การพัฒนาระบบการประเมินมลพิษทางเสียงสำหรับคนงานก่อสร้าง

นายวาริน จัน

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
สาขาวิชาวิศวกรรมโยธา ภาควิชาวิศวกรรมโยธา
คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2554

DEVELOPING A SYSTEM OF NOISE HAZARD ASSESSMENT FOR CONSTRUCTION WORKERS

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering Program in Civil Engineering
Department of Civil Engineering
Faculty of Engineering
Chulalongkorn University
Academic Year 2011

Thesis Title	DEVELOPING A SYSTEM OF NOISE HAZARD ASSESSMENT FOR CONSTRUCTION WORKERS
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Field of Study	Civil Engineering
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วาริน จัน : การพัฒนาระบบการประเมินมลพิษทางเสียงสำหรับคนงานก่อสร้าง. (DEVELOPING A SYSTEM OF NOISE HAZARD ASSESSMENT FOR CONSTRUCTION WORKERS) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ.ดร.วัชระ เพียรสุภาพ, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม : รศ.ดร.ธนิต ธงทอง, 152 หน้า.

งานวิจัยที่ผ่านมาพยายามประเมินระดับมลพิษทางเสียงของผู้ปฏิบัติงานในงานก่อสร้าง ซึ่งผู้ปฏิบัติงานที่เกี่ยวข้องในกิจกรรมงานก่อสร้างอาจได้รับระดับมลพิษทางเสียงที่แตกต่างกันเนื่องจากปัจจัยด้านระยะทางระหว่างแหล่งกำเนิดเสียงและจำนวนชั่วโมงการทำงาน อย่างไรก็ตามการวิเคราะห์มลพิษทางเสียงด้วยเครื่องมือวัดปริมาณเสียงในปัจจุบันยังมีข้อจำกัดเนื่องจากเครื่องมือวัดปริมาณเสียงมีราคาค่อนข้างสูง นอกจากนี้การใช้เครื่องมือดังกล่าวยังไม่เหมาะสมต่อการประเมินและการเตือนสำหรับผู้ปฏิบัติงานที่เกี่ยวกับอันตรายที่เกิดจากมลพิษทางเสียง โดยงานวิจัยนี้มีวัตถุประสงค์เพื่อเสนอระบบทางเลือกสำหรับการประเมินมลพิษทางเสียงสำหรับผู้ปฏิบัติงานก่อสร้างหลายคนในเวลาเดียวกัน การศึกษานี้สามารถจัดว่าเป็นงานวิจัยประเภทการทดลอง งานวิจัยนี้เลือกใช้งานเสาเข็มเป็นกรณีศึกษาสำหรับการออกแบบและทดลอง งานวิจัยเริ่มต้นที่การพัฒนากรอบแนวคิดในการประเมินมลพิษทางเสียงและพัฒนาระบบเพื่อการประเมินระดับมลพิษทางเสียงเทียบเท่า ปริมาณมลพิษทางเสียง และสถานะของมลพิษทางเสียงที่ผู้ปฏิบัติงานได้รับจากไฟล์ข้อมูล โดยการพัฒนาระบบประเมินมลพิษทางเสียงออกแบบและทดสอบในห้องปฏิบัติการทางเสียง และหน่วยงานก่อสร้างเพื่อทดสอบความน่าเชื่อถือและความถูกต้องของระบบ นอกจากนี้งานวิจัยเก็บข้อมูลจากแบบสอบถามเพื่อสำรวจทัศนคติและความตระหนักของมลพิษทางเสียงที่เกิดขึ้นในหน่วยงานก่อสร้าง โดยข้อมูลที่ใช้ในการวิเคราะห์ประกอบด้วย ข้อมูลจากเครื่องมือวัดปริมาณเสียงที่หน่วยงานจำนวน 24 ชุด ข้อมูลจากแบบสอบถามจำนวน 24 ชุด และข้อมูลจากระบบประเมินมลพิษระดับมลพิษทางเสียงที่วัดจากหน่วยงาน 72 ชุด ผลการศึกษาพบว่าระบบประเมินระดับมลพิษทางเสียงที่พัฒนาให้ค่าใกล้เคียงกับเครื่องมือวัดปริมาณเสียงมาตรฐาน และระบบที่พัฒนาขึ้นนี้มีความน่าเชื่อถือและมีความเที่ยงตรง นอกจากนี้ผลการศึกษาพบว่าผู้ปฏิบัติงานประมาณ 40 เปอร์เซ็นต์ขาดทัศนคติทางด้านมลพิษทางเสียงแต่มีความตระหนักต่อผลกระทบที่เกิดขึ้นในระยะยาว

ภาควิชา............วิศวกรรมโยธา............. ลายมือชื่อนิสิต..
สาขาวิชา..........วิศวกรรมโยธา............. ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก..................
ปีการศึกษา.......2554.............................. ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์ร่วม ....

5270856021 : MAJOR CIVIL ENGINEERING

KEYWORDS : NOISE HAZARD / EQUIVALENT NOISE LEVEL / DOSE OF NOISE / WORKERS' PERCEPTION

VARIN CHAN : DEVELOPING A SYSTEM OF NOISE HAZARD ASSESSMENT FOR CONSTRUCTION WORKERS. ADVISOR : ASST. PROF. VACHARA PEANSUPAP, Ph.D., CO-ADVISOR : ASSOC. PROF. TANIT TONGTHONG, Ph.D., 152 pp.

Many research studies attempt to assess the noise hazards at construction worker level. Workers of different positions may receive different equivalent noise levels under the same construction activity due to the distance and working time. However, the use of commercial noise dosimeters for noise hazard assessment is expensive. In addition, this method may not be the practical for assessing and reminding workers about the health hazard. Therefore, this research aims to propose an alternative system for assessing noise hazard for multiple construction workers. This research methodology is classified as the experimental research approach. A piling work is used as a case study for system design and experiment. The research starts with development of the conceptual framework of noise hazard assessment and development of a system to evaluate equivalent noise level, dose of noise and status of noise hazard from electronic sound signal. Next, this system was tested in acoustic laboratory and in construction site for reliability and validity. In addition, questionnaire was also used to explore workers' perception and awareness of noise hazard in construction site. Data was analyzed based on 24 samples from the noise dosimeter, 24 samples from questionnaires and 72 samples resulting from the proposed system. It is found that results of the proposed system present the same trend and high correlation with those of standard equipment. Significantly, the proposed system is reliable and accurate. Findings also show that nearly 40% of sample workers do not perceive noise hazard as their problem but they are aware of noise affecting them in a long term period.

Department : Civil Engineering	Student's Signature ....
Field of Study : Civil Engineering	Advisor's Signature ....
Academic Year : 2011	Co-advisor's Signature ....

ACKNOWLEDGEMENTS

I would like to firstly express my deepest thanks and gratitude to my advisor, Assist. Prof. Vachara Peansupap, for his kindness, valuable support, encouragement, and helpful guidance with high supervision throughout the study which enabled the completion of this thesis. My deepest thankfulness is also expressed to my co-advisor, Assoc. Prof. Tanit Tongthong, for his guidance, meaningful advice and supportive thought. They always shared their valuable time to cooperatively discuss my research. I consider this to be great fortune to have had the opportunity to work with them and also the best experience in conducting the research.

My respect and appreciation go to Assoc. Prof. Wisanu Subsompon, Assist. Prof. Noppadon Jokkaw and Dr. Sarawut Thepanondh for their valuable suggestions and comments, for being available for the oral defense, reading, and serving in the committee during proposal exam as well as final defense. Furthermore, I would like to extend my grateful thanks to Dr. Wisit Leelasiriwong for his helpfulness, kindness and meaningful advice during my experimental in acoustic laboratory. Moreover, my great thanks are given to all project managers in Thailand, who kindly allowed me to have a chance to collect my data and information for conducting my research.

My sincere gratitude is extended to all lecturers in Construction Engineering and Management division, Department of Civil Engineering, Chulalongkorn University, for their lectures and efforts in providing invaluable knowledge. Many thanks also go to all my classmates, all Cambodian students in Thailand, especially all my seniors, friends and my juniors in Ploi apartment, for their motivation, care, help, discussion and friendship. Unforgettably, I wish to deeply thank Mr. Panuwat Phangaew and Mr. Gun Thangthong for their encouragement and care every time I felt down. Furthermore, I also thank all officers working in the International School of Engineering and AUN/SEED-Net for their kindness, useful preparation and information during my study.

My profound thanks are given to all lecturers in Department of Civil Engineering at the Institute of Technology of Cambodia (ITC) in supporting me to undertake my master degree in Chulalongkorn University. I would also like to extend my grateful thanks to AUN/SEED-Net for their financial support as well. Without this support, this research would not have been possible.

Finally, my very special thanks from the bottom of my heart is gratefully expressed to my beloved parents, Chhourng Chanva and Chhaing Lychin, my brother and sisters, for their great motivation, encouragement, care and support.

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LISTS OF ABBREVIATIONS

ACGIH	American Conference of Government Industrial Hygienists
ANNs	Artificial Neural Networks
D%	Dose of noise
dB	Decibel
dBA	A-weighted decibel
EPA	Environmental Protection Agency
FFT	Fast Fourier Transform
GUI	Graphical User Interface
HPD	Hearing Protection Device
LCF	Low Cut Filter
Leq	Equivalent noise Level
Lmax	Maximum noise Level
Lmin	Minimum noise Level
MATLAB	MATrix LABoratory
ND	Noise Dosimeter
NIHL	Noise Induce Hearing Loss
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PELs	Permissible Exposure Limits
REL	Recommended Exposure Limit
SLM	Sound Level Meter
SPL	Sound Pressure Level
TWA	Time-Weighted Average
VOR	Voice-Operated Recording
WAV	Waveform Audio Format
WCB	Workmen’s Compensation Board
WISHA	Washington Industrial Safety and Health Act

CHAPTER I
INTRODUCTION

1.1 Significance of Research

In general, the term noise refers to an unwanted sound that can block, distort, change or interfere with the meaning of a message in human communication. Significantly, noise exposure has also been recognized as a causal factor in hearing impairment. Several effects of hearing loss have serious impact on the individual's ability including job stress, unrecognized auditory warnings, social communication difficulty, and decrease of job performance (Reilly et al, 1998). In the construction industry, noise is recognized as a harmful exposure that is a result of heavy equipment's operation or power tool use in construction site (Kyle, 1999). Therefore, the impact of noise in construction industry should be a concern.

Many researchers have identified the impacts of noise hazard in construction industry. German Workmen's Compensation Board (WCB) showed that deafness caused by noise exposure was the most frequent occupational diseases in the German construction industry (Arndt et al, 1996). Miyakita and Ueda (1997) mentioned that 410,000 of 5.8 million Japanese construction workers are suffering from Noise-Induced Hearing Loss (NIHL). That is roughly 16% of Japan population. In addition, construction noise exposure and the hearing loss were a big problem in Washington State where 21% of accepted construction workers were compensated for hearing loss claims. Furthermore, WCB of British Columbia presented 50% of 32,800 audiometric tests with significant hearing loss while 22% of total tests were classified as severe to profound (Fig. 1.1). Moreover, it was staggering when WCB estimated the financial costs for covering the roughly 10,000 potential could cost 20 million dollars in that year (Richard, 1998). In addition, a study by Dobie in 1995 found that numerous agencies in the US compensated several hundred million dollars every year for suffering individual noise-induced hearing loss. Moreover, noise-induced hearing loss was also believed to cost over one hundred million dollars each year in Sweden (Dobie, 1995).

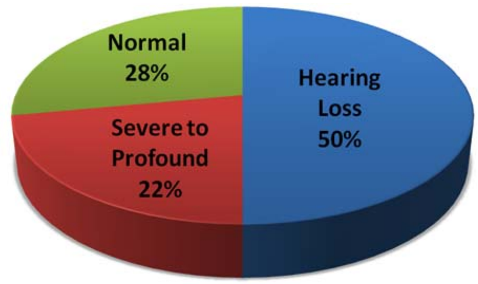


Figure 1.1 Result of 32,800 audiometric tests on construction workers (Richard, 1998)

Due to high impact of noise hazard in construction, many research studies were conducted in order to assess the noise exposure. In general, measurements of noise were conducted during normal operations using a sound level meter. Several research findings indicated high level of noise in some construction trades/tasks were too high and over the standard. One of the statistics from the US Bureau showed that nearly a half million of the construction workers were exposed to high noise levels above standard of 85 dBA. Estimates also showed that 15% of these workers developed hearing impairments when they were exposed to noise levels of 85 dBA or higher (Koushki et al., 2004). In Washington State, a major general contractor was recently required to make a more comprehensive noise hazard assessment in the construction industry (Neitzel, 1999). The task base studied by Richard covered four trades and five construction sites. The analysis of 338 samples of all trades indicated the mean exposure level at 82.8 dBA with a range of 61.6 to 99.3 dBA. Moreover, 12.7% of sampled workers exceeded noise level of 90 dBA, OSHA PEL, while 40% of them exceeded an 85 dBA, TWA. Richard illustrated the highest mean of TWA was 83.5 dBA, followed by 83.3 dBA, 82.3 dBA and 82.2 dBA which were absorbed by Operating engineers, Laborers, Ironworkers and Carpenters, respectively. In addition, the highest noise exposure levels presented in construction methods utilizing a combination of tilt-up concrete and cast-in-place technique (Richard, 1998).

The high level of noise may be caused from some equipment operations in construction site. For example, a study by McClymont (1989) mentioned portable power tools such as circular saws and hammer drills were operated at extremely high noise levels, 113 dBA and 105 dBA respectively. Moreover, construction operation with heavy machinery exposure noise levels under range from 90 dB to 120 dB (Ringen et al, 1995).

In response to noise hazard, many noise regulations have been proposed as a guideline attempting to prevent workers from noise hazard. One of the current regulations in the European Union is based on the Directive 2003/10/CE (Appendix A). This document states a set of minimum disposals attempts to prevent the workers from the risks of noise hazard. They insist on mechanisms directed to reduction or avoidance of noise exposure, so it meant that the risks derived from noise exposure might be reduced as much as possible to the lowest level or could disappear in their origin source (Marcos et al., 2009).

Because noise hazard is a major problem for construction workers in many trades/occupations, the researches on noise hazard have been carried out to explore the methods to minimize this problem. Some proposed the guidelines and regulations attempting to protect those workers from noise hazard. These researches contributed an extra great part in controlling noise in construction. However, it might not be applied enough for construction site in some developing countries. Most construction workers operated their tasks under high level of noise without using hearing protection (Koushki et al., 2004). The lack of wearing hearing protection may be caused by several factors. First, lack of construction managers provided hearing protection. Second, construction workers lack of knowledge of noise. Third, some workers are unaware of noise hazard and may have negative perception on using hearing protection. Last, some workers are familiar with unsafe condition. To understand the current practice of construction workers, the future study of construction noise hazard is still needed.

1.2 Problem Statement

Most of the previous researches needed numerous noise dosimeters in order to assess noise hazard in construction site. One of the examples is a study by Richard (1998). In his studied, five devices of “Metrosonics db-308”, five devices of “Quest Q-300” and one device of “Metrosonics db-3100” datalogging noise dosimeter were used for assessment of occupational noise exposure in four construction trades such as carpenter, laborer, ironworker, and operation engineer. In addition, five datalogging noise dosimeters model “Quest Q-300” were used in Kyle’s research (1999) for assessment noise exposure to electricians in construction industry.

The reasons related to their usage are discussed. One is they need various data from many construction workers who operated in different zone from sources of noise at construction site. Furthermore, there is limitation of time for data collection so it is necessary to use several noise dosimeters at the same time. Thus, it may require a large amount of money in order to conduct such kind of assessments because the price of noise dosimeter, shown by many manufacturers in 2010, was noticeably expensive for some contractors. Therefore, it's still an urgent and important mission to find an alternative approach that responds to this issue.

As discussed, high cost of the use of noise dosimeter is that previous concept used the inside hardware (circuit) in order to detect sound and evaluate noise exposure level and dose of noise. In contrast, the concept of this study aims to propose a compatible method by using a device that can detect noise exposure from worker activities. This research uses electronic sound recorder to capture the sound signal under construction operation. Then, the electronic file of sound is computed into noise exposure level by MATLAB computer programming. Therefore, it should be stated the purpose of this research attempts to develop an inexpensive system of noise hazard assessment for construction workers.

1.3 Research Objectives

The main objective of this research is to develop an inexpensive system of noise hazard assessment for construction workers. To achieve this main objective, the following sub-objectives are addressed:

- To propose the conceptual framework of inexpensive noise hazard assessment for construction workers
- To develop a system for evaluating the status of noise hazard at construction worker level
- To apply the proposed system to construction workers in various occupations.

1.4 Scope of Research

This research is conducted under several scopes. First, it involves the noise hazard of construction workers based on a dose of noise under their operation in construction site. Second, this study is limited to construction projects with two case studies such as drop hammer piling and bored piling operation. The samples are collected from construction sites in Thailand.

1.5 Research Methodology

To accomplish the above objectives of this research, the methodology is designed and arranged in several steps as following:

1. Review of the relevant literature in order to get the systemization knowledge related to noise exposure on construction worker.
2. Development of noise hazard assessment system which contains three steps:
    2.1 Testing for finding suitable tools:
    - Selection of computer programming for system development
    - Review of the instruments operating instruction; sound recorder and noise dosimeter.

    2.2 Conducting of a preliminary study:
    - Development of an initial system for evaluation sound pressure level
    - Experimental of system in acoustic laboratory (control room)
    - Experimental of system in construction site
    - Discussion of result from both experimental
    - Testing the reliability of the proposed system.

    2.3 Conducting of full scale of system development
    - Process of noise hazard assessment system
    - Development user interface of noise hazard assessment system
    - Adopting theory for calculation dose of noise
    - Programming the procedure of calculation dose of noise
    - Verification of the proposed system with workers in construction site
3. Application of noise hazard assessment system
    3.1 Selection of sampling and sample size
    3.2 Data collection:
    - Data collection by using the proposed system
    - Data collection by using survey questionnaire

    3.3 Data analysis
    - Result of noise hazard under worker's operation
    - Result of workers' perception of noise hazard and awareness of noise impact
    - Analysis of workers' perception and awareness with noise hazard
4. Research conclusion

1.6 Research Outline

The thesis presents the whole research process and findings, and is organized as follows.

Chapter 1 provides a background of the research process and contributions, including the background to the research, the research problems, the research objectives, the research scopes, the methodology, and contributions.

Chapter 2 discusses the research issues, presents a literature review of noise hazard in construction industry, measurement of noise exposure level, research gaps and research framework.

Chapter 3 explains the details of the research method and the envisaged outcome for each stage of the research. Specifically, this chapter describes the system development, experimental of system, data analysis technique and desired research outcomes.

Chapter 4 focuses on preliminary study of system development. The chapter describe the experimental of noise hazard assessment system in acoustic laboratory and construction site. Then it presents the method for defining calibration constrant C of the proposed system. Last, the chapter addresses the system reliability.

Chapter 5 presents a detailed discussion on the full scale of system development. It inculdes the process of system development, the graphical user interface of noise hazard assessment system, the calcuation of noise dose, the system design and programming, and the verification of system.

Chapter 6 details the application of system with workers in construction site. The chapter provides the chacracteristic of sampling data, the result of noise hazard under two cases such as drop hammer piling and bored piling, and the analysis with result of workers' perception and awareness of noise impact.

Chapter 7 presents the main findings of the research, explores the contribution of research, and addresses the research limitations and highlights the potential areas for future study.

1.7 Expected Benefits

This study is designed to develop a new method of noise hazard assessment for building construction workers. Upon the completion of the study, the following benefits are expected:

- Reduce cost of noise hazard assessment by using a new alternative to evaluate noise hazard at worker level.
- The new alternative derived from this research will be useful for managers to remind their workers
- The proposed system should be practical for noise hazard assessment.

CHAPTER II
LITERATURE REVIEW

The objective of this chapter is to provide the basic knowledge and theory about noise hazard in construction industry. The chapter begins with the review of construction noise hazard. It explains the meaning of noise, noise source and exposure, noise-induce hearing loss and regulation related to noise. Then the chapter summarizes previous research on noise hazard within different categories such as the research about effects of noise on construction, noise assessment, engineering noise control and model for prediction noise level. Next, it explains the method and instrument used for noise measurement. After that, standard of occupational noise exposure is reviewed for understanding the noise exposure with duration limit. Finally, a research framework is established to achieve the research objectives.

2.1 Noise hazard in construction industry

2.1.1 Definition

Noise and sound refer to audible pressure that fluctuates in air. Both are characterized by sound level in decibels (dB) and frequency contents in hertz (Hz) (Charles, 2006). Although sound is vital for communication, noise is one of our greatest problems. Noise is a term used to identify unwanted sound, including sound generated as a by- product of other activities including transportation and industrial operation (Charles, 2006). In construction industry, noise is recognized as a harmful exposure that results from necessity of heavy equipment which operates in construction site (Kyle, 1999). Chales (2006) pointed out the effects of noise including hearing damage, interference with communication, masking of warning signals, sleep interruption, and annoyance.

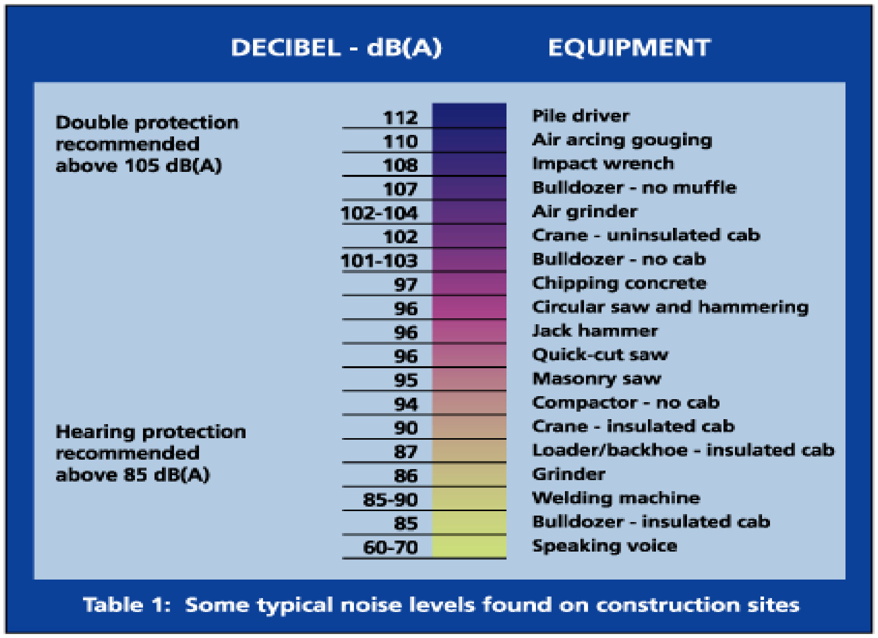
2.1.2 Occupational noise sources and exposures

Noise is the main hazard in construction industry. It was found noise came from many different sources such as the use of heavy vehicles as well as noisy tools and equipment was common (Mohamed, 2008). Table 2.1 exhibits the available data by both traditional groupings and by a set of equipment/ occupational categories created from a free-form description of “job title” recorded by the OSHA inspectors. In addition, Figure 2.1 is found in *OSHA’s Approach to Noise Exposure in*

Construction which was presented by Kim and Chalies (2003). This figure presented some typical noise levels which are caused by many types of equipment in construction site. In 1971, Environmental Protection Agency (EPA) published the noise level of some construction equipment utilized in Earth moving, materials handling and stationary work (Figure 2.2). The report emphasized that dozer was the equipment that could produce the highest noise level (82 to 96 dBA) compared to standard outdoor level.

Table 2.1 Noise sources and occupations from job title (Kim and Chalies, 2003)

1. Categories based on noise source
1.1. Noise of a part of the machine acting on a target 1.1.1. Operators of cutting machines, N.E.C. (Not Elsewhere Classified) 1.1.2. Chippers (except jackhammers) 1.1.3. Jackhammers and related equipment 1.1.4. Operators of machines for modifying surfaces (except blasters) 1.1.5. Operators of crushing and grinding machines 1.1.6. Drills & Pile drivers 1.1.7. Press operators 1.2. Noise from collisions/energy dissipated outside the machine 1.2.1. Abrasive/sand/shot blasters 1.2.2. Other machines using compressed air 1.2.3. Machines spraying compressed liquids 1.3. Engine noise primarily 1.3.1. Operators of material handling/transport/miscellaneous machines 1.3.2. Paving/grading/road construction 1.3.3. Back hoe/bulldozer/bob cat/front end loader operators 1.3.4. Crane workers 1.3.5. Drivers, truck and not otherwise specified
2. Categories based on occupation/type of work
2.1. Electricians (includes "wiremen") 2.2. Brick layers/masons/hod carriers, N.E.C. 2.3. Boiler makers 2.4. Welders, N.E.C. 2.5. Assemblers 2.6. Carpenters, millwrights, drywall workers 2.7. Grounds keepers 2.8. Insulation workers 2.9. Iron workers 2.10. Mechanics 2.11. Painters 2.12. Plumbers and pipe fitters 2.13. Sheet metal workers 2.14. Supervisors 2.15. Laborers, helpers, equipment cleaners and miscellaneous occupations



DECIBEL - dB(A)		EQUIPMENT
Double protection recommended above 105 dB(A)	112	Pile driver
	110	Air arcing gouging
	108	Impact wrench
	107	Bulldozer - no muffle
	102-104	Air grinder
	102	Crane - uninsulated cab
	101-103	Bulldozer - no cab
	97	Chipping concrete
	96	Circular saw and hammering
	96	Jack hammer
	96	Quick-cut saw
	95	Masonry saw
	94	Compactor - no cab
Hearing protection recommended above 85 dB(A)	90	Crane - insulated cab
	87	Loader/backhoe - insulated cab
	86	Grinder
	85-90	Welding machine
	85	Bulldozer - insulated cab
	60-70	Speaking voice

Table 1: Some typical noise levels found on construction sites

Figure 2.1 Typical noise levels from construction equipment (Kim and Chalies, 2003)

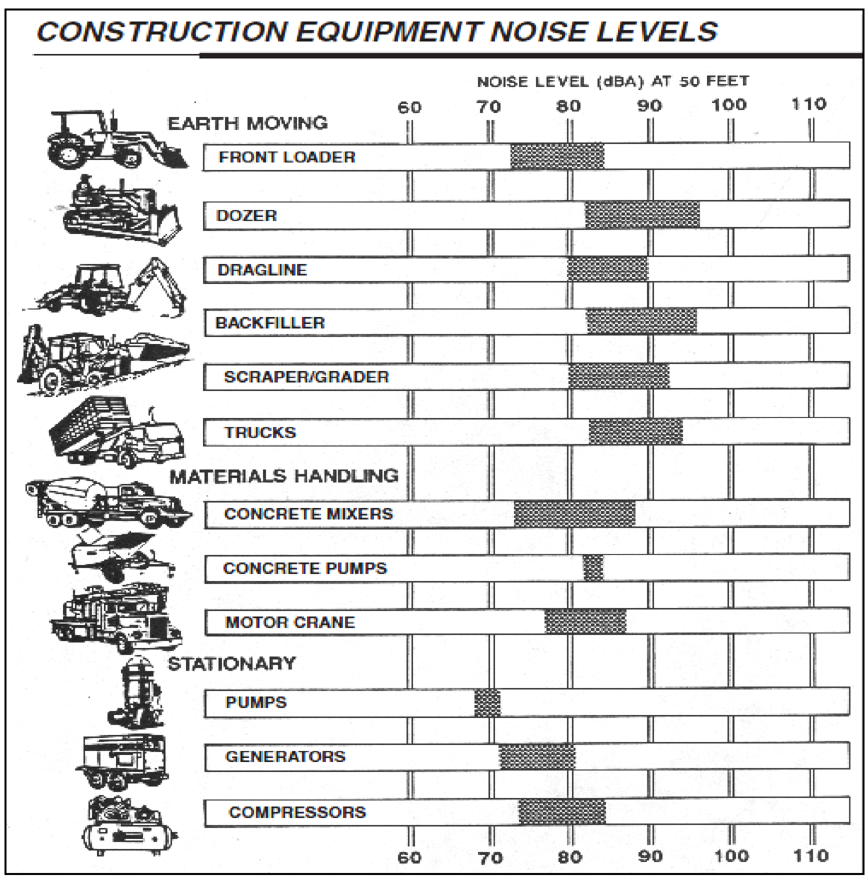


Figure 2.2 Noise from building construction equipment and operations (US Environmental Protection Agency, 1971)

Construction workers and machine operators were the major target of noise hazard because both of them mostly work around source of noise in construction site. Figure 2.3 reported by Kim and Chalies (2003) which indicated average sound pressure level, above standard (85 dBA), that those construction trades might face in their tasks. Those trades include carpenter, masonry, framer, forming, sheet metal, ironworker, boilermaker, and heavy equipment operators as well.

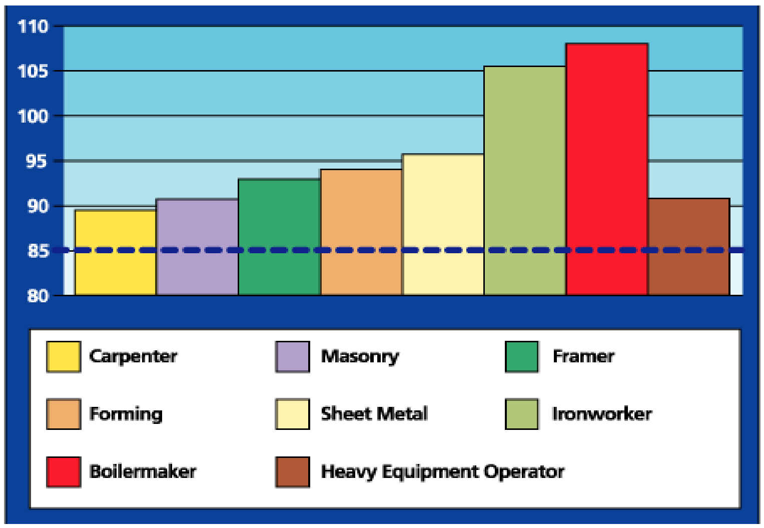


Figure 2.3 Average dBA for some construction trades (Kim and Chalies, 2003)

2.1.3 Noise-induced hearing loss

Many researchers claim noise exposure is a causal factor in hearing loss. One study, by Ministry of Labor in Japan in 1997, estimated that 410,000 (roughly 16%) of 5.8 million Japanese construction workers suffered from Noise Induced Hearing Loss (NIHL) greater than 40 dB at 4 kHz (Miyakita and Ueda, 1997). In addition, nearly 10,000 of Taiwan construction workers in several trades had the highest proportion of severe hearing loss. The study mentioned that hearing ability of the individual's weakest ear was assessed at 4 kHz during audiometric test (Wu et al, 1998). In addition, a study by Sataloff in 1993 demonstrated that occupational NIHL is normally categorized by loss of the higher frequencies under range from 3 kHz to 6 kHz with depression around 4 kHz. Moreover, the tested of 215 construction workers indicated that 24.2 percent of them suffered from NIHL under range from 40 and 55 dB and another 38.6 percent had NIHL more than 55 dB. Furthermore, a study conducted by WCB of British Colombia found that nearly 50 percent of almost 5,000 of sampled construction workers had hearing loss. In response to NIHL, a hearing conversation program was instigated by government of Bristish Colombia in order to provide free audiometric tests for construction workers. Moreover, WCB in 1987 presented 50% of 32,800 audiometric tests with significant hearing loss while 22% of total tests were classified as severe to profound. In addition, it was staggering when WCB estimated the financial costs for covering the roughly 10,000 potential could cost 20 million dollars in that year (Richard, 1998). Therefore, effect of noise-induce hearing is not only a serious problem on worker's health but also the cost of construction industry. Thus, the research related to guideline and regulation of noise hazard needs to be explored.

2.1.4 Regulation related to noise

Many noise regulations have been proposed by several organizations such as National Institute for Occupational Safety and Health (NIOSH), Occupational Safety and Health Administration (OSHA), and American Conference of Governmental Industrial Hygienists (ACGIH) (Figure 2.4), as a guideline to prevent workers from noise hazard. One of the current regulations in the European Union is based on the Directive 2003/10/CE (Appendix A). This document states a set of minimum disposals attempts to prevent the workers from the risks of noise hazard such as their hearing risks. They insist on mechanisms directed to reduction or avoidance of noise exposure, so it meant that the risks derived from noise exposure might be reduced as much as possible to the lowest level or could disappear in their origin source (Marcos et al., 2009).

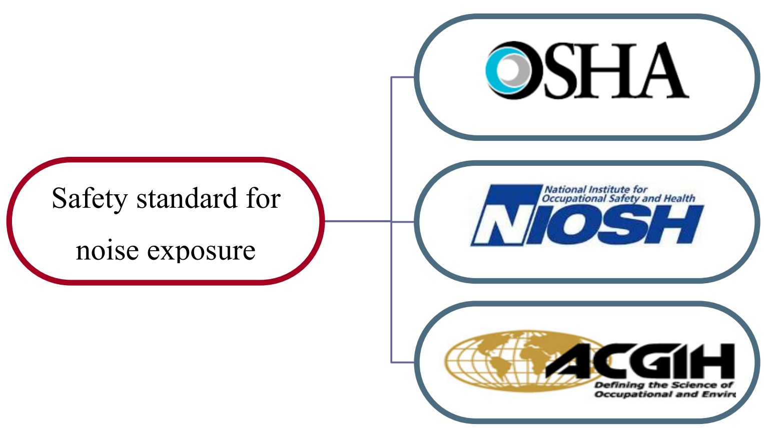


Figure 2.4 Some organizations related to noise regulation

Regulations for worker protection against the effects of noise exposure were also published by OSHA. Firstly, this organization states noise exposure of 90 dBA for an 8 hour with 5 dB exchange rate as an exposure limit. Then, it was revised after NIOSH published the Criteria for a Recommended Standard in 1972. A recommended limit of noise exposure was designed in order to avoid NIHL in 85 percent of noise exposed workers. Therefore, noise exposure level of 85 dBA for an 8 hour and 5 dB exchange rates should be a recommended exposure limit. In response to NIOSH, OSHA in 1977 required a hearing conversation program in details for common industry that faced noise exposure levels equal to or over 85 dBA. Significantly, Time-Weighted Average of 90 dBA was applied for construction industrial but a hearing conversation program is only required for noise exposure level greater than recommended limit. Nonetheless, Washington Industrial Safety and Health Act required a hearing conversation program for all industries when noise exposure levels exceeded 85 dBA (Kyle, 1999).

Although many directives and regulations were stated in order to help workers avoid risk of noise exposure, the prevention of noise hazard is still not fully applied in construction sector. A study by Koushki in 2004 illustrated that no one was seen to be equipped with hearing protection device during most of his monitoring periods. Thus, it could be stated that there are some major reasons for this situation. One of those is that some constructions workers are not aware of impacts of noise exposure on their health while other workers are, but they don’t have enough protective equipment. However, this awareness may be encouraged when some activities produce less noise exposure. In contrast, unaware workers should be warned about the issue of noise hazard.

For all of the above reasons, noise hazard in construction still affects the health and safety of workers. It should be mentioned that noise hazard can have long-term effect on workers. Therefore, this issue should be focused on and prevented.

2.2 Previous research on noise hazard in construction

This section reviews previous research on construction noise hazard. It is divided into four (4) parts based on the research areas, as presented in Table 2.2. The first part presents the researches on the effect of noise on construction; the second part introduces a large amount of research that investigated construction noise assessment;

the third part is the researches on noise control in order to minimize noise from work activity; and last part shows the researches which involve modeling for prediction of noise.

Table 2.2 Previous research on noise hazard in construction

Areas	Related fields	Relative researches
Effect of noise	Construction	Miyakita and Ueda (1997); Dobie (1995); Richard (1998); Kim and Chalies (2003); Engel, *et al.* (2006);
Noise hazard assessment	Construction	LaBenz, *et al.* (1967); Ringen (1995); Utley, *et al.* (1985); Sinclair and Haflidson (1995); Richard (1998); Kyle (1999);
Construction Noise control	Construction	Charles (2006); Engel, *et al.* (2006); Erich (2000)
Prediction of noise level	Construction	Carpenter (1997); Waddington and Lewis (2000); Gilchrist, *et al.* (2003); Zaiton and Khairulzan (2009);
	Environmental	Mohamed (2008); Perdicoulis, *et al.* (2006)

2.2.1 Effect of noise on construction industry

The effects of noise on construction industry have been explored and quantified by several research studies. For example, Miyakita and Ueda (1997) mentioned that 410,000 of 5.8 million Japanese construction workers are suffering from Noise-Induced Hearing Loss (NIHL). That is roughly 16% of Japan population. In the same manner, 32,800 audiometric tests were administered by the Workers' Compensation Board (WCB) of British Columbia in 1989. Results showed that 50% have considerable hearing loss, while 22% were classified to have severe to profound effect. In addition, it was staggering when WCB estimated the financial costs for covering the roughly 10,000 potential could cost 20 million dollars in that year (Richard, 1998). Furthermore, a study by Dobie in 1995 found that numerous agencies in the US compensated several hundred million dollars every year for suffering individual noise-induced hearing loss (NIHL). In addition, NIHL was also believed to cost over one hundred million dollars each year in Sweden (Dobie, 1995).

Figure 2.5 Jack hammering in construction site

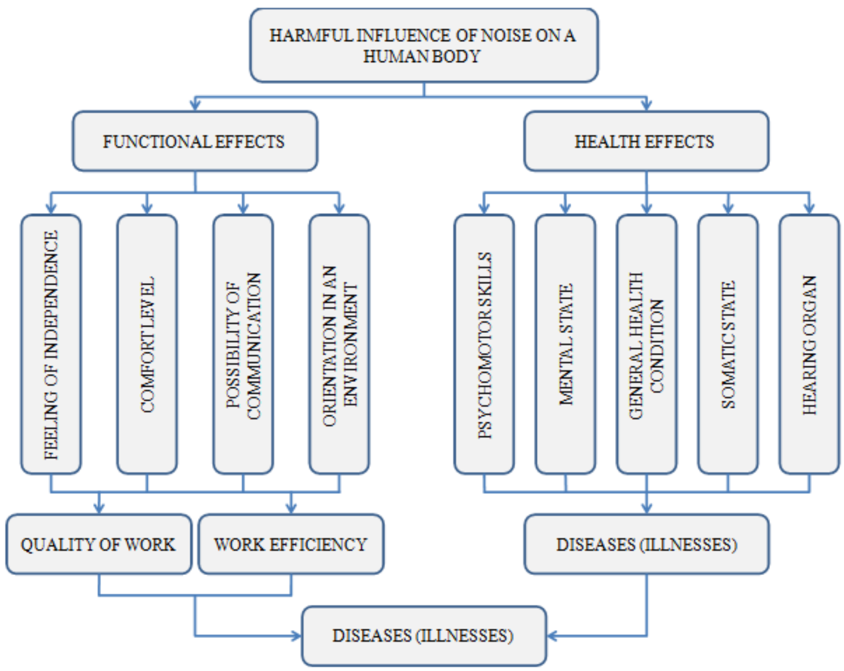


Figure 2.6 Harmful influence of noise on a human body (Engel et al., 2006)

Several researchers have attempted to identify the relationships between noise and health effects. According to Richard (1998), noise exposure is a safety and health issue in nearly every industry, but most prevalent in the construction firm. In figure 2.5, an example of jack hammering activity and a worker in construction site is shown. Referring to OSHA, this activity could expose workers up to 102 dBA of noise level which was observed to have caused the casual problem of noise hearing loss (Kim and Chalies, 2003). On the other hand, Engel (2006) divided the negative impacts of noise on the human body into two (2) kinds of effects under the condition of occupational risk (Figure 2.6). The first effect involves the hearing organ and general health condition that lead to health hazard. The second effect focuses on the functional effects which describe the low quality and low work efficiency.

2.2.2 Noise hazard assessment

Many research studies investigated the noise exposure in construction site with many tasks and trades. A study was made in 1967 by LaBenz et al on earth-moving equipment at 16 construction sites including road, canal, and dam construction. The sound level meters conducted in this research were placed with the machine operator in enclosed cab, and its microphone clipped near operator's head. The study demonstrated scraper-loader and tractor-dozers were associated with higher noise exposure levels under range from 90 to 120 dB. Interestingly, the findings demonstrated that no exposure levels were lower than Permissible Exposure Limit (PEL) of 90 dBA (LaBenz et al, 1967). In the same manner, Ringen (1995) pointed out that the noise exposure level around large earth-moving machine under site development and site preparation exceeding 95 dBA. Furthermore, exposure levels of smaller tasks measured around power tools range from 95 to 105 dBA. According to the reporting of Utley et al (1985) from which a study was made on potential noise exposures on construction sites. The measurement of noise mostly conducted on individual pieces of equipment operating off-site. The findings illustrated that average noise exposure level from 12 power tools equal to 97.5 dBA under range from 87 to 107 dBA. In addition, for large earth- and material-moving equipment, an average of noise level under ranges from 80 dBA is recorded as the measurement for tracked excavators to 93 dBA for forklift trucks. These noise level measurements were taken from a 10 cm - distance from the equipment and tool operator's ear. It is also noted that noise exposure, under the case of large equipment, may affect surrounding construction workers more than the machine operator, as the operators are seated in enclosed cabs of machine during the construction operation, as well as when these measurement are taken. They were reported to have noise exposures not exceeding 90 dBA. A limitation of the Utley study was that it was not actually indicative of an actual operating condition and does not reflect the ambient noise levels present at the construction site. Within the scope of the study, noise contours in construction site that were sketched illustrated that a large portion of an open construction site may contain noise exposure levels that exceed 90 dBA.

During a 14-month duration (from May 1991 to July 1992), a study in Canada in 1995 was conducted which attempted to assess noise exposure levels on 27 construction sites. In this study, sampled workers were attached by noise dosimeter for up to five hours. The authors of this study affirmed that the repetitiveness of the work justified partial- work-shift sampling procedures. Following the Canadian regulations, noise dosimeters used for the study were required to select a 3 dB as an exchange rate. According to Sinclair and Haflidson (1995), the noise data was sampled at the residential construction site in Canada. The data collected for this study analyzed had Time-Weighted Average (TWA) noise exposure with an arithmetic mean of 93.1 dBA. In addition, the findings demonstrated that construction trades of ironworkers had an average TWA exposure of 105.4 dBA whereas carpenters were found to have an average TWA of 89.4 dBA.

Many types of instruments were used for measuring level of noise exposure to workers in construction site. A study by LaBenz used sound level meter model Bruel & Kjaer 2203 for measuring noise exposure level of earth moving equipment operations at 16 construction sites. The result found that noise level of this operation presented under range of 90 to 120 dB and the overall noise levels measured were higher than the OSHA PEL of 90 dBA (LaBenz et al., 1967). Furthermore, a study by Richard used eleven (11) datalogging noise dosimeters for assessment of occupational noise exposure in four construction trades such as carpenter, laborer, ironworker, and operation engineer. The study used three models of noise dosimeter including Quest Q-300 (5 devices), Metrosonics db-308 (5 devices), and Metrosonics db-3100 (1 device). The finding illustrated that the noise exposure levels were not depended on workers' trades, but significantly depended on the method and stage of construction operation (Richard, 1998). In addition, five of Quest Q-300 datalogging noise dosimeters were also used for measuring noise exposure to electricians in construction industry (Kyle, 1999).

2.2.3 Construction noise control

Noise control involves reduction of noise at the original source, control of noise transmission paths, and protection of the receiver (Charles 2006). Many studies were conducted on this issue in order to develop a guideline and strategy for noise control. One of the examples is that Erich (2000) proposed a studied on construction noise control program and mitigation strategy at the Central Artery/ Tunnel (CA/T) project. The estimation of cumulative noise-related costs from the start of the noise program in 1987 through to project completion in late 2004 is $16,958,000, summarized in table 2.3. Furthermore, table 2.4 represented the method of noise control that applied on the CA/T project. Three main parts concerned in noise control of this project included sources control, path control and Receptor (Erich, 2000).

Table 2.3 CA/T noise control program cost estimate (Erich, 2000)

Noise Control Program Cost Category	Total Estimated Cost
Direct Expenses: Project Noise staff, Home-Office staff, and Sub-consultants	$5,326,000
Indirect Expenses: Noise monitoring equipment and instrumentation	$102,000
Mitigation Costs: Noise barriers/curtains, windows treatments, legal settlements	$6,109,000
Contractor Costs: Contractors fulfillment of Noise Spec. 721.560 requirements	$5,421,000
Total =	$16,958,000

Table 2.4 Method of noise control (Erich, 2000)

1. Source Controls	
Time Constraints	Prohibiting work during sensitive nighttime hours
Scheduling	Performing noisy work during less sensitive time periods
Equipment Restrictions	Restricting the type of equipment used
Emission Restrictions	Specifying stringent noise emission limits
Substitute Methods	Using quieter methods/equipment when possible
Exhaust Mufflers	Ensuring equipment has quality mufflers installed
Lubrication & Maintenance	Well maintained equipment is quieter
Reduced Power Operation	Use only necessary size and power
Limit Equipment On-Site	Only have necessary equipment on-site
Noise Compliance Monitoring	Technician on site to ensure compliance
Quieter Backup Alarms	Manually-adjustable or ambient sensitive types
2. Path Controls	
Noise Barriers	Semi-permanent or portable wooden or concrete barriers
Noise Curtains	Flexible intervening curtain systems hung from supports
Enclosures	Encasing localized and stationary noise sources
Increased Distance	Perform noisy activities farther away from receptors
3. Receptor Controls	
Window Treatments	Reinforcing the building’s noise reduction ability
Community Participation	Open dialog to involve affected residents
Noise Complaint Process	Ability to log and respond to noise complaints
Temporary Relocation	Extreme otherwise unmitigatable cases

In addition, methods of noise control (Figure 2.7) are schematically presented by Engel (2006). This author introduced the technical means of noise reduction such as change of noisy technological process into a less noisy, mechanization and automation of technological processes, constructing and implementing of silent running machines, equipment and tools, acoustically correct layout of a plant and utilization of rooms, acoustic dampers, sound insulated enclosures, sound absorbing screens, sound absorbing materials, hearing protectors and active methods of noise reduction (Engel at al. 2006).

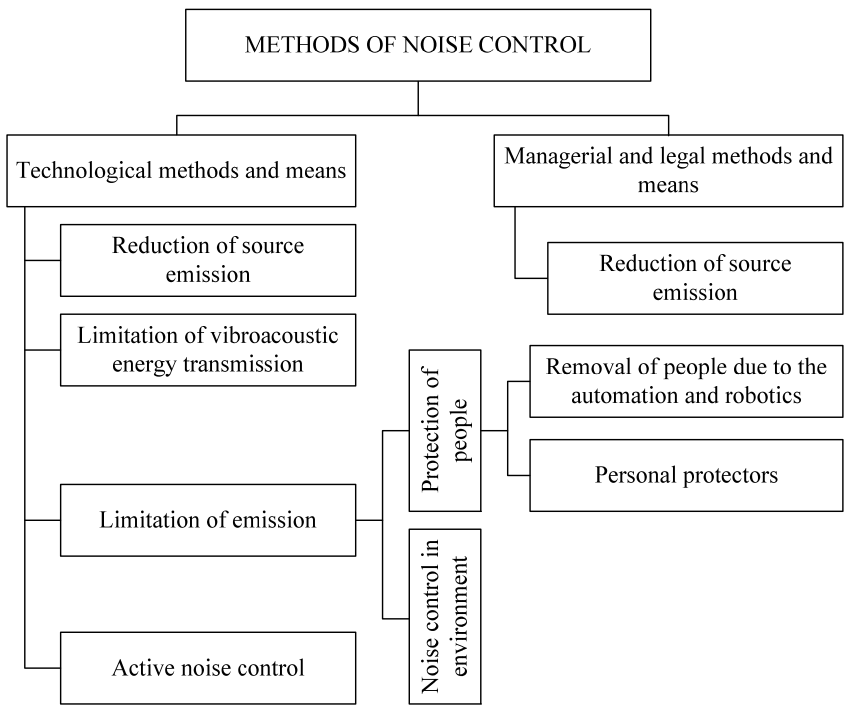


Figure 2.7 General methods of noise control (Engel, 2006)

2.2.4 Prediction of noise

There have been relatively few studies focusing specifically on prediction of noise from a construction site. In this issue, a 1997 study by Carpenter was suggested the Monte Carlo approach for modeling construction noise prediction. After that, this approach was firstly developed by Waddington and Lewis in year 2000. The model development aims to investigate the variation of noise level from a well-defined area at a construction site by random the location and power of the source of noise. A study conducted by Gilchrist et al. in 2003 has also been applied Monte Carlo simulation to study noise under construction operation at construction site by taking into consideration the random operating status of the machine. Nonetheless, both studies did not produce a temporal distribution in their analysis. Therefore, Zaiton and Khairulzan (2009) have defined a basic temporal distribution for prediction noise levels generated from single source (Figure 2.8) and multiple sources noise (Figure 2.9) at construction site. In order to achieve this objective, stochastic variables are used including the random position and duty cycle. In addition, the source of noise was selected based on construction machinery that randomly operation around construction site. As a result, the model employs the important noise sources of earth-moving machinery. Furthermore, the modeling was simulated by using computer programming implemented in MATLAB 7.2. After that the results of Monte Carlo simulations are compared with that achieved from BS5228 (1997).

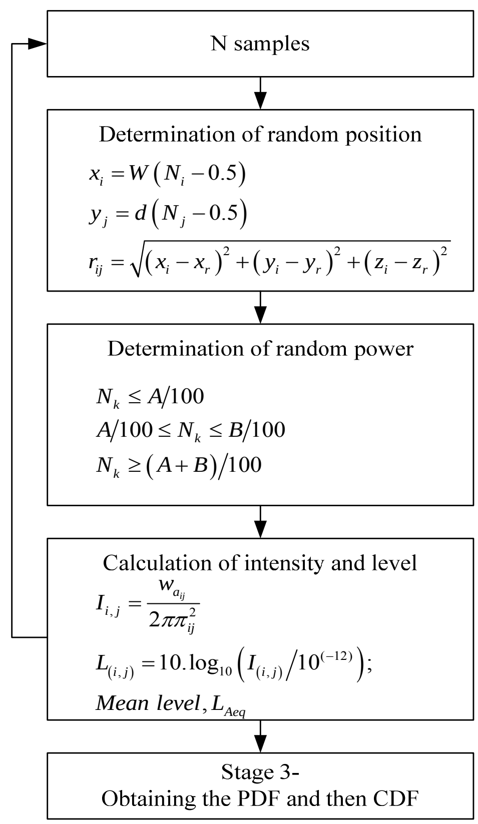


Figure 2.8 Flowchart for Monte Carlo Simulation - Single Piece of Equipment (Zaiton and Khairulzan, 2009)

Not only Monte Carlo simulation but also the Expert system was used for construction noise prediction. One of the examples is a study by Mohamed in 2008. In his study, a modeling of construction noise for environmental impact assessment was proposed by using Artificial Neural Networks (ANNs). Actually, ANNs have been used to model as alternative method for prediction in several fields (Hamoda et al., 1999; Predicoulis and Glasson, 2006). However, it was applied recently by Mohamed for modeling of construction noise which attempts to predict levels of noise exposure. In addition, Mohamed (2008) studied the application of ANNs as sophisticated techniques having elastic and independent structure to model the variation of construction noise exposure levels. The main purpose of the research was to measure noise at construction sites and uses the noise measurements to test the ability of a structured network to predict the construction noise. The findings illustrated that the application of ANNs is supposed to be satisfactory for prediction of noise levels while nearly 93 percent of the overall results were inside observed values at 5 percent (Table 2.5). Interestingly, the prediction result showed in high correction with that measured sound level meter while correlation coefficient equal to 0.81. Figure 2.10 represented the correlation of noise exposure level predicted by ANNs and that by observing field construction site (Mohamed, 2008).

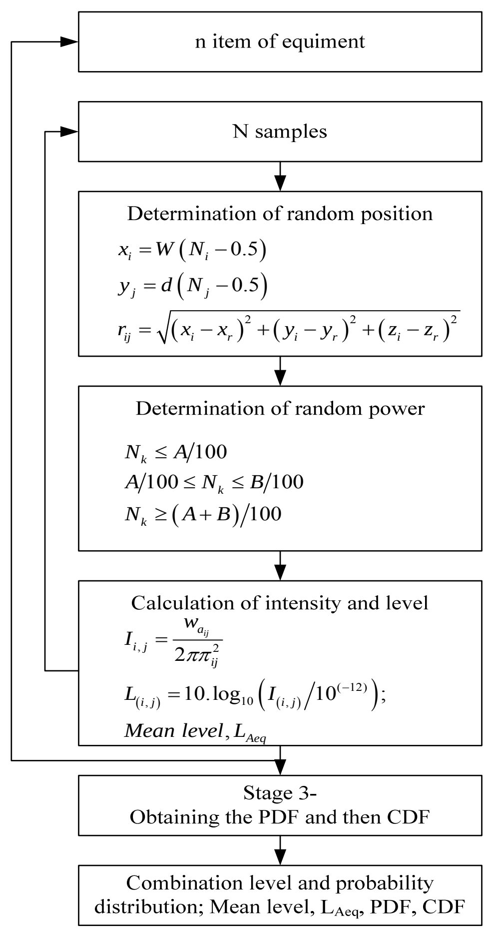


Figure 2.9 Flowchart for Monte Carlo Simulation - Multiple Sources (Zaiton and Khairulzan, 2009)

Table 2.5 Statistical Results of the Predicted Model (Mohamed, 2008)

Parameters	Result
R^2	= 0.6572
Mean squared error	= 17.7 dBA
Mean absolute error	= 3.157 dBA
Min. absolute error	= 0.004 dBA
Max. absolute error	= 17.573 dBA
Correlation coefficient	= 0.8107
Percent with 5%	= 70.652
Percent with 5% - 10%	= 22.826
No. of patterns	= 184

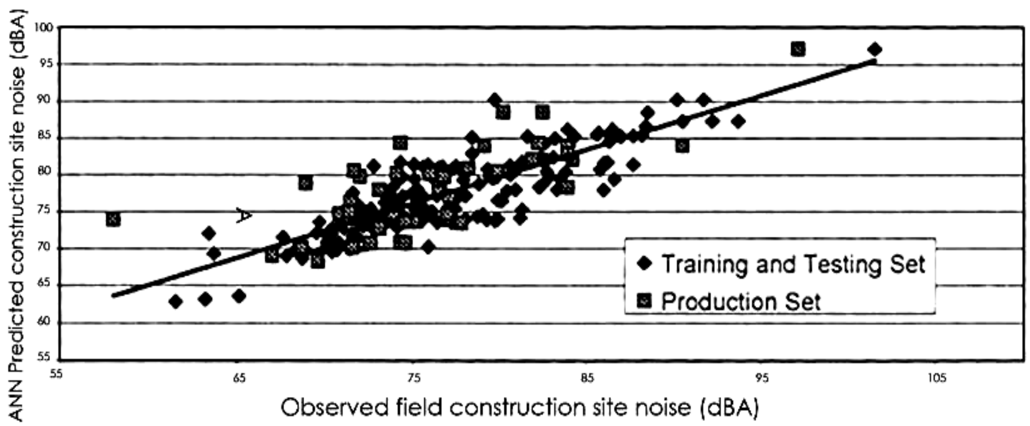


Figure 2.10 Field (observed) versus ANN (predicted) Construction Noise (Mohamed, 2008)

From literature reviews, we can state that noise exposure is a casual problem in construction industry. Many researchers in different regions studied the effect of noise exposure to construction workers. Moreover, they proposed various methods attempting to assess the level of noise from workers' activities in construction site. The result found that most construction workers faced the hazard of noise. Therefore, construction noise control was proposed in order to reduce noise at the original source, control of noise transmission paths, and protect the receiver. In addition, there have been relatively few studies focusing specifically on prediction of noise exposure in construction site.

Based on problem statement discussed in chapter 1, our research study will focus on a new alternative for assessing noise hazard of construction workers.

2.3 Noise measurement

2.3.1 Method of measurement

We took into consideration the methods for measuring noise in place occupied by workers which are used for establishing the degree of risk to noise exposure for workers at their work places and specified distances from the noise source. Basically, there are two methods of measurement as following (Engel et al., 2006):

- **Direct method** consists of the continuous measurement during the whole time of worker exposure and of reading the meters such as the noise dosimeter or the integrating sound level meter. Those results precisely describe the workers' risk.
- **Indirect method** is based on the noise measurement done in the shorter time than the one being assessed and the use of mathematical formulae for the estimation of values needed.

2.3.2 Instrumentation for noise measurement

National Institute for Occupational Safety and Health (NIOSH), in 1998, presented the most common instruments which were the Sound Level Meter (SLM) and Noise Dosimeter for measuring noise exposure.

2.3.2.1 Sound Level Meter (SLM)

The SLM is an instrument basically used for noise measurement and the evaluation of noise exposure level in dB SPL. A sound level meter contains a microphone, an indicator, and a selective amplifier (NIOSH, 1998). It is relatively simple for measuring noise with SLM when the noise exposure level is continuous under workers operation and when they remain stationary during the working task. Dose of noise and Time-Weighted Average are automatically calculated by the integrating function with SLM.

2.3.2.2 Noise dosimeter (ND)

The ND is an instrument used for measurement and storages of data of noise levels during a period of noise exposure and which computes the output into the percentage of dose or TWA. It is different from SLM with details of time history, additional storage and computational functions. Nowadays, many available dosimeters can provide an output in dose or TWA using various exchange rates. This instrument can be used for measuring exposure to noise levels which consist of impulsive components and vary during the work shift. Moreover, it is suitable for workers who move around frequently during their operations.

2.4 Standard of occupational noise exposure

Recommended expose limit (REL) for occupational noise exposure is established by NIOSH. The standard REL is equal to 85 decibels, A-weighted, as an 8hour times-weighted average. Exposures at and above this level are considered hazardous. In addition, exposure to noise shall not exceed 140 dBA (NIOSH, 1998). The below section will describe more about the criteria for the recommended limit of exposure.

2.4.1 Exposure levels and durations

Occupational noise exposure shall be controlled so that worker exposures are less than the combination of exposure level (L) and duration (T). The exposure duration can be calculated by equation 2.1 or determined by table 2.6. Where T is maximum exposure duration in minute(s), L is exposure level in dBA, 3 is exchange rate in dB, 85 is recommended exposure limit in dBA (REL), 480 (8hr) is time-weight average in minutes.

$$T = 480/2^{(L-85)/3} \qquad (2.1)$$

Table 2.6 Combinations of noise exposure levels and duration (NIOSH, 1998)

Exposure level, L (dBA)	Duration, T			Exposure level, L (dBA)	Duration, T		
	Hours	Minutes	Seconds		Hours	Minutes	Seconds
80	25	24	–	91	2	–	–
81	20	10	–	92	1	35	–
82	16	–	–	93	1	16	–
83	12	42	–	94	1	–	–
84	10	5	–	95	–	47	37
85	8	–	–	96	–	37	48
86	6	21	–	97	–	30	–
87	5	2	–	98	–	23	49
88	4	–	–	99	–	18	59
89	3	10	–	100	–	15	–
90	2	31	–	101	–	11	54

Table 2.6 Combinations of noise exposure levels and duration (Continued)

Exposure level, L (dBA)	Duration, T			Exposure level, L (dBA)	Duration, T		
	Hours	Minutes	Seconds		Hours	Minutes	Seconds
102	–	9	27	117	–	–	18
103	–	7	30	118	–	–	14
104	–	5	57	119	–	–	11
105	–	4	43	120	–	–	9
106	–	3	45	121	–	–	7
107	–	2	59	122	–	–	6
108	–	2	22	123	–	–	4
109	–	1	53	124	–	–	3
110	–	1	29	125	–	–	3
111	–	1	11	126	–	–	2
112	–	–	56	127	–	–	1
113	–	–	45	128	–	–	1
114	–	–	35	129	–	–	1
115	–	–	28	130	–	–	<1
116	–	–	22	140	–	–	–

2.4.2 Daily Noise Dose

Daily noise dose is calculated according to equation 2.2 when the daily noise exposure contains periods of different noise levels. Where C_n is total time of exposure at a specified noise level, and T_n is exposure duration for which noise at that level. In addition, the daily dose (D) should not equal or exceed 100 otherwise, it becomes hazardous.

$$D = [C_1/T_1 + C_2/T_2 + \ldots + C_n/T_n] \times 100 \qquad (2.2)$$

2.4.3 Time-Weighted Average (TWA)

Time-Weighted Average (TWA) is the average of different exposure levels during exposure period. Under NIOSH standard, given 85 dBA exposure limit and 3 dB exchange rates, the TWA is calculated according to equation 2.3 where D is daily dose of noise. In accordance with daily noise dose, the recommended exposure limit for an 8-hr (480 min) work shift is a TWA of 85 dBA using a 3-decibel exchange rate.

$$TWA = 10.0 \times \log (D/100) + 85 \qquad (2.3)$$

2.5 Research gaps

During construction operation, several activities produce noise. It is not easy to determine by individual perception whether the noise has level of hazard. Different people have various perceptions on the level of noise hazard. Therefore, most of previous research used the instruments for measuring noise level in order to assess noise hazard. Refer to price of these instruments which was shown by many manufacturers in year 2010 (Table 2.7), the use of many current noise dosimeter for noise hazard assessment at workers level was expensive to measure. In addition, this method may not be the practical method for assessing and reminding construction workers in developing country about their health hazard. Therefore, the current research aims to propose an inexpensive system for assessing noise hazard for multiple construction workers.

Table 2.7 Noise at work: Sound level Meters and Noise Dosimeters price list (Noise meters, 2010)

Product	Description	Price
Sound Level Meters		
CR262A	Type 2 Integrating Sound Level Meter	$1356.00
CR264A	Type 2 Integrating Sound Level Meter with Octave Band Filters	$2074.00
CR720B	Integrating Sound Level Meter for OSHA Compliance	$1744.00
CR812C	Type 2 Integrating Sound Level Meter with data storage and other advanced features	$2260.00
CR831C	Type 1 Third Octave Band Integrating Sound Level Meter with data storage	$4802.00
Pulsar30-2	Type 2 Integrating Sound Level Meter with Real Time Octave Band Filters	$3863.00
Noise Dosimeters		
CR110A	doseBadge Noise dosimeter with Dose, TWA, Lavg, Leq in a small and robust package	$3606.00
CR110AIS	Intrinsically safe noise dosimeter approved for use in hazardous environments	$3925.00
Combo	Combination Kits with doseBadge Dosimeter and a Sound Level Meter	$4499.00

2.6 Research framework

To fulfill these gaps, framework of noise hazard assessment system is designed and arranged as shown in figure 2.11. First of all, construction activities with noise exposure were selected for conducting the research. Next, sound recorder and noise dosimeter were attached with workers for detecting noise in construction site and 20 cm from their ear. When daily working time began, both devices simultaneously started recording noise at the same time. At the end of testing, sound recorder and noise dosimeter were stopped and downloaded data via their own software. Furthermore, collected data was stored in computer hard drive.

There are two types of data in this study including signal of noise in WAV file and dose of noise. WAV file is the signal of noise that is recorded from the testing. It is the output of sound recorder device. This signal would be inputted to MATLAB script for computing noise level and dose of noise. On the other hand, the result of noise dosimeter is noise level and dose of noise which are evaluated automatically by circuit inside. This device also provided noise level and dose of noise. Finally, noise level and dose of noise from both parts would be used for finding the mathematical model that explained the relationship of the proposed system and standard noise dosimeter.

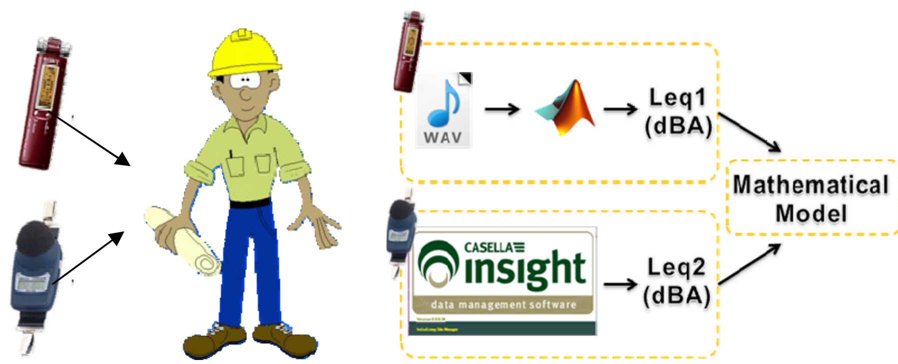


Figure 2.11 Research framework of noise hazard assessment system

2.7 Summary

In summary, noise in construction industry has been discussed by many researchers due to the noise hazard being one of the main concerns in health and safety of construction workers. Previous research on noise hazard in construction is categorized into four areas including effect of noise, noise hazard assessment, construction noise control and prediction of noise level. In addition, most of the studies are to assess level of noise hazard for construction workers in various activities. Interestingly, many researchers used several noise meters in order to measure noise hazard from multiple construction occupations and trades. Based on the price of noise meters, the use of these meters may not be a practical method for assessing noise hazard at construction workers level since the budget of some sub constructor is limited. Thus, there is still a research gap to further propose a new alternative of noise hazard assessment for construction worker. To cope with the gaps, research framework is designed as presented in figure 2.11. Then the research methodology is discussed in the following chapter.

CHAPTER III
RESEARCH METHODOLOGY

The purpose of this chapter is to describe the proposed research method for developing a noise hazard assessment system, defining the conceptual design and developing the final system for evaluating the level of noise hazard of construction workers. The chapter begins with a brief description, classification the type and approach of this research. Next, the chapter introduces a framework of research methodology (Figure 3.1) with clear process in order to achieve research purposes. Then, the section starts to explain the processes in details from section 3.3, system development which contains three subsections such as tools testing, preliminary study, and full scale of system development. After that, section 3.4 describes the application of system with workers in construction site, including data collection and data analysis.

3.1. Research type and approach

Different types of research have been discussed by many people. One of those types is experimental research which is known as hypothesis-testing research studies. Basic concept of this research is the process of examining the truth of a statement, hypothesis (absolute or comparative experiment). There are three basic principles of experimental design which were propounded by Prof. R A Fisher (Kothari, 2004):

1. Replication: experimental repeated several times for better results/ increasing statistical accuracy/ precision.
2. Randomization: protects experiment against extraneous factors of chance and leads to better estimation of experimental error.
3. Local control: known source of variability (extraneous factor) is made to widely vary deliberately so that its effects can be measured and eliminated from experimental error.

As describe with many reasons in chapter 1 and 2, this research attempts to develop an inexpensive system of noise hazard assessment at construction workers level. Therefore, many data are needed for experimental on the development system in order to achieve research objective. In addition, the research also makes comparisons between noise exposure level measured by standard equipment, noise dosimeter, and that evaluated by the proposed system, sound recorder and MATLAB programming. Significantly, the outcome of this system was also validated by some implementations with workers in construction site. Therefore, this research can be categorized into an experimental research. In terms of data collection, this research should be classified as the quantitative research approach.

This research mainly focuses on quantitative research approach. The purpose of quantitative research approach is generally to generalize about of control phenomena. The data of quantitative research approach was mostly collected by questionnaires, surveys, checklist, and test. According to the reporting of William in year 2011, the important of quantitative approach consists of four features including (1) problems and questions identification to be studied and a hypotheses development that predicts the results of the study before the research begins, (2) control of contextual factors which might influence the results of the study, (3) data collection from samples of participants, and numerical, statistical approaches used to analyze the collected data. Related to this research, quantitative research approach plays an important role in data collection process. It could be used to express the quantities of noise hazard exposure to construction workers. In addition, the research used survey questionnaires to explore workers' perception on level of noise hazard and workers' awareness of noise impact under their operation in construction site.

3.2. Research design

Research in common parlance refers to a search for knowledge. One can also define research as a scientific and systematic search for pertinent information on a specific topic. In order to achieve the research objective, research methodology is designed at the beginning. It is a way to systematically solve the research problem. The various steps studied in this research are generally adopted by researcher in studying the research problem. The research methodology is significantly a guideline with clear process and objectives of each process according to the conditions such as time, money, and research quality. The research on developing a system of noise hazard assessment for construction workers was carried out through following steps as shown below:

1. Review of the relevant literature in order to get the systemization knowledge related to noise exposure on construction worker.
2. Development of noise hazard assessment system which contains three steps:
   - 2.4 Testing for finding suitable tools:
     - Selection of computer programming for system development
     - Review of the instruments operating instruction; sound recorder and noise dosimeter.
   - 2.5 Conducting of a preliminary study:
     - Development of an initial system for evaluation sound pressure level
     - Experimental of system in acoustic laboratory (control room)
       - Installation of instruments for experimental
       - Simulation of noise source in laboratory
       - Detecting and storing of sound signal
       - Result of experimental: calibration constant C
     - Experimental of system in construction site
       - Installation of instruments for experimental
       - Selection of noise source
       - Selection of recording level for sound recorders
       - Detecting and storing of sound signal
       - Result of experimental: calibration constant C
     - Discussion of result from both experimental
     - Testing the reliability of system.
   - 2.6 Conducting of full scale of system development
     - Process of noise hazard assessment system
     - Development user interface of noise hazard assessment system
     - Adopting theory for calculation of dose of noise
     - Programming the procedure of calculation of dose of noise
     - Verification of the proposed system with workers in construction site
       - Data collection by attaching instruments with construction workers during their operation in construction site

- Data analysis:
    - Comparison between result of the proposed system and that of standard equipment
    - Percent error of result from the proposed system
    - Mathematical formula represent the correlation of system and standard equipment
- Adjustment of noise hazard assessment system
- Testing the validity of the proposed system.

3. Application of noise hazard assessment system

3.4 Selection of sampling and sample size

3.5 Data collection:

- Data collection by using sound recorder
- Data collection by using survey questionnaire

3.6 Data analysis

- Result of noise hazard under worker's operation
    - Equivalent level of noise
    - Dose of noise
    - Status of noise hazard
- Result of workers' perception of noise hazard and awareness of noise impact
- Analysis of workers' perception and awareness
    - Difference between status of noise hazard and workers' perception
    - Difference between status of noise hazard and workers' awareness
    - Difference between workers' perception and workers' awareness

The research methodology process in figure 3.1 is the overall procedure which will be used as a guide to achieve the research objectives. This process is classified into two main categories based on the purpose of the research project, including development of noise hazard assessment system and application of the proposed system. In addition, the conceptual model of system development is used to systemize the relevant knowledge to define the research gaps, clarify the problem statement, and setup a clear objective to explore the new topic. The aim of this study is to develop an inexpensive system of noise hazard assessment for construction workers.

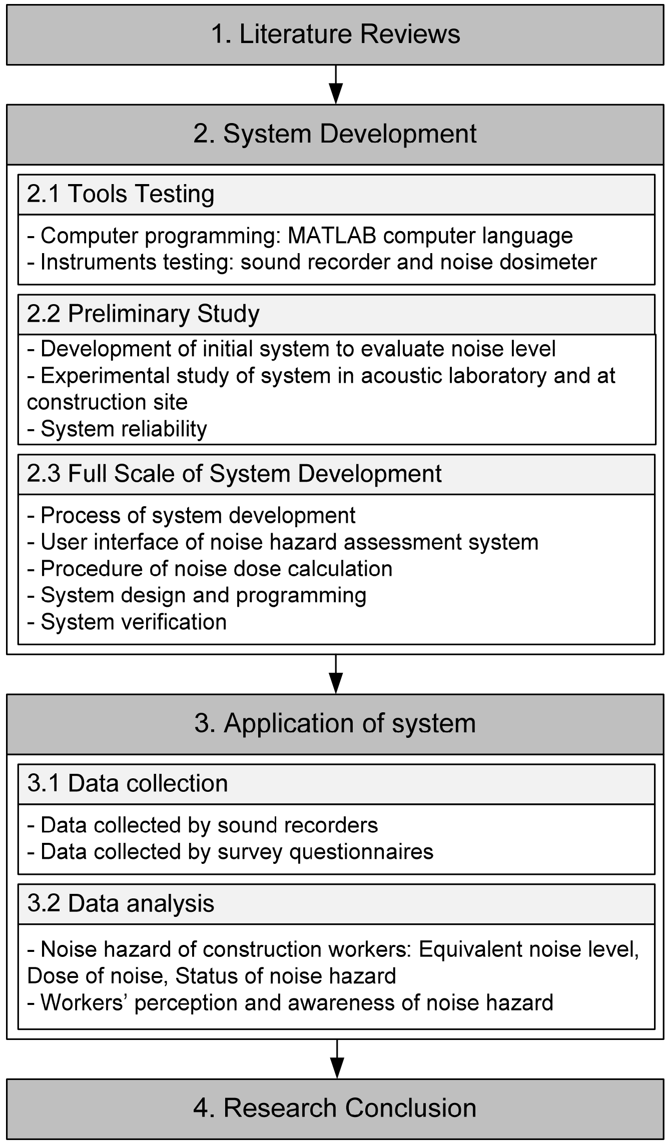


Figure 3.1 Research methodology

3.3. System development

A system development process involves many stages which require many activities over a long period of time in order to identify the potential requirement. In addition, the result of the final system needs to be fully implemented and accepted by the end user. The main stages of system development are highlighted in the section below. This research system development is designed into three steps, including (1) tools testing, (2) preliminary study and (3) full scale of system development. The overview of these steps is presented in following sections.

3.3.1 Tools testing for system development

The testing tools are considered to be a starting point of our noise hazard system development. It is conducted to identify and check the ability of instruments that are involved with computer programming languages. In addition, the testing is not only used to find the appropriate tools, noise dosimeter and sound recorder, for data collection, but also developed a brief of programming to support the understanding of noise level evaluation. This section is described in detail by following steps mentioned in the table 3.1. It involves the selection of computer programming and instruments that will be used in this research.

Table 3.1 Summary of tools testing for system development

Tools Testing	• Computer Programming: o *MATLAB computing language*
	• Instrument Testing: o *Sound recorder* o *Noise dosimeter*

3.3.1.1 Computer programming

Many types of computer programming are developed by various companies over the world. One among those types is MATLAB computing language. It is a high-level language and interactive environment that enables users to perform computationally intensive tasks faster than with traditional programming languages such as C, C++, and FORTRAN (Mathworks, 2010). From tools testing process, MATLAB is an appropriate programming for development of noise hazard assessment system. This computer language is selected because of many reasons such as its ability to read the properties of electronic sound signal, to transform signal for time domain to frequency domain, to create and link various functions, to export results to other parties, and to display the results in many formats. Most especially, MATLAB programming also allows user to develop their system interface.

Based on objectives, this research attempts to develop noise hazard assessment system. Therefore, a brief code of system programming was developed as a trial of noise assessment system using MATLAB computing language.

3.3.1.2 Instrument testing

From conceptual design, there are two types of instruments used in this research including sound recorder and noise dosimeter. Thus, the review of instrument operating instruction (User Manual) is needed in order to match system requirement.

- *Sound recorder*

Sound recorder is an instrument used to detect and store a sound signal that exposure around its microphone. Recording sound and reproduction is an electrical or mechanical inscription and re-creation of sound waves, such as spoken voice, singing, instrumental music, or sound effects. There are two main classes of sound recording technology are analog recording and digital recording (Wikipedia, 2010). In addition, digital recording is considered higher quality than analog recordings not necessarily because they have higher fidelity.

Focusing on the system requirement, the specification of various sound recorders was reviewed and the comparison was simultaneously performed. Of those, sound recorder “Sony IC-SX850” and “Sony IC-SX713” were selected. The main reason is that IC-SX850 and IC-SX713 can register sound in “WAV” format with CD quality (Frequency of sampling rate Fs = 44.1 kHz) which is necessary for our system. Furthermore, the operating instruction of these recorder models is reviewed to qualify their abilities and their build-in function.

- *Noise dosimeter*

Noise dosimeter is an instrument that can be used to measure construction worker’s percent dose of noise exposure when the noise levels consist of impulsive components and vary during the work shift. Moreover, it is suitable with construction workers who frequently move around during their operation in construction site. Furthermore, noise dosimeter is a sound level meter with additional storage and computational functions to automatically calculate the percentage of noise dose or time-weighted-average (TWA). In addition, many noise dosimeters can provide an output in dose or TWA using various exchange rates (NOISH, 1998).

The selection of noise dosimeter would be performed by reviews from previous research. As a result, Noise dosimeter model CEL-350 dBage was selected based on several reasons. Firstly, this model had the capacity to collect two channels of data which allows measuring noise with different exposure metric. Secondly, it is suitable for worker clipped during their work shift.

3.3.2 Preliminary study of system development

The preliminary study is done in order to test the selected instruments and system development procedure and to obtain the reliable system. In addition, the preliminary study is a guiding tool for the full scale system development.

The study consists of three main parts including an initial system development, experimental of the proposed system, and testing of system reliability (Figure 3.2). The initial system is focused on the development of noise hazard assessment system. It means that a brief code of MATLAB is written up to evaluate only noise exposure level from electronic sound signal. Then, the system is tested by experimenting in control room before conducting at construction site. It is done in acoustic laboratory until MATLAB code can be evaluated for noise exposure level. In addition, the initial system is further tested by experimenting in real environment in order to investigate the influence on the proposed system such as wind, nature of construction noise, distance of system to source of noise. Furthermore, the details of experimental of system will be presented in chapter IV. The results of both experimental are used to compare with the result of standard equipment in order to define calibration constant (C) of the proposed system. Finally, the reliability of the proposed system is tested at the end of preliminary study. The following section describes the procedure of reliability.

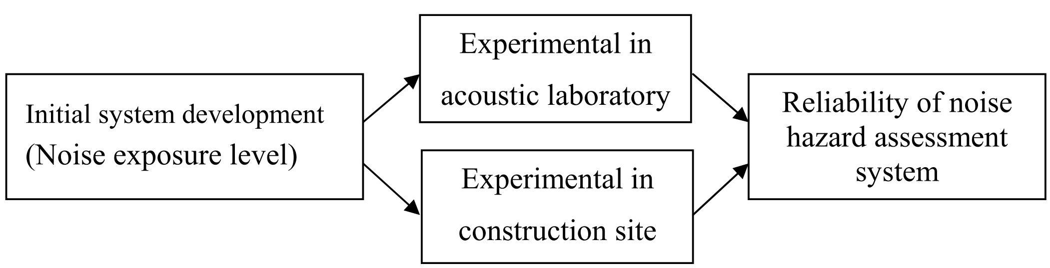


Figure 3.2 Process of preliminary study

Reliability is probability that a device can perform its intended function during a specified period of time under stated conditions. It was concerned with meeting the specified probability of success, at a specified statistical confidence level (Wikipedia, 2010). Related to this current research, the proposed system contains two parts that are hardware (sound recorder) and software (MATLAB script and Calibration constant C). The system reliability testing was performed by checking both of these parts (Figure 3.3). First, source of noise was simulated in a control room. Then, sound recorder is used to record that noise, for five times, with a fixed distance and stated duration. The "WAV" files which were got from recording process were inputted to MATLAB script in order to compute dose of noise. In addition, we can conclude our system is reliable if all the outputs of our proposed system, equivalent noise level, are presented at confidence level.

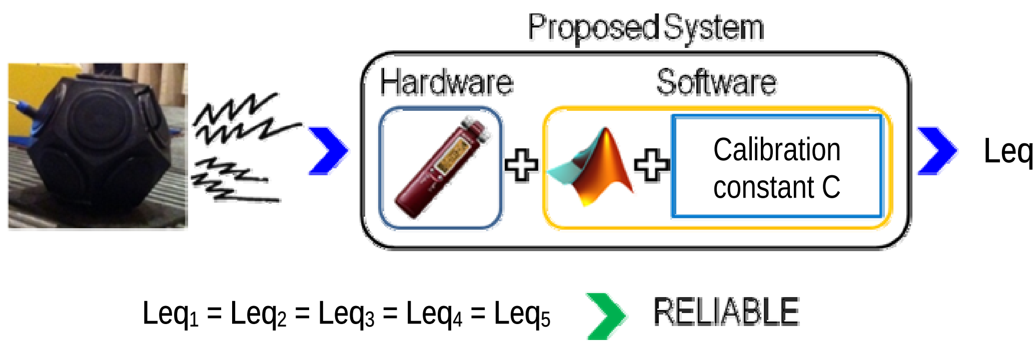


Figure 3.3 Testing the reliability of noise hazard assessment system

3.3.3 Full scale of system development

The main objective of the full scale system development is to finalize the noise hazard assessment system with enough reliability and validity. The full scale of system development is designed based on the research objective, literature review and lesson learnt from the preliminary study. In particular, the preliminary study provided the possibility of the system implementation, the clarity of the entire system, refining data collection plans, gaining an initial idea of the validity and reliability of the conceptual design. Therefore, final system development is defined and discussed in this section.

From the preliminary study, the proposed system is not complete, while some parameter of noise hazard is required and could be improved. It means that system development does not yet fulfill the objective of our research and the facilitation for user is still not provided; thus some developments are needed. Therefore, the process of full scale system development is designed. There are four main steps for system development including user interface development, theory of noise dose calculation, system design and programming, and system verification. First of all, user interface of noise hazard assessment is developed in order to facilitate user for navigating the system. It will be done in Graphical User Interface (GUI) of MATLAB programming. After that, the theories of noise dose calculation are adopted for evaluating the status of noise hazard. Then, the procedure of calculation will be programmed in MATLAB in order to support the user interface. Furthermore, full scale of system development is implemented with workers at construction site. The implementation of system is to verify the proposed system with standard equipment. The further purposes are to compare the trend of noise level evaluation by noise hazard assessment system with standard equipment, determine percent error of the proposed system and define mathematical formula of the proposed system with noise standard equipment. In addition, the evaluation of noise hazard is reported based on the standard that is provided by the National Institute for Occupational Safety and Health (NIOSH).

In order to verify of noise hazard assessment system, sound recorders and noise dosimeter are attached to construction workers for detecting noise under their operation. The subject firm for this study was the workers at construction site. Moreover, the duration for each sampling was approximately 8 hours, depending on their working time. The data from sound recorder is firstly input to the final system in order to compute to equivalent noise level. Then it is set as a pair with equivalent noise level from noise dosimeter. As shown in below framework (Figure 3.4), noise levels from both sources are exported to Ms. Excel. Then noise levels are used to find the suitable mathematical model that can define the relationship of this pair.

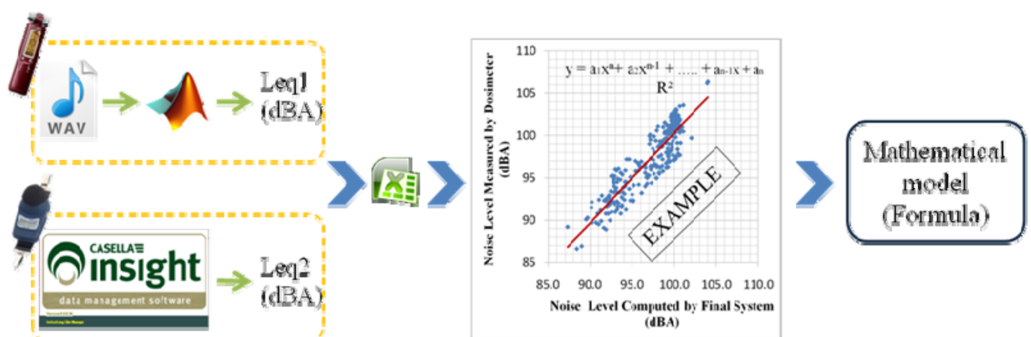
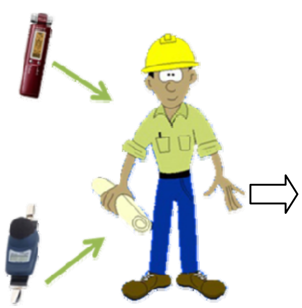


Figure 3.4 Framework of noise data analysis

The term of mathematical model referred to a description of a system using mathematical language which usually compiled by variables. This model can be classified into linear and non-linear. It was categorized as a linear if all the operators, which can be functions, algebraic, and differential, in the model presented linearity. Otherwise, this model is defined as nonlinear (Wikipedia, 2011). The mathematical model in this research will be developed to estimate the noise level measured by standard equipment, noise dosimeter, as function with the noise level computed by assessment system. The output of this model is an equation that is used to define the actual noise level from standard equipment. In particular, this equation should be the one that can approach the noise level. Therefore, the final system validity needs to be performed.

Data collected by noise dosimeter and sound recorder are also used in the validation process. The status of noise hazard evaluated by final system will be compared with the reality that is indicated by noise dosimeter. If our proposed system indicated the same result with reality, we can state that our system is valid (Figure 3.5). Otherwise, the system derived from this research is invalid. In addition, it is appropriate to use our noise hazard assessment system when the result shows our system is valid.



Validity	Reality: Hazard	Reality: No Hazard
Proposed system : Hazard	Agree	Disagree
Proposed system : No Hazard	Disagree	Agree

Figure 3.5 Testing the validity of noise hazard assessment system

3.4. Application of noise hazard assessment system

In this section, noise hazard assessment system is assumed to have been completely developed in previous section. Therefore, the system in this step can be applied for assessing noise hazard of construction workers in multiple occupations. The following section describes procedure of data collection and data analysis of noise hazard.

3.4.1 Data collection

Data collection method is a key step influencing the valid and reliability of survey research. The main purpose of data collection is gathering enough data for analyzing the noise hazard assessment system. Data collection in this research consists of two main parts including data collected by noise hazard assessment system and data collected by survey questionnaire. Moreover, the summary of data collection is described in table 3.2.

Table 3.2 Summary of data collection

Data Collection	• Data collected by noise hazard assessment system o *Instrument preparation : Sound Recorder – Model Sony IC-SX850, IC-SX713* o *Sound recorder will be attached with construction workers for recording data* o *A target of 72 samples from the proposed system*
	• Data collected by survey questionnaire o *Questionnaire design* o *Questionnaires will take place at the end of workday* o *A target of 24 samples from surveys questionnaires*

3.4.1.1 Data collected by noise hazard assessment system

- *Instrument preparation: Sound recorder – Model Sony IC-SX850, IC-SX713*

Instrument preparation is considered the significant process that is required at the beginning stage of data measurement. Before collecting data, sound recorder is needed to be well prepared. Sound recorder is firstly tested for a few minutes in advance to check the procedure of data recording. The most important part of setting is summarized in table 3.3. This table is considered as a default setting for our sound recorders model. First of all, sound recorder is selected “LPCM 44/16” as recording mode that provides a WAV file with sampling rate 44.1 KHz and 16 bit. Then, IC recorder set “Manual” as the recording level which is used to expand or compress circuit for recording high noise. This selection is presented in section 4.2.3 of chapter IV. Next, the Low Cut Filter (LCF) function of the sound recorder should be turned “ON” to cut out a frequency that is lower than 200 Hz to reduce the roaring noise from wind. Furthermore, this function helps us to record a sound source more clearly. Next is the Voice-Operated Recording (VOR) function. Within this function, IC-recorder started recording when it detected sound and paused when no sound was heard. In contrast, this function should be turned “OFF”. Similar to VOR, the Limiter function of IC-Recorder should be turned “OFF” because this function affects real sound exposure. Furthermore, we have to turn “ON” the Pre-Recording function because this function allows us to record sound sources for a maximum of 5 seconds prior to the point when the recording started. Thus, it helped us to cut the starting level out. Finally, we had also to turn "OFF" function "Noise Cut" because this function is used to cut out the noise" from the reality.

Table 3.3 Summary of selected function for sound recorder (Sony Corporation, 2009)

N°	Item	Setting	Selected	Description Note
1.	REC Mode	MP3 192K MP3 128K MP3 48K, LPCM 22/16 LPCM 44/16 ,LPEC LP LPEC SP ,LPEC STLP LPEC ST ,LPEC STHQ	LPCM 44/16	LPCM 44/16 : Stereo (44.1 kHz/16 bit/ WAV) long play high- quality recording mode. *Note: Turn on device to mono*
2.	REC Level	Low, High, S-High, Music, Manual	Manual	Manual: During manual recording, we can adjust the recording level manually.
3.	LCF	ON, OFF	ON	Sets the LCF (Low Cut Filter) function to cut a low frequency to reduce the roaring noise from wind; therefore it can record a message more clearly. ON – to activate
4.	VOR	ON, OFF	OFF	Voice-Operated Recording: saves time and tape expense by starting recording automatically when sound is sensed. When the sound stops, recording automatically stops. OFF – to cancel
5.	Limiter	ON, OFF	OFF	Sets the input level automatically to prevent the sound distortion that occurs when a sound that is too loud is input. OFF – to cancel
6.	Pre REC	ON, OFF	ON	Allows to record sound sources for a maximum of 5 seconds prior to the point when the recording is started. ON- to activated
7.	Noise Cut	ON, OFF	OFF	When the Noise Cut set to "ON", the distortion of very low and high frequencies which are outside the human voice range are reduced. In contrast, set to "OFF" in our case.

- Data collection process

Data collection is simultaneously performed when the construction started. Sound recorders are checked prior to and after each measurement. Participating workers are attached to the proposed system for an entire work shift. The recorders are clipped on their shirt and located within 20 cm of the worker's ear. After the instruments are completely setup, the start buttons of both instruments are pressed at the same time to begin recording data. The sample workers are allowed to work with their normal activities in construction site. During monitoring time, short notes about their environmental works have to written. Finally, recorders are stopped and collected for transferring data to computer.

3.4.1.2 Data collected by survey questionnaires

- Questionnaire design

Questionnaire is an efficient instrument for data collection. It contents are a list of questions related to the research objectives that requires respondents providing their answers. A great deal of care is necessary to write the best question for a survey. Researchers have to know exactly what the purpose of each question is and the scale to measure the variables. With an efficient questionnaire, researcher can achieve their research objective faster and cheaper that other mechanism. However, it is not easy to get a good questionnaire. There are three steps in designing a questionnaire, namely:

- Constructing questions to ask which includes defining the research objectives and question wording.
- Responding to question contents categorized, scaled and coded responses for analyzing after collected.
- Finalizing the questionnaire includes formatting the questionnaire and refining questions to be more attractive and professional.

By following these principles steps, a set of questionnaire is designed to take the views of workers' perception and awareness on noise hazard in construction works. Moreover, some gathering information related to these questionnaires is also reviewed from previous research, for example, Koushki et al. (2004) on workers' perceptions and awareness of noise pollution at construction sites in Kuwait. Then, the final version of the questionnaire is developed as presented in Appendix C. The developed questionnaire addressed three groups of questions (Table 3.4) including (1) the workers' personal data; (2) workers' perceptions of noise at the site; and (3) workers' awareness of noise impacts. Furthermore, a personal interview questionnaire survey of workers at the selected construction sites is also simultaneously performed with the measurements of noise.

Table 3.4 Contents of survey questionnaire

Questionnaire	Group Title	Expected Outcome
Section 1	Workers' personal data	Socio-Occupational Traits of the Sample Construction Workers
Section 2	Workers' perceptions of noise	Sample workers' perceptions of Noise at Study Construction Sites
Section 3	Workers' awareness of noise impact	Sample workers' awareness of noise impact

The data collection by survey questionnaire will take place at the end of workday. The volunteer construction workers were selected to respond to our survey questionnaire. All respondents are asked to fill in their own information and their opinion; therefore it will be face-to-face interview. In addition, the duration for each interview is expected to be approximately from 15 minutes to 20 minutes. The questionnaire survey contains three sections, presented in table 3.2. The first section examined personal data of sample workers, such as, their current age, education background, years of experience in construction. The second section requires workers' perception of noise hazard at construction site. This section asks them to check list on a few question as stated in appendix C. The last section was pretested about the awareness of the workers on noise impact. Furthermore, the machine type, manufacturer, model, and serial number and the engine manufacturer, model number, power rating, and rated speed were additionally documented as an additional data note via handwritten notes on data sheets. It should be noticed that entire questionnaire was translated into Thai language to ensure that all questionnaire items would be properly understood.

3.4.2 Data analysis

Based on the data collection, there are two different kinds of data involved in our research that is data from noise hazard assessment system and data from survey questionnaires. Therefore, data analysis is divided into two parts including noise hazard of construction workers and workers' perception and awareness on noise hazard.

3.4.2.1 Noise hazard of construction workers

The signals of noise collected by sound recorders are analyzed with the noise hazard assessment system. The analysis included: equivalent noise level, dose of noise and status of noise hazard. The data analysis and results for the whole set of noise hazard assessment are detailed in chapter VI.

Equivalent noise level (Leq) is the sound pressure level of steady sound over worker's operation period in construction site, approximately eight hours. It is an average and is measured in decibel scale. In addition, it will be evaluated from electronic sound signal by using the proposed system.

Dose of noise (D%) is expressed as a percentage of the maximum permitted exposure. If a construction worker has received a noise dose of 100% over a work shift, this means that the average noise exposure is at the maximum permitted.

Status of noise hazard categorized based on amount of noise dose. It helps to inform construction worker about hazard of noise in their current practice. The status will be presented "Hazard" if construction worker has obtained a dose of noise over exposure limit. Otherwise, status of noise hazard will be defined in "No hazard".

3.4.2.2 Workers' perception and awareness on noise hazard

The data collected from the questionnaire surveys are analyzed with the support from Microsoft Excel. In addition, descriptive statistics are applied for analyzing the characteristics of respondent sample, the construction workers' perception on their occupational noise, and their awareness of noise impact. In addition, it is used to describe the difference of their perception and their awareness on noise hazard with status of noise hazard presented in above section. Furthermore, the result will also define the difference between their perception on noise hazard in current practice and their awareness of noise impact on their health in the future. The data analysis and the results of questionnaire survey are detailed in chapter VI.

3.5. Summary

This chapter described the methodology to achieve the research objectives addressed in previous chapter. This research is classified as the experimental research using quantitative data. The study mainly focused on system development and system application in construction site. The noise hazard assessment system is developed using three steps. First, the tools testing are performed in order to select the suitable tools and instruments. Then, it requires two distinct research stage attempts to develop the final system including preliminary study and full scale of system development. The preliminary study tests and checks the possibility of an initial system development by experimental in acoustic laboratory and in construction site. Then the full scale study fulfills preliminary study based on the objective of research and facilitates the navigation of the proposed system. In addition, the chapter presented the methodology of system application with construction workers in multiple occupations.

The next chapter describes the procedure of preliminary study for noise hazard assessment system development in detail.

CHAPTER IV
PRELIMINARY STUDY OF SYSTEM DEVELOPMENT

The main purpose of preliminary study was to check the possibility of noise hazard assessment system development. This chapter started with section 4.1 which describes the trial system development. Then section 4.2 discusses experimental of system in acoustic laboratory and in construction site. Finally, this chapter presents the reliability of the proposed system.

4.1 Initial system development

Initial system focuses on the development of noise hazard assessment system. The initial system was used to systemize the relevant knowledge to set up a clear process for developing a full scale system. First of all, the theory of calculation of noise exposure level was reviewed from literature. Then, the procedure of noise calculation was adopted by programming in MATLAB. In addition, a brief code of system development in preliminary study contains three functions of MATLAB such as (1) the decibel level analyzer, (2) the A-weighting filter coefficient, and (3) the sound signal analyzer, as presented in table 4.1.

Table 4.1 Functions of system programming for preliminary study

Function name	Description
A-weighting filter	Generate an A-weighting filter.
Decibel level analyzer	Estimate sound signal level in dBA.
Sound signal analyzer	Evaluation of dBA level.

At the beginning, initial system analyzes the properties of sound signal inputs. Next, the signal to sound pressure level is estimated using decibel level analyzer function. After that, this system transforms that pressure level to A-weighting filter as will be discussed in the next chapter; the A-weighting is designed to model the response of the human ear. The final result of sound level is presented in dBA and plotted into the graph which functions with working time.

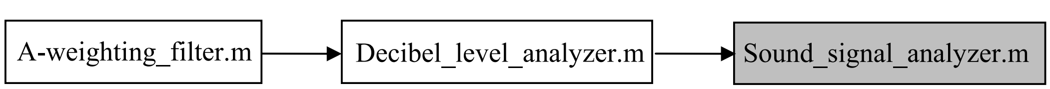


Figure 4.1 Process of MATLAB function in trial system development

4.2 Experimental of the proposed system

Experimental of noise hazard assessment system was performed in order to calibrate system with standard equipment and check the influence of wind on the proposed system. Therefore, experimental of system was implemented in acoustic laboratory and at construction site. The following section describes overview of experimental, instrument installation for experimental, selection of recording level for sound recorder, and result of experimental.

4.2.1 Overview of experimental in acoustic laboratory

In conceptual design, the proposed system was firstly experimented in a control room. Therefore, the experimental of system was conducted in acoustic laboratory. In addition, two main agents were necessary for this experimental (Figure 4.2). First agent was a source of noise, which had controlled decibel level by setting up their amplitude and frequencies. It was simulated as a noise in construction site by using sound generator including amplifier, speaker and computer with software “dB01”. Second agent was a sound detector that was used for noise measurement such as noise dosimeter, sound recorder, and sound level meter.

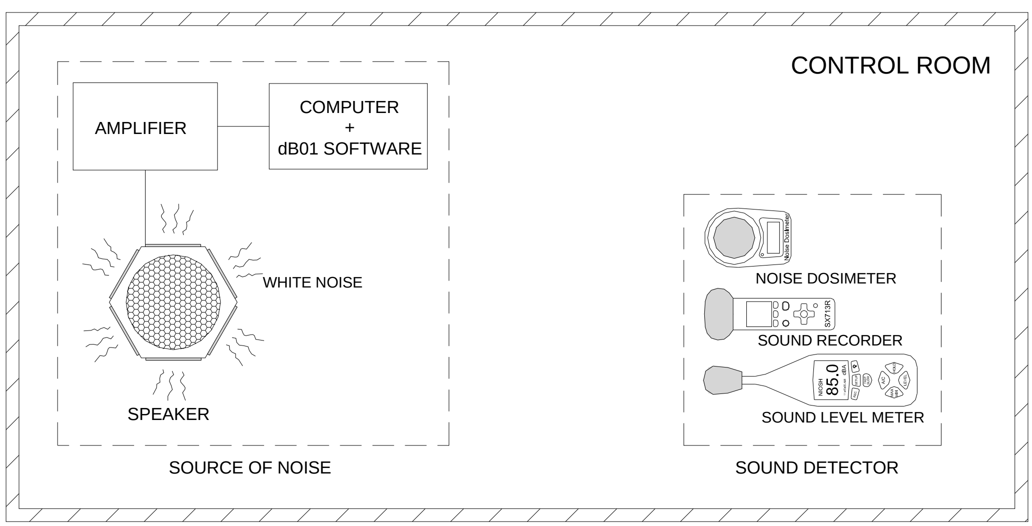


Figure 4.2 Diagram represented an experimental in laboratory

Both agents were located in acoustic laboratory or control room. Then white noise that contained all frequencies was generated and amplitude varied until it reached noise level ~ 65dBA, ~75dBA, ~85dBA, ~95dBA and ~100dBA (limitation of amplifier). Next, all instruments of sound detector were started at the same time to measure one by one level of noise. When noise measurement was completed, data from sound detector was transferred to PC and computed to equivalent noise level (Leq) in minutes. Finally, Leq of noise from the proposed system was compared with that from standard equipment in order to find a calibration constant for the proposed system.

4.2.2 Overview of experimental in construction site

Beside experimental in laboratory, noise hazard assessment system required an experimental at construction site to test the implementation of system in real environment. Experimental in this step also required two necessary agents (Figure 4.3). First agent was a source of noise that was produced by machine at construction site. The level of this noise varied along construction activities. Second agent was our sound detector that was used for noise measurement such as noise dosimeter, sound recorder and sound level meter.

Both agents were located at construction site with an uncontrollable source of noise since it was exposed by machine at construction site. On the other hand, part of sound detector was influenced by wind. Microphone of all instruments in sound detector was covered by a microphone screen that helps keep wind pressure from activating the microphone.

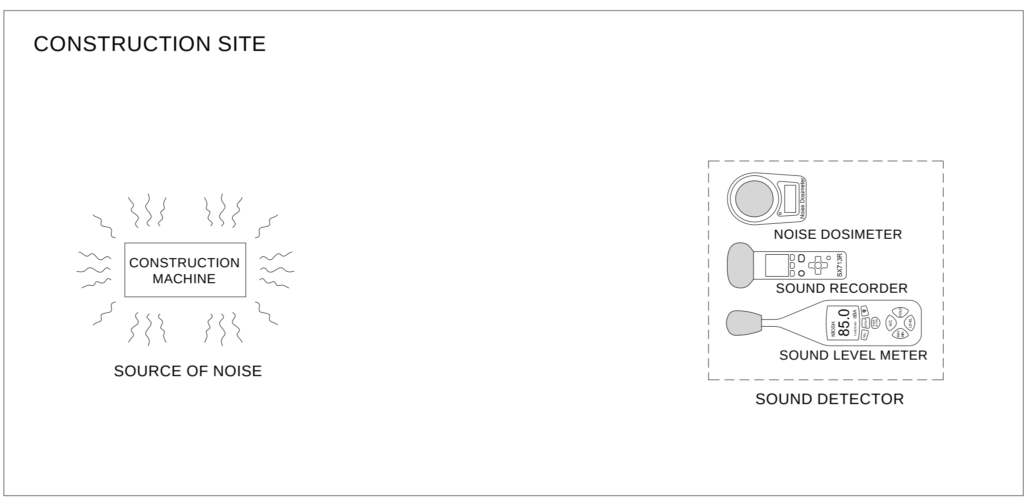


Figure 4.3 Diagram represented an experimental at construction site

The procedures for identifying calibrator constant C in this experimental was quite the same with that in acoustic laboratory. All instruments of sound detector were started at the same time to measure level of noise from construction machine. At the end of measurement, data from sound detector was transferred to PC and computed to equivalent noise level (Leq) in minutes. Finally, Leq of noise from the proposed system was compared with that from standard equipment in order to calibrate the proposed system by adding a calibration constant to the proposed system.

4.2.3 Instrument installation for experimental

This section describes the installation of instruments for both experimental, in acoustic laboratory and at construction site. There are three main subsections including instruments of sound detector that were used in experimental, sources of noise in each experimental, and instrument installation for performing experimental.

4.2.3.1 Instruments of sound detector

Sound detector in this research consisted of three types of instruments such as noise dosimeter, sound recorder, and sound level meter. These instruments contained one dosimeter model CEL 350, one sound level meter model DT 8852, one sound recorder model SX850, and two sound recorder models SX713. These instruments were used for experimental in acoustic laboratory and at construction sites. They were used for different purposes as presented in table 4.2. First, noise dosimeter was used for measuring equivalent noise level (Leq) and dose of noise (D%). Next sound level meter was used to measure and store level of noise. Last, two models of sound recorders were applied to detect and record electronic sound signal in “WAV” format.

Table 4.2 Summary of instruments used in this research

Instrument	Name	Purpose
	Noise dosimeter: Model CEL 350	Measurement equivalent noise level (Leq) and evaluation dose of noise (D%).
	Sound level meter: Model DT 8852	Display and Measurement sound pressure level in decibel A with Fast and Slow response type.
	Sound recorder: Model Sony SX850 and Sony SX713	Record electronic sound signal in “WAV” format.

Additionally, noise dosimeter and sound level meter were considered as the standard equipment and the reference of our proposed system (Sound recorder). The data recorded by these instruments were recorded in different parameters. However, these parameters were computed to equivalent noise level (Leq) and dose of noise. Then the final result that was computed by the proposed system was compared with that given by standard equipment.

4.2.3.2 Source of noise

Source of noise was necessary for performing both of these experimental. There were two kinds of noise that were used for conducting this testing. First, source of noise was controllable by setting up their amplitude and frequencies. It was simulated in acoustic laboratory. Another was a source of noise that was exposure to construction machine in real environment of construction site. The following section describes both of these sources.

4.2.3.2.1 Source of noise for experimental in laboratory

White noise was a random signal with a flat power spectral density. In addition, the signal of white noise contains equal power within a fixed bandwidth at any center frequency (Wikipedia, 2011). In this research, white noise was generated as a source of noise for experimental in laboratory. This noise was selected based on many reasons. First reason was white noise could be simulated as noise from construction machine. Another reason was white noise could be produced by using software namely "dB01" in laboratory.

Besides white noise generator, we also needed amplifier to adjust amplitude of sound. Therefore, we connected "dB01" with amplifier before transferring to speaker (Figure 4.4).

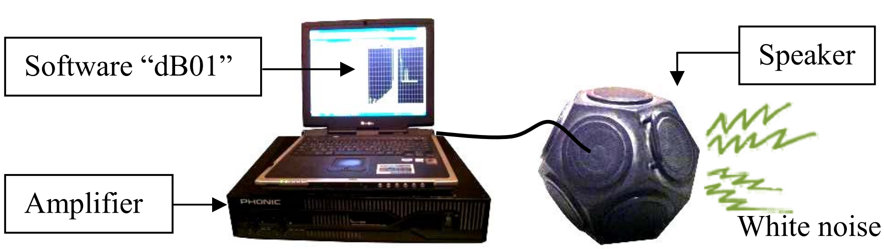


Figure 4.4 Source of noise simulated in acoustic laborary

Based on our noise dosimeter, level of noise exposure needs to be at least 64 dBA. Therefore, we varied amplitude of white noise until it reached noise level ~65dBA. In addition, we would like to increase noise level every 10 dBA so next levels of noise were ~75dBA, ~85dBA, ~95dBA and ~100dBA (limitation of amplifier).

4.2.3.2.2 Source of noise for experimental at construction site

Similar to experimental in laboratory, experimental at construction site also required source of noise in order to start testing. However, source of noise under construction environment was uncontrollable since construction activities were complex and level of noise varies by types and amount of construction machine. Furthermore, this source was affected by another agent such as wind at construction site. Based on selected case studies, piling machine in construction site is considered as a source of noise for conducting this testing (Figure 4.5).

Figure 4.5 Source of noise produced by piling machine at construction site

4.2.3.3 Instruments installation

Prior to starting recording data, the installation of instruments was needed. The source of noise and sound detector that we prepared in above section would be used in this section. The following section describes the procedure for installing instruments in acoustic laboratory and at construction site.

4.2.3.3.1 Instruments installation in acoustic laboratory

Acoustic laboratory was considered as a control room. This room was separated from real environment since the wall of room could block noise or sound from the outside or we could say that all sources of noise were controlled.

Furthermore, it was designed for the acoustic experimental. Therefore, it was an appropriate room for performing our experimental intended to calibrate our proposed system.

Firstly, speaker was located at a side and on floor of the laboratory. In addition, this speaker was connected with amplifier and computer in order to generate noise. After that, all instruments of sound detector were positioned on the opposite side of speaker including noise dosimeter, sound level meter and sound analyzer. Moreover, microphone direction of those instruments was needed to be straight to source of noise. Also, their height needed to be similar to that of speaker or equal 0.5 meter from floor. Furthermore, the distance between source of noise and sound detector was around 2 meters. Significantly, all instruments in sound detector itself were supposed to be in the same position. Figure 4.6 represents the location of all instruments concerned in this experimental.

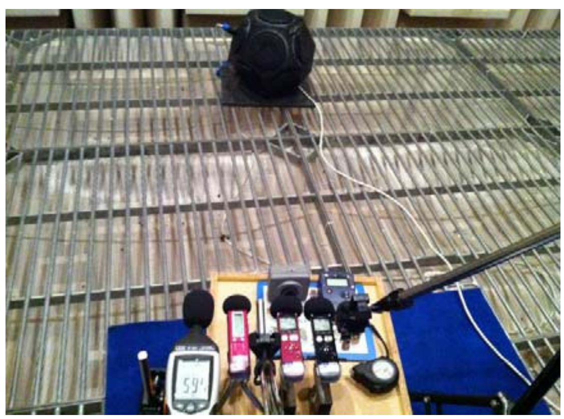


Figure 4.6 Experimental of noise hazard assessment system in laboratory

4.2.3.3.2 Instruments installation at construction site

The procedure of instrument installation in this stage was performed in real environment or construction site (Figure 4.7). Construction machine that runs at construction site was considered as our source of noise. Therefore, this experimental was begun when machine started working in construction site. On the other hand, sound detector was placed in front of construction machine and 6 meters from source of noise. These instruments stood on tripod in order to adjust their height following source of noise. In addition, it was around 1.5 meters from land. In the same manner with experimental in laboratory, the direction of microphone was needed to be straight to construction machine.

Figure 4.7 Experimental of noise hazard assessment system in construction site

4.2.3 Selection of recording level for sound recorder

Recording level (REC Level) had an option to expand or compress circuit of sound recorder in order to prevent sound distortion (Figure 4.8). The subject of this section was to describe the selection of recording level for sound recorder of both models, SX850 and SX713. The selection took place before performing experimental.

There were five options of recording level contained in our sound recorder such as Low, High, S-High, Music, and Manual. However, “Manual” was a significant option that we used in this experimental. The reason was that this option allowed user to select the recording level manually. In addition, we could adjust their level by a scale from 0 to 30.

Figure 4.8 Sound distortion presented in sound signal

Recording level of SX850 and SX713 is selected based on the maximum level of noise presented in our cases studies. The procedure of this selection was processed at construction site. Furthermore, “REC Level” was adjusted by pressing ⏮ or ⏭ until sound recorder stopped displaying “OVER” on their monitor.

As a result, recording level of SX850 and SX 713 should be equal to 2 and 5 respectively. This setting up is fixed as a default of our sound recorder in order to perform experimental in laboratory and construction site.

4.2.4 Characteristic of sampling data for experimental

The sampling data for experimental consists of two parts including data collected in acoustic laboratory and at construction site. The following section describes the sampling size of each part.

4.2.4.1 Sampling data in acoustic laboratory

Data in this part was captured from the source of noise simulated in acoustic laboratory. A target of 75 samples was estimated at the beginning of the study, corresponding to 25 samples per sound recorders such as SX850, SX713R and SX713B and 5 minutes per sound level of white noise including ~65 dBA, ~75 dBA, ~85 dBA, ~95 dBA, and ~100 dBA (Table 4.3).

Table 4.3 Summary of data for experimental in acoustic laboratory

Noise level simulated in laboratory	SX850	SX713R	SX713B
~ 65 dBA	5 minutes	5 minutes	5 minutes
~ 75 dBA	5 minutes	5 minutes	5 minutes
~ 85 dBA	5 minutes	5 minutes	5 minutes
~ 95 dBA	5 minutes	5 minutes	5 minutes
~ 100 dBA	5 minutes	5 minutes	5 minutes
Total	25 samples	25 samples	25 samples

4.2.4.2 Sampling data in construction site

Data in this part was collected from the source of noise at construction site. The data was recorded by using the same sound recorder in previous experimental but the length of sound recording was different since source of noise was random level. Therefore, 40 samples were obtained from each recorder (Table 4.4). In addition, the total samples for this experimental equals 120 samples.

Table 4.4 Summary of data for experimental at construction site

Noise level from Construction machine	SX850	SX713R	SX713B
Random level	40 minutes	40 minutes	40 minutes
Total	40 samples	40 samples	40 samples

4.2.5 Result of experimental

Electronic sound signal from sound recorders in both experimental was inputted to MATLAB programming in order to compute equivalent noise level (Leq). In addition, Leq of our proposed system and standard equipment were plotted against exposure time (Figure 4.9). It could be seen that trend of noise level from both instruments were similar. As a result, gap between both noise levels was adjusted by adding a constant C_{add}. Finally, calibration constant C was the summation of C_{add} and C_{ref} where $C_{Ref} = 10\log_{10}(\tilde{\varepsilon}_{ref}) = 36.90\,\text{dBA}$.

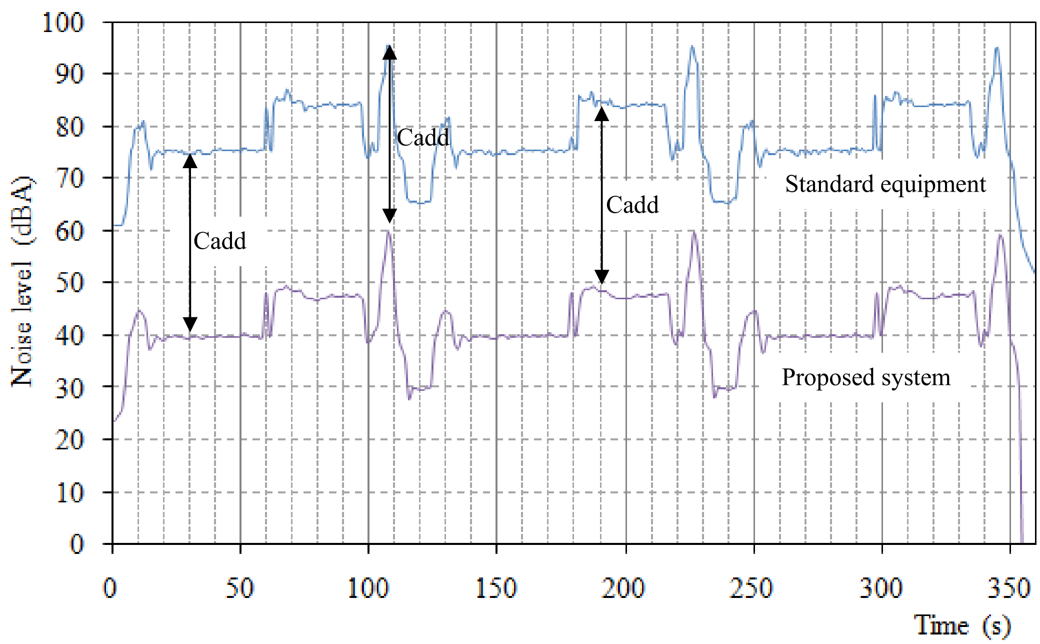


Figure 4.9 Noise levels of standard equipment and the proposed system

Table 4.5 and 4.6 represent the calibration constant C from experimental in acoustic laboratory and in construction site, respectively. It can be seen that calibration constants C in each sampled are similar. Therefore, we could conclude that noise level did not affect the result of constant C. However, we found that constant C from different model of sound recorder had different value. Lastly, constant C from both experiments was also similar. Thus, it could be concluded that our proposed system was not influenced much by wind. Finally, we defined constant C of SX850 and SX713 equal to 74 dBA and 78 dBA (Table 4.7), respectively.

Table 4.5 Calibration constant C from experimental in acoustic laboratory

Equivalent Level in dBA				C_{Add}			$C = C_{Ref}+C_{Add}$		
Item	SX850	SX713R	SX713B	ND	SX850 Vs. ND	SX713R Vs. ND	SX713B Vs. ND	SX850	SX713R	SX713B
~65dBA	28.8	25.2	23.9	65.5	36.7	40.3	41.6	73.6	77.2	78.5
~75dBA	39.1	35.9	34.4	75.9	36.8	40.0	41.5	73.7	76.9	78.4
~85dBA	49.2	45.9	44.4	86.0	36.8	40.1	41.6	73.7	77.0	78.5
~95dBA	59.8	56.5	54.8	96.9	37.1	40.4	42.1	74.0	77.3	79.0
~100 dBA	62.4	59.0	57.4	99.5	37.1	40.5	42.1	74.0	77.4	79.0
							Average	73.8	77.2	78.7
							Min	73.6	76.9	78.4
							Max	74.0	77.4	79.0

Table 4.6 Calibration constant C from experimental at construction site

Equivalent Level in dBA				C_{Add}			$C = C_{Ref}+C_{Add}$		
N^{o}	SX850	SX713R	SX713B	ND	SX850 Vs. ND	SX713R Vs. ND	SX713B Vs. ND	SX850	SX713R	SX713B
1	45.3	41.3	39.5	82.9	37.6	41.5	43.3	74.5	78.4	80.2
2	42.0	38.5	36.5	79.5	37.5	41.0	43.0	74.4	77.9	79.9
3	41.6	38.3	36.4	78.9	37.3	40.6	42.5	74.2	77.5	79.4
4	63.3	58.9	57.8	99.4	36.1	40.5	41.7	73.0	77.4	78.6
5	62.8	58.4	57.3	98.9	36.1	40.5	41.6	73.0	77.4	78.5
6	55.0	51.0	49.3	92.4	37.4	41.3	43.1	74.3	78.2	80.0
7	55.4	51.5	49.7	92.6	37.2	41.1	42.9	74.1	78.0	79.8
8	51.3	47.3	45.3	88.5	37.2	41.2	43.2	74.1	78.1	80.1
							Average	74.0	77.9	79.6
							Min	73.0	77.4	78.5
							Max	74.5	78.4	80.2

Table 4.7 Final calibration constant C of each model of sound recorders

Item	SX850	SX713R	SX713B
Calibration constant C from laboratory	73.8	77.2	78.7
Calibration constant C from construction site	74.0	77.9	79.6
Average	73.9	77.6	79.1
Final constant C	74	78	

4.3 Reliability of the proposed system

Recalling section 3.3.2 in chapter 3, noise hazard assessment system was required to test the reliability. As discussed in previous chapter, system reliability was needed to perform in acoustic laboratory since we would like to produce a source of noise with the same properties, amplitude and frequencies, for five times.

In order to do this, we firstly installed all instruments into laboratory by following the instruction in section 4.2.3.3.1. Next, we generated white noise, with level of ~ 65dBA, ~75dBA, ~85dBA, ~95dBA and ~100dBA, as the source of noise. After that, our proposed system was used to measure each level of noise for five times. Then electronic sound signal from both models of sound recorders was computed by MATLAB programming in order to identify equivalent noise level (Leq). Finally, five of Leq in each level of noise were compared to each other to attempt to test reliability of noise hazard assessment system.

From the results, table 4.8 and table 4.9 represents equivalent noise level that was computed from sound recorder model SX850 and SX713, respectively. It could be seen that equivalent noise levels in each case are quite the same. Therefore, we could declare that our proposed system is reliable.

Table 4.8 Equivalent noise level computed from sound recorder model SX850

N^o	~65dBA	~75dBA	~85dBA	~95dBA	~100dBA
1	65.67	76.04	85.99	96.92	99.57
2	65.62	76.00	86.00	96.90	99.50
3	65.67	76.07	85.98	96.87	99.48
4	65.67	76.05	86.00	96.93	99.52
5	65.65	76.04	85.98	96.90	99.50
Average	65.66	76.04	85.99	96.90	99.51

Table 4.9 Equivalent noise level computed from sound recorder model SX713

N^o	~65dBA	~75dBA	~85dBA	~95dBA	~100dBA
1	65.61	76.06	86.00	96.91	99.56
2	65.59	76.07	86.01	96.90	99.50
3	65.68	76.10	86.00	96.87	99.48
4	65.68	76.14	86.00	96.89	99.51
5	65.67	76.10	86.00	96.88	99.54
Average	65.65	76.09	86.00	96.89	99.52

4.4 Summary

In summary, the procedures employed in this preliminary study started from the development of trial system and the experimental of the proposed system in acoustic laboratory and at construction site. From the results of the experimental, calibration constant of noise hazard assessment system is equal to 74 dBA and 78 dBA for sound recorder model SX850 and SX713, respectively. Thus, it confirmed that different sound recorder model gave different calibration constant C. However, both of constant C was used for the same purpose, that is, to calibrate our proposed system to refer to standard equipment, noise dosimeter.

Moreover, system reliability was also discussed in this chapter. It was tested in acoustic laboratory since we required source of noise that contained the same sound properties, amplitude and frequencies. Results indicated that noise hazard assessment system that we proposed was reliable. Therefore, the study showed the high opportunity for further development of the proposed system. The following chapter will describe the development of full scale of noise hazard assessment system.

CHAPTER V

FULL SCALE OF SYSTEM DEVELOPMENT

This chapter aims to describe the development of noise hazard assessment system in full scale. The content of system development consists of five main sections. The first section presents the process of system development. Then section 5.2 describes the development of graphical user interface (GUI). After that section 5.3 shows the steps of noise dose calculation. Next, section 5.4 describes the system design and programming. Finally, system verification is discussed in section 5.5.

5.1 Process of system development

The concept of system development was mainly focused on an evaluation of noise dose used for indicating the status of noise hazard of construction worker exposure. Process of system development consists of four mains steps (Figure 5.1). We firstly designed a graphical user interface (GUI) of system which could be applied at manager and worker level. Then, the procedures for calculation of noise dose were studied in order to support above GUI. In addition, these procedures were designed and written up in a MATLAB programming for computing noise dose from electronic sound signal. Finally, noise hazard assessment system was verified with equipment standard at construction site.

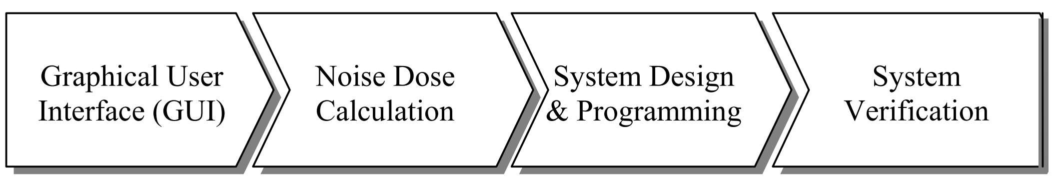


Figure 5.1 Process of system development

5.2 Graphical user interface of noise hazard assessment system

The conceptual design of user interface development intended to facilitate users for reporting the status of noise hazard. Under this system, the development of GUI contains three main parts which are INPUT, CALCULATION and RESULT of noise hazard assessment (Figure 5.2). Users were firstly required to input their information to the system, especially, sound signals that were recorded during their workday. Then the system would evaluate the status of noise hazard after

"Calculation" button was clicked. In addition, the result of noise hazard assessment was displayed at the end of calculation.

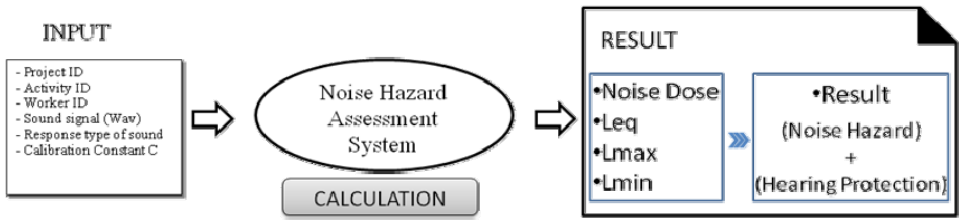


Figure 5.2 Conceptual design of graphical user interface development

Furthermore, graphical user interface of noise hazard assessment system was developed by using MATLAB programming (Figure 5.3). The procedure of this GUI development was described in subsections below including 5.2.1 System inputs, 5.2.2 Calculation of noise hazard, and 5.2.3 Result of noise hazard assessment.

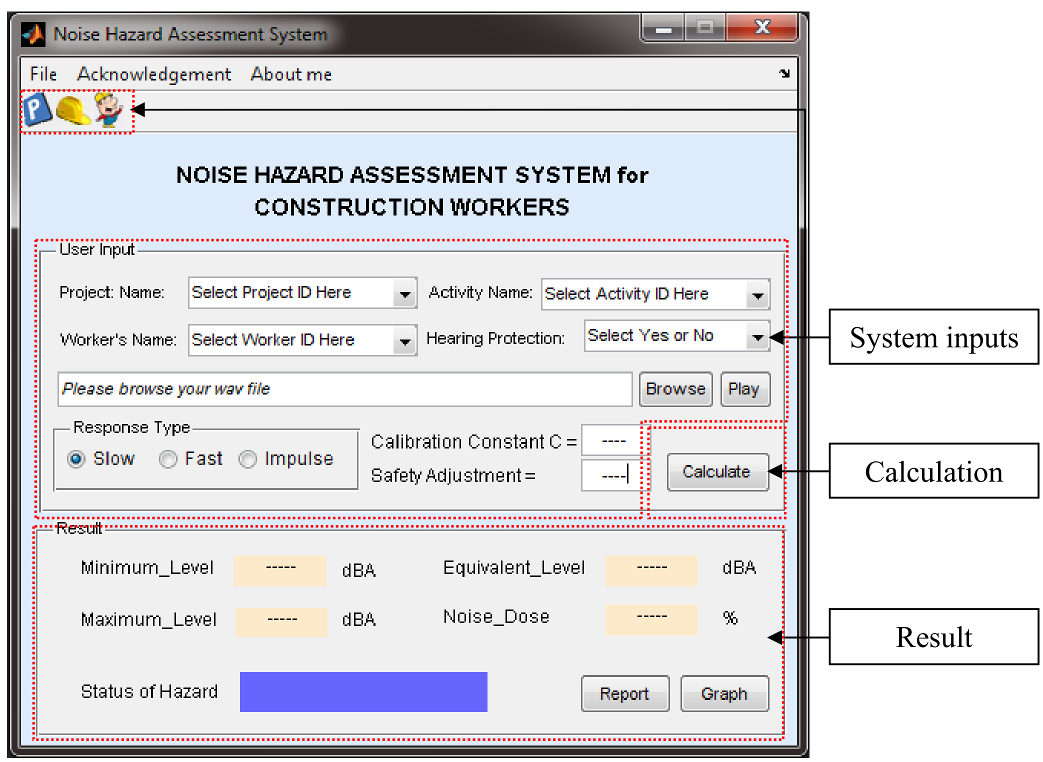


Figure 5.3 Main user interface of the system

5.2.1 System inputs

This section presents all of the inputs that were required for running noise hazard assessment system. There were two parts of inputs that were involved in this system. First part contained three packages including Project details, Workers' profile, and Work activity which user could input and save into database. Then second part consisted of a package namely "Main input" that requires when system runs. In addition, all of information stored in first part of input was linked to second part by the ID of each package (Figure 5.4).

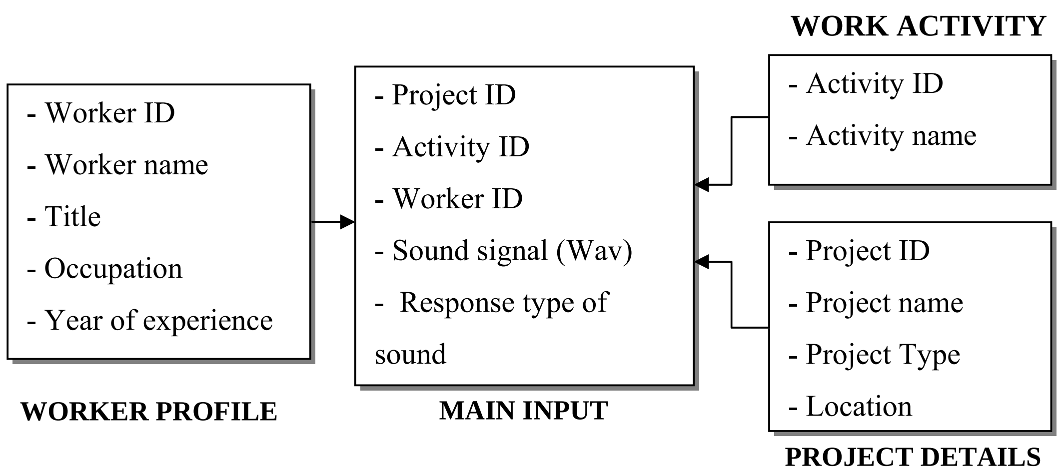


Figure 5.4 Queries of user input in Noise Hazard Assessment System

5.2.1.1 Input of worker information

First part of input is designed for construction managers. The information of this input helps construction managers to manage noise hazard of their workers. General data in this part required managers to create and store in database at the beginning. It included Project details, Workers' profile, and Work activity that intends to create general information related to construction work environment. In addition, all users can access to these inputs by following buttons.

 : represented Project Details. This package consisted of data related to project information such as Project ID, Projection name, Project Type, Location and note for a special case (Figure 5.5.a).

 : represented construction activity. This package contained the information related to activity of workers during their working day which include Activity ID, Activity name and note (Figure 5.5.b).

 : represented workers' profile. This package consisted of the information related to workers such as Worker ID, Worker name, Title, Occupation, Year of experience, and note (Figure 5.5.c)

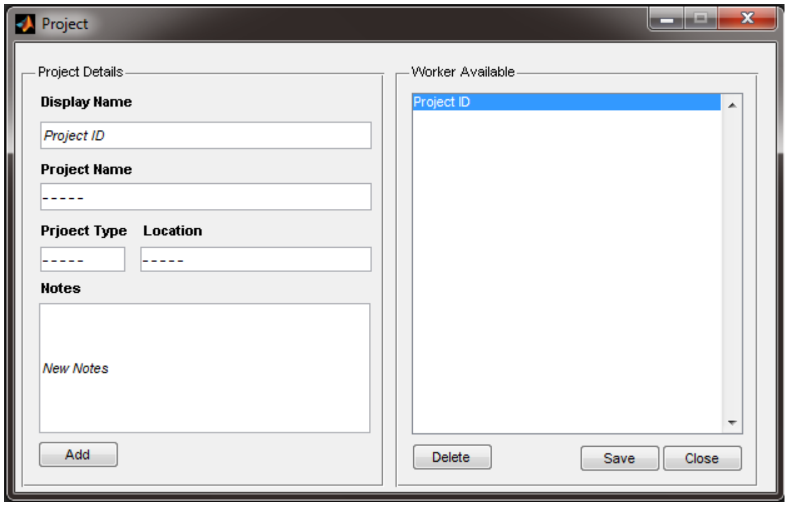


Figure 5.5.a Interface of project details

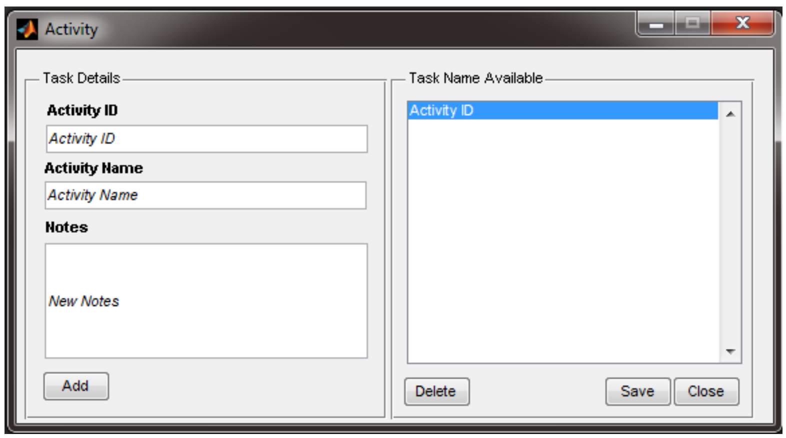


Figure 5.5.b Interface of work activity

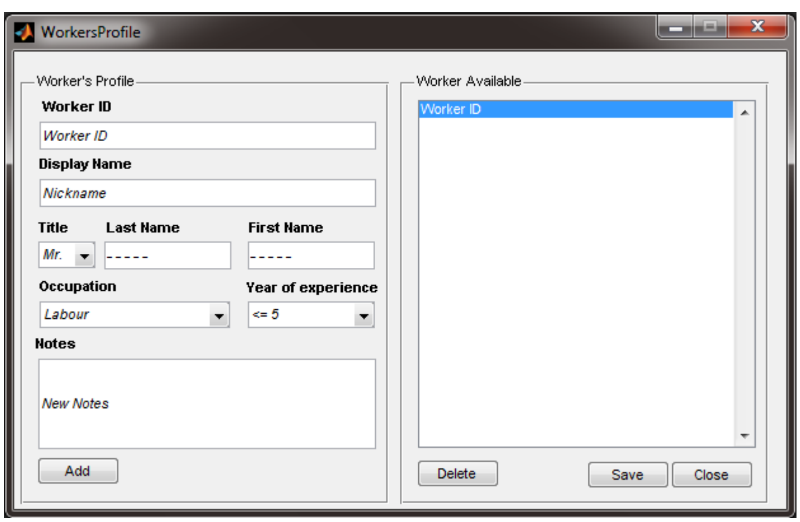


Figure 5.5.c Interface of workers' profile

5.2.1.2 Input of noise data

Second part of input was designed as a main input for noise hazard assessment system. There were four components in this part of input such as ID of elements in database, Sound signal in “WAV” format, Response type of sound, Calibration constant C and Safety adjustment value of system. In addition, these data were required every time for running system.

Firstly, the system was designed to select Project ID, Worker ID and Activity ID in order to link with database of worker information. These ID represented all information that was stored under their ID of worker information then it was used as supportive information for noise hazard assessment. Users could access this step by using interface in figure 5.6.a.

Figure 5.6.a Interface of linkage between first and second part of input

Secondly, the system allowed users to select the location of sound signal that was recorded during their work activities. Users needed to click “Browse” button of interface in figure 5.6.b then find the location of signal. Moreover, users can playback the signal by using “Play” button.

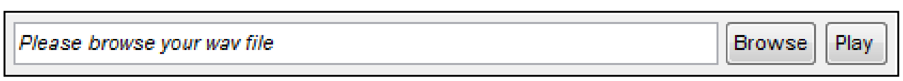


Figure 5.6.b Interface for selection location of sound signal

Thirdly, the system was designed to select the response type of sound signal. It was required after sound signal was inputted. There were three types of sound response concerning this assessment system including Slow, Fast and Impulse. Users can select one of them based on their nature of sound signal. However, response type of slow was used as a default for the system (Figure 5.6.c).

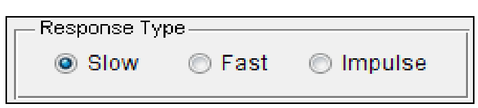


Figure 5.6.c Interface for selection response type of sound

Finally, user interface was designed to input calibration constant and safety adjustment value of system (Figure 5.6.d). The detail calculation of both parameters is described in section 4.2.5 of previous chapter and section 5.5.3, respectively.

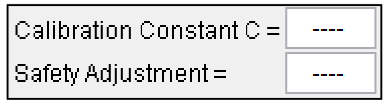


Figure 5.6.d Interface of calibration constant and safety adjustment value

5.2.2 Calculation of noise hazard

One of the main functions in this system was calculation after all inputs were prepared. A button was designed to contain the source code of noise hazard calculation namely “Calculate” button. In the other meaning, the system would calculate or assess noise hazard after “Calculate” button was clicked. This button is located at middle right of graphical user interface of noise hazard assessment system. The procedure of noise hazard calculation is discussed in section 5.3

5.2.3 Result of noise hazard assessment

The result of noise hazard assessment system was automatically shown in GUI after procedure of calculation was completed. This result consists of five parameters which include Minimum Level (Lmin), Maximum level (Lmax), Equivalent Level (Leq), Noise Dose (D%), and Status of noise hazard (Figure 5.7). In addition, the system illustrated the details of sound level that was present during their works, by clicking on “Graph” button then the interface of graphical result would appear (Figure 5.8). Furthermore, user could reported their

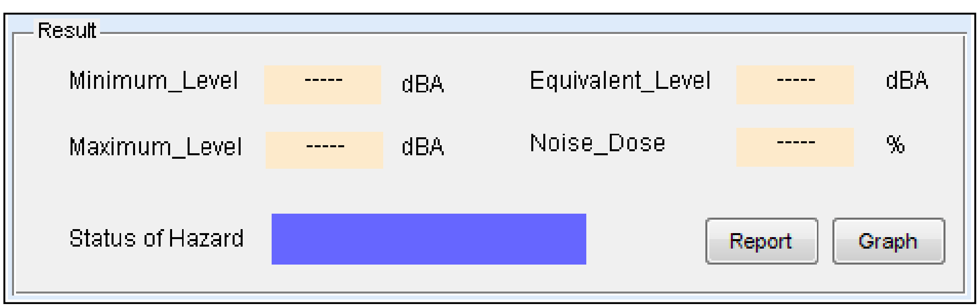


Figure 5.7 Interface for showing result of noise hazard assessment system

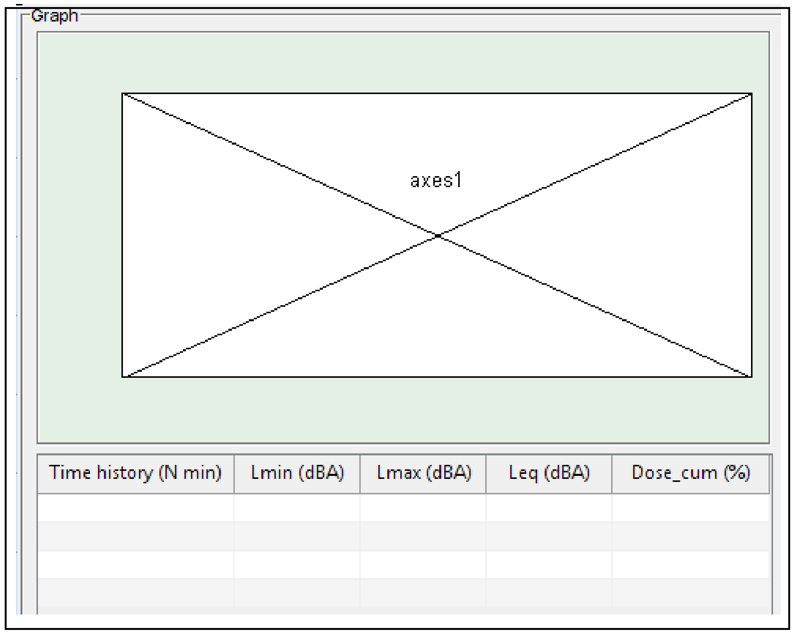


Figure 5.8 Interface for showing result of noise hazard in graphic

5.3 Noise dose calculation

This section aims to support the conceptual framework of graphical user interface that was described in the previous section. The subject of this section is to describe the procedure of noise dose calculation (Figure 5.9).

It began from sound signal in Wav file and type of sound response that is considered as the main input for noise hazard assessment system. The calculation of noise dose was divided into two main parts, which used both of these inputs as a starting point. However, the first part of calculation was separated to other two subparts while two properties of sound were required as the inputs such as Sampling rate (Fs) and Input voltage (x) of sound. Therefore, the real calculation consisted of three parts including part of sound response, sampling rate and input voltage.

First of all, the first part of calculation intended to find minimum number (N_{min}) of input samples that were used in the system. Then it started to calculate observation interval (N) that was the next power two of N_{min}. The reason is N will use as amount of sample in Fast Fourier Transform (FFT). After that, the first part and second part of calculation were combined in order to identify frequencies of each FFT (f_n). Next, this parameter (f_n) was used to calculate A-Weighted ($A(f_n)$) of sound level for transformation sound level from decibel to decibel A (dBA). The third part of calculation which contained input voltage (x) proceeded as well. Input voltage (x) in time domain was transformed into frequency domain by using FFT (Fast Fourier Transform) in MATLAB for finding Magnitude of sound signal (X). Last, all calculation parts were combined to calculate Magnitude of sound signal in A-weighted (X_A).

The procedure of calculation at this step remained only one part since all of the previous parts were combined. Then it was used further on the calculation of Energy of sound signal such as Total Energy (ε_x) and Average Energy$(\tilde{\varepsilon}_x)$. Then average energy was used to find sound pressure level with A-weighted (L(dBA)). Next, equivalent of sound level (L_{eq}) was also obtained after L(dBA) was calculated. Finally, L_{eq} and duration of sound exposure (T) was inputted to formula in order to find dose of noise. In addition, the dose of noise obtained at this step was used to indicate the status of noise hazard for construction workers (Figure 5.9).

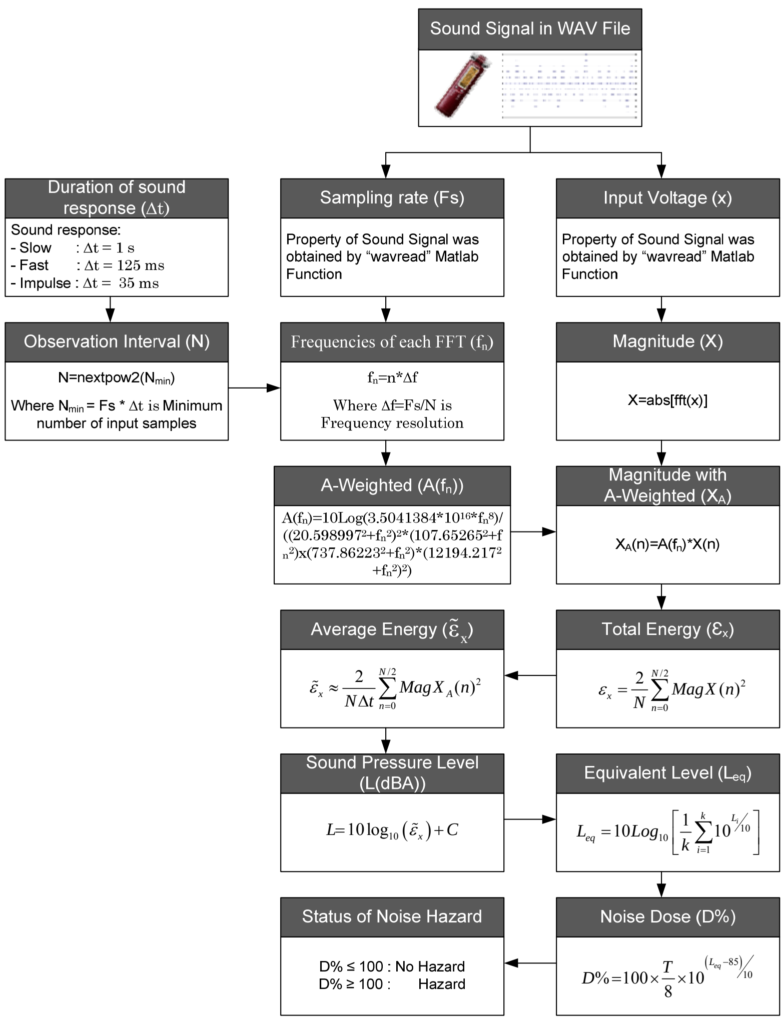


Figure 5.9 Procedures of noise dose calculation

5.3.1 Input of noise data

The input of noise hazard assessment system consisted of two main parts such as Sound signal in WAV file and Type of sound response. The below section describes the details of these inputs.

5.3.1.1 Sound signal of WAV file

Sound signal of WAV file obtained from sound recorder was used to record sound during construction activities. Sound recorder was clipped with a shirt of construction workers and around 0.2 m from worker's ear. We started recording from the beginning until the end of their workday. It took around 8 hours per day. Then sound recording was transferred and stored in computer hard drive by a specific location. More information related to this installation is described in chapter 3.

5.3.1.2 Type of sound response

Type of sound response is generally divided into three main types which includes "Slow", "Fast" and "Impulse" and it responded to a duration (Δt) of 1s, 125ms and 35ms respectively (Brüel and Kjær, 1998). One of these types was selected based on the nature of sound that was present in construction activities.

5.3.2 Sound properties

The calculation process started at this step. First of all, we defined the properties of sound signal that were input to the system. There were two parameters concerning this noise dose calculation such as Sampling rate (Fs) and Input Voltage (x). Both of these parameters were obtained directly from sound signal by using "wavread" in MATLAB function.

5.3.2.1 Sampling rate (Fs)

Sampling rate is the amount of samples per a second of time taken from a continuous signal to make a discrete signal (Douglas, 2005). This amount relied on the quality of sound signal that was required. Based on our case study, we selected a quality of sound signal with an input sampling rate of 44100 Hz. It means that the amount sampled per second was equal to 44100 sampled data.

5.3.2.2 Input voltage (x)

Input voltage (x) is a sampled data that represented voltage of sound signal in time domain (Douglas R., 2005). An example of input voltage x is presented in figure 5.10.

The input voltage received from properties of sound signal by using "wavread" MATLAB Function. The value of x was stored in a table against a time along sound signal. In addition, the amount of x per second is sampling rate (Fs).

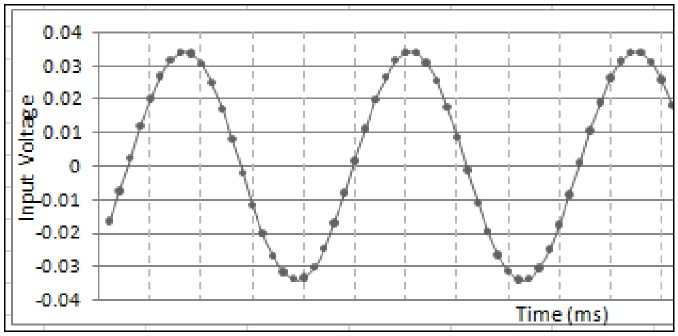


Figure 5.10 Input voltage of sound signal in time domain

5.3.3 Observation interval (N)

Observation interval (N) is an amount of sampling used in an interval of calculation. This interval is an appropriate length of FFT that must have length N equal to a power of 2 (Elena P., 2010). Firstly, we identified a minimum number of input samples (N_{min}) by using equation (5.1). Where Fs was sampling rate of wave signal and Δt was duration of each type of sound response that we selected. Since this amount of sample was unlikely to be a power of two. "nextpow2" in MATLAB function is used in order to find an observation interval (N) that was the next power of two of N_{min}.

$$N_{\min} = F_s \times \Delta t \qquad (5.1)$$

Based on our case of study, a default input sampling rate of 44100 Hz was used in order to support a Nyquist rate of 22050 Hz. The specific FFT lengths N is shown in table 5.1.

Table 5.1 summary of FFT lengths N used for 44100 Hz

Response Type	Duration (Δt)	Minimum Length (N_{min})	FFT Length (N)	Actual Period
Slow	1 s	44,100	65,536	1.486 s
Fast	125 ms	5,513	8,192	186 ms
Impulse	35 ms	1544	2,048	47 ms

5.3.4 Identification of A-weighted magnitude of sound (X_A)

The subject of this section was to identify A-weighted Magnitude of sound. There were three steps before X_A calculation. First was calculation of frequencies of each FFT. Second was evaluation of A-weighted coefficient. And third was a calculation of magnitudes of sound signal. Sub-sections below described how to calculate those parameters.

5.3.4.1 Frequencies of each FFT (f_n)

Frequencies of each FFT (f_n) were used to evaluate the A-weighted coefficient. These frequencies were obtained by using equation 5.2. Where $\Delta f = F_s/N$ is a frequency resolution.

$$f_n = n \times \Delta f \tag{5.2}$$

5.3.4.2 A-Weighted coefficient ($A(f_n)$)

Weighting filters were used to determine the "loudness" of sounds, particularly noise. In this section, the A-weighting filter was designed to model the response of the human ear. From American National Standards Institute (ANSI), we obtained the A-weighting curve (Figure 5.11) by using equation 5.3 where f_n was a frequency contents in Hz. The filter response $A(f_n)$ was applied directly to FFT frequency bin which was automatically achieved by using FFT function in MATLAB.

$$A(f_n) = 10Log\left(\frac{3.5041384\times10^{16}\times f_n^{\,8}}{\left(20.598997^2+f_n^{\,2}\right)^2\left(107.65265^2+f_n^{\,2}\right)\left(737.86223^2+f_n^{\,2}\right)\left(12194.217^2+f_n^{\,2}\right)^2}\right) \tag{5.3}$$

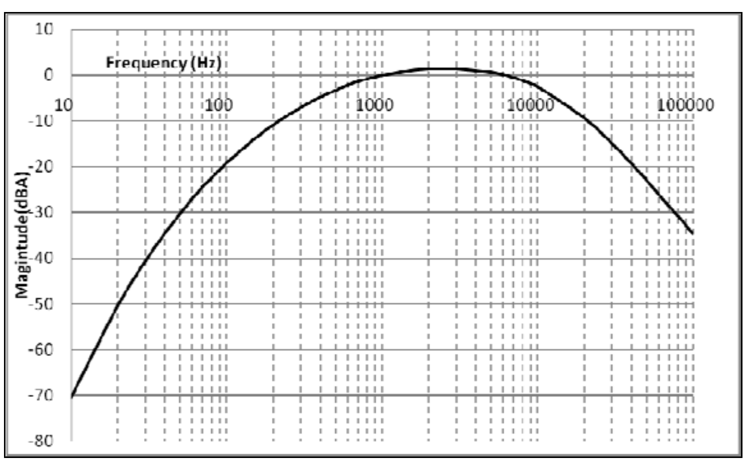


Figure 5.11 A-Weighting filters in decibel scale

5.3.4.3 Magnitude (X)

Magnitude of sound signal is absolute of complex valued of transformation input voltage to frequency domain (Steven W., 1999). In our case, magnitude was achieved by using FFT function in MATLAB (Equation 5.4).

$$X = abs\left[fft(x) \right] \tag{5.4}$$

5.3.4.4 A-weighted magnitude (X_A)

Finally, A-weighted coefficient was applied to magnitude of sound signal by using equation 5.5 in order to determine A-weighted magnitude.

$$X_A(n) = A(f_n)X(n) \tag{5.5}$$

5.3.5 Sound signal energy

Sound signal energy is the area under the squared signal (Figure 5.12.b). Sound energy can also be calculated by equation 5.6 (Anders G. et al., 2004). Since we divided the whole signal by observation interval (N), total energy and average energy were needed. The following section discusses both of these parameters.

$$E_a = \int_{-\infty}^{+\infty} \left(|x(t)|\right)^2 dt \tag{5.6}$$

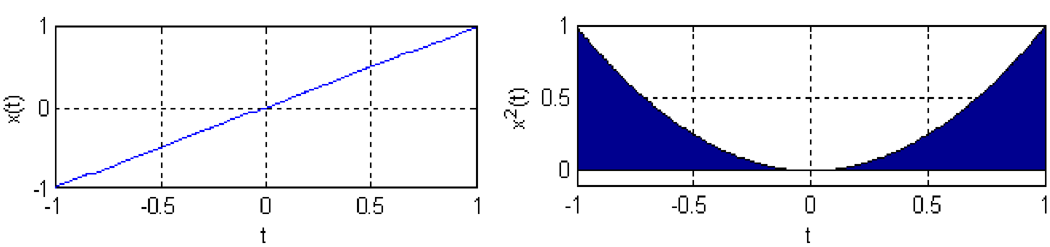


Figure 5.12 Sketch of energy calculation (a) Signal (b) The energy of signal is the shaded region (Anders G. et al., 2004)

5.3.5.1 Total Energy (ε_x)

Total signal energy is a summation of energy over a FFT length (Douglas R., 2005). It means the energy of signal level corresponds to the observation interval. Since we computed A-weighted frequency spectrum, signal level obtained at this step was in dBA (A-weighted decibels). In the same manner, sound energy was needed to be calculated in frequency domain. Furthermore, total sound energy can be determined by using Parseval's relation that is shown in equation 5.7 (Steven W., 1999).

$$\varepsilon_x = \sum_{i=0}^{N-1} x(i)^2 = \frac{2}{N}\sum_{n=0}^{N/2} MagX(n)^2 \tag{5.7}$$

Where x(i) is a time domain signal with i running from 0 to N-1, and X(n) is its modified frequency spectrum, with n running from 0 to N/2. X(n) was achieved by using equation 5.4 to transform input voltage of sound signal to frequency domain, as described in section 5.3.4.3.

5.3.5.2 Average Energy $\left(\tilde{\varepsilon}_x\right)$

Based on our purpose, noise hazard assessment system supports several types of sound response and several sampling rates. Therefore, average of signal energy is relevant. It was computed by equation 5.8

$$\tilde{\varepsilon}_x \approx \frac{2}{N\Delta t}\sum_{n=0}^{N/2} MagX_A(n)^2 \tag{5.8}$$

5.3.6 Sound Pressure Level (L(dBA))

Sound pressure level (SPL) was calculated from above sound signal energy. Furthermore, we needed reference signal energy ($\tilde{\varepsilon}_{ref}$) in order to get the final sound pressure level in dBA. Thus, the calculation of SPL is given by equation 5.9 where the standard reference pressure $\tilde{\varepsilon}_{ref}$ is 0.000204 dynes/cm^2 (Douglas R., 2005).

$$L(dBA) = 10\log_{10}\left(\frac{\tilde{\varepsilon}_x}{\tilde{\varepsilon}_{ref}}\right) = 10\log_{10}\left(\tilde{\varepsilon}_x\right) - 10\log_{10}\left(\tilde{\varepsilon}_{ref}\right) \tag{5.9}$$

As discussed in section 5.4.1 about the experimental in laboratory, we needed to add a constant (C_{add}) to equation 5.9 in order to achieve actual sound pressure level. Therefore, we got a new equation (5.10) as shown below. Where calibration constant C = $-\left(10\log_{10}\left(\tilde{\varepsilon}_{ref}\right) + C_{add}\right)$

$$L(dBA) = 10\log_{10}\left(\frac{\tilde{\varepsilon}_x}{\tilde{\varepsilon}_{ref}}\right) = 10\log_{10}\left(\tilde{\varepsilon}_x\right) + C \tag{5.10}$$

At this point, we defined constant C corresponding to input voltage of sound recorders that was used for our system development. Next, this constant would be used as a calibrator constant for estimation of sound pressure level.

5.3.7 Equivalent Level (L_{eq})

Equivalent level is the equivalent steady sound level of a noise energy-averaged over time (WorkSafeBC, 2007). Given the sound pressure level over an observation interval, the equivalent level was given by equation 5.11.

$$L_{eq} = 10 Log_{10}\left[\frac{1}{k}\sum_{i=1}^{k} 10^{L_i/10}\right] \tag{5.11}$$

5.3.8 Noise dose (D%)

Dose of noise is expressed as a percentage of the maximum permitted exposure. It helps worker to easily know if it is hazard or not based on the value relative to unity or 100% (85 dBA for 8h) of an "acceptable" amount of noise. Noise dose was determined by using equation 5.12 where T was the sampling time of the measurement, in hours.

$$D\% = 100 \times \frac{T}{8} \times 10^{(L_{eq}-85)/10} \tag{5.12}$$

5.4 System design and programming

All necessary algorithm and procedure for noise hazard assessment was programmed in MATLAB programming as discussed in previous chapter. A summary of source code files was presented in below section.

5.4.1 MATLAB functions

As mentioned in preliminary study, the system development was programmed to estimate noise exposure level from sound signal. Next the system development was extended to be a final system since it was found that this initial system could be implemented for noise hazard assessment. It meant that system in this step could be used to assess noise hazard for construction workers.

Table 5.2 Summary of main functions implementation for the proposed system

Function name	Description
A-weighting_filter.m	Generate an A-weighting filter.
Decibel_level_analyzer.m	Estimate sound signal level in dBA.
Sound_Parameter.m	Computed minimum, maximum, equivalent level and noise dose for an interval
Noise_Dose_calculator.m	Evaluating the status of noise hazard

The concept and procedure of source code development are described in section 5.2 and 5.3 of this chapter. The final system consisted of four functions which include (1) the A-weighting filter, (2) Decibel level analyzer, (3) Sound Parameter, and (4) Noise Dose calculator (Table 5.2). The overall source code of MATLAB function is contained in Appendix B.

5.4.2 Running the noise hazard assessment system

Our proposed noise hazard assessment system for construction workers was considered as an off-line evaluation of hazard. It meant that the hazard evaluation could be performed after their workday.

The main source code of system development was “Noise Dose calculator.m”. It was supported by other three functions in MATLAB such as “A-weighting filter.m”, “Decibel level analyzer.m” and “Sound Parameter.m” as presented in figure 5.13. The procedures of noise dose calculation were contained in “Noise Dose calculator.m”. While sound signal and type of response were inputted, “Noise Dose calculator.m” was used to compute the dose of noise and evaluate the status of noise hazard.

In addition, minimum, maximum and equivalent level of input sound signal was also estimated and plotted versus sampling time. Moreover, the results of these parameters were stored in an excel file. Finally, noise hazard assessment system was compiled to run on platform of window without using MATLAB.

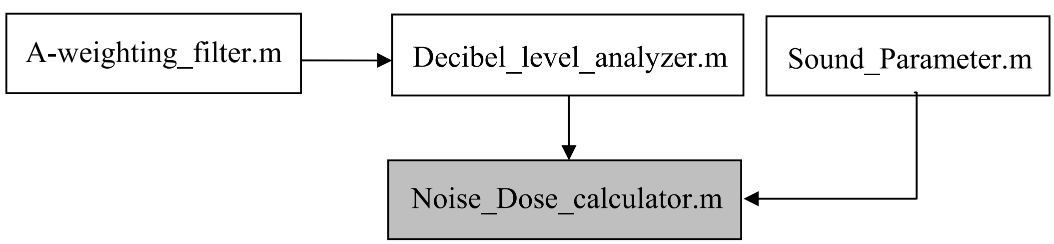


Figure 5.13 Implementation of MATLAB function in noise hazard assessment system

5.5 System verification

Noise hazard assessment system is verified in this section. The subject firm for this verification was an implementation of system with workers at construction site. The section describes the characteristic of sampling data, result, adjustment, and validation of noise hazard assessment system.

5.5.1 Characteristic of sampling data for system verification

The sampling data in this study was collected by using two kinds of instruments including sound recorder and noise dosimeter. Both of these devices are attached as a pair in order to compare between the proposed system and standard equipment. Due to the limitation of standard equipment, the research was designed to collect three days per construction site. The reason was that we needed to use standard equipment as a reference of the proposed system. It means that standard equipment was attached to the system that was developed and their position switched in order to cover all of these three occupations such as foreman, labourer and machine operator. List of this design is shown in table 5.3.

From this design, we collected data in construction site with two types of piling work, drop-hammer piling and bored piling. We collected data from 8 construction projects and started from April 29, 2011 until June 24, 2011. It took around two months in order to get the final data. In addition, the number of sampling from each case study was summarized as seen in table 5.4. The number of samples for system verification was 24 including 12 samples from drop-hammer piling and 12 samples from bored piling.

Table 5.3 Distribution of instruments for 1 construction site

SX 850 (Foreman)	SX713R (Labourer)	SX713B (Operator)	
			First day
			Second day
			Third day
1 sample for SX850	1 sample for SX713R	1 sample for SX713B	3 samples for validation / 1 construction site

Table 5.4 Summary of total data for piling work

Type of piling work	Samples for foreman	Samples for labourer	Samples for Operator	Samples/ Piling Worker
Drop hammer	4	4	4	12
Bored Pile	4	4	4	12
Total	8	8	8	24

Furthermore, in order to see the ouput of system in detail, this research shows the data set in minute scale. The numbers of sampling in each working day of drop-hammer piling work and bored piling work are presented in table 5.5 and table 5.6, respectively.

Table 5.5 Summary of the amount of data points in drop-hammer piling work

Day	Type of Piling	Project	Working Time	Data Points
1	Drop Hammer	Department Store	6h 35min	395
2	Drop Hammer	Department Store	7h 32min	452
3	Drop Hammer	Department Store	7h 20min	440
4	Drop Hammer	Railway	6h 31min	391
5	Drop Hammer	Railway	6h 30min	390
6	Drop Hammer	Railway	7h 45min	465
7	Drop Hammer	Toll way	7h 34min	454
8	Drop Hammer	Toll way	8h 22min	502
9	Drop Hammer	Toll way	7h 37min	457
10	Drop Hammer	Warehouse	7h 19min	439
11	Drop Hammer	Warehouse	8h 44min	524
12	Drop Hammer	Warehouse	6h 25min	385
			Total	5294

Table 5.6 Summary of the amount of data points in bored piling work

Day	Type of Piling	Project	Working Time	Data Points
1	Bored Pile	Dormitory, Chula, M1	8h 30min	510
2	Bored Pile	Dormitory, Chula, M1	9h 05min	545
3	Bored Pile	Dormitory, Chula, M1	9h 34min	574
4	Bored Pile	Dormitory, Chula, M2	8h 47min	527
5	Bored Pile	Dormitory, Chula, M2	8h 01min	481
6	Bored Pile	Dormitory, Chula, M2	9h 48min	588
7	Bored Pile	Sorinthon Building	8h 39min	519
8	Bored Pile	Sorinthon Building	8h 43min	523
9	Bored Pile	Sorinthon Building	8h 23min	503
10	Bored Pile	Rama9 Square	9h 14min	554
11	Bored Pile	Rama9 Square	8h 49min	529
12	Bored Pile	Rama9 Square	9h 23min	563
			Total	6416

5.5.2 Result of the proposed system

The result of the proposed system is categorized into two parts based on our case study including result of the proposed system from case 1: drop-hammer piling operation and result of the proposed system from case 2: bored piling operation. The result is described in following section.

5.5.2.1 Result of the proposed system from case 1: Drop-Hammer Piling

The results were analyzed based on the collected data from 4 construction sites or 12 working days. The results consist of four parts; comparison between the proposed system with standard equipment, Percent error of Leq evaluated by the proposed system, and Mathematical formula represented Leq of the proposed system.

5.5.2.1.1 Comparison between system and standard equipment

First of all, we discussed the comparison between the proposed systems with standard equipment. Figure 5.14 represented the trend of equivalent noise level measured by the proposed system and standard equipment in case study 1, drop-hammer piling operation, based on daily calculation. It can be seen that our proposed system has the same trend with standard equipment. However, the rank of error is between -2.3 and 1.4 dBA. The details are presented in table 5.7.

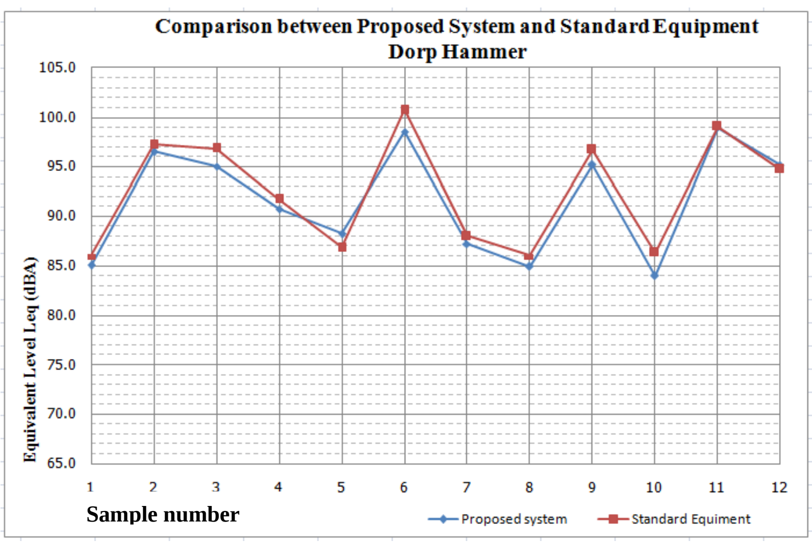


Figure 5.14 The trend of equivalent noise level measured by the proposed system and standard equipment in case study 1, drop-hammer piling

Table 5.7 The differences of equivalent noise level measured by the proposed system and standard equipment in case study 1, drop hammer piling

Day	Project Type	Model of Recorder	Leq (System)	Leq (ND)	ΔLeq
1	Department Store	SX850	85.0	86.0	- 1.0
2	Department Store	SX713R	96.5	97.2	- 0.7
3	Department Store	SX713B	95	96.8	- 1.8
4	Railway	SX850	90.7	91.7	- 1.0
5	Railway	SX713R	88.2	86.8	1.4
6	Railway	SX713B	98.5	100.7	- 2.2
7	Toll way	SX850	87.2	88.0	- 0.8
8	Toll way	SX713R	84.9	86	- 1.1
9	Toll way	SX713B	95.2	96.7	- 1.5
10	Warehouse	SX850	84.0	86.3	- 2.3
11	Warehouse	SX713R	98.9	99	- 0.1
12	Warehouse	SX713B	95.1	94.7	0.4

5.5.2.1.2 Percent error of Leq evaluated by the proposed system

Percent error in this study addressed the differences between Leq of the proposed system and standard equipment. Percent error was calculated by using formula 5.13 where Leq_{SYS} was equivalent noise level computed by the proposed system and Leq_{STD} was equivalent noise level evaluated by standard equipment (Gregory L., 2004). The analysis of percent error is based on 5294 samples of Leq in minute scale that were collected from construction site of drop-hammer piling. In addition, the details of percent error would be presented in appendix D.

$$Percent\ Error = \frac{Leq_{SYS} - Leq_{STD}}{Leq_{STD}} \times 100 \qquad (5.13)$$

The frequencies of percent error are shown figure 5.15. Normal distribution curve was also plotted in order to demonstrate behavior of percent error. The result illustrated the mean of percent error of the proposed system equal to -1.81 percent with standard deviation equal to 3.208. Interestingly, the interval of percent error with 95 percent of confident level was presented in range from -8.23 percent to 4.61 percent.

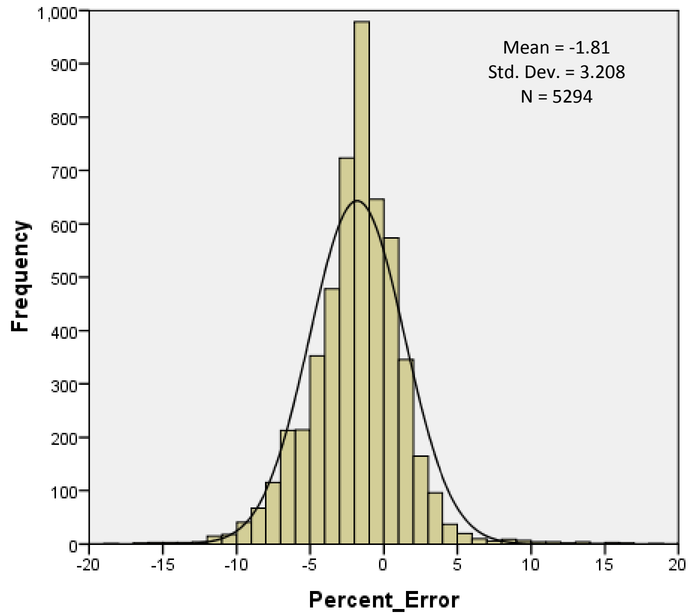


Figure 5.15 Distribution of percent error of Leq evaluated by the proposed system

5.5.2.1.3 Mathematical formula represented Leq of the proposed system

In addtion, the sampling was plotted as a graph in figure 5.16 and the detail of this sampling is described in appendix D. It could be indicated that the correlation between the proposed system and standard equipment is high while the value of correction coefficient R is equal to 0.977. Furthermore, a mathematical formula representing this data set is $Leq_{STD} = 0.94Leq_{SYS} + 6.40$.

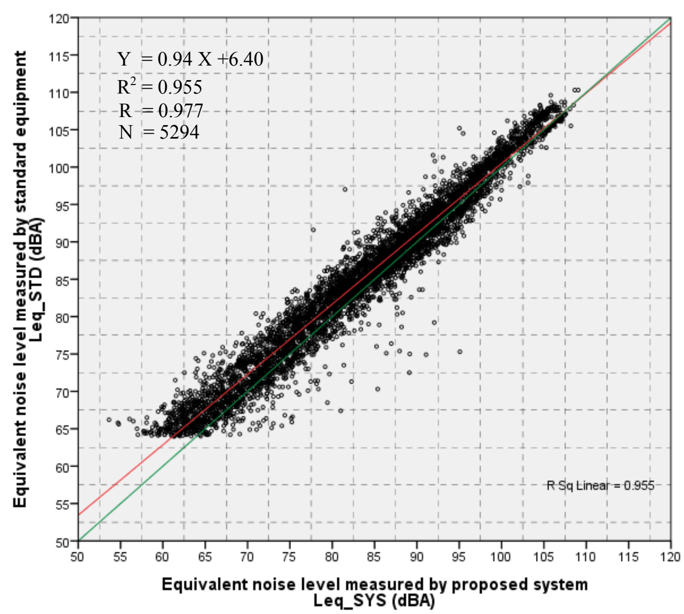


Figure 5.16 Correlation of noise level measured by the proposed system and that by standard equipment in case study 1

5.5.2.2 Result of the proposed system from case 2: Bored Piling

The results were analyzed based on the collected data from 4 construction sites or 12 working days. The results consist of three parts; comparison between the proposed system with standard equipment, Percent error of Leq evaluated by the proposed system, and Mathematical formula represented Leq of the proposed system.

5.5.2.2.1 Comparison between system and standard equipment

Table 5.8 The differences of equivalent noise level measured by the proposed system and standard equipment in case study 2, bored piling

Day	Project Type	Model of Recorder	Leq (System)	Leq (ND)	ΔLeq
1	Dormitory, Chula, M1	SX850	83.5	84.7	-1.2
2	Dormitory, Chula, M1	SX713R	87.4	88.1	-0.7
3	Dormitory, Chula, M1	SX713B	89.9	91.3	-1.4
4	Dormitory, Chula, M2	SX850	85.9	86.1	-0.3
5	Dormitory, Chula, M2	SX713R	90.5	92.7	-2.2
6	Dormitory, Chula, M2	SX713B	98.66	100	-1.3
7	Sorinthon Building	SX850	84.5	85.7	-1.2
8	Sorinthon Building	SX713R	93.23	92.9	0.3
9	Sorinthon Building	SX713B	88.7	90.2	-1.5
10	Rama9 Square	SX850	83.7	84.2	-0.5
11	Rama9 Square	SX713R	85.1	85	0.1
12	Rama9 Square	SX713B	83	83.5	-0.5

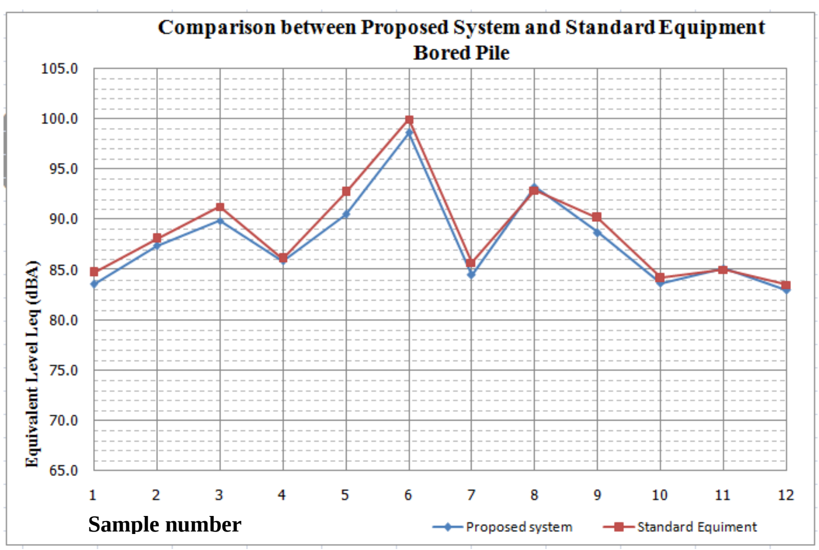


Figure 5.17 The trend of equivalent noise level measured by the proposed system and standard equipment in case study 2

We initially discussed the comparison between the proposed systems with standard equipment. Figure 5.17 describes the trend of equivalent noise level measured by the proposed system and standard equipment in case study 2, bored pile, based on daily calculation. The graph indicates that the equivalent noise level that was evaluated by noise hazard assessment system had the same trend with that computed by standard equipment. In addition, table 5.8 presented the rank of error between our proposed system and standard equipment that is -2.2 to 0.3 dBA.

5.5.2.2.2 Percent error of Leq evaluated by the proposed system

The analysis of percent error is based on 6416 samples of Leq in minute scale that were collected from construction site of bored pile operation. Moreover, the details of percent error would be presented in appendix D. The frequencies of percent error are shown in figure 5.18. Normal distribution curve was also plotted in order to demonstrate behavior of percent error. The result illustrated the mean of percent error of the proposed system equal to -1.99 percent with standard deviation equal to 2.62. Interestingly, the interval of percent error with 95 percent of confident level was presented in range from -8.40 percent to 4.43 percent.

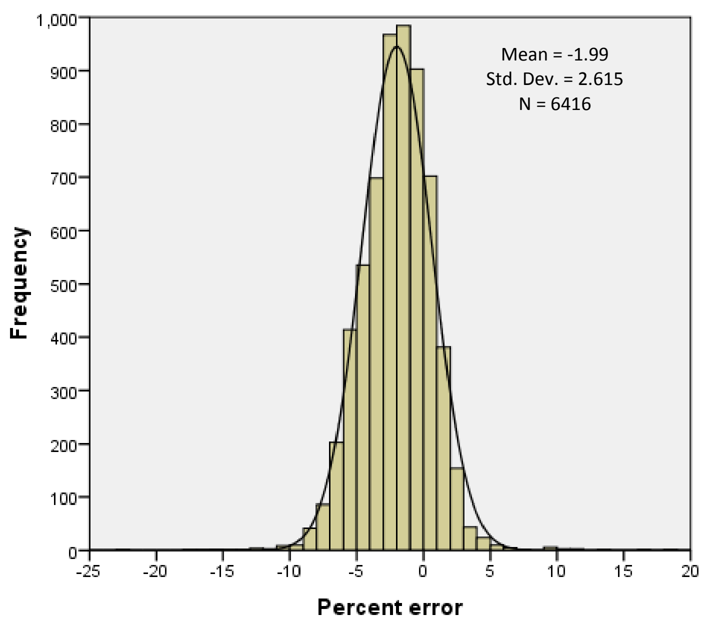


Figure 5.18 Distribution of percent error of Leq evaluated by the proposed system

5.5.2.2.3 Mathematical formula represented Leq of the proposed system

Nevertheless, in order to see the ouput of system in detail, this research showed the data set in minute scale. In addition, this sampling was plotted as a graph in figure 5.19 and the detail of this sampling is described in appendix D. It could be indicated that the correlation between the proposed system and standard equipment is high while the value of correction coefficient R is equal to 0.968. Furthermore, a mathematical formula representing this data set is $Leq_{STD}= 0.95Leq_{SYS} + 5.90$.

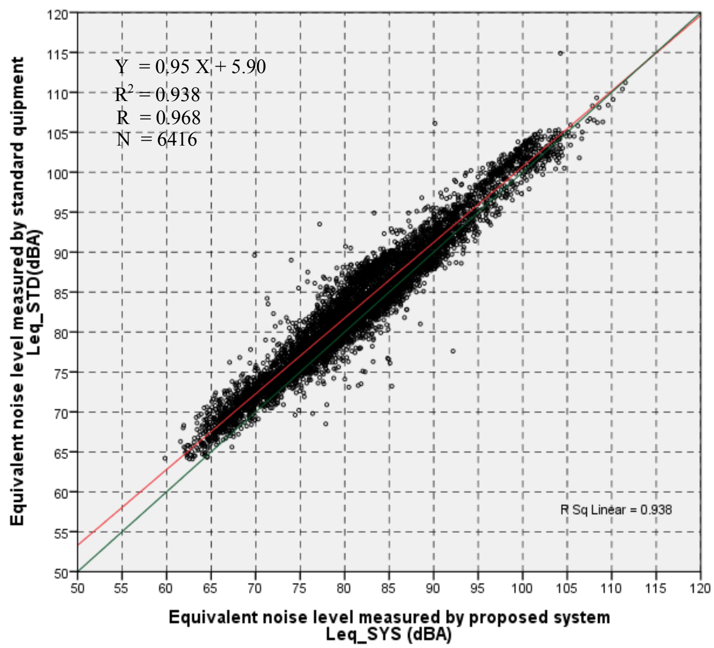


Figure 5.19 Correlation of noise level measured by the proposed system and that by standard equipment in case study 2, bored piling operation.

5.5.3 Adjustment of noise hazard assessment system

Referring to figure 5.14 and 5.17, most of the results of the proposed system presented lower than that of standard equipment. Therefore, the noise hazard assessment system needed to be adjusted in order to improve the safety of noise hazard evaluation.

The adjustment of system would be done by adding a constant namely safety adjustment value to equation 5.10 of previous section. In addition, the safety adjustment value is an average of error between the proposed system and standard in minute scale. Thus, a new formula for noise level calculation in this study is equation 5.14 where C is calibration constant derived from experimental system in preliminary study, and Adj is safety adjustment value of system. Last, it would be programmed in MATLAB.

$$L(dBA) = 10\log_{10}\left(\tilde{\varepsilon}_x\right) + C + Adj \qquad (5.14)$$

Based on current data set from both cases of study, the “Adj” was equal to 1.6 dBA. The detail of adjustment value is described in appendix D. The following section presented the result of the proposed system after adjustment.

5.5.3.1 Adjustment of result in case 1: Drop-Hammer Piling

Similar to the result of the proposed system in previous section, this section presented the result of system after adjustment. It consists of three parts; comparison between the proposed system after adjustment and standard equipment, Percent error of Leq evaluated by the proposed system after adjustment, and Mathematical formula represented Leq of the proposed system after adjustment.

5.5.3.1.1 Comparison between system after adjustment and standard equipment

Figure 5.20 indicated that our proposed system after adjustment still had the same trend with standard equipment. However, it could be seen that equivalent noise level evaluated by final system is slightly higher than that measured by standard equipment. Therefore, system should be safer in terms of evaluation status of noise hazard for construction workers.

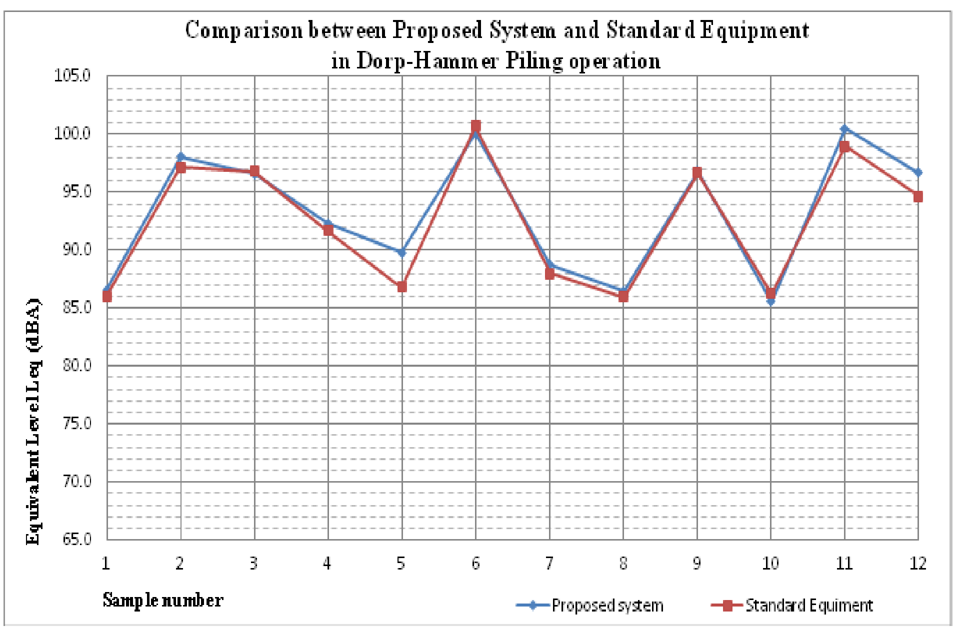


Figure 5.20 The trend of equivalent noise level after adjustment of the proposed system in case study 1: drop-hammer piling operation

5.5.3.1.2 Percent error of Leq evaluated by the proposed system after adjustment

Figure 5.21 represented the distribution of percent error of Leq evaluated by the proposed system after adjustment with drop-hammer piling operation. Interestingly, the result illustrated the mean of percent error of final system equal to 0.11 percent only and standard deviation equal to 3.18. Furthermore, the interval of percent error with 95 percent of confident level was presented in range from -6.25 percent to 6.47 percent. In addition, it should be stated that the result of system after adjustment was quite better compared to previous result.

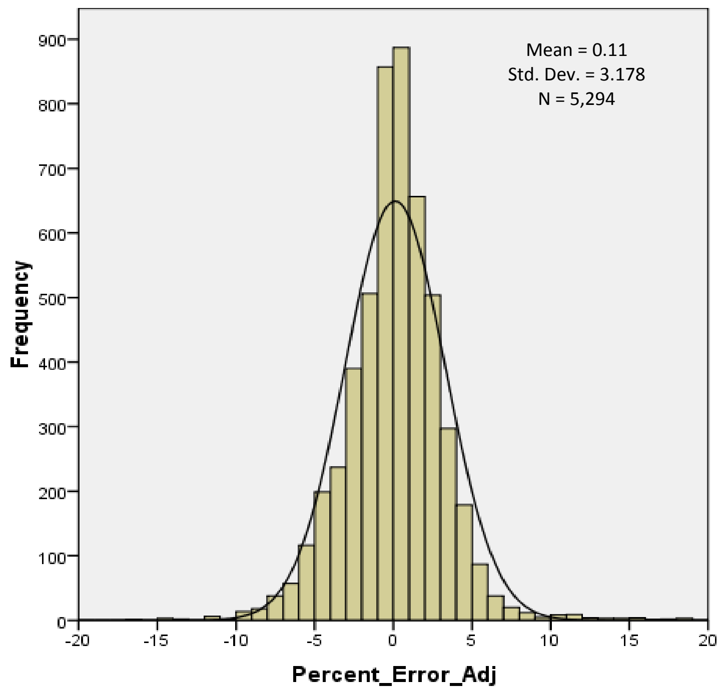


Figure 5.21 Distribution of percent error of Leq evaluated by the proposed system after adjustment in case 1: drop-hammer piling operation

5.5.3.1.3 Mathematical formula represented Leq of the proposed system after adjustment

Figure 5.22 represented the correlation between the proposed system after adjustment and standard equipment in case study of drop-hammer piling operation. It could be seen that the correlation of both instruments is still high while the value of correction coefficient R is equal to 0.977. Last, the mathematical formula of final system development is $Leq_{STD} = 0.94Leq_{SYS} + 4.89$.

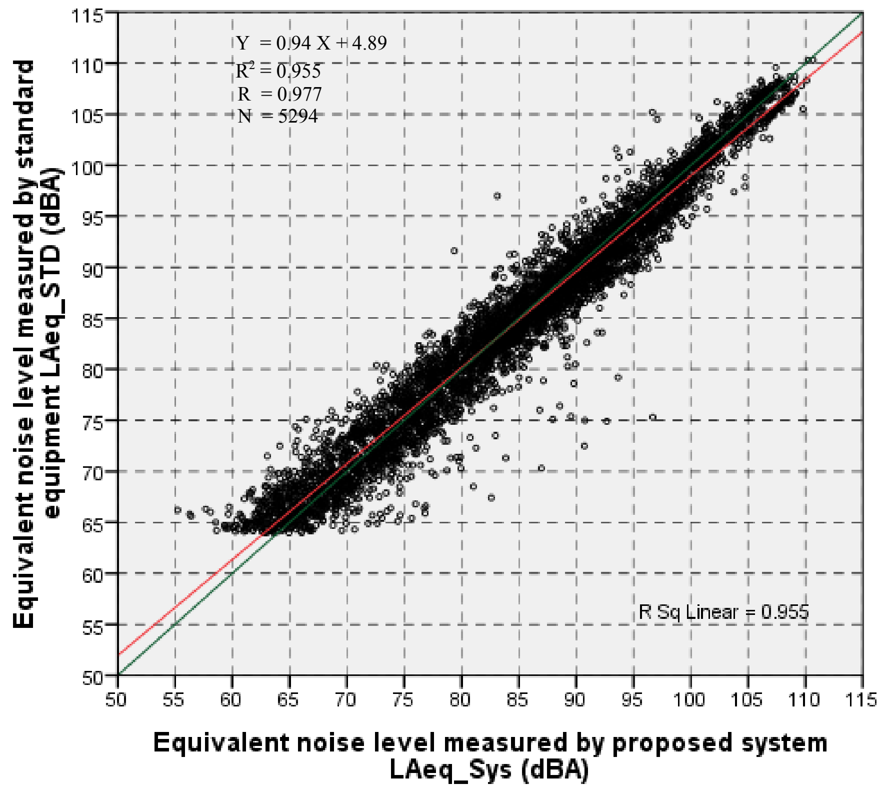


Figure 5.22 Correlation of noise level measured by the proposed system after adjustment and that by standard equipment in case study 1, drop-hammer piling operation.

5.5.3.2 Adjustment of result in case 2: Bored Piling operation

Similar to previous section, this section consists of three parts; comparison between the proposed system after adjustment and standard equipment, Percent error of Leq evaluated by the proposed system after adjustment, and Mathematical formula represented Leq of the proposed system after adjustment.

5.5.3.2.1 Comparison between system after adjustment and standard equipment

We initially discussed the comparison between the proposed systems after adjustment with standard equipment. Figure 5.23 demonstrated that the proposed system after adjustment still has the same trend with standard equipment. However, it could be seen that equivalent noise level evaluated by final system is slightly higher than that measured by standard equipment. Therefore, system should be safer in terms of evaluation status of noise hazard for construction workers.

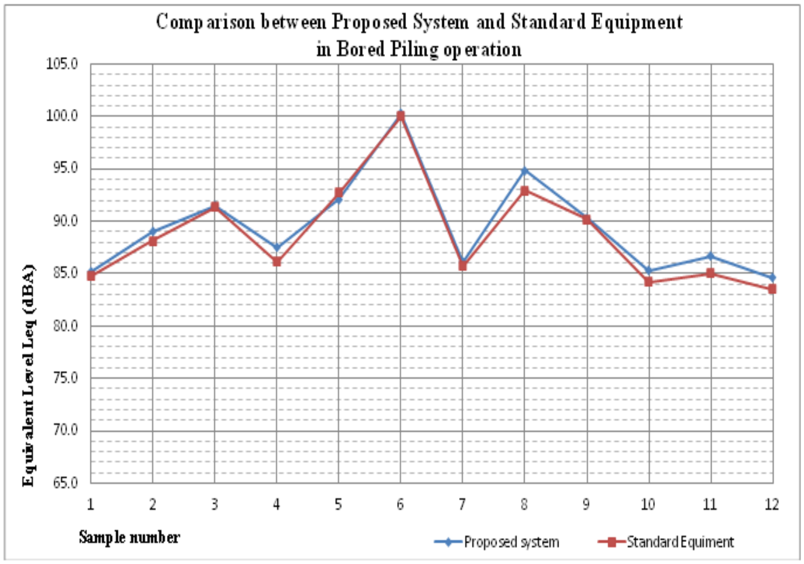


Figure 5.23 The trend of equivalent noise level after adjustment of the proposed system in case study 2: Bored piling operation

5.5.3.2.2 Percent error of Leq evaluated by the proposed system after adjustment

Figure 5.24 represented the distribution of percent error of Leq evaluated by the proposed system after adjustment with bored piling operation.

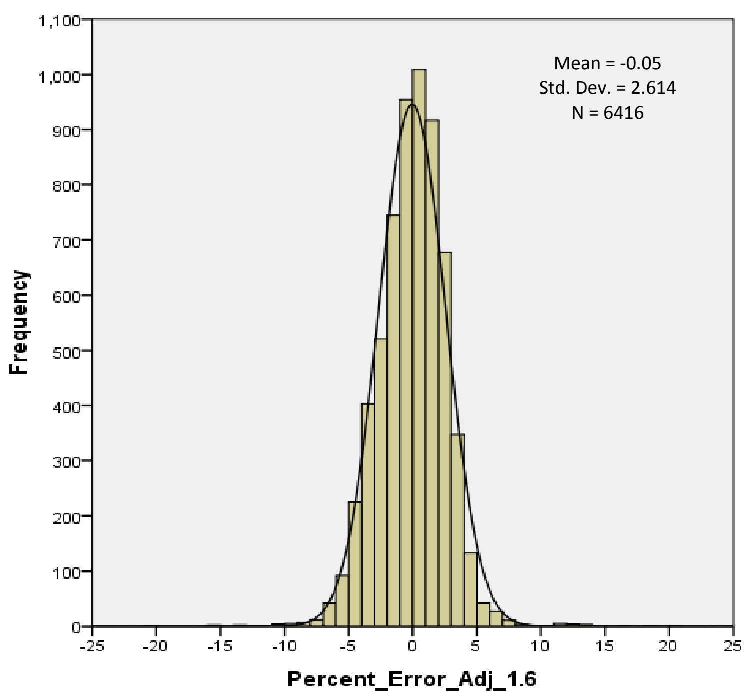


Figure 5.24 Distribution of percent error of Leq evaluated by the proposed system after adjustment in case study 2: Bored piling operation

It could be seen that the result illustrated the mean of percent error of final system equal to -0.05 percent only and standard deviation equal to 2.614. Interestingly, the interval of percent error with 95 percent of confident level was presented in range from -5.28 percent to 5.18 percent. In addition, it should be stated that the result was quite better after adjustment of system.

5.5.3.2.3 Mathematical formula represented Leq of the proposed system after adjustment

Figure 5.25 represented the correlation between the proposed system after adjustment and standard equipment in case study of bored piling operation. It could be seen that the correlation of both instruments is still high while the value of correction coefficient R is equal to 0.968. However, the mathematical formula representing this data set is changed to $Leq_{STD} = 0.95Leq_{SYS} + 4.39$.

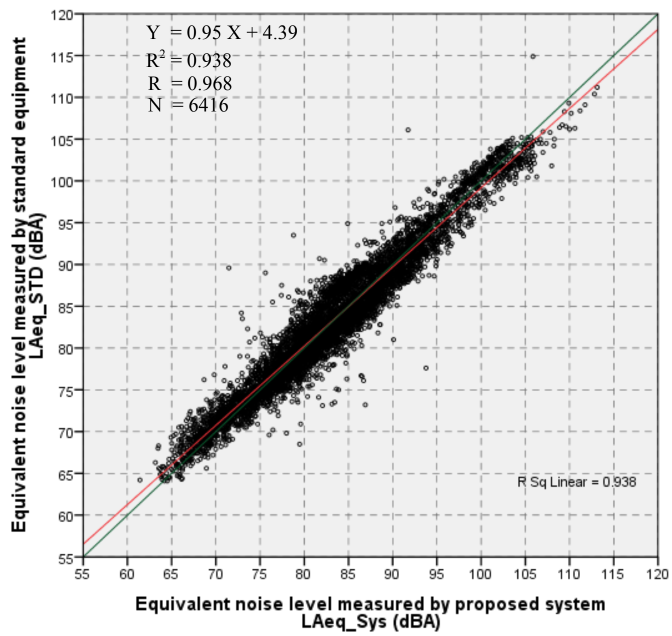


Figure 5.25 Correlation of noise level measured by the proposed system after adjustment and that by standard equipment in case study 2: bored piling operation.

5.5.4 Validation of noise hazard assessment system

The results of system validation were analyzed from the collected data of 24 working days in selected case studies. Table 5.9 represents the status of noise hazard indicated by noise hazard assessment system and standard equipment. Only two from twenty-four results of the proposed system mismatched with the value from standard noise dose. The difference of these results may be the fact that equivalent noise level from standard equipment and the proposed system is close to exposure limit, 85 dBA. One of examples is that Leq of the proposed system and standard equipment in day 13 is equal to 85.2 dBA and 84.7 dBA, respectively. In the same manner, day 22 presented Leq of the proposed system and standard equipment equal to 85.4 dBA and 84.2 dBA, respectively. In addition, the equivalent noise level from the proposed system is designed to adjust constant to cover the variance from the proposed system. Therefore, the equivalent noise level from the proposed system will be slightly higher than standard equipment. In general, it can be stated that our proposed system is valid. However, system fails to evaluate status of noise hazard when Leq is close to exposure limit. Nonetheless, it is still safe for construction workers who used our system since the result of system was greater than that of standard equipment.

Table 5.9 Status of noise hazard indicated by the proposed system and standard equipment

Day	Type of piling	Recorder	Status of Hazard (Proposed system)	Status of Hazard (Standard equipment)
1	Drop Hammer	SX850	Hazard	Hazard
2	Drop Hammer	SX713R	Hazard	Hazard
3	Drop Hammer	SX713B	Hazard	Hazard
4	Drop Hammer	SX850	Hazard	Hazard
5	Drop Hammer	SX713R	Hazard	Hazard
6	Drop Hammer	SX713B	Hazard	Hazard
7	Drop Hammer	SX850	Hazard	Hazard
8	Drop Hammer	SX713R	Hazard	Hazard
9	Drop Hammer	SX713B	Hazard	Hazard
10	Drop Hammer	SX850	Hazard	Hazard
11	Drop Hammer	SX713R	Hazard	Hazard
12	Drop Hammer	SX713B	Hazard	Hazard
13	Bored Pile	SX850	Hazard	No hazard
14	Bored Pile	SX713R	Hazard	Hazard
15	Bored Pile	SX713B	Hazard	Hazard
16	Bored Pile	SX850	Hazard	Hazard
17	Bored Pile	SX713R	Hazard	Hazard
18	Bored Pile	SX713B	Hazard	Hazard
19	Bored Pile	SX850	Hazard	Hazard
20	Bored Pile	SX713R	Hazard	Hazard
21	Bored Pile	SX713B	Hazard	Hazard
22	Bored Pile	SX850	Hazard	No hazard
23	Bored Pile	SX713R	Hazard	Hazard
24	Bored Pile	SX713B	No hazard	No hazard

5.6 Comparison of the price of instruments

After noise hazard assessment system was completely developed, this section started to compare the price of the proposed system with noise dosimeter. Referring to table 2.7 in chapter II, we found that the average of noise dosimeter price is around 4,000 USD or 120,000 THB per device. In addition the price CEL350 dBage used in this research cost around 110,000 THB per device. On the other hand, the total price of our proposed system is briefly calculated and equal to 8,000 THB per set including sound recorder 7,000 THB and external memory 1,000 THB. It could be stated that the use of the proposed system could save the cost of noise assessment while the result of noise assessment still has similar quality with standard equipment. Therefore, the use of noise hazard assessment system could overcome the high cost of noise assessment at construction worker level.

5.7 Summary

This chapter has discussed the procedure of noise hazard assessment system development in full scale study. Firstly, the conceptual framework of system development is presented in the first section and followed by the development of graphical user interface (GUI), noise dose calculation, system design and programming, and system verification.

The process of noise dose calculation is described in order to support the procedure of system development. First of all, sound signal obtained from workers' activities was contained in "WAV" format. It was the main input for the system. Next, energy of signal was defined by using Perseval's relation in frequency domain and filter in A-weighted. Then, this energy was used to estimate sound pressure level in dBA. Afterward, dose of noise was calculated based on final SPL. At the end, the proposed system could be used for evaluating the status of noise hazard. However, calibration constant "C" and safety adjustment value "Adj" were required for calibrating the system to get a standard. In addition, constant C was determined from experimental of system in both laboratory and construction site. On the other hand, safety adjustment value was obtained from system verification in construction site.

Under system verification, the deviation of noise hazard assessment system compared to standard equipment was defined under rank of -0.8 to 2.9 dBA. Therefore, limitation of this system is an equivalent noise level that is present in the rank of 84.2 to 87.9 dBA. In addition, construction workers should be careful when noise hazard assessment system indicated Leq between 84.2 and 85 dBA. At the same time, we recommended using hearing protection under this rank in case of using our proposed system. The following chapter discusses application of noise hazard assessment system with construction workers in multiple occupations.

CHAPTER VI
APPLICATIONS OF THE PROPOSED SYSTEM AT CONSTRUCTION SITES

The subject of this chapter was to explain the application of noise hazard assessment system at construction sites. It presented the analysis of data that was obtained from the proposed system. In addition, this chapter aimed to explore the status of noise hazard of workers in three occupations including foreman, labourer and operator. First, section 6.1 presented the characteristic of sampling data that was used for conducting this research. Next, section 6.2 showed the result of the proposed system from case 1: drop-hammer piling. Additionally, section 6.3 indicated the result of the proposed system from case 2: bored piling. Finally, last section presented the result of workers' perception and awareness of noise hazard.

6.1 Characteristic of sampling data

The sampling data in this research was categorized into two parts. The first part concerned data collection by instruments and the second part related to the data collection by questionnaire. The following section discusses both types of the data.

6.1.1 Data collected by system

Data collection in this part was designed to capture the dose of noise from three occupations of construction workers such as foreman, labourer, and operator. In order to do this, noise assessment system is attached to those workers. From the design, the data collection is done at the same time and same construction site with data collection for system verification in previous chapter. It meant that we collected data in construction site with two types of piling works, drop hammer piling operation and bored pile. We collected data from 8 construction projects and started from April 29, 2011 until June 24, 2011. In addition, the number of sampling from each case study is summarized in table 6.1.

Table 6.1 Summary of total data collected by system

Type of piling work	Foreman (Samples)	Labourer (Samples)	Operator (Samples)	Piling Workers (Samples)
Drop hammer	12	12	12	36
Bored Pile	12	12	12	36
Total	24	24	24	72

6.1.2 Data collected by questionnaire

Referring to the objective of this research, we also used questionnaire in order to interview construction workers about their perception and awareness related to noise hazard and their usage of hearing protection in construction site. The questionnaire was collected with the same workers to whom our equipment was attached. In addition, it was performed at the end of their work day. The numbers of samplings are summarized in table 6.2.

Table 6.2 Summary of total data collected by survey questionnaires

Type of piling work	Foreman (Samples)	Labourer (Samples)	Operator (Samples)	Piling Workers (Samples)
Drop hammer	4	4	4	12
Bored Pile	4	4	4	12
Total	8	8	8	24

6.2 Result of noise hazard in case study 1: Drop hammer piling

The results were analyzed based on the collected data from 4 construction sites or 12 working days. The results consist of three parts; Equivalent noise level for workers in drop-hammer piling operation, Dose of noise for workers in drop-hammer piling operation, and Status of noise hazard for workers in drop-hammer piling operation.

6.2.1 Equivalent noise level for workers in drop-hammer piling operation

Result in this section explored equivalent noise level that three occupations of piling workers obtained under their work activities in construction site. Figure 6.4 represented comparison between equivalent noise level (Leq) of foreman, labourer, and operator who worked in drop hammer piling operation.

Based on their occupations, foreman, labourer and operator got different Leq even though they worked in the same activities and at the same construction site. The rank of equivalent noise level for foreman, labourer and operator in drop hammer piling operation was 82.4 to 92.3 dBA, 86.5 to 100.5 dBA and 90.8 to 100.9 dBA, respectively (Table 6.3). It could be pointed out that operator obtained the highest equivalent noise level follow by labourer and foreman. However, labourer in first construction site received Leq higher than operator when they worked near generator in welding process (Figure 6.2).

Table 6.3 Summary of equivalent noise level in each occupation

Day	Project Type	Leq of foreman (dBA)	Leq of labourer (dBA)	Leq of operator (dBA)
1	Department Store	83.6	97.6	90.8
2	Department Store	85.8	98.1	94.4
3	Department Store	82.8	96.8	96.6
4	Railway	92.3	98.0	100.9
5	Railway	91.2	89.8	95.5
6	Railway	88.1	88.8	100.1
7	Tollway	88.8	90.2	94.3
8	Tollway	85.3	86.5	91.2
9	Tollway	86.3	90.3	96.8
10	Warehouse	85.6	95.3	98.5
11	Warehouse	82.4	100.5	98.0
12	Warehouse	85.2	92.1	96.7
		Max = 92.3	100.5	100.9
		Min = 82.4	86.5	90.8

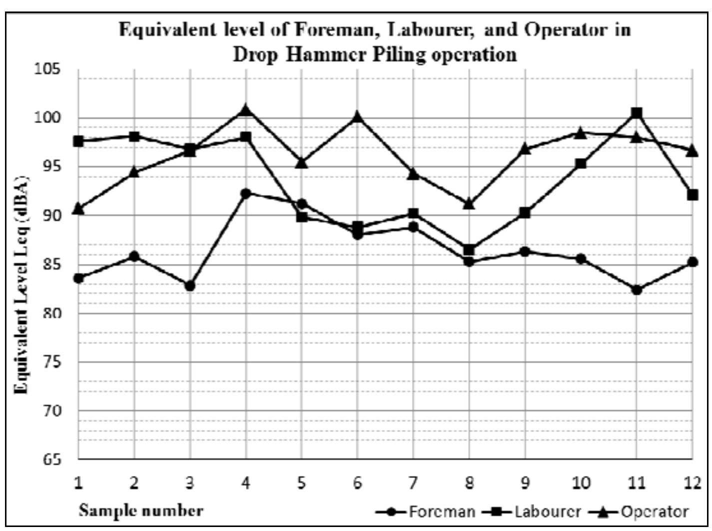


Figure 6.1 Comparison between equivalent noise levels in each occupation

Figure 6.2 Labourers operating near generator in welding process

6.2.2 Dose of noise for workers in drop-hammer piling operation

Beside equivalent noise level, noise hazard assessment system also computed dose of noise for construction workers. Table 6.4 represents dose of noise presented in each occupation, foreman, labourer and operator of drop hammer piling operation.

Table 6.4 Dose of noise presented in each occupation, foreman, labourer and operator in case study 1, drop hammer piling operation

Day	Project Type	Noise dose of foreman (%)	Noise dose of labourer (%)	Noise dose of operator (%)
1	Department Store	72.4	1809.0	375.9
2	Department Store	120.2	2041.7	871.0
3	Department Store	60.8	1513.6	1445.4
4	Railway	533.9	1995.3	3890.5
5	Railway	419.1	302.0	1122.0
6	Railway	201.9	239.9	3235.9
7	Tollway	238.4	331.1	851.1
8	Tollway	106.9	141.3	416.9
9	Tollway	136.0	338.8	1513.6
10	Warehouse	113.7	1071.5	2238.7
11	Warehouse	55.0	3548.1	1995.3
12	Warehouse	104.7	512.9	1479.1
	Max =	533.9	3548.1	3890.5
	Min =	55.0	141.3	375.9

We noticed that dose of noise acquired by these occupations is varied although they work with the same machine and same task at construction site. In addition, each occupation presented different dose of noise even though they worked in same area at construction site. Based on current data set, the rank of dose of noise for foreman, labourer and operator in drop hammer piling operation is 55.0% to 533.9%, 141.3% to 3548.1% and 375.9% to 3890.5%, respectively.

6.2.3 Status of noise hazard for workers in drop-hammer piling operation

Table 6.5 presents the status of noise hazard in each occupation including foreman, labourer and operator of drop hammer piling operation. It could be seen that most of them operated under noise hazard at construction site. Seriously, no one was seen to be equipped with hearing protection. Therefore, this group of workers should be informed about the hazard.

Table 6.5 Status of noise hazard presented in each occupation, foreman, labourer and operator in case study 1, drop hammer piling operation

Day	Project Type	Foreman	Labourer	Operator
1	Department Store	No Hazard	Hazard	Hazard
2	Department Store	Hazard	Hazard	Hazard
3	Department Store	No Hazard	Hazard	Hazard
4	Railway	Hazard	Hazard	Hazard
5	Railway	Hazard	Hazard	Hazard
6	Railway	Hazard	Hazard	Hazard
7	Tollway	Hazard	Hazard	Hazard
8	Tollway	Hazard	Hazard	Hazard
9	Tollway	Hazard	Hazard	Hazard
10	Warehouse	Hazard	Hazard	Hazard
11	Warehouse	No Hazard	Hazard	Hazard
12	Warehouse	Hazard	Hazard	Hazard

Interestingly, foreman did not always obtain noise hazard. It depends on their activities including their distance to sources of noise and their working time in construction site (Figure 6.3). Furthermore, the overview of foreman's, labourer's and operator's activities (Appendix E) could support the understanding of the noise hazard.

Figure 6.3 Position of foreman, labourer, operation in piling operation

6.3 Result of noise in case study 2: Bored Piling

The results in this section were analyzed based on the collected data from 4 construction sites or 12 working days. The results consist of three parts; Equivalent noise level for workers in bored piling operation, Dose of noise for workers in bored piling operation, and Status of noise hazard for workers in bored piling operation.

6.3.1 Equivalent noise level for workers in bored piling operation

Result in this section explored equivalent noise level that three occupations of piling workers obtained under their work activities at construction site. Figure 6.4 represented comparison between equivalent noise level (Leq) of foreman, labourer, and operator of bored pile activities.

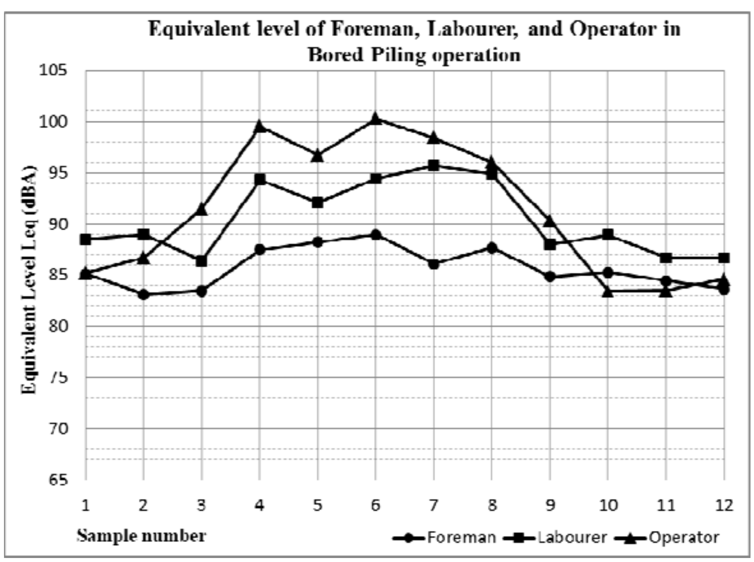


Figure 6.4 Comparison between equivalent noise levels in each occupation

Table 6.6 Summary of equivalent noise level in each occupation

Day	Project Type	Leq of foreman (dBA)	Leq of labourer (dBA)	Leq of operator (dBA)
1	Dormitory, Chula, M1	85.1	88.5	85.2
2	Dormitory, Chula, M1	83.1	89.0	86.7
3	Dormitory, Chula, M1	83.5	86.4	91.5
4	Dormitory, Chula, M2	87.5	94.3	99.5
5	Dormitory, Chula, M2	88.2	92.1	96.7
6	Dormitory, Chula, M2	88.9	94.4	100.3
7	Sorinthon Building	86.1	95.7	98.4
8	Sorinthon building	87.7	94.8	96.0
9	Sorinthon building	84.9	88.0	90.3
10	Rama9 Square	85.3	88.9	83.4
11	Rama9 Square	84.4	86.7	83.5
12	Rama9 Square	83.6	86.7	84.6
		Max = 88.9	95.7	100.3
		Min = 83.1	86.4	83.4

Based on their occupations, foreman, labourer and operator got different Leq even though they worked in the same activities and at the same construction site. The rank of equivalent noise level for foreman, labourer and operator in bored piling work was 83.1 to 88.9 dBA, 86.4 to 95.7 dBA and 83.4 to 100.3 dBA, respectively (Table 6.6). It could be pointed out that operator obtained the highest equivalent noise level follow by labourer and foreman. However, operators at some construction site obtained Leq lower than the other occupations when they worked inside the enclosed cabs of machine (Figure 6.5).

Figure 6.5 Current practices of operator and workers at some construction sites

6.3.2 Dose of noise for workers in bored piling operation

Beside equivalent noise level, noise hazard assessment system also computed dose of noise for construction workers. Table 6.7 represents dose of noise presented in each occupation, foreman, labourer and operator of drop hammer piling operation. We noticed that dose of noise acquired by these occupations is varied although they work with the same machine and same task at construction site. In addition, each occupation presented different dose of noise even though they worked in same area at construction site. Based on current data set, the rank of dose of noise for foreman, labourer and operator in drop hammer piling operation is 64.6% to 247.2%, 138.0% to 1174.9% and 69.2% to 3357.4%, respectively.

Table 6.7 Dose of noise presented in each occupation, foreman, labourer and operator in case study 2, bored pile

Day	Project Type	Noise dose of foreman (%)	Noise dose of labourer (%)	Noise dose of operator (%)
1	Dormitory, Chula, M1	103.3	223.9	104.7
2	Dormitory, Chula, M1	95.1	251.2	147.9
3	Dormitory, Chula, M1	136.3	138.0	446.7
4	Dormitory, Chula, M2	177.0	851.1	2818.4
5	Dormitory, Chula, M2	210.4	512.9	1479.1
6	Dormitory, Chula, M2	247.2	871.0	3357.4
7	Sorinthon Building	128.8	1174.9	2187.8
8	Sorinthon Building	184.9	961.6	1258.9
9	Sorinthon Building	97.1	199.5	338.8
10	Rama9 Square	107.0	245.5	69.2
11	Rama9 Square	88.1	147.9	70.8
12	Rama9 Square	73.1	147.9	91.2
	Max =	247.2	1174.9	3357.4
	Min =	64.6	138.0	69.2

6.3.3 Status of noise hazard for workers in bored piling operation

Table 6.8 presents the status of noise hazard in each occupation including foreman, labourer and operator of drop hammer piling operation. It could be seen that most of them operated under noise hazard at construction site. Seriously, no one was seen to be equipped with hearing protection. Therefore, this group of workers should be informed about the hazard.

Table 6.8 Status of noise hazard presented in each occupation, foreman, labourer and operator in case study 2, bored piling operation

Day	Project Type	Foreman	Labourer	Operator
1	Dormitory, Chula, M1	Hazard	Hazard	Hazard
2	Dormitory, Chula, M1	No Hazard	Hazard	Hazard
3	Dormitory, Chula, M1	No Hazard	Hazard	Hazard
4	Dormitory, Chula, M2	Hazard	Hazard	Hazard
5	Dormitory, Chula, M2	Hazard	Hazard	Hazard
6	Dormitory, Chula, M2	Hazard	Hazard	Hazard
7	Sorinthon Building	Hazard	Hazard	Hazard
8	Sorinthon Building	Hazard	Hazard	Hazard
9	Sorinthon Building	No Hazard	Hazard	Hazard
10	Rama9 Square	Hazard	Hazard	No Hazard
11	Rama9 Square	No Hazard	Hazard	No Hazard
12	Rama9 Square	No Hazard	Hazard	No Hazard

Interestingly, operators in last construction site did not face the hazard of noise. Based on the sound signal analysis, we noticed that the equivalent noise level of machine operator is between 79.2 dBA to 83.4 dBA only while they worked inside the enclosed cabs of machine (Figure 6.5). Therefore, this current practice should be recommended for other operator who faces in hazard of noise. Similar to previous case study, foreman did not always obtain noise hazard. It depends on their activities including their distance to sources of noise and their working time at construction site (Figure 6.6). Furthermore, the overview of foreman's, labourer's and operator's activities (Appendix D) could support the understanding of the noise hazard.

Figure 6.6 Position of foreman at bored pile construction site

6.4 Result of workers' perception and awareness of noise hazard

Worker's perception and awareness of noise hazard was analyzed based on 24 questionnaires derived from sample piling workers. The results were divided into four parts; sample workers' profile, workers' perception on noise hazard, workers' awareness, and analysis of workers' perception and awareness. The following sections describe these results.

6.4.1 Sample workers' profile

Sample construction workers were selected based on our case studies, drop hammer piling operation and bored pile. The distribution of the selected piling workers by their profile is presented in table 6.9. It can be seen that the majority (46%) of these sample workers were between 36 and 45 years old; and most of these surveyed workers (42%) finished their education in secondary school. In addition, the sample workers were selected from three occupations includes labourer (33%), machine operator (33%) and foreman (33%). A surprisingly high percentage (54%) of surveyed workers had work experience between 5 to 10 years in construction industry.

Table 6.9 Information of sample piling workers

Variable name	Case1	Case2	Total	Percentage	Cumulative
1. Age (years old):					
≤ 25	2	3	5	21%	21%
26 – 35	1	5	6	25%	46%
36 – 45	7	4	11	46%	92%
46 – 55	2	0	2	8%	100%
2. Education:					
Primary school	4	4	8	33%	33%
Secondary school	5	5	10	42%	75%
High school	3	3	6	25%	100%
3. Occupation:					
Labourer	4	4	8	33%	33%
Machine operator	4	4	8	33%	67%
Forman	4	4	8	33%	100%
4. Years of work experiences:					
≤ 5	1	2	3	13%	13%
5 – 10	6	7	13	54%	67%
11 – 15	2	1	3	13%	79%
16 – 20	1	1	2	8%	88%
> 20	2	1	3	13%	100%

6.4.2 Piling workers' perception of noise hazard

Table 6.10 represents piling workers' perception of noise hazard at construction site. This table indicated that most of sampled piling workers (58%) perceived noise as a general problem under their operation at construction site. Nevertheless, only 17% of workers did not perceive noise as their problem. Nearly 65% of surveyed workers declared that their construction site is noisy and followed by 21 % of them who confirmed their environment was very noisy.

Relating to duration of noise exposure at construction site, the majority (71%) of selected workers showed that it was noisy during 8 and more than 8 hours. In addition, nearly 55% of these workers perceived that it's very/high risk when you are exposed to high level of noise. However, a surprisingly high percentage (54%) of workers stated that they sometimes wore hearing protection device (HPD) when noise is high. From my site observation, in contrast, no one was equipped with HPD during their operation.

Table 6.10 Piling workers' perceptions of noise hazard at construction site

Variable name	Case1	Case2	Total	Percentage	Cumulative
1. Is noise generally a problem?					
Yes	6	8	14	58%	58%
Not sure	3	3	6	25%	83%
No	3	1	4	17%	100%
2. How noisy is the construction site?					
Very noisy	2	3	5	21%	21%
Noisy	7	8	15	63%	83%
Little	3	1	4	17%	100%
3. How many hours a day is the construction site noisy?					
6	4	1	5	21%	21%
7	1	1	2	8%	29%
8	5	8	13	54%	83%
> 8	2	2	4	17%	100%
4. How dangerous do you think is being exposed to any high-noise level?					
Very high risk	3	1	4	17%	17%
High risk	2	7	9	38%	54%
Risk	7	4	11	46%	100%
5. Do you wear Hearing Protection Devices (HPD) when noise is high?					
Sometimes	7	7	14	54%	54%
No	5	5	10	46%	100%

6.4.3 Piling workers' awareness of noise impact

The awareness of noise impact of piling workers is presented in table 6.11. More than 70% of sample workers stated that it was very annoying or to some amount annoying in their current work activities. Furthermore, only 50% of workers were aware of noise impact on their health, while 42% were not sure about the potential health impact of noise. Nearly 70% of surveyed workers stated that they were not sure that noise affected their work productivity. Importantly, only 21 % were aware of the likely contribution of noise hazard to the causes of accidents in construction site.

Table 6.11 Piling workers' awareness of noise impact

Variable name	Case1	Case2	Total	Percentage	Cumulative
1. Does noise annoy you today?					
Very much	3	5	8	33%	33%
To some amount	5	4	9	38%	71%
Little	4	3	7	29%	100%
2. Do you think noise affects your health adversely?					
Yes	7	5	12	50%	50%
May be	3	7	10	42%	92%
Don't know	1	0	1	4%	96%
No	1	0	1	4%	100%
3. Do you think noise affects your productivity?					
Very much	3	3	6	25%	25%
May be	8	8	16	67%	92%
Not at all	1	1	2	8%	100%
4. Do you think noise affects accident at site?					
Very much	1	4	5	21%	21%
May be	11	7	18	75%	96%
Not at all	0	1	1	4%	100%

6.4.4 Analysis of workers' perception and awareness

The analysis of workers' perception and awareness was based on data set that was collected from both of case studies. Table 6.12 presents the status of noise hazard against workers' perception and awareness. The results of data analysis were divided into three parts; difference between status of noise hazard and workers' perception, difference between status of noise hazard and workers' awareness, and difference between workers' perception and workers' awareness. The results are described as following section.

6.4.4.1 Difference between status of noise hazard and workers' perception

The analysis in this section was a comparison between status of noise hazard and first question of workers' perception column (Table 6.12). Based on this table, it can be seen that nearly 40 % of surveyed workers misunderstood level of noise hazard under their operation since their responses mismatched status of noise hazard under their work operation. In addition, most sampled workers (50%) stated that it was noisy during their work while the status of noise hazard indicated "Hazard". Therefore it demonstrated that the perception of piling workers was not strong for perceiving level of noise hazard. Thus, this group of worker should be warned about their noise hazard.

6.4.4.2 Difference between status of noise hazard and workers' awareness

The comparison between status of noise hazard and question of workers' awareness column (Table 6.12) is to analyze the contrast of piling workers' awareness. The findings showed that almost 70% (17 of 24 results) of surveyed workers were aware of noise impact from their operation while the status of noise indicated "Hazard". The high percentage of this matching can be interpreted that piling workers knew about effects of noise hazard from their work activities. However, no one was ever seen to be equipped with hearing protection device during our data collection at construction site. Some reasons were identified. Most of them said that they couldn't talk to their colleague when they used hearing protection device (HPD); HPD didn't allow them to hear useful sound; lack of providing HPD.

6.4.4.3 Difference between workers' perception and workers' awareness

Beside comparison of workers' perception and workers' awareness with status of noise hazard, this research also analyzes the differences between workers' perception and workers' awareness. This analysis was based on second question of workers' perception column and question in workers' awareness column (Table 6.12). It can be grouped by three teams; high perception with high awareness (54%), low perception with high awareness (38%), and low perception with low awareness of noise hazard (8%). Interestingly, nearly 40% of sample workers were present in second team. It means that they do not perceive current noise hazard as their problem but they are aware of noise impact in the future.

Table 6.12 Status of noise hazard against workers' perception and awareness

Case studies	Occupations	Nº	NOISE HAZARD ASSESSMENT SYSTEM: Equivalent level in decibel A (Leq); Dose of noise in percentage (D)						WORKERS' PERCEPTION: How noisy is the construction site (Piling work)?					WORKERS' PERCEPTION: How dangerous do you think is being exposed to any high-noise level?					WORKERS' AWARENESS: Do you think noise affects your health?				
			Parameter	Day 1	Day 2	Day 3	Average	Status of Hazard	Very noisy (4)	Noisy (3)	Little (2)	Not Noisy (1)	Score	Very high risk (4)	High risk (3)	Risk (2)	No risk (1)	Score	Yes (4)	May be (3)	Don't know (2)	No (1)	Score
Case study 1: Drop hammer piling operation	Foreman	1	Leq(dBA)=	83.6	85.8	82.8	84.3	No Hazard	0	1	0	0	3	0	1	0	0	3	0	1	0	0	3
			D (%) =	72.4%	120.2%	60.3%	84.3%																
		2	Leq(dBA)=	92.3	91.2	88.1	90.9	Hazard	0	1	0	0	3	0	1	0	0	3	1	0	0	0	4
			D (%) =	537.0%	416.9%	204.2%	386.0%																
		3	Leq(dBA)=	88.8	85.3	86.3	87.1	Hazard	0	0	1	0	2	0	0	1	0	2	1	0	0	0	4
			D (%) =	239.9%	107.2%	134.9%	160.6%																
		4	Leq(dBA)=	85.6	82.4	85.2	84.6	No Hazard	1	0	0	0	4	1	0	0	0	4	1	0	0	0	4
			D (%) =	114.8%	55.0%	104.7%	91.5%																
	Labourer	1	Leq(dBA)=	97.6	98.1	96.8	97.5	Hazard	0	1	0	0	3	0	0	1	0	2	0	1	0	0	3
			D (%) =	1819.7%	2041.7%	1513.6%	1791.7%																
		2	Leq(dBA)=	98.0	89.8	88.8	94.3	Hazard	0	1	0	0	3	0	0	1	0	2	0	0	1	0	2
			D (%) =	1995.3%	302.0%	239.9%	845.7%																
		3	Leq(dBA)=	90.2	86.5	90.3	89.3	Hazard	0	0	1	0	2	0	0	1	0	2	0	0	0	1	1
			D (%) =	331.1%	141.3%	338.8%	270.4%																
		4	Leq(dBA)=	95.3	100.5	92.1	97.3	Hazard	0	1	0	0	3	1	0	0	0	4	1	0	0	0	4
			D (%) =	1071.5%	3548.1%	512.9%	1710.8%																
	Operator	1	Leq(dBA)=	90.8	94.4	96.6	94.5	Hazard	0	1	0	0	3	0	0	1	0	2	0	1	0	0	3
			D (%) =	380.2%	871.0%	1445.4%	898.9%																
		2	Leq(dBA)=	100.9	95.5	100.1	99.4	Hazard	0	1	0	0	3	0	0	1	0	2	1	0	0	0	4
			D (%) =	3890.5%	1122.0%	3235.9%	2749.5%																
		3	Leq(dBA)=	94.3	91.2	96.8	94.7	Hazard	1	0	0	0	4	1	0	0	0	4	1	0	0	0	4
			D (%) =	851.1%	416.9%	1513.6%	927.2%																
		4	Leq(dBA)=	98.5	98.0	96.7	97.8	Hazard	0	0	1	0	2	0	0	1	0	2	1	0	0	0	4
			D (%) =	2238.7%	1995.3%	1479.1%	1904.4%																

Table 6.12 Status of noise hazard against workers' perception and awareness (Continued)

Case studies	Occupations	Nº	NOISE HAZARD ASSESSMENT SYSTEM						WORKERS' PERCEPTION										WORKERS' AWARENESS				
			Equivalent level in decibel A (Leq) Dose of noise in percentage (D)						How noisy is the construction site (Piling work)?					How dangerous do you think is being exposed to any high-noise level?					Do you think noise affects your health?				
			Parameter	Day 1	Day 2	Day 3	Average	Status of Hazard	Very noisy (4)	Noisy (3)	Little (2)	Not Noisy (1)	Score	Very high risk (4)	High risk (3)	Risk (2)	No risk (1)	Score	Yes (4)	May be (3)	Don't know (2)	No (1)	Score
Case study 2: Bored Pile	Foreman	1	Leq(dBA)=	85.1	83.1	83.5	84.0	No Hazard	1	0	0	0	4	0	1	0	0	3	1	0	0	0	4
			D (%) =	102.3%	64.6%	70.8%	79.2%																
		2	Leq(dBA)=	87.5	88.2	88.9	88.2	Hazard	1	0	0	0	4	1	0	0	0	4	0	1	0	0	3
			D (%) =	177.8%	208.9%	245.5%	210.7%																
		3	Leq(dBA)=	86.1	87.7	84.9	86.4	Hazard	0	1	0	0	3	0	0	1	0	2	0	1	0	0	3
			D (%) =	128.8%	186.2%	97.7%	137.6%																
		4	Leq(dBA)=	85.3	84.4	83.6	84.5	No Hazard	0	1	0	0	3	0	1	0	0	3	0	1	0	0	3
			D (%) =	107.2%	87.1%	72.4%	88.9%																
	Labourer	1	Leq(dBA)=	88.5	89	86.4	88.1	Hazard	0	1	0	0	3	0	0	1	0	2	0	1	0	0	3
			D (%) =	223.9%	251.2%	138.0%	204.4%																
		2	Leq(dBA)=	94.3	92.1	96.7	94.8	Hazard	0	1	0	0	3	0	1	0	0	3	0	1	0	0	3
			D (%) =	851.1%	512.9%	1479.1%	947.7%																
		3	Leq(dBA)=	95.8	94.8	88	94.0	Hazard	0	0	1	0	2	0	0	1	0	2	0	1	0	0	3
			D (%) =	1202.3%	955.0%	199.5%	785.6%																
		4	Leq(dBA) =	88.9	86.7	86.7	87.6	Hazard	0	1	0	0	3	0	1	0	0	3	1	0	0	0	4
			D (%) =	245.5%	147.9%	147.9%	180.4%																
	Operator	1	Leq(dBA)=	85.2	86.7	91.5	88.7	Hazard	1	0	0	0	4	0	0	1	0	2	1	0	0	0	4
			D (%) =	104.7%	147.9%	446.7%	233.1%																
		2	Leq(dBA)=	99.5	96.7	100.3	99.1	Hazard	0	1	0	0	3	0	1	0	0	3	1	0	0	0	4
			D (%) =	2818.4%	1479.1%	3388.4%	2562.0%																
		3	Leq(dBA)=	98.4	96	90.3	96.0	Hazard	0	1	0	0	3	0	1	0	0	3	0	1	0	0	3
			D (%) =	2187.8%	1258.9%	338.8%	1261.8%																
		4	Leq(dBA)=	83.4	83.5	84.6	83.9	No Hazard	0	1	0	0	3	0	1	0	0	3	1	0	0	0	4
			D (%) =	69.2%	70.8%	91.2%	77.1%																

6.5 Summary

The noise hazard assessment system in construction site was applied in order to explain the application of system with construction workers. In addition, the study aims to address noise hazard of construction workers by using the proposed system. Data for conducting this research was collected from two cases of studies including drop hammer piling operation and bored pile. The data analysis of this system was used to explore equivalent noise level, dose of noise, and status of noise hazard of workers in each occupation and each case study. Beside data analysis with standard equipment, this research analyzed piling workers' perception and awareness on current status of noise hazard under their operation. The findings showed that piling workers had medium perception on noise hazard since their perception was not strong for perceiving level of noise hazard. In addition, the findings showed that piling workers had high percentage of their awareness matched to noise hazard under their work activities. However, no one was ever seen to be equipped with hearing protection device during our data collection at construction site. Nonetheless, there still was a group of piling workers who do not perceive current noise hazard as their problem, but they are aware of noise impact as a health issue. Finally, it is hoped that the current study can contribute to helping construction workers understanding their noise hazard in their current practice at construction site.

CHAPTER VII
RESEARCH CONCLUSIONS

This final chapter will firstly discuss research findings. Next implication for research and implication for practice will be presented and followed up by contribution of research, limitation and directions for future research.

7.1 Research findings

The findings of this study consist of three main parts which includes conceptual framework of noise hazard assessment system, development of the proposed system, and application of system with workers at construction site.

This research proposed a conceptual framework of noise hazard assessment system at construction workers level. The conceptual framework aims to support noise hazard assessment from multiple occupations of construction workers at the same time. Our concept also proposes the new alternative for construction manager that have budget limit for noise management. We found a compatible method for evaluation of noise hazard at construction worker level by developing software in MATLAB. This software is developed for computed equivalent noise level and dose of noise from electronic sound signal, noise in construction site. Last, the report about noise hazard is simultaneously released at the end of noise dose calculation. The procedure of developing noise hazard assessment system is mentioned in section below.

The system development of this research contains three main steps; (1) Tools testing, (2) Preliminary study, and (3) Full scale of system development.

1. From tools testing for system development, we concluded MATLAB was a computer program that was appropriate for conducting this study. In addition, two models of sound recorders including SONY IC-SX850 and IC-SX713 were selected as tools for WAV signal collection and also one model of noise dosimeter CEL-350 dBage as a reference equipment standard.

2. In preliminary study, a trial system was developed as a conceptual model of system development. After that, we tested the proposed system in acoustic laboratory and at construction site to test possibility of system development. As a result, we

found the calibration constant C for each model of selected sound recorders, SX850 and SX713, equal to 74 dBA and 78 dBA, respectively. In addition, the experimental results illustrated that the proposed system was reliable. Therefore, the study showed the high opportunity for further development of the proposed system.

3. In full scale of system development, we firstly developed Graphical User Interface (GUI) of noise hazard assessment system attempting to apply at construction worker level. GUI facilitated user to input, calculate and report their noise hazard from sound signal of their work at construction site. Next step, we adopted theory of noise dose calculation in order to support the conceptual framework of GUI. Last, we designed and programmed the proposed system in a source code under MATLAB, for computing noise dose of noise hazard. After that, we performed the system verification by implementation of system with workers in two cases of study including drop-hammer piling operation and bored piling operation. Finally, noise hazard assessment system was compiled to run on platform of window without using MATLAB.

Under system verification, we found that noise level of our proposed system needed adjusting by safety value equal to 1.6 dBA in order to improve the confidence of noise hazard evaluation. Moreover, the findings confirmed that the trend of noise evaluation by our proposed system was the same with standard equipment while minimum and maximum errors were -0.7 dBA and 3.0 dBA, respectively. In addition, the result of final system showed that mean of percent error of system in case study 1 was equal to 0.11 percent with standard deviation equal to 3.18 percent and mean of percent error of system in case study 2 equal to -0.05 percent with standard deviation equal to 2.62 percent.

Next finding stated that equivalent noise level computed by system had high correlation with that evaluated by noise dosimeter while correlation coefficient $R = 0.977$ with mathematical model $Leq_{STD} = 0.94Leq_{SYS} + 4.89$ and $R = 0.968$ with mathematical model $Leq_{STD} = 0.95Leq_{SYS} + 4.39$ for case study 1 and 2, respectively. Lastly, only two from twenty-four results of the proposed system mismatched the value from standard noise dose. The difference of these results may be the fact that equivalent noise level from standard equipment and the proposed system is close to exposure limit, 85 dBA. In addition, the equivalent noise level from the proposed system is designed to adjust constant to cover the variance from the proposed system.

Therefore, the equivalent noise level from the proposed system will be slightly higher than standard equipment. In general, it can be stated that our proposed system is valid. However, system fails to evaluate status of noise hazard when Leq is close to exposure limit. Nonetheless, it is still safe for construction workers who used our system since the result of system was greater than that of standard equipment. Finally, it could be stated that noise hazard assessment system was developed and applicable.

The application of the proposed system was to address noise hazard of construction workers in multiple occupation such as foreman, labourer, and operator in both cases of study. The findings illustrated the equivalent noise level, dose of noise, and status of noise hazard of workers in each occupation and each case studied. Under drop hammer piling operation, foreman, labourer and operator got different Leq even though they worked in the same activities and at the same construction site. The rank of equivalent noise level for foreman, labourer and operator was from 82.7 to 92.2 dBA, 86.4 to 100.4 dBA and 90.7 to 100.8 dBA, respectively. Based on current data set, the rank of dose of noise for foreman, labourer and operator in drop hammer piling was from 59.4% to 521.7%, 138.0% to 3467.4% and 367.4% to 3801.9%, respectively. Under bored piling operation, the rank of equivalent noise level for foreman, labourer and operator was from 83.7 to 89.0 dBA, 86.5 to 95.8 dBA and 83.5 to 100.4 dBA, respectively. In addition, the rank of dose of noise for foreman, labourer and operator in drop hammer piling operation was 74.8% to 253.0%, 141.3% to 1202.3% and 70.8% to 3435.6%, respectively. Furthermore, it could be concluded that most of construction workers in both cases of study worked under noise hazard at construction site. Importantly, during site observation, no one was seen to be equipped with hearing protection. Therefore, this group of workers should be informed about the hazard. Besides that, next finding provided construction worker's perception on level of noise hazard and their awareness on noise impact in both case studies. The research found that some of piling workers (9 of 24 cases or 37.5%) had different perception from noise hazard under their work activities. Therefore, this group of workers should be warned about the risk of noise. However, the finding showed that almost 70% of surveyed workers were aware of noise impact from their operation while the status of noise indicated "Hazard". Interestingly, nearly 40% of sample workers had low perception of noise hazard but high awareness of noise impact on their health. It can be stated that piling workers did not perceive current noise hazard as their problem, but they were aware of noise as an impact in the future. Finally, noise hazard assessment system should be applied to make sure that construction workers correctly perceive of noise hazard under their operation.

7.2 Contribution of research

This research contributed to two important sectors; research point of views and industry point of views.

In first point of view, this research contributed a framework of developing system to assessment noise hazard at worker level. It started since the conceptual framework of noise hazard assessment system until this system was developed for construction workers. In process of system development, we created user interface and also wrote a script in MATLAB for supporting the interface of this system. Furthermore, this research contributed the calibration constant C for sound recorder model SONY SX850 and SX713 used for conducting this research. Next, this study evaluated equivalent noise level and dose of noise in three occupations of construction workers in piling operation, foreman, labourer and operator.

In industry point of view, on the other hand, noise hazard assessment system was applied for measurement of worker's noise hazard in order to improve construction worker's perception of noise hazard and awareness of noise impact. This system could be used to remind construction workers who have different perception of noise hazard in their current practice.

7.3 Limitation and directions for future research

The limitation of this research consists of four main points. The first limitation is noise level for experimental in acoustic laboratory. Because of amplifier limit, the reliability of the proposed system is tested with maximum noise level around 100 dBA only. Furthermore, next limitation of this research came from time sampling limit. The sample used for conducting this research was collected from construction in two cases of piling works only, piling with drop hammer and bored pile. In addition, following limitation is hardware of noise hazard assessment system. There are only two models of sound recorders, SONY SX850 and SX713R, used as conceptual framework of system development. Thus, the other models are required to calibrate before using for noise hazard assessment. In addition, next limitation is amount of standard equipment (Noise dosimeter). Because of budget limit, there is only one noise dosimeter used as a reference of our proposed system. Therefore, sample for data analysis was collected three days at one construction site in order to cover three occupations of piling workers, foreman, labourer, and machine operator. The lack of sampling from construction workers at other construction sites may affect the results of system validation because noise sources are also concerned with construction operation, amount of machine, type of machine at construction site.

Therefore, it is recommended for future research in this context to generate noise level in acoustic laboratory higher than 100 dBA to test the reliability of the proposed system. Moreover, it is highly recommended for next researchers to use larger amount of sample for experimental and analysis of noise hazard assessment system. In addition, it is suggested that the future study should be conducted on the validation of system validation of noise hazard at other construction activities such as concrete work, steel work, welding, and earth moving at construction site. Besides building construction, this research also needs to be done in another area including road construction, tunnel construction, and construction material manufacture. Workers in these activities or area may also be affected by noise hazard under their operation.

Finally, noise hazard assessment system for construction workers may improve by next research. Further testing and expansion of our system may help to better facilitate a more accurate system for construction workers. We ought to give more attention to the selected sound signal for validation. Site observation is required before attaching noise hazard assessment system with them.

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APPENDICES

APPENDIX A

Noise Regulation & Directive related to noise

DIRECTIVE 2003/10/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 6 February 2003

on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise)

(Seventeenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC)

THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION,

Having regard to the Treaty establishing the European Community, and in particular Article 137(2) thereof,

Having regard to the proposal from the Commission ([1]), submitted after consultation with the Advisory Committee on Safety, Hygiene and Health Protection at Work,

Having regard to the opinion of the Economic and Social Committee ([2]),

Having consulted the Committee of the Regions,

Acting in accordance with the procedure laid down in Article 251 of the Treaty ([3]), in the light of the joint text approved by the Conciliation Committee on 8 November 2002,

Whereas:

(1) Under the Treaty, the Council may adopt, by means of directives, minimum requirements for encouraging improvements, especially in the working environment, to guarantee a better level of protection of the health and safety of workers. Such directives are to avoid imposing administrative, financial and legal constraints in a way which would hold back the creation and development of small and medium-sized undertakings.

(2) While, in accordance with the Treaty, this Directive does not prevent any Member State from maintaining or introducing more stringent protective measures, its implementation should not serve to justify any regression in relation to the situation which already prevails in each Member State.

(3) Council Directive 86/188/EEC of 12 May 1986 on the protection of workers from the risks related to exposure to noise at work ([4]) made provision for its re-examination by the Council on a proposal from the Commission and with a view to reducing the risks concerned, taking into account in particular progress made in scientific knowledge and technology.

([1]) OJ C 77, 18.3.1993, p. 12 and OJ C 230, 19.8.1994, p. 3.
([2]) OJ C 249, 13.9.1993, p. 28.
([3]) Opinion of the European Parliament of 20 April 1994 (OJ C 128, 9.5.1994, p. 146), confirmed on 16 September 1999 (OJ C 54, 25.2.2000, p. 75), Council Common Position of 29 October 2001 (OJ C E 45, 19.2.2002, p. 41) and decision of the European Parliament of 13 March 2002 (not yet published in the Official Journal).
([4]) OJ L 137, 24.5.1986, p. 28. Directive as amended by Directive 98/24/EC (OJ L 131, 5.5.1998, p. 11).

(4) The communication from the Commission on its programme concerning safety, hygiene and health at work ([5]) provides for the adoption of measures to promote safety at work, particularly with a view to extending the scope of Directive 86/188/EEC and the re-evaluation of the threshold values. The Council, in its resolution of 21 December 1987 on safety, hygiene and health at work ([6]), took note of this.

(5) The communication from the Commission concerning its action programme relating to the implementation of the Community Charter of the Fundamental Social Rights of Workers provides for the introduction of minimum health and safety requirements regarding the exposure of workers to the risks caused by physical agents. In September 1990 the European Parliament adopted a resolution concerning this action programme ([7]), inviting the Commission in particular to draw up a specific directive on the risks caused by noise and vibration and by any other physical agent at the workplace.

(6) As a first step, the European Parliament and the Council adopted on 25 June 2002 Directive 2002/44/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration) (sixteenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC) ([8]).

(7) As a second step, it is considered appropriate to introduce measures protecting workers from the risks arising from noise owing to its effects on the health and safety of workers, in particular damage to hearing. These measures are intended not only to ensure the health and safety of each worker on an individual basis, but also to create a minimum basis of protection for all Community workers in order to avoid possible distortions of competition.

(8) Current scientific knowledge of the effects which exposure to noise may have on health and safety is not sufficient to enable precise exposure levels covering all risks to health and safety, especially as regards the effects of noise other than those of an auditory nature, to be set.

([5]) OJ C 28, 3.2.1988, p. 3.
([6]) OJ C 28, 3.2.1988, p. 1.
([7]) OJ C 260, 15.10.1990, p. 167.
([8]) OJ L 177, 6.7.2002, p. 13.

(9) A system of protection against noise must limit itself to a definition, free of excessive detail, of the objectives to be attained, the principles to be observed and the fundamental values to be used, in order to enable Member States to apply the minimum requirements in an equivalent manner.

(10) The level of exposure to noise can be more effectively reduced by incorporating preventive measures into the design of work stations and places of work and by selecting work equipment, procedures and methods so as to give priority to reducing the risks at source. Provisions relating to work equipment and methods thus contribute to the protection of the workers involved. In accordance with the general principles of prevention as laid down in Article 6(2) of Council Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work (1), collective protection measures have priority over individual protection measures.

(11) The Code on noise levels on board ships of the International Maritime Organisation Resolution A 468(12) provides guidance for achieving a reduction of noise at source on board ships. Member States should be entitled to provide for a transitional period with regard to the personnel on board seagoing vessels.

(12) In order to correctly assess the exposure of workers to noise it is useful to apply an objective measuring method, and thus references to the generally recognised standard ISO 1999:1990 are made. The assessed or objectively measured values should be decisive for initiating the actions envisaged at the lower and upper exposure action values. Exposure limit values are needed to avoid irreversible damage to workers' hearing; the noise reaching the ear should be kept below the exposure limit values.

(13) The particular characteristics of the music and entertainment sectors require practical guidance to allow for an effective application of the provisions laid down by this Directive. Member States should be entitled to make use of a transitional period for the development of a code of conduct providing for practical guidelines which would help workers and employers in those sectors to attain the levels of protection established in this Directive.

(14) Employers should make adjustments in the light of technical progress and scientific knowledge regarding risks related to exposure to noise, with a view to improving the health and safety protection of workers.

(1) OJ L 183, 29.6.1989, p. 1.

(15) Since this Directive is an individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC, that Directive applies to the exposure of workers to noise, without prejudice to more stringent and/or specific provisions contained in this Directive.

(16) This Directive constitutes a practical step towards creating the social dimension of the internal market.

(17) The measures necessary for the implementation of this Directive should be adopted in accordance with Council Decision 1999/468/EC of 28 June 1999 laying down the procedures for the exercise of implementing powers conferred on the Commission (2),

HAVE ADOPTED THIS DIRECTIVE:

SECTION I

GENERAL PROVISIONS

Article 1

Aim and scope

1. This Directive, which is the 17th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC, lays down minimum requirements for the protection of workers from risks to their health and safety arising or likely to arise from exposure to noise and in particular the risk to hearing.

2. The requirements of this Directive shall apply to activities in which workers are or are likely to be exposed to risks from noise as a result of their work.

3. Directive 89/391/EEC shall apply fully to the whole area referred to in paragraph 1, without prejudice to more stringent and/or specific provisions contained in this Directive.

Article 2

Definitions

For the purposes of this Directive, the physical parameters used as risk predictors are defined as follows:

(a) peak sound pressure (p_{peak}): maximum value of the 'C'-frequency weighted instantaneous noise pressure;

(2) OJ L 184, 17.7.1999, p. 23.

(b) daily noise exposure level ($L_{EX,8h}$) (dB(A) re. 20 µPa): time-weighted average of the noise exposure levels for a nominal eight-hour working day as defined by international standard ISO 1999: 1990, point 3.6. It covers all noises present at work, including impulsive noise;

(c) weekly noise exposure level ($L_{EX,8h}$): time-weighted average of the daily noise exposure levels for a nominal week of five eight-hour working days as defined by international standard ISO 1999:1990, point 3.6 (note 2).

Article 3

Exposure limit values and exposure action values

1. For the purposes of this Directive the exposure limit values and exposure action values in respect of the daily noise exposure levels and peak sound pressure are fixed at:

(a) exposure limit values: $L_{EX,8h}$ = 87 dB(A) and p_{peak} = 200 Pa ([1]) respectively;

(b) upper exposure action values: $L_{EX,8h}$ 85 dB(A) and p_{peak} = 140 Pa ([2]) respectively;

(c) lower exposure action values: $L_{EX,8h}$ = 80 dB(A) and p_{peak} = 112 Pa ([3]) respectively.

2. When applying the exposure limit values, the determination of the worker's effective exposure shall take account of the attenuation provided by the individual hearing protectors worn by the worker. The exposure action values shall not take account of the effect of any such protectors.

3. In duly justified circumstances, for activities where daily noise exposure varies markedly from one working day to the next, Member States may, for the purposes of applying the exposure limit values and the exposure action values, use the weekly noise exposure level in place of the daily noise exposure level to assess the levels of noise to which workers are exposed, on condition that:

(a) the weekly noise exposure level as shown by adequate monitoring does not exceed the exposure limit value of 87 dB(A); and

(b) appropriate measures are taken in order to reduce the risk associated with these activities to a minimum.

SECTION II

OBLIGATIONS OF EMPLOYERS

Article 4

Determination and assessment of risks

1. In carrying out the obligations laid down in Articles 6(3) and 9(1) of Directive 89/391/EEC, the employer shall assess and, if necessary, measure the levels of noise to which workers are exposed.

([1]) 140 dB (C) in relation to 20 µPa.
([2]) 137 dB (C) in relation to 20 µPa.
([3]) 135 dB (C) in relation to 20 µPa.

2. The methods and apparatus used shall be adapted to the prevailing conditions particularly in the light of the characteristics of the noise to be measured, the length of exposure, ambient factors and the characteristics of the measuring apparatus.

These methods and this apparatus shall make it possible to determine the parameters defined in Article 2 and to decide whether, in a given case, the values fixed in Article 3 have been exceeded.

3. The methods used may include sampling, which shall be representative of the personal exposure of a worker.

4. The assessment and measurement referred to in paragraph 1 shall be planned and carried out by competent services at suitable intervals, taking particular account of the provisions of Article 7 of Directive 89/391/EEC concerning the necessary competent services or persons. The data obtained from the assessment and/or measurement of the level of exposure to noise shall be preserved in a suitable form so as to permit consultation at a later stage.

5. When applying this Article, the assessment of the measurement results shall take into account the measurement inaccuracies determined in accordance with metrological practice.

6. Pursuant to Article 6(3) of Directive 89/391/EEC, the employer shall give particular attention, when carrying out the risk assessment, to the following:

(a) the level, type and duration of exposure, including any exposure to impulsive noise;

(b) the exposure limit values and the exposure action values laid down in Article 3 of this Directive;

(c) any effects concerning the health and safety of workers belonging to particularly sensitive risk groups;

(d) as far as technically achievable, any effects on workers' health and safety resulting from interactions between noise and work-related ototoxic substances, and between noise and vibrations;

(e) any indirect effects on workers' health and safety resulting from interactions between noise and warning signals or other sounds that need to be observed in order to reduce the risk of accidents;

(f) information on noise emission provided by manufacturers of work equipment in accordance with the relevant Community directives;

(g) the existence of alternative work equipment designed to reduce the noise emission;

(h) the extension of exposure to noise beyond normal working hours under the employer's responsibility;

(i) appropriate information obtained following health surveillance, including published information, as far as possible;

(j) the availability of hearing protectors with adequate attenuation characteristics.

7. The employer shall be in possession of an assessment of the risk in accordance with Article 9(1)(a) of Directive 89/391/EEC, and shall identify which measures must be taken in accordance with Articles 5, 6, 7 and 8 of this Directive. The risk assessment shall be recorded on a suitable medium, according to national law and practice. The risk assessment shall be kept up to date on a regular basis, particularly if there have been significant changes which could render it out of date, or when the results of health surveillance show it to be necessary.

Article 5

Provisions aimed at avoiding or reducing exposure

1. Taking account of technical progress and of the availability of measures to control the risk at source, the risks arising from exposure to noise shall be eliminated at their source or reduced to a minimum.

The reduction of such risks shall be based on the general principles of prevention set out in Article 6(2) of Directive 89/391/EEC, and take into account in particular:

(a) other working methods that require less exposure to noise;

(b) the choice of appropriate work equipment, taking account of the work to be done, emitting the least possible noise, including the possibility of making available to workers work equipment subject to Community provisions with the aim or effect of limiting exposure to noise;

(c) the design and layout of workplaces and work stations;

(d) adequate information and training to instruct workers to use work equipment correctly in order to reduce their exposure to noise to a minimum;

(e) noise reduction by technical means:

(i) reducing airborne noise, e.g. by shields, enclosures, sound-absorbent coverings;

(ii) reducing structure-borne noise, e.g. by damping or isolation;

(f) appropriate maintenance programmes for work equipment, the workplace and workplace systems;

(g) organisation of work to reduce noise:

(i) limitation of the duration and intensity of the exposure;

(ii) appropriate work schedules with adequate rest periods.

2. On the basis of the risk assessment referred to in Article 4, if the upper exposure action values are exceeded, the employer shall establish and implement a programme of technical and/or organisational measures intended to reduce the exposure to noise, taking into account in particular the measures referred to in paragraph 1.

3. On the basis of the risk assessment referred to in Article 4, workplaces where workers are likely to be exposed to noise exceeding the upper exposure action values shall be marked with appropriate signs. The areas in question shall also be delimited and access to them restricted where this is technically feasible and the risk of exposure so justifies.

4. Where, owing to the nature of the activity, a worker benefits from the use of rest facilities under the responsibility of the employer, noise in these facilities shall be reduced to a level compatible with their purpose and the conditions of use.

5. Pursuant to Article 15 of Directive 89/391/EEC, the employer shall adapt the measures referred to in this Article to the requirements of workers belonging to particularly sensitive risk groups.

Article 6

Personal protection

1. If the risks arising from exposure to noise cannot be prevented by other means, appropriate, properly fitting individual hearing protectors shall be made available to workers and used by them in accordance with the provisions of Council Directive 89/656/EEC of 30 November 1989 on the minimum health and safety requirements for the use by workers of personal protective equipment at the workplace (third individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC) [1] and Article 13(2) of Directive 89/391/EEC and under the conditions set out below:

(a) where noise exposure exceeds the lower exposure action values, the employer shall make individual hearing protectors available to workers;

(b) where noise exposure matches or exceeds the upper exposure action values, individual hearing protectors shall be used;

(c) the individual hearing protectors shall be so selected as to eliminate the risk to hearing or to reduce the risk to a minimum.

2. The employer shall make every effort to ensure the wearing of hearing protectors and shall be responsible for checking the effectiveness of the measures taken in compliance with this Article.

[1] OJ L 393, 30.12.1989, p. 18.

Article 7

Limitation of exposure

1. Under no circumstances shall the exposure of the worker as determined in accordance with Article 3(2) exceed the exposure limit values.

2. If, despite the measures taken to implement this Directive, exposures above the exposure limit values are detected, the employer shall:

(a) take immediate action to reduce the exposure to below the exposure limit values;

(b) identify the reasons why overexposure has occurred; and

(c) amend the protection and prevention measures in order to avoid any recurrence.

Article 8

Worker information and training

Without prejudice to Articles 10 and 12 of Directive 89/391/EEC the employer shall ensure that workers who are exposed to noise at work at or above the lower exposure action values, and/or their representatives, receive information and training relating to risks resulting from exposure to noise concerning, in particular:

(a) the nature of such risks;

(b) the measures taken to implement this Directive in order to eliminate or reduce to a minimum the risks from noise, including the circumstances in which the measures apply;

(c) the exposure limit values and the exposure action values laid down in Article 3 of this Directive;

(d) the results of the assessment and measurement of the noise carried out in accordance with Article 4 of this Directive together with an explanation of their significance and potential risks;

(e) the correct use of hearing protectors;

(f) why and how to detect and report signs of hearing damage;

(g) the circumstances in which workers are entitled to health surveillance and the purpose of health surveillance, in accordance with Article 10 of this Directive;

(h) safe working practices to minimise exposure to noise.

Article 9

Consultation and participation of workers

Consultation and participation of workers and/or of their representatives shall take place in accordance with Article 11 of Directive 89/391/EEC on the matters covered by this Directive, in particular:

— the assessment of risks and identification of measures to be taken, referred to in Article 4,

— the actions aimed at eliminating or reducing risks arising from exposure to noise, referred to in Article 5,

— the choice of individual hearing protectors referred to in Article 6(1)(c).

SECTION III

MISCELLANEOUS PROVISIONS

Article 10

Health surveillance

1. Without prejudice to Article 14 of Directive 89/391/EEC, Member States shall adopt provisions to ensure the appropriate health surveillance of workers where the results of the assessment and measurement provided for in Article 4(1) of this Directive indicate a risk to their health. Those provisions, including the requirements specified for health records and their availability, shall be introduced in accordance with national law and/or practice.

2. A worker whose exposure exceeds the upper exposure action values shall have the right to have his/her hearing checked by a doctor or by another suitably qualified person under the responsibility of a doctor, in accordance with national law and/or practice. Preventive audiometric testing shall also be available for workers whose exposure exceeds the lower exposure action values, where the assessment and measurement provided for in Article 4(1) indicate a risk to health.

The objectives of these checks are to provide early diagnosis of any loss of hearing due to noise, and to preserve the hearing function.

3. Member States shall establish arrangements to ensure that, for each worker who undergoes surveillance in accordance with paragraphs 1 and 2, individual health records are made and kept up to date. Health records shall contain a summary of the results of the health surveillance carried out. They shall be kept in a suitable form so as to permit any consultation at a later date, taking into account any confidentiality.

Copies of the appropriate records shall be supplied to the competent authority on request. The individual worker shall, at his or her request, have access to the health records relating to him or her personally.

4. Where, as a result of surveillance of the hearing function, a worker is found to have identifiable hearing damage, a doctor, or a specialist if the doctor considers it necessary, shall assess whether the damage is likely to be the result of exposure to noise at work. If this is the case:

(a) the worker shall be informed by the doctor or other suitably qualified person of the result which relates to him or her personally;

(b) the employer shall:

(i) review the risk assessment carried out pursuant to Article 4;

(ii) review the measures provided for to eliminate or reduce risks pursuant to Articles 5 and 6;

(iii) take into account the advice of the occupational healthcare professional or other suitably qualified person or the competent authority in implementing any measures required to eliminate or reduce risk in accordance with Articles 5 and 6, including the possibility of assigning the worker to alternative work where there is no risk of further exposure; and

(iv) arrange systematic health surveillance and provide for a review of the health status of any other worker who has been similarly exposed.

Article 11

Derogations

1. In exceptional situations where, because of the nature of the work, the full and proper use of individual hearing protectors would be likely to cause greater risk to health or safety than not using such protectors, Member States may grant derogations from the provisions of Articles 6(1)(a) and (b) and 7.

2. The derogations referred to in paragraph 1 shall be granted by Member States following consultation with both sides of industry and, where appropriate, with the medical authorities responsible, in accordance with national laws and/or practice. Such derogations must be accompanied by conditions which guarantee, taking into account the special circumstances, that the resulting risks are reduced to a minimum and that the workers concerned are subject to increased health surveillance. Such derogations shall be reviewed every four years and withdrawn as soon as the justifying circumstances no longer obtain.

3. Every four years Member States shall forward to the Commission a list of derogations referred to in paragraph 1, indicating the exact reasons and circumstances which made them decide to grant the derogations.

Article 12

Technical amendments

Amendments of a strictly technical nature shall be adopted in accordance with the regulatory procedure laid down in Article 13(2) and in line with:

(a) the adoption of directives in the field of technical harmonisation and standardisation with regard to the design, building, manufacture or construction of work equipment and/or workplaces; and

(b) technical progress, changes in the most appropriate harmonised European standards or specifications and new findings concerning noise.

Article 13

Committee

1. The Commission shall be assisted by the Committee referred to in Article 17 of Directive 89/391/EEC.

2. Where reference is made to this paragraph, Articles 5 and 7 of Council Decision 1999/468/EC shall apply, having regard to the provisions of Article 8 thereof.

The period laid down in Article 5(6) of Decision 1999/468/EC shall be set at three months.

3. The Committee shall adopt its Rules of Procedure.

Article 14

Code of conduct

In the context of the application of this directive Member States shall draw up in consultation with the social partners, in accordance with national law and practice, a code of conduct providing for practical guidelines to help workers and employers in the music and entertainment sectors to meet their legal obligations as laid down in this Directive.

Article 15

Repeal

Directive 86/188/EEC is hereby repealed with effect from the date set out in the first subparagraph of Article 17(1).

SECTION IV

FINAL PROVISIONS

Article 16

Reports

Every five years Member States shall provide a report to the Commission on the practical implementation of this Directive, indicating the points of view of both sides of industry. It shall contain a description of best practice for preventing noise with a harmful effect on health and of other forms of work organisation, together with the action taken by the Member States to impart knowledge of such best practice.

On the basis of those reports, the Commission shall carry out an overall assessment of the implementation of this Directive, including implementation in the light of research and scientific information, and, *inter alia*, taking into account the implications of this Directive for the music and entertainment sectors. The Commission shall inform the European Parliament, the Council, the European Economic and Social Committee and the Advisory Committee on Safety, Hygiene and Health Protection at Work thereof and, if necessary, propose amendments.

Article 17

Transposition

1. The Member States shall bring into force the laws, regulations and administrative provisions necessary to comply with this Directive before 15 February 2006. They shall forthwith inform the Commission thereof.

When Member States adopt these measures, they shall contain a reference to this Directive or shall be accompanied by such reference on the occasion of their official publication. The methods of making such reference shall be laid down by the Member States.

2. In order to take account of particular conditions, Member States may, if necessary, have an additional period of five years from 15 February 2006, that is to say a total of eight years, to implement the provisions of Article 7 with regard to the personnel on board seagoing vessels.

In order to allow for the drawing up of a code of conduct providing for practical guidelines for the implementation of the provisions of this Directive, Member States shall be entitled to make use of a maximum transitional period of two years from 15 February 2006, that is to say a total of five years from the entry into force of this Directive, to comply with this Directive, with regard to the music and entertainment sectors on the condition that during this period the levels of protection already achieved in individual Member States, with regard to the personnel in these sectors, are maintained.

3. The Member States shall communicate to the Commission the text of the provisions of national law which they adopt or have already adopted in the field covered by this Directive.

Article 18

Entry into force

This Directive shall enter into force on the day of its publication in the *Official Journal of the European Union*.

Article 19

Addressees

This Directive is addressed to the Member States.

Done at Brussels, 6 February 2003.

For the European Parliament	*For the Council*
The President	*The President*
P. COX	G. EFTHYMIOU

APPENDIX B

MATLAB script for noise hazard assessment system

1. Noise_Dose_calculator.m

```
[FileName, PathName] = uigetfile( {  '*.wav','WAV-files (*.wav)';
'*.*', ...
    'All Files (*.*)'}, 'Pick a file', 'MultiSelect', 'on');
FileName = cellstr(FileName);   %in case only one selected

for K = 1

Size(K,:)=wavread([PathName FileName{K}],'Size');
[x,Fs]=wavread([PathName FileName{K}],[1 10]);
clear x

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
C=74; %Rec 2 SX850
% C=78; %Rec 5 Mic SX713

responseType = 'slow';

if strcmp(responseType,'slow')
   duration = 1.0;
elseif strcmp(responseType, 'fast')
   duration = 0.125;
else
   duration = 0.035;
end

N = ceil(duration*Fs);
N = 2^nextpow2(N);

Cut_start=1;
first=Cut_start*Fs;
last=N+first;
count=0;

Interval=N/Fs;

while (last<Size(K,1))
count=count+1;
    [x,Fs]=wavread([PathName FileName{K}],[first last]);
    x=x(:,1);
    t = (1/Fs)*(0:(length(x)-1));
    [X,dBA(count)] = Decibel_Level_Analyzer(x,Fs,C);
    if count==1
        windowTime(count)=Interval/2;
        dose(count)=100*windowTime(count)/60/(480/(2^((dBA(count)-
85)/3)));
    else
        windowTime(count) =windowTime(count-1)+Interval;
        dose(count)=dose(count-1)+(100*(windowTime(count)...
            -windowTime(count-1))/60/(480/(2^((dBA(count)-85)/3))));
    end

first=last+1;
last=last+N;
end

dBA=dBA';
```

```
windowTime=windowTime';

end

for K = 2 : length(FileName)

Size(K,:)=wavread([PathName FileName{K}],'Size');

first=Fs;
last=N+first;
count=length(dBA);

Interval=N/Fs;

while (last<Size(K,1))
count=count+1;
    [x,Fs]=wavread([PathName FileName{K}],[first last]);
    x=x(:,1);
    t = (1/Fs)*(0:(length(x)-1));
    [X,dBA(count)] = Decibel_Level_Analyzer(x,Fs,C);
    windowTime(count) =windowTime(count-1)+Interval;
    dose(count)=dose(count-1)+(100*(windowTime(count)...
            -windowTime(count-1))/60/(480/(2^((dBA(count)-85)/3))));
first=last+1;
last=last+N;
end
end

Size=sum(Size(:,1));

%Final Minimum Level(dBA)
Lmin_F = min(dBA);

%Final Maximum Level (dBA)
Lmax_F = max(dBA);

%Final Equivalent Level (dBA)
Leq_F=10*log10((1/length(dBA))*sum(10.^(dBA*0.1)));

%Final Noise Dose (%)
Dose_F=dose(end);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%

DeltaT=60;
if DeltaT>(Size/Fs)
    disp('Your time interval may be larger than duration of input
sound');
    disp('Please check your it again!');
else
%     tStart=(0:DeltaT:((Size/Fs)-Cut_start));
tStart=(0:DeltaT:(Size/Fs));
    Lmin=zeros((length(tStart)-1),1);
    Lmax=zeros((length(tStart)-1),1);
    Leq=zeros((length(tStart)-1),1);
    Dose=zeros((length(tStart)-1),1);
    for j=(1:(length(tStart)-1))
```

```
        indT = find(tStart(j)<=windowTime & windowTime < tStart(j+1));
       [Lmin(j),Lmax(j),Leq(j),Dose(j)]=Sorter(dBA(indT),DeltaT);
           if j>1
           Dose(j)=Dose(j-1)+Dose(j);
           end
       end
   end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Statistic table of sound level in dBA
xlsName = 'Test_20110624_Rama9Square';

Data_xls(:,1)=Lmin;
Data_xls(:,2)=Lmax;
Data_xls(:,3)=Leq;
Data_xls(:,4)=Dose;

Data_xls(1,7)=Lmin_F;
Data_xls(2,7)=Lmax_F;
Data_xls(3,7)=Leq_F;
Data_xls(4,7)=Dose_F;

xlswrite(xlsName,Data_xls,'SX850_A');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clear
clc
```

2. A_Weighting_Filter.m

```
function A = A_Weigthing_Filter(f,plotFilter)

% FILTERA Generates an A-weighting filter.

c1 = 3.5041384e16;
c2 = 20.598997^2;
c3 = 107.65265^2;
c4 = 737.86223^2;
c5 = 12194.217^2;

% Evaluate A-weighting filter.
f(find(f == 0)) = 1e-17;
f = f.^2; num = c1*f.^4;
den = ((c2+f).^2) .* (c3+f) .* (c4+f) .* ((c5+f).^2);
A = num./den;

% Plot A-weighting filter (if enabled).
if exist('plotFilter') & plotFilter

   % Plot using dB scale.
   figure(2); clf;
   semilogx(sqrt(f),10*log10(A));
   title('A-weighting Filter');
   xlabel('Frequency (Hz)');
   ylabel('Magnitude (dB)');
   xlim([10 100e3]); grid on;
   ylim([-70 10]);
```

```
    % Plot using linear scale.
    figure(3); plot(sqrt(f),A);
    title('A-weighting Filter');
    xlabel('Frequency (Hz)');
    ylabel('Amplitude');
    xlim([0 44.1e3/2]); grid on;

end
```

3. Decibel_Level_Analyzer.m

```
function [X,dBA] = Decibel_Level_Analyzer(x,Fs,C)

% ESTIMATELEVEL Estimates signal level in dBA.

% Calculate magnitude of FFT.
X = abs(fft(x));

% Add offset to prevent taking the log of zero.
X(find(X == 0)) = 1e-17;

% Retain frequencies below Nyquist rate.
f = (Fs/length(X))*(0:(length(X)-1));
ind = find(f<Fs/2); f = f(ind); X = X(ind);

% Apply A-weighting filter.
A = A_Weigthing_Filter(f);
X = A'.*X;
% X=(2/length(x))*X;

% Estimate dBA value using Parseval's relation.
totalEnergy = 2*(sum(X.^2)/length(X));
meanEnergy = totalEnergy/((1/Fs)*length(x));

dBA = 10*log10(meanEnergy)+C;
% dBA=10*log10(meanEnergy)-10*log10(0.000204);

% Estimate decibel level (for visualization).
X = 20*log10(X);
```

4. Sound_Pamareter.m

```
function [Lmin,Lmax,Leq,Dose] = Sound_ParameterdBA,DeltaT)

%Minimum Level (dBA)
Lmin = min(dBA);

%Maximum Level (dBA)
Lmax = max(dBA);

%Equivalent Level (dBA)
Leq=10*log10((1/length(dBA))*sum(10.^(dBA*0.1)));

%Noise Dose (%)
Dose=100*((DeltaT/3600)/8)*10^((Leq-85)/10);
```

APPENDIX C

Questionnaires in English and Thai version

Date: ____________________

SURVEY ON THE WORKERS' PERCEPTIONS AND AWARENESS OF NOISE HAZARD AT CONSTRUCTION SITE
Case Study: Piling Worker

Please take a few minutes to answer these questions. There will be 3 sections in this survey. Section 1 will ask about the socio-occupational traits. Section 2 measures the perceptions of noise hazard at construction site. And section 3 will ask about the awareness of noise impacts.

Respondent name: ______________________

Project name: __________________________ Location: _______________________

Project Type: _________________________ Type of Piling ___________________

Section 1: Socio-occupational traits

Please tick (√) one of the choices shown below:

1. Age (years old): ☐ ≤ 25 ☐ 26 – 35
   ☐ 36 – 45 ☐ 46 – 55 ☐ > 55
2. Education: ☐ No education ☐ Primary
   ☐ Secondary ☐ High school ☐ Institute
3. Occupation: ☐ Labourer ☐ Forman
   ☐ Engineer ☐ Office staff ☐ Manager
4. Years of work experiences: ☐ ≤ 5 ☐ 5 – 10
   ☐ 11 – 15 ☐ 16 – 20 ☐ > 20

Section 2: Your perceptions of noise hazard at construction site

Please tick (√) one of the choices shown below:

1. Is noise generally a problem?
   ☐ Yes ☐ To some extent ☐ No
2. How noisy is the construction site?
   ☐ Very noisy ☐ Noisy ☐ Little
   ☐ Not noisy

3. How many hours a day is the construction site noisy?

☐ 1 ☐ 2 ☐ 3 ☐ 4

☐ 5 ☐ 6 ☐ 7 ☐ 8

☐ > 8

4. How dangerous do you think is being exposed to any high-noise level, very closely:

☐ Very high risk ☐ high risk ☐ Risk ☐ No risk

5. Do you wear Hearing Protection Devices (HPD) when noise is high?

☐ Yes ☐ Sometimes ☐ No

6. *Self – Efficacy for using Hearing Protection Devices (HPD)

How do you agree with the following statements:	Strongly agree to Strongly disagree				
	1	2	3	4	5
a. When I use HPD, I can't talk to my colleagues[1]					
b. HPD don't allow me to hear useful sound[1]					
c. When I use HPD I feel that I'm not protected enough[1]					
d. I know exactly how to use correctly my HPD					
e. I can't always use HPD as it should be[1]					
f. I know the better way to use HPD					
g. I make all efforts to have HPD always well fitted					
h. I am sure that I use HPD in an efficient way					

* For respondent who have used Hearing Protection Devices
[1] : Questions whose scores' were inverted

Section 3: Your awareness of noise impact

Please tick (√) one of the choices shown below:

1. Does noise annoy you today?

☐ Very much ☐ To some extent ☐ Little ☐ No

2. Do you think noise affects your health adversely?

☐ Yes ☐ May be ☐ I don't know ☐ No

3. Do you think noise affects your productivity?

☐ Very much ☐ May be ☐ Not at all

4. Do you think noise affects accident at site?

☐ Very much ☐ May be ☐ Not at all

Thank you very much for your participation

วันที่: ____________________

การสำรวจการรับรู้และตระหนักถึงอันตรายต่อเสียงของคนงานในหน่วยงานก่อสร้าง กรณีศึกษา : คนงานที่ทำงานเกี่ยวกับเสาเข็ม

โปรดใช้เวลาสักครู่ในการตอบคำถามเหล่านี้ ในแบบสอบถามนี้ประกอบด้วย 3 ส่วนที่1 จะถามเกี่ยวกับลักษณะทางสังคมและการประกอบอาชีพ ส่วนที่2 วัดการรับรู้อันตรายของเสียงในหน่วยงานก่อสร้าง และส่วนที่3 จะถามเกี่ยวกับการรับรู้ผลกระทบทางเสียง

ชื่อผู้ตอบแบบสอบถาม: ____

ชื่อโครงการ: ______________________________ สถานที่ตั้ง: ______________

ประเภทโครงการ:____________________ ประเภทของงานเสาเข็ม: ______________

ส่วนที่ 1: ลักษณะสังคมและการประกอบอาชีพ

โปรดกา (√) หนึ่งในตัวเลือกดังต่อไปนี้:

1. อายุ (ปี): ☐ ≤ 25 ☐ 26 – 35
   ☐ 36 – 45 ☐ 46 – 55 ☐ > 55
2. การศึกษา: ☐ ไม่มี ☐ ประถมศึกษา
   ☐ มัธยมศึกษาตอนต้น ☐ มัธยมศึกษาตอนปลาย ☐ มหาวิทยาลัย
3. อาชีพ: ☐ คนงาน ☐ โฟร์แมน
   ☐ วิศวกร ☐ เจ้าหน้าที่สำนักงาน ☐ ผู้จัดการ
4. ประสบการณ์ทำงาน(ปี): ☐ ≤ 5 ☐ 5 – 10
   ☐ 11 – 15 ☐ 16 – 20 ☐ > 20

ส่วนที่ 2: วัดการรับรู้อันตรายของเสียงในหน่วยงานก่อสร้าง(งานเสาเข็ม)

โปรดกา (√) หนึ่งในตัวเลือกดังต่อไปนี้:

1. เสียงเป็นปัญหาปกติหรือไม่
   ☐ ใช่ ☐ ไม่แน่ใจ ☐ ไม่
2. เสียงรบกวนดังขนาดไหนในหน่วยงานก่อสร้าง
   ☐ เสียงรบกวนดังมาก ☐ เสียงรบกวนดัง ☐ เสียงรบกวนดังเล็กน้อย
   ☐ ไม่มีเสียงรบกวน

3. กี่ชั่วโมงต่อวันที่มีเสียงรบกวนในหน่วยงานก่อสร้าง

☐ 1 ☐ 2 ☐ 3 ☐ 4
☐ 5 ☐ 6 ☐ 7 ☐ 8
☐ > 8

4. คุณคิดว่าอันตรายขนาดไหน ที่สัมผัสกับเสียงรบกวนระดับสูงอย่างใกล้ชิด:

☐ มีความเสี่ยงสูงมาก ☐ มีความเสี่ยงสูง ☐ มีความเสี่ยง ☐ ไม่มีความเสี่ยง

5. เมื่อเสียงดัง คุณสวมใส่อุปกรณ์ป้องกันเสียงหรือไม่

☐ ใช่ ☐ บางครั้ง ☐ ไม่

6. *ประสิทธิภาพในการรับรู้เมื่อใช้อุปกรณ์ป้องกันเสียง

คุณเห็นด้วยกับรายการดังต่อไปนี้อย่างไร	เห็นด้วยอย่างยิ่งไปถึงไม่เห็นด้วยอย่างยิ่ง				
	1	2	3	4	5
a. เมื่อฉันใช้อุปกรณ์ป้องกันเสียง ฉันไม่สามารถพูดคุยกับผู้ร่วมงานของฉัน					
b. อุปกรณ์ป้องกันเสียงทำให้ฉันไม่ได้ยินเสียงที่เป็นประโยชน์					
c. เมื่อฉันใช้อุปกรณ์ป้องกันเสียง ฉันรู้สึกว่าไม่ได้ป้องกันที่เพียงพอ					
d. ฉันรู้ว่าวิธีการใช้อุปกรณ์ป้องกันเสียงอย่างถูกต้อง					
e. ฉันไม่สามารถใช้อุปกรณ์ป้องกันเสียงได้ตลอด ตามที่ควรจะเป็น					
f. ฉันรู้ว่าวิธีที่ดีกว่าที่จะใช้อุปกรณ์ป้องกันเสียง					
g. ฉันใช้ความพยายามทั้งหมดเพื่อจะทำให้อุปกรณ์ป้องกันเสียงแนบสนิทกับหูพอดี					
h. ฉันแน่ใจว่าฉันใช้อุปกรณ์ป้องกันเสียงได้อย่างมีประสิทธิภาพ					

* สำหรับผู้ตอบที่มีการใช้อุปกรณ์ป้องกันเสียง

ส่วนที่ 3 จะถามเกี่ยวกับการรับรู้ผลกระทบทางเสียง

โปรดกา (√) หนึ่งในตัวเลือกดังต่อไปนี้:

1. เสียงดังรบกวนคุณในวันนี้หรือไม่

☐ อย่างมาก ☐ ไม่แน่ใจ ☐ เล็กน้อย ☐ ไม่

2. คุณคิดว่าเสียงดังส่งผลเสียต่อสุขภาพของคุณหรือไม่

☐ ใช่ ☐ บางที ☐ ไม่รู้ ☐ ไม่

3. คุณคิดว่าเสียงดังส่งผลกระทบต่อการทำงานของคุณหรือไม่

☐ อย่างมาก ☐ บางที ☐ ไม่เลย

4. คุณคิดว่าเสียงมีผลต่อการเกิดอุบัติเหตุในหน่วยงานก่อสร้างหรือไม่

☐ อย่างมาก ☐ บางที ☐ ไม่เลย

อบคุณอย่างมากครับสำหรับการมีส่วนร่วมของคุณ

APPENDIX D

Calculation note

Comparison of Leq of the proposed system and noise dosimeter in minute scale (a part of results)

Min	Sample Time	LAeqSTD	LAeqSYS	ΔLeq	Min	Sample Time	LAeqSTD	LAeqSYS	ΔLeq
1	21-05-11 8:42	66.3	68.88086	3.892706	71	21-05-11 10:07	92.5	87.84214	-5.03553
2	21-05-11 8:46	70.5	68.71639	-2.52995	72	21-05-11 10:08	92	87.86355	-4.49615
3	21-05-11 8:48	71.8	70.98682	-1.13256	73	21-05-11 10:09	91.9	87.99761	-4.24634
4	21-05-11 8:49	76.4	77.48339	1.418049	74	21-05-11 10:10	90.8	87.64586	-3.47372
5	21-05-11 8:50	80.1	80.74671	0.80738	75	21-05-11 10:11	90.5	87.99408	-2.76897
6	21-05-11 8:51	79.6	80.37163	0.969379	76	21-05-11 10:12	91.4	87.87339	-3.85843
7	21-05-11 8:52	78.9	79.86269	1.220138	77	21-05-11 10:13	86.7	81.71074	-5.75463
8	21-05-11 8:53	70.5	67.08671	-4.84154	78	21-05-11 10:14	93.2	89.09603	-4.4034
9	21-05-11 8:54	74.6	73.29371	-1.75106	79	21-05-11 10:15	92.7	89.49455	-3.45788
10	21-05-11 8:55	75.6	73.07031	-3.34615	80	21-05-11 10:16	92.1	90.15321	-2.11378
11	21-05-11 8:56	73.4	71.25509	-2.92222	81	21-05-11 10:17	91.8	89.44456	-2.56584
12	21-05-11 8:57	70.9	68.62215	-3.21277	82	21-05-11 10:18	92.5	87.61655	-5.2794
13	21-05-11 8:58	73.8	72.12111	-2.27491	83	21-05-11 10:19	91.5	87.96212	-3.86654
14	21-05-11 8:59	66.3	66.54347	0.367219	84	21-05-11 10:20	89	85.95896	-3.4169
15	21-05-11 9:00	72.4	66.52044	-8.12094	85	21-05-11 10:21	88.2	84.21548	-4.51759
16	21-05-11 9:03	70.1	63.20994	-9.8289	86	21-05-11 10:22	79.4	79.29367	-0.13392
17	21-05-11 9:04	74.3	74.51116	0.2842	87	21-05-11 10:23	88.9	89.47139	0.642739
18	21-05-11 9:05	70.1	68.04138	-2.93669	88	21-05-11 10:24	76.2	77.25683	1.38692
19	21-05-11 9:07	70.4	68.93529	-2.08055	89	21-05-11 10:25	76.7	76.39257	-0.40082
20	21-05-11 9:08	67.3	69.4387	3.177866	90	21-05-11 10:26	66.4	75.1456	13.17109
21	21-05-11 9:09	69.1	68.19884	-1.30414	91	21-05-11 10:30	64.6	64.11353	-0.75304
22	21-05-11 9:10	82.3	87.33434	6.117065	92	21-05-11 10:31	64.3	65.02299	1.124398
23	21-05-11 9:11	74.1	72.35334	-2.35717	93	21-05-11 10:33	68.8	67.47313	-1.9286
24	21-05-11 9:12	65.3	63.74638	-2.3792	94	21-05-11 10:34	71.6	69.30025	-3.21195
25	21-05-11 9:13	71.2	70.0965	-1.54985	95	21-05-11 10:35	64.8	61.72777	-4.7411
26	21-05-11 9:19	65.6	59.21988	-9.7258	96	21-05-11 10:39	65.2	58.76625	-9.86771
27	21-05-11 9:21	64.8	60.53738	-6.57811	97	21-05-11 10:42	83.9	78.26865	-6.71197
28	21-05-11 9:23	64	61.21264	-4.35525	98	21-05-11 10:43	87.3	84.54246	-3.1587
29	21-05-11 9:24	71.3	70.11615	-1.66038	99	21-05-11 10:44	83.8	81.1252	-3.19188
30	21-05-11 9:26	69.9	67.77276	-3.04325	100	21-05-11 10:45	81	77.64233	-4.14527
31	21-05-11 9:27	74.7	74.54478	-0.20779	101	21-05-11 10:46	83.1	79.72651	-4.05956
32	21-05-11 9:28	73.8	73.43955	-0.48841	102	21-05-11 10:47	76.6	73.96134	-3.44472
33	21-05-11 9:29	81.8	78.31483	-4.2606	103	21-05-11 10:48	87	84.06881	-3.36919
34	21-05-11 9:30	72.5	70.70732	-2.47266	104	21-05-11 10:49	88.1	87.59441	-0.57389
35	21-05-11 9:31	76.1	74.39921	-2.23494	105	21-05-11 10:50	87	83.2519	-4.30816
36	21-05-11 9:32	80	79.2903	-0.88712	106	21-05-11 10:51	82.5	81.81551	-0.82968
37	21-05-11 9:33	78.4	77.41634	-1.25466	107	21-05-11 10:52	85.1	83.67271	-1.6772
38	21-05-11 9:34	79.1	79.06106	-0.04923	108	21-05-11 10:53	87.2	83.53165	-4.20682
39	21-05-11 9:35	84.7	83.71631	-1.16139	109	21-05-11 10:54	88	83.024	-5.65454
40	21-05-11 9:36	79.8	80.04291	0.304401	110	21-05-11 10:55	74.7	71.57837	-4.17889
41	21-05-11 9:37	86.1	82.98106	-3.62246	111	21-05-11 10:56	86.5	82.70633	-4.38575
42	21-05-11 9:38	90.8	87.5547	-3.57412	112	21-05-11 10:57	80.8	77.58832	-3.97485
43	21-05-11 9:39	81.4	78.45493	-3.61802	113	21-05-11 10:58	87.7	88.40628	0.805332
44	21-05-11 9:40	85	82.04424	-3.47736	114	21-05-11 10:59	92	93.17328	1.275302
45	21-05-11 9:41	85.6	84.48232	-1.3057	115	21-05-11 11:00	91.9	93.31816	1.543158
46	21-05-11 9:42	85.5	83.79808	-1.99055	116	21-05-11 11:01	91.5	92.61909	1.223044
47	21-05-11 9:43	87.7	85.08448	-2.98235	117	21-05-11 11:02	91.9	92.91728	1.106938
48	21-05-11 9:44	78.4	78.03291	-0.46822	118	21-05-11 11:03	92.9	94.10959	1.302034
49	21-05-11 9:45	83.2	80.26231	-3.53088	119	21-05-11 11:04	91.9	92.43008	0.576806
50	21-05-11 9:46	85.5	83.51795	-2.31819	120	21-05-11 11:05	82.7	80.85024	-2.23671
51	21-05-11 9:47	85.6	83.12256	-2.89421	121	21-05-11 11:06	86.9	84.46452	-2.80263
52	21-05-11 9:48	81.2	78.79206	-2.96545	122	21-05-11 11:07	89.3	86.4956	-3.14043
53	21-05-11 9:49	77.1	72.99457	-5.32481	123	21-05-11 11:08	90.4	86.89904	-3.87274
54	21-05-11 9:50	76.8	76.44871	-0.45741	124	21-05-11 11:09	88.3	86.03597	-2.56403
55	21-05-11 9:51	81.1	80.09723	-1.23646	125	21-05-11 11:10	88	86.25465	-1.98335
56	21-05-11 9:52	80.9	82.09688	1.47946	126	21-05-11 11:11	89.9	88.23072	-1.85682
57	21-05-11 9:53	87.7	87.82128	0.13829	127	21-05-11 11:12	91.5	89.84511	-1.80862
58	21-05-11 9:54	89.3	88.19321	-1.23941	128	21-05-11 11:13	91.1	90.56308	-0.58938
59	21-05-11 9:55	89.8	89.82031	0.022613	129	21-05-11 11:14	90.8	90.10771	-0.76243
60	21-05-11 9:56	88.8	87.94069	-0.96769	130	21-05-11 11:15	90.7	90.03772	-0.73019
61	21-05-11 9:57	91.4	90.75737	-0.7031	131	21-05-11 11:16	84.5	83.73207	-0.90879
62	21-05-11 9:58	90.7	89.79817	-0.9943	132	21-05-11 11:17	86.1	84.88351	-1.41289
63	21-05-11 9:59	91.9	91.9527	0.057347	133	21-05-11 11:18	86	84.80435	-1.39029
64	21-05-11 10:00	92.6	93.70758	1.196089	134	21-05-11 11:19	76	75.79039	-0.2758
65	21-05-11 10:01	90.9	91.50707	0.667839	135	21-05-11 11:20	74.7	72.53555	-2.89752
66	21-05-11 10:02	83.3	80.17524	-3.75121	136	21-05-11 11:21	80.3	79.03287	-1.578
67	21-05-11 10:03	88.2	85.45275	-3.1148	137	21-05-11 11:22	73	71.40062	-2.19093
68	21-05-11 10:04	89.6	86.90424	-3.00866	138	21-05-11 11:23	74.4	72.85983	-2.07012
69	21-05-11 10:05	89.3	85.82856	-3.88739	139	21-05-11 11:24	74.1	75.37727	1.723716
70	21-05-11 10:06	93.2	87.42511	-6.19623	140	21-05-11 11:25	66.4	69.4904	4.654213

Min	Sample Time	LAeqSTD	LAeqSYS	ΔLeq	Min	Sample Time	LAeqSTD	LAeqSYS	ΔLeq
150	21-05-11 14:42	70.1	67.25245	-4.06212	225	21-05-11 16:26	88.3	87.503	-0.9026
151	21-05-11 14:48	72.9	73.76383	1.184948	226	21-05-11 16:27	89.3	87.37712	-2.15328
152	21-05-11 15:03	83.6	81.49723	-2.51527	227	21-05-11 16:28	89.9	86.79272	-3.45637
153	21-05-11 15:04	88.8	87.01402	-2.01123	228	21-05-11 16:29	76.5	74.22291	-2.97658
154	21-05-11 15:05	87.5	85.4648	-2.32594	229	21-05-11 16:30	75.2	76.2009	1.330983
155	21-05-11 15:06	66.6	62.74807	-5.78368	230	21-05-11 16:31	74.9	73.99773	-1.20463
156	21-05-11 15:07	68.6	64.13877	-6.50325	231	21-05-11 16:32	72.8	74.00374	1.653483
157	21-05-11 15:15	67.1	60.27941	-10.1648	232	21-05-11 16:33	79.6	79.04011	-0.70337
158	21-05-11 15:18	68.6	64.71151	-5.66835	233	21-05-11 16:34	71.2	70.76938	-0.60481
159	21-05-11 15:19	68.5	64.85632	-5.31925	234	21-05-11 16:35	73.6	72.47594	-1.52726
160	21-05-11 15:20	68.1	63.72498	-6.4244	235	21-05-11 16:36	83.2	79.94367	-3.91386
161	21-05-11 15:21	70.8	70.11233	-0.97129	236	21-05-11 16:37	76.7	73.28415	-4.45352
162	21-05-11 15:22	64.3	63.94642	-0.54988	237	21-05-11 16:38	82.6	81.66037	-1.13757
163	21-05-11 15:24	69.8	66.06974	-5.34421	238	21-05-11 16:39	81.6	80.54086	-1.29796
164	21-05-11 15:25	74.3	69.81828	-6.03193	239	21-05-11 16:40	77.8	74.8941	-3.7351
165	21-05-11 15:26	82.2	79.8064	-2.91193	240	21-05-11 16:41	82.1	78.35808	-4.55776
166	21-05-11 15:27	91	89.50543	-1.64239	241	21-05-11 16:42	89.8	82.96019	-7.61671
167	21-05-11 15:28	93.5	92.20634	-1.38359	242	21-05-11 16:43	83	83.3059	0.368558
168	21-05-11 15:29	95.1	92.91368	-2.29897	243	21-05-11 16:44	87.1	86.98158	-0.13596
169	21-05-11 15:30	94.1	91.57831	-2.6798	244	21-05-11 16:45	83	82.31056	-0.83065
170	21-05-11 15:31	94.4	91.97661	-2.56715	245	21-05-11 16:46	77.9	75.93855	-2.5179
171	21-05-11 15:32	94.3	92.47334	-1.93708	246	21-05-11 16:47	83.6	80.29022	-3.95907
172	21-05-11 15:33	94.3	91.80703	-2.64366	247	21-05-11 16:48	75.4	74.87453	-0.69691
173	21-05-11 15:34	95.1	92.58871	-2.64069	248	21-05-11 16:49	75.2	75.5597	0.478324
174	21-05-11 15:35	95.1	92.6489	-2.5774	249	21-05-11 16:50	69	69.4232	0.613336
175	21-05-11 15:36	94.3	92.24444	-2.17981	250	21-05-11 16:51	87.6	89.0376	1.641097
176	21-05-11 15:37	92.8	90.06707	-2.94497	251	21-05-11 16:52	90	91.30054	1.445042
177	21-05-11 15:38	87.2	84.22492	-3.41179	252	21-05-11 16:53	89.1	89.98685	0.995344
178	21-05-11 15:39	74.9	75.77726	1.171242	253	21-05-11 16:54	89.2	89.83861	0.715932
179	21-05-11 15:40	82.1	80.65275	-1.76279	254	21-05-11 16:55	88.4	88.88252	0.545839
180	21-05-11 15:41	78.6	79.83198	1.567404	255	21-05-11 16:56	89.2	89.70897	0.570596
181	21-05-11 15:42	81.3	82.44246	1.405243	256	21-05-11 16:57	88.8	89.58055	0.878996
182	21-05-11 15:43	80.7	82.77402	2.570034	257	21-05-11 16:58	82.9	83.15627	0.309128
183	21-05-11 15:44	74.1	75.11922	1.375468	258	21-05-11 16:59	85.3	83.23549	-2.4203
184	21-05-11 15:45	73.8	74.71636	1.241677	259	21-05-11 17:00	86.1	82.95236	-3.65579
185	21-05-11 15:46	70.9	70.94919	0.069379	260	21-05-11 17:01	88.3	85.87187	-2.74986
186	21-05-11 15:47	73.9	73.80011	-0.13516	261	21-05-11 17:02	88.2	86.70228	-1.6981
187	21-05-11 15:48	73.1	73.4322	0.454442	262	21-05-11 17:03	88.3	88.05165	-0.28126
188	21-05-11 15:49	74.4	74.68053	0.377051	263	21-05-11 17:04	89.3	90.45744	1.296129
189	21-05-11 15:50	83.2	81.54584	-1.98817	264	21-05-11 17:05	89.1	91.2642	2.428951
190	21-05-11 15:51	76.8	75.21667	-2.06162	265	21-05-11 17:06	89.2	91.00598	2.024643
191	21-05-11 15:52	74.7	72.93853	-2.35806	266	21-05-11 17:07	88.4	90.83108	2.750094
192	21-05-11 15:53	83	80.99881	-2.41108	267	21-05-11 17:08	89.3	91.63353	2.61313
193	21-05-11 15:54	83	82.16268	-1.00882	268	21-05-11 17:09	88.9	91.12393	2.501613
194	21-05-11 15:55	86.9	87.60164	0.807411	269	21-05-11 17:10	88.2	90.4935	2.600339
195	21-05-11 15:56	80.3	80.19926	-0.12545	270	21-05-11 17:11	81	83.26514	2.796468
196	21-05-11 15:57	83.2	81.07123	-2.55861	271	21-05-11 17:12	87.1	87.3923	0.335596
197	21-05-11 15:58	77.8	77.66113	-0.17849	272	21-05-11 17:13	89.7	89.4971	-0.2262
198	21-05-11 15:59	74.7	74.1639	-0.71768	273	21-05-11 17:14	89.7	88.29941	-1.56142
199	21-05-11 16:00	72.4	72.51451	0.158168	274	21-05-11 17:15	89.6	87.93498	-1.85829
200	21-05-11 16:01	88.3	89.16398	0.978465	275	21-05-11 17:16	90.7	88.50424	-2.42091
201	21-05-11 16:02	90.9	92.04486	1.259472	276	21-05-11 17:17	89.9	88.52787	-1.52628
202	21-05-11 16:03	91.4	91.47818	0.085536	277	21-05-11 17:18	91.1	89.07071	-2.22755
203	21-05-11 16:04	91.2	91.83449	0.695711	278	21-05-11 17:19	84.7	81.85519	-3.35869
204	21-05-11 16:05	92.2	93.49672	1.406417	279	21-05-11 17:20	81.1	82.01329	1.126133
205	21-05-11 16:06	91.7	92.40462	0.768392	280	21-05-11 17:21	87.4	88.56534	1.333339
206	21-05-11 16:07	91.4	91.517	0.128011	281	21-05-11 17:22	85.6	87.26172	1.941262
207	21-05-11 16:08	72.9	72.07401	-1.13304	282	21-05-11 17:23	79.1	80.62511	1.928073
208	21-05-11 16:09	84.3	82.81582	-1.7606	283	21-05-11 17:24	77.6	78.79194	1.536005
209	21-05-11 16:10	85.1	83.57323	-1.79409	284	21-05-11 17:25	81.3	82.7616	1.797791
210	21-05-11 16:11	89.1	87.34255	-1.97244	285	21-05-11 17:26	78.1	79.2586	1.48348
211	21-05-11 16:12	90.6	89.93268	-0.73656	286	21-05-11 17:27	77.2	76.04351	-1.49804
212	21-05-11 16:13	88.9	90.14328	1.398515	287	21-05-11 17:28	82.8	78.68712	-4.96725
213	21-05-11 16:14	87.8	88.53742	0.839886	288	21-05-11 17:29	82.9	79.51888	-4.07856
214	21-05-11 16:15	89.5	90.3495	0.949164	289	21-05-11 17:30	81.5	78.6975	-3.43865
215	21-05-11 16:16	90.2	91.70073	1.66378	290	21-05-11 17:31	79.2	75.67534	-4.45033
216	21-05-11 16:17	89.7	91.89129	2.442912	291	21-05-11 17:32	75.5	70.55242	-6.55309
217	21-05-11 16:18	89.2	90.94214	1.953074	292	21-05-11 17:33	78.1	73.76686	-5.5482
218	21-05-11 16:19	64.6	65.04764	0.692937	293	21-05-11 17:34	77.4	73.01557	-5.66464
219	21-05-11 16:20	87.7	88.73552	1.180754	294	21-05-11 17:35	84.2	83.28783	-1.08333
220	21-05-11 16:21	88.2	88.6731	0.536393	295	21-05-11 17:36	82	80.05903	-2.36704
221	21-05-11 16:22	88.4	87.25888	-1.29086	296	21-05-11 17:37	69.3	68.5821	-1.03593
222	21-05-11 16:23	89.3	88.55512	-0.83413	297	21-05-11 17:38	82.5	76.34191	-7.46435
223	21-05-11 16:24	88.4	86.88973	-1.70845	298	21-05-11 17:39	78.3	75.44268	-3.64919
224	21-05-11 16:25	89.1	88.71828	-0.42841	299	21-05-11 17:40	75.5	73.65105	-2.44895

Min	Sample Time	LAeqSTD	LAeqSYS	ΔLeq	Min	Sample Time	LAeqSTD	LAeqSYS	ΔLeq
300	21-05-11 17:41	75.4	74.45903	-1.24797	375	22-05-11 9:00	101.7	102.589	0.874188
301	21-05-11 17:42	79.6	79.41162	-0.23666	376	22-05-11 9:01	102.7	102.1051	-0.57925
302	21-05-11 17:43	80.9	80.82543	-0.09218	377	22-05-11 9:02	104.7	103.5291	-1.11829
303	21-05-11 17:44	80.9	80.66008	-0.29656	378	22-05-11 9:03	104.9	103.3506	-1.47701
304	21-05-11 17:45	80.9	80.66869	-0.28593	379	22-05-11 9:04	102.8	101.2913	-1.4676
305	21-05-11 17:46	81	80.46206	-0.66413	380	22-05-11 9:05	103.3	101.8829	-1.37186
306	21-05-11 17:47	81.2	79.75544	-1.77901	381	22-05-11 9:06	102.1	101.4046	-0.68107
307	21-05-11 17:48	76.4	74.46294	-2.53541	382	22-05-11 9:07	102.7	101.4884	-1.1797
308	21-05-11 17:49	86.1	83.8054	-2.66504	383	22-05-11 9:08	101.9	100.9339	-0.94805
309	21-05-11 17:50	84.3	83.47913	-0.97374	384	22-05-11 9:09	105.1	104.1761	-0.87904
310	21-05-11 17:51	78.4	75.28954	-3.96742	385	22-05-11 9:10	104.4	103.4145	-0.944
311	21-05-11 17:52	64.3	65.09542	1.237039	386	22-05-11 9:11	103.3	102.291	-0.97674
312	21-05-11 17:53	73.1	71.20804	-2.58818	387	22-05-11 9:12	100.3	99.16097	-1.13562
313	21-05-11 17:54	66.6	64.89515	-2.55984	388	22-05-11 9:13	98.5	97.72983	-0.7819
314	21-05-11 17:55	70.1	68.57471	-2.17588	389	22-05-11 9:14	100.8	100.0594	-0.73468
315	21-05-11 17:56	84.5	81.33472	-3.7459	390	22-05-11 9:15	101	100.7437	-0.2538
316	21-05-11 17:57	88.2	83.95573	-4.8121	391	22-05-11 9:16	100.1	99.80226	-0.29744
317	21-05-11 17:58	89.2	84.64737	-5.10384	392	22-05-11 9:17	100	99.76766	-0.23234
318	21-05-11 17:59	89.4	86.06236	-3.73338	393	22-05-11 9:18	99.2	99.347	0.148186
319	21-05-11 18:00	92.5	89.06755	-3.71076	394	22-05-11 9:19	98.3	98.49226	0.195589
320	21-05-11 18:01	92.3	90.69194	-1.74221	395	22-05-11 9:20	95.1	94.58005	-0.54674
321	21-05-11 18:02	91.8	90.35383	-1.57535	396	22-05-11 9:21	94.1	91.9169	-2.31998
322	21-05-11 18:03	90.4	89.05611	-1.48661	397	22-05-11 9:22	70.2	70.18679	-0.01881
323	21-05-11 18:04	88.3	86.78751	-1.7129	398	22-05-11 9:23	75.4	75.73786	0.448085
324	21-05-11 18:05	91.9	90.15573	-1.89801	399	22-05-11 9:24	83.2	81.04565	-2.58936
325	21-05-11 18:06	91.7	89.9086	-1.95354	400	22-05-11 9:25	83.2	82.06494	-1.36426
326	21-05-11 18:07	91.7	89.77827	-2.09567	401	22-05-11 9:26	85.6	83.50136	-2.45168
327	21-05-11 18:08	91.3	88.63063	-2.92374	402	22-05-11 9:27	88	86.60473	-1.58553
328	21-05-11 18:09	90.8	89.78126	-1.12196	403	22-05-11 9:28	81.7	80.03952	-2.03241
329	21-05-11 18:10	91.7	89.26774	-2.65241	404	22-05-11 9:29	85.5	83.48277	-2.35933
330	21-05-11 18:11	90.9	87.91623	-3.28247	405	22-05-11 9:30	87.8	85.37591	-2.76093
331	21-05-11 18:12	84.3	83.59097	-0.84107	406	22-05-11 9:31	91.3	88.8541	-2.67897
332	21-05-11 18:13	70.6	74.8113	5.965012	407	22-05-11 9:32	79.9	78.9655	-1.16959
333	21-05-11 18:14	67.1	65.50389	-2.37871	408	22-05-11 9:33	83.2	81.77448	-1.71337
334	21-05-11 18:15	66	62.3349	-5.55318	409	22-05-11 9:34	88.5	86.90642	-1.80065
335	21-05-11 18:16	71.3	68.57703	-3.81904	410	22-05-11 9:35	95.1	94.29487	-0.84662
336	22-05-11 8:21	83.5	83.95992	0.550807	411	22-05-11 9:36	93.4	91.18979	-2.36639
337	22-05-11 8:22	82.5	82.83999	0.412103	412	22-05-11 9:37	88.3	87.0004	-1.4718
338	22-05-11 8:23	85.5	85.52317	0.027095	413	22-05-11 9:38	88.3	85.50891	-3.16092
339	22-05-11 8:24	87.5	88.15294	0.746214	414	22-05-11 9:39	95.4	94.62419	-0.81321
340	22-05-11 8:25	98.7	97.64829	-1.06556	415	22-05-11 9:40	88.7	89.96407	1.425155
341	22-05-11 8:26	103.9	102.8357	-1.02438	416	22-05-11 9:41	83.1	87.9558	5.843327
342	22-05-11 8:27	103.7	102.8983	-0.77311	417	22-05-11 9:42	87.8	89.26597	1.669675
343	22-05-11 8:28	102.5	101.8328	-0.65091	418	22-05-11 9:43	85.7	86.48717	0.918514
344	22-05-11 8:29	94.5	93.52755	-1.02905	419	22-05-11 9:44	72	75.25156	4.516058
345	22-05-11 8:30	95	94.47926	-0.54815	420	22-05-11 9:45	85.9	86.71318	0.946659
346	22-05-11 8:31	76.6	76.9819	0.498567	421	22-05-11 9:46	93.1	93.97256	0.937232
347	22-05-11 8:32	77.8	78.51658	0.921057	422	22-05-11 9:47	99.4	100.1426	0.747039
348	22-05-11 8:33	81.5	82.6039	1.354477	423	22-05-11 9:48	91.4	91.39597	-0.00441
349	22-05-11 8:34	78.8	78.72777	-0.09166	424	22-05-11 9:49	89.1	89.87136	0.865725
350	22-05-11 8:35	80.8	77.8978	-3.59183	425	22-05-11 9:50	90.5	89.68355	-0.90215
351	22-05-11 8:36	75.7	74.26532	-1.89522	426	22-05-11 9:51	88.5	88.6241	0.140223
352	22-05-11 8:37	78.9	76.72924	-2.75128	427	22-05-11 9:52	89.9	91.15682	1.398016
353	22-05-11 8:38	85.5	83.53665	-2.29631	428	22-05-11 9:53	90.2	89.62341	-0.63923
354	22-05-11 8:39	93.1	91.98677	-1.19574	429	22-05-11 9:54	86.9	88.13138	1.417014
355	22-05-11 8:40	94.3	93.24035	-1.1237	430	22-05-11 9:55	86.5	86.97679	0.551205
356	22-05-11 8:41	85.7	84.42599	-1.48659	431	22-05-11 9:56	92.3	93.18837	0.962476
357	22-05-11 8:42	91.7	89.80049	-2.07144	432	22-05-11 9:57	95.2	95.86874	0.702456
358	22-05-11 8:43	85.9	84.08596	-2.11181	433	22-05-11 9:58	94.6	95.70547	1.168575
359	22-05-11 8:44	88.1	85.15326	-3.34477	434	22-05-11 9:59	86.7	87.92473	1.412602
360	22-05-11 8:45	92.7	90.71266	-2.14384	435	22-05-11 10:00	95.8	96.69334	0.932506
361	22-05-11 8:46	84.7	83.96245	-0.87077	436	22-05-11 10:01	81.9	82.07461	0.213199
362	22-05-11 8:47	86.1	85.71708	-0.44473	437	22-05-11 10:02	94.9	95.85203	1.003193
363	22-05-11 8:48	82.6	81.83591	-0.92505	438	22-05-11 10:03	100.9	102.2382	1.326246
364	22-05-11 8:49	80.7	79.49805	-1.48941	439	22-05-11 10:04	93.5	93.83939	0.362989
365	22-05-11 8:50	78	75.99373	-2.57214	440	22-05-11 10:05	93.7	94.47985	0.832284
366	22-05-11 8:51	83.4	81.49795	-2.28063	441	22-05-11 10:06	105.8	103.5821	-2.09631
367	22-05-11 8:52	95	95.7084	0.74568	442	22-05-11 10:07	102.1	100.3758	-1.68873
368	22-05-11 8:53	94.4	95.8479	1.533795	443	22-05-11 10:08	99.7	98.759	-0.94383
369	22-05-11 8:54	90.2	90.47933	0.309682	444	22-05-11 10:09	102.6	101.1312	-1.43155
370	22-05-11 8:55	95.3	96.27962	1.027929	445	22-05-11 10:10	104.7	103.5521	-1.09638
371	22-05-11 8:56	94.6	94.73818	0.146065	446	22-05-11 10:11	105.2	103.7214	-1.40554
372	22-05-11 8:57	89.4	90.4968	1.226841	447	22-05-11 10:12	104.2	102.7015	-1.43807
373	22-05-11 8:58	87.5	87.59141	0.104466	448	22-05-11 10:13	103.3	101.9434	-1.31324
374	22-05-11 8:59	105.4	106.3193	0.872165	449	22-05-11 10:14	103.8	102.7734	-0.98903

Min	Sample Time	LAeqSTD	LAeqSYS	ΔLeq	Min	Sample Time	LAeqSTD	LAeqSYS	ΔLeq
450	22-05-11 10:15	101.6	100.0214	-1.55376	525	22-05-11 11:30	88.4	86.46747	-2.18612
451	22-05-11 10:16	98.6	97.56126	-1.05349	526	22-05-11 11:31	83.2	82.33349	-1.04147
452	22-05-11 10:17	103.1	102.1594	-0.91232	527	22-05-11 11:32	90	88.68978	-1.45581
453	22-05-11 10:18	101.7	100.7623	-0.92205	528	22-05-11 11:33	90.2	89.07472	-1.24754
454	22-05-11 10:19	100.5	99.70437	-0.79167	529	22-05-11 11:34	85.2	83.82567	-1.61306
455	22-05-11 10:20	99.5	98.07423	-1.43294	530	22-05-11 11:35	93	92.30585	-0.7464
456	22-05-11 10:21	91.3	92.12116	0.899414	531	22-05-11 11:36	95.3	94.93413	-0.38392
457	22-05-11 10:22	94.4	93.64229	-0.80266	532	22-05-11 11:37	94.3	93.31892	-1.04039
458	22-05-11 10:23	81.8	80.65355	-1.40153	533	22-05-11 11:38	88.5	87.41721	-1.2235
459	22-05-11 10:24	75.5	74.52434	-1.29226	534	22-05-11 11:39	93.1	90.82656	-2.44193
460	22-05-11 10:25	81.8	81.86545	0.080013	535	22-05-11 11:40	89.4	90.13054	0.817164
461	22-05-11 10:26	76.6	76.58527	-0.01923	536	22-05-11 11:41	93.3	96.00772	2.902165
462	22-05-11 10:27	89.8	90.91362	1.240114	537	22-05-11 11:42	89.6	89.76161	0.180367
463	22-05-11 10:28	81.1	80.97851	-0.1498	538	22-05-11 11:43	83.3	82.41679	-1.06028
464	22-05-11 10:29	73.7	72.69412	-1.36483	539	22-05-11 11:44	85.5	86.66102	1.357913
465	22-05-11 10:30	79	81.08871	2.643937	540	22-05-11 11:45	89.3	90.50866	1.353488
466	22-05-11 10:31	79.3	76.59619	-3.4096	541	22-05-11 11:46	88.3	91.41304	3.525524
467	22-05-11 10:32	84.9	83.18313	-2.02223	542	22-05-11 11:47	101.7	102.548	0.833821
468	22-05-11 10:33	92	88.49937	-3.80503	543	22-05-11 11:48	95	95.33606	0.35375
469	22-05-11 10:34	87	84.88334	-2.43294	544	22-05-11 11:49	98.2	96.76146	-1.4649
470	22-05-11 10:35	89.3	87.1158	-2.44591	545	22-05-11 11:50	104.6	103.5631	-0.99126
471	22-05-11 10:36	90.7	88.3361	-2.60629	546	22-05-11 11:51	102.2	100.5999	-1.56563
472	22-05-11 10:37	85.5	83.38078	-2.47862	547	22-05-11 11:52	102	100.877	-1.101
473	22-05-11 10:38	84	82.56467	-1.70872	548	22-05-11 11:53	102.3	100.7824	-1.48349
474	22-05-11 10:39	91	89.81085	-1.30675	549	22-05-11 11:54	103.1	101.9351	-1.1299
475	22-05-11 10:40	92.1	91.49153	-0.66066	550	22-05-11 11:55	104.6	103.5015	-1.05018
476	22-05-11 10:41	94.9	93.74363	-1.21852	551	22-05-11 11:56	104.1	102.8672	-1.18422
477	22-05-11 10:42	83.9	82.83633	-1.26778	552	22-05-11 11:57	104.9	102.9561	-1.85313
478	22-05-11 10:43	85.5	85.59071	0.106096	553	22-05-11 11:58	106.6	104.1922	-2.25869
479	22-05-11 10:44	86.7	87.90475	1.389559	554	22-05-11 11:59	102.6	99.50645	-3.01516
480	22-05-11 10:45	79.2	77.15739	-2.57906	555	22-05-11 12:00	100.7	99.07474	-1.61396
481	22-05-11 10:46	74.9	77.80709	3.881294	556	22-05-11 12:01	103.8	101.7223	-2.00162
482	22-05-11 10:47	75.5	74.48234	-1.3479	557	22-05-11 12:02	106.3	103.3428	-2.78193
483	22-05-11 10:48	88.1	87.78189	-0.36108	558	22-05-11 12:03	100.4	99.66746	-0.72962
484	22-05-11 10:49	90.3	88.15903	-2.37096	559	22-05-11 12:04	100.1	98.77382	-1.32485
485	22-05-11 10:50	89.8	87.90735	-2.10763	560	22-05-11 12:05	91.8	92.0803	0.305339
486	22-05-11 10:51	88.8	87.44613	-1.52462	561	22-05-11 12:06	91	90.12476	-0.9618
487	22-05-11 10:52	88.6	90.15519	1.755297	562	22-05-11 12:07	80.7	79.55395	-1.42014
488	22-05-11 10:53	90.8	92.11103	1.443867	563	22-05-11 12:08	89.9	88.38902	-1.68074
489	22-05-11 10:54	91.8	93.3652	1.705008	564	22-05-11 12:09	91.7	89.53428	-2.36175
490	22-05-11 10:55	94.1	93.90017	-0.21236	565	22-05-11 12:10	84.2	81.89909	-2.73267
491	22-05-11 10:56	92.3	94.36571	2.238041	566	22-05-11 12:11	76.2	74.62976	-2.06069
492	22-05-11 10:57	91.5	93.26771	1.931925	567	22-05-11 12:12	82.4	80.51154	-2.29183
493	22-05-11 10:58	91.5	92.53051	1.12624	568	22-05-11 12:13	85.1	85.0205	-0.09342
494	22-05-11 10:59	94.4	94.79747	0.421053	569	22-05-11 12:14	83.7	85.33436	1.952646
495	22-05-11 11:00	94.6	96.16324	1.652476	570	22-05-11 12:15	88	86.36843	-1.85406
496	22-05-11 11:01	94.2	94.97439	0.822065	571	22-05-11 12:16	80	80.96671	1.208384
497	22-05-11 11:02	103.7	104.8305	1.090188	572	22-05-11 12:17	91.9	90.53316	-1.48731
498	22-05-11 11:03	99	99.50481	0.509906	573	22-05-11 12:18	88.5	86.84007	-1.87563
499	22-05-11 11:04	94.1	93.31631	-0.83283	574	22-05-11 12:19	90.8	88.57581	-2.44955
500	22-05-11 11:05	100.4	99.04137	-1.35322	575	22-05-11 12:20	91.2	89.26408	-2.12272
501	22-05-11 11:06	100.6	99.60966	-0.98444	576	22-05-11 12:21	91.4	89.4229	-2.16313
502	22-05-11 11:07	99.6	98.77276	-0.83056	577	22-05-11 12:22	87.4	85.47697	-2.20026
503	22-05-11 11:08	101.5	100.622	-0.865	578	22-05-11 12:23	87.1	84.79877	-2.64205
504	22-05-11 11:09	100.8	100.1497	-0.64517	579	22-05-11 12:24	83.6	85.08206	1.772797
505	22-05-11 11:10	100.3	100.0263	-0.2729	580	22-05-11 12:25	90.3	87.39189	-3.2205
506	22-05-11 11:11	100.4	100.228	-0.17127	581	22-05-11 12:26	93.3	92.6474	-0.69946
507	22-05-11 11:12	99.8	99.55722	-0.24327	582	22-05-11 12:27	96.3	93.73474	-2.66382
508	22-05-11 11:13	102.9	102.293	-0.58993	583	22-05-11 12:28	93	90.74684	-2.42276
509	22-05-11 11:14	100.9	100.5593	-0.33763	584	22-05-11 12:29	81.4	80.81493	-0.71876
510	22-05-11 11:15	92	91.60796	-0.42613	585	22-05-11 12:30	84.9	82.66666	-2.63055
511	22-05-11 11:16	100.6	99.80285	-0.79239	586	22-05-11 12:31	97.2	97.66379	0.477152
512	22-05-11 11:17	101.1	100.7648	-0.33151	587	22-05-11 12:32	87.7	89.02981	1.516316
513	22-05-11 11:18	102.7	101.3037	-1.35957	588	22-05-11 12:33	91.4	92.58938	1.301286
514	22-05-11 11:19	95	94.90919	-0.09558	589	22-05-11 12:34	93.9	93.92206	0.023491
515	22-05-11 11:20	92.7	92.35883	-0.36804	590	22-05-11 12:35	95.5	94.75921	-0.7757
516	22-05-11 11:21	95.9	96.15509	0.265993	591	22-05-11 12:36	93.1	93.99076	0.956781
517	22-05-11 11:22	80.4	78.16458	-2.78037	592	22-05-11 12:37	93.7	94.12453	0.453074
518	22-05-11 11:23	73.3	72.85786	-0.6032	593	22-05-11 12:38	91.7	92.42961	0.795652
519	22-05-11 11:24	72.7	72.18576	-0.70734	594	22-05-11 12:39	91.6	91.61025	0.011191
520	22-05-11 11:25	69	69.36304	0.526148	595	22-05-11 12:40	88.8	90.92186	2.389476
521	22-05-11 11:26	75.9	77.05756	1.525107	596	22-05-11 12:41	88.7	91.42553	3.072749
522	22-05-11 11:27	73	73.17879	0.244912	597	22-05-11 12:42	95.4	96.77268	1.438873
523	22-05-11 11:28	77.8	76.58918	-1.55633	598	22-05-11 12:43	76.2	77.33622	1.491107
524	22-05-11 11:29	87.8	86.34914	-1.65245	599	22-05-11 12:44	64.2	65.17901	1.524936

Min	Sample Time	LAeqSTD	LAeqSYS	ΔLeq	Min	Sample Time	LAeqSTD	LAeqSYS	ΔLeq
600	22-05-11 12:50	68.6	69.06338	0.675476	675	22-05-11 14:32	85.2	84.99313	-0.2428
601	22-05-11 13:15	74.1	71.72303	-3.20779	676	22-05-11 14:33	80.4	80.70619	0.380839
602	22-05-11 13:16	97.9	103.1141	5.325953	677	22-05-11 14:34	78.4	78.81345	0.527358
603	22-05-11 13:17	98.8	103.1503	4.403155	678	22-05-11 14:35	86.4	87.93187	1.773003
604	22-05-11 13:18	102.3	101.2221	-1.05371	679	22-05-11 14:36	84.2	84.92876	0.865516
605	22-05-11 13:19	106.7	105.8936	-0.75574	680	22-05-11 14:37	79	77.8617	-1.44089
606	22-05-11 13:20	97.8	97.54594	-0.25977	681	22-05-11 14:38	80.2	80.71166	0.63798
607	22-05-11 13:21	99	98.7178	-0.28505	682	22-05-11 14:39	81.4	80.08791	-1.6119
608	22-05-11 13:22	99.8	99.4425	-0.35822	683	22-05-11 14:40	81.5	79.92865	-1.92803
609	22-05-11 13:23	98.7	99.32719	0.635452	684	22-05-11 14:41	75.5	74.41383	-1.43864
610	22-05-11 13:24	98.5	99.3262	0.838785	685	22-05-11 14:42	84	82.8121	-1.41416
611	22-05-11 13:25	98.7	98.59717	-0.10419	686	22-05-11 14:43	83.1	81.4381	-1.99988
612	22-05-11 13:26	95.8	95.91455	0.119567	687	22-05-11 14:44	86.3	84.23588	-2.39179
613	22-05-11 13:27	94.7	95.79885	1.160352	688	22-05-11 14:45	88.5	90.90238	2.714559
614	22-05-11 13:28	99.1	98.93207	-0.16946	689	22-05-11 14:46	94.7	92.09309	-2.75281
615	22-05-11 13:29	97.8	98.07334	0.279492	690	22-05-11 14:47	88.4	85.68673	-3.0693
616	22-05-11 13:30	99.7	99.28777	-0.41347	691	22-05-11 14:48	83.2	81.28038	-2.30724
617	22-05-11 13:31	100.1	99.69203	-0.40756	692	22-05-11 14:49	86	87.0759	1.251045
618	22-05-11 13:32	97.2	97.25886	0.060556	693	22-05-11 14:50	83.6	81.78693	-2.16874
619	22-05-11 13:33	90.5	90.10949	-0.43151	694	22-05-11 14:51	87.7	86.09797	-1.82671
620	22-05-11 13:34	82.2	82.31961	0.145506	695	22-05-11 14:52	91.6	90.45143	-1.2539
621	22-05-11 13:35	75.4	74.77221	-0.83262	696	22-05-11 14:53	89	87.38281	-1.81707
622	22-05-11 13:36	77.2	77.61141	0.532915	697	22-05-11 14:54	87.7	87.06525	-0.72377
623	22-05-11 13:37	80.2	78.32509	-2.33779	698	22-05-11 14:55	85.7	82.79123	-3.39413
624	22-05-11 13:38	80.8	78.70519	-2.59258	699	22-05-11 14:56	86.3	86.12879	-0.19839
625	22-05-11 13:39	83.9	83.63389	-0.31718	700	22-05-11 14:57	92.8	92.01382	-0.84718
626	22-05-11 13:40	86.5	84.49452	-2.31848	701	22-05-11 14:58	94.3	92.66826	-1.73037
627	22-05-11 13:41	78.6	78.45084	-0.18976	702	22-05-11 14:59	86.9	85.53919	-1.56595
628	22-05-11 13:42	86	86.6276	0.729764	703	22-05-11 15:00	82.9	80.35392	-3.07126
629	22-05-11 13:43	85	83.2084	-2.10777	704	22-05-11 15:01	92.1	90.83885	-1.36932
630	22-05-11 13:44	88.3	87.8229	-0.54032	705	22-05-11 15:02	93.4	94.45275	1.127146
631	22-05-11 13:45	84.5	83.4256	-1.27148	706	22-05-11 15:03	91.7	92.66582	1.053236
632	22-05-11 13:46	82.8	81.97834	-0.99234	707	22-05-11 15:04	102.7	103.6134	0.88935
633	22-05-11 13:47	88.7	89.32909	0.709232	708	22-05-11 15:05	94.8	95.5264	0.76624
634	22-05-11 13:48	93.8	94.99372	1.272626	709	22-05-11 15:06	97.4	102.1658	4.893013
635	22-05-11 13:49	93.7	93.72139	0.022833	710	22-05-11 15:07	102.5	101.4545	-1.02004
636	22-05-11 13:50	91.8	92.63636	0.911072	711	22-05-11 15:08	98.5	100.947	2.484288
637	22-05-11 13:51	87	86.81058	-0.21772	712	22-05-11 15:09	93.5	95.19328	1.810998
638	22-05-11 13:52	84.7	83.55173	-1.35569	713	22-05-11 15:10	88.5	89.34789	0.958073
639	22-05-11 13:53	72.8	72.52562	-0.3769	714	22-05-11 15:11	95.6	94.91094	-0.72078
640	22-05-11 13:54	72.5	72.00541	-0.68219	715	22-05-11 15:12	100.4	99.56525	-0.83143
641	22-05-11 13:55	92	89.39073	-2.83616	716	22-05-11 15:13	103.4	102.2148	-1.14623
642	22-05-11 13:56	78.3	75.01597	-4.19416	717	22-05-11 15:14	103.5	102.7676	-0.70763
643	22-05-11 13:57	88.7	86.70666	-2.24728	718	22-05-11 15:15	106.4	105.2931	-1.04032
644	22-05-11 13:58	80.9	80.52792	-0.45992	719	22-05-11 15:16	103.5	102.3335	-1.12706
645	22-05-11 13:59	85.9	88.45922	2.9793	720	22-05-11 15:17	104.7	102.6287	-1.9783
646	22-05-11 14:00	84.9	83.14271	-2.06983	721	22-05-11 15:18	101.6	100.0942	-1.48204
647	22-05-11 14:01	85.6	84.87961	-0.84158	722	22-05-11 15:19	103	101.9912	-0.97943
648	22-05-11 14:02	88.8	86.86651	-2.17735	723	22-05-11 15:20	104.9	101.7393	-3.01302
649	22-05-11 14:03	87.9	90.48554	2.941452	724	22-05-11 15:21	93.5	94.1782	0.725347
650	22-05-11 14:04	80.4	80.87334	0.588727	725	22-05-11 15:22	101	100.2825	-0.71039
651	22-05-11 14:05	65.8	67.48024	2.553557	726	22-05-11 15:23	100.7	100.2703	-0.42669
652	22-05-11 14:06	69.1	71.19423	3.03072	727	22-05-11 15:24	100.5	100.2606	-0.23819
653	22-05-11 14:10	73.7	75.96636	3.075119	728	22-05-11 15:25	95.8	96.39098	0.616886
654	22-05-11 14:11	76	73.03581	-3.90025	729	22-05-11 15:26	89.8	87.84096	-2.18156
655	22-05-11 14:12	72.5	71.50663	-1.37017	730	22-05-11 15:27	69.6	68.89799	-1.00863
656	22-05-11 14:13	90.4	90.72765	0.36245	731	22-05-11 15:28	73.6	71.93027	-2.26865
657	22-05-11 14:14	93.4	93.27033	-0.13884	732	22-05-11 15:29	76.4	77.25948	1.12498
658	22-05-11 14:15	96.6	96.16906	-0.44611	733	22-05-11 15:30	92.7	93.78676	1.172336
659	22-05-11 14:16	96.1	96.39929	0.311436	734	22-05-11 15:31	99.7	99.18704	-0.5145
660	22-05-11 14:17	97.2	97.25205	0.053549	735	22-05-11 15:32	83.9	86.91755	3.596609
661	22-05-11 14:18	97.4	97.6479	0.254515	736	22-05-11 15:33	87.8	86.55039	-1.42325
662	22-05-11 14:19	100.4	100.5173	0.116856	737	22-05-11 15:34	90.1	88.65242	-1.60664
663	22-05-11 14:20	97.6	97.98601	0.395503	738	22-05-11 15:35	86.9	84.39002	-2.88835
664	22-05-11 14:21	97.8	97.87606	0.077775	739	22-05-11 15:36	87.4	87.5398	0.159952
665	22-05-11 14:22	97.2	97.15832	-0.04288	740	22-05-11 15:37	92.1	93.61475	1.644683
666	22-05-11 14:23	96.4	96.70087	0.312106	741	22-05-11 15:38	94.1	92.52103	-1.67797
667	22-05-11 14:24	94.5	94.87108	0.392679	742	22-05-11 15:39	93.2	93.61214	0.442214
668	22-05-11 14:25	81.2	82.2873	1.339041	743	22-05-11 15:40	84.1	83.48377	-0.73274
669	22-05-11 14:26	96	97.44325	1.503389	744	22-05-11 15:41	88.1	87.02414	-1.22118
670	22-05-11 14:27	100.5	100.0402	-0.45753	745	22-05-11 15:42	88.3	93.15756	5.501203
671	22-05-11 14:28	97.7	98.06757	0.37622	746	22-05-11 15:43	91.1	91.03698	-0.06918
672	22-05-11 14:29	98.4	98.52585	0.127901	….	….	….	….	….
673	22-05-11 14:30	96.5	97.7124	1.256373	….	….	….	….	….
674	22-05-11 14:31	95.6	96.2586	0.688917	….	….	….	….	….

CEL-35X Result Data - 811029 - 14-Jun-11 8:49:44 AM

Summary | Profile

Proj Dose Duration HH:MM	08:00
Pa2Sec	4896.0
Dose% (Q3 C=85 T1=0)	134.6%
Dose% (Q3 C=85 T2=0)	134.6%
LAE	130.9 dB
LCeq	---.-
LCeq - LAeq	---.-
Proj Dose (Q3 C=85 T1=0)	125.4%
Proj Dose (Q3 C=87 T1=0)	79.1%
Start Date & Time	14-Jun-11 8:49:44 AM
Duration HH:MM:SS	08:35:07
Notes	
LAeq	86.0 dB
Cpeak	133.8 dB
Lepd	86.3 dB
Lex8h	86.3 dB
Pa2Hrs	1.36
Dose% (Q3 C=85)	134.6%
Cal (before) SPL	114.0 dB
Overload	No
Proj Dose (Q3 C=80 T1=0)	396.6%

Summary of result data by noise dosimeter CEL350 dBage

CEL-35X Result Data - 811029 - 14-Jun-11 8:49:44 AM

Summary | Profile

Sample Time	CPeak	LAeq	Notes
14-Jun-11 9:16:44 AM	109.8 dB	84.2 dB	
14-Jun-11 9:17:44 AM	132.0 dB	92.1 dB	
14-Jun-11 9:18:44 AM	114.5 dB	81.8 dB	
14-Jun-11 9:19:44 AM	112.9 dB	82.7 dB	
14-Jun-11 9:20:44 AM	112.2 dB	81.1 dB	
14-Jun-11 9:21:44 AM	108.4 dB	80.4 dB	
14-Jun-11 9:22:44 AM	113.3 dB	83.1 dB	
14-Jun-11 9:23:44 AM	131.2 dB	95.6 dB	
14-Jun-11 9:24:44 AM	125.0 dB	92.2 dB	
14-Jun-11 9:25:44 AM	123.5 dB	92.8 dB	
14-Jun-11 9:26:44 AM	110.5 dB	80.8 dB	
14-Jun-11 9:27:44 AM	126.7 dB	97.9 dB	
14-Jun-11 9:28:44 AM	116.3 dB	93.6 dB	
14-Jun-11 9:29:44 AM	132.2 dB	101.8 dB	
14-Jun-11 9:30:44 AM	117.2 dB	85.8 dB	
14-Jun-11 9:31:44 AM	109.3 dB	80.0 dB	
14-Jun-11 9:32:44 AM	106.8 dB	80.9 dB	
14-Jun-11 9:33:44 AM	129.0 dB	87.3 dB	
14-Jun-11 9:34:44 AM	121.4 dB	85.8 dB	
14-Jun-11 9:35:44 AM	106.1 dB	81.8 dB	
14-Jun-11 9:36:44 AM	98.5 dB	67.3 dB	

Equivalent noise level in minute scale by noise dosimeter CEL350 dBage

Case 1: Piling with drop hammer (Original)

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.977[a]	.955	.955	2.39237	.955	1.089E5	1	5172	.000

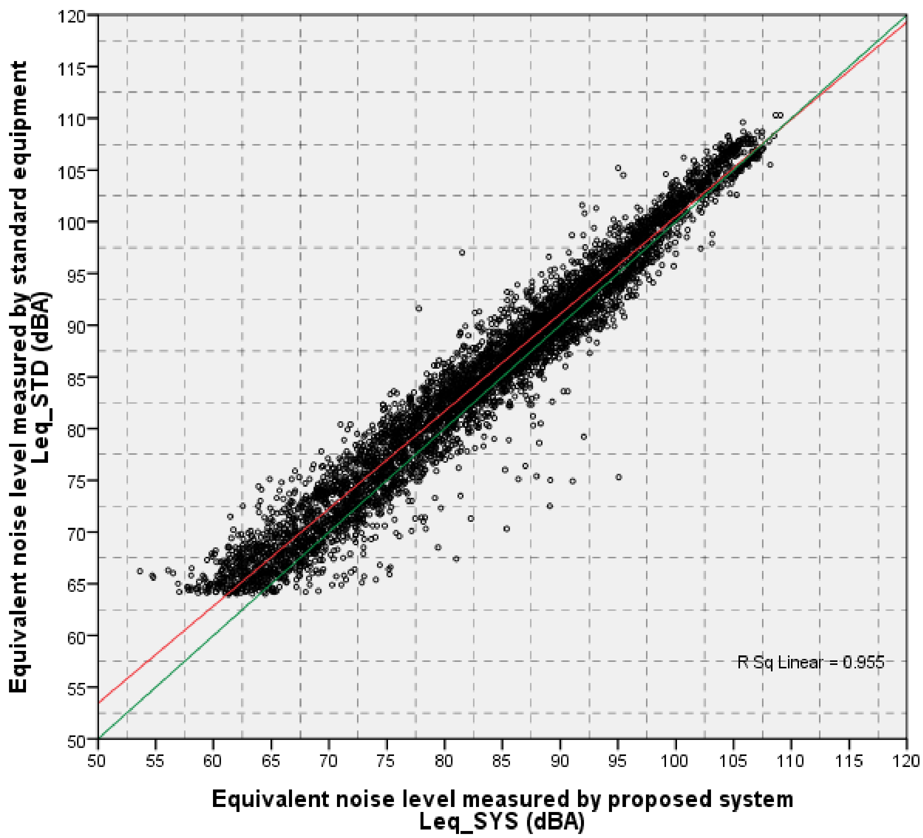
a. Predictors: (Constant), LAeq_Sys

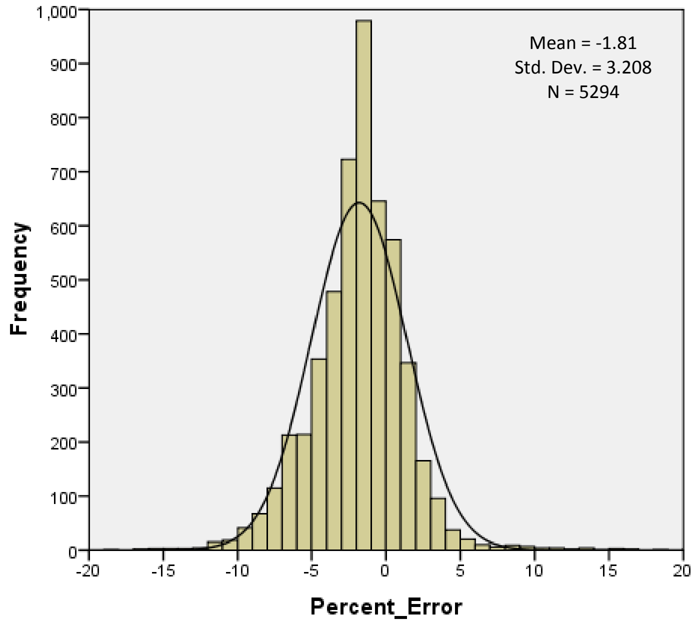
b. Dependent Variable: LAeq_ND

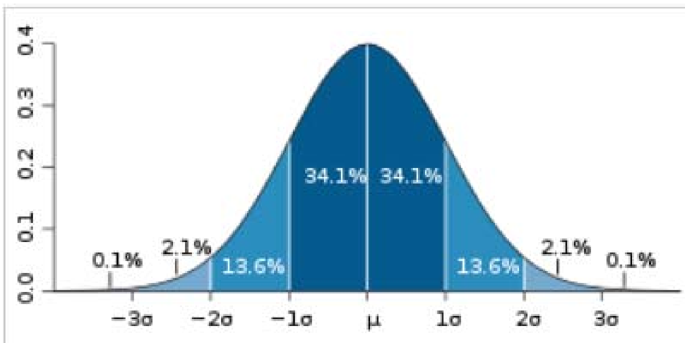
Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	6.402	.240		26.730	.000					
	LAeq_Sys	.941	.003	.977	329.988	.000	.977	.977	.977	1.000	1.000

a. Dependent Variable: LAeq_ND







Item	Confident level	Lower bound	Mean	Upper bound
μ±σ	68%	-5.02	-1.81	1.40
μ±2σ	95%	-8.23	-1.81	4.61
μ±3σ	99%	-11.43	-1.81	7.81

Case 2: Bored pile (Original)

Model Summary

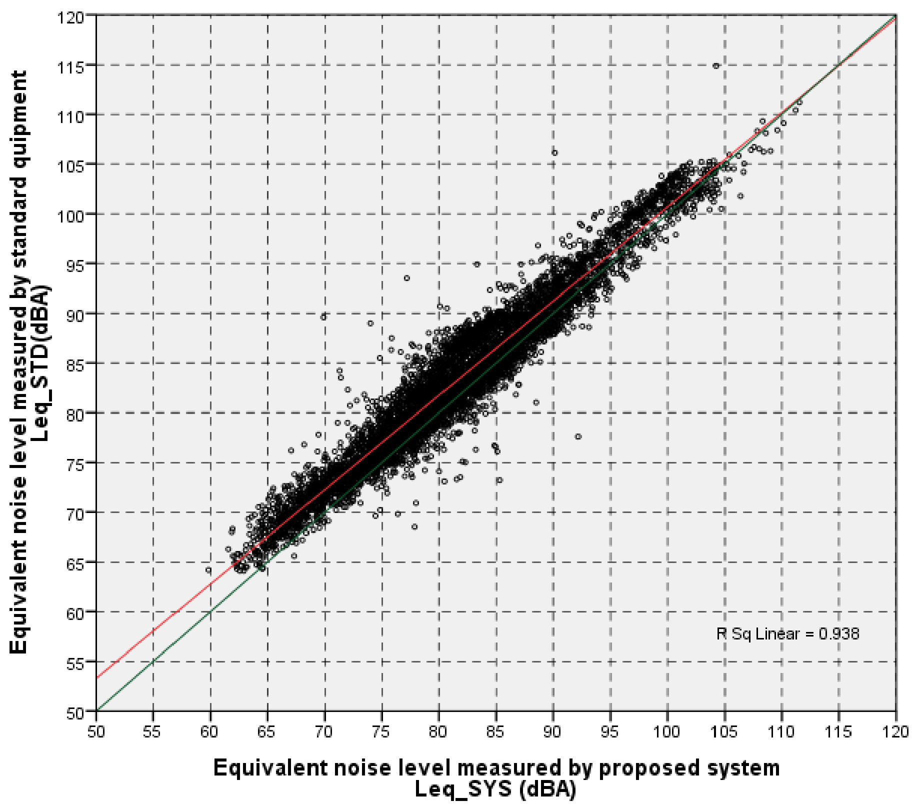
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.968[a]	.938	.938	2.12491	.938	9.364E4	1	6199	.000

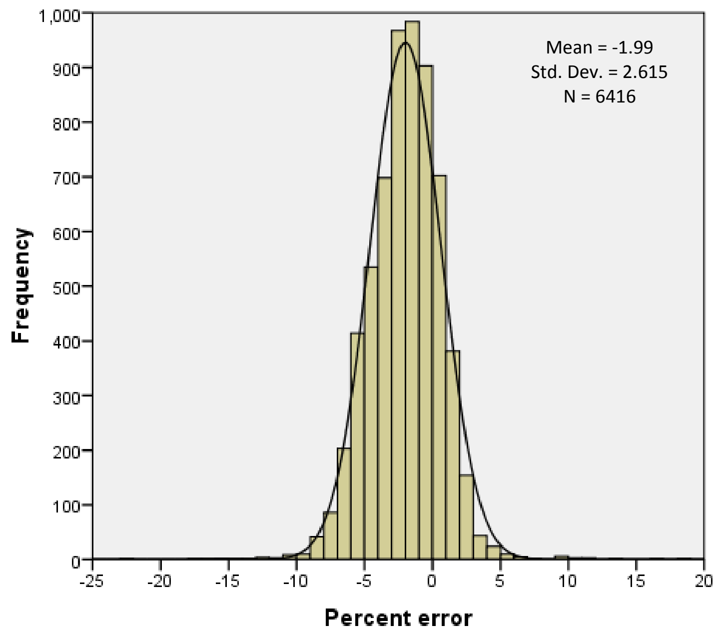
a. Predictors: (Constant), LAeqSys

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	5.905	.255		23.189	.000	5.405	6.404					
	LAeqSys	.948	.003	.968	306.014	.000	.942	.954	.968	.968	.968	1.000	1.000

a. Dependent Variable: LAeqND





Item	Confident level	Lower bound	Mean	Upper bound
μ±σ	68%	-5.20	-1.99	1.22
μ±2σ	95%	-8.4	-1.99	4.43
μ±3σ	99%	-11.62	-1.99	7.63

Case 1: Piling with drop hammer (Adjustment 1.6)

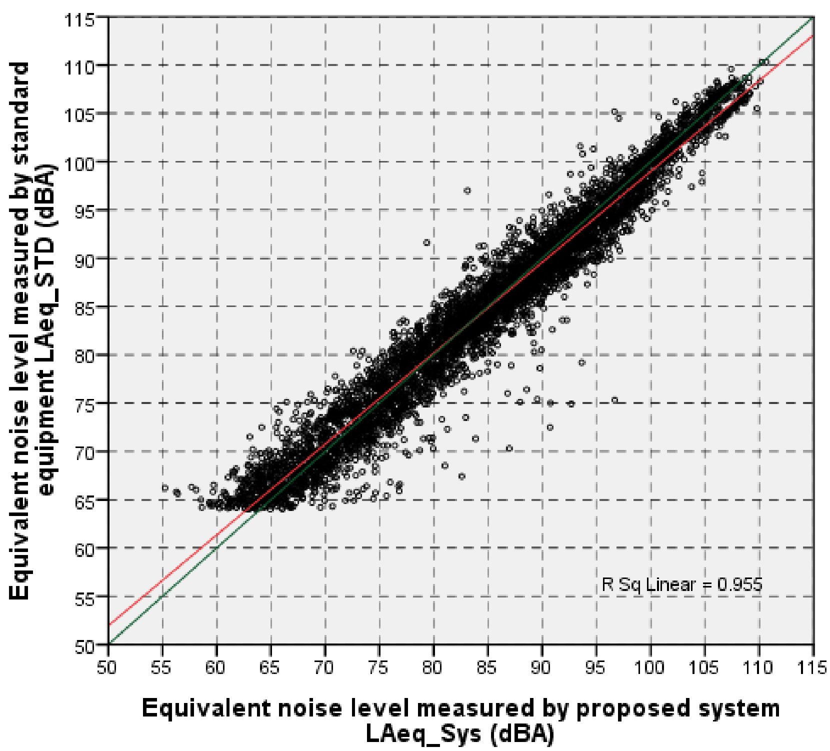
Model Summary

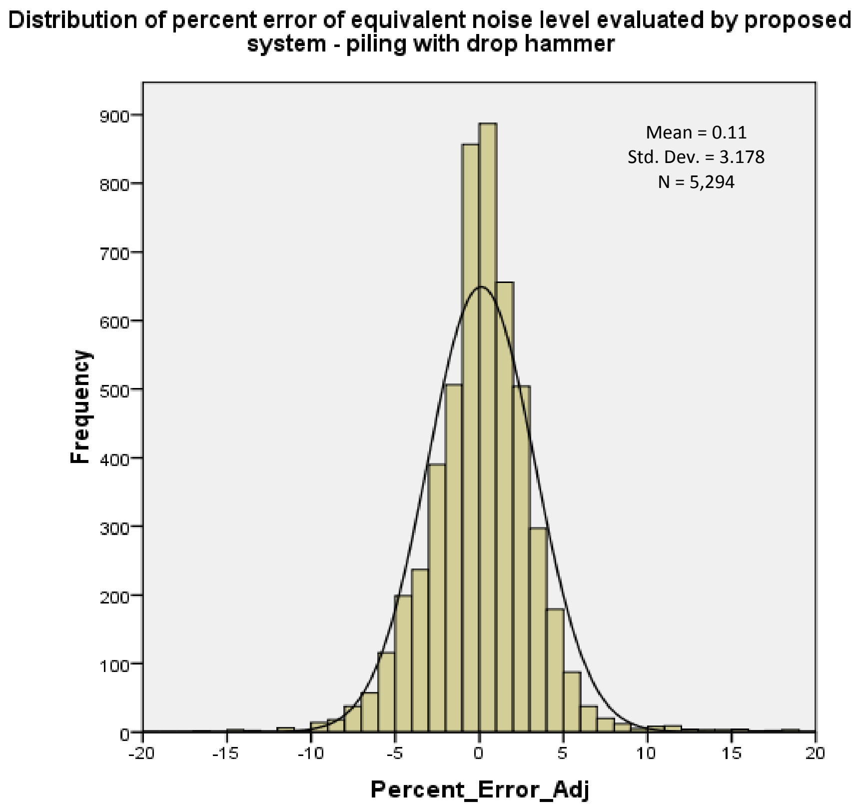
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.977[a]	.955	.955	2.39235	.955	1.089E5	1	5172	.000

a. Predictors: (Constant), LAeq_Sys_Adj_1.6

Model	Unstandardized Coefficients		Standardized Coefficients	t	95% Confidence Interval for B		Correlations			Collinearity Statistics	
	B	Std. Error	Beta		Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1 (Constant)	4.896	.244		20.064	4.418	5.375					
LAeq_Sys_Adj_1.6	.941	.003	.977	329.990	.935	.946	.977	.977	.977	1.000	1.000

a. Dependent Variable: LAeq_ND





Item	Confident level	Lower bound	Mean	Upper bound
μ±σ	68%	-3.068	0.11	3.288
μ±2σ	95%	-6.246	0.11	6.466
μ±3σ	99%	-9.424	0.11	9.644

Case 2: Bored pile (Adjustment 1.6)

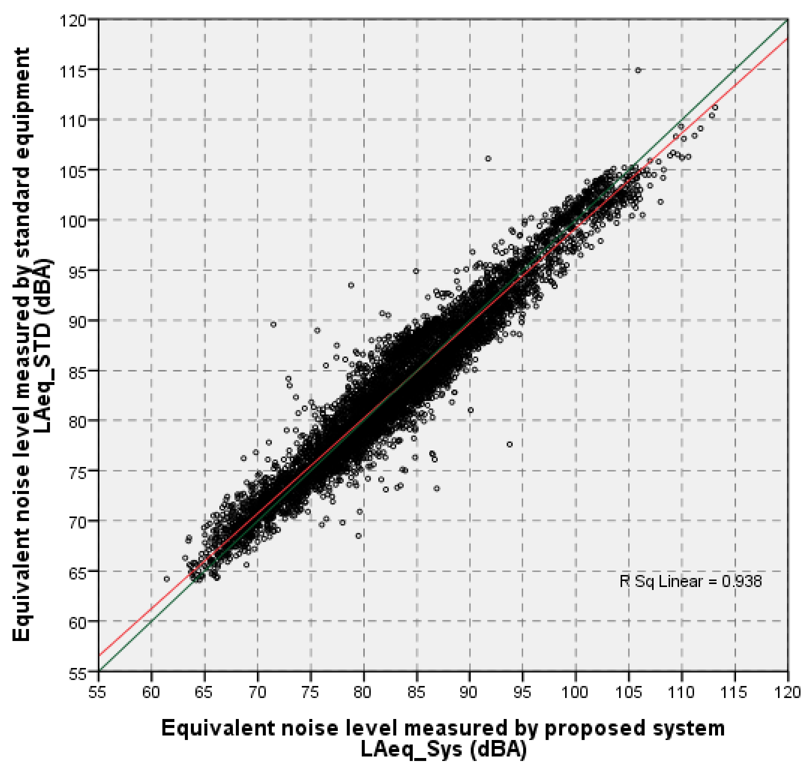
Model Summary

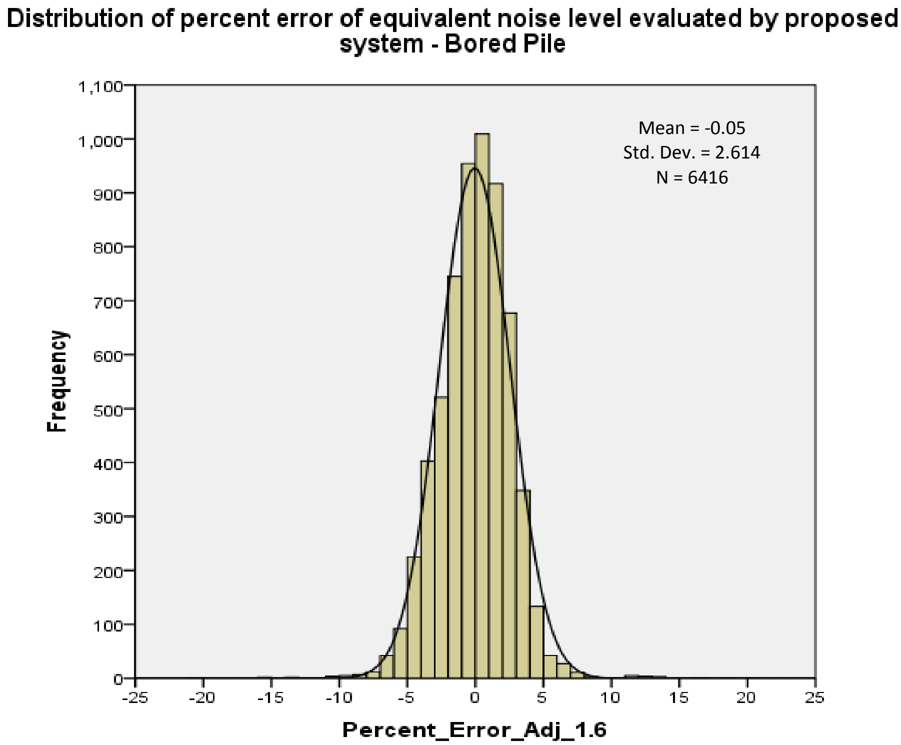
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.968[a]	.938	.938	2.12489	.938	9.365E4	1	6199	.000

a. Predictors: (Constant), LAeqSys_Adj_1.6

Model	Unstandardized Coefficients		Standardized Coefficients	t	95% Confidence Interval for B		Correlations			Collinearity Statistics	
	B	Std. Error	Beta		Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1 (Constant)	4.388	.260		16.905	3.879	4.897					
LAeqSys_Adj_1.6	.948	.003	.968	306.017	.942	.954	.968	.968	.968	1.000	1.000

a. Dependent Variable: LAeqND

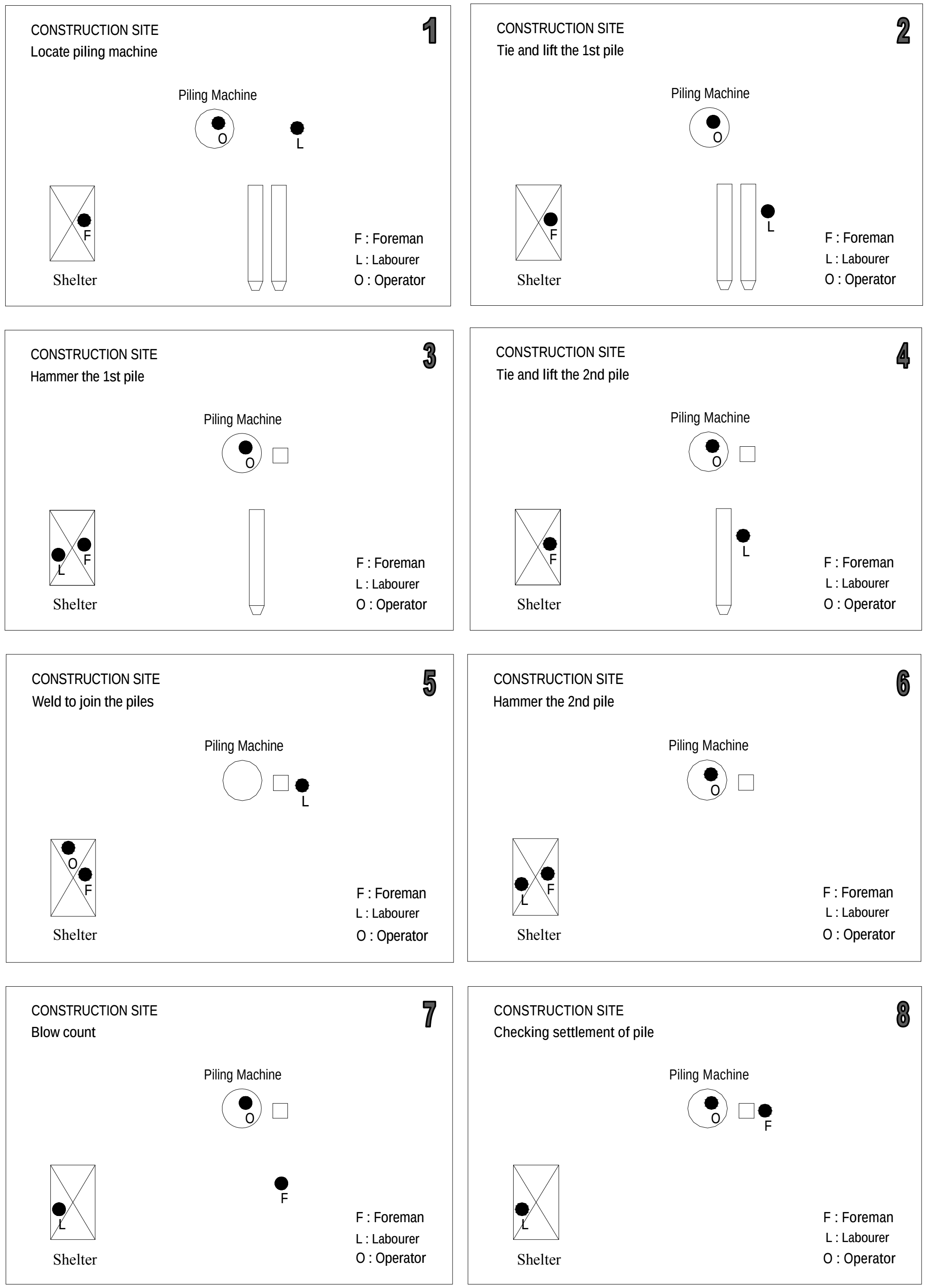




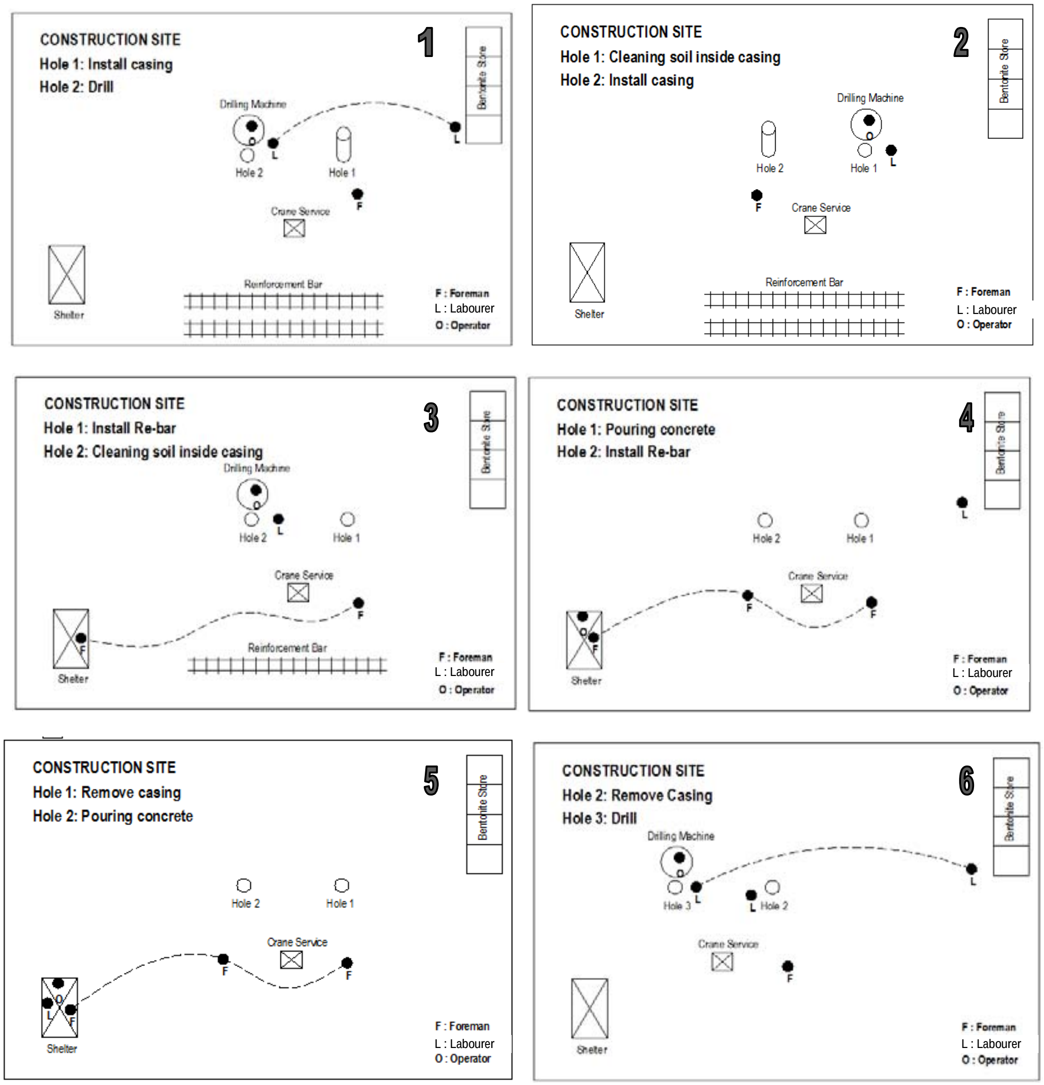
Item	Confident level	Lower bound	Mean	Upper bound
$\mu \pm \sigma$	68%	-2.664	-0.05	2.564
$\mu \pm 2\sigma$	95%	-5.278	-0.05	5.178
$\mu \pm 3\sigma$	99%	-7.892	-0.05	7.792

APPENDIX E

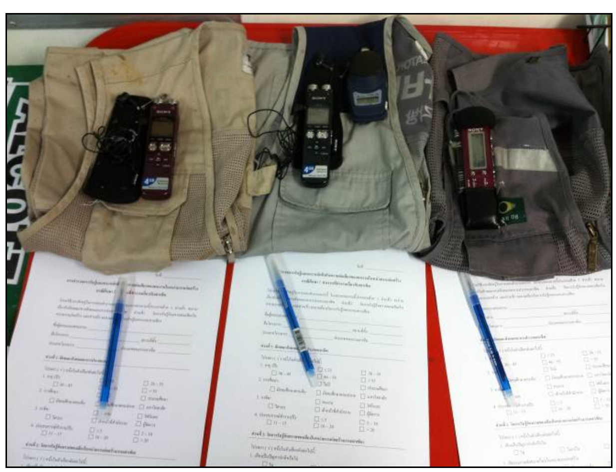
Piling operation and Photo at construction site



Main activities of drop hammer piling operation at construction site



Main activities of bored piling operation at construction site



Instruments and Survey questionnaire used for sampling data

Attachment of instruments with construction workers

Position of foreman under shelter in drop hammer piling operation

Position of foreman, labourer and machine operator in drop hammer piling operation

Machine operator in drilling work of bored piling operation

Labourer position near betonite storage during drilling work

Foreman inspecting drilling work in bored piling operation

BIOGRAPHY

Varin Chan was born in 1986 in Battambang province, Cambodia. He finished high school in 2004 at Phreah Monivong High school in Battambang province. In the same year, he came to Phnom Penh, the capital city of Cambodia, and passed the entrance exam to pursue his study at the Institute of Technology of Cambodia (ITC) where he earned his Bachelor of Engineering in 2009. He studied in Department of Civil Engineering, Institute of Technology of Cambodia. Soon after he graduated, he was awarded AUN/SEED-Net scholarship to continue his Master's study in field of construction engineering and management, Department of Civil Engineering, Faculty of Engineering, Chulalongkorn University, Thailand in 2009. Upon graduation, Varin plans to pursue his Ph.D. in construction engineering and management with the research interest of infrastructure management before returning to work in Cambodia.