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# Analysis of Noise Level and Sound Transmission Loss (STL) of Noise Barrier Material for the Construction Site

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**Abstract:** The construction activities are commonly known as the noisy and annoying work that affects a human's routine. Those students and lecturers whose location are at the noise receptor locations might be suffering from the health impairment. The objective of this study is to assess and determine the noise level present throughout the daytime period (9AM - 12PM and 2PM - 5PM) at respective measurement points. The analysis of noise spectrum of the sound source from 125 Hz to 4 kHz is part of the scope of study as well. The analysis was carried out by comparing the recommended safe noise level with the equivalent continuous sound level (LAeq) and sound pressure level (Lp) gathered from this study. By setting up a barrier to shield or enclose the sound source is the common way to control the noise transmission. Therefore, selection of the best noise barrier materials is based on the sound transmission loss (STL) value. In this study, the experiment STL of four different types of noise barrier material (newspaper, aluminium foil, cotton and EPS foam) also was carried out in the small scale of reverberation chambers equipped with the LMS Test Lab and LMS SCADAS Mobile device. The 16 tested one-third octave frequency band ranging from 125 Hz to 4 kHz had been utilized in this study. The results revealed that the material of newspaper produced the STL ranging from 0 dB to 9.7 dB within the low frequency of 125 Hz to 800 Hz. Meanwhile, the aluminium foil, had the optimum performance with at least 5.4 dB and above for the STL value at higher frequency ranging from 1 kHz to 4 kHz. Generally, the newspaper is considered as the best noise barrier material as it able to reduce the noise level more throughout the selected frequency range in this study.

**Keywords:** Sound Pressure Level (SPL), noise spectrum, sound transmission loss (STL), construction site

## 1. Introduction

Noise is defined as a sound that is elevated to a certain undesirable and unpleasant loud level until caused the effect of disturbance and annoyance, with the measurement unit of dB(A) or dBA. By extension, noise is classified as one of the pollutants that disrupts the productivity of work conducted by a human. This noise also extends to a level of interrupting the wellness and quality of the living environment [1]. This concludes that noise pollution is an environmental hazard to the ecosystem. The common and insidious occupational health issue debated over years is the Noise Induced Hearing Loss (NIHL). The NIHL occurs with extended exposure to noise level higher than 85 dB and within the high frequency range, no matter at a time or over a course of time [2]. The research of Department of Occupational Safety and Health, Malaysia (DOSH) found that hearing loss impairment is mainly caused by frequent

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exposure to the high frequency hearing loss threshold of 3000 – 6000 Hz [2]. Some surveys conducted by the World Health Organization (WHO) proved that there was approximately 15.2 million of person were suffering from the noise-induced hearing loss impairment with 10 million of them being adults and 5.2 million of them being children [3].

Due to the proximity of the surrounding buildings such as lecture halls and laboratories to the area of construction site, the propagation of noise is hard to attenuate. Students and the university staffs are facing the issue of temporary disruption in their daily routine since the construction activities occurs during the normal weekday time periods. In fact, this time period with the lecture class. The Department of Environment Malaysia has adopted the Environmental Quality Act, 1974 (Amendment), 1985 to legally enforce control and abate the noise pollution. The maximum permissible equivalent continuous sound level at institutional areas in daytime (7am-10pm) is 50 dBA [4], and any range exceeding this reading is not recommended [5]-[6]. Therefore, noise level assessment should be always conducted for ensuring the construction side noise level will not over the permitted noise level, especially nearby the educational and healthcare area.

Sound transmission loss (STL) is defined as the level of the sound attenuation value that is isolated by a panel or partition when the sound waves passes through it. The most common method to conduct the STL of a sound insulation material is by using the reverberation room [7]-[9]. The basic theory explains that there are sound waves called as incident waves passing through the partition, with the partition acting like an obstacle to block the sound waves propagation. Here, some of the sound waves will reflect or bounce back into the room, while some will be absorbed by the partition. The remaining waves will transmit into another side of room. Hence, the lesser the sound waves passing through the partition, the higher the transmission loss. Factors such as the porosity, thickness and density are considered for the selection of the sound insulation materials [7], [10]-[13].

By setting up a barrier to shield or enclose the sound source is the common way to control the noise transmission [13]. Therefore, the study on sound transmission loss (STL) of four different types of noise barrier material is carried out in this study. The main objective of this study is to reduce the unwanted noise that initiates the feeling or symptom of unwell and discomfort. Four different types of material that are used as the receiver are newspaper, aluminium foil, cotton and EPS foam.

The preference of using aluminium foil sheet as sound insulation material is due to the characteristics of being recyclable, possesses good thermal insulation, a promising sound proofing material, and environmentally friendly [14]-[16]. The polymer material such as expanded polystyrene (EPS) is considered as a suitable choice of material as the outdoor noise barrier due to the characteristics of being lightweight, good thermal insulation, recyclable and a well-known sound insulator [17]. Considering the biodegradability, environmentally safe, lightweight, and low cost of the cotton raw material, it is widely used in sound attenuation as the cost-effective acoustical materials in building [18]-[19]. Besides that, recycled papers such as magazine and newspaper contain plant cellulose which is eco-friendly to environment and resistant to weather and thermal exposure [20]. Recycled paper poses high fiber porosity and can be manufactured in a manner which the properties can be easily controlled, making them ideal to be made into sound absorbers [21].

## 2. Methodology

### 2.1 Measurement of Equivalent Continuous Noise Level Corresponding to Time Zone

The study area is deliberately selected at a distance of 0.06 km to the School of Mechatronic Engineering, Universiti Malaysia Perlis (UniMAP). Fig. 1 shows the location of school and the total area of the construction site, which is about 34752.48 m$^2$. The noise data is measured in two daytime sessions; one in the morning (9AM-12PM) and another one in the noon session (2PM-5PM) for two semesters of study period [22]. Each semester runs from November to December 2018 and from February to March 2019 [23]. The sound level meter is used as the noise level measuring tool at three measurement points of M1, M2 and M3 as shown in Fig. 2 [24]-[27]. The type of measurement is set as A-weighted equivalent continuous sound level, LAeq and collected it as 60 min at each measurement point. Six sample readings were taken at each measurement points.

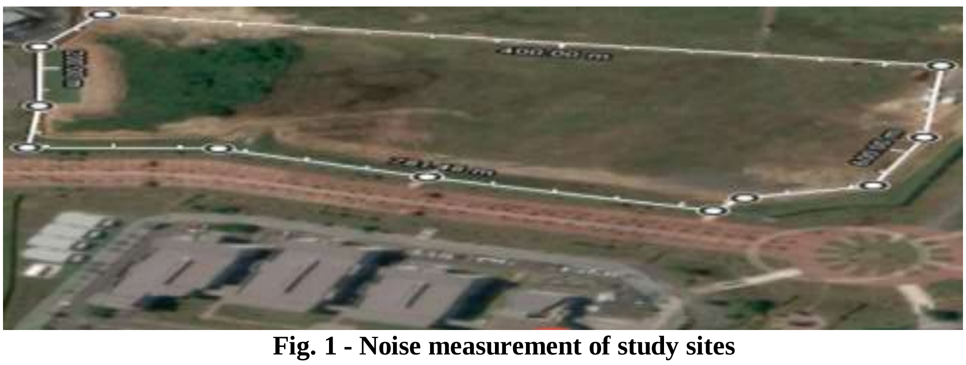

**Fig. 1 - Noise measurement of study sites**

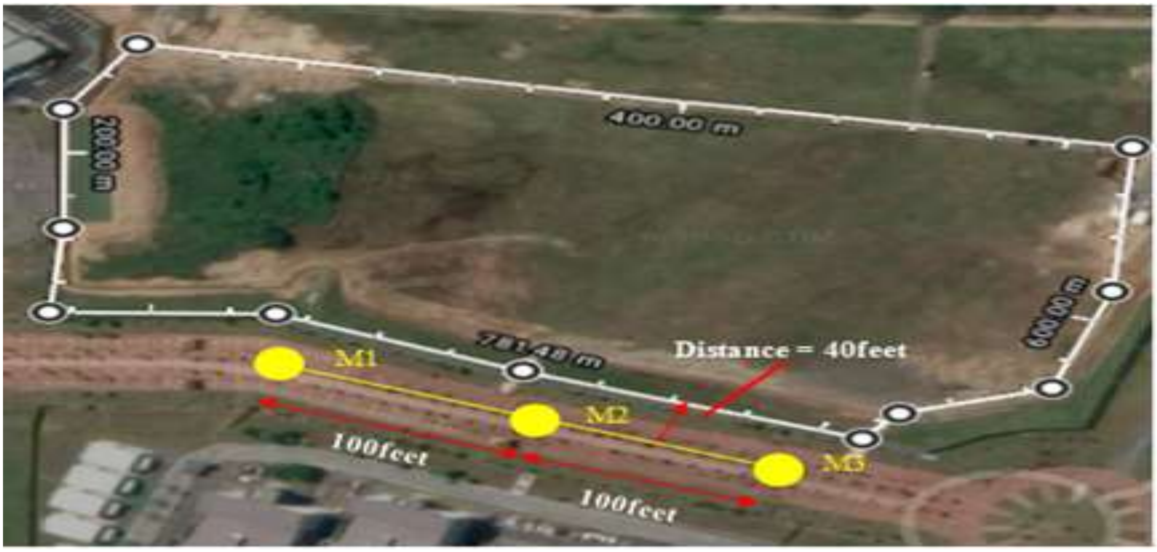


**Fig. 2 - Three measurement points**

## 2.2 Measurement of Sound Pressure Level Corresponding to Noise Spectrum

The sound pressure level, Lp versus the noise spectrum readings are collected for two days in week 2 of April 2019. There are two selected timings of measurement, at 10AM and 3PM. The data collection was carried out at the M2 only when the measurement time runs for 10 minutes. LMS SCADAS Mobile device is the frequency analyser used for the measurement of noise spectrum [28]. This device is equipped with a laptop, LMS Test Lab software, microphone and sound level calibrator. The sound level calibrator is used to calibrate the microphone at the frequency of 1 kHz and sound level of 94 dB before starting the sound pressure level measurement. The experimental setup for this measurement is shown in Fig. 3.

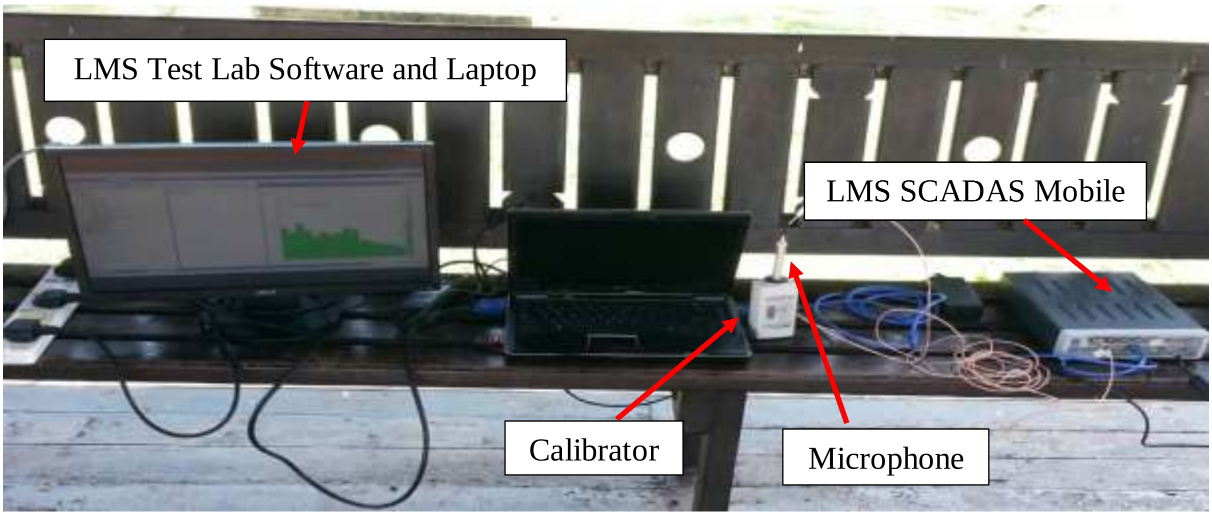


**Fig. 3 - Noise spectrum experimental setup**

## 2.3 Sound Transmission Loss Theoretical Framework

An intensity of sound incident is determined when there are no any sound insulation materials, such as panel or partition are installed. Once the required data were obtained, the test sample is inserted into the panel and the intensity of sound on the transmitted side is measured. The measured values of the sound intensity with and without the test samples are used to determine the sound transmission loss (STL) characteristics of each material. The STL is calculated by using the relation of power ratio of the incident to transmit sound in decibel unit as denoted in Equation (1).

The formula of STL [9]:

$$STL = 10\,log(\frac{W_i}{W_t}) \quad (1)$$

*Where*
$W_i$ = sound power of incident wave
$W_t$ = sound power of transmitted wave

In a free field the power based STL can be expressed in term of a ratio of squared pressures as Equation (2)

$$STL = 10\,log(\frac{P_i^2}{P_t^2}) = 20\,log(\frac{P_i}{P_t}) \quad (2)$$

*Where*
$P_i$ = incident sound pressure obtained in the sound source side
$P_r$ = reflected sound pressure obtained in sound source side
$P_t$ = transmitted sound pressure obtained in the receiver side

## 2.4 Preparation of Sound Insulation Material

In this study, the test specimens such as expanded polystyrene (EPS), aluminium foil, cotton and newspaper are selected for the sound transmission loss (STL) measurement. For aluminium foil, cotton and newspaper, they had been fixed into the panel and mixed with the egg white to ensure the materials are compacted to the based and tally to the required thickness similar to the mould. The panel mould is as shown in Fig. 4. The size of the panel is 0.184 m (L) x 0.184 m (W) x 0.025 m (H). The plate form of newspaper, aluminium foil, cotton and EPS are displayed in Fig. 5 (a), (b), (c) and (d) respectively. The physical characteristics for each sample are listed in Table 1. The volume for each sample was measured using vernier calliper, and the mass was weighted by using the electronic weighing scale.

**Fig. 4 - Panel mould**

**Fig. 5 - Plate form of (a) newspaper, (b) aluminium foil, (c) cotton, (d) EPS**

**Table 1 - Physical characteristics of each sample**

| No | Mass (× $10^{-3}$kg) | Volume (× $10^{-4}$$m^3$) | Density (kg/$m^3$) |
|---|---|---|---|
| (a) | 25.5 | 8.464 | 30.128 |
| (b) | 19.9 | 8.464 | 23.511 |
| (c) | 6.7 | 8.464 | 7.916 |
| (d) | 9.8 | 8.464 | 11.578 |

## 2.5 Acoustics Performance Experimental Measurement Setup

Fig. 6 depicts the sound transmission loss (STL) experimental measurement setup in the laboratory. Both microphones are fixed at the distance of 0.1 m from the opening by using the 0.2 m height of holder in the sound source chamber and receiver chamber respectively. The speaker was placed at the distance of 0.25 m from the opening and faced towards the microphone. Three wires that were connected to the speaker and microphone were pulled out through a small hole which then connected to the LMS SCADAS Mobile. The adhesive material (clay) was inserted into the small hole to prevent the leakage of sound waves. The plate form of the material will be placed on the specimen holder and installed in the centre of both chambers as showed in Fig. 7. Both the chambers were mated the both chambers together. Lastly, the LMS SCADAS Mobile was connected to laptop for obtaining the STL materials.

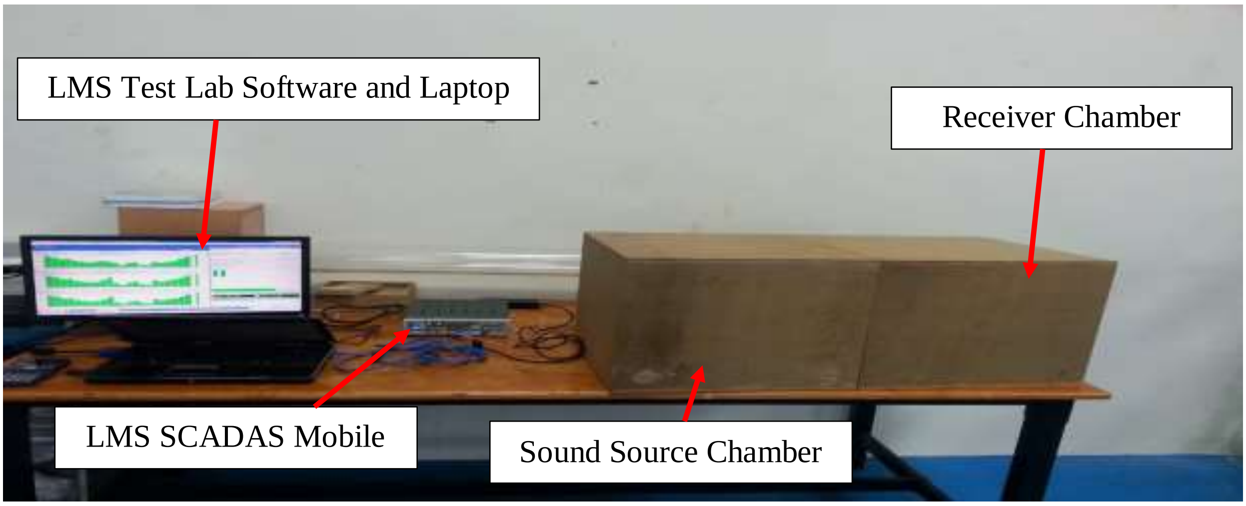


**Fig. 6 - Acoustics performance measurement experimental setup**

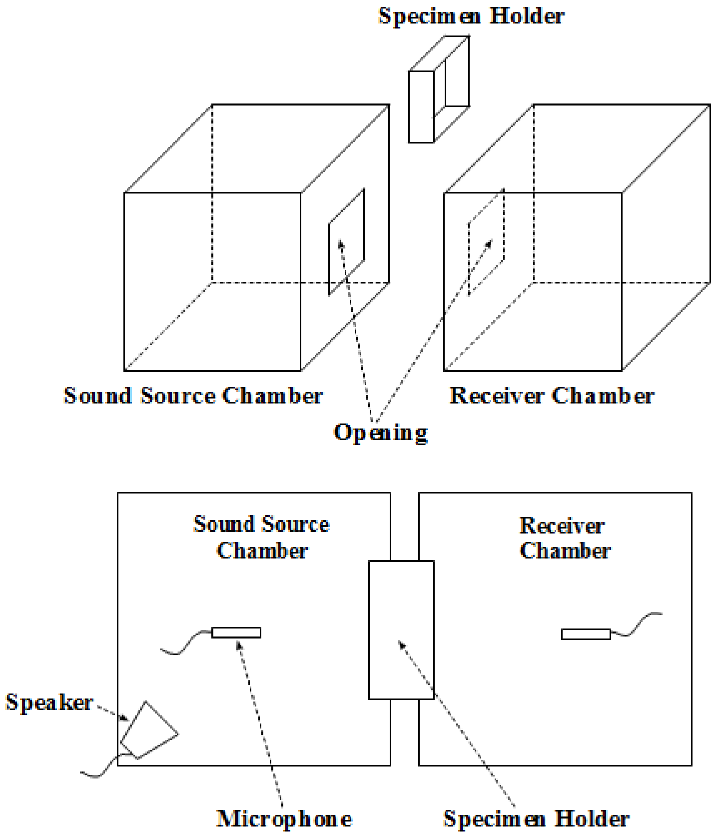


**Fig. 7 - Schematic diagram of experiment setup**

## 3. Results and Discussions

### 3.1 Equivalent Continuous Noise Level Corresponding to Time Zone

The comparison of noise level corresponding to the time zone and location between the month of November and December 2018 is depicted in Fig. 8(a). The overall construction phases in November and December mainly were the ground cleaning and demolition process. The plotted graph in Fig. 8(a) gives a glimpse that the pattern of each trend in November 2018 is mostly the same with each other as well as each trend in December 2018. There are three time slots; 9AM-10AM, 11AM-12PM and 4PM-5PM are under the safe level, 50 dBA. At the first interval, it is represented by three locations in November 2018 while the other two time slots are represented by the three locations in December 2018. Meanwhile, the inverse situation of three noise detector locations in November 2018 and December 2018 that exceeds the concern level occurred in the morning session of 10AM to 11AM and afternoon session of 2PM to 4PM.

The main construction activity that occurred in the time slot between 10AM-11AM and 2PM-4PM is the earthwork. It involved the activities of excavation and transportation of the soil from one location to another location. Since some of the soil surface area in the construction site are considered as weak, piling of the foundation being done. Such two processes are the main dominating factor in the increment of noise level in November and December respectively. The increasing trend in November 2018 occurred at the daytime period between 9AM to 12PM reaching a peak value of 63.2 dBA. Such condition is due to the emission of noise level continuously from static heavy equipment and impact tools. However, the trend tends to slightly decrease in the rest time period. There was a decrease to the value of 45.8 dBA at the duration of 11AM-12PM, which then fluctuates to the maximum value of 65.5 dBA from 2PM to 3PM and followed sharp decrease to 44.8 dBA at the time period between 16PM-17PM. At the location of M1, the largest difference of noise level between November and December is about 13.3 dBA, which falls in the daytime period of 11AM-12PM. Similarly, the largest differences of noise level at M2 and M3 falls in the same time zone with the value of 16.3 dBA and 15 dBA respectively.

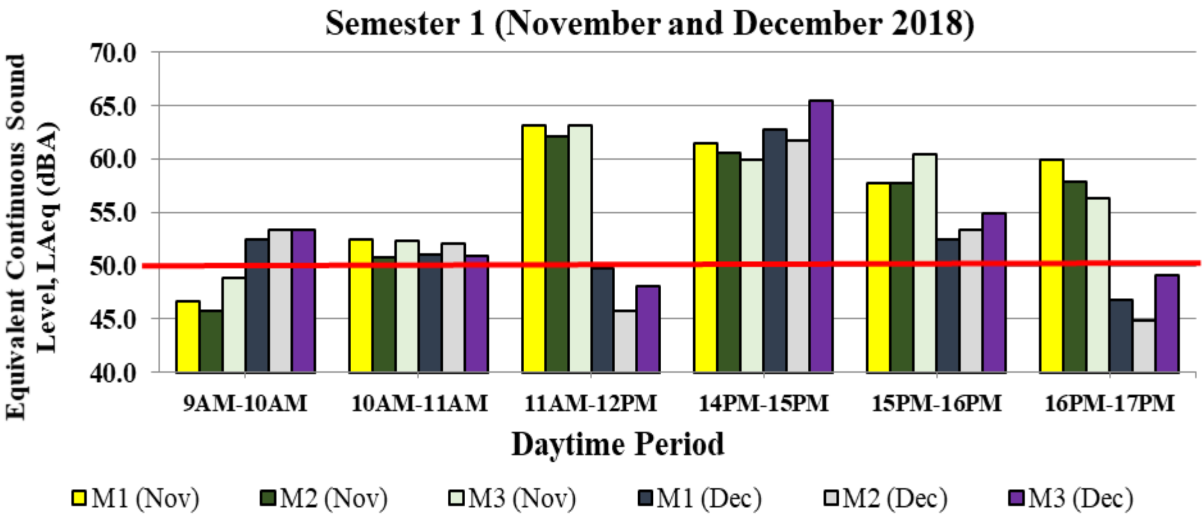


**Fig. 8 (a) - Equivalent continuous noise level in semester 1**

Fig. 8(b) displays the comparison of noise level corresponding to the time zone and location between the month of February and March 2019. The earthwork phase had come to a slower progress in February. However, there are some new phases of the construction such as concrete floor slab and concrete mixing occurrence in both months. By entering these stages, the number of workers and the machines hikes up. The collected data revealed that pattern of each trend in February 2019 did not adhere much changes. Conversely, the trend formed in March 2019 is inconsistent. Nevertheless, no fluctuations in the trend was noted. Based on the overall time zone, there are three consecutive of time slots which are within the safe level (50 dBA) which is from 11AM to 4PM in March 2019. Concerning the noise level recorded in February 2019, none of the location and time slot produced the safe level. All noise levels are contributed to at least 55 dBA and above. At the whole time period, it is believed that the movement of the concrete mixer truck in the three locations contributes to the higher noise level. Combinations of various types of sources from workforce and machine contributes to the continuous increase in the noise level. Additionally, drilling and hammering process involved in the making process of floor slab are also added factor to increase in the noise level. Both trends at M1 and M2 showed increasing trend up to 75 dBA and 66.9 dBA respectively. Meanwhile, the trend of M3 showed an increment until the noon session, which afterward remains stable at 60 dBA. Comparing to the receptor location of M2 and M3, M1 showed a stable trend until it hits the peak value of 56.1 dBA. The trend of M2 reached 47.3 dBA of noise level at 2PM-3PM, which is equal to the lowest noise level in Semester 2. It is seen that overall noise level in March has come to a quiet zone since all the trends are lower than all trends in February. The construction activities in March 2019 mainly focuses on the brick laying of building and the underground water and sewerage system, and these processes are considered as low noise activities.

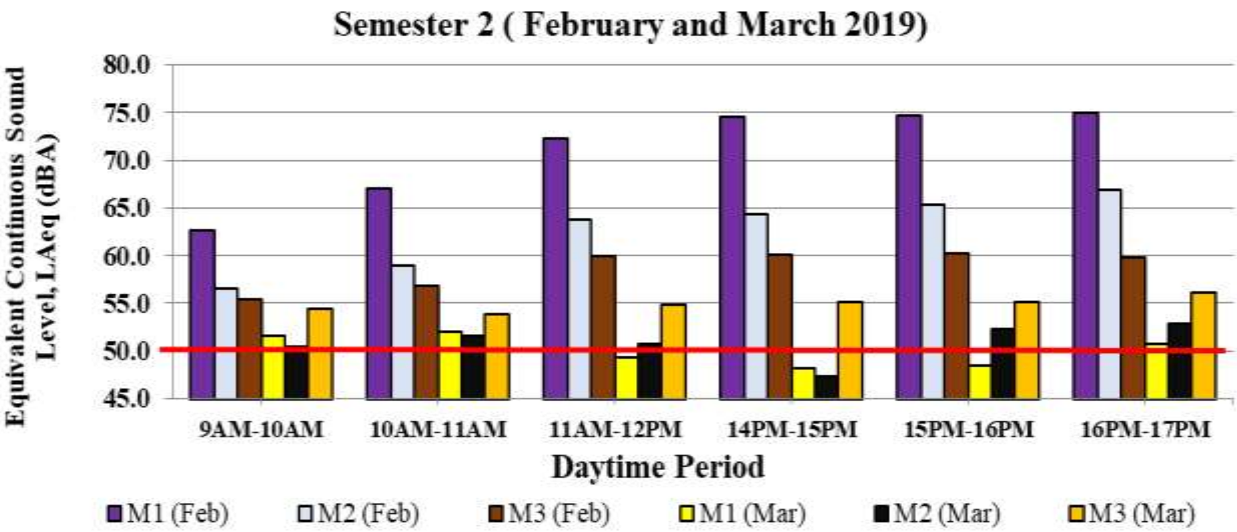


**Fig. 8 (b) - Equivalent continuous noise level in semester 2**

Overall, it is obvious that the noise level in the 2 semesters exceeded the concern level, 50 dBA in daytime period for a temporarily construction stages as mentioned. The result of higher noise level might be due to the combination of noise produced from the passing vehicle nearby the area. For instance, there are about 50% of the time zone in Semester 1 that exceeded the safe level, which is represented as 10AM-11AM, 2PM-3PM and 3PM-4PM respectively. This was also noted in Semester 2. There are 50% of time slot below the safe level, which is represented as one hour from 11AM to 12PM and two hours from 2PM to 4PM. Such conditions are predicted to cause irritation to human such as headache, and lack of concentration on study. The simplest attenuation way identified to protect someone from suffering such problem implementation of the earmuff. However, such method will be not suitable to students and staffs as clearly disrupts the teaching and learning process. Alternative yet even more effective, is to enclose or shield the noise source by using a suitable barrier. The barrier will act as the source of sound wave attenuation and blocks emission to the campus.

### 3.2 Sound Pressure Level Corresponding to Noise Spectrum

The environmental evaluation of noise produced corresponding to the noise spectrum is carried out in 2 days of week 2 in April 2019. Such analysis is conducted to observe the respective noise level emitted in a range of frequency from 125 Hz to 4 kHz. It is important to determine how far the sound pressure level is produced to hit the dangerous sound level. In this study, the bandwidth frequency is divided into three classes of frequency; low frequency ranges from 125 Hz to 315 Hz, medium frequency ranges from 400 Hz to 1 kHz and, high frequency range between 1.25-4 kHz. This range are shown in Fig 9(a). The overall noise level at both time slot of 10AM and 3PM throughout the frequency is under the safe hearing level, which is lower than 85dB. This is a safe range that all the staffs and students are free away from suffering of hearing loss risk. The peak noise level for 10AM and 3PM falls between the frequency range of 4 kHz and 3.15 kHz, which scores as 40 dB and 39.7 dB respectively. Obviously, most of the noise levels in 10AM and 15PM which are in the high frequency range are higher than the noise levels in the low frequency spectrum and medium frequency spectrum with the minimum sound level exceeds 30 dB and above. Those low and medium frequencies such as 200 Hz, 315 Hz, 400 Hz and 630 Hz all are having insignificant difference of noise level from 0.1 dB to 0.6 dB.

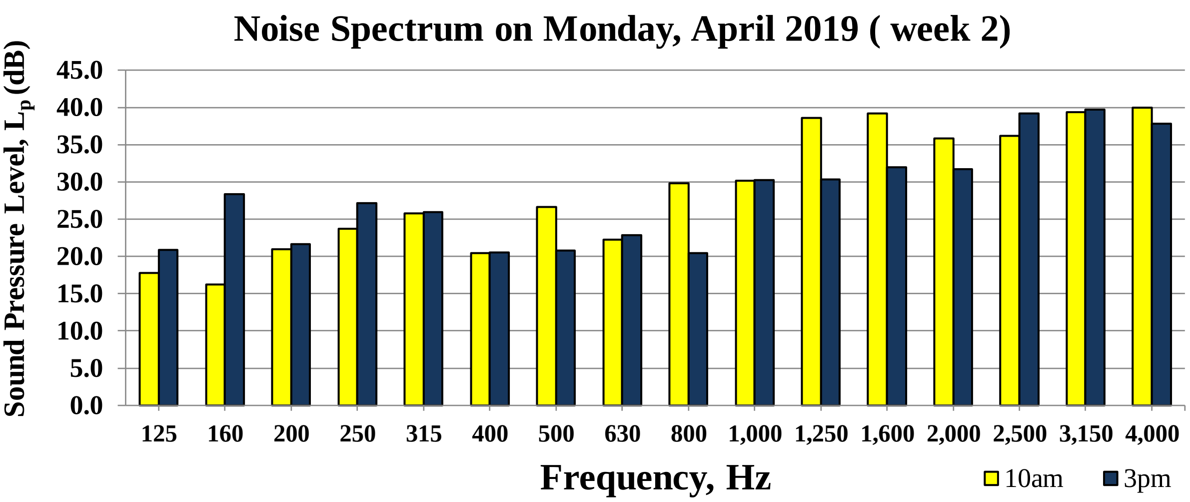


**Fig. 9 (a) - Noise spectrum on Monday**

Fig. 9(b) represents the detection of noise level that provides positive outcome as none of the noise level exceeds the dangerous level. Such analysis indicated those proximity buildings such as the lecturer hall can be categorized under the safe zone at the time slot of 10AM and 3PM. Students are able to concentrate in quiet environment. The trend of the noise level slowly increases from the category of low frequency to high frequency at the time of 10AM compared to 3PM. Both noise levels for the time slot of 10AM and 3PM hits the maximum noise level at frequency of 2.5 kHz, which are represented by 39.4 dB and 38 dB respectively. Those noise levels in high frequency bandwidth are likewise to be contributed due to the louder noise level as compared to medium and low frequency noise level of at least 31 dB and above.

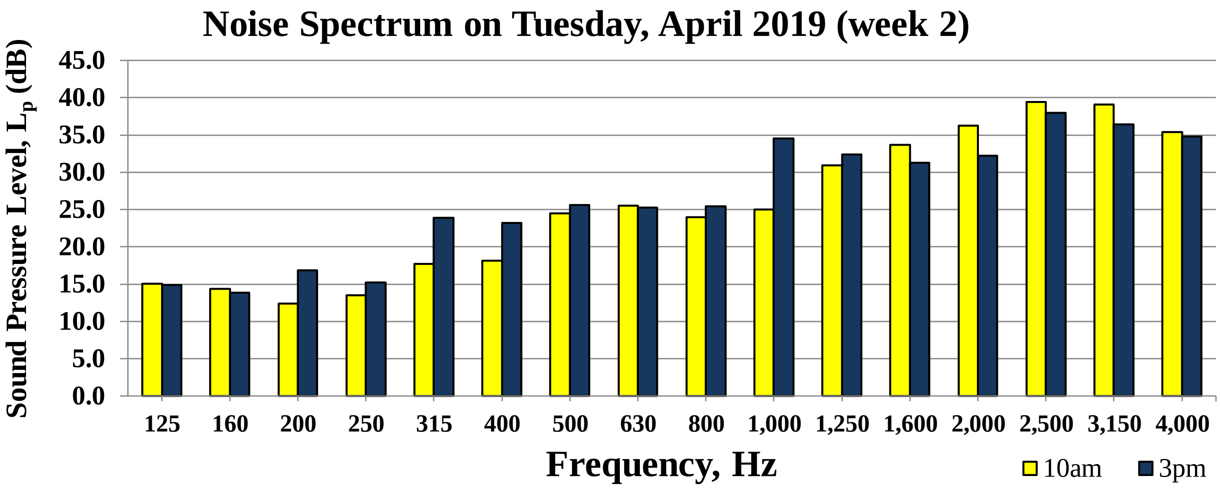


**Fig. 9 (b) - Noise spectrum on Tuesday**

The overall result concludes that the proximity area of lecturer hall is under the safe zone as the sound pressure level, Lp detected across the 1/3 octave band frequency all are below the dangerous level, 85 dB for a temporary stage. Students and staffs would have less chances of suffering from hearing loss impairment with the positive outcome recorded earlier.

## 3.3 Comparison of Sound Transmission Loss of Four Types of Material

This section discusses the comparison of sound transmission loss (STL) against the frequency between four types of material with the same thickness is plotted in the Fig. 10. Based on the presented data, it is seen that the all test panels showed respective sharp point at the low frequency of 315 Hz and deliver to 0 dB at 400 Hz within the medium frequency range. The reading of 0 dB in the STL might be due to the less sensitivity to detect the sound pressure level at a lower frequency range. At the frequency range of 125-200 Hz, aluminium foil, cotton and newspaper showed low but consistent reading of STL. On the other hand, the EPS shows a decrement in the trend. Slow and steady increment trend at 200 Hz to 315 Hz was demonstrated by the aluminium foil, newspaper and EPS as compared to cotton. Also, it was commonly observed that both EPS and newspaper reached the same highest STL value in this range. In the medium frequency, cotton showed the stable trend from 400 Hz to 800 Hz as compared to other sample materials. The trend of the newspaper and aluminium foil are the same in high frequency at 1.6-2.5 kHz. At this frequency, the two-peak value of 23.5 dB and 23.3 dB are presented by the aluminium foil and newspaper which results in difference of 0.2 dB only. As a conclusion, the test sample of newspaper performs well by having the STL value from 0 dB to 9.7 dB in the low frequency range from 125 Hz to 800 Hz as compared to the other three materials. Meanwhile, at the high frequency range from 1 kHz to 4 kHz, the best STL value was scored by the aluminium foil with the minimum value of 5.4 dB, which was 0.4 dB higher than the STL value of the newspaper.

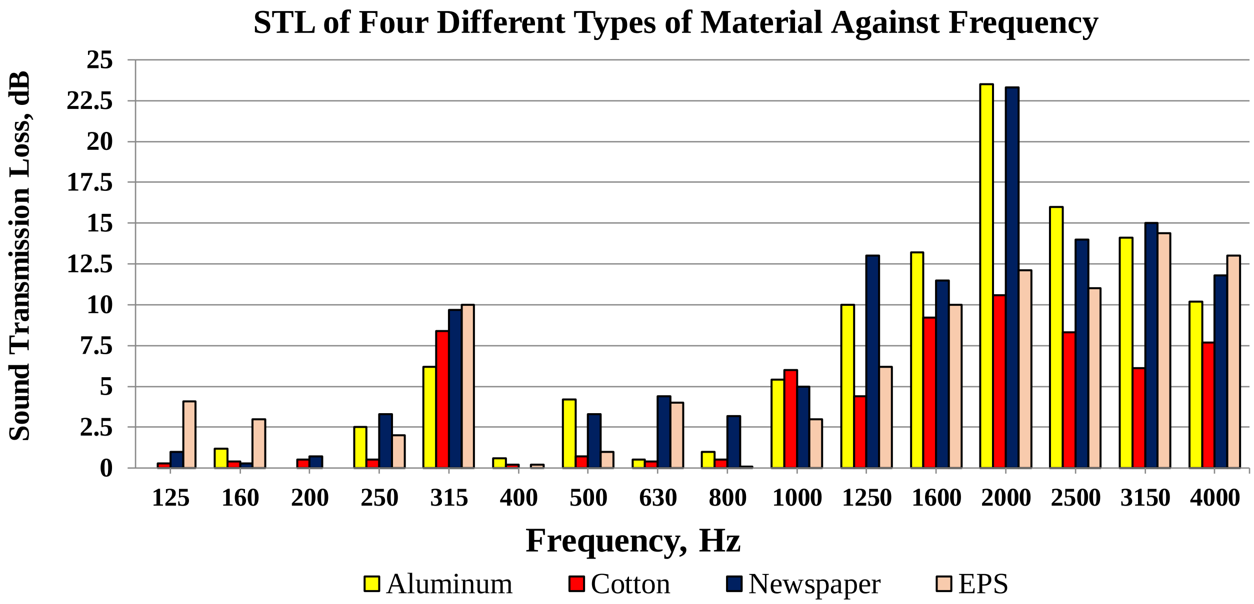


**Fig. 10 - STL performance of four different types of material**

## 3.4 Effect of Sound Transmission Loss of Material on Noise Level

The result of noise spectrum at 10AM on Monday was selected to further the analysis as the average noise level was recorded as the highest among others. Based on the STL result collected in the previous section, the sound insulation material of newspaper performs well at the low frequency spectrum while the aluminium foil showed the similar at the high frequency spectrum. Therefore, these two samples are taken as the reference to make as an outdoor noise barrier in order to determine the reduction in the total noise level at the construction site.

Table 2 displays the total sound pressure level blocked by these two materials at the respective octave band frequency. The presented data revealed that the newspaper is able to decrease the sound level pressure efficiently at the frequencies of 125 Hz, 200 Hz, 250 Hz, 315 Hz, 630 Hz and 800 Hz as compared to aluminium foil. The newspaper showed a better improvement at these three frequencies of 1.25 kHz, 3.15 kHz and 4 kHz at the higher frequency range. The highest STL value for the newspaper and aluminium foil are recorded 23.3 dB and 23.5 dB each, which occurred at the same frequency of 2 kHz. The conclusion of selecting the newspaper is made relying to the improvement made the STL value compared to other materials at the frequency range from 125 Hz to 4 kHz.

**Table 2 - Total sound pressure level reduced**

| Octave Band, (Hz) | Sound Pressure Level, (dB) (Construction Site) | Sound Transmission Loss, (dB) | | Sound Pressure Level After Applying Material, (dB) | |
|---|---|---|---|---|---|
| | Monday, 10AM | Newspaper | Aluminium | Newspaper | Aluminium |
| 125 | 17.8 | 1.0 | 0.0 | 15.9 | 17.8 |
| 160 | 16.3 | 0.3 | 1.2 | 15.7 | 14.2 |
| 200 | 21.0 | 0.7 | 0.0 | 19.4 | 21.0 |
| 250 | 23.7 | 3.3 | 2.5 | 16.2 | 17.8 |
| 315 | 25.8 | 9.7 | 6.2 | 8.4 | 12.6 |
| 400 | 20.5 | 0.0 | 0.6 | 20.5 | 19.1 |
| 500 | 26.6 | 3.3 | 4.2 | 18.2 | 16.4 |
| 630 | 22.3 | 4.4 | 0.5 | 13.4 | 21.1 |
| 800 | 29.8 | 3.2 | 1.0 | 20.6 | 26.6 |
| 1000 | 30.1 | 5.0 | 5.4 | 21.3 | 16.2 |
| 1250 | 38.6 | 13.0 | 10.0 | 16.9 | 12.2 |
| 1600 | 39.2 | 11.5 | 13.2 | 8.6 | 8.6 |
| 2000 | 35.8 | 23.3 | 23.5 | 2.4 | 2.4 |
| 2500 | 36.2 | 14.0 | 16.0 | 7.2 | 5.7 |
| 3150 | 39.4 | 15.0 | 14.1 | 7.0 | 7.8 |
| 4000 | 40.0 | 11.8 | 10.2 | 10.3 | 12.4 |

## 4. Conclusion

This study had been carried out successfully to monitor and detect the respective noise level of the construction site in term of equivalent continuous sound level (LAeq) and sound pressure level (Lp) which is emitted to the proximity surrounding institutional area. The presented results, LAeq shows that the construction activities during daytime is associated with three noise receptor locations measuring reading exceeding the safe level of 50 dBA, recommended by the Department of Environment Malaysia. Overall, only 50% of time zone’s data falls under the safe level. Definitely, such negative phenomenon affects most of the learning process of students. Conversely, the results of Lp versus noise spectrum displayed a good acoustic environmental phenomenon as 100% of the noise level across one-third octave band frequency of noise source is under safe level in the specific selected daytime period. It is a worth mentioning here that the probability to suffer the high frequency hearing loss and low frequency hearing loss is 0%. The newspaper is selected as the greatest sound insulation material among other three types of materials. It portrayed the optimum performance in lower frequency range from 125 Hz to 800 Hz and higher frequency ranged from 1 kHz to 4 kHz, which is represented by the STL value from 0 dB to 9.7 dB and 5.0 dB to 23.3 dB respectively.

An improved understanding on the study of analysis of sound pressure in amplitude should be taken into account for further research. Different amplitude of noise level (dB) will be result in different dangerous level of the sound source is. By conducting such study, a new perspective for the study of construction noise can provide the local governments to enforce a new law or regulations for noise mitigation plan in construction site. Looking at the improvements that can be made in this field, further study on the STL performance using various combinations of sound insulation material would close more research gap. Aspect like different thicknesses and masses of material can be tested in different atmosphere to provide wide range of data that can be used as references in any other studies.

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