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A case study of acoustic efficiency of existing noise barrier in reducing road traffic noise in school area

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Abstract. The study investigates the effectiveness of existing noise wall barrier installed in a school for shielding noise from heavy traffic. The objectives of this study are to investigate the effect of this barrier on the characteristic of traffic noise spectra, and evaluate its efficiency on broadband noise insertion loss and low frequency noise attenuation. The barrier is of absorptive type with slightly aging condition where small holes and cracks in some places are spotted in both surfaces of wall. The barrier is made of panels of fibre cement mortar infill with absorbent materials with the height is 4m x 0.25m thickness x 132 m length with the distance of the barrier to the highway as main noise source is 17 m. Investigation of the efficiency of barrier started with the determining of noise frequency spectra near the barrier at 0.5m in front of barrier, and 0.5 m and 6m behind the barrier, all at five points along the barrier length. The efficiency of barrier was determined by its insertion loss of broadband noise and attenuation of low frequency in the range 20 to 200 Hz. The results showed that barrier changed the characteristic of traffic noise spectrum. It was found that barrier efficiently achieved insertion loss of 5 dBA or above if the receiver was at distance more than 3.5m behind the wall. At 6m meter behind wall, although the barrier was considered effective but it was failed in reducing the sound pressure level below the World Health Organisation (WHO) permissible limit for school area and attenuating the low frequency noise sufficiently. These results highlighted that the barrier unable to combat the noise disturbance in school playing field area.

1. Introduction

School area including school playing field, class room, laboratory and hall is an important place for student curricular and co-curricular activities. School is noise sensitive area and is concerned by many researchers as noise will decrease the capability of hearing and make a decrease in concentration of learning for the children. Traffic noise is measured by the unit of decibels and to consider the human sensitivity it is converted into A-weighted. In Malaysia studies in school area have been conducted since 1980s covering west Malaysia even before the establishment of noise regulation. These include noise level conducted in school at three school at Klang Valley in 1985[1]. All these selected schools exceeded the 55dB(A) recommendation by the WHO [2] for outdoor school areas that may affect teachers' and students' performance. After the establishment of DOE regulation in 2004[3], Elfaig et al.[1], observed that LaSalle Secondary School located in busiest part of Klang Valley had



exceeded DOE limit during day (between 68.2dB(A) to 73.7dB(A)). Many researches had investigated the noise level climate in school area exposed to traffic during rush hours. Mohmadisa et al. [4] found that all school in Batu Pahat area in the range of 59.9 to 71.3 dBA. Ismail, Abdullah and Fong [5] reported that noise level of three primary schools in Kuala Terengganu with different surrounding activities i.e. industrial, commercial and residential had exceeded the permissible level for noise sensitive areas. The exceedance of the level were due to exposure to high road traffic as main sources that consist of 64% car and van, 24% motobikes and 12% heavy vehicles.

Road traffic noise is categorised as line source with propagation over distance cylindrically. It attenuation per doubling of distance is 3 dBA [6]. Noise barriers are commonly used to block this noise propagation and requires special design and material that it attenuation can be as high as 24 dBA. However, due to high cost of noise barrier construction, only selected schools are being shielded by noise barrier. Its functions by blocking the line-of- sight between road traffic as noise source and a receiver in school area, thus creating a sound shadow zone. When a noise barrier is inserted between a noise source and a receiver (located in school area), the direct noise is reflected, absorbed and diffracted (Figure 1). The attenuation of barrier depends on the height and dimensions of the barrier, the distance between the noise source and the receiver, the reflection factor of the barrier surface facing the road, and the frequency spectrum of traffic noise. Daigle [7] stated that typical height of noise barrier are often between 2 to 6m with attenuation for A-weighted broadband noise between 5 to 12 dBA but 3 dBA also normally found in countries around the world. Noise barriers generally provide more effective attenuation to high frequencies of traffic noise spectrum rather than low frequencies as low frequencies has short wavelengths and easily diffracted into the shadow zone [7]. Barrier efficiency is measured by its insertion loss defined as the difference in sound pressure level before and after the barrier is constructed. According to Daigle [7], in the case of existing noise barrier, insertion loss also can be obtained by difference in sound level with construction of barrier and free field condition. Insertion loss depend on the path length difference, δ defined as different between the direct (c) and the diffracted sound (a+b)(Fig. 1). There two empirical expression are popularly used to estimate the insertion loss which are Maekawa and Kurze- Anderson, for semi-infinite length and finite thin barriers, respectively. The barrier is said to be effective when the insertion loss are between 5 to 12dB [7,8].

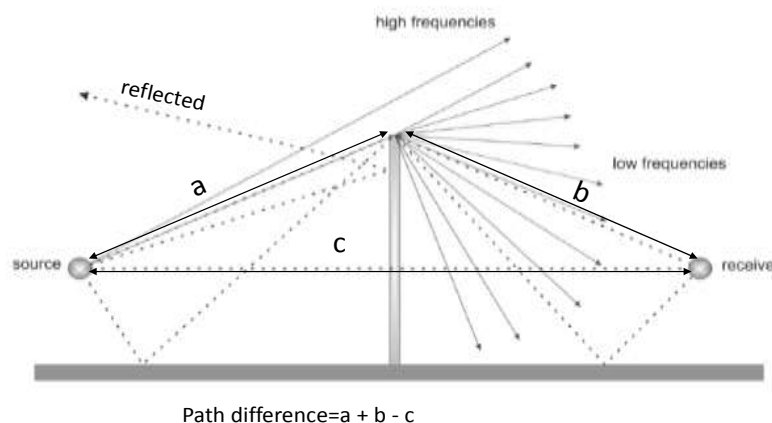


Figure 1. Path length difference.

Saliunas and Volkovas [9] suggested barrier efficiency can also be measured by the ability in attenuating the Low frequency noise (LFN) within the region of 20 to 200 Hz. LFN has been recognised as problem in many countries in the world. Thus, many countries especially in Europe, limits the LFN in order to reduce annoyance to specific group of people. Research also found that LFN contributes to annoyance responses by creating a sensation of pressure in the ear, periodically masking effects on

medium to high frequency sound with a strong modulation effect that can disturb normal conversation, and by creating secondary vibrating effects typically experienced within homes [10]. In addition, Leventhall, Pelmeier and Benton [11] documented a number of potential behavioural dysfunctions associated with LFN, such as task performance deterioration, reduced wakefulness, and sleep disturbance, headaches, and irritation. It has also been learnt that LFN does not need to be considered “loud” for it to cause such forms of annoyance and irritation.

The current study investigates the effectiveness of existing wall barrier installed in a school for shielding noise from heavy traffic. The condition of barrier is somewhat lack of maintenance and some part of it has been replaced with plastered concrete block. The objectives of this study are to investigate the effect of this barrier on the characteristic of traffic noise spectra, and evaluate its efficiency for insertion loss of broadband noise and attenuation of LFN. The research could give an idea whether the noise barrier could be still effective in shielding the school playing area from the transportation noise.

2. Methodology

A noise barrier build at a primary school for shielding the traffic noise from Skudai-Johor Bahru Highway was investigated. The highway is considered heavy traffic with average traffic volume of 11,571 vehicles/hr, calculated by Ministry of work Malaysia [12] through their continuous observation of 24 hours traffic volume for 7 days. To the best of authors knowledge, this is the only noise barrier installed at school area in Johor Bahru. The barrier is of absorptive type with the unsatisfied condition which is slightly aging with there are small holes and cracks in some places and some panels are replaced with plastered block. The barrier is made of panels of fibre cement mortar infill with absorbent materials (Figure 2). The height is 4m with thickness of 25cm and length 132 m while the distance of the barrier to the highway as main noise source is 17 m. Investigation of the efficiency of barrier started with the determining of noise frequency spectra near the barrier at 0.5m then followed by the reading at 6m behind the barrier, both at five points (P1 to P5) along the barrier length (Figure 3). Further, LAeq readings at 0.5m behind the barrier along the five location (P1 to P5) were determined. Noise spectrum were measured by using SLM Type 1 at every point at near the wall and 6m behind wall while sound pressure level at right behind wall were measured by using SLM Type 2, with all measurement by using fast mode. Reading at 0.5 m in front of wall (facing the noise source) and behind wall was to obtain the reduction of noise by barrier. Measurements were made three times (15 minutes each) at every point during normal hours during good weather condition, temperature 31°C and wind speed 0.7 m/s. For the receiver at 0.5m and 6m behind wall, these points were located at school playing field which the sound level must not exceed 55 dBA as per WHO requirement [2]. The sound level meters were mounted at 1.5m from ground to represent the average height of a person. Free field propagation condition for the highway were measured at 200m from noise wall, at two point which is a row with noise barrier (17m) and doubling distance 34 m. This method was also used by Saliunas and Volkovas [9]. The doubling distance measurement is used to determine the characteristic of the propagation of noise source from the road with and without barrier.



(a)



(b)

Figure 2. (a) The view of perforated noise barrier from road. (b) The view of perforated noise barrier from school.

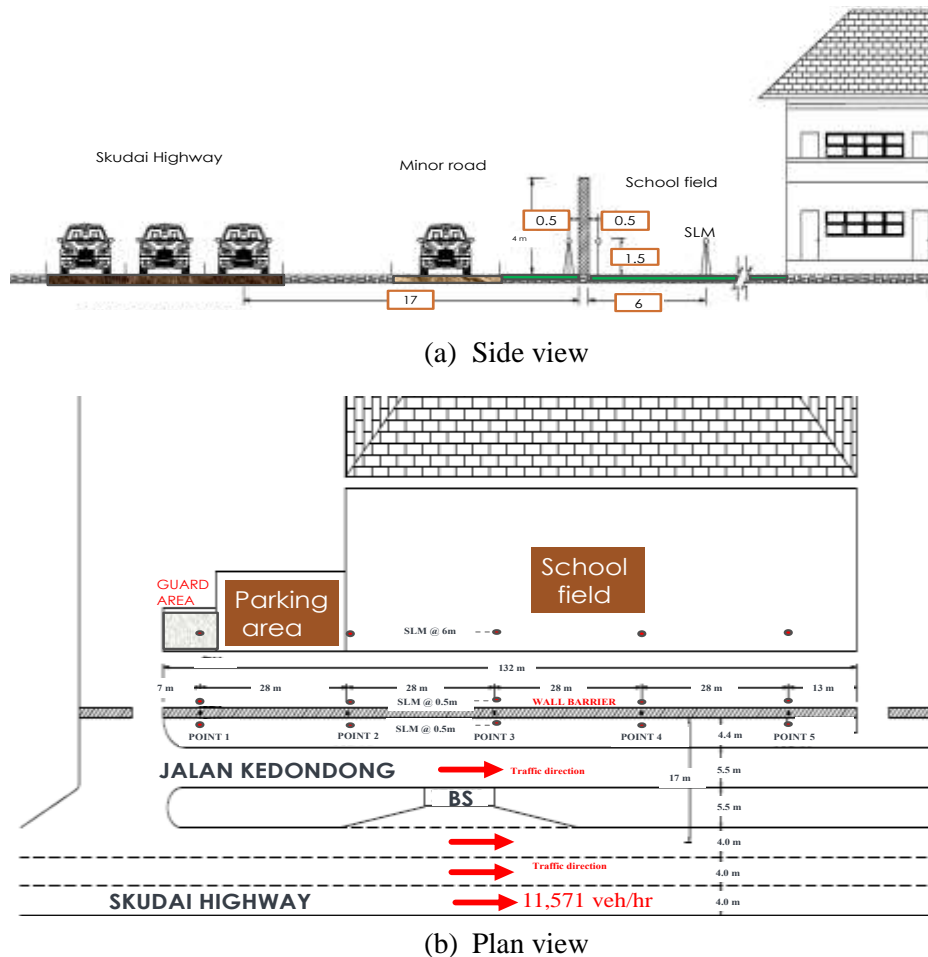


Figure 3. Measurement points.

2.1 Analysis of data for acoustic efficiency by insertion loss

Acoustic efficiency in this study is divided into two categories which are insertion loss of broadband noise and attenuation of LFN. Sound pressure level reduction defined as different of incident sound pressure level and the transmitted sound pressure level is also used. This study considered the insertion loss by using the average different of LAeq at location with noise barrier and free field condition. The obtained insertion loss were compared with Maekawa and Kurze-Anderson [13-17] formula in identifying the possible causes of the deviation. The path length difference (Figure 1), δ is characterised by the frequency wavelength in 1/3 octave band called Fresnel number (N) that can be calculated using Equation (1).

$$N = \frac{2\delta}{\lambda} = \frac{2\delta}{C} \quad (1)$$

where c is speed of sound and f is the 1/3rd-octave-band center frequency

Maekawa derived the simple formula for insertion loss due to linear source (Equation 2) based on experimental investigation while Kurze-Anderson modified it to improve the insertion loss for the $N < 1$ (Equation 3). Both formula has been used widely due its simplicity.

$$\Delta L = 10 \log (2 + 5.5N) \quad (2)$$

$$\Delta L = 15 \log \left[\frac{\sqrt{2\pi N}}{\tanh \sqrt{2\pi N}} \right] - 10 \log \left(2e^{\frac{-h}{2\lambda}} + 1 \right) + 5 \quad (3)$$

A correction factor (Equation 4) is applied for finite length barrier in considering the lateral edges. Considerably, two other Fresnel number, N_1 and N_2 , are introduced.

$$\Delta L_N = \Delta L - 10 \log \left(1 + \frac{N}{N_1} + \frac{N}{N_2} \right) \quad (4)$$

Where $N, N_1, N_2 > 1$.

2.2 Analysis of data for efficiency of attenuating LFN

Efficiency of barrier in attenuating the LFN were analysed by using data on frequency spectra at 6m behind barrier. The extend of LFN problem were evaluated by using four criterias. First was by comparing sound pressure level with reference limit of LFN threshold imposed on several European country including Germany, Denmark, Poland, Netherlands, United Kingdom, Sweden, and ISO Threshold [10]. Second was by finding if the difference between C and A-weighted values (dBC-dBA) exceeds limit of 15dB [18]. Third was the examination of the presence of a tone by checking the sound level in one 1/3rd octave band to the level in the two adjacent bands that should not exceed 15 dB in the low-frequency one-third-octave bands (25 Hz to 125 Hz). Finally, the 60 dB limit sound pressure level at the 31.5 Hz octave band were examined. An additional weighting factor of 5 dB can be added to the average A-weighted if the limit is exceeded for the consideration of LFN annoyance.

3. Results and discussions

3.1 Characteristics of traffic noise spectra

The unweighted equivalent sound pressure level in Free Field Condition is shown in Figure 3 while the unweighted equivalent sound pressure level near and behind noise barriers is shown in Figure 4. Data in Fig. was obtained by averaging data obtained at points 1 to 5. From data measurements at free fields, near barrier and behind barrier, it is obvious that noise spectrum of the road has 2 peaks which are at 63 Hz and 1000 Hz. The peak at 63 Hz represent the engine noise while at 100 Hz represents the interaction between road and tyre. Considering the free field, $L_{Aeq(20-10KHz)}$ at 17m and 34m from driving are 71.5 and 68.3 dBA, respectively. There is reduction of 3.2 dBA for the doubling distance which showed the traffic characteristic is line source. This shows that sound decay at free field is near to the theory value for line source, 3 dBA per doubling of distance as reported by Lee et al., [6]. The effect of barrier on characteristic of noise can be seen on measurement results near noise barrier and 6m behind wall. The maximum reduction of sound pressure level occurs at 500 to 630 Hz as much as 9.2 to 9.6 dB. The difference between $L_{Aeq(20-10KHz)}$ at distance of 17 m from driving lane in a row with barrier and 6m behind noise barrier is 12.4 dBA.

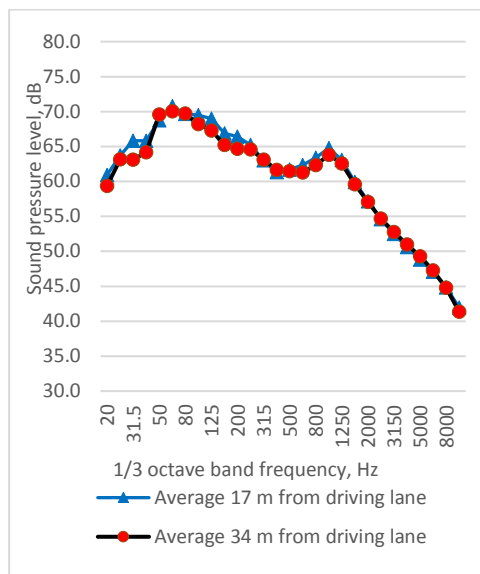


Figure 4. The unweighted equivalent sound pressure levels in free field conditions.

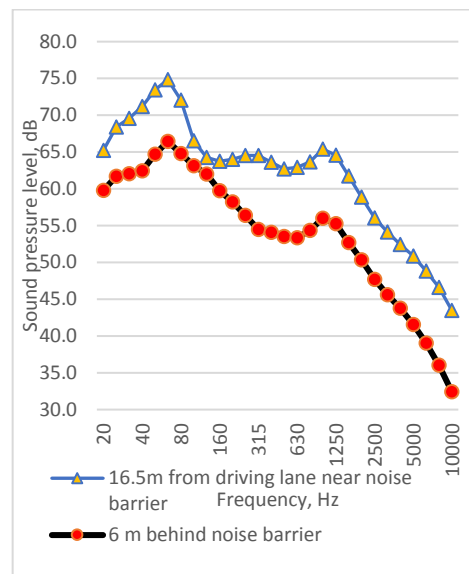


Figure 5. The unweighted equivalent sound pressure levels near barrier and 6m behind barrier.

3.2 Evaluation of Insertion Loss

The average of unweighted SPL at 1/3 octave band in dB at 16.5m from driving lane near noise barrier at point P1 to P5 is shown in Figure 6. Traffic noise demonstrated high sound pressure level at low frequency below 200 Hz and the total equivalent sound pressure level in dBA, $L_{Aeq(20-10KHz)}$ are 73.2, 72.6, 73.1, 71.9 and 71.6 dBA with average of equivalent sound pressure level 72.5 dBA. The level are relatively high compared free field in a row with barrier due to the effect of the reflection from the noise barrier. According to WHO [2] if a person expose to this level for 24 hrs, it can potentially impair the hearing. However, this is only the waiting area for the parents during morning and evening and it is considered safe. The noise that pass through the noise barriers, loss it energy and the SPL reading suddenly decreased and this can be seen at reading behind wall at 0.5m (Table 1). Average of equivalent sound level of point P1 to Point 5 is 67.6 dBA, consequently results in insertion loss of 3.7 dBA, less than 5 dBA and considered non effective although the previous research [7] stated that 3-25 dBA is commonly found.

According to WHO [2], school field should be bellow 55 dBA and in this case the 0.5 m behind wall barrier is part of school field area which is not a safe place as it exceeded the limit by 12.6 dBA. Physically, the barrier height is sufficient to cut the line of sight of 1.5m height of receiver to source and the 0.5m behind wall is located at 'shadow zone'. There are many reason influence the insertion loss including a) a direct diffracted field, b) a diffracted field due to the image receiver, c) a diffracted field due to the image source, d) a diffracted field due to the image source and image receiver and e) physical of wall. The reason (a) to (d) were discussed by Diagle [7] while physical of wall are the condition of wall such as the possibility of existing of small holes and gaps (Figure 7 and 8). Kotzen and English [19] reported that when there are holes present, the reduction of sound level can be zero and can severely affect the performance of barrier. In this study the reduction sound level at 0.5m behind barrier is 4.3 dBA which categorized as barely perceptible to perceptible (Table 2).

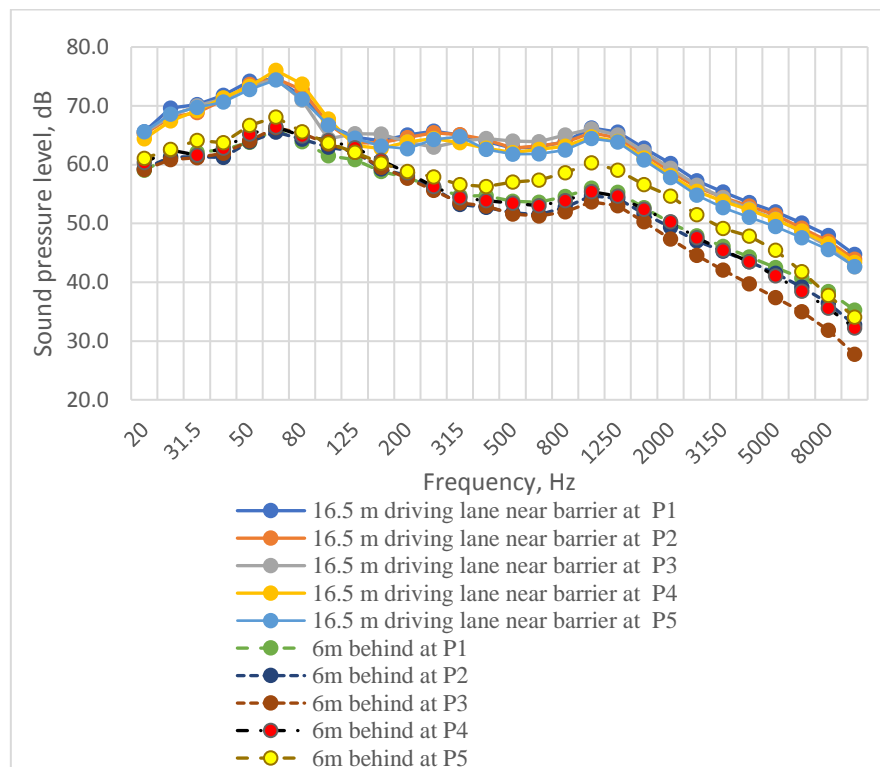


Figure 6. The unweighted equivalent sound pressure levels at 5 measurement points near barrier and 6m behind barrier.

Table 1. Insertion loss at 0.5m behind Barrier.

Location of Testing	0.5m Behind Noise Barrier	Free field At 0.5m behind noise barrier	Insertion loss dBA
Point 1	67.9	71.3	3.7
Point 2	66.6		
Point 3	66.9		
Point 4	68.5		
Point 5	68.2		
Average	67.6 (std=0.47)	71.3	

Table 2. Reduction of noise by Barrier.

Location of Testing	0.5m In Front Noise Barrier (dBA)	0.5m Behind Noise Barrier (dBA)	reduction dBA
Point 1	72.7	67.9	4.8
Point 2	72.0	66.6	5.4
Point 3	72.5	66.9	5.6
Point 4	71.2	68.5	2.7
Point 5	71.4	68.2	3.2
Average	72.0	67.6	4.3

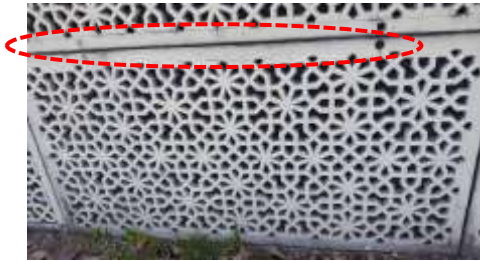


Figure 7. Gaps between the panels where noise can intrude.



Figure 8. Holes present on wall barrier.

The A-weighted equivalent sound pressure levels at 6m behind barrier and free fields for every 1/3 octave band and their insertion loss is shown in Figure 9. As expected it can be seen that barrier reduce high frequency rather than low frequency and the total loss of broadband noise is 5.4 dBA. The insertion loss at frequency of 500 Hz is 5.52 dB and this value can be used in the approximate calculation of diffraction and noise reduction of a sound barrier. This result indicates that barrier is effective in reducing noise at 6m behind barrier as the insertion loss is between 5 to 12 dBA. By comparing the insertion loss value right behind wall at 0.5m and 6m, it can be observed that as the receiver moved farther from 0.5m of barrier the insertion loss increased. Based on the minimum criteria of insertion loss of 5 dBA for the noise barrier to be effective, it was found that this will be achieved at 3.5m or greater from the back of noise barrier (Figure 10). Moreover, when the WHO guideline are to be considered, the barrier is not acoustically efficient as the sound pressure level at 6m is greater than 55 dBA.

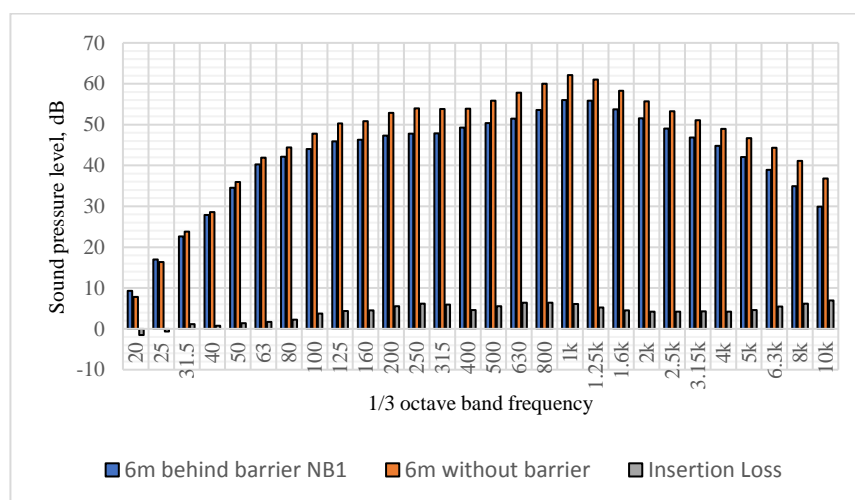


Figure 9. The A-weighted equivalent sound pressure levels at 6m behind barrier and free fields.

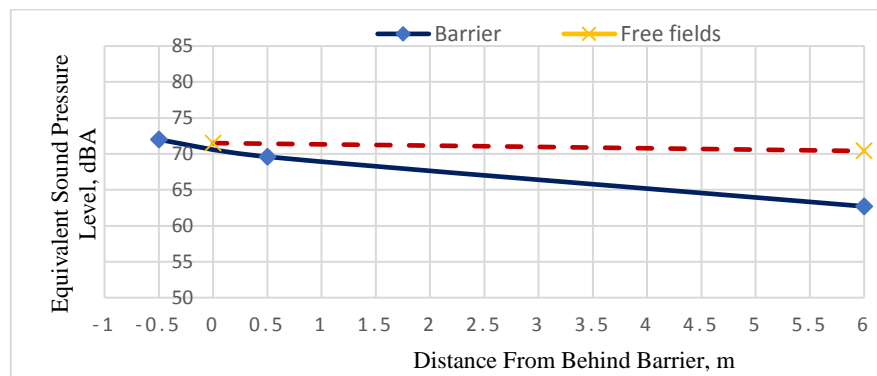


Fig. 10. The A-weighted equivalent sound pressure levels at 6m behind barrier and free fields.

Figure 11 shows the comparison between measurement and prediction by using Maekawa and Kurze-Anderson formula. In this study, measurement for wall barrier show deviations about the Maekawa and Kurze-Anderson Curves more than 3 dB for the Fresnel number greater than 1.3. Maekawa and Kurze-Anderson's formula usually give the higher value of barrier attenuation, due to the fact that does not include ground, air and other absorption effects. However, according to previous research [7], perforated wall should absorb more sound than those calculated by using Maekawa and Kurze-Anderson Curves. This study results vice versa and it is believed that the unsatisfied physical condition of wall compounded these effect.

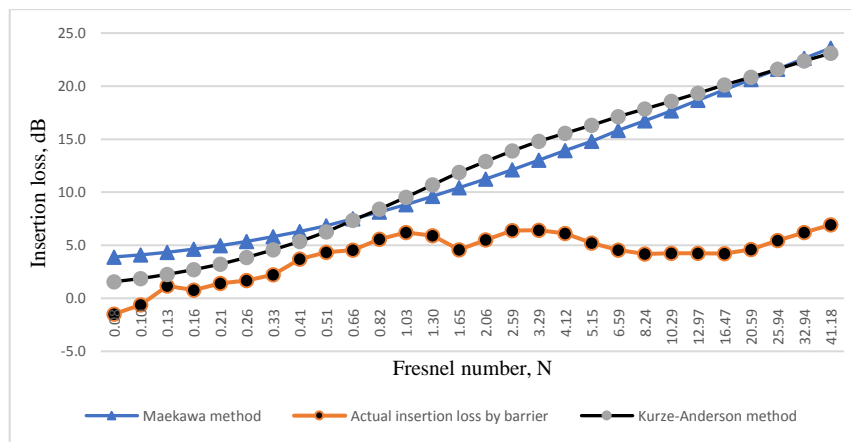


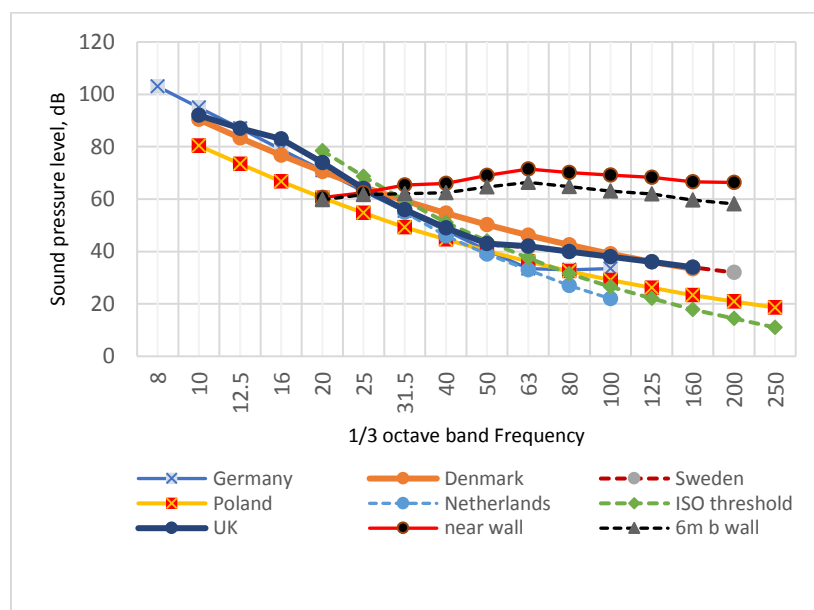
Figure 11. Comparison between theory and measurement at 6m behind wall.

3.3 Evaluation of LFN attenuation

Table 3 shows un-weighted equivalent sound pressure level near to barrier and behind barrier for LFN (LFN). It can be seen that barrier increase the attenuation of sound as the frequency become higher. The total attenuation of LFN $\Delta L_{Aeq\ 20-200Hz}$ is 6.9 dBA. When $L_{Aeq\ 20-200Hz}$ compared with the limit for imposed from different countries (criteria 1), it was observed that LFN near barrier and behind 6m wall indicate that at 31.5 Hz and above exceed the limit values applied in many countries. This indicates that traffic noise is a source of LFN that could cause disturbance (Figure 12). This is in agreement with the fourth criteria that the sound pressure level at 31.5Hz greater than 60 dB. Thus, a 5 dBA must be added to the average A-weighted $L_{Aeq\ 20-20KHz}$ to consider the LFN annoyance. The second and third criteria were not exceeded.

Table 3. Reduction of LFN.

1/3 octave band centre frequencies, Hz	20	25	31.5	40	50	63	80	100	125	160	200
17m from driving lane, dB	60.6	62.5	65.4	66.0	69.0	71.5	70.1	69.2	68.3	66.6	66.4
6m from noise barrier No.1, dB	59.8	61.7	62.1	62.4	64.7	66.4	64.8	63.1	62.0	59.7	58.2
Difference, dB	0.8	0.8	3.3	3.6	4.3	5.0	5.3	6.1	6.3	6.8	8.2

**Figure 12.** Comparison between measurement and limits in European countries.

4. Conclusion

Physically, the investigated barrier has the height within the range of typical height of noise barrier (4m). The efficiency of barrier was determined by its insertion loss of broadband noise and attenuation of low frequency in the range 20 to 200 Hz. The insertion loss is the difference in the noise environment after the barrier is constructed and free field. It was found despite the unsatisfied condition of the barrier, investigation at the receiver height of 1.5m shows that the barriers is still effective method of abating transportation noise at distance more than 3.5m behind the wall. However, the disturbance free from traffic noise still cannot be granted as the noise level behind wall still exceeded the WHO permissible limit for school playing area and the LFN exceeded the suggested limit. An improvement of the investigated barrier need to be carried out to increase the insertion loss and reduce LFN annoyance, for example by installing absorber strip at the top of a barrier.

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