FEASIBILITY STUDY OF USING CRUMB RUBBER AS FILLER IN NOISE BARRIER WALL

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by

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CERTIFICATION OF APPROVAL

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Approved by,

Mr. Kalaikumar a/l Vallyutham

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TRONOH, PERAK

June 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

ROSHAZLIN BINTI RASHID

ABSTRACT

Recent development in automobile sector has increased the use of car as the main mode of transportation thus tremendously boosted tyres production. This situation has led to generation of massive stockpiles of used tyres which resulted in uncountable environmental implications since they are non-biodegradable. Therefore, this study is conducted aiming to recycle used tyres in the form of crumb rubber by producing a prototype noise barrier wall which used crumb rubber as the filler. The experimental study focused primarily on the capability of the crumb rubber noise barrier wall to reduce noise. The methodologies adopted in this study consist of four stages. First, field investigation was conducted to obtain the average traffic noise and noise reduction value. Then, sieve analysis was carried out to determine the percentage of crumb rubber passing sieve no. 3.35 mm and 600 μm as these sizes will be used as filler in the noise barrier wall. Next, a prototype noise barrier wall of dimension 1200 mm x 1000 mm was constructed in a laboratory using hollow concrete blocks. The crumb rubber noise barrier wall was built in four different arrangements to see the differences of noise reduction value between noise barrier wall with and without side wall, noise barrier wall with and without crumb rubber filler and noise barrier wall with sealed and unsealed joints. After that, sound reduction testing was conducted for each arrangement. The results obtained indicated that different arrangements yielded different noise levels. More importantly, the results proved that crumb rubber do has potential in absorbing noise. In the end of the study, it can be concluded that crumb rubber could be used as filler for noise barrier wall to reduce traffic noise as it is capable of absorbing noise.

ACKNOWLEDGEMENT

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CHAPTER 1
INTRODUCTION

This report presents the details of the feasibility study of using crumb rubber as filler for noise barrier wall. This introduction describes the background of this research, the problem concerned which led to the study, the research objectives as well as scope of the study.

1.1 Background of Study

1.1.1 Noise Barrier Wall

Noise barrier is one of the approaches for controlling highway noise. It is specially built to reduce noise levels created by surrounding traffic hence improving quality of life for people living behind it. According to Federal Highway Administration (FHWA) (2009), noise barrier wall must meet the following conditions:

- They must not create a safety or engineering problem
- They must be able to reduce noise level by at least 5 dB for the impacted properties that the noise wall protects

Noise barriers reduce the sound by absorbing the sound, transmitting it, reflecting it, or forcing it to take a longer path over and around the barrier.

To effectively achieve a 5 dB noise level reduction, a noise barrier must be tall and long enough to break the line-of-sight from the highway to the home or receiver. After it breaks the line-of-sight, it manages to reduce approximately 1.5 dB of additional noise level for each meter of the wall height. The relationship between line-of-sight and ability to reduce noise is represented in Figure 1.1 (FHWA, 2009).

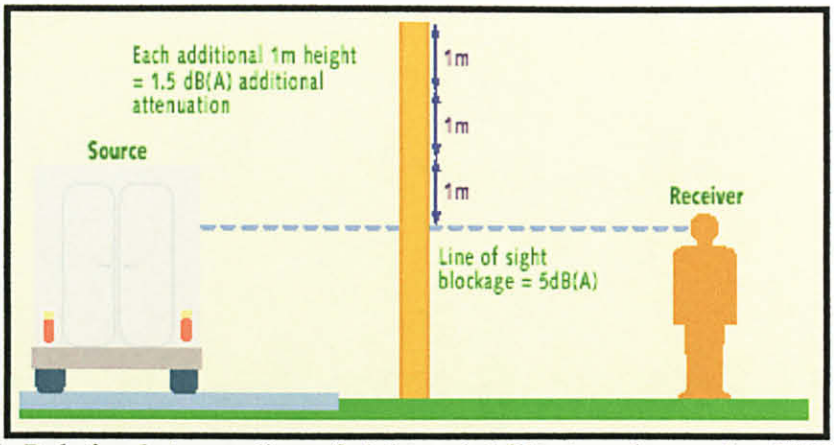

Figure 1.1: Relation between line-of-sight and ability to reduce noise (FHWA, 2009)

Besides that, a barrier should be at least eight times the distance from the home or receiver for it to effectively reduce the noise coming around its ends as demonstrated in Figure 1.2 below (FHWA, 2009).

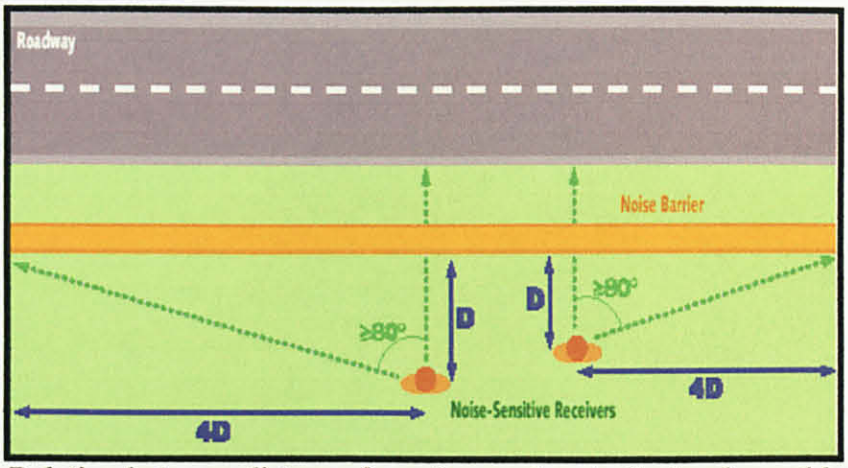

Figure 1.2: Relation between distance from the receiver to the barrier and barrier length (FHWA, 2009)

Apart from that, openings in noise barriers for driveway connections or intersecting streets are not preferred as they will compromise noise barrier's effectiveness. Noise barriers are normally most effective in reducing noise for the first row of homes which are approximately 61 meters from the highway.

According to World Health Organization (WHO), noise limits for community environment is 55 dBA daytime and 45 dBA nighttime. Meanwhile, Malaysian DOE guidelines stated that they are 55 dBA daytime and 50 dBA nighttime. As for indoor/domestic areas, WHO recommended noise limits of 45 dBA daytime and 35 dBA nighttime. To date, there is no Malaysian recommended indoor noise limits (Yusoff & Ishak, 2005).

1.1.2 Crumb Rubber

Crumb rubber is produced by grinding the scrap tyres of cars, trucks, buses and other transporter tyres. Each type of tyres is different with regard to constituent materials, especially natural and synthetic rubber contents (Ganjian, Khorami & Maghsoudi, 2008). The manufacturing process of crumb rubber consists of three steps. The first step is sorting and selecting only those parts which have been manufactured without radial steel components which are unsuitable for the grinding process that follows. The second step is the grinding process. Rubber pieces are fed into the cutting wheel repeatedly until the desired particle size has been achieved. The most widely used processes for grinding are the ambient process and cryogenic process. In the ambient process, chunks of tyres are shredded at ambient temperature using flying knives attached to a rotor. The gradation of the crumb rubber produced is controlled by attached screens which separate the product by size. In the cryogenic process, the tyres chunks are crushed after being subject to freezing conditions using liquid nitrogen (Shatanawi, 2008). Lastly, the third and final step is sorting the crumb rubber by particle size (Sokuntasukkul, 2008).

1.2 Problem Statement

Recent development in automobile sector has increased the use of car as the main mode of transportation thus tremendously boosted tyres production. This situation has led to generation of massive stockpiles of used tyres. Ganjian et al. (2008) in their research had also agreed with this.

In Malaysia, the production of mobile used tyres has been constantly increasing each year. It is estimated that 8.2 million or approximately 57391 tonnes of mobile used tyres were generated annually (Kumar, 2006). The same increment has also occurred at other parts of this world such as Thailand, Dubai, United Kingdom, USA and many more countries. The piling of used tyres in USA is shown in Figure 1.3.

Figure 1.3: Oxford tyres piles, Westley, California 1999 (http://carbonpressure.dmau.com/)

According to Kumar (2006), 40% of the used tyres were dumped in landfills. What to do with the disposed tyres becomes a problem for environmental protection more and more each day. This is due to the fact that the standard method with dealing with trash in Malaysia is burying it in landfills. It became evident now that this way of dealing with garbage has drawbacks when used on a massive scale. The major problem resulting from this method is finding enough space for the trash. While the number of landfills has significantly decreased, the flow of refuse continues to increase hence causing the remaining landfills straining to meet the need. Due to that, recycling is proven to be an important supplement to the commonly used refuse disposal method. The idea is simple and straightforward. The more materials that are recycled, the fewer are left to bury (Jamgocian, 1997).

Meanwhile, the other 60% of the used tyres were disposed through uncertain ways. These improper ways of disposing used tyres have resulted in environmental implications. Besides that, the fact that tyre is composed of ingredients that are non-degradable in nature at ambient conditions has also contribute to these environmental mal-effects. Among them are mosquito breeding, air pollution associated with open burning of tyres (particulates, odour, visual impact, and other harmful contaminants such as polycyclic aromatic hydrocarbon, dioxins, furans and oxides of nitrogen), aesthetic pollution caused by waste tyre stockpiles and illegal waste tyre dumps (habitat for vermin such as rat and snake) and other effects such as alteration in hydrological regime when gullies and watercourses become dumping sites (Kumar, 2006).

It appears that the best way to solve this problem is to recycle waste materials generally and used tyres specifically. By recycling, landfill voids could be increased and the environmental mal-effects could be reduced. These used tyres which are also known as scrap tyres could be utilized various products thus saving in the virgin materials. The first step in recycling used tyres is to re-process (shred) them into small pieces with the fiber and metal removed, which is called crumb rubber (Zhu et al., 1999).

Crumb rubber can be used in a wide variety of rubber material applications. Research projects on how to use crumb rubber in different applications have been extensively carried out since the early 1990s (Ganjian et al., 2008). In the last decade, significant researches and developments have been conducted for the applications of crumb rubber in asphaltic pavement layers. Besides that, the uses of crumb rubber as cement replacement and aggregate replacement in concrete have also been studied.

1.3 Objectives

The purpose of this study is to recycle the used tyres which would normally end up in a landfill and become a wasted resource. The used tyres could be grinded and produced as crumb rubber that can be reused. The objectives of this study are:

- To introduce a new green product in highway field by recycling used tyres
- To use crumb rubber brick wall to replace conventional noise barrier brick wall
- To study the potential of crumb rubber in reducing highway noise

1.4 Scope of Study

In this study, a prototype noise barrier wall which consists of crumb rubber as filler was constructed. A field investigation was conducted to obtain the average value of traffic noise. Noise levels in front of and behind the noise barrier wall along Jalan Sultan Azlan Shah were measured. Then, a prototype crumb rubber noise barrier wall of dimension 1200 mm x 1000 mm was built using standard hollow concrete blocks. The blocks' voids were filled with crumb rubber. A laboratory setting was used to construct the wall. The wall was constructed in four different settings which will be explained later on in this report. A similar noise level to real traffic noise was created. Then, the level of noise reduced by the noise barrier wall was measured using a manual sound level meter.

CHAPTER 2
LITERATURE REVIEW

A considerable number of literatures have been gathered and reviewed to collect all related information in order to proceed with this study. The literature review is separated into three parts where the first part covers the theory related to sound and noise, the second part is continued with the researches related to noise barrier wall while the third part explained current application and contribution of crumb rubber.

2.1 Sound and Noise

Sound is defined as a disturbance of mechanical energy that propagates through a medium as a wave. Sound propagates as waves of alternating pressure. This condition cause local regions of compression (increase in density) and decompression (reduction in density). Sound is characterized by the generic properties of waves; frequency, wavelength, period, amplitude, speed, and direction. Due to that, sound can also be described as a vibration transmitted through a solid, liquid or gas which composed of different frequencies capable of being identified by organs of hearing. An average human ear can detect frequencies ranges from 20 to 20000 Hz with mostly sensitive between 500 and 4000 Hz. Sounds below 20 Hz are infrasound and above 20000 Hz are ultrasound at which both are not detectable to the human ear. From a practical point of view, approximately 1000 Hz can be considered to be the middle frequency the human ear is mostly sensitive to.

Numerous literatures define noise as unwanted and/or excessive sound. It can cause discomfort and has the potential to cause severe physical and psychological damages. The amplitude of noise is expressed in terms of sound pressure level (SPL) using a logarithmic scale and is reported in decibels (dB).

The definition of sound pressure level is:

$$SPL = 10 \log_{10} (P^2/P^2_{ref})$$

where P is the sound pressure of concern, and P_{ref} is the standard reference sound pressure in air (20×10^{-6} Pa). Sound levels are measured by meters and their unit is called decibel (dB) (Shatanawi, 2008).

In highway traffic noise, an adjustment called "A-weighted levels" is used. Scientific researchers have proven that the A-weighted network weights the contribution of sounds of different frequencies as simulated by the response of an average human ear whereby the acoustic spectrum of traffic noise composes of multiple frequencies ranging between 250 Hz and 5000 Hz (Yusoff & Ishak, 2005).

The human ear is exposed to varied sources of noise during the daily activities. Some of the noise types and their effects on health are presented in Table 2.1 (Shatanawi, 2008)

.

Table 2.1: Sound levels of different sources and their effects on human health (Shatanawi, 2008)

Sound Source (Distance from source)	Sound Level (dBA)	Effects
Space rocket launch	140	Serious hearing damage
Jet engine (25 m)	130	Hearing damage and pain
Air-raid alarm (5 m)	120	Hearing damage after short exposure
Rock music concert (close to stage)	110	Serious hearing damage hazard
Jet plane take off (300 m)	100	Serious hearing damage hazard
Noisy industrial hall	90	Some hearing hazard
Heavy truck, 70 km/hr (10 m)	80	Health effect
Car, 60 km/h (10 m)	70	Some health effect, severe annoyance
Normal conversation (1 m)	60	Annoyance
Quiet conversation (1 m)	50	Some annoyance
Subdued radio music	40	Good environment
Whispering (1m)	30	
Quiet bedroom	20	
Rustling leave	10	
Anechoic room for sound measurements	0	Uncomfortably quiet

2.2 Noise Barrier Wall

2.2.1 Noise Barrier Wall Using Recycle Material

A study had been done by Jamgocian (1997) where the acoustic properties of concrete blocks filled with recycle material are investigated. He had developed noise barrier with a concrete block design which incorporated recycle material as filler in specially designed voids. Foam products, paper, fiberglass and other type of materials were used as a filler material in uniquely design void spaces in the concrete block. In this study, the author put emphasis on using recycled foam products since they can take up large volume and very light in weight. Furthermore, foam seems to have good noise absorption qualities. The acoustic qualities tested for were the Sound Transmission Loss and Sound Absorption Coefficient. The results show that at the frequency of 125 Hz, the best performing material above all is the fiberglass however only by negligible amount of 1 dB on the average as shown in Figure 2.1 (Jamgocian, 1997). Since the fiberglass is very expensive and hard to recycle, it would be much economical to use other materials (Jamgocian, 1997).

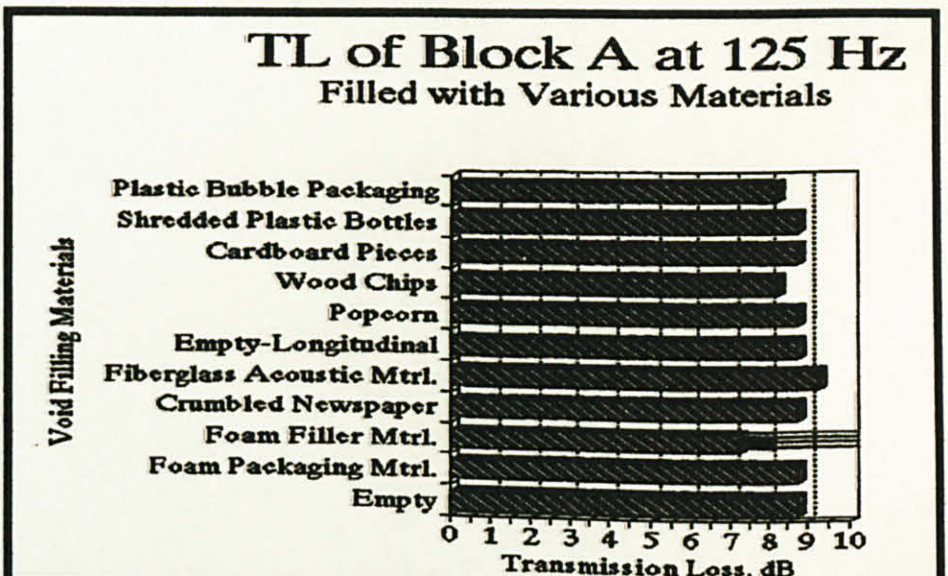

Figure 2.1: Overall transmission analysis at 125 Hz (Jamgocian, 1997)

2.3 Application of Crumb Rubber

2.3.1 Application of Crumb Rubber for Noise Barrier Wall

In investigating the application of crumb rubber for noise barrier wall, the research conducted by Zhu et al. (2008) is referred. Their paper presents a study of crumb rubber blends aiming at the application in noise reduction. The main issues addressed by them are the fabrication method in making crumb rubber blends, the tensile strength measures, measurement of the coefficient of acoustic absorption (AAC), surface textures of crumb rubber blends, analytic analysis on AAC and noise absorption. In this study, four different types of mat specimens for measuring AAC had been prepared. The first type (Type-1) is made by the spray method and the second type (Type-2) is made by the moisture curing method. Both specimens' surfaces are flat. Both the third type (Type-3) and fourth type (Type-4) are by the moisture curing method. However, Type-3 surface is grooved with its orientation being unilaterally directional and discontinued sidewise by one strip width while Type-4 is a variation out of Type-3 by reorienting the grooves in a bi-directional fashion. The objective of having various surfaces is to find out whether the surface texture will affect AAC. The noise reduction coefficients (NRC) for Type-1, Type-2, Type-3 and Type-4 specimens are 0.35, 0.25, 0.3 and 0.3 respectively. In the end, Zhu et al. (2008) concluded that Type-1 specimen has the highest average value for AAC due to the fact that it contains a large amount of polymer that makes it very viscous and consequently, it can have a good acoustic absorption. They also added that the average AAC value for Type-2 specimen is less than Type-3 and Type-4 suggested that surface texture does have an effect on AAC, and grooved surface texture is better than flat surface texture in this regard. The graph of the AAC value for each type together with the concrete value is shown in Figure 2.2 (Zhu et al., 2008). All in all, the results obtained in this study show that crumb rubber blends are potential as a practicable alternative to current concrete highway noise barriers (Zhu et al., 2008).

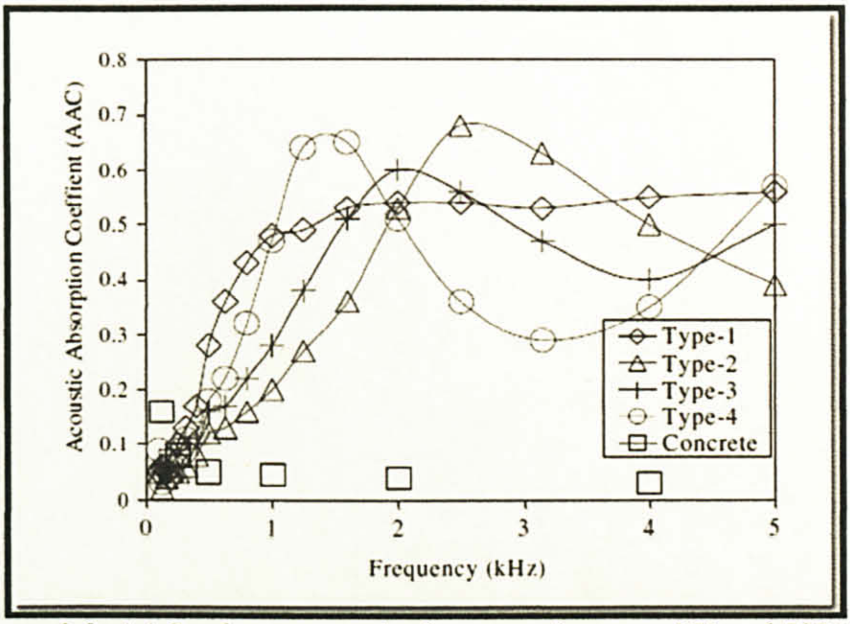

Figure 2.2: AAC values versus the frequency between 250 and 5000 Hz (Zhu et al., 2008)

Apart from the previous study, Zhu had also conducted another research together with Carlson regarding a new technology development on the application of crumb rubber in highway noise reduction systems. Four types of spray devices are further investigated. As part of this study, a number of crumb rubber panels are made by the spraying process and the test of acoustic absorption (ASTM C423-90a) is performed on one type of the panels. The values of the acoustical absorption coefficient versus frequency are shown in Figure 2.3 (Zhu & Carlson, 1999). The same coefficient for concrete and Carsonite noise barriers also displayed in for the comparison purpose. It can be observed that the crumb rubber based specimen shows superiority in acoustical absorption. In a nutshell, the acoustic testing result proves that crumb rubber panels exhibit a great noise reduction capability (Zhu & Carlson, 1999).

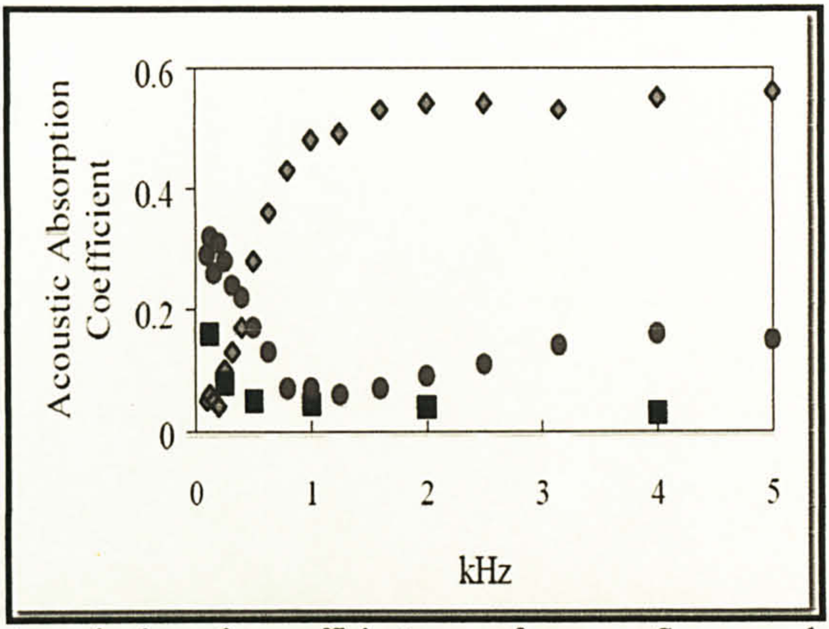

Figure 2.3: Acoustic absorption coefficient versus frequency. Square symbols represent for concrete noise barriers, circular symbols for Carsonite noise barriers, and diamond symbols for the crumb rubber mix. (Zhu & Carlson, 1999)

2.3.2 Application of Crumb Rubber in Asphaltic Pavement

A recent study to identify the effects of modifying asphalt with crumb rubber as an approach for reducing highway traffic noise has been carried out by Shatanawi (2008). In order to do so, different scenarios of asphalt mixtures were produced using different binder sources and different rubber sources, gradations, and concentrations. The results showed that sound absorption coefficients and permeability are highly correlated. When permeability increases, the sound absorption also increases. The relation between both can be seen in Figure 2.4 (Shatanawi, 2008). Therefore, in order to obtain high sound absorption coefficients, high permeability values are recommended. Besides that, increasing the pavement thickness will also results in higher sound absorption values for high permeability mixes apart from longer time will be required for the porous pavement to get filled with dirt thus clogged (Shatanawi, 2008).

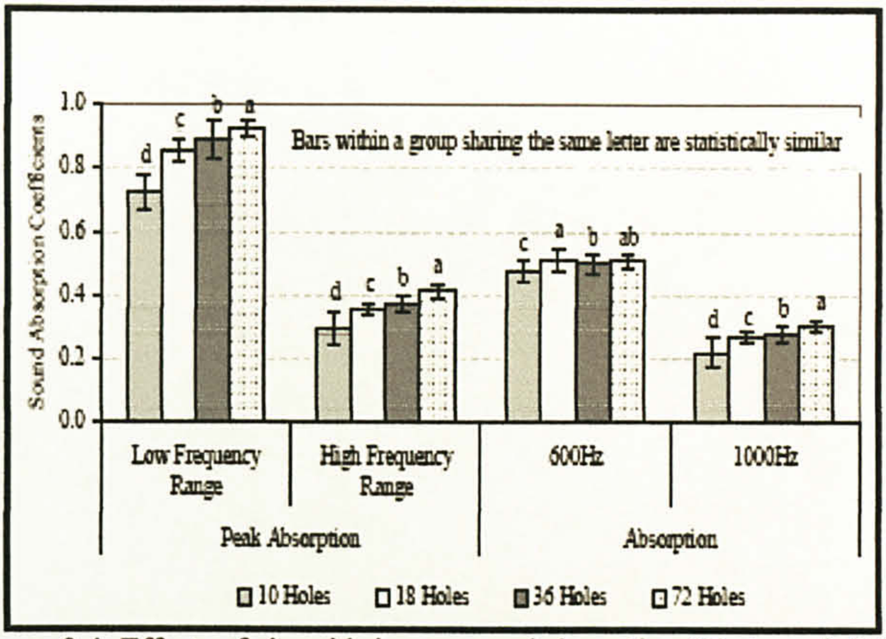

Figure 2.4: Effects of air void size on sound absorption (Shatanawi, 2008)

Other than Shatanawi (2008), Gowda (1996) has also conducted a similar study regarding role of crumb rubber in enhancing properties of asphalt. Blending crumb rubber with asphalt was reported to increase the viscosity of the resulting blend. This was said to make the mix more pliable. It is found that blending crumb with asphalt increased the low and high temperature range. Therefore resistance to thermal cracking and rutting are also increased. Apart from that, relation between crumb rubber percentage and asphalt fatigue property was also developed as tabulate din Table 2.2 (Gowda, 1996). This study also indicated that an increase of the crumb rubber in the asphalt mixture reduced the fatigue life (Gowda, 1996).

Table 2.2: Reproducability in the fatigue test results (Gowda, 1996)

Mix type	Free end deflection level	Sample Size	Mean	CV %
CRM 1%	0.125	2	624738 605211	2.2
CRM 1.5%	0.125	2	242186 200597	13.2
CRM 2.0%	0.125	2	113557 113738	0.11

2.3.3 Application of Crumb Rubber in Concrete

In 2008, a research on the use of crumb rubber to improve sound properties of concrete paper of crumb rubber is performed by Sukontasukkul (2008). The capability of material to absorb sound can be determined with the sound absorption coefficient. In his study, the sound absorption of the crumb rubber concrete was measured under two different ranges of frequency. They are low-mid-frequency (125, 250 and 500 Hz) and high-frequency (1000, 2000 and 4000 Hz). The result shows that the crumb rubber lightweight concrete seemed to have superior sound absorption properties compared to plain concrete. However, this result was inconclusive at the lower frequency range. Both plain and crumb rubber concrete exhibited similar sound absorption coefficient values at the low frequency ranges of 125 and 250 Hz. Nevertheless, the crumb rubber concrete started to show slightly higher sound absorption coefficient values at the mid-frequency of 500 Hz. At the frequency higher than 1000 Hz, the ability to absorb sound at this range of all crumb rubber lightweight concrete was discovered to be much better compared to plain concrete. Therefore, it can be concluded that crumb rubber concrete is a better sound absorber at the high-frequency range than plain concrete. The value of the noise reduction coefficient for each mix was also obtained from this study (Figure 2.5) (Sukontasukkul, 2008).

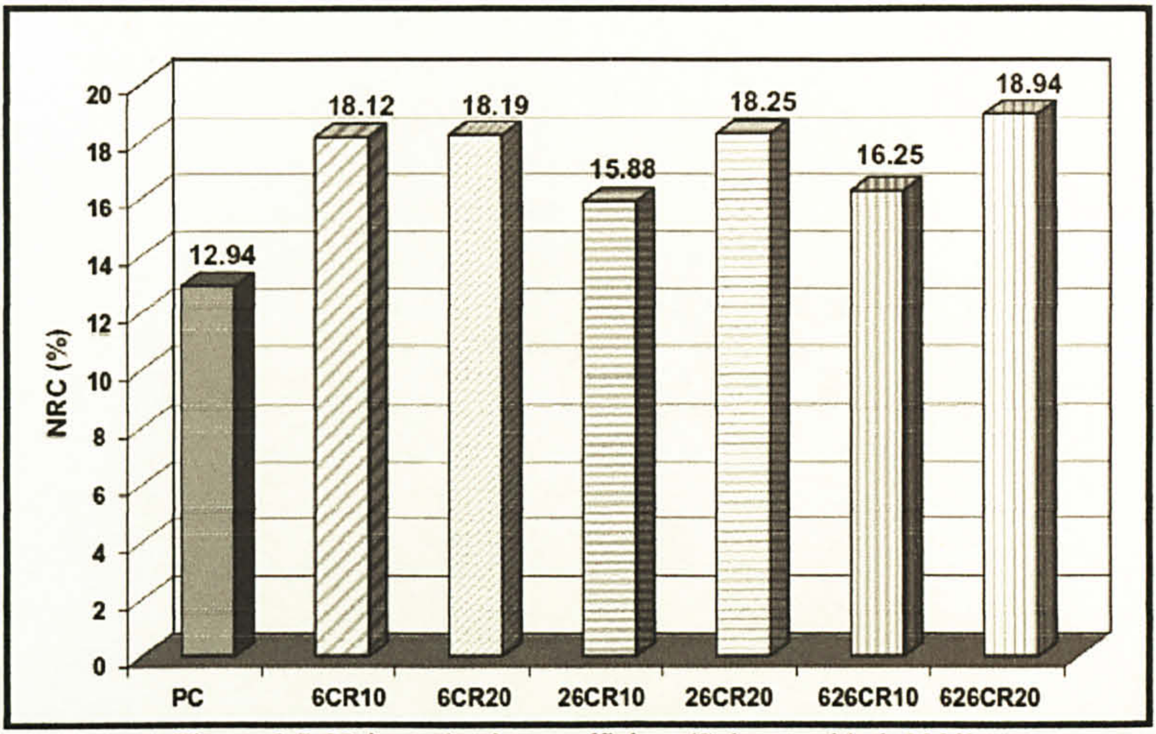

Figure 2.5: Noise reduction coefficient (Sukontasukkul, 2008)

Apart from that, another study had also been carried out by Ganjian et al. (2008) in evaluating the role of crumb rubber as replacement for aggregate and filler in concrete. In this research, the performance of concrete mixtures incorporating 5%, 7.5% and 10% of discarded tyre rubber as aggregate and cement replacements was investigated. The results showed that with up to 5% replacement, no major changes on concrete characteristics would occur. However, with further increase in replacement ratios significant changes were noticed. Compressive strength, tensile strength, flexural strength and modulus of elasticity were decreased with the increment percentage of rubber replacement in concrete. On the other hands, the water permeability depth was increased (Ganjian et al., 2008).

CHAPTER 3
METHODOLOGY

This chapter covers the materials which were used in completing this study as well as the employed methods. There are four steps of methodologies adopted namely: field investigation, sieve analysis, construction of prototype crumb rubber noise barrier wall and sound reduction resting.

3.1 Material

Prior to conducting the experiment, the required materials have been prepared. In order to carry out this study, the following materials have been used.

1. Hollow concrete blocks
   - 25 units of 200 mm x 100 mm x 400 mm hollow concrete blocks were used. The blocks used conform to ASTM C 652: Specification for Hollow Brick (Hollow Masonry Units Made from Clay or Shale). These standards ensure consistent properties like appearance, durability, absorption (and initial rate of absorption), freezing and thawing resistance, and strength. Hollow blocks were used because they contain void areas or cells that permit easy placement of reinforcement and grouting. There are three voids per block with measurement 50 mm x 90 mm each. Concrete blocks were also chosen because the noise barrier wall is a non-load bearing wall thus compressive strength is insignificant. The blocks used are shown in Figure 3.1 and 3.2 below. The blocks were bought from a hardware store located in Tronoh, Perak.

Figure 3.1

Figure 3.2

Figure 3.1 & 3.2: The hollow concrete blocks used

2. Crumb rubber

   - The most important material in this study is crumb rubber where 20 kg of crumb rubber was sieved to be used as filler for the voids. The crumb rubber used in this study is portrayed in Figure 3.3 and 3.4. It was obtained from a supplier located at Tambun, Perak. There are many other suppliers as the recycling of used tyres by mean of crumb rubber has been fairly conducted.

Figure 3.3

Figure 3.4

Figure 3.3 & 3.4: Crumb rubber used

3. Plaster sealer

- Plaster sealer was also used to seal the blocks' joints. This was done to ensure the sound would not travel behind barrier wall through blocks' joints because it will reduce the accuracy of the experiment. Figure 3.5 and 3.6 show the plaster sealer used in sealing the block's joints.

Figure 3.5

Figure 3.6

Figure 3.5 & 3.6: Plaster sealer

4. Sound level meter

- Last but not least, a portable sound level meter was also used. The sound level meter used is Sound Meter Model CA832. The sound measurement was done manually and it able to measure sound ranging from 35 dB to 130 dB. The pictures of Sound Meter Model CA832 are shown in Figure 3.7 and 3.8.

Figure 3.7

Figure 3.8

Figure 3.7 & 3.8: Sound Meter Model CA832

3.2 Methodology

3.2.1 Field Investigation

First of all, field investigation was carried out in order to proceed with this study. It was conducted along Jalan Sultan Azlan Shah, Perak. Figure 3.9 below shows the satellite view of the said road. The steps for conducting field investigation are as per following.

Figure 3.9: Satellite view of Jalan Sultan Azlan Shah (http://www.dromoz.com/satellite/directory/?gps=59f62ad453332a5fa0d75317c1f31b9d&p=Jalan+Sultan+Azlan+Shah+106)

1. Readings from 1.37 p.m. until 1.47 p.m. were taken to obtain the average noise produced by traffic. The 10 minutes duration was chosen based on the study conducted by Jamgocian (1997).
2. The readings for both in front of and behind the noise barrier wall were measured. This was done to know the capacity of the noise barrier wall in dissipating noise.
3. The equipment used is as follow:
    - Sound Meter Model CA832

    This equipment is able to measure noise ranging from 35 dB to 130 dB.

3.2.2 Sieve Analysis

After field investigation had been carried out, the next methodology to follow is sieve analysis. Sieve analysis was conducted to determine the percentage of crumb rubber passing sieve no. 3.35 mm and 600 μm. These two sieve sizes were chosen based on study done by Sokuntasukkul (2008) where he found that combination of crumb rubber passing sieve no. 3.35 mm and 600 μm yielded the highest noise reduction coefficient. Below are the steps involved.

1. 20 kg of crumb rubber was sieved in order to fill the blocks' voids where roughly each void needed 300 g of crumb rubber filler.
2. In order to plot the gradation of the crumb rubber, it was sieved through sieve no. 3.35 mm, 2.36 mm, 2.00 mm, 1.18 mm, 600 μm, and 425 μm.

3.2.3 Construction of Prototype Crumb Rubber Noise Barrier Wall

After conducted field investigation and sieve analysis, then a prototype noise barrier wall was constructed. A 1200 mm x 1000 mm prototype noise barrier wall was built to represent the actual noise barrier wall.

The materials used are as follow:

- 200 mm x 100 mm x 400 mm hollow concrete blocks
- Crumb rubber passing sieve no. 3.35 mm and 600 μm
- Plaster sealer

Hollow blocks were needed so that they can be filled with crumb rubber. The brickwork used is Stretcher Bond which is the common bond used in construction. It is composed of overlapping courses of stretchers. four settings were created in order construct the wall.

3.2.3.1 First setting (Noise barrier wall without crumb rubber filler and side wall)

The following steps were taken in constructing noise barrier wall without crumb rubber filler and side wall.

1. The hollow concrete blocks were arranged as shown in Figure 3.10 and 3.11. No crumb rubber was filled into the concrete blocks' voids. Figure 3.12 shows the completed wall.
2. Sound reduction testing was conducted.

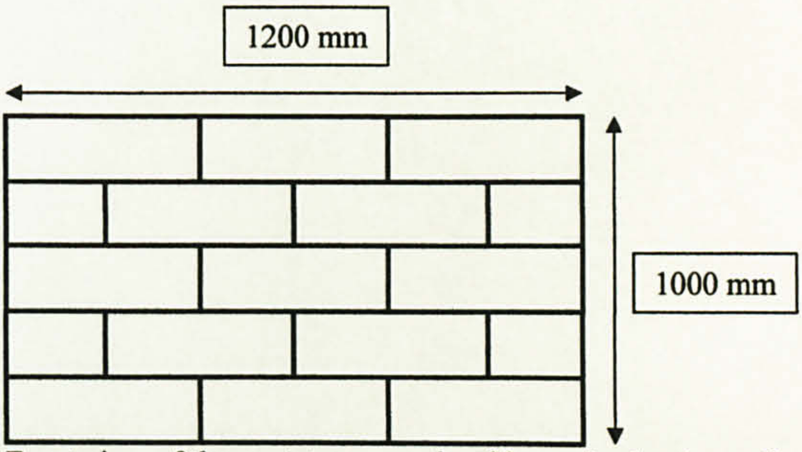

Figure 3.10: Front view of the prototype crumb rubber noise barrier wall without crumb rubber filler and side wall

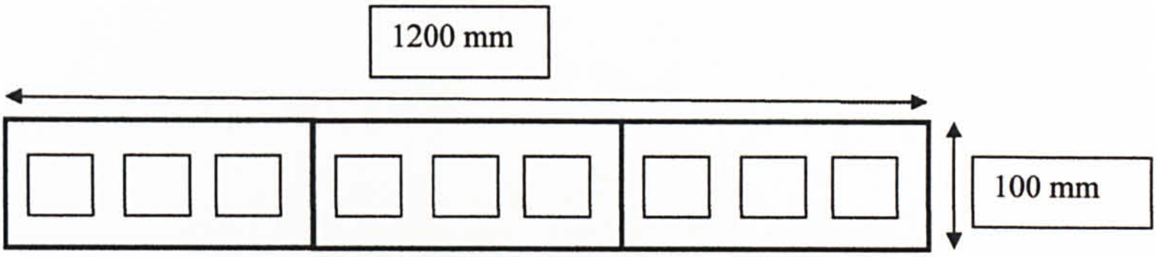

Figure 3.11: Plan view of the prototype crumb rubber noise barrier wall without crumb rubber filler and side wall

Figure 3.12: Completed prototype crumb rubber noise barrier wall without crumb rubber filler and side wall

3.2.3.2 Second setting (Noise barrier wall without crumb rubber filler but with side wall)

The following steps were taken in constructing noise barrier wall without crumb rubber filler but with side wall.

1. The hollow concrete blocks were arranged as per Figure 3.13 below. No crumb rubber was filled into the concrete blocks' voids. Figure 3.14 shows the completed wall.
2. Sound reduction testing was conducted.

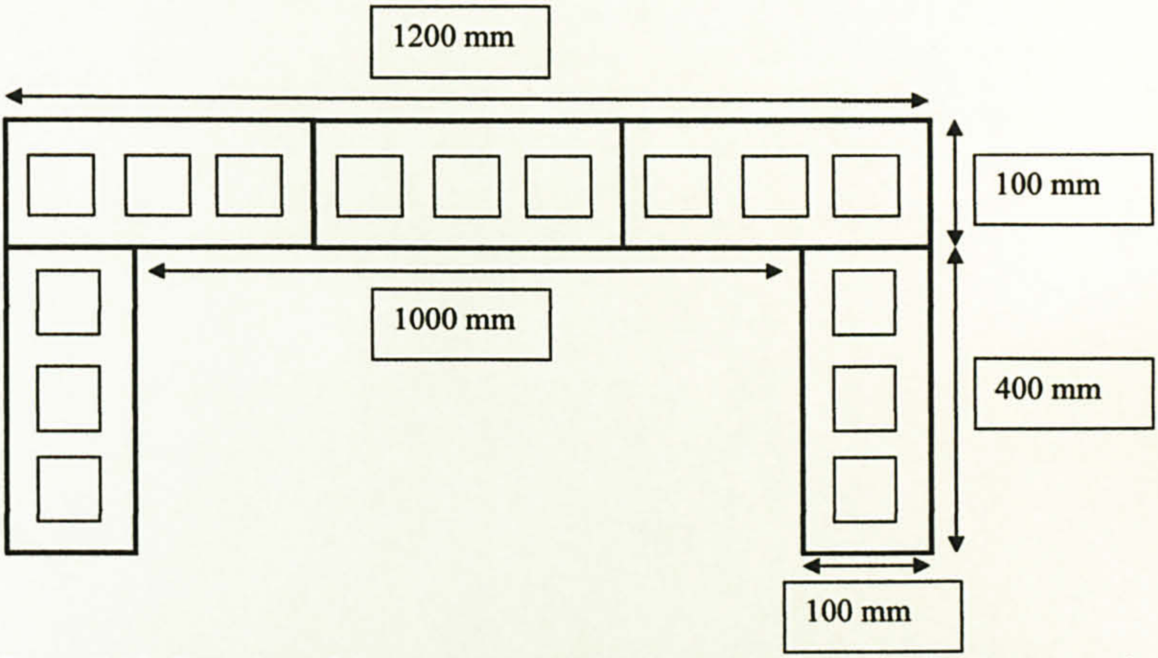

Figure 3.13: Plan view of the prototype crumb rubber noise barrier wall without crumb rubber filler but with side wall

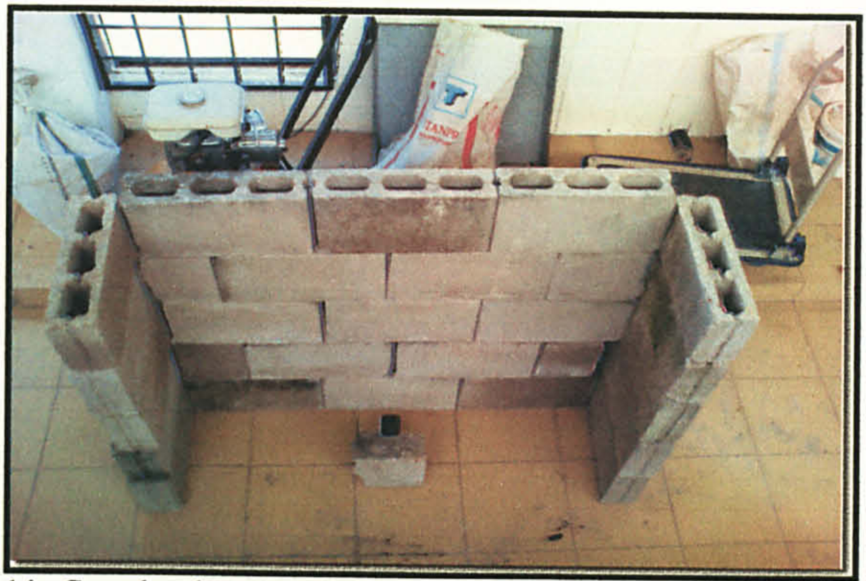

Figure 13.14: Completed prototype crumb rubber noise barrier wall without crumb rubber filler but with side wall

3.2.3.3 Third setting (Noise barrier wall with crumb rubber filler and side wall)

The following steps were taken in constructing noise barrier wall with crumb rubber filler and side wall.

1. The hollow concrete blocks were arranged as shown in the Figure 3.15. Sieved crumb rubber was willed into the concrete blocks' voids. Figure 3.16, 3.17, 3.18 and 3.19 show the construction in progress of noise barrier wall while Figure 3.20 shows the completed wall.
2. Sound reduction testing was conducted.

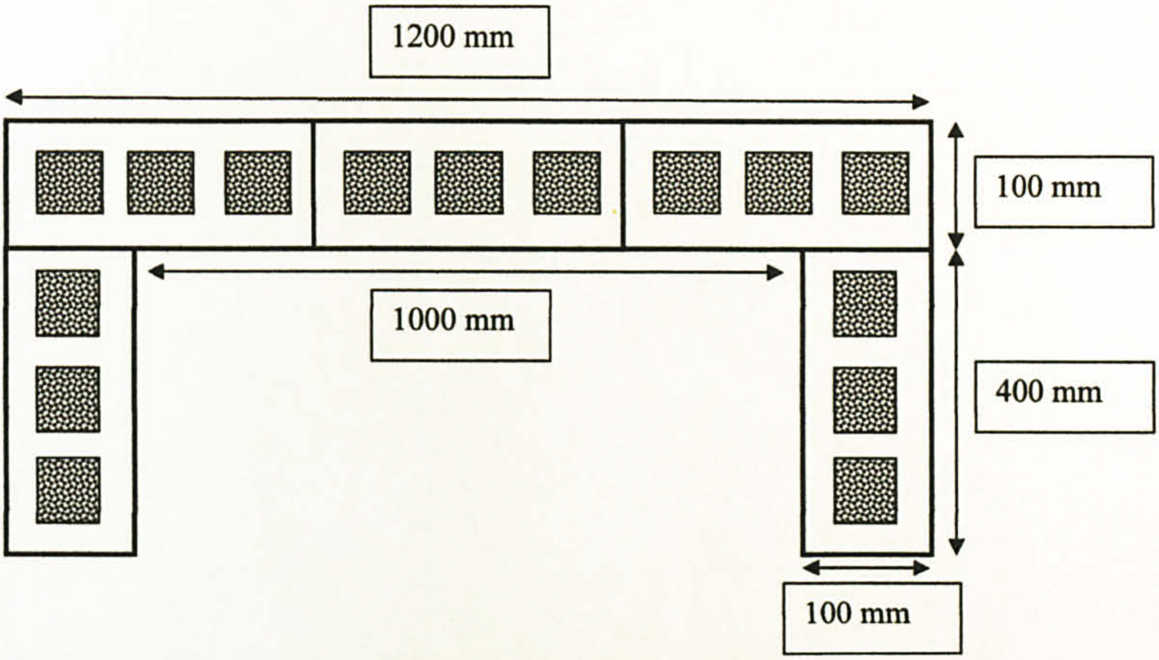

Figure 3.15: Plan view of the prototype crumb rubber noise barrier wall with crumb rubber filler and side wall

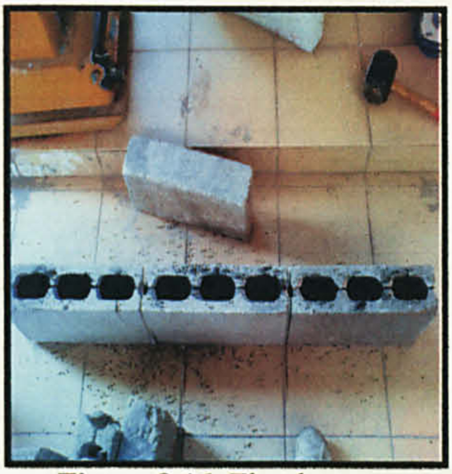

Figure 3.16: First layer

Figure 3.17: Second layer

Figure 3.18: Third layer

Figure 3.19: Fourth layer

Figure 3.20: Completed prototype crumb rubber noise barrier wall with crumb rubber filler and side wall

3.2.3.4 Fourth setting (Noise barrier wall with crumb rubber filler, side wall and sealed joint)

The following steps were taken in constructing noise barrier wall with crumb rubber filler, side wall and sealed joint.

1. The hollow concrete blocks were arranged using the same previous arrangement. However, this time the joints were sealed with plaster sealer. Figure 3.21, 3.22 and 3.23 show the sealed wall.
2. Sound reduction testing was conducted.

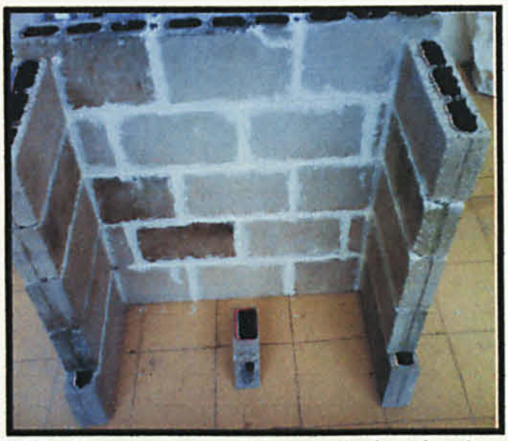

Figure 3.21: Front view of the sealed noise barrier wall

Figure 3.22: Side view (left)

Figure 3.23: Side view (right)

3.2.4 Sound Reduction Testing

After the construction of the prototype crumb rubber noise barrier wall was completed, sound reduction testing was then carried out. The following steps were employed in conducting sound reduction testing for this study.

1. In order to imitate the noise produced by traffic, noise of similar decibel was created. This was done by recording sound ranging from 82 – 90 dB.
2. The recorded sound was then played for 100 seconds. Every 10 seconds, the readings of the noise level meter were taken. Then, the average noise level was calculated.
3. The sound level readings in front of and behind the wall were measured. The equipment used is as follow:
    - Sound Meter Model CA832
4. After that, the noise reduction was calculated.
5. The setup of the experiment is as illustrated below. According to the US Department of Transportation, Federal Highway Administration, the length of the wall should be eight times the distance between receiver and the wall. There is no specified standard for the distance between source and the wall. Therefore, this experiment was carried out with the same distance for both receiver and source. There is also no information regarding the appropriate height of either source or receiver, thus heights of both were assumed to be 1/5 of the wall's height which is 200 mm.

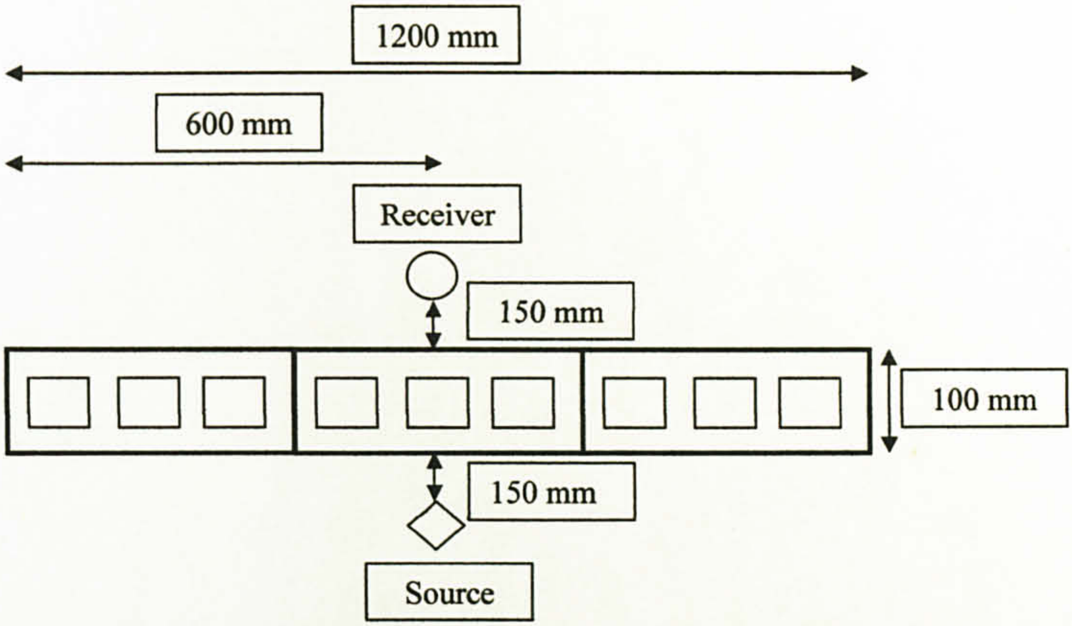

Figure 3.24: Plan view of the sound reduction testing setup (without side wall)

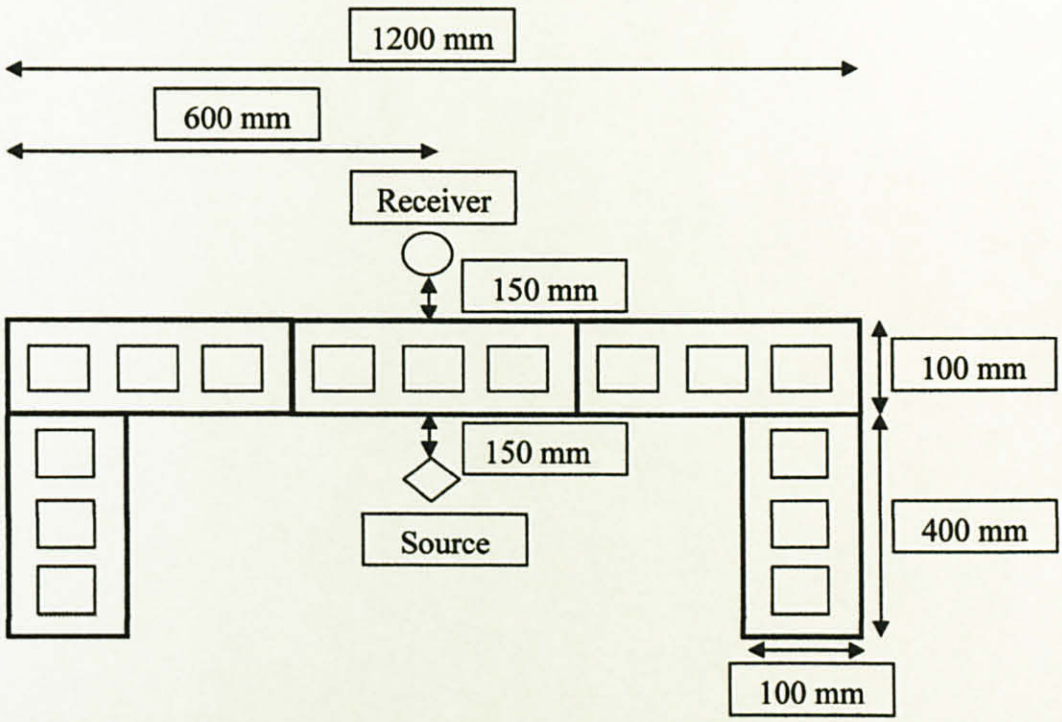

Figure 3.25: Plan view of the sound reduction testing setup (with side wall)

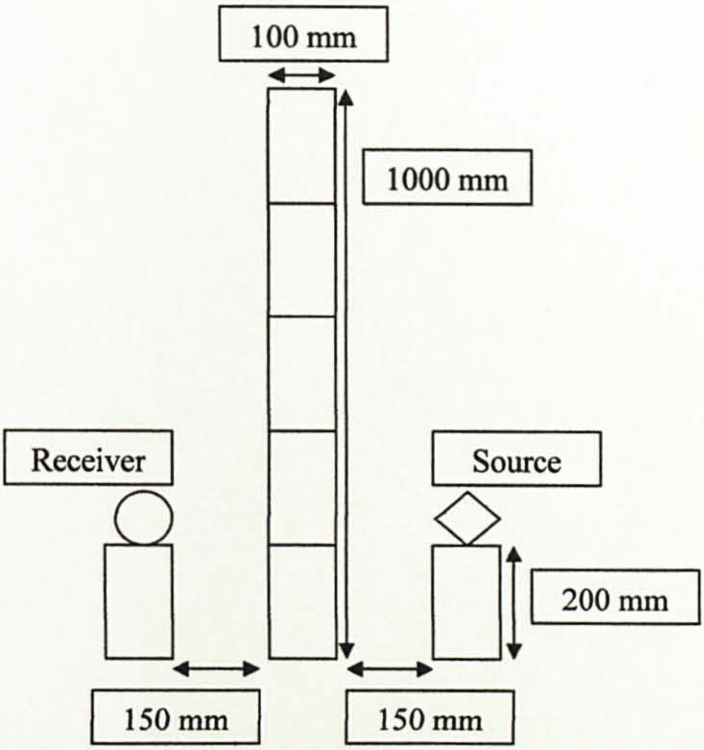

Figure 3.26: Side view of the sound reduction testing setup (without side wall)


Figure 3.27: Actual side view of the sound reduction testing setup (without side wall)

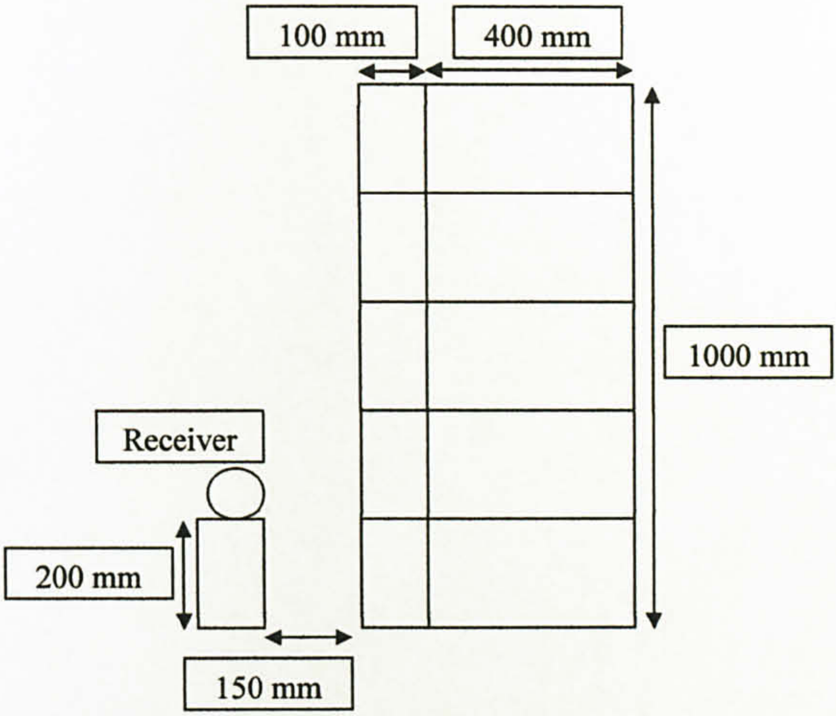

Figure 3.28: Side view of the sound reduction testing setup (with side wall)

Figure 3.29: Actual side view of the sound reduction testing setup (with side wall)

CHAPTER 4
RESULT AND DISCUSSION

4.1 Field Investigation

The results obtained from the field investigation conducted along Jalan Sultan Azlan Shah, Ipoh from 1.37 p.m. until 1.47 p.m. are plotted as in Figure 4.1. The noise levels were measured for both in front of and behind noise barrier wall in order to know the capacity of the wall in dissipating noise.

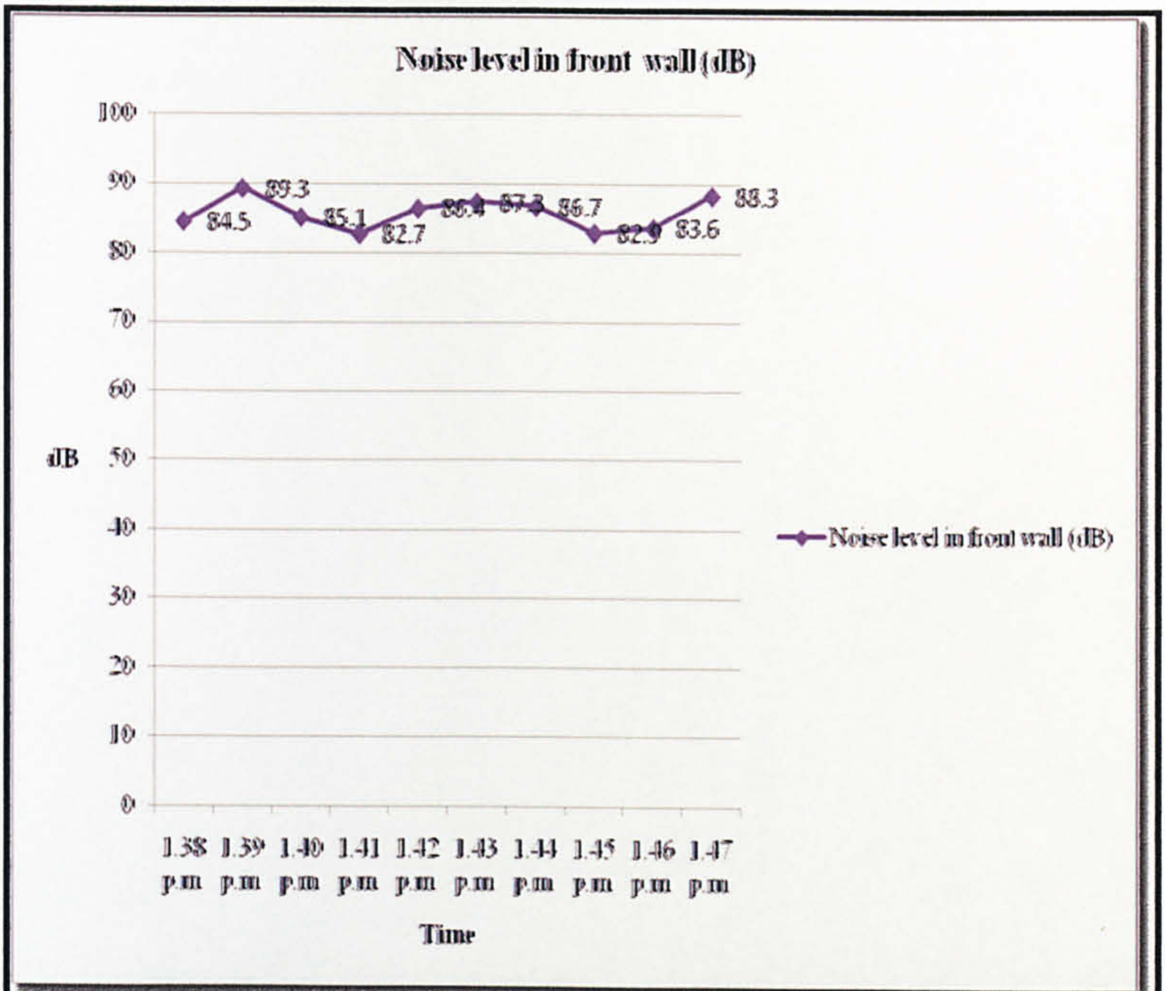

Figure 4.1: Recorded traffic noise during the field investigation

The average noise level is calculated.

$$\text{Ave. noise level} = \frac{84.5+89.3+85.1+82.7+86.4+87.3+86.7+82.9+83.6+88.3}{10}$$

$$= \mathbf{85.7\ dB}$$

From the calculation above, the average noise level in front of noise barrier wall is obtained. The value is 85.7 dB. Meanwhile, the mean noise level behind the wall is 76.2 dB. By comparing these two values, a difference of 9.5 dB is acquired. This value means that the noise barrier wall installed at the chose site able to reduce noise as much as 9.5 dB.

Since the noise barrier wall must reduce noise level by at least 5 dB, the implementation of noise barrier wall here is considered a success since it reduces noise by 9.5 dB. However, the noise level after the wall which is 76.2 dB is higher than World Health Organization (WHO) noise limits for community environment; 55 dBA daytime and 45 dBA nighttime; and Malaysian DOE guidelines; 55 dBA daytime and 50 dBA nighttime.

4.2 Sieve Analysis

The crumb rubber used was sieved using sieve no 3.35 mm, 2.36 mm, 2.00 mm, 1.18 mm, 600 μm and 425 μm to determine its gradation. The result is plotted in the graph below (Figure 4.2).

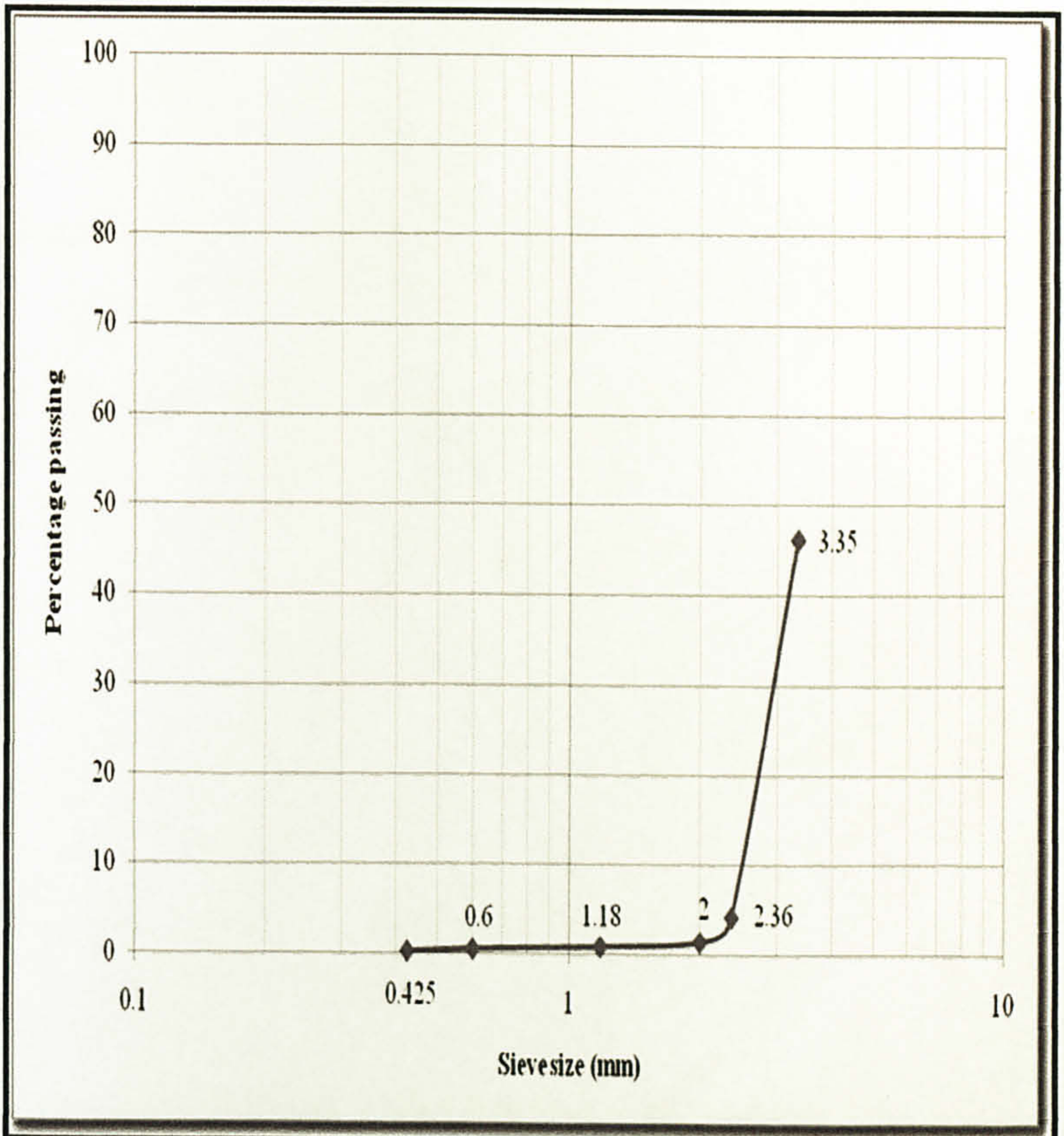

Figure 4.2: Sieve analysis

4.3 Sound Reduction Testing

4.3.1 Creating Sound of Similar Noise Level to the Recorded Traffic Noise

Sound of similar noise level to the recorded traffic noise was created by recording the chosen sound within the same decibel range or 100 seconds. Every 10 seconds, the readings of the noise level meter were taken. The recorded sound ranges from 82 dB to 89 dB. The data of the recorded sound are plotted in Figure 4.3.

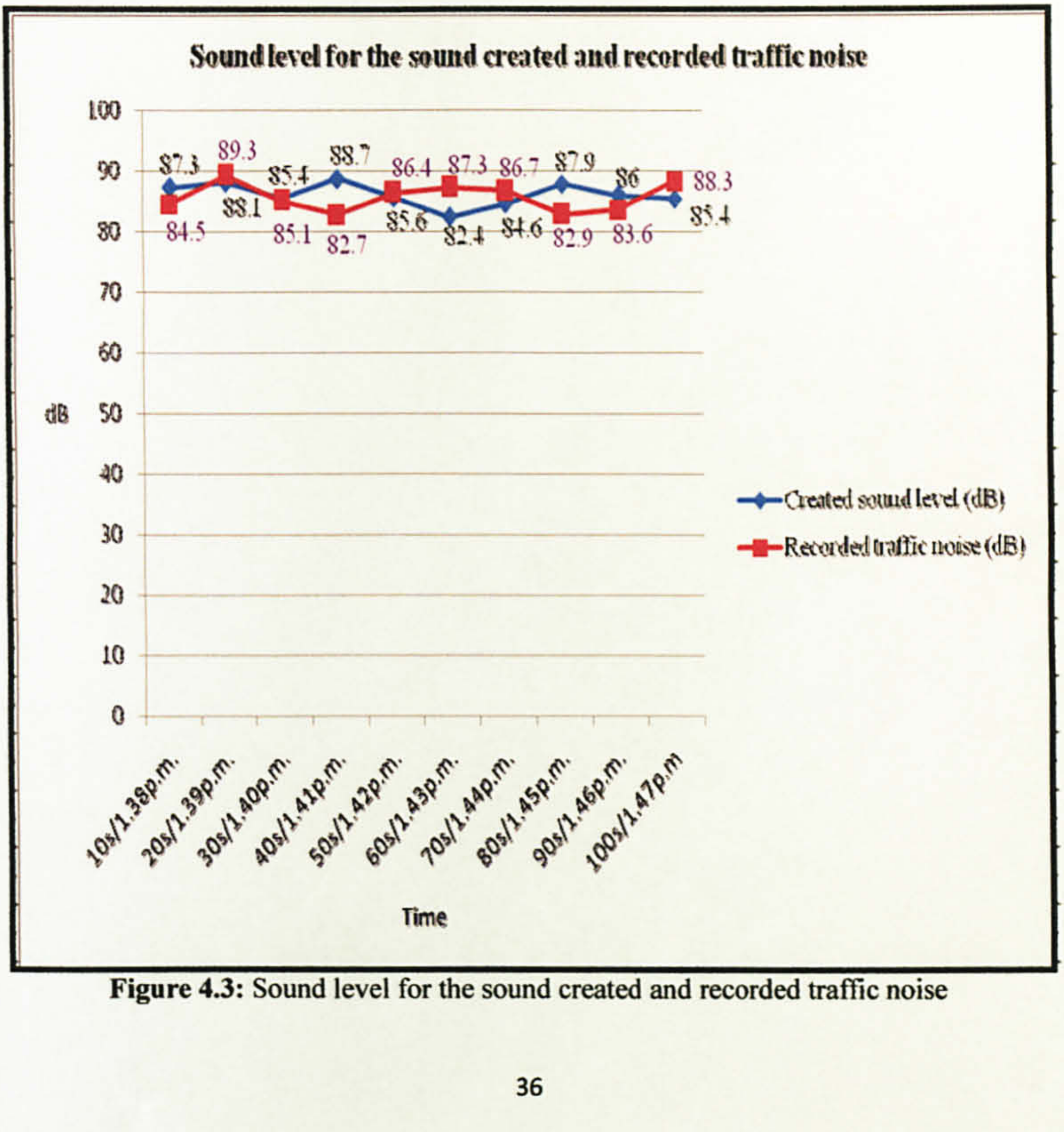

Figure 4.3: Sound level for the sound created and recorded traffic noise

The average noise level is calculated.

$$\text{Ave. noise level} = \frac{87.3+88.1+85.4+88.7+85.6+82.4+84.6+87.9+86+85.4}{10}$$

$$= \mathbf{86.1\ dB}$$

Comparing the value to the recorded traffic noise which is 85.7 dB, the difference is only 0.4 dB.

4.3.2 First Setting (Noise Barrier Wall without Crumb Rubber Filler and Side Wall)

The experiment was done based on the procedure explained in the previous chapter. Three readings were taken to increase the accuracy of the experiment. The results of the testing are shown in Figure 4.4.

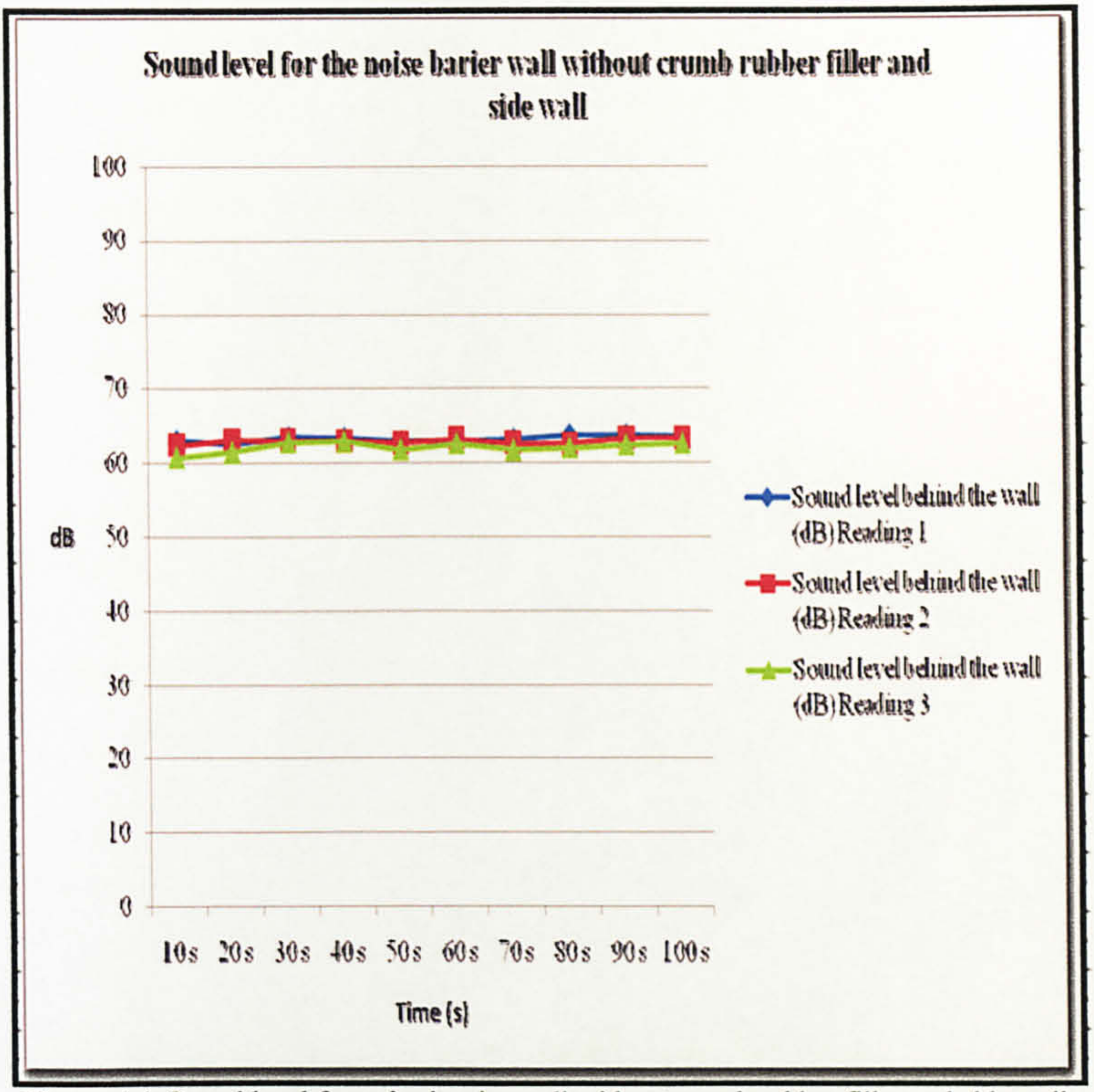

Figure 4.4: Sound level for noise barrier wall without crumb rubber filler and side wall

The average noise level for first, second and third readings are 63.3 dB, 62.9 dB and 62.1 dB respectively. Then, the overall average noise level is calculated.

$$\text{Ave. noise level} = \frac{63.3+62.9+62.1}{3}$$

$$= \mathbf{62.8\ dB}$$

The ambience noise in the laboratory was measured beforehand and the value is 58.5 dB. It can be seen that there is a 4.3 dB difference between these two values. This proves that the sound level meter indeed recorded the reduced noise by the barrier wall and not ambience noise. Then, comparing the calculated value of the average noise level to the recorded traffic noise which is 86.1 dB, the difference is 23.3 dB. Based on the result, it can be concluded that the wall able to reduce noise as much as 23.3 dB. Again, comparing the reduction value of laboratory testing to the value obtained during field investigation, there is a difference of 13.8 dB.

It is safe to say that the high reduction value obtained for laboratory testing could be due to the fact that the laboratory is a controlled environment. There is a possibility that the noise level meter not only recorded the reduced traffic noise behind the wall solely, but also recorded other noise sources which came from behind the wall itself. The difference properties of the bricks used could also contribute.

4.3.3 Second Setting (Noise Barrier Wall without Crumb Rubber Filler but with Side Wall)

The experiment was done based on the procedure explained in the previous chapter. The readings were taken to increase the accuracy of the experiment. The results of the testing are plotted in Figure 4.5.

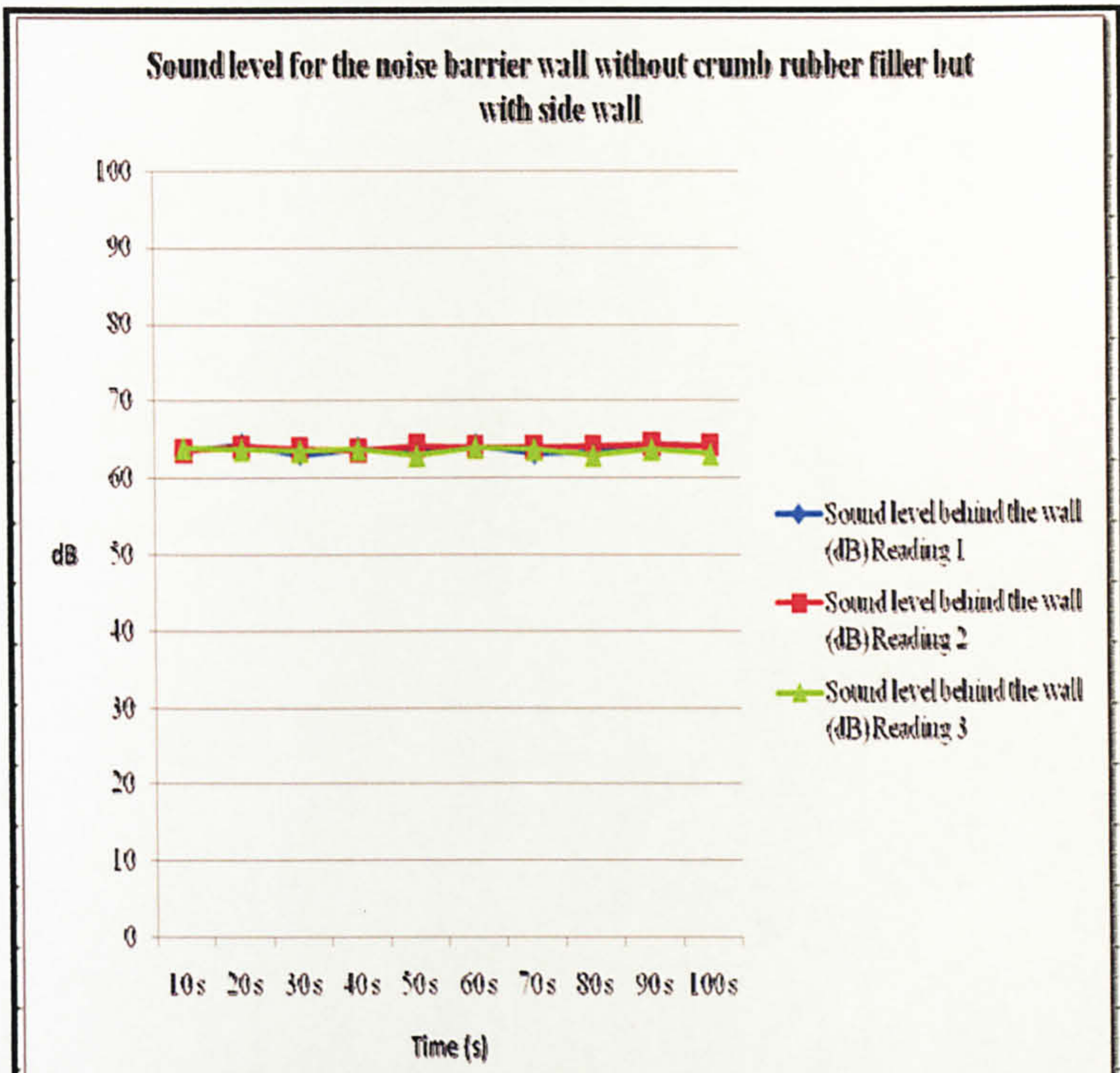

Figure 4.5: Sound level for noise barrier wall without crumb rubber filler but with side wall

The average noise level for first, second and third readings are 63.8 dB, 63.8 dB and 63.5 dB respectively. Then, the overall average noise level is calculated.

$$\text{Ave. noise level} = \frac{63.8+63.8+63.5}{3}$$

$$= \mathbf{63.7\ dB}$$

Comparing the calculated value to the recorded traffic noise which is 86.1 dB, the difference is 22.4 dB. Based on the result, it can be concluded that the wall able to reduce noise as much as 22.4 dB. As obtained earlier, the reduction for the noise barrier wall without side wall is 23.3 dB. This means the noise level behind the wall for noise barrier wall without side wall is slightly lower than with side wall.

One of the logical reasons behind this situation is that there are path for noise to travel to the left and right side in the case of noise barrier wall without side wall. Meanwhile, the same situation did not happen for noise barrier wall with side wall as the side wall would either reflect or absorb the noise if it travels sideway. Due to this criterion, the second setting has been chosen to further proceed with this study.

4.3.4 Third Setting (Noise Barrier Wall with Crumb Rubber Filler and Side Wall)

The experiment was done based on the procedure explained in the previous chapter. Three readings were taken to increase the accuracy of the experiment. The results obtained are shown in Figure 4.6.

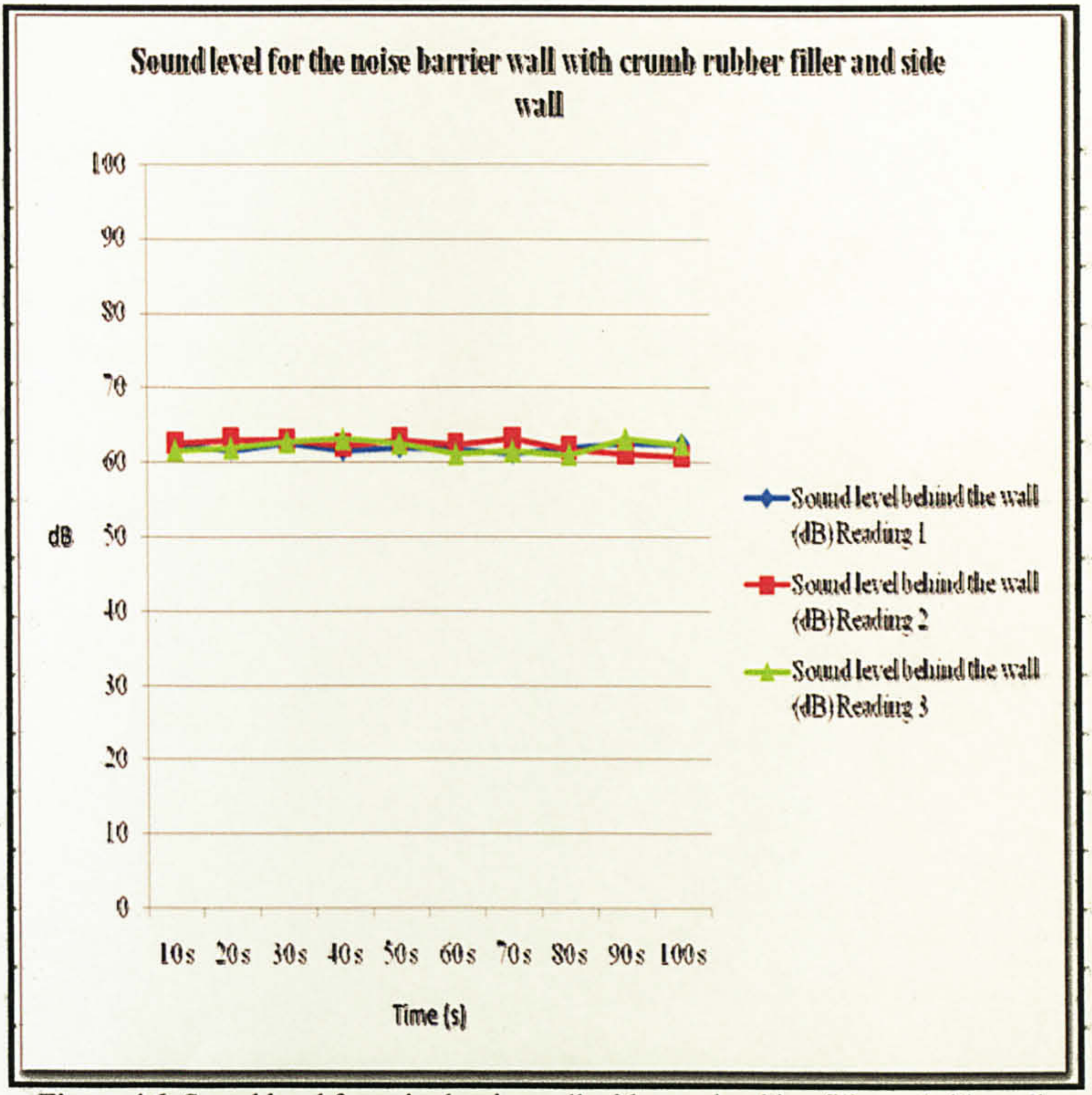

Figure 4.6: Sound level for noise barrier wall with crumb rubber filler and side wall

The average noise level for first, second and third readings are 62.1 dB, 62.4 dB and 62.1 dB respectively. Then, the overall average noise level is calculated.

$$\text{Ave. noise level} = \frac{62.1+62.4+62.1}{3}$$

$$= \mathbf{62.2\ dB}$$

Comparing the calculated value to the recorded traffic noise which is 86.1 dB, the difference is 23.9 dB. Based on the result, it can be concluded that the wall able to reduce noise as much as 23.9 dB. Earlier, the reduction value for noise barrier wall without crumb rubber filler with identical arrangement is calculated to be 22.4 dB.

It can be seen that by having crumb rubber as filler, noise reduction value could be increased by 1.5 dB. Although the difference is not that significant, the value is fairly acceptable considering that the dimension of the prototype crumb rubber noise barrier wall is relatively small compared to the real noise barrier wall. Size of the noise barrier wall does play role in determining its efficiency. The longer and taller the noise barrier wall, the higher its efficiency in reducing traffic noise.

4.3.5 Fourth Setting (Noise Barrier Wall with Crumb Rubber Filler, Side Wall and Sealed Joint)

The experiment was done based on the procedure explained in the previous chapter. Three readings were taken to increase the accuracy of the experiment. The results obtained are shown in Figure 4.7.

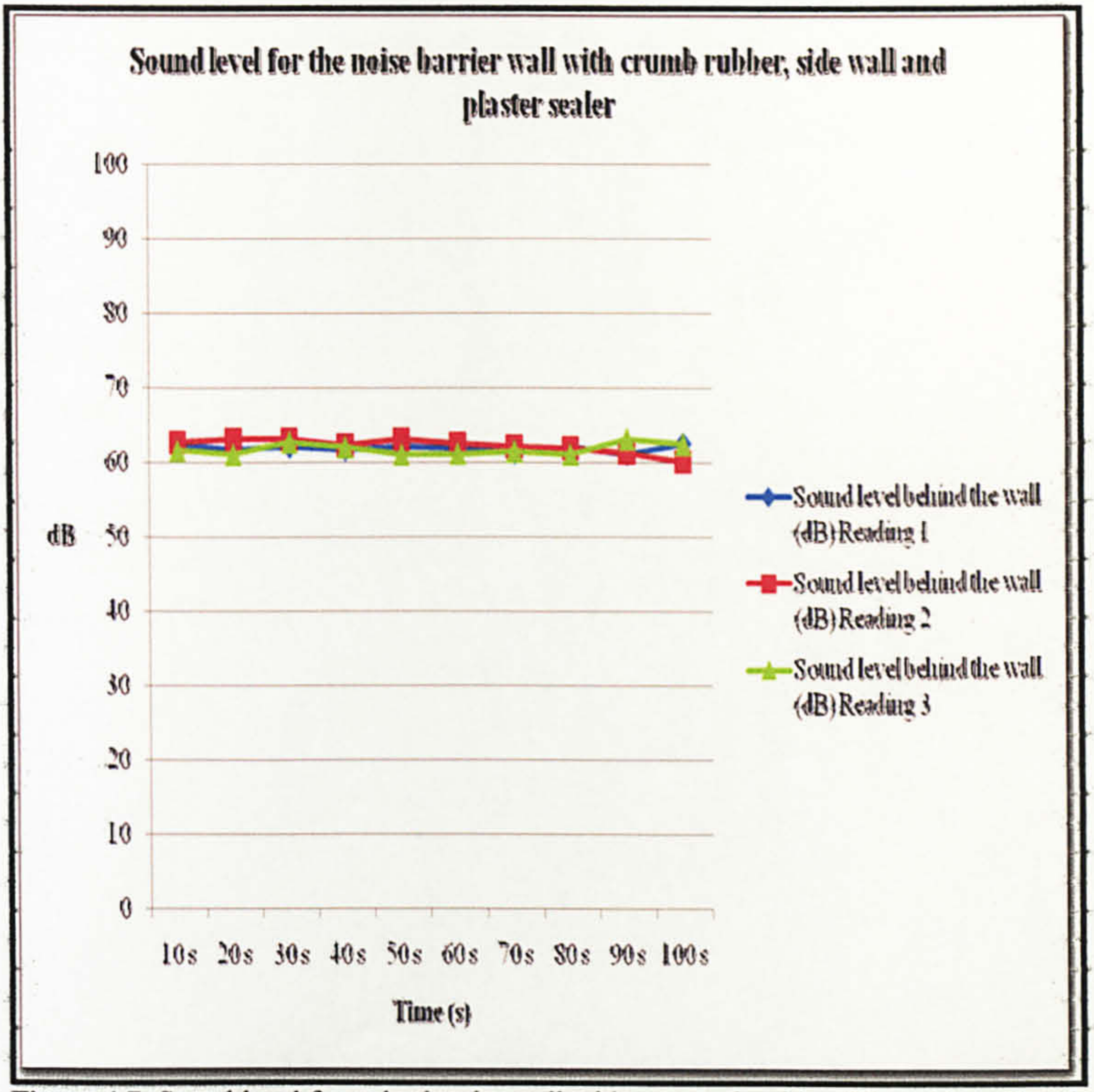

Figure 4.7: Sound level for noise barrier wall without crumb rubber filler, side wall and sealed joint

The average noise level for first, second and third readings are 61.8 dB, 61.5 dB and 61.0 dB respectively. Then, the overall average noise level is calculated.

$$\text{Ave. noise level} = \frac{61.8+61.5+61.0}{3}$$

$$= \mathbf{61.4\ dB}$$

Comparing the calculated value to the recorded traffic noise which is 86.1 dB, the difference is 24.7 dB. Based on the result, it can be concluded that the wall able to reduce noise as much as 24.7 dB. As calculated in the previous section, the unsealed noise barrier wall with the same arrangement able to reduce noise as much as 23.9 dB.

It can be observed that by sealing the blocks' joints with plaster sealer, noise reduction could be increased thus increasing efficiency. This is because this process ensures that no noise will travel through the blocks' joints which would reduce the efficiency. Although the difference is not that significant, the value is fairly acceptable considering that the dimension of the prototype crumb rubber noise barrier wall is relatively small compared to the real noise barrier wall. It is believed that more significant result will be obtained if the testing is carried out with larger size of crumb rubber noise barrier wall.

After that, the testing was continued by measuring the noise level in front of and behind the wall at the left end, middle and right end of the wall as shown in Figure 4.8 and 4.9.

Figure 4.8: Measuring noise behind the the wall for the left end

Figure 4.9: Measuring noise behind wall for the right end

The results obtained were plotted in the graph shown in Figure 4.10.

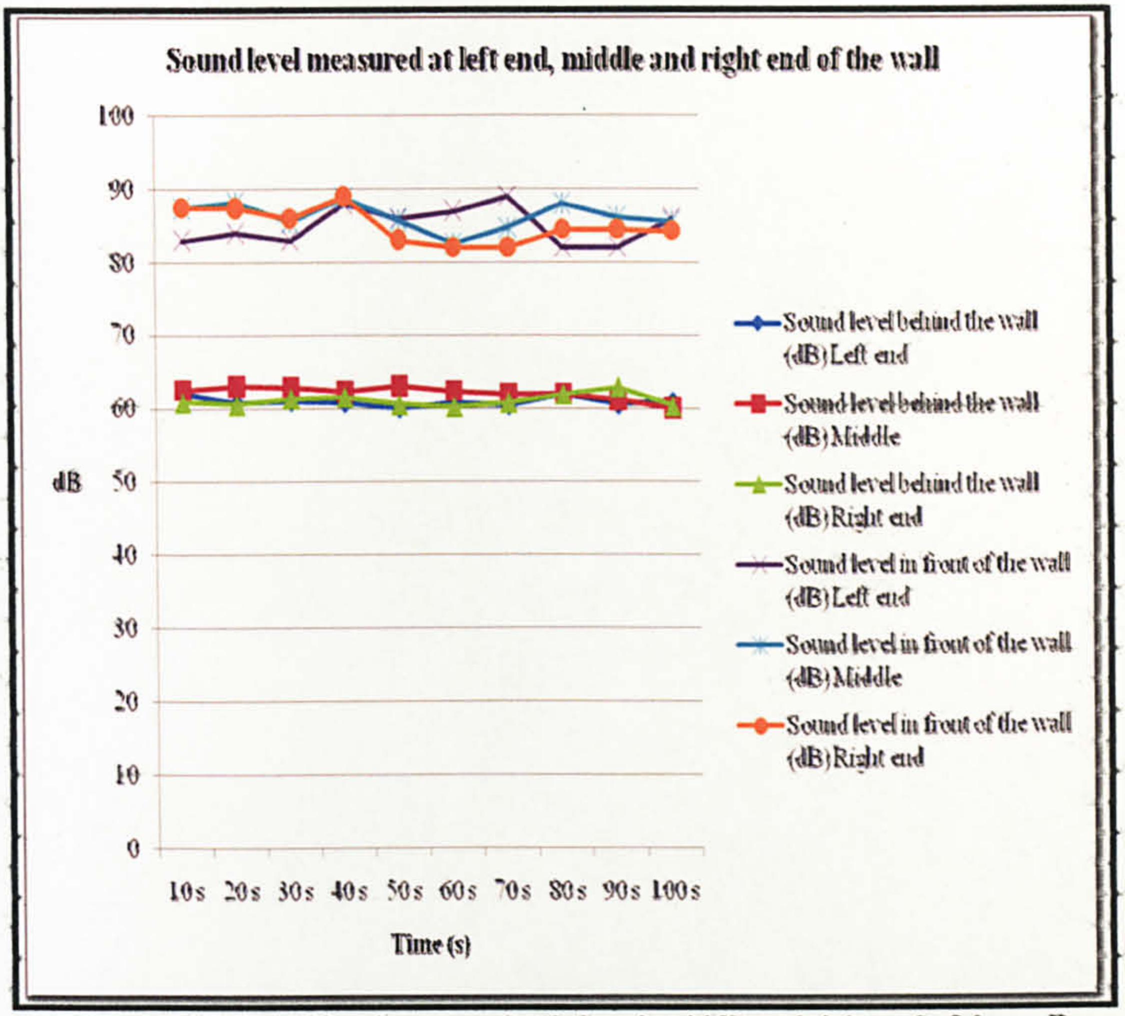

Figure 4.10: Sound level measured at left end, middle and right end of the wall

From the graph, the average noise levels in front of the wall measured at the left end, middle and right end of the wall are 85.0 dB, 86.1 dB and 85.2 dB respectively. Meanwhile, the mean noise levels behind the wall measured at the left end, middle and right end of the wall are 60.9 dB, 61.5 dB and 61.0 dB respectively. It can be observed that the noise levels measured at both wall's end wall are lower than the noise levels measured at the middle. This situation applies to both measurements in front of and behind the wall.

Next, another testing had been conducted. This time, the height of the noise source and receiver was increased from 200 mm to 400 mm and lastly to 600 mm. The testing setups with the height increment are portrayed in Figure 4.11, 4.12, 4.13 and 4.14.

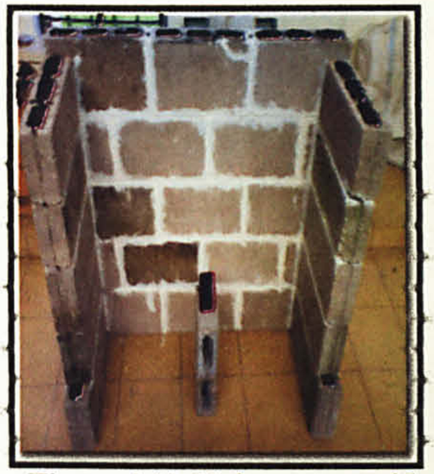

Figure 4.11: Noise source with 400 mm height

Figure 4.12: Receiver with 400 mm height

Figure 4.13: Noise source with 600 mm height

Figure 4.14: Receiver with 600 mm height

The results acquired were plotted in the graph (Figure 4.15).

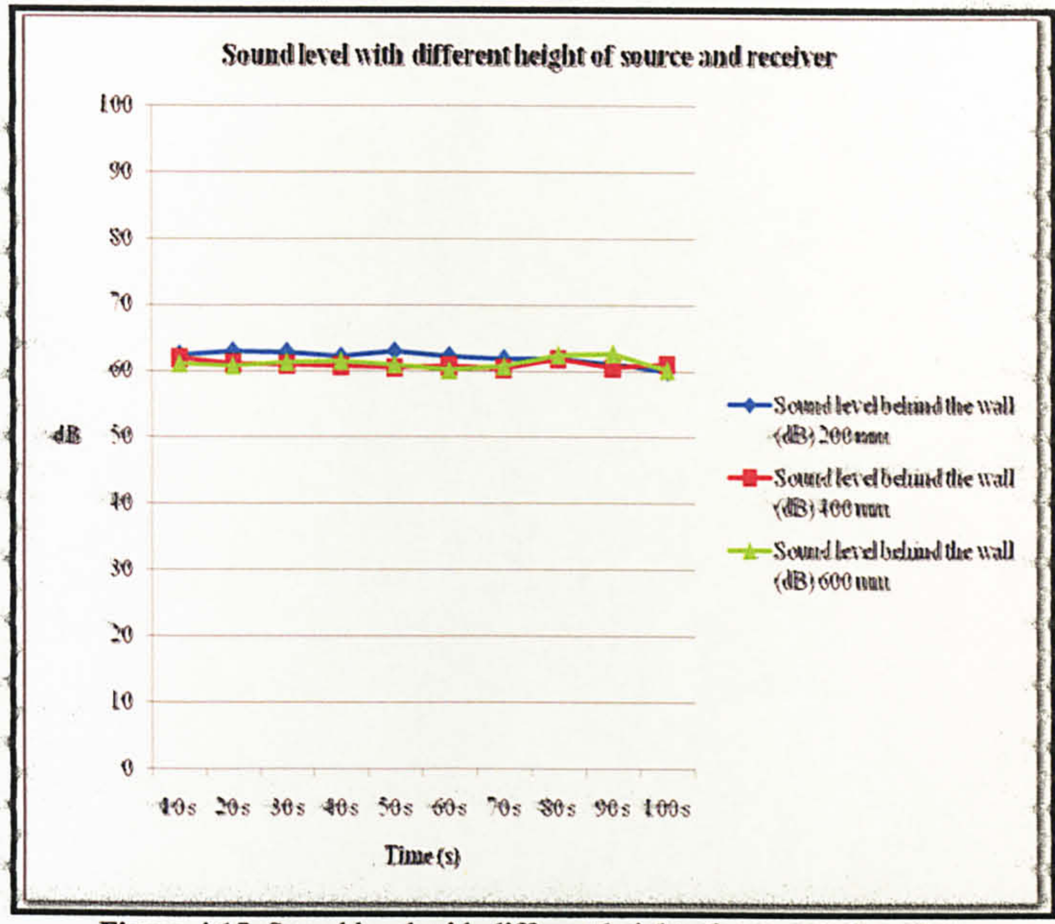

Figure 4.15: Sound level with different height of source and receiver

The average noise level for height of 200 mm, 400 mm and 600 mm are 61.5 dB, 62.1 dB and 62.9 dB respectively. From the results achieved, it can be seen that the higher the noise source and receiver, the lower the noise reduction value. The theory of noise barrier wall efficiency supports these values. According to the theory, a noise barrier wall will effectively achieve a 5 dB noise level reduction once it breaks the line-of-sight from the source to the receiver. After breaks the line-of-sight, it manages to reduce approximately 1.5 dB of additional noise level for each meter of wall height (FHWA, 2009). Therefore, the noise reduction value for noise source and receiver height of 200 mm is the highest since it broke the line-of-sight at lowest height.

Lastly, the sound reduction testing was again conducted to investigate the relation between the distance of the noise source from the wall with the noise reduction value. The noise source is positioned against the wall as portrayed in Figure 4.16 and the measurements were recorded.

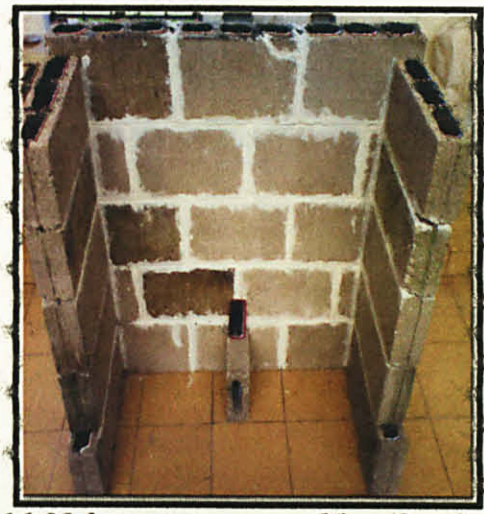

Figure 4.16: Noise source was positioned against the wall

The results acquired were plotted in Figure 4.17.

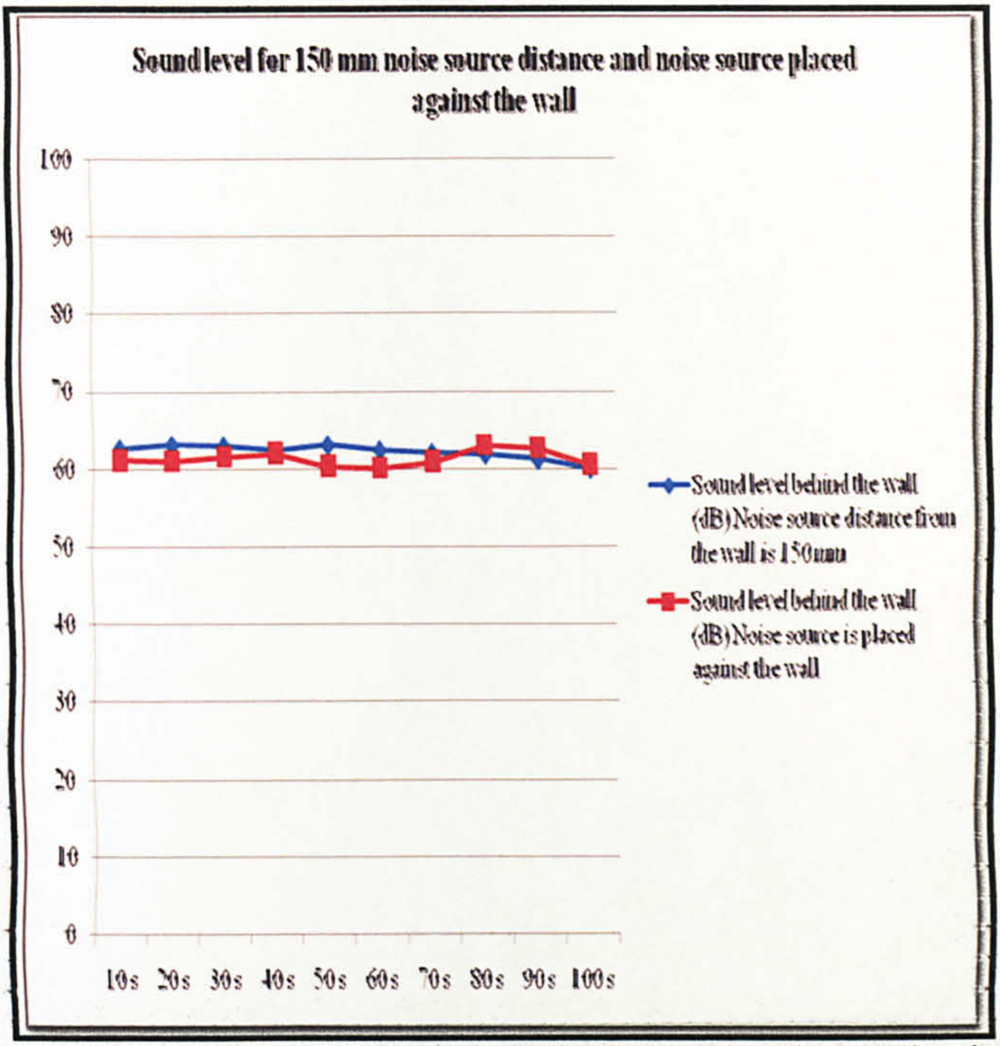

Figure 4.17: Sound level for 150 mm noise source distance and noise placed against the wall

The average noise levels when the noise source distance from the wall is 150 mm and when noise source was placed against the wall are 61.5 dB and 62.4 dB respectively. It can be seen that the noise reduction value when the noise source was placed against the wall is lower. This is due to the fact that the distance between noise source and receiver had decreased which cause the noise level behind the wall to increase.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In the end of the study, it is proved that crumb rubber does have potential to absorb noise. Therefore, the decision to apply crumb rubber as filler for noise barrier is a good initiative as it is able to reduce traffic noise. All in all, the study had accomplished all of its objectives which are:

- To introduce a new green product in highway field by recycling used tyres
- To use crumb rubber brick wall to replace conventional noise barrier brick wall
- To study the potential of crumb rubber in reducing highway noise

5.2 Recommendation

The results obtained from the previous chapter indicate that there is only slight difference between each prototype barrier noise wall setting. Based on the results, it is recommended that a larger scale prototype crumb rubber noise barrier is to be constructed for future study. It is believed that, more significant results will be obtained if the testing is done for the larger size crumb rubber noise barrier wall. Size of the noise barrier wall does play role in determining its efficiency. The longer and taller the noise barrier wall, the higher its efficiency in reducing traffic noise.

The size of the crumb rubber used in this study was determined according to the research done by Sukontasukkul (2008) where he found that combination of crumb rubber passing sieve no. 3.35 mm and 600 μm yield the highest noise reduction coefficient. However, his research referred to best crumb rubber size to produce crumb rubber brick. Therefore, it is recommended that different sizes of crumb rubber could be used for future study. Then, the reduction values for each size are compared to determine if there is any relationship between crumb rubber size and their potential in absorbing noise thus determine the best crumb rubber size to be used as filler.

Besides that, the accuracy and reliability of the results will increase if the noise frequency could be measured. This is because two noise sources which have the same noise level (dB) could have different frequency (Hz). By measuring the frequency (Hz) together with the noise level (dB), the results obtained would be much more accurate and reliable.

CHAPTER 6

COST BENEFIT

In order to realize this study, a sum of amount had been spent. The total amount for this project is tabulated in Table 1.

Table 6.1: Cost to construct 1200 mm x 1000 mm noise barrier wall

Item	Price per unit	Unit	Total
400 mm x 200 mm x 100 mm hollow concrete blocks	RM 1.50	25	RM 37.50
Crumb rubber	RM 0.70	20kg	RM 14.00
RS300 Acrylic Sealant (Gap Filler)	RM 6.00	5	RM 30.00
Silicone gun	RM 8.00	1	RM 8.00
		Total	**RM 89.50**

Form the table above, it can be seen that the final amount spent for this study is RM 89.50. This is the amount needed to construct 1200 mm x 1000 mm crumb rubber noise barrier wall. However, if the project is to be commercialized, say to build 1 km of crumb rubber noise barrier wall, the amount would be significantly reduced. In this case, only one unit of silicone gun could be used for the whole project while hollow concrete blocks and acrylic sealant could be purchased for lower cost per unit. Apart from that, there is no need to purchase the crumb rubber as it can be obtained by grinding the used tyres found at the dump site. The reduced cost is then shown in Table 2.

Table 6.2: Reduced cost to construct 1200 mm x 1000 mm noise barrier wall

Item	Price per unit	Unit	Total
400 mm x 200 mm x 100 mm hollow concrete blocks	RM 0.50	25	RM 12.50
RS300 Acrylic Sealant (Gap Filler)	RM 4.00	5	RM 20.00
Injection gun	RM 8.00	1	RM 8.00
		Total	**RM 40.50**

From Table 2, it is evident that the amount to build crumb rubber noise barrier wall for the same dimension if it is commercialized could be reduced to only RM 40.50.

REFERENCES

Unknown, *Federal Highway Administration (FHWA)*, Unknown, [http://www.fhwa.dot.gov/environment/keepdown.htm], 28/11/09.

Zhu et al. (2008), Crumb Rubber Blends in Noise Absorption Study, *Materials and Structures* (2008)41: 383-390.

Ganjian E., Khorami M. & Maghsoudi A.A. (2008), Scrap-Tyre-Rubber Replacement for Aggregate and Filler in Concrete, *Construction and Building Materials* 23(2009): 1828-1836.

Gowda G. V. (1996), *An Investigation into the Role of Crumb Rubber Modifiers in Enhancing the Performance Properties of an Asphalt Mix*, Ph.D. Thesis, University of Bangalore.

Huang L.H., Kung T.M. (1992), Noise Barrier Simulated by Rigid Screen with Back Wall, *Journal of Engineering Mechanics* Vol. 118, No. 1, January, 1992.

Jamgocian A. (1997), *Acoustic Properties of Concerete Blocks Filled with Recycle Materials for Noise Barrier Application*, Msc Thesis, The Cooper Union Albert Narken of School Engineering.

Kumar S. (2006), *Waste Tyre Management in Malaysia*, Ph.D. Thesis, Universiti Putra Malaysia.

Shatanawi K.M. (2008), *The Effects of Crumb Rubber Particles on Highway Noise Reduction – A Laboratory Study*, Ph.D. Thesis, Graduate School of Clemson University.

Sukontasukkul P. (2008), Use of Crumb Rubber to Improve Thermal and Sound Properties of Pre-Cast Concrete Panel, *Construction and Building Materials* 23(2008): 1084-1092.

Yusoff S. & Ishak A. (2005), Evaluation of Urban Highway Environmental Noise Pollution, *Sains Malaysiana* 34(2)(2005): 81-87.

Zhu H. & Carlson D.D. (1999), A Spray Based Crumb Rubber Technology in Highway Noise Reduction Application, October 1999.

Unknown, Carbon Pressure, Unknown, [http://carbonpressure.dmau.com/], 11/8/09.

Unknown, Dromoz, Unknown, [http://www.dromoz.com/satellite/directory/?gps=59f62ad453332a5fa0d75317c1f31b9d&p=Jalan+Sultan+Azlan+Shah+106], 11/8/09.