:17	0:09:28	driving2
12:19:20	0:09:30	driving2
14:06:45	0:09:15	driving2
14:39:25	0:09:08	driving2
15:00:30	0:08:49	driving2
15:26:45	0:14:37	driving2
17:11:30	0:11:50	driving2
17:38:22	0:08:45	driving2
18:03:55	0:08:42	driving2

Location : Langkawi MALAYSIA
Machine : Drop Hammer 1.2 ton
Falling height : 1 m
Anvil : Steel Pipe
Pile : 2 pieces of 6m long of square pile (150x150)
Man Power : 1 Operator, 1 Helper

Non Productive Activity		
Time	**Duration**	**Activity**
9:51:44	0:03:46	taking
16:58:55	0:01:30	taking
11:50:30	0:00:30	taking
12:07:45	0:02:10	taking
14:17:42	0:05:08	taking
14:34:55	0:00:55	taking
14:48:33	0:00:47	taking
15:11:14	0:01:21	taking
16:33:06	0:01:04	taking
17:28:56	0:02:19	taking
17:59:20	0:01:17	taking
9:15:27	0:02:03	welding preparation
9:35:15	0:00:25	welding preparation
9:59:47	0:00:53	welding preparation
10:23:50	0:00:25	welding preparation
14:58:41	0:01:14	welding preparation
16:46:10	0:00:40	welding preparation
17:06:33	0:00:27	welding preparation
17:26:43	0:00:37	welding preparation
17:51:01	0:00:39	welding preparation
18:12:12	0:00:33	welding preparation
11:14:41	0:02:47	welding preparation
11:55:30	0:00:47	welding preparation
12:16:25	0:00:38	welding preparation
14:03:44	0:00:56	welding preparation
14:36:23	0:00:57	welding preparation
14:58:05	0:00:45	welding preparation
15:23:20	0:00:40	welding preparation
16:41:15	0:00:43	welding preparation
17:08:40	0:00:54	welding preparation
17:36:24	0:00:36	welding preparation
18:01:35	0:01:27	welding preparation
15:58:00	0:32:00	brake
9:37:00	0:01:40	no activity
18:01:05	0:00:45	nothing
	1:14:18	**Total**
	13.57%	**Percentage**

Location : Langkawi MALAYSIA
Machine : Drop Hammer 1.2 ton
Falling height : 1 m
Anvil : Steel Pipe
Pile : 2 pieces of 6m long of square pile (150x150)
Man Power : 1 Operator, 1 Helper

Driving energy productivity

bowl frequency 10x / scnd	Driving energy (kg.m/s)	bowl frequency 10x / scnd	Driving energy (kg.m/s)	bowl frequency 10x / scnd	Driving energy (kg.m/s)
21.844	2621.28	18.572	2228.64	21.558	2586.96
21.512	2581.44	19.232	2307.84	21.743	2609.16
20.796	2495.52	18.816	2257.92	19.518	2342.16
21.263	2551.56	18.992	2279.04	19.361	2323.32
21.927	2631.24	18.886	2266.32	18.269	2192.28
22.776	2733.12	18.203	2184.36	19.587	2350.44
22.740	2728.80	18.023	2162.76	19.744	2369.28
23.220	2786.40	18.170	2180.40	19.721	2366.52
23.132	2775.84	17.963	2155.56	19.610	2353.20
23.326	2799.12	18.401	2208.12	19.430	2331.60
22.343	2681.16	18.909	2269.08	20.446	2453.52
22.306	2676.72	19.075	2289.00	20.589	2470.68
21.216	2545.92	19.167	2300.04	21.396	2567.52
21.881	2625.72	20.040	2404.80	20.538	2464.56
22.107	2652.84	19.726	2367.12	20.413	2449.56
20.553	2466.36	19.666	2359.92	19.629	2355.48
21.180	2541.60	18.627	2235.24	18.756	2250.72
19.061	2287.32	18.936	2272.32	19.573	2348.76
19.541	2344.92	19.896	2387.52	19.181	2301.72
20.598	2471.76	19.620	2354.40	19.250	2310.00
19.892	2387.04	19.735	2368.20	19.333	2319.96
21.336	2560.32	19.343	2321.16	19.929	2391.48
19.500	2340.00	19.827	2379.24	20.529	2463.48
19.606	2352.72	20.132	2415.84	20.441	2452.92
19.056	2286.72	20.630	2475.60	20.353	2442.36
18.507	2220.84	19.564	2347.68	17.806	2136.72
18.664	2239.68	19.716	2365.92	18.687	2242.44
18.720	2246.40	19.813	2377.56	21.876	2625.12
19.172	2300.64	19.993	2399.16	21.355	2562.60
18.830	2259.60	20.796	2495.52	21.535	2584.20
19.135	2296.20	20.935	2512.20	21.166	2539.92
				19.721	2366.52
			average	**20.066**	**2407.90**
			Standard deviation	**1.302**	**156.24**
			minimum	**17.806**	**2136.72**

RECORDS OF DATA

Location : Chulalongkorn University, THAILAND
Machine : Drop Hammer 5 ton
Falling height : 0.3 m & 0.6 m
Anvil : Steel rail
Pile : 1 pieces of 22 m length of I-shape pile (260x260 & 350x350)
Man Power : 1 Operator, 3 Helper

Time	Duration	Activity	Distance (m)	Blow frequency (10x / s)	
				stroke=30cm)	stroke=60cm)
The first DAY					
8:33:00	1:27:00	moving sideward	3	12.396	23.280
10:00:00	0:20:40	setting (small pile)		11.349	20.436
10:20:40	0:15:20	driving		11.455	20.635
10:36:00	-	stop driving		11.533	20.764
BRAKE					
13:59:40	0:17:10	moving sideward	3	11.57	20.976
14:16:50	0:13:40	setting (small pile)		11.593	21.013
14:30:30	0:08:55	driving setting		11.667	21.406
14:39:25	0:03:01	setting (small pile)		11.672	21.498
14:42:26	0:24:24	driving		11.695	21.544
15:06:50	-	stop		11.746	21.743
The second DAY					
8:00:00	0:25:00	moving backward	1	11.856	21.909
8:25:00	0:15:00	moving sideward	4	11.866	22.043
8:40:00	0:14:00	setting (big pile)		11.912	22.056
8:54:00	0:08:40	driving setting		11.921	22.075
9:02:40	0:22:00	driving		11.976	22.112
9:24:40	0:06:35	taking over take		12.083	22.121
9:31:15	0:27:15	moving backward	1	12.092	22.126
9:58:30	0:03:40	taking pile		12.12	22.435
10:02:10	0:08:10	setting (small pile)		12.198	22.527
10:10:20	0:10:00	driving setting		12.253	22.901
10:20:20	0:14:02	driving		12.258	22.933
10:34:22	0:08:18	taking		12.295	23.275
10:42:40	0:04:45	taking		12.300	23.764
10:47:25	0:03:25	taking (big pile)		12.336	25.486
10:50:50	0:33:30	moving sideward	4	12.341	26.547
11:24:20	0:01:59	consolidation (briefing)		12.346	21.272
11:26:19	0:10:58	setting (big pile)		12.35	20.893
11:37:17	0:07:43	driving setting		12.369	23.090
11:45:00	-	driving		12.383	23.598
BRAKE					
13:57:58	0:14:42	setting (big pile)		12.396	26.418
14:12:40	0:15:00	driving setting		12.396	24.553
14:27:40	0:18:55	driving		12.521	25.144
14:46:35	0:08:40	rolling pile		12.526	25.301
14:55:15	-	BRAKE		12.526	21.295
The third DAY					
10:08:30	0:43:10	moving sideward	4	12.530	22.993
10:51:40	0:02:20	prepare location		12.540	25.264
10:54:00	0:03:00	taking pile		12.553	25.606
10:57:00	0:09:50	setting (small pile)		12.564	24.272
11:06:50	0:17:18	driving setting		12.590	25.656
11:24:08	0:18:42	driving		12.636	20.672
11:42:50	-	BRAKE		12.655	19.684
BRAKE					

Location : Chulalongkorn University, THAILAND
Machine : Drop Hammer 5 ton
Falling height : 0.3 m & 0.6 m
Anvil : Steel rail
Pile : 1 pieces of 22 m length of I-shape pile (260x260 & 350x350)
Man Power : 1 Operator, 3 Helper

Time	Duration	Activity	Distance (m)	Blow frequency (10x / s)	
				stroke=30cm)	stroke=60cm)
13:56:20	0:08:27	setting (small pile)		12.701	20.473
14:04:47	0:08:43	driving setting		12.706	20.127
14:13:30	0:11:58	driving		12.720	19.763
14:25:28	0:29:50	moving sideward	4	12.738	21.745
14:55:18	0:09:42	setting (small pile)		12.752	
15:05:00	0:09:55	driving setting		12.775	
15:14:55	0:12:05	driving		12.784	
15:27:00	0:21:00	moving sideward	4	12.821	
15:48:00	0:07:40	setting (small pile)		12.835	
15:55:40	0:12:20	driving setting		12.872	
16:08:00	0:12:33	driving		12.881	
16:20:33	0:25:02	moving sideward	4	12.900	
16:45:35	0:08:02	setting (small pile)		12.927	
16:53:37	0:10:58	driving setting		12.941	
17:04:35	-	driving (BRAKE)		13.029	
The fourth DAY					
8:29:40	0:12:00	setting (small pile)		13.061	
8:41:40	0:09:50	driving setting		13.107	
8:51:30	0:14:06	driving		13.112	
9:05:36	0:24:04	moving sideward	4	13.126	
9:29:40	0:02:25	taking		13.163	
9:32:05	0:12:50	setting (big pile)		13.232	
9:44:55	0:12:31	driving setting		13.250	
9:57:26	0:30:09	driving		13.264	
10:27:35	0:46:47	moving sideward	4	13.370	
11:14:22	0:04:35	taking		13.435	
11:18:57	0:09:43	setting (small pile)		13.647	
11:28:40	0:09:05	driving setting		13.767	
11:37:45	0:13:35	driving		13.971	
11:51:20	0:18:00	taking		13.974	
12:09:20	-	moving sideward		14.020	

Location : Bang Na, THAILAND
Machine : Drop Hammer 5 ton
Falling height : 0.6 m
Anvil : Steel rail
Pile : 2 pieces of 12 m length of I-shape pile 350x350
Man Power : 1 Operator, 3 Helper

Time	Duration	Activity	Distance (m)	Blow frequency (10x / s)
The First DAY				
15:42:12	0:26:28	moving sideward +forward	0.6 + 1.0	25.486
16:08:40	0:09:26	setting 1		26.547
16:18:06	0:02:59	driving 1		21.272
16:21:05	0:03:05	setting 2		20.893
16:24:10	0:03:10	welding preparation		23.09
16:27:20	0:05:05	setting 2		23.598
16:32:25	0:05:25	welding preparation		26.418
16:37:50	0:20:05	welding		24.553
16:57:55	0:00:47	nothing		25.144
16:58:42	0:00:33	driving 2		25.301
16:59:15	0:03:45	machine broken		21.295
17:03:00	0:26:40	driving 2		22.993
17:29:40	-	finished		25.264
The Second DAY				
8:52:00	0:04:15	setting 1		25.606
8:56:15	0:09:53	setting 1		24.272
9:06:08	0:03:17	driving 1		25.656
9:09:25	0:04:03	setting 2		20.672
9:13:28	0:01:04	welding preparation		19.684
9:14:32	0:04:23	setting 2		20.473
9:18:55	0:04:25	welding preparation		20.127
9:23:20	0:03:06	setting 2		19.763
9:26:26	0:04:54	welding preparation		21.745
9:31:20	0:18:02	welding		23.764
9:49:22	0:31:28	driving 2		
10:20:50	0:04:20	moving side	1.0	
10:25:10	0:10:10	setting 1		
10:35:20	0:02:54	driving 1		
10:38:14	0:22:16	setting 2		
11:00:30	0:05:30	welding preparation		
11:06:00	0:21:30	welding		
11:27:30	0:28:05	driving 2		
11:55:35	0:22:55	moving sideward +forward	0.5 + 1.0	
12:18:30	0:02:50	setting 1		
12:21:20	-	take a brake		
TAKE A BREAK				
13:46:30		setting		
13:54:00	0:30:15	moving sideward +forward	0.6 + 1.0	
14:24:15	0:16:03	setting 1		
14:40:18	0:06:22	driving 1		
14:46:40	0:09:20	setting 2		
14:56:00	0:01:20	welding preparation		
14:57:20	0:16:43	welding		
15:14:03	0:09:41	driving 2		
15:23:44	0:13:46	refill fuel		
15:37:30	0:15:15	driving 2		
15:52:45	0:03:28	moving side	1.0	
15:56:13	0:04:59	setting 1		
16:01:12	-	driving 1		

GROUPING THE DATA AND ITS STATISTICAL ANALYSIS

Location : Bang Na + Chula* (Sideward movement), THAILAND
Machine : Drop Hammer 5 ton
Falling height : 0.6 m
Anvil : Steel rail
Pile : 2 pieces of 12 m length of I-shape pile 350x350
Man Power : 1 Operator, 3 Helper

time	duration	activity	distance (m)	movement speed (time/m)
8:25:00	0:15:00	moving sideward (Chula)	4	0:03:45
10:50:50	0:33:30	moving sideward (Chula)	4	0:08:23
10:08:30	0:43:10	moving sideward (Chula)	4	0:10:47
14:25:28	0:29:50	moving sideward (Chula)	4	0:07:28
15:27:00	0:21:00	moving sideward (Chula)	4	0:05:15
16:20:33	0:25:02	moving sideward (Chula)	4	0:06:16
9:05:36	0:24:04	moving sideward (Chula)	4	0:06:01
10:27:35	0:46:47	moving sideward (Chula)	4	0:11:42
10:20:50	0:04:20	moving sideward (Bang Na)	1.0	0:04:20
15:52:45	0:03:28	moving sideward (Bang Na)	1.0	0:03:28
			average	**0:06:44**
			Standard deviation	**0:02:50**
			minimum	**0:03:28**
15:42:12	0:26:28	moving sideward +forward	0.6 + 1.0	unknown
11:55:35	0:22:55	moving sideward +forward	0.5 + 1.0	unknown
13:54:00	0:30:15	moving sideward +forward	0.6 + 1.0	unknown
			average	unknown
			Standard deviation	unknown
			minimum	unknown

time	duration	activity	pile's length (m)
16:08:40	0:09:26	setting 1	12
8:52:00	0:14:08	setting 1	12
10:25:10	0:10:10	setting 1	12
14:24:15	0:16:03	setting 1	12
15:56:13	0:04:59	setting 1	12
16:21:05	0:08:10	setting 2	12
9:09:25	0:11:32	setting 2	12
10:38:14	0:22:16	setting 2	12
14:46:40	0:09:20	setting 2	12
	0:11:47	**average**	
	0:05:05	**Standard deviation**	
	0:04:59	**minimum**	

time	duration	activity	Welding	
			Length (m)	Speed (time/m)
16:37:50	0:20:05	welding	1.75	0:11:29
9:31:20	0:18:02	welding	1.75	0:10:18
11:06:00	0:21:30	welding	1.75	0:12:17
14:57:20	0:16:43	welding	1.75	0:09:33
	0:19:05		**average**	**0:10:54**
	0:02:07		**Standard deviation**	**0:01:13**
	0:16:43		**minimum**	**0:09:33**

Location : Bang Na + Chula* (Sideward movement), THAILAND
Machine : Drop Hammer 5 ton
Falling height : 0.6 m
Anvil : Steel rail
Pile : 2 pieces of 12 m length of I-shape pile 350x350
Man Power : 1 Operator, 3 Helper

Time	Duration	Activity
16:18:06	0:02:59	driving 1
9:06:08	0:03:17	driving 1
10:35:20	0:02:54	driving 1
14:40:18	0:06:22	driving 1
16:58:42	0:27:13	driving 2
9:49:22	0:31:28	driving 2
11:27:30	0:28:05	driving 2
15:14:03	0:09:41	driving 2
15:37:30	0:15:15	driving 2

Non Productive Activity		
Time	**Duration**	**Activity**
16:32:25	0:05:25	welding preparation
9:13:28	0:10:23	welding preparation
11:00:30	0:05:30	welding preparation
14:56:00	0:01:20	welding preparation
16:24:10	0:03:10	welding preparation
16:59:15	0:03:45	machine broke down
16:57:55	0:00:47	nothing
15:23:44	0:13:46	refill fuel
	0:44:06	**Total**
	9.93%	**Percentage**

Location : Chulalongkorn University and Bang Na, THAILAND
Machine : Drop Hammer 5 ton
Falling height : 0.6 m
Anvil : Steel rail
Pile : I-shape pile (260x260 & 350x350)
Man Power : 1 Operator, 3 Helper

Driving energy productivity			
bowl frequency 10x / scnd	**Driving energy (kg.m/s)**	**bowl frequency 10x / scnd**	**Driving energy (kg.m/s)**
20.436	6130.80	23.764	7129.20
20.635	6190.50	25.486	7645.80
20.764	6229.20	26.547	7964.10
20.976	6292.80	21.272	6381.60
21.013	6303.90	20.893	6267.90
21.406	6421.80	23.09	6927.00
21.498	6449.40	23.598	7079.40
21.544	6463.20	26.418	7925.40
21.743	6522.90	24.553	7365.90
21.909	6572.70	25.144	7543.20
22.043	6612.90	25.301	7590.30
22.056	6616.80	21.295	6388.50
22.075	6622.50	22.993	6897.90
22.112	6633.60	25.264	7579.20
22.121	6636.30	25.606	7681.80
22.126	6637.80	24.272	7281.60
22.435	6730.50	25.656	7696.80
22.527	6758.10	20.672	6201.60
22.901	6870.30	19.684	5905.20
22.933	6879.90	20.473	6141.90
23.275	6982.50	20.127	6038.10
23.28	6984.00	19.763	5928.90
		21.745	6523.50
	average	**22.56**	**6769.49**
	Standard deviation	**1.85**	**553.56**
	minimum	**19.68**	**5905.20**

VITA

Arief Setiawan Budi Nugroho was born on September 1st year 1975 in Semarang, Indonesia. He was a student in elementary school and high school in Semarang. In 1994, he continued to study bachelor's degree in Gadjah Mada University, Yogyakarta, Indonesia. He spent 4 years and 8 months to be a civil engineer from this University. When he graduated in 1999, he dedicated to be a lecturer in the Gadjah Mada University. He has taught for 4 subjects; Structure Analysis, Steel Structure, Structure Design and Concrete Structure.