PILING INDUCED GROUND VIBRATION OBSERVATION

By

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This dissertation is submitted to

UNIVERSITI SAINS MALAYSIA

as partial fulfillment of requirements for the degree of

BACHELOR OF ENGINEERING (CIVIL ENGINEERING)

School of Civil Engineering,

Universiti Sains Malaysia.

March 2006

ABSTRACT

Vibration due to piling work can cause numerous implications towards buildings and local residents around the area of the piling work. Its impact becomes more crucial if the piling work is done in compact urban locations whereby the buildings and area are densely populated. Five sets of data had been collected in order to determine which kind of waves carries the most significance in term of its magnitude. These data was attained using an instrument called Blastronic Micro Monitor which has been located at five different points of different lengths (20m, 23m, 30m, 39m and 70m) from the vibration source. The results generally show a decay of peak particle velocity (PPV) magnitude over distance in a straight line from the point of vibration source. However the maximum reading were, 9.2 mm/s for radial wave, 3.0 mm/s for transverse wave and 2.2 mm/s for vertical wave. The vibration induced by piling consists mainly of radial wave, transverse and vertical wave. The relationship between these waves and the length from where they were taken is analyzed. The intensity of the vibration is determined by analyzing the vector sum value of the wave. This thesis provides an understanding on how various signals from piling differ with each other in terms of their magnitude.

ABSTRAK

Gegaran akibat kerja pemacuan cerucuk mengundang pelbagai implikasi terhadap struktur bangunan dan juga keharmonian penduduk-penduduk sekeliling kawasan pemacuan cerucuk. Parameter gegaran menjadi lebih kritikal apabila kerja pemacuan dilakukan di kawasan bandar di mana struktur- struktur bangunan bertumpu di kawasan yang padat. Lima set data telah diperolehi dan dianalasis untuk menentukan parameter-parameter kritikal di dalam gelombang gegaran akibat kerja pemacuan cerucuk. Data-data ini diperolehi melalui alat *Blastronic Micro Meter* yang telah diletakkan di lima kedudukan yang mempunyai jarak yang berbeza(20m, 23m, 30m, 39m, dan 70m) daripada pusat sumber gegaran. Gegaran akibat pemacuan diuraikan kepada tiga bentuk gelembang iaitu gelombang *radial*, gelombang *transverse* and gelombang *vertical*. Perhubungan antara jenis-jenis gelombang ini dan jarak dinyatakan melalui graf-graf yang telah diplotkan. Data-data menunjukkan bahawa terdapat pengurangan dalam magnitud *Peak Pariticle Velocity (PPV)* dari titik punca gegaran ke suatu jarak dalam satu garisan lurus. Namun, nilai maksimum yang diperolehi untuk setiap jenis gelombang ialah, 9.2 mm/s untuk gelombang *radial*, 3.0 mm/s untuk gelombang *transverse* and 2.2 mm/s for gelombang *vertical*. Keamatan gegaran boleh ditunjukkan dengan merujuk analisis jumlah vektor gelombang. Hasil keputusan projek ini akan dapat membantu meningkatkan kefahaman tentang perkaitan antara parameter-parameter gegaran akibat kerja pemacuan cerucuk dari aspek magnitudnya.

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CHAPTER 1

INTRODUCTION

1.1 PREFACE

Vibration due to construction work, in this particular case by piling, can bring many negative impacts to the surrounding buildings and residents. The vibration from nearby pile driving can cause local damage to these structures, which can be triggered by a combination of factors such as poor condition of the structures because of age, inadequate foundations, settlement over the years, etc. Owners of industrial premises, affected by piling vibration, very often complain about malfunctioning of precision machinery, instruments, and other equipments such as computer installations and telephone exchanges. Problems such as psychological disturbance and annoyance to surrounding occupants of buildings will not just bring a bad image to the contractor; it will also affect the reputation of the project's client and engineers. Therefore, it is important to accurately predict vibrations of ground, structures, and sensitive devices prior to the beginning of construction activities to avoid undesirable effect of generated vibrations. Furthermore, the cost to compensate such problems will be an unnecessary addition to the whole project's cost. Though the issue has affected the construction industry for many years, information on the characteristics of the ground vibration due to pile driving is lacking. Thus, studies about piling induced vibration and how to mitigate the problems are necessary to determined the critical parameters and how to mitigate them.

1.2 OBJECTIVES

The main objectives of this project are:

- to study on the theory and basic concept of piling induced vibration wave and the parameters involved
- to experience the method used to collect data from a construction site using *Blastronic µMX*
- To determine the relationship between different type of waves (radial wave, vertical wave and transverse wave) with respect to the length from the vibration source

1.3 SCOPE OF STUDY

Understanding the basic concept piling induced wave vibration such as the characteristic of the vibration, the propagation of the vibration wave and the parameters involved which bring significant impact to the vibration wave. Able to operate *Blastronic µMX* efficiently and thus appreciate the data given.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

2.1.1 Piles and Piling

Piles and pile foundations have been in use since prehistoric times. According to Fleming (1994), 12,000 years ago; the Neolithic people in Switzerland drive wooden poles in the soft bottoms of shallow lakes and built their homes on them. Fleming also mentioned that Venice was built on timber piles in the delta of the Po River to protect the Italians from the invaders of Eastern Europe and at the same time to enable them to be close to the sea; their main source of food. Meanwhile, in Venezuela, Fleming added that the Indians lived in pile-supported huts in lagoons around the shores of Lake Maracaibo. Today, pile foundations serve the same purpose as it always been; to make it possible to build structures in areas where the soil conditions are unfavorable for shallow foundations.

Nowadays, there are various types of pile to be considered in construction. Each one of it have its own advantage and disadvantages. There are also types of piles which only serve certain type of soil. In Malaysia, driven piles are among the most commonly piling method used. Based on Randolf (1988), driven piles are prefabricated elements driven into the ground. Among the common materials used to manufacture piles are steel, concrete and timber. Randolf also reported that the advantage of using this type of pile is that the pile can be thoroughly inspected before driving, thus quality control is easy to organize and enforce. Furthermore, it is relatively easy to operate.

2.1.2 Vibration Theory and Assessment

Displacement occurs when an object is in contact with a vibrating surface. Therefore, in this particular case, soil's displacement, which is induced by the hammer, is one parameter that can be used to describe the magnitude of a vibration (Elson, 1988).

Elson later on explained that sinusoidal signals, displacement, velocity and acceleration amplitudes are related mathematically by a function of frequency and time. According to him, if phase is neglected (as is always the case when making time-average measurements), the velocity can be obtained by dividing the acceleration signal by a factor proportional to frequency (measured in Hertz, Hz) and the displacement can then be obtained by dividing the acceleration signal by a factor proportional to the square of frequency. Modern electronic integrating meters are capable of providing a wide range of measurement parameters during any single vibration measurement. Elson also mentioned that, for a complex acceleration signal giving rise to a complicated time history, there are several additional quantities which can be used to describe the vibration:

- the root mean square value (rms) is obtained by taking the square root of the mean of the sum of the squares of the instantaneous acceleration measured during the total measurement time (T);
- the peak value is the maximum instantaneous acceleration measured during the measurement time, T. It is a useful indicator of the magnitude of short duration

shocks;

- the peak particle velocity (ppv) is the maximum instantaneous velocity of a particle at a point during a given time interval.

2.1.3 Vibration Perception

Humans are sensitive to any vibration. Humans can easily feel panic especially there is no warning about the vibration that they are experiencing.

According to Weltman (1992), human sensitivity towards vibration is in the range of $0.15mms^{-1}$ to $0.3mms^{-1}$ ppv; frequency range 0.1 Hz to 1500 Hz. Weltman also reported that the human body is not equally sensitive to all frequencies of vibration and weighting curves to reflect the frequency dependency of the body have been developed and are contained in the ISO Standards. Weltman described that the weighting indicates the relationship between the measured vibration level and the subjective feeling of impact produced by the vibration. The weightings can act as an input into modern vibration meters, thus enabling measurement of vibration levels that correspond to humans. Weltman also mentioned that the human body responds differently when standing (longitudinal) compared to when lying down (lateral).

2.2 EQUIPMENT FOR DRIVEN PILES

2.2.1 A Typical Pile-Driving Rig

Base on Fleming (994), there are two key players in pile driving operation; pile and the hammer. The hammer is operated and guided on a rig. Different types of rigs are available in the pile-driving industry. However, the basic components of these rigs are similar. Various components of a typical rig are first identified in the Figure 2.1.

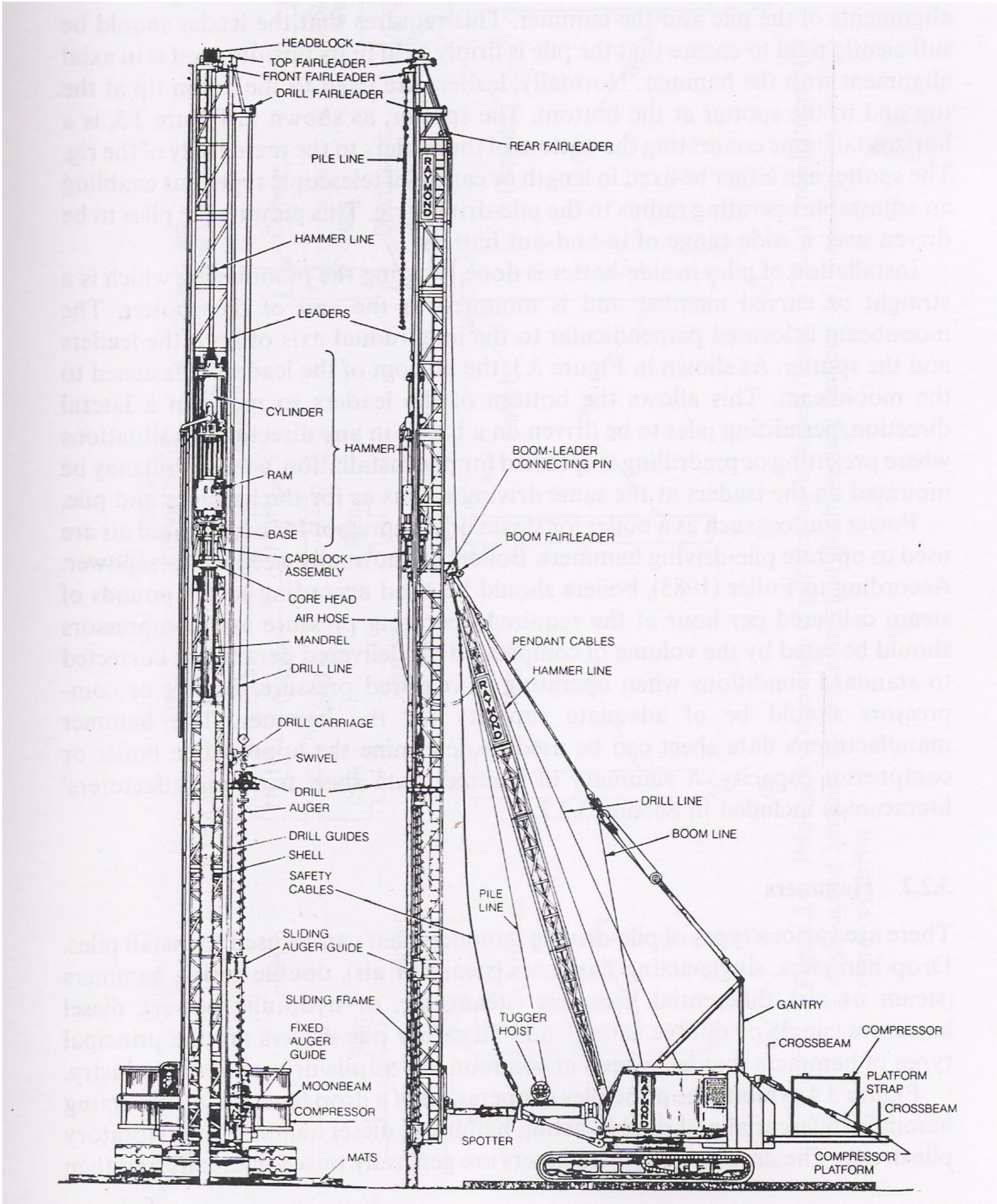

Figure 2.1 : Typical pile-driving rig:Various components labeled

(after Fleming,1996)

2.2.2 Rigs

Figure 2.1 presents various components of a typical pile-driving rig. Fleming later on described the typical pile-driving rig concisely. The leaders will hold the pile in position and maintain the axial alignments of the pile and the hammer. The leaders needed to be rigid to ensure the pile is firmly held in its position and is in axial alignment with the hammer. Fleming added that leaders are normally fixed to the boom tip at the top and to the spotter at the bottom. The spotter is a horizontal frame connecting the bottom of the leaders to the main body of the rig. The spotter is either fixed in length or can be of telescopic type thus enabling an adjustable operating radius to the pile driving rig. This permits the piles to be driven over a wide range of in-and-out batters. Boiler for steam or compressor for compressed air is used as a power source to operate pile-driving hammers. Boilers are normally sized by horsepower. According to Fuller(1983), boilers should be sized according to the pounds of steam delivered per hour at the required operating pressure and compressors should be rated by the volume of compressed air delivered per minute.

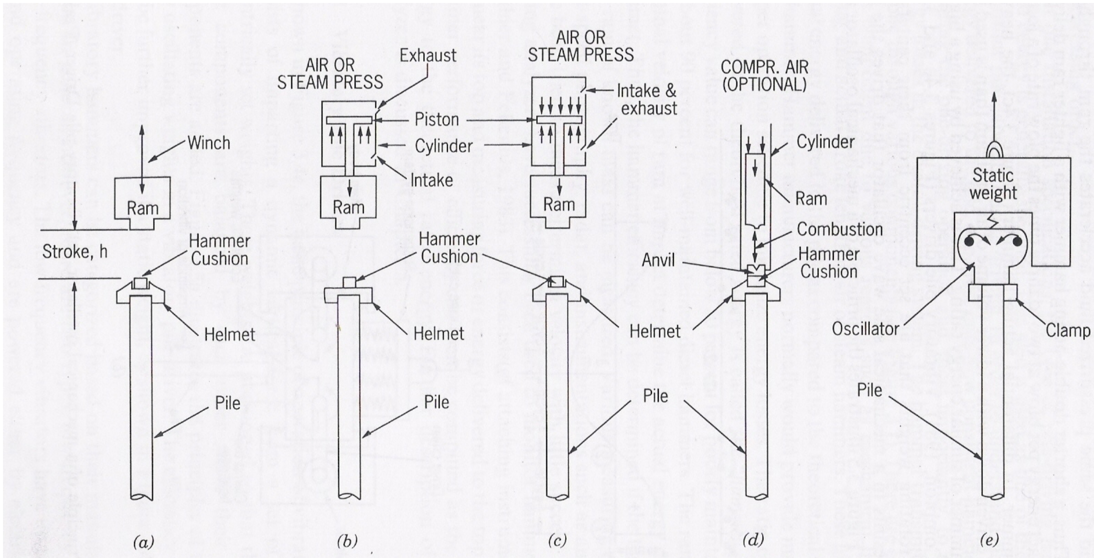

Figure 2.2 : Principles of operation of pile-driving hammers(after Versic, 1977). (a) Drop hammer, (b) single-acting hammer, (c) differential and double-acting hammer. (d) diesel hammer and (c) vibratory driver

2.2.3 Hammers

There are various types of pile-driving hammers that are being used to install piles. Drop hammers, single-acting hammers(steam or air), double-acting hammers(steam or air), differential hammers (steam, air, or hydraulic power), diesel hammers (single or double acting), and vibratory pile drivers are the types of hammers that have been in common use as pile drivers in the industry.

Figure 2.2 shows the principles of operation of a drop hammer, single-acting hammer, differential and double-acting hammers, diesel hammer, and vibratory pile driver. The drop of gravity hammers are raised manually and then impact to the pile is delivered by its free fall. The energy is calculated by multiplying the weight of the hammer by its fall.

Generally, in pile installation specifications, the type of pile-driving hammer and the rated energy is specified. In order to understand clearly the actual energy delivered to the pile, one must note how consistent hammer performance is during the pile driving operation and, to understand the energy losses due to the process. The hammer transmits energy to pile through various components. There are certain loses at each component due to various reasons such as mechanical friction, valving timing, and actual stroke length in air or steam hammers. These losses will reduce the actual energy delivered to the pile as compared to the theoretical calculated energy of the hammer. The ratio of actual energy delivered to the theoretical calculated energy is called the "hammer efficiency". The efficiency value ranges from below 50 percent for poorly maintained hammers to about 90 percent for well-maintained diesel hammers. The ram's mass and the terminal velocity of ram at impact determine the actual energy delivered by the hammer. Thus, the hammer efficiency can be determined if the terminal velocity of a ram of known mass can be measured. Various measuring devices such as high-speed photography, radar, and instrumentations such as an accelerator have been tried to measure terminal velocity with little success (Elson, 1996). Recently, pile-driving analyzers have successfully been used to monitor hammer performance. This is done by attaching instrumentation to the pile near its top and measuring force or energy delivered to the top of the pile. Then, the hammer performance or efficiency can be computed as the ratio of actual energy to the theoretical rated energy.

2.3 ACTION OF SOILS AROUND A DRIVEN PILE

Pile driving activity will remold the soil around the pile. Different type of soil respond to pile driving differently.

2.3.1 Clay

The effects of pile driving in clays are listed in four major categories, De Mello(1969), as follows:

1. Remolding or disturbance to structure of the soil surrounding the pile
2. Changes of the state of stress in the soil in the vicinity of the pile
3. Dissipation of the excess pore pressures developed around a pile
4. Long term phenomena of strength regain in the soil

2.3.2 Sand

A pile in sand is usually installed by driving. According to (Randolph, 1994),
the vibrations from a driving a pile in sand has two effects:

1. Density the sand,
2. Increase the value of lateral pressure around the pile

Through penetration tests in sand prior to pile driving and after pile driving indicate significant densification of the sand for distances as large as eight diameters away from center of the pile. Driving of a pile displaces soil laterally and thus increases the horizontal stress acting on the pile.

2.4 DISPLACEMENTS OF GROUND AND BUILDINGS CAUSED BY PILE DRIVING

Pile driving causes a heave of the clay surrounding the pile, excess pore pressures, consolidation of the clay and dissipation of pore pressures. This movement may have a significant effect on adjacent structures. To avoid this situation bored piles are used.

According to a study by Fleming (1994), the ratio of the total volume of initial heave to the total volume of driven piles within a foundation has been found to be about 100 percent by Adams and Hanna (1970) for steel H-piles in a firm till, 50 percent for piles in clay by Hagerty and Peck (1971), 60 percent by Avery and Wilson (1950) and 30 percent by Orrje and Broms (1967) for precast concrete piles in a soft, sensitive, silty clay (Poulos and Davis, 1979). Orrje and Broms (1967) found that the heave near the edge of the foundation was about 40 percent of the value at the center. Adams and Hanna (190) found that the maximum radial movement was about 1.5 in. and the maximum tangential displacement about 0.4 in. while the average vertical heave was about 4.5 in.. As with vertical heave, very small lateral movements occurred beyond the edge of the group. Lambe and Horn (1965) reported the movement of an existing building due to driving of piles for the new building. It was found that, at the near corners of the existing building, a heave of about 0.3 in. occurred during driving. Despite the fact the piles were preaugered to within about 30 ft. of their final elevation, excess pore pressures of about 40 ft. of water were measured near the corner of the existing building, even before a substantial building load was carried by the piles (Fleming, 1996).

2.5 GROUND VIBRATIONS AND THEIR PROPAGATION

Vibrations propagate from a piece of construction equipment through the ground by means of Rayleigh (surface) waves and secondarily by body (shear and compressional) waves. The amplitude of these waves diminishes with distance from the source. This attenuation is due to two factors: expansion of the wave front (geometrical attenuation) and dissipation of energy within the soil itself (material damping). The rate of geometrical attenuation depends upon the type of wave and the shape of the associated wave front. Material damping is generally thought to be attributable to energy loss due to hysteresis, perhaps caused by internal sliding of soil particles. In addition to other factors, the amount of material damping that occurs is a function of the vibration amplitude; this discussion will be limited to what are generally considered low-amplitude cases. Material damping in soil is a function of many parameters, including soil type, and moisture.

2.6 PILING-INDUCED GROUND VIBRATIONS

According to (White, 2000), piling-induced ground vibrations can cause human disturbance and structural damage. White added that, round vibrations are quantified by the peak velocity of particles in the ground as they are disturbed by the passing wave (peak particle velocity- ppv). White described that instantaneous particle velocity consists of three orthogonal components which are usually measured independently using a tri-axial geophone. The most commonly used definition of peak particle velocity is the simulated resultant ppv; this is the vector sum of the maximum of each component regardless of whether these component maxima occurred simultaneously (Hiller & Hope, 1998). The vibrations induced by dynamic piling methods typically influence a zone stretching 10- 50m from the operation, and can be easily measured using geophones.

The Eurocode 3 provides values for guidelines of acceptable human and building exposure to ground vibrations depending on the length from the vibration source.

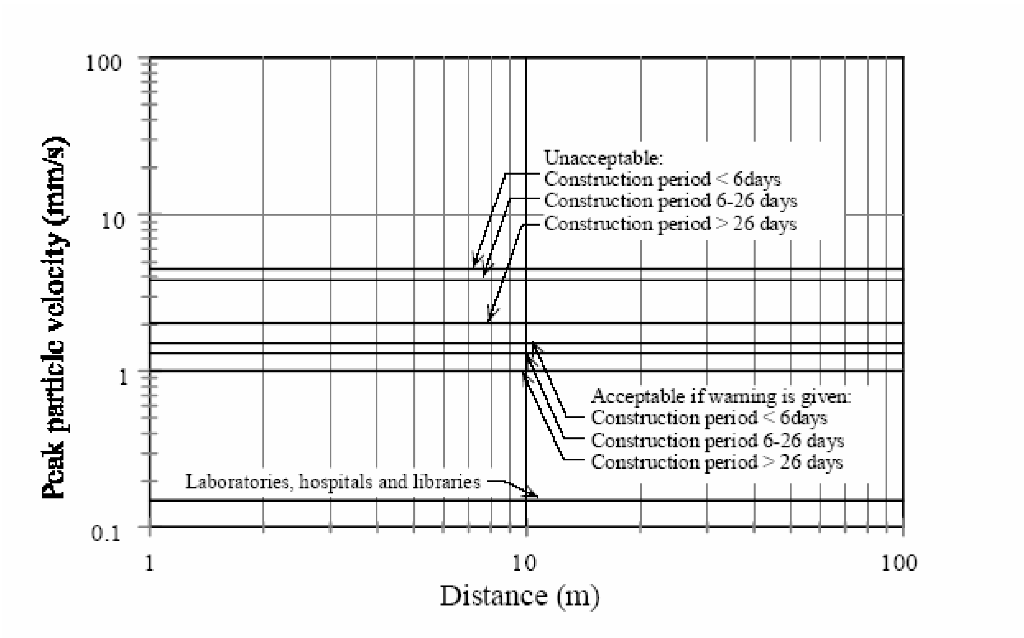

Figure 2.3: Maximum acceptable vibrations to prevent human disturbance (after Eurocode 3).

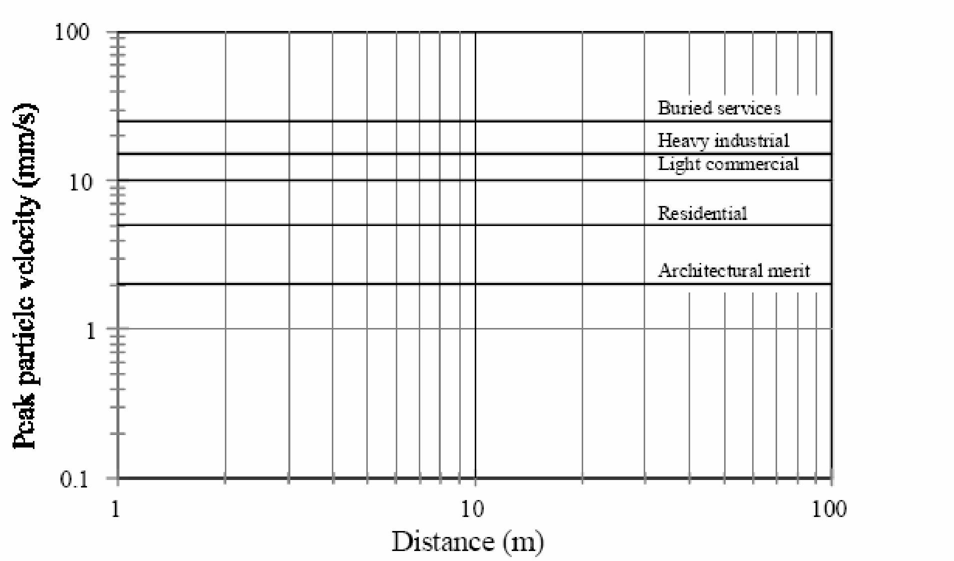

Figure 2.4 : Maximum acceptable vibrations to avoid structural damage (after Eurocode 3).

Measurements of ground vibrations during dynamic piling has been tabulated (Head & Jardine, 1992). The ground vibrations reduce in an almost linear fashion with log radius.

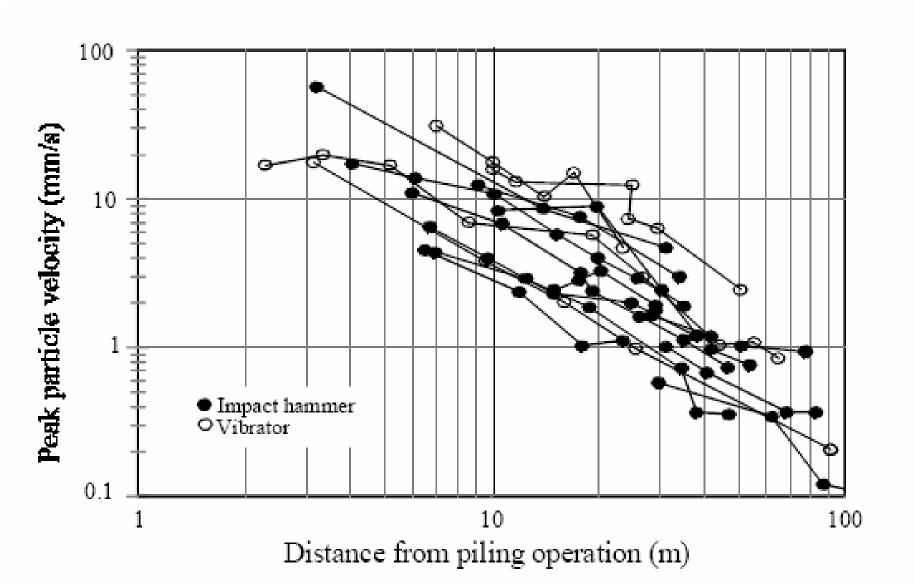

Figure 2.5 : Measured ground vibrations during dynamic piling (data from Head & Jardine, 1992).

CHAPTER 3

METHODOLDOGY

Site experience is crucial for one to appreciate the data from the vibration monitoring. So, the first task is to do a vibration monitoring at any construction site which is doing piling work. There were a few construction site in Parit Buntar which was doing piling work but permission were not given by these site's project managers to do any observation. Fortunately, there was a construction at Teluk Intan which was doing piling work. This particular site is constructing a new bridge near Teluk Intan town. On the day of the observation, the piling work involves piling for the embankment of the bridge. These piles were round piles with a diameter of 500 mm. It uses a hammer with a weight of 7 tones. Observation of the vibration was done from the initial part of piling process using an instrument called Blastronics µMX Micro Meter. The *Blastronics µMX Micro Meter* is specially designed for field measurements of vibration and overpressure. The instrument was provided by The School of Civil Engineering of U.S.M. with the authorization from Prof. Madya Dr. Ir. Razip Bin Selamat. The instrument is small in size – weighing under 2 kg, and with maximum dimension less than 20 cm, it's very easily mobilized. It is built with a custom alloy cast casting, optional protective helmet and mil – spec connectors to ensure durability. It is supported by battery which needs to be charged overnight to ensure its lasting performance throughout the day after. It has also a backup energy supplier which is the solar panel that can be a good substitute of energy provider. The instrument must be stiffly connected to the substrate without chance for wobble or secondary motion. Its spikes are pushed all the way in the ground so that the base is firmly in contact with the surface. Then the bubble of the instrument is checked to make sure it is centered. The fuse is fitted into the fuse holder at the rear of the monitor. The monitor on the front panel will beep and a list of Menu will appear on the monitor.

CHOOSE: System

Test Run Data

Figure 3.1: Main menu of The Blastronics µMX Micro Meter

In order to change the trigger level, the “Geo” Mode is selected . The trigger level is then set at 1 mm/s to avoid spurious events. Then, “Test” Mode is selected. “Test” Mode is used to see what the background vibration and pressure levels are. Observation started at a distance of 2 meters from the piling point and then moved on to the fourth meter, then to the sixth and so on. This is done in a straight line. Values from a point near the piling point were taken right to the point furthest where values can still be gained. In this particular site, the data which is managed to be gained is up to 14 meters in length from the piling point.

During the observation, the site’s technician helped to synchronize between the piling machine and the data collection in order to gain the data from the initial stage of the piling process right to the end.

For the analysis, a set of data of an observation of piling vibration which was conducted at Route 6 Extension Works, Penang is analyzed. The observation was done on the 12th February 2004. It consists of 5 sub sets of data. These data consist of data taken 20 m, 23 m, 30 m, 39 m and 70 m from the vibration point.

Using these data, I then tabulated 6 types of graphs which is:

a) Radial, Transverse and Vertical Wave Over Time
b) Vector Sum Values Over Time
c) Radial, Transverse and Vertical Wave Value Of One Particular Segment Over Depth
d) Vector Sum Wave Value Of One Particular Segment Over Depth
e) Radial, Transverse and Vertical Wave of 3 Segments Over Depth
f) Vector Sum Value of 3 Segments Over Depth
g) Average Radial, Transverse and Vertical Wave Values Over Length
h) Average Vector Sum Value Over Depth

Figure 3.2 : Collecting data using Blastronic Micro Meter at a site in Teluk Intan.

CHAPTER 4

RESULTS

4.1 Introduction

The vibration wave from the piling point consists of three types of wave forms which is the radial wave, transverse wave and vertical wave. The purpose of dividing the vibration wave into these three types of waves is mainly for analyzing purpose

$$\textbf{Vector Sum}^2 = \textbf{Radial Wave}^2 + \textbf{Transverse Wave}^2 + \textbf{Vertical Wave}^2 \quad \textbf{(4.1)}$$

Vector sum value is taken as the characteristic value for describing the level of vibration intensity for any particular location.

4.2 Graph of Radial, Transverse and Vertical Wave Over Time

The graphs below consist of graphs which are tabulated from the radial, transverse and vertical wave values which had been collected from 5 points of different distance (20m, 23m, 30m, 39m and 70m) from the vibration source over time. The values will show the magnitude of three type of waves which is experienced by the soil particles in the particular area throughout the particular time.

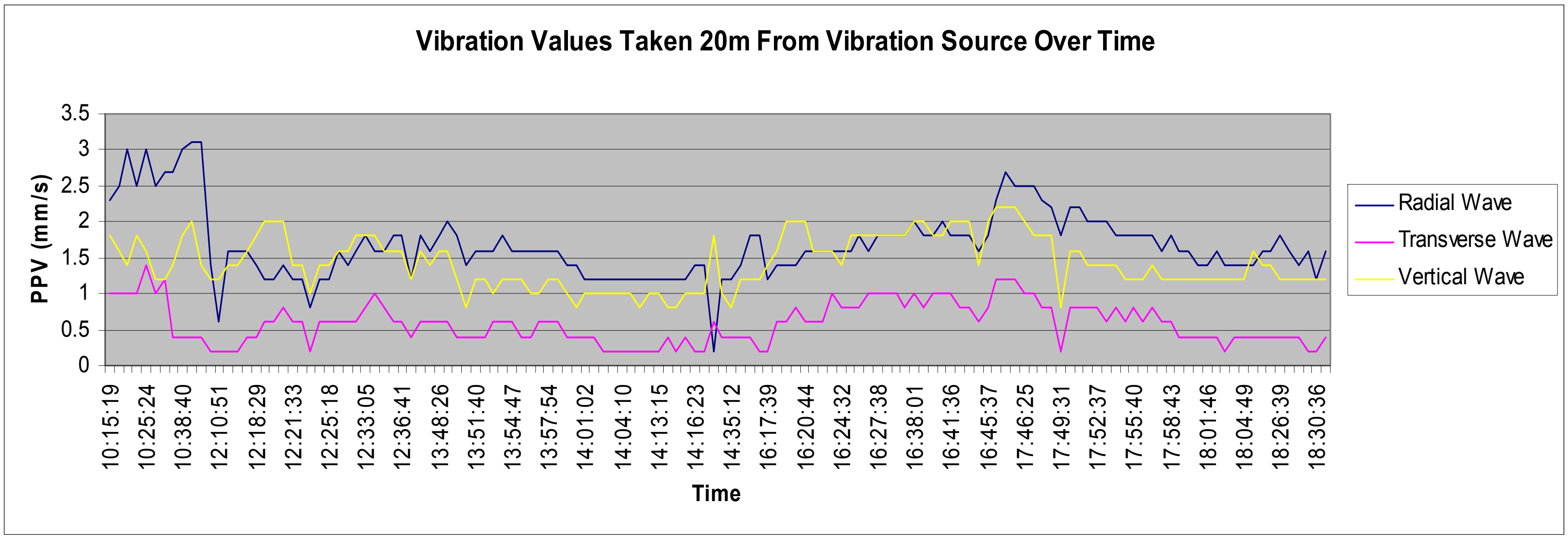

Figure 4.2.1 : Vibration Values Taken 20m From The Vibration Source Over Time

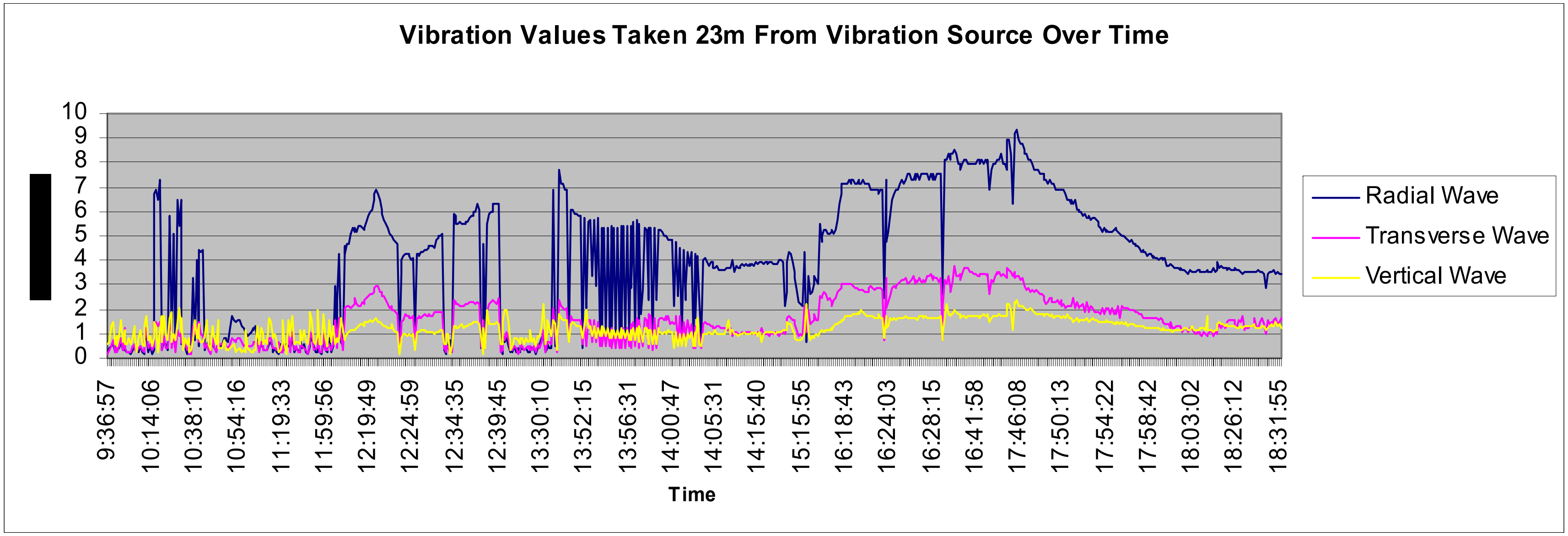

Figure 4.2.2 : Vibration Values Taken 23m From The Vibration Source Over Time

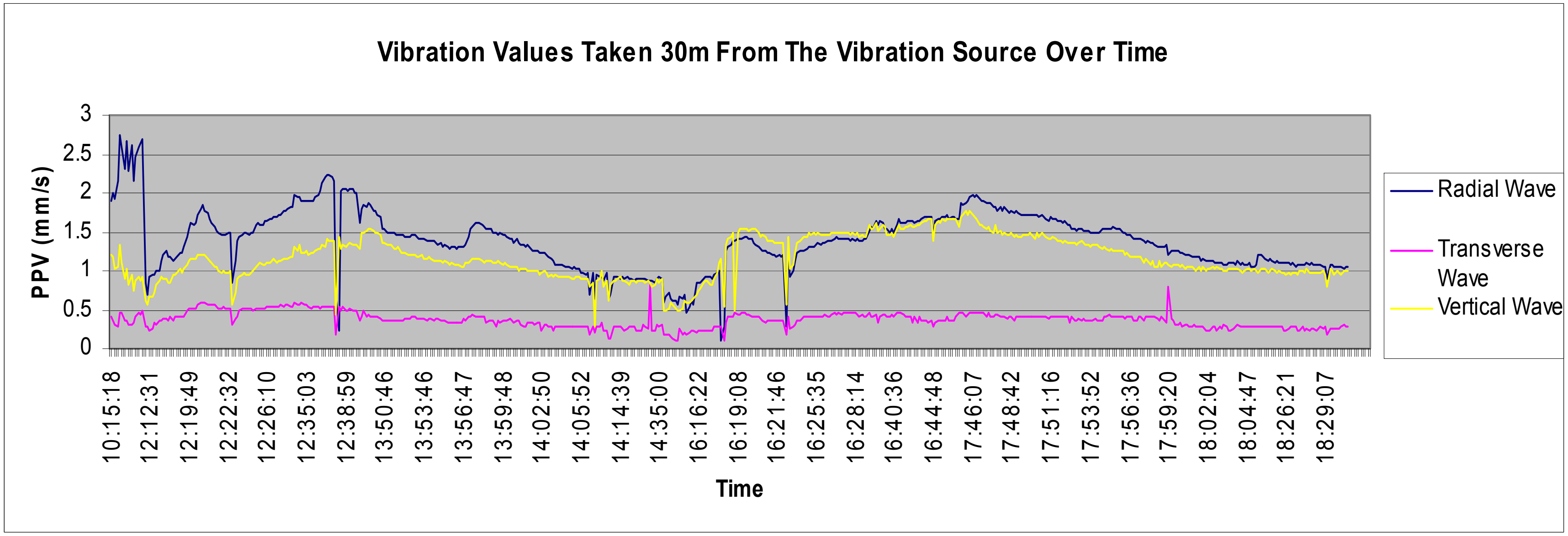

Figure 4.2.3 : Vibration Values Taken 30m From The Vibration Source Over Time

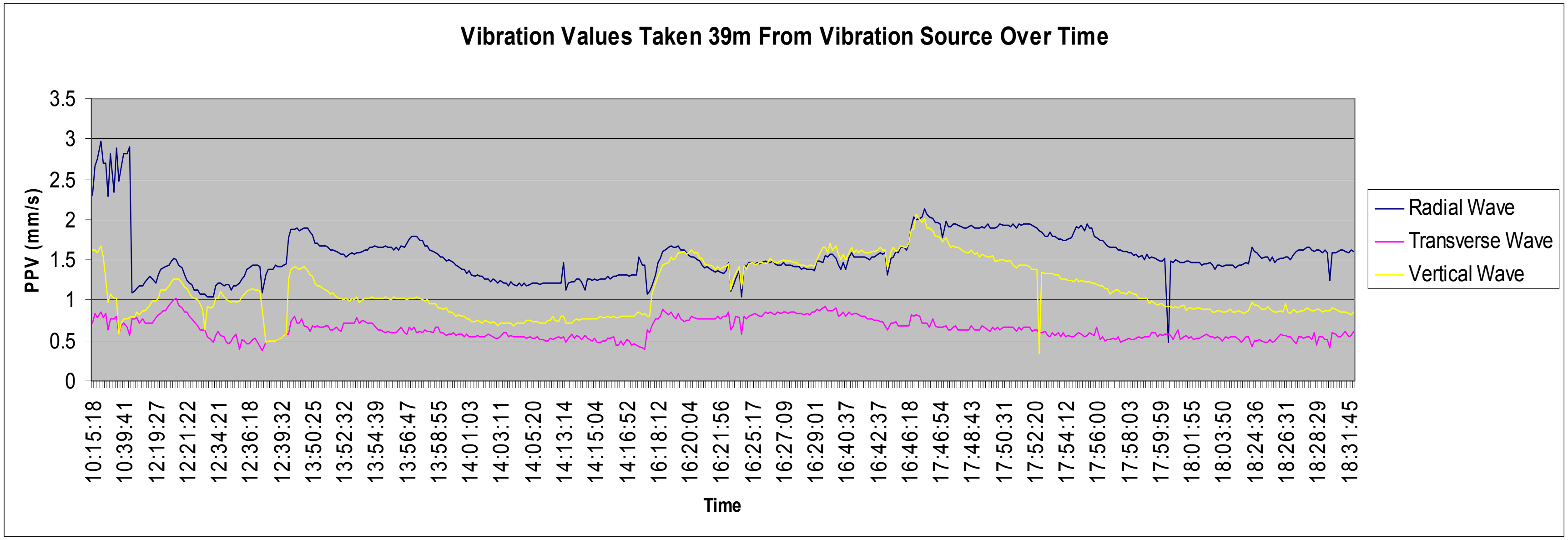

Figure 4.2.4 : Vibration Values Taken 39m From The Vibration Source Over Time