AN INVESTIGATION ON VIBRATION IMPACT DURING CONSTRUCTION BORE PILING ACTIVITY ON PUBLIC RECEPTORS IN KLANG VALLEY MASS RAPID TRANSIT SERDANG PROJECT

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RESEARCH PROJECT REPORT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING (SAFETY, HEALTH AND ENVIRONMENT)

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
KUALA LUMPUR

2018

UNIVERSITY OF MALAYA

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Matric No: KQD160015

Name of Degree: Master of Safety, Health and Environmental Engineering

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ABSTRACT

Bored piling activity was found to produce low impact energy that could induce vibrational impact towards existing surrounding structures. The vibrational energy could cause disturbances or annoyance to the occupants of surrounding buildings that could affect the occupant’s quality of life. The Klang Valley Mass Rapid Transit (KVMRT) construction in Taman Serdang Raya has fulfilled the criteria of urban development where a high density of buildings were located. This study aims to investigate the vibration impact during KVMRT construction bored piling activity on public receptors within the vicinity of the project site in Taman Serdang Raya. The bored piling activities were monitored by using a vibration level meter in three designated points all across the construction site. The three monitoring points selected were the closest receptor of the bored pile points which is known by its pier’s name, SRN01, SRN10 and SRN22. A baseline study was conducted prior to the bored pile activity. The baseline study was conducted to obtain the existing ambient vibrational condition of the monitoring points. The baseline data is then compared to the Department of Environment (DOE) vibration’s guideline as a benchmarking data to be compared with. Three baseline data were observed to exceed the DOE’s guideline limit which is x axis of SRN01, z-axis of SRN01 and z-axis of SRN10. The baseline data were used as comparison for the bored pile data along with the DOE’s guideline limit. The actual vibration bored pile results have shown two breaches which have exceeded both of the baseline data and DOE’s guideline limit. The exceedances occurred at SRN22 y-axis and SRN22 z-axis. Both of the exceedances were recorded at the same exact time and were contributed by the bored piling activity. Wilcoxon Signed Ranks test conducted has found six out of nine measurement conducted have significant differences between baseline data and bored pile data with two of them achieve a 95% confidence level ($p < 0.05$) and four have achieved a 99% confidence level

($p < 0.01$). This study have shown a significant changes of ambient vibration level during bored piling activity was conducted which could provide a basis for vibrational analysis of construction activity.

ABSTRAK

Aktiviti cerucuk gerek didapati menghasilkan kesan tenaga rendah yang boleh menghasilkan getaran terhadap struktur persekitaran sedia ada. Tenaga getaran boleh menyebabkan gangguan dan ketidaksenangan kepada penghuni bangunan di sekeliling yang boleh menjejaskan kualiti hidup penghuni bangunan. Pembinaan Transit Aliran Massa Lembah Klang (KVMRT) di Taman Serdang Raya telah memenuhi kriteria pembangunan bandaraya di mana ketumpatan kuantiti bangunan yang tinggi terletak. Kajian ini bertujuan untuk mengkaji kesan getaran semasa kerja cerucuk gerek dalam pembinaan KVMRT terhadap penerima awam di sekitar kawasan tapak projek tersebut di Taman Serdang Raya. Aktiviti cerucuk gerek telah diukur menggunakan meter tahap getaran di tiga titik yang ditetapkan bagi melambangkan keseluruhan kawasan tapak bina. Tiga titik pemantauan yang dipilih adalah penerima paling dekat dengan titik cerucuk gerek yang dikenali dengan nama tiang yang akan dibina iaitu SRN01, SRN10 dan SRN22. Kajian penanda aras telah dijalankan bagi mendapatkan keadaan getaran ambien semasa di titik pemantauan. Data penanda aras kemudiannya dibandingkan dengan garis panduan getaran oleh Jabatan Alam Sekitar (DOE) sebagai data penanda yang akan dibandingkan bersama. Tiga data penanda aras telah melebihi had garis panduan DOE iaitu paksi-x di SRN01, paksi-z di SRN01 dan paksi-z di SRN10. Data penanda aras kemudiannya dibandingkan dengan data cerucuk gerek bersama dengan had garis panduan oleh DOE. Data yang melebihi had telah berlaku di paksi-y SRN22 dan paksi-z SRN22. Kedua-dua data yang melebihi had itu telah dicatatkan berlaku pada masa dan cerucuk gerek yang sama. Ujian Wilcoxon Signed Ranks yang dijalankan telah mendapati enam dari Sembilan ukuran mempunyai perbezaan yang signifikan di antara data penanda aras dan data cerucuk gerek dengan dua daripadanya mencapai tahap keyakinan 95% ($p < 0.05$) dan empat lagi telah mencapai tahap keyakinan 99% ($p < 0.01$). Kajian ini telah

menunjukkan perubahan yang signifikan terhadap tahap getaran ambien semasa kerja cerucuk gerek dijalankan yang boleh menyediakan asas analisis getaran kerja pembinaan.

ACKNOWLEDGEMENTS

I would like to express highest gratitude to the Almighty God for blessing, love, oppurtunity, health, and mercy to complete this research report entitled "An Investigation on Vibration Impact during Construction Bored Piling Activity on Public Receptors in Klang Valley Mass Rapid Transit Serdang Project".

In this valuable chance, I would like to express my gratitude and appreciation to all of them. First, my deepest appreciation for my beloved parents, my mother Che Kalsom binti Murad for the endless love, pray and support, my father Mohd Yatim bin Mohd Noor for the support and courage.

I would like to thank and express my deep and sincere gratitude to my supervisor Dr. Nasrin Aghamohammadi, Department Of Social And Preventive Medicine, Faculty Of Medicine for her supervision, advice and guidance

Special thanks to a very special person, my wife, Sufinas for her love, support and understanding during my pursuit of Master degree. Thank you to my father in law and mother in law for their love and moral support.

Last, but far from least, my sincere thanks to who are not mentioned personally here, without their patience, guidance, support and cooperation this report could have never been written.

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LIST OF SYMBOLS AND ABBREVIATIONS

%	:	Percentage
DEIA	:	Detail Environmental Impact Assessment
DOE	:	Department of Environment
Et al	:	Et alii
etc	:	et cetera
Hz	:	Hertz
ISO	:	International Standard Organization
KVMRT	:	Klang Valley Mass Rapid Transit
m	:	Metre
mm/s	:	Millimetre per second
PPV	:	Peak Particle Velocity
VLM	:	Vibration Level Meter

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

1.1 Background Study

Construction activities are well-known to generate a lot of environmental impacts (Ding, 2008; Zolfagharian et al., 2012; Lawrence, 2015). According to the ISO 14001 (2015), environmental impact was defined as 'change to the environment, whether adverse or beneficial, wholly or partially resulting from an organization's environmental aspects'. The impact to the environment includes the annoyance or disturbance towards the public receptors such as surrounding building structures and human perceptions.

In the early stage of construction activities, the foundation of the built structures was installed by using piling methods whether it is a driven pile or bore pile. According to Poulos & Davis (1980), driven pile is a piling method where a precast pile is driven into the soil and bore pile is the excavation and boring of pile core and concrete pour along with its reinforcement. The used of piling work as foundations have been discussed in 1970s and early 1980s by Vesić (1977) and Poulos & Davis (1980) to date (Viggiani et al., 2012; Ma, 2017) where it has been agreed that it could hold heavy loads by buildings or structures and transferred it to the neighboring soils. In the process of constructing the foundation, the environmental aspects identified include green house gas emissions (Sandanayake et al., 2015), dust emissions (Dong & Ng, 2015), noise emissions and vibration (White et al., 2002; Massarsch & Felelnius, 2008).

The driven pile is well known to generate high noise and vibration emission (BSI, 1992; Massarsch & Felelnius, 2008; Svinkin, 2017) where the hammer blow towards the precast pile would transmit impulses to the surrounding area and cause vibrations. To overcome this, construction in urban areas use bored piling method where chiselling hammers were used that produce low impact energy. However, this method of bored piling could cause the low impact energy to produce stress waves to the ground and could induce disturbances to the existing surrounding structures (Balan et al., 2016). The disturbance to the surrounding structures is termed as 'structural vibration' where it can be perceived by the occupants that could affect their quality of life, in term of annoyance and disturbance (BSI, 2008).

Vibration has been defined by DOE Malaysia (2007) as 'an oscillatory motion of solid bodies of deterministic or random nature described by displacement, velocity, or acceleration with respect to a given reference point'. Three directions are used to measure the vibration as a function of time, which are vertical, radial and tangential direction (BSI, 1992) as shown in figure 1.1 or generally known as x, y and z axis (DOE Malaysia, 2007).

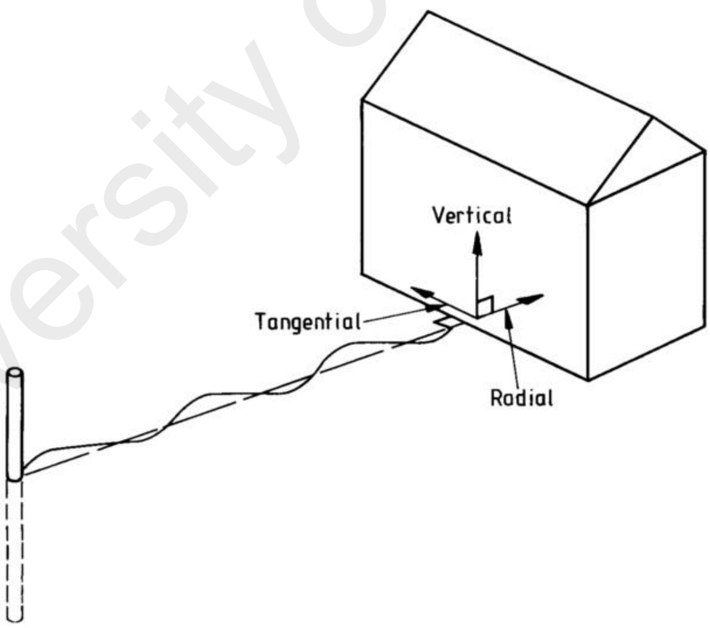

Figure 1.1: Directions of vibration measurement

Source: (BSI, BS 5228-4:1992 - Noise Control on Construction and Open Sites - Part 4: Code of Practice for Noise and Vibration Control Applicable to Piling Operations, 1992)

1.2 Problem Statement

Klang Valley Mass Rapid Transit (KVMRT) Line 2 Project has been prescribed under Activity 16 of the Environmental Quality (Prescribed Activities) (Environmental Impact Assessment) Order of 1987. The Detailed Environmental Impact Assessment (DEIA) has been conducted where it was found that the viaduct constructed will pass several public amenities, residential, commercial and heritage area (ERE Consulting Group, 2015). Package V205 begins in Kampung Muhibbah, Kuala Lumpur to Serdang Raya, Selangor. Department of Environment (DOE) has approved the DEIA with several conditions where the compliance with 'The Planning Guidelines for Vibration Limits and Control in the Environment (DOE Malaysia, 2007)' is a must.

The piling activity during the project construction could produce vibration towards surrounding area (Balan et al., 2016) which could affect the surrounding structural receptors such as public facilities, residential and commercial area. This vibrational impact could cause annoyance or structural damage to the receptors. DOE Malaysia (2007) has provided a guideline in which a recommended vibrational limits were stated.

Since the vibrational limits are provided in quantitative manner, the measurement has to be conducted using monitoring instrumentation to obtain the vibrational level from the piling activities. The result obtained is then compared to the guideline provided by DOE to measure the actual compliances of vibration level generated by the piling activity. This study is conducted to investigate the compliances of vibrational impact during bored piling activity with the regulatory requirement set by DOE.

1.3 Objectives

1.3.1 Main Objective

To investigate on vibration impact during construction bored piling activity on public receptors in Klang Valley Mass Rapid Transit Serdang project

1.3.2 Specific Objectives

1.3.2.1 To quantify vibrational impact of bored piling activities toward public receptors

1.3.2.2 To assess the vibration levels of bored piling activities according to regulatory guideline

1.3.2.3 To explore the differences between vibration baseline data and bored pile activity

1.4 Study Justifications

The rapid urbanisation in Klang Valley has caused the government to plan develop an efficient public transport system within the city. Public transport infrastructure is being built all across Klang Valley where the line for the viaduct construction is constructed within the vicinity of residential and commercial area, which consist of buildings that involve human activity within it. The construction of viaduct involves a process of foundation installation where a bore pile is normally used to support the whole structures on top of it.

The process of ground boring have been cited to cause several disturbances toward surrounding building occupants within the vicinity (Waddington et al., 2014) such as the generation of noise and vibration. The high magnitude of vibration can be an annoyance to the building occupants and may affect their quality of life. Since the perception of vibration can be the combination of both physiology and psychology (Silva, 2007), a measurement should be recorded to measure the exact vibrational level to the receptor. By studying the magnitude of the vibration impact towards the building, the understanding of vibrational impact to the environment can be enhanced which may help future researchers to learn further of this topic. The knowledge of this topic could also be used to develop a mitigation strategies and early detection measures toward the annoyance and disturbance of the vibrational impact.

Therefore, the purpose of this project is to study the vibration impact by measuring the magnitude of vibration before and during the bored piling activity to obtain a relationship between the existing, ambient vibration and the additional vibration caused by the bored piling activity. The analysis consisted the comparison between the bored piling vibration data with the local regulatory standard and the existing vibration level.

1.5 Significance of Research

This study provides a basic database for bored pile vibration study and basis for the improvement of guidelines for planners, decision makers or engineers to improve the technique and control measures of construction activity in term of annoyance and disturbance toward public receptors.

1.6 Study Outline

This research report contains five main chapters. Begin with Chapter 1, introduction to the study is discussed and followed by a series of literature review in Chapter 2. Chapter 3 provides the methodology of the research conducted and the results and discussions are presented in Chapter 4. Finally, Chapter 5 concludes the report of this research project. A brief introduction of each chapter is shown as in figure 1.2.

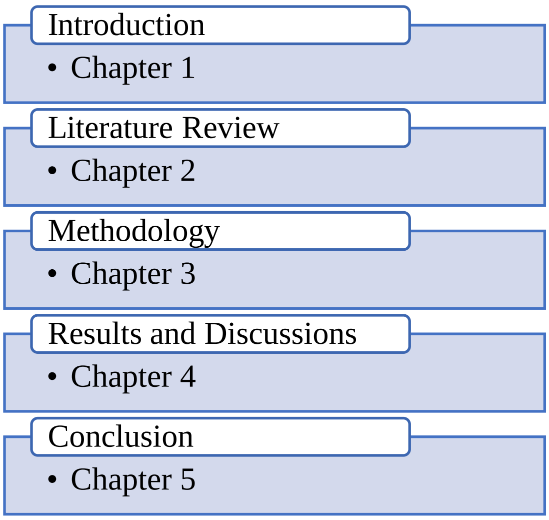

Figure 1.2: Outline of study

CHAPTER 2: LITERATURE REVIEW

2.1 Basic Principles of Vibration

A simple way to describe vibration is the oscillatory motion of an object (Griffin, 2012). The oscillatory motion is a movement of an object from the original point to another reference point and back to its original point repetitively. DOE Malaysia (2007) has defined vibration as 'an oscillatory motion of solid bodies of deterministic or random nature described by displacement, velocity, or acceleration with respect to a given reference point'. Griffin (2012) has described that the deterministic nature is predictable from the previous information of oscillation while random nature can only be characterised as having some statistical properties.

Three types of vibrations were identified which are continuous vibration, impulsive vibration and intermittent vibration (Department of Environment and Conservation NSW, 2006). Continuous vibration is an uninterrupted vibration for a defined period and is usually measured throughout daytime or night time. Impulsive vibration is a rapid or sudden vibrational build up to a peak, followed by a decay that may or may not involve several cycles of vibration with a very short duration. Intermittent vibration is defined as 'interrupted periods of continuous or repeated periods of impulsive vibration, or continuous vibration that varies significantly in magnitude' (Department of Environment and Conservation NSW, 2006; BSI, 2008).

The measurement of vibration can be conducted by measuring either displacement, acceleration, or frequency of the oscillatory motion. As the object is moved in oscillation, the magnitude can be defined by the velocity and direction of the oscillation movement

(Griffin, 2012) as it is more related to the energy involved in the motion. The velocity unit (mm/s) will be used as reference throughout this paper as it is used as guideline reference by the Malaysia Department of Environment (DOE Malaysia, 2007). The usage of velocity as a reference unit is used due to the measurement of the peak displacement over time which is the maximum velocity in one direction in a given period or the measurement interval time (Griffin, 2012). The peak velocity measured is called Peak Particle Velocity (PPV).

The perception of a body (receptor) towards vibration can be measured through three different orthogonal axes, which are radial axis or x-axis (back to chest), tangential axis or y-axis (right side to left side), and vertical axis or z-axis (foot to head) (Department of Environment and Conservation NSW, 2006). All of the orthogonal axes are depicted as in figure 2.1.

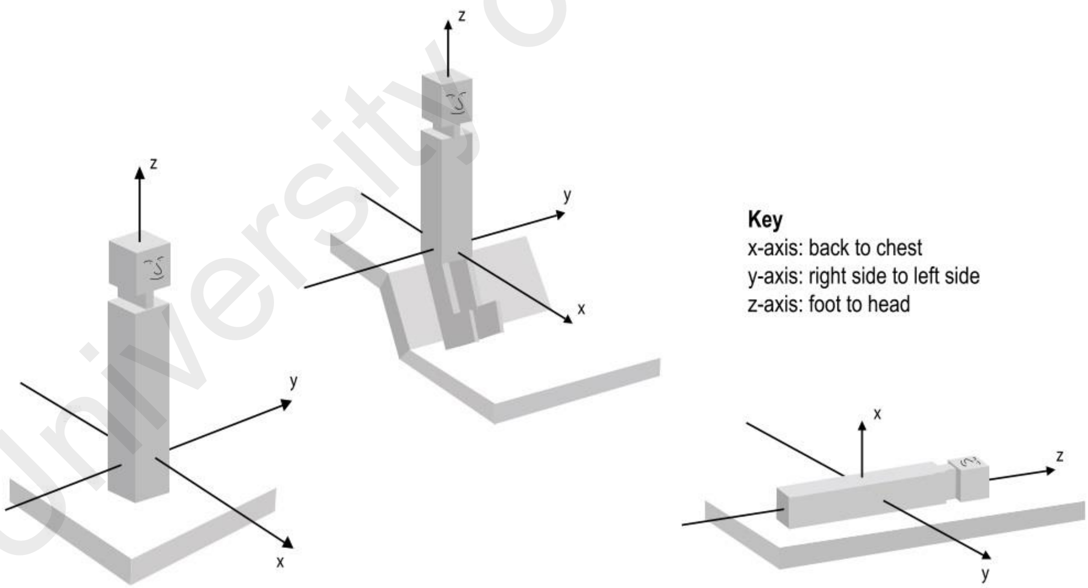

Figure 2.1: Orthogonal axes of vibration's perception

Source: (Department of Environment and Conservation NSW, 2006)

The measurement of vibration is conducted in horizontal and vertical plane. As shown in figure 2 above, the horizontal plane of a standing and sitting person is x and y axis where for people in lateral position (lying down), the horizontal plane is y and z axis.

Within this paper, the measurement that will be used as a reference unit is velocity (mm/s) in the direction of the three aforementioned axes above. In this study of monitoring the impact of vibration towards a building (including the occupants), the axes of standing position will be used as the building is in upright position. Since the bored piling activity is considered as intermittent source, the expected graph would be irregularly increase and decrease as the measurement go through time.

2.2 Types of Vibration

As per discussed in sub-chapter 2.1, there are three types of vibration in term of the vibrational time pattern which are continuous, impulsive and intermittent vibration. However, in term of oscillatory motion, it can be divided into two types which are deterministic motion and random motion (Griffin, 2012). It is due to the predictability of the oscillations either it can be determined or happened in random motion. Both deterministic motion and oscillatory motion can be further sub-divided as shown in figure 2.2.

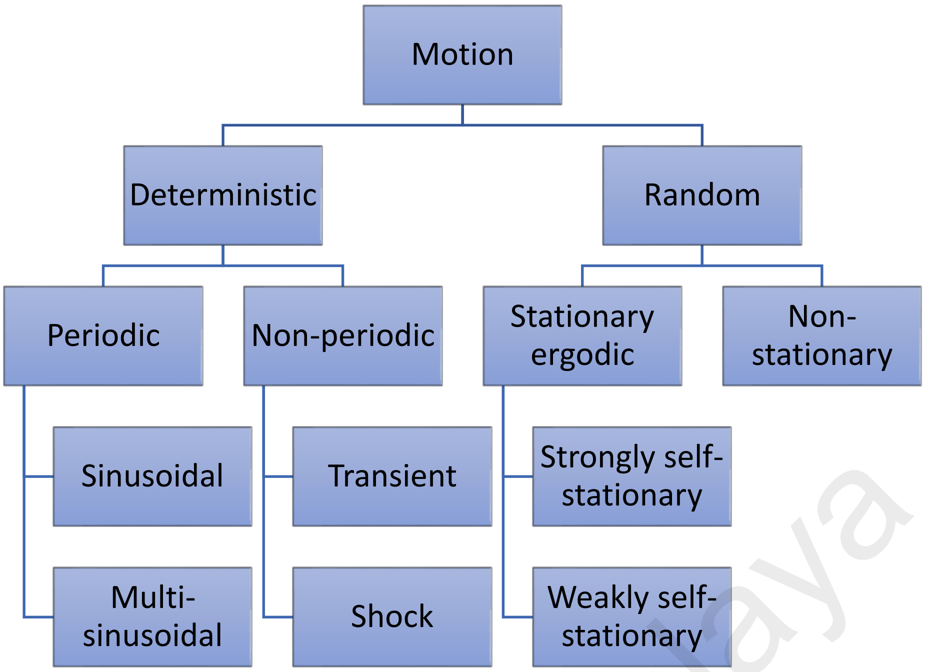

Figure 2.2: Types of Oscillatory Motion

Source: (Griffin, 2012)

Sinusoidal vibration provides a single frequency of motion which could be studied to obtain the possible response of a certain vibrational frequency. In real practice, the imperfection in vibrational generators could produce a multiple mixture of sinusoidal frequencies which is multi-sinusoidal. As explained by Griffin (2012), only few experimental studies have been conducted on non-periodic deterministic motion. Random vibrational motion is usually encountered in everyday activities such at work or at home. Stationary random vibration could be measured from a sufficiently long period at a pre-identified location. The waveforms or oscillatory motion of all the vibrational types are shown as in figure 2.3.

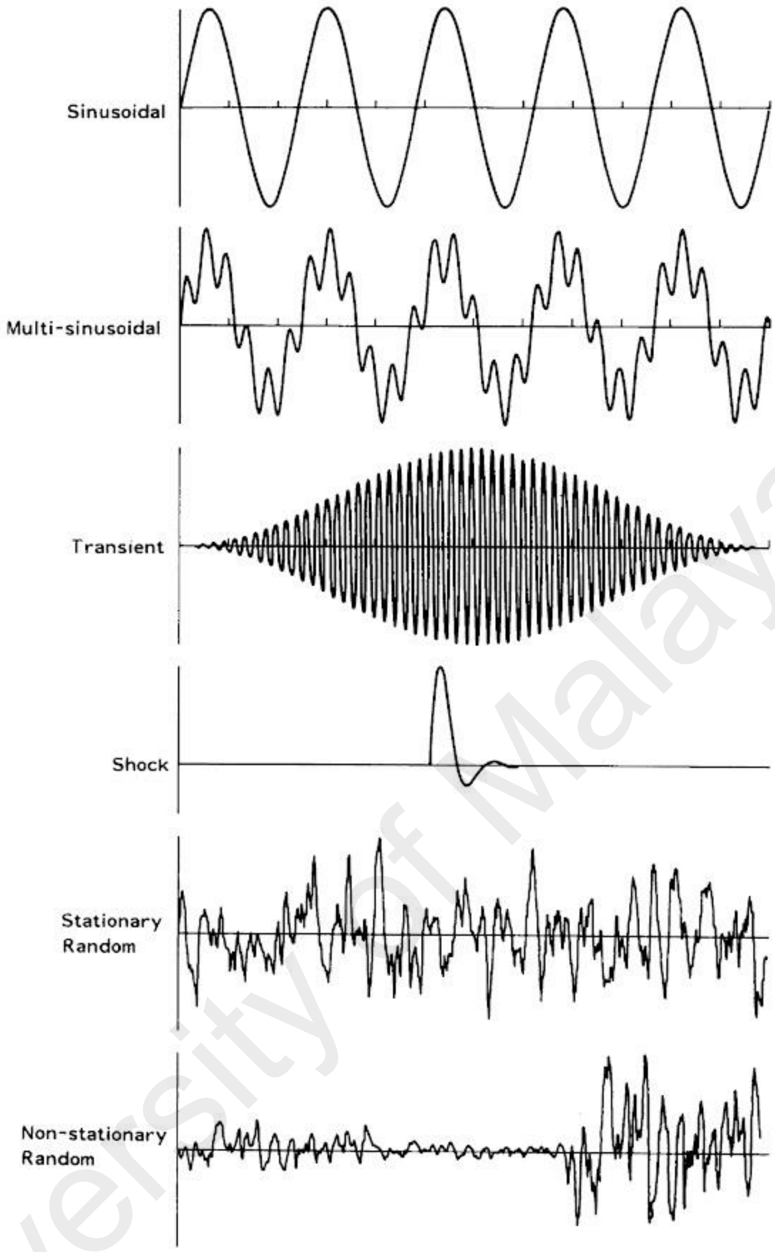

Figure 2.3: Waveforms of Different Types of Oscillatory Motion

Source: (Griffin, 2012)

The type of oscillatory motion in this study is stationary random vibration since the monitoring will be conducted on a certain monitoring point for a certain period of time. The changes of graph might be significant during the active boring of the boring rig and will be denoted in the results and discussions chapter.

2.3 Human Response to Vibration

Brammer (2010) has highlighted a few human responses toward vibration such as mechanical damage, physiological responses, subjective responses, and discomfort. However, in term of building vibration, which is the main study of this paper, the acceptable criteria for intermittent or continuous vibration in building lies at or slightly above the perception threshold for living spaces (Brammer, 2010). Building vibration, or structural vibration in buildings could affect the quality of life and the working efficiency of the occupants (BSI, 2008). The negative responses of occupant shows the overt sign of undesirable reaction in response to vibration.

As vibration is considered as one of the ambient stressors, along with noise, the disturbances toward residential populations have been proven to cause sleep disturbance (Ogren & Ohrstrom, 2009) and increase of stress level which would subsequently leads to blood pressure levels increases and rates of cardiovascular disease (World Health Organization, 2012; Whittle, et al., 2015). Lot of previous studies regarding vibrational impact were conducted in the past in a controlled condition which is a laboratory based such as magnitude study (Howarth & Griffin, 1988) and equal comfort contours (Morioka & Griffin, 2006) and studies of vibrational impacts to human response is newly explored for the past four years (Sica et al., 2014; Waddington et al., 2014; Whittle et al., 2015).

According to Silva (2007), the perception of vibration by human involves psychological aspect along with physiological aspect. The brain will assimilate both of these aspects and provide what human perceive as the vibration perception of the body. To obtain the actual vibration level, a monitoring instrument is needed which will be the main aspect of this study since the public may complain about the vibrational impact when they see a construction activity is being conducted.

2.4 Basic Information of Bored Pile

Piles are needed as an element in structural foundation which functions as load transfer of a superstructure to the surrounding soils or rocks which having a lot of methods to install the pile (Tomlinson & Woodward, 2015). The studied method of piling in this paper is bore pile as it generates a low noise and vibration emission (Clayton et al., 2013) which is favourable for a construction in an urban or high density area compared to other type of piling methods.

Bored piling involves a circular hole boring by a mechanical drilling into the ground, steel reinforcement installation and pouring of concrete into the hole (Shao et al., 2016). According to Kempfert et al (2003), optimal adjusment of bored pile depth is achievable with flexible working height and the boring process is easily controlled.

The process of drilling a hole from bored piling activity is the one that actually generate vibration emission. The magnitude of vibration will also depends on the type of soil that will be bored. The study will be conducted during the process of drilling.

2.5 Vibration Study in Malaysia

Vibration study in Malaysia is mainly conducted on the safety and health aspects such as whole body vibration (Nuawi et al., 2011; Ismail et al., 2015) and hand-arm vibration (Su et al., 2013) which focuses more on the individual receiving the vibration dose. A few other vibration study that monitor the ground vibration, which is quite related to this study were conducted for blasting activities (Armaghani et al., 2015; Hajihassani et al., 2015) and vibration from passing vehicles (Tuan Chik et al., 2013; 2015).

The study of building vibration by Tuan Chik et al. (2013; 2015) compared the result of vibration levels with the International Standards Organization (ISO) guidelines for the vibration effects on people in buildings. This approach is being used within this paper by comparing the vibration levels with the local regulatory standard (DOE Malaysia, 2007). The study of vibration impact from construction activities is not well-explored in Malaysia as people are concern more on the noise pollution from construction activities compared to vibration in the country (Zolfagharian et al., 2012).

CHAPTER 3: METHODOLOGY

3.1 Study Design

Study design used in this report is observational descriptive study. The study involves measurement of vibrational impact towards public receptor in the form of Peak Particle Velocity (PPV) which is quantitative and compared with the local regulatory standards (DOE Malaysia, 2007). Three axes were measured as it involves three direction of vibrational velocity movement. To obtain a comparable data of the bored piling activities toward the receptor’s perception of vibration, baseline data were measured on each measuring point. All of the data obtained (baseline and bore pile data) is then presented together along with the guideline limit by DOE. The comparison of baseline data and the main activity is essential to obtain non-bias results which may come from the existing or ambient influences. The selection of instrument, study location, monitoring points and monitoring methods will be discussed in this chapter.

3.2 Methodology Flow Chart

After literature studies were conducted, Vibration Level Meter Rion VM-55 was selected as it consists transducers that could measure three axes according to the DOE’s guideline (DOE Malaysia, 2007). By using the vibration level meter, the vibrational data were collected which involve baseline data collection and the bored pile data collection. The baseline data collection were compared with the DOE’s guideline limit and were compared with the bored pile vibration data which establishes the relationship. The results are then discussed and concluded. The flow chart of methodology is shown in figure 3.1.

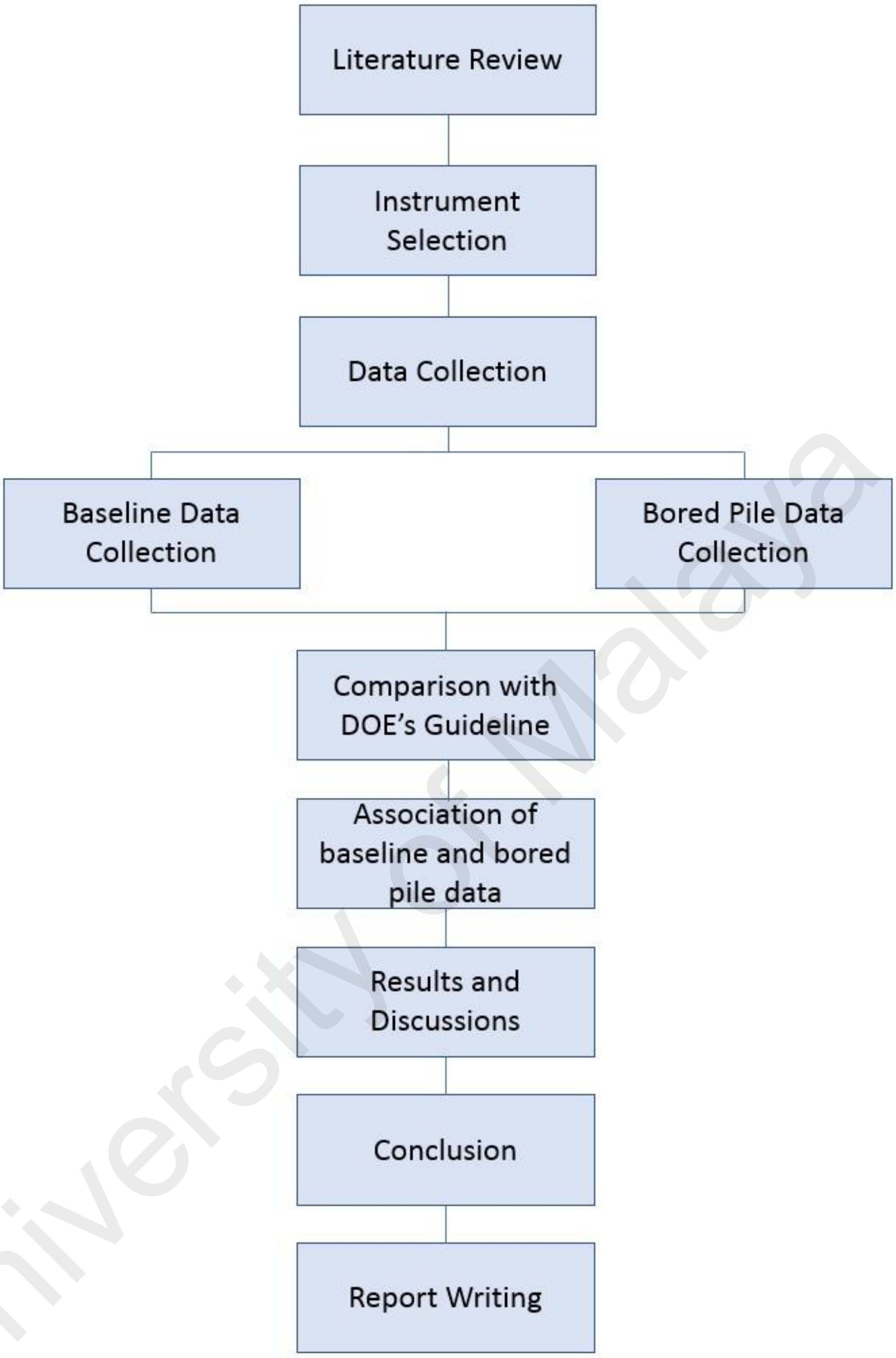

Figure 3.1: Flow chart of research methodology

3.3 Study Area

As rapid development for public transportation infrastructure has been constructed in the main city in Malaysia, Klang Valley which involves two states which are Kuala Lumpur and Selangor, was selected to be the subject of the study. The construction of Klang Valley Mass Rapid Transit Line 2 (KVMRT2) which extends from Sungai Buloh to Putrajaya was used as the study subject with a specific location at Taman Serdang Raya which is in Seri Kembangan district in Selangor. The location of Taman Serdang Raya in Selangor state can be viewed as in figure 3.2 and the zoom in location in figure 3.3.

Figure 3.2: Location of Taman Serdang Raya in Selangor

Source: (Google Map, 2018)

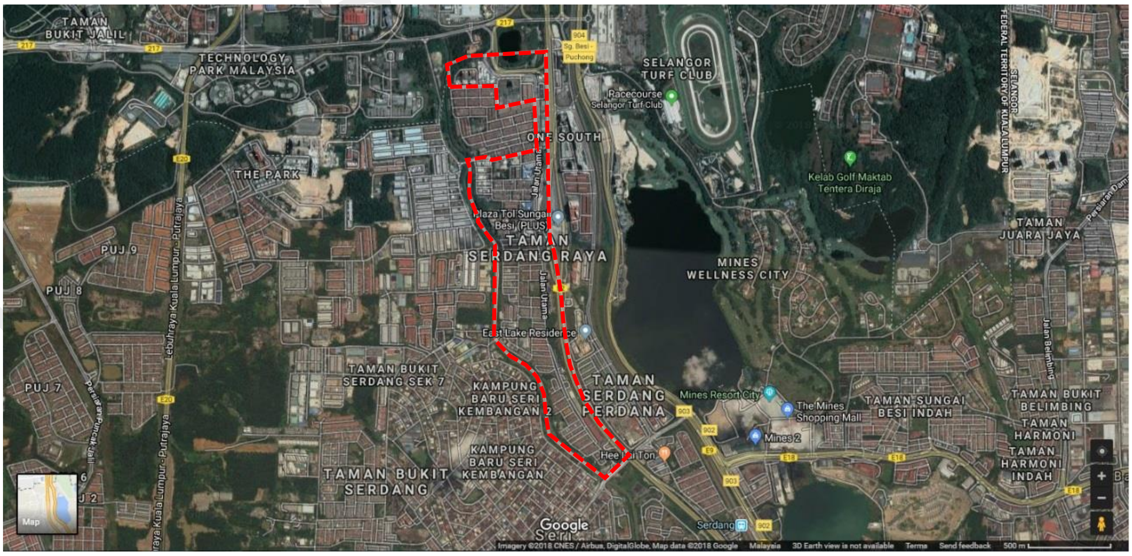

Figure 3.3: Location of Taman Serdang Raya

Source: (Google Map, 2018)

Three monitoring points have been identified during the bore piling activities which are close to public structure which are commercial and residential area. The monitoring points were located at property boundary of the receptors (outside the physical work site) to establish vibration levels at the receptors of concern closest to the construction activities. The distance between the bore pile location and the monitoring point was measured by using Google Maps. Figure 3.4, figure 3.5 and figure 3.6 shows the receptors of SRN01, SRN10 and SRN22 respectively along with its distance from the vibration sources. All of the photos were taken from mobile phone camera Xiaomi Mi 4.

Figure 3.4: SRN01 Plaza Serdang Raya (57.24 m)

Figure 3.5: SRN10 beside shop lot (37.83 m)

Figure 3.6: SRN22 back of commercial block (21.82 m)

All of the receptors' coordinate were recorded by using GPS Status Pro apps version 8.0.170. The details for all the receptors such as coordinate and distance were summarized as in table 3.1.

Table 3.1: Detail location of monitoring point

Point	Location	Latitude	Longitude	Distance
SRN01	In front of Plaza Serdang Raya	3˚2.534'N	101˚42.301'E	57.24 m
SRN10	Beside shop lot	3˚2.371'N	101˚42.265'E	37.83 m
SRN22	At the back of commercial block	3˚2.099'N	101˚42.337'E	21.82 m

The whole stretch of MRT construction activity in Serdang Raya of Package V205 along with its bored piling points and vibration monitoring points can be viewed as in figure 3.7. Each pier in Serdang Raya was marked with specific demarcation of numbers started from SRN01 to SRN29 (Refer Appendix B).

Legends:

◆ Bored Piling Point

● Vibration Monitoring Point

Figure 3.7: Bored piling point and monitoring point layout

Source: (Google Map, 2018)

3.4 Study Instrument

3.4.1 Vibration Level Meter

The model for vibration level meter is Rion VM-55 (Refer Appendix A). The vibration level meter could be used to measure vibrational levels in buildings, bridges, towers, etc. The measurements could serve to decide mitigation strategies of preventing possible structural damages or disturbances to people. This vibration level meter contains a sensor, recording and evaluation electronics and an accumulator in its robust casing. It is especially suitable for autonomous operation over longer period of time e.g on construction sites.

A seismograph is set up continues monitor mode for 15 min interval measurement of ground vibration at each location for hours. The transducer's cable is plugged into socket marked "seismic" and the transducer is position to the ground. The instrument measures the vibrations in three orthogonal axes, namely radial (x-axis), transverse (y-axis) and vertical (z-axis) vibrations. Pre-calibration was conducted for the instrument to ensure accuracy and reliability of the data. The vibration level meter can measure in accordance with to the following standard:

a) ISEE – International Society of Explosives Engineers

b) DIN 45669 – Measurement of Vibration Emission

The vibration level meter can be viewed as in figure 3.8.

Figure 3.8: Rion VM-55 Vibration level meter in its robust casing

3.5 Monitoring Activity

The monitoring activity was conducted according to the Annex B (Procedures for the Measurement of Vibration in the Environment) of The Planning Guidelines for Vibration Limits and Control in The Environment (DOE Malaysia, 2007) (Refer Appendix C). The measurements were conducted with 15 minutes interval for each monitoring.

3.5.1 Baseline Monitoring

Baseline vibration measurements were conducted and completed prior to the commencement of bored piling activities to establish prevailing ambient vibration at identified locations in the absence of construction activities.

The identified locations, undertaken at the closest receptors are marked up in the figure 11. At these location, prevailing ambient levels were established from 24 hours continuous monitoring over a typical day and night period. However, in this study the reported results were for day time only since the bore piling activity will be conducted only in day time.

3.5.2 Monitoring During Piling Activity

Continuous vibration monitoring of bore piling activity were taken at sensitive receptors for the entire duration of piling works potential to generate vibration. For piling works, the monitoring was conducted at the exact same location with the baseline monitoring to be compared with. The monitoring includes a continuous log of vibration levels at the respective receptors of concern as indicated in the figure 3.7 for the entire duration of works undertaken at the piers that are nearest to the receptors.

3.6 Data Analysis

The data recorded were extracted from the memory card inside the vibration level meter to Microsoft Excel 2010. Line chart is then constructed with PPV against time for each axis and is discussed in chapter 4. The results were compared to the DOE's guideline to obtain the information on any breach of compliances. IBM SPSS version 25 was used for the data analysis. Shapiro-Wilk is used for normality test and Wilcoxon signed ranks test was used for the establishment of relationship between baseline and bored pile data results.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

The results and discussion of study will be presented in this chapter. The results will be divided into two sections which are baseline result and bored pile vibration result. As per discussed in chapter 3, three monitoring points have been identified. The first point is demarcated as SRN01 monitoring point located in front of Plaza Serdang Raya which is a mixed residential-commercial area. The monitoring was conducted by installing the vibration level meter at the property boundary of Plaza Serdang Raya as shown in figure 4.1.

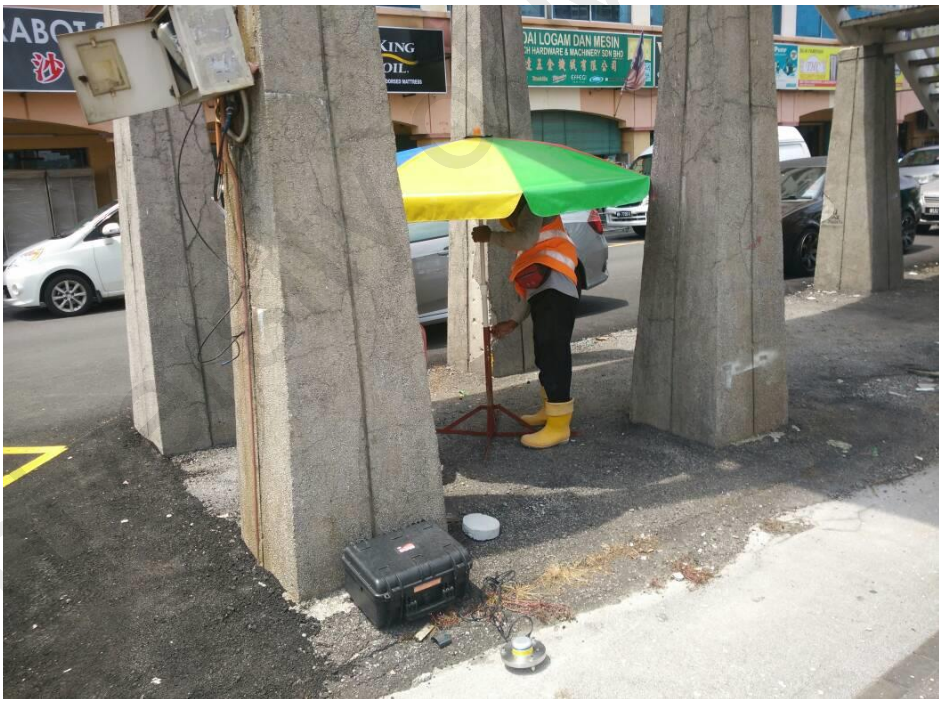

Figure 4.1: Vibration measurement at SRN01

SRN10 monitoring point is located beside residential-commercial area where annoyances or disturbances are expected. Figure 4.2 shows the placement of vibration level meter on top of solid base to ensure accuracy in measurement was achieve.

Figure 4.2: Vibration measurement at SRN10

SRN22 monitoring point is the closest receptor with source of bore piling activity (21.82 m). From figure 4.3, it can be observed that the vibration level meter is placed at the vicinity of property’s boundary with a boring rig is operating behind the plastic barrier.

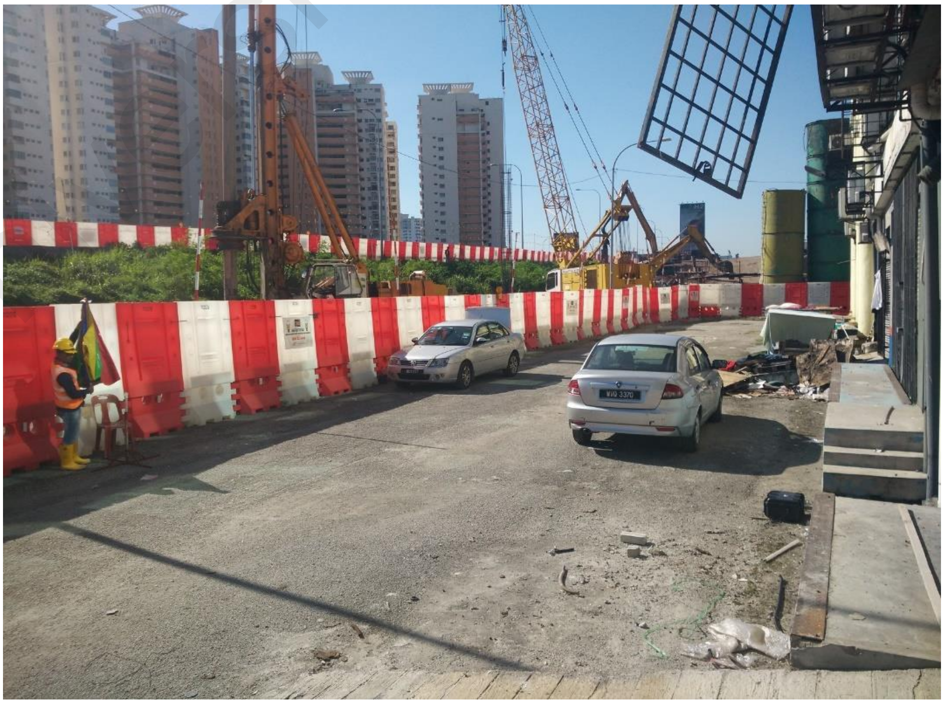

Figure 4.3: Vibration measurement at SRN22

4.2 Baseline Result

The raw data were compared with the regulatory standard, schedule 6 of The Planning Guidelines for Vibration Limits and Control in the Environment (DOE Malaysia, 2007) and tabulated in the table 4.1 along with its graph to provide a clear presentation of the existing ambient vibration condition. The results for x and y axis were reported together as it moves on the same plane whereas the results for z axis is reported in table 4.2. The baseline results were provided for day time (7.00 am to 10.00 pm) only since the bore pile activities were carried out in the day to compliment the limit provided by the guideline. Data collected from each monitoring point was gathered in a raw data that can be viewed in Appendix B. From the raw data, the maximum PPV is extracted for each axis and compared with the recommended PPV limit by DOE. These data were opened using Microsoft Excel and transferred into table and chart.

The ambient vibration data were collected in three different date, which are 14 December 2017 for SRN22, 7 February 2018 for SRN10 and 10 February 2018 for SRN01. During the measurement were recorded, no construction activity has been conducted yet. The data were contributed from the existing activities in surrounding area such as the traffic use on the main road.

4.2.1 Baseline Results for x (back to chest) and y (right side to left side) axis

Table 4.1 shows all maximum peak particle velocity recorded were within the limit of the guideline except for the x-axis of SRN01 at 12.00 pm with a PPV of 7.23 mm/s on a frequency of 18.8 Hz. It exceeds the curve 16 of schedule 6 of the guideline by 0.73 mm/s PPV. This value could be contributed by the moving traffic as the monitoring point is located directly beside the Jalan Utama which is the main road of Serdang Raya. This value will be used to compare with the result of the bore piling activity in SRN01.

Table 4.1: Results of baseline vibration monitoring for x and y axis

Location	Orthogonal axis	Time and date	Maximum Peak Particles Velocity, PPV (mm/s)	Frequency (Hz)	Recommended PPV (mm/s)
SRN01	x-axis	10/2/2018 12:00	7.23	18.8	Between 3.3 and 6.5 (Curve 8 – 16)
	y-axis	10/2/2018 11:00	2.68	22.2	
SRN10	x-axis	7/2/2018 14:30	2.69	18.6	Between 3.3 and 6.5 (Curve 8 – 16)
	y-axis	7/2/2018 21:15	1.44	97.8	
SRN22	x-axis	14/12/2017 15:38	0.68	13.2	Between 3.3 and 6.5 (Curve 8 – 16)
	y-axis	14/12/2017 17:23	0.77	15.8	

Exceeds stipulated limit

4.2.1.1 SRN01 Monitoring Point

In SRN01 monitoring point, the velocity movement of x-axis were recorded to have three significant surges at 9.00 am, 12.00 pm and 8.15 pm. The trend shows high vibration movement during this three different hours which is the peak hour where the traffic is heavy with the PPV reading of 3.65 mm/s, 7.23 mm/s and 5.26 mm/s respectively. All of the three surges exceed the limit stated in curve 8 (3.3 mm/s) while only one reading exceeds curve 16 (6.5 mm/s) which is at 12.00 pm. The reading of x-axis at the other hours were generally low with the reading between 0.06 mm/s to 1.43 mm/s. Two significant surges were recorded in y-axis at 11.00 am and 7.30 pm with PPV reading of 2.68 mm/s and 2.56 mm/s respectively. All measurement recorded were well below the curve 8 limit (3.3 mm/s) with the PPV reading between 0.07 mm/s and 2.68 mm/s. Figures 4.4 illustrate the hourly vibration of SRN01 monitoring point that will be established as baseline result.

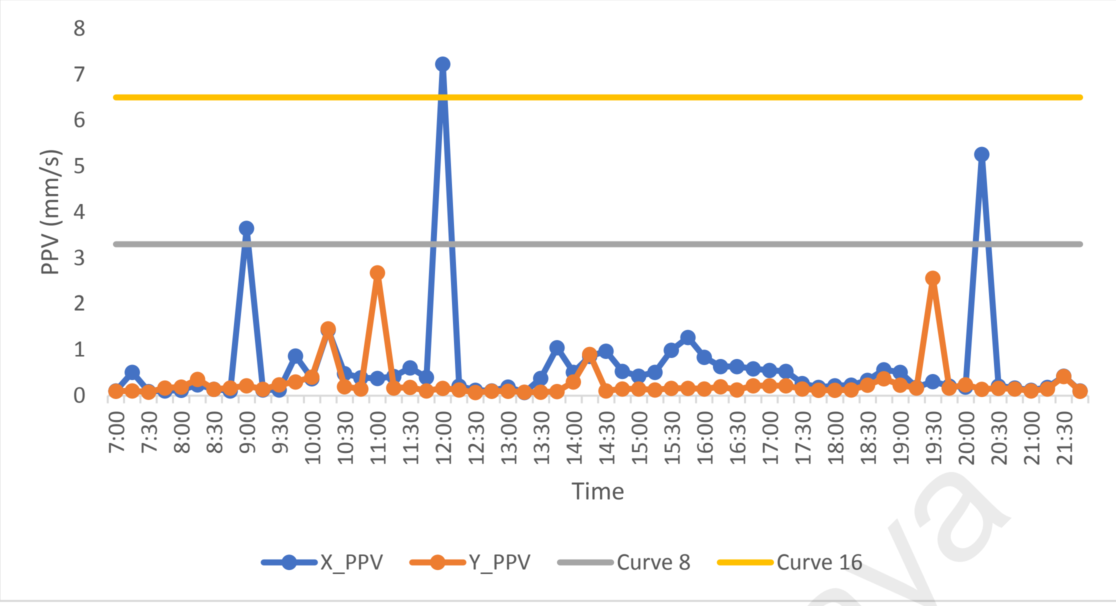

Figure 4.4: Day Time Baseline Data for SRN01

4.2.1.2 SRN10 Monitoring Point

Three peaks were observed in x-axis at SRN10 with the PPV reading of 2.38 mm/s at 12.45 pm, 2.69 mm/s at 2.30 pm and 1.89 mm/s at 9.30 pm. The only peak of y-axis happened at 9.15 pm with a PPV reading of 1.44 mm/s. All of the reading were found well below the curve 8 limit which is 3.3 mm/s. The line chart for SRN10 can be viewed in figure 4.5.

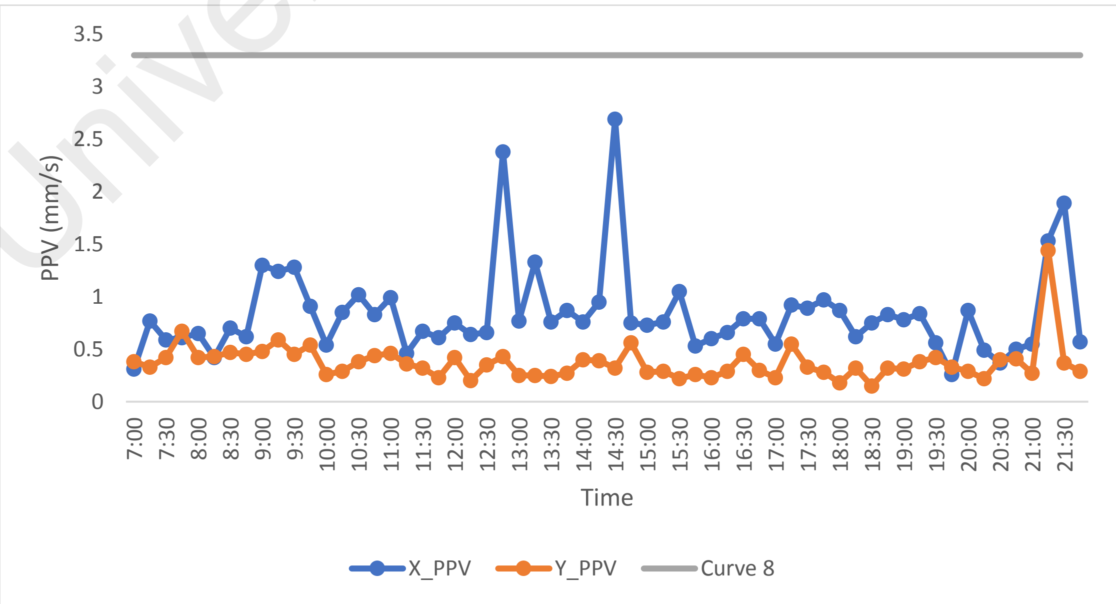

Figure 4.5: Day Time Baseline Data for SRN10

4.2.1.3 SRN22 Monitoring Point

The reading in SRN22 shows a very low vibrational level in x and y axis with a maximum value of 0.68 mm/s (3.38 pm) for x-axis and 0.77 mm/s (5.23 pm) for y-axis. All of the readings were well below the curve 8 limit which is 3.3 mm/s. the line chart is as shown in figure 4.6.

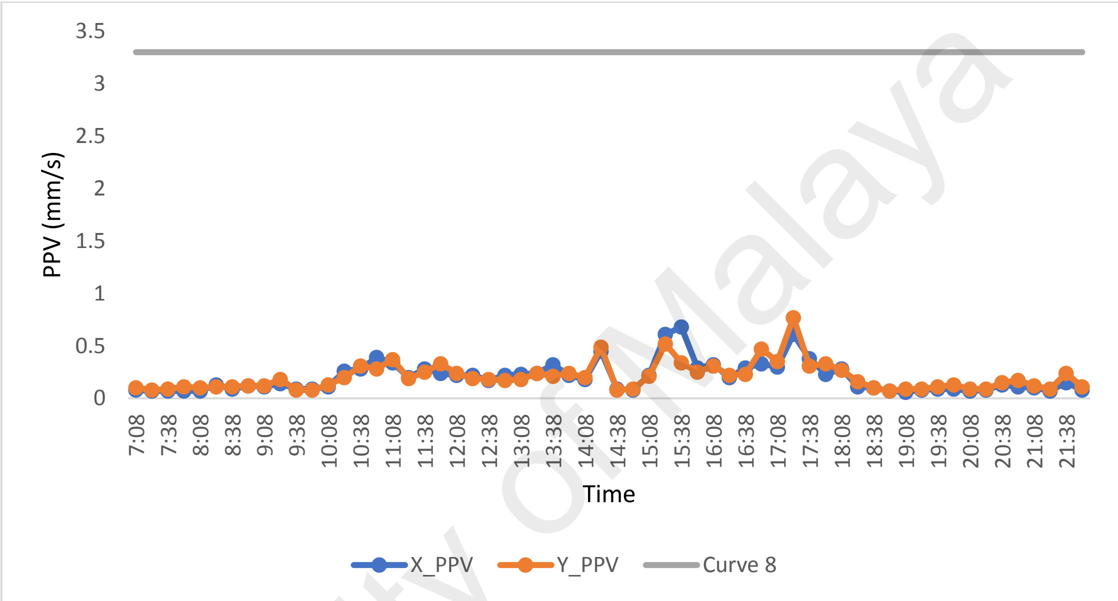

Figure 4.6: Day Time Baseline Data for SRN22

4.2.2 Baseline Results for z (foot to head) axis

Table 4.2 shows the baseline results for z-axis. As the vertical axis is more sensitive towards receptor, the recommended PPV limit is lower which is 1.2 mm/s for curve 8 and 2.4 mm/s for curve 16. Two readings out of three measurement measured was found to be below the guideline's limit which are SRN01 and SRN10 with a PPV reading of 3.86 mm/s (10.15 am) and 2.62 mm/s (9.15 pm) respectively.

Table 4.2: Results of baseline vibration monitoring for z axis

Location	Axis	Time and date	Maximum Peak Particles Velocity, PPV (mm/s)	Frequency (Hz)	Recommended PPV (mm/s)
SRN01	z-axis	10/2/2018 10:15	3.86	>100	Between 1.2 and 2.4 (Curve 8 – 16)
SRN10	z-axis	7/2/2018 21:15	2.62	>100	Between 1.2 and 2.4 (Curve 8 – 16)
SRN22	z-axis	14/12/2017 15:23	2.25	14	Between 1.2 and 2.4 (Curve 8 – 16)

Exceeds stipulated limit

4.2.2.1 SRN01 Monitoring Point

According to the line chart presented in figure 4.7, one significant peak was observed at 10.15 am with a PPV reading of 3.86 mm/s. The reading has exceeded the curve 16 (2.4 mm/s) of the guideline. One other reading has exceed the curve 8 limit (1.2 mm/s) which occurs at 9.30 pm with a PPV reading of 1.63 mm/s.

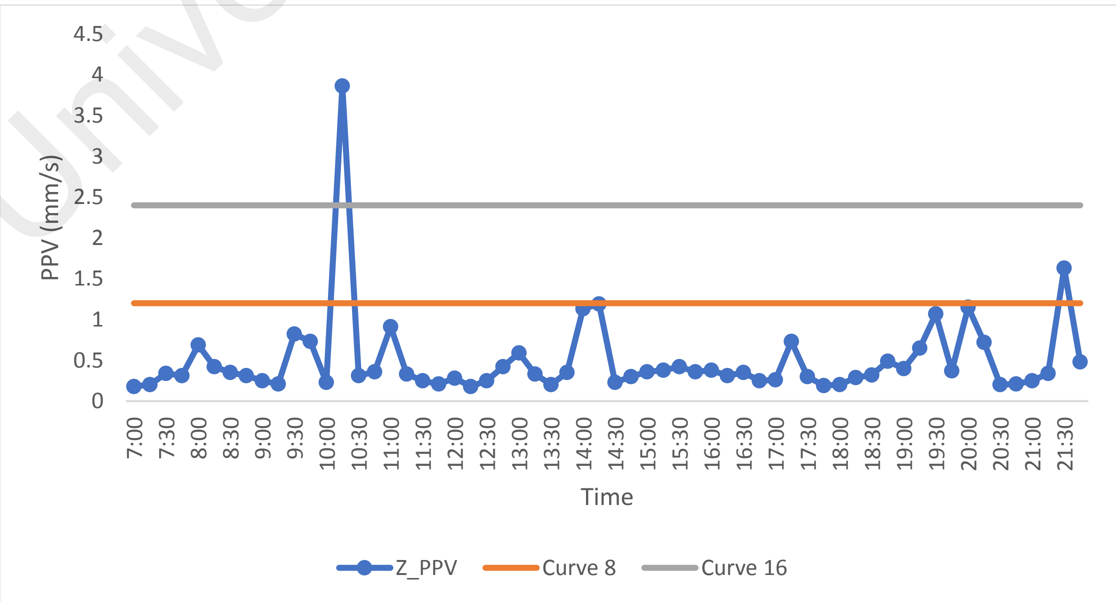

Figure 4.7: Day Time Baseline Data for SRN01

4.2.2.2 SRN10 Monitoring Point

High vibration level was observed at 9.15 pm for SRN10 z-axis with a PPV reading of 2.62 mm/s. the reading has exceeded the curve 16 limit which is 2.4 mm/s. Other measurements were found below the curve 8 limit with a PPV reading between 0.17 mm/s and 0.62 mm/s. The line chart can be viewed as in figure 4.8.

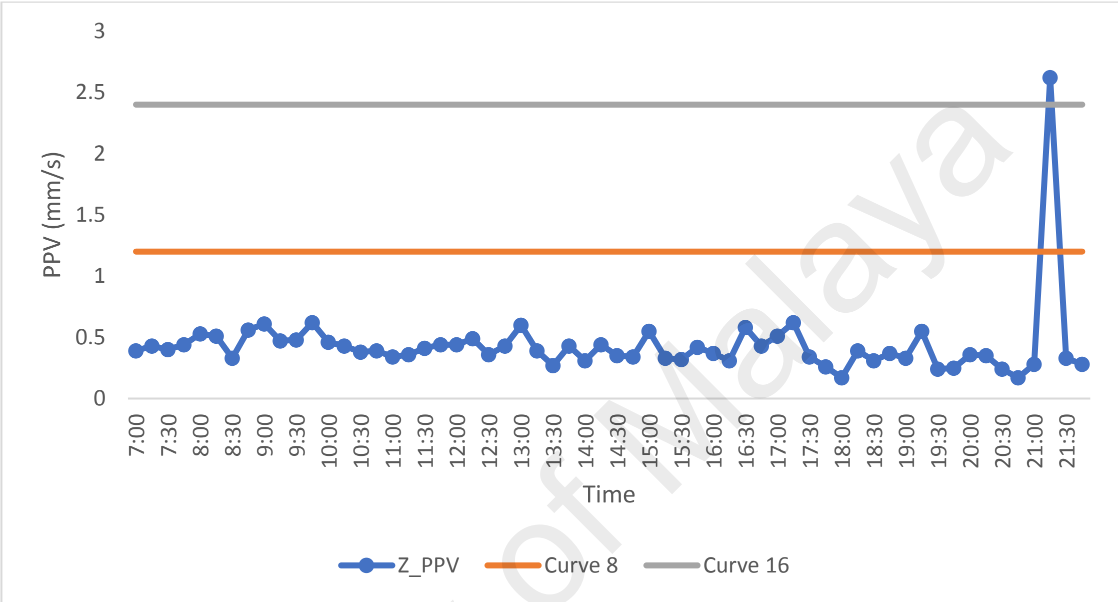

Figure 4.8: Day Time Baseline Data for SRN10

4.2.2.3 SRN22 Monitoring Point

From figure 4.9, all of the recorded measurements show compliances with the guideline with readings below the curve 16 limit (2.4 mm/s). However, nine readings have exceeded the curve 8 limit (1.2 mm/s) with the maximum PPV reading of 2.25 mm/s at 3.23 pm.

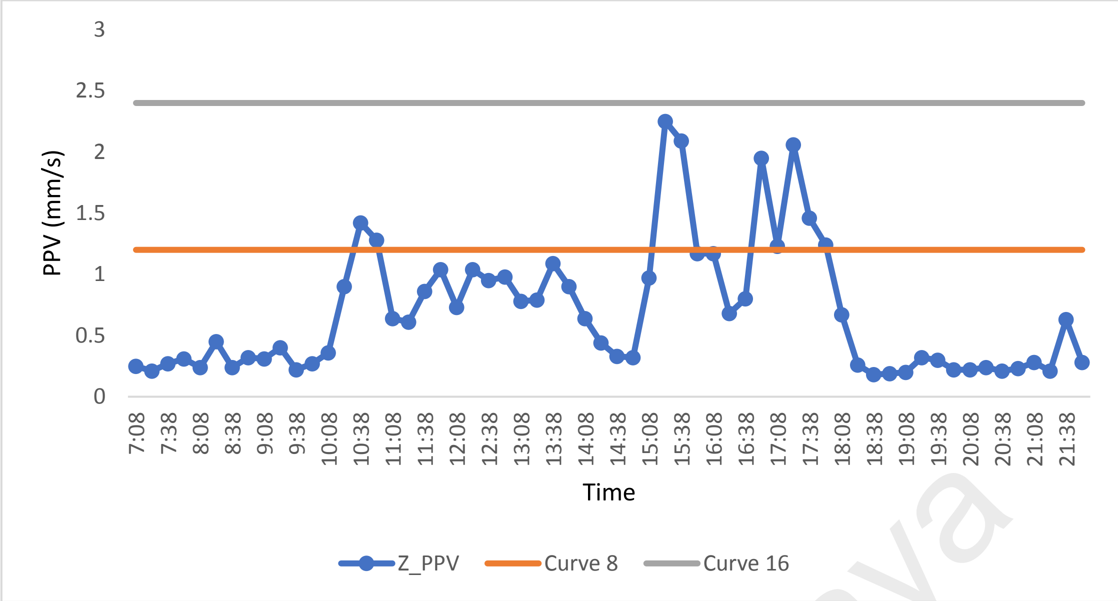

Figure 4.9: Day Time Baseline Data for SRN22

4.3 Bore Pile Result

As the monitoring for bored piling activities were conducted for the duration of bore piling activities were active, the result will not cover 24 hours of monitoring such as presented in the baseline data results. Instead, the results of bored piling vibration monitoring only covered the time where the boring rig is active. The results are then compared to both baseline data and the stipulated regulatory limit to assess the non-compliances of the activities. The results can be viewed as in table 4.5 for x and y axis and table 4.6 for z axis.

Prior to the establishment of relationship, Shapiro-Wilk normality test was conducted for all of the data set to obtain the information of the data set whether it is normally distributed or not. This is to justify a proper relationship test selection between the baselines and bore pile data. Table 4.3 shows the result of the normality test.

Table 4.3: Normality test results of all data set

Location	Orthogonal Axis	Shapiro-Wilk			Normality test
		Statistic	df	P-value*	
SRN01	Baseline x-axis	.412	29	.000	Not normal
	Bore Pile x-axis	.956	29	.259	Normal
	Baseline y-axis	.446	29	.000	Not normal
	Bore Pile y-axis	.711	29	.000	Not normal
	Baseline z-axis	.427	29	.000	Not normal
	Bore Pile z-axis	.883	29	.004	Not normal
SRN10	Baseline x-axis	.622	29	.000	Not normal
	Bore Pile x-axis	.817	29	.000	Not normal
	Baseline y-axis	.924	29	.039	Not normal
	Bore Pile y-axis	.739	29	.000	Not normal
	Baseline z-axis	.934	29	.070	Normal
	Bore Pile z-axis	.864	29	.001	Not normal
SRN22	Baseline x-axis	.865	29	.002	Not normal
	Bore Pile x-axis	.736	29	.000	Not normal
	Baseline y-axis	.928	29	.049	Not normal
	Bore Pile y-axis	.270	29	.000	Not normal
	Baseline z-axis	.898	29	.009	Not normal
	Bore Pile z-axis	.538	29	.000	Not normal

*P-value more than 0.05 is normally distributed

From table 4.3 above, only SRN01 bore pile x-axis and SRN10 baseline z-axis are normally distributed while others are deviated from the normal distribution. Therefore, in the establishment of relationship, non-parametric Wilcoxon Sign rank test was used to obtain the p-value. From all of the differences test conducted, table 4.4 shows the differences of results between all of the relationships tested.

Table 4.4: Differences of baseline data and bored pile data

Monitoring Point	Orthogonal Axes	Z-value	p-value	Confidence Level (%)	Relationship
SRN01	x-axis	-4.31	0.000	99	Significant
	y-axis	-3.699	0.000	99	Significant
	z-axis	-9.60	0.337	-	Not significant
SRN10	x-axis	-2.508	0.012	95	Significant
	y-axis	-3.575	0.000	99	Significant
	z-axis	-5.432	0.000	99	Significant

SRN22	x-axis	-1.331	0.183	-	Not significant
	y-axis	-0.353	0.724	-	Not significant
	z-axis	-2.141	0.032	95	Significant

Of all nine relationship between baseline and bored pile data tested, six have shown a significant differences between both of the variables and three are found to be insignificant.

4.3.1 Bored Pile Results for x and y axis

Table 4.5 shows all maximum peak particle velocity recorded were within the limit of the guideline except for the y-axis of SRN22 at 11.16 am with a PPV of 20.17 mm/s on a frequency of 46 Hz. It exceeds the curve 16 of schedule 6 of the guideline which is 6.5 mm/s PPV. This value occurred during the bore piling activity and is most likely happened due to the SRN22 bore pile activity.

Table 4.5: Results of bore pile vibration monitoring for x and y axis

Location	Axis	Time and date	Maximum Peak Particles Velocity, PPV (mm/s)	Frequency (Hz)	Baseline PPV	Recommended PPV (mm/s)
SRN01	x-axis	5/2/2018 10:48	4.97	12.7	7.23	Between 3.3 and 6.5 (Curve 8 – 16)
	y-axis	5/2/2018 11:18	0.96	13	2.68	
SRN10	x-axis	16/3/2018 20:02	1.62	23	2.69	Between 6.5 and 8.3 (Curve 16 - 20)
	y-axis	16/3/2018 21:17	1.84	7	1.44	
SRN22	x-axis	9/3/2018 12:01	1.94	19.8	0.68	

	y-axis	9/3/2018 11:16	20.17	46	0.77	Between 3.3 and 6.5 (Curve 8 – 16)

Exceeds stipulated limit

4.3.1.1 SRN01 Monitoring Point

Wilcoxon Signed Ranks Test shown a significant difference between baseline and bore pile data of x-axis with p-value less than 0.01 (Z = -4.31, p = 0.000) while y-axis also shows a significant difference between the baseline and bore pile data set (Z = -3.699, p = 0.000). From figure 4.10, it is clearly observed that the vibrational impact is higher than the baseline vibration with a significant difference ($p < 0.01$) in both x and y axis. No breach of compliance was observed where all of the reading measured is well below the curve 16 (6.5 mm/s).

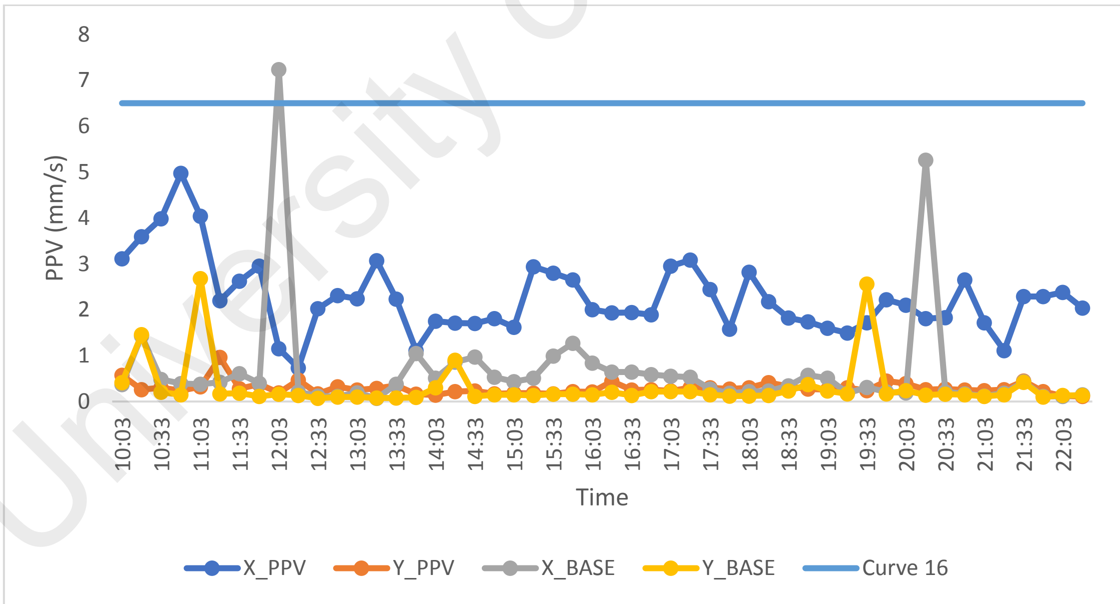

Figure 4.10: Bore Pile Vibration Data for SRN01

4.3.1.2 SRN10 Monitoring Point

In SRN10 monitoring point, the Wilcoxon signed rank test shows a 95% significant difference between x-axis baseline and bore pile reading with a Z value of -2.508 and p value of 0.012. While for y-axis, the p-value is 0.000 which shows a 99% significant difference (Z = -3.575) between baseline and bore pile data. Therefore, the effect of bore piling is significantly denoted even if the reading do not exceed the guideline's limit. Figure 4.11 shows the line chart of x and y axis of SRN 10 with no breach of compliance was observed.

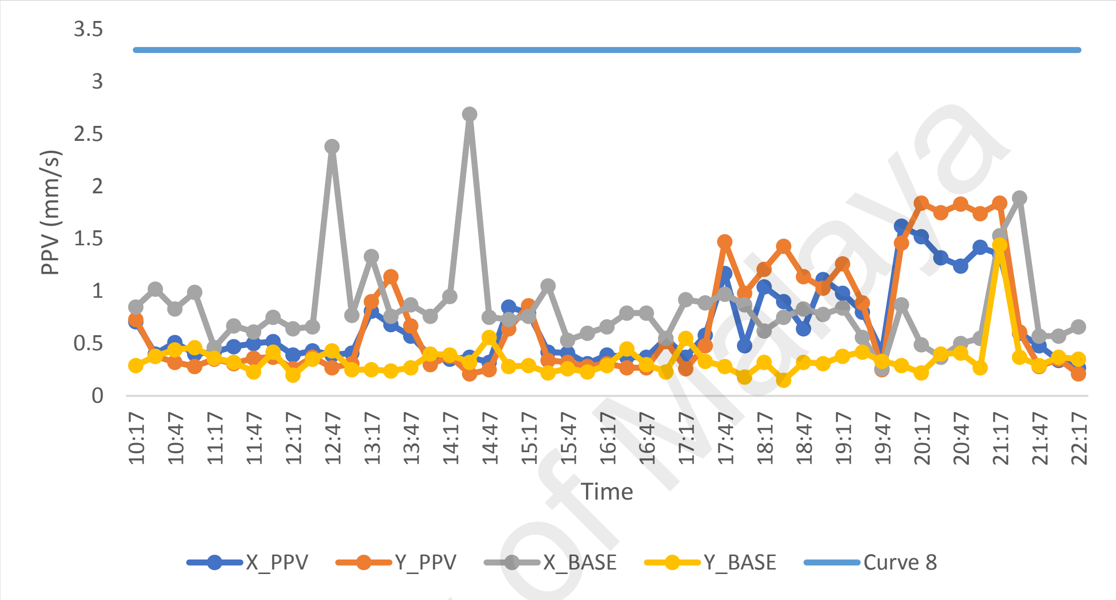

Figure 4.11: Bore Pile Vibration Data for SRN10

4.3.1.3 SRN22 Monitoring Point

One peak was observed in figure 4.12 at 11.16 am in y-axis with a PPV reading of 20.17 mm/s which is significantly high. The reading has exceeds the curve 16 guideline limit (6.5 mm/s) and is considered as non-compliance of the guideline. However, the Wilcoxon signed rank test shows no significant difference between baseline and bore pile data in both x and y axis with a Z value of -1.331 and a p-value of 0.183 for x-axis and Z value of -0.353 and p-value of 0.724. There might be no differences observed but the breach of vibrational limit should be denoted as it could affect the quality of life of the building occupants.

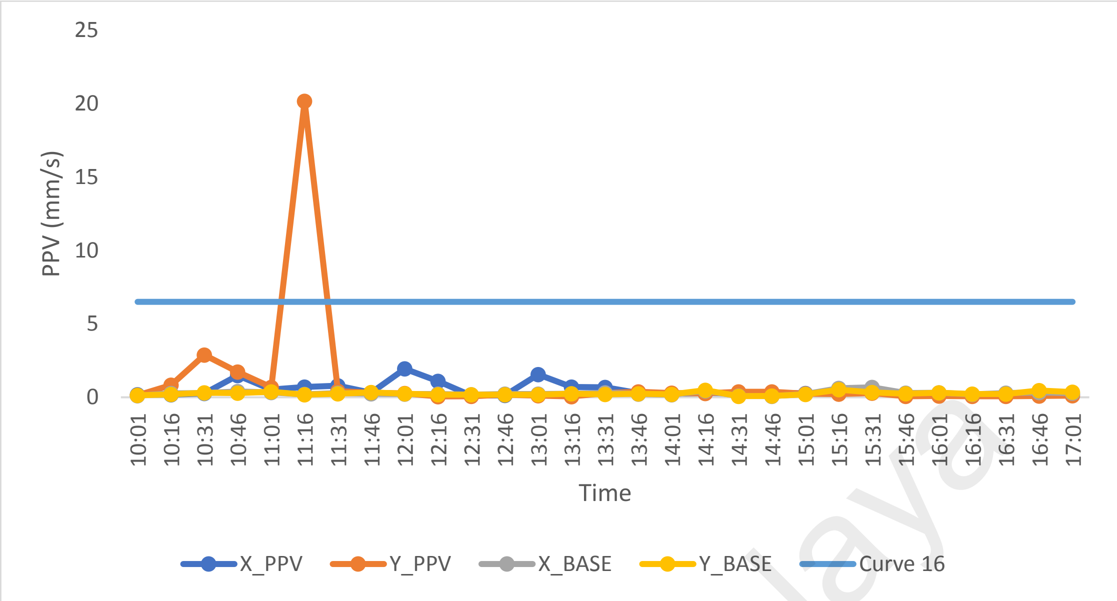

Figure 4.12: Bore Pile Vibration Data for SRN22

4.3.2 Bored Pile Results for z-axis

Table 4.6 shows the bore pile results for z-axis. There is only one reading that has exceeded the guideline's limit which occurred at 11.16 am at SRN22. The other measurements were observed to be in compliance with the aforementioned guideline.

Table 4.6: Results of bore pile vibration monitoring for z axis

Location	Axis	Time and date	Maximum Peak Particles Velocity, PPV (mm/s)	Frequency (Hz)	Baseline PPV	Recommended PPV (mm/s)
SRN01	z-axis	5/2/2018 16:48	0.53	10.1	3.86	Between 1.2 and 2.4 (Curve 8 – 16)
SRN10	z-axis	16/3/2018 10:17	1.45	10.2	2.62	Between 1.2 and 2.4 (Curve 8 – 16)
SRN22	z-axis	9/3/2018 11:16	5.56	>100	2.25	Between 1.2 and 2.4 (Curve 8 – 16)

Exceeds stipulated limit

4.3.2.1 SRN01 Monitoring Point

From figure 4.13, it was observed that all of the bore pile vibrational levels were in compliance with the guideline's limit with a range of 0.22 mm/s and 0.53 mm/s. From Wilcoxon signed ranks test, there is no significant difference of z-axis baseline and bore pile data in SRN01 (Z = -9.60, p = 0.337).

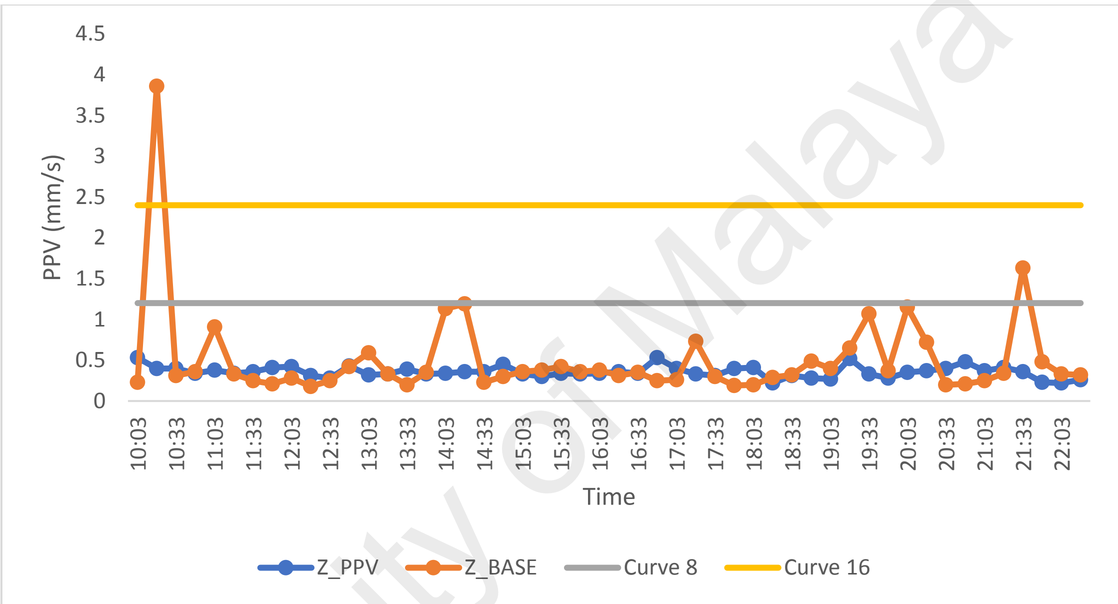

Figure 4.13: Bore Pile Vibration Data for SRN01

4.3.2.2 SRN10 Monitoring Point

The Wilcoxon signed ranks test shows there is 99% significant difference between baseline and bore pile data with Z value of -5.432 and p-value of 0.000. Figure 4.14 shows the comparison of baseline and bore pile line chart with a higher reading of vibrational level for the bore pile compared to the baseline data. No reading has exceeds the curve 16 limit which shows a full compliance toward the guideline's limit for bore pile activity in SRN10.

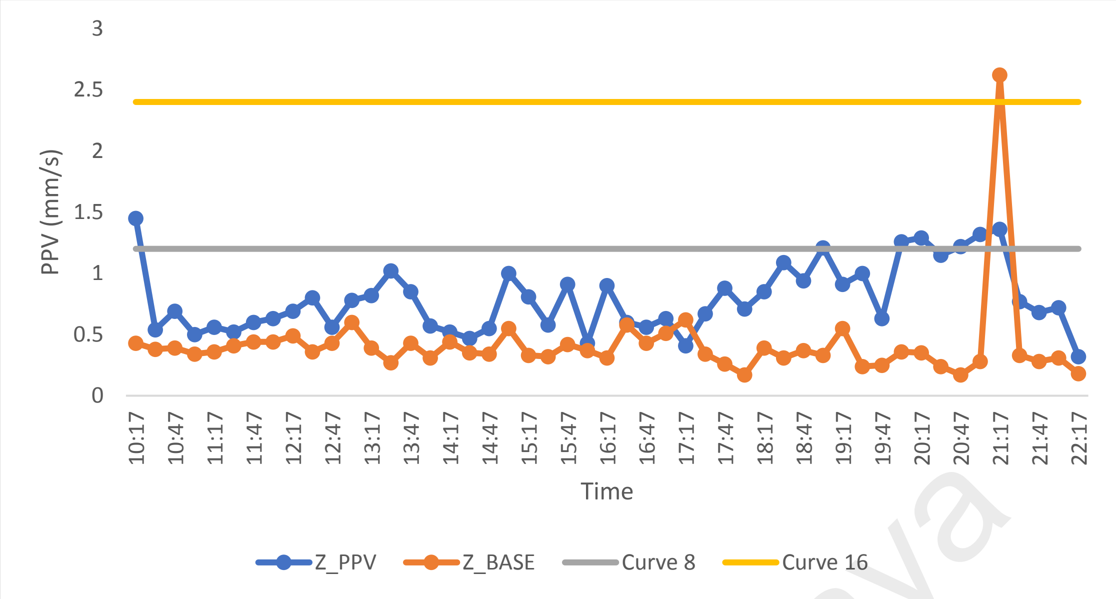

Figure 4.14: Bore Pile Vibration Data for SRN10

4.3.2.3 SRN22 Monitoring Point

Wilcoxon signed ranks test shows 95% significant difference between z-axis baseline data and bore pile data (Z = -2.141, p = 0.032). One significant peak was observed at 11.16 am with a PPV reading of 5.56 mm/s which is significantly higher than the curve 16 limit which is 2.4 mm/s. figure 4.15 shows the SRN22 bore pile vibration data compared to the baseline data.

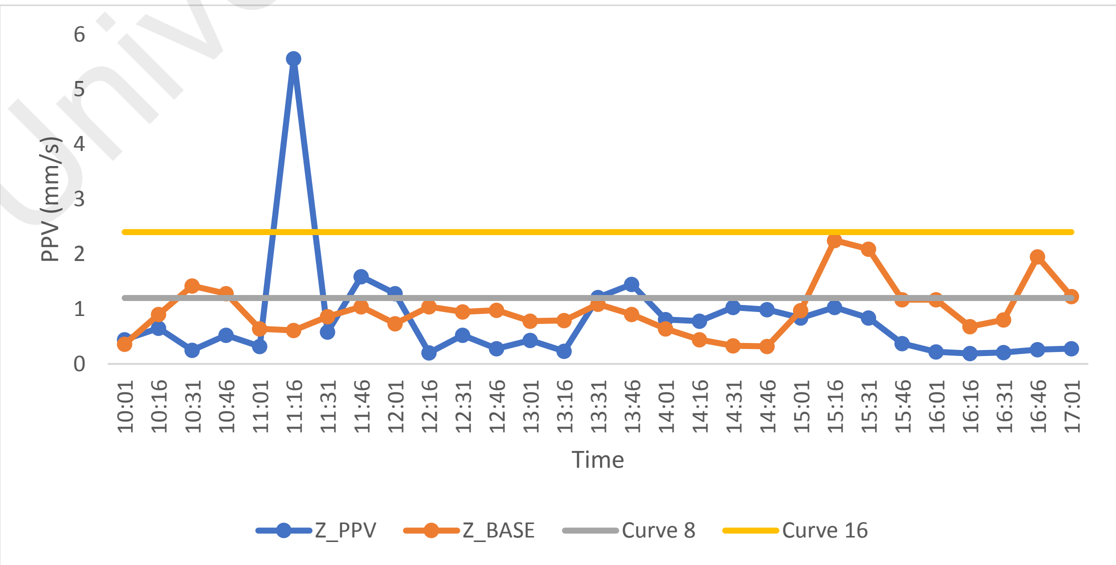

Figure 4.15: Bore Pile Vibration Data for SRN22

CHAPTER 5: CONCLUSION

This study sought to establish the relationship of the vibrational level of baseline and bore pile activity in KVMRT project in Taman Serdang Raya. Three monitoring points were identified and measured to analyse the effect of bore pile activity toward public receptors in term of vibrational impact. The conclusion were drawn based on the objectives with the following information:

5.1 Quantifying vibrational impact of bored piling activities toward public receptors.

From all of the tabulated results in chapter 4, the vibration levels were measured in three axes and was quantified in the form of Peak Particle Velocity (PPV) with a reference of frequency for the maximum PPV recorded. As described by Griffin (2012), vibration can be quantified in the form of its magnitude (displacement, velocity, acceleration, peak, average or dose measures) and frequency. To mirror the guideline by DOE, displacement and frequency were chosen as quantification of vibrational levels in this study. The displacement were recorded for each of the axis with a 15 minutes interval and was tabulated in the form of table and line chart. By using the quantitative data achieved in the first objective, comparison could be made as to achieve the second objective.

5.2 Assessing the vibration levels of bored piling activities according to regulatory guideline

From the results obtained in the first objective, a DOE's guideline limit were placed as a benchmarking to obtain the compliance level of bored piling activities in Taman Serdang Raya KVMRT project. One point was found to breach the guideline's limit which is at

SRN22 monitoring point which breached y and z axis at 9^{th} March 2018, 11.16 am with a reading of 20.17 mm/s for y-axis and 5.56 mm/s for z-axis. The breach was recorded during the boring rig is active. Out of all three monitoring point, SRN22 has the closest distance toward source (21.82 m) which could contributing the breach. Other monitoring points were found to be well under guideline's limit and is considered not significant toward public perceptions.

5.3 Exploring differences between vibrational baseline data and bored pile activity

Wilcoxon signed ranks test were conducted to establish relationship between baseline data and bored pile vibration data as the data collected is not normally distributed. Therefore, non-parametric test is the most favourable when compared to paired T-test. In SRN01, z-axis was observed to have no significant difference between baseline data and bored pile data. However, the x and y axis have shown a very significant differences with 99% confidence level which shows that bored piling activity does have significant impact towards ambient environment. In SRN10 monitoring point, all axes were found to have significant differences between baseline data and bored pile data while in SRN22 monitoring point, only z-axis has significant difference between baseline and bored pile data with 95% confidence level.

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