Journal of Civil & Environmental Engineering

Lee et al., J Civil Environ Eng 2015, 5:2
DOI: 10.4172/2165-784X.1000171

Research Article Open Access

Reduction Effects of Shaped Noise Barrier for Reflected Sound

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Abstract

Noise Barriers are widely installed to control the propagation of vehicle noise from highway. However, the installation may result in a secondary noise caused by reflection, especially, if there exists a residential area on the opposite side. Hence, to effectively use noise barrier, it is mandatory to first predict the noise sources taking place on the roadsides and to apply the findings afterwards. In this study, by evaluating the reduction effects of reflection noise according to different panel shapes including wing, zigzag and curved type, the optimal soundproof panel shape and design factor that can minimize the reflection noise are suggested. The sound reduction was modeled by general linear model for the case of zigzag and curved shape with nominal variances. To simulate the effects of each shape, Nord 2000 with sound traveling model was used. As a result, all panel types have shown reduction effects on reflected sound, with maximum of 2.2 dB for zigzag and 1.2 dB for curved shapes. The designing factors had impact on the density of zigzag type and on the degree of bending in the curved shape. Specifically, for first noise level (up to 5 story building), reduction effect is improved for smaller size of wing type, wider angle between zigzag type panels and gentle slope of curved type. Overall, curved noise barrier labeled as C-9 is found to be the best in diminishing reflection noise. This type of barrier can be effectively used to control damages caused by reflection noise at downtown region, where extent of traffic is increasing from day to day.

Keywords: Noise barrier; Noise sources; Sound proof panel; Panel shape; Reflection noise

Introduction

The current urbanization rate of Korea is very high with staggering 90.9% [1]. Consequently, the number of cases regarding traffic noise damage caused by cars and trains is increasing every year, especially in areas highly dense with population and facilities. The Environmental Standards for Noise (roadside areas) stated in the Basic Environmental Law notes that the daytime (06:00~22:00) standard equals 65 Leq dB (A), whereas the night time (22:00~06:00) standard is 55 Leq dB (A) in areas "A" and "B". Also, the daytime standard for area "C" is 70 dB, while 60 Leq dB (A) is the standard for the night time. According to the Report on Conditions of Environmental Noise in Major Cities (Statistics Korea, 2012), noise damages in areas "A" and "B" exceed a maximum of 10 Leq dB (A) during the daytime, and a maximum of 10 Leq dB (A) in areas "A" and "B" in the night time as well as 7 Leq dB (A) in area "C" during the night time.

Effective control of the undesirable consequences of highway generated noise requires a three-part approach; namely, source emission reduction, improved highway design and land use control [2]. Since each noise control approach has limitations when applied separately, the three part approach is essential. As to the source emission reduction, significant progress is being made in research to reduce vehicle engine and exhaust noise, but tire design, the major source of high speed traffic noise, yet needs further improvements.

Improved highway design involves greater attention to noise impacts in choosing the route and layout of new highways [3]. This involves issuing standards for highway noise levels in government Policy. Standards are not a complete solution to highway noise, but represent a balancing of that which may be desirable and that which may be achieved. Highway agencies have the responsibility for taking measures that are feasible to assure that the location and design of highways are compatible with existing land use.

Thus, land use control will be a crucial component of the three-part approach to noise control. Local governments will continue to have the responsibility for discouraging the development of noise sensitive land uses (such as homes and schools) in highway noise impacted areas or for ensuring that any such development that does occur is planned to minimize the adverse effects of noise. Dealing with the problems of noise-sensitive land uses encompasses ways of reducing the impact of highway-generated noise upon existing developed activities [2].

Noise barriers have been used for decades to reduce traffic noise levels for highway-adjacent residential areas and other noise-sensitive land uses [4-6]. In recent years, an increasing demand for multi-functionality, such as visual impact, sound absorption on the receiver side and durability, in the design of noise barriers has been noticed [7]. In order to effectively meet the requirements, it is necessary to install the barriers by accurately predicting the propagation characteristics of traffic noise that occurs on the road [8]. Based on propagation, noise barriers can be classified as sound-absorbing noise barriers, reflective noise barriers and combined noise barriers.

In case of sound-absorbing noise barriers, the soundproof effect is extraordinary since the barriers use sound-absorbing materials and thus are usually installed in residential areas and highways in the downtown region. The barriers effectively reduce noise levels, but often cause undesirable secondary impacts, such as blocked views of mountains and other scenic features, decreased visibility from the roadway, or large shadows cast across a resident's backyard for extended periods of the day. This exerts a negative image to opaque construction materials including aluminum and galvanized sheet iron.

Combined noise barriers do merge sound-absorbing and reflective noise barriers to simultaneously decrease the noise absorption and insulation, and are usually installed in places that require partial visibility. Representative examples of reflective noise barriers are

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Received March 11, 2015; **Accepted** March 28, 2015; **Published** April 08, 2015

Citation: Lee J, Kim J, Park T, Chang S, Kim I (2015) Reduction Effects of Shaped Noise Barrier for Reflected Sound. J Civil Environ Eng 5: 171. doi:10.4172/2165-784X.1000171

transparent materials, which are commonly used whenever aesthetical and visual impact issues are of concern. Because they can optimize their unique transparency as much as possible to secure the sight of nature and visibility, the demand for transparent noise barrier installation is particularly increasing. At the moment, materials such as Polycarbonate (PC), Polymethylmethacrlate (PMMA) and stratified glass are commonly used as transparent noise barriers for both aesthetical and safety reasons [7].

Based on their characteristics, transparent noise barriers block noise by reflecting. Such reflections of noise path exist when single or parallel barriers are built to control noise. In the single barrier case, reflections may cause the noise levels to increase on the opposite side of the road and could exacerbate the problem and cause potential annoyance to nearby residents. In the parallel barriers case, the multiple sound reflections between barriers can cause reverberant build-up between them, which in turn constitutes a higher sound level that can seriously degrade the acoustical performance expected from each wall. Thus, despite the various benefits of transparent noise barriers to secure view and light, a weakness lies in the limited areas available for installation. In spite of this fact, there is a constant increase in requests to install transparent noise barriers considering their advantages. In consequence, damages caused by noise reflected from the transparent noise barriers are likely to increase in the future [4].

Either tilting the sound proofs or making them sound absorbing are two potential ways applied to prevent the performance degradation. The barrier performance can be restored by sloping the barriers in which required angle depends on the separation of the barriers. But this may not be an optimum solution that should be encouraged, as the reflected sound could cause problem elsewhere. If the sloping surface has dimensions less than the wave length of the sound, a scattering rather than reflection process occurs [9]. On the other hand, some traffic noise prediction model studies have indicated that sound absorptive materials can reduce noise levels substantially, especially where barriers are placed on both sides of the road and there is a possibility of multiple reflections between the parallel barrier faces [10]. However, a study by Nelson [11] failed to show degradation in performance when 3 m reflective barriers were erected 33 m away on the far side of the carriageway.

Computer modelling [12], laboratory experiment [13] and field measurement [14] studies confirmed the improvement of insertion loss for various shape designs compared with simple plane reflective barriers of identical height. Material configurations are designed to promote destructive interferences between waves following two different paths. There are two distinct cases: one case is considering different shapes and the other is the case of multiple edge barriers. Research on various types of barriers with reflective and absorptive materials showed an absorbing barrier's performance in better design and at the top modification provided slight changes in performance, i.e. T-shaped barrier provided the best performance [15]. As an alternative method to control reflective or absorptive performance of soundproof panel, it is considerable to use surface strengthening techniques to plastic materials [16,17].

This study evaluates the reduction effects of reflection noise by soundproof panel shapes, to develop a method to lessen the reflection noise. The reduction effect of reflection noise according to shapes of each soundproof panel is compared and analyzed through a simulation with different panel shapes and design factors. Hence, the research proposes the best possible soundproof panel shape and design factor to minimize the occurrence of reflection noise.

Materials and Methods

Selecting the noise prediction model

For the purposes of this research, selecting the noise source model is a critical factor in calculating the overall noise level. Domestic models of traffic noise prediction include the NIER (National Institute of Environmental Research)-type developed by the National Institute of Environmental Research and the KHTN (Korea Highway Traffic Noise) prediction program developed by the Korea Expressway Corporation. But, NIER is only applicable for above 1.5 m from the ground level and KHTN can only be used at highway settings [18]. The Ministry of Environment recommends using 5 prediction models of Calculation of Road Traffic Noise (CRTN), RLS90, NMPB, Nord 2000, ASJ2008 when producing a traffic noise map [19].

CRTN is a prediction model crafted by the Department for Transport in the United Kingdom and used in calculating traffic noise to conduct environmental impact assessment when constructing roads, design highways, and establish plans for land use. Whereas, RLS90 is a prediction model announced by the road construction department under the Federal Ministry of Transport and Digital Infrastructure of Germany in 1990 as a succeeding model to RLS81. It uses the point source prediction method and takes into account factors such as sound diffusion, ground attenuation, sound insulation and reflection.

The NMPB is a French prediction model which was developed in 1996 to predict traffic noises and was amended in 2008. Nord 2000 is a prediction model for noise from roads and trains in Northern European countries, first announced at DELTA (Denmark), SINTEF (Norway), and SP (Sweden) in 2001 and revised for 5 years to optimize the prediction of traffic noise. The fifth one, Model ASJ2008, was introduced at the Acoustic Society of Japan (ASJ) and used to predict the noise level by assuming the noise source as omni-direction as a point source in half space [20].

Among the aforementioned noise prediction models, CRTN, RLS90 and NMPB simply categorize mid-size (or sedans) and full-size cars, whereas Nord 2000 employs a more sophisticated categorization of mid-size cars and full-size cars of 2 axis, 3 or more than 4 axis. Also, since the octave analysis is based on a range of 1/3 octave, 25~10,000 Hz, the analysis is much wider than other models (CRTN, RLS90: only overall levels, NMPB: 1/1 octave, 125~4,000 Hz). Therefore, this research implemented Nord 2000 that has comparatively an abundant amount of information. The sound source model of Nord 2000 used in this research is based on Eq. (1) [21].

$$L_{E,10m} = L_E + 10 \cdot \left[\frac{\sqrt{\left(d - \frac{w}{2}\right)^2 + h_r^2}}{10} \right] - 10 \cdot \log \left[\frac{\Delta\alpha}{2 \cdot \arctan(5)} \right] \quad (1)$$

Where, $L_{E',10m}$=noise level at more than 10 m away from noise source [dB]

L_E=measurement noise level [dB]

d=measurement distance

w=axle width of the vehicle (car=1.5 m, truck=2.5 m)

h_r=height of the microphone

$\Delta\alpha$=the angle affecting on a receiver [rad]

From Eq. (1), we can obtain sound power levels of vehicles by substituting a correlation term, C (v).

$$L_w = L_{E,10m} + C(50) + 10 \cdot \log\left(\frac{v}{50}\right) \quad (2)$$

Where, L_w=sound power levels of vehicles

v=velocity of vehicle

When calculating the noise level, Nord 2000 applies the data measured where the distance between the road and the receiving point is between 7.5 m and 15 m and the height is 0.2 m and 4 m above the ground level. Eq. (1) will be used for noise levels at points where more than 10 m is apart from the middle of the road. The directivity and revised distance attenuation, C (v) is calculated from the Nord 2000 model. Eq. (2) indicates how to calculate L_w (sound power levels by frequency) according to the change of car speeds, by using Eq. (1) and (2). 50 kmh^{-1} will be the standard speed and the value of C (50) transforms the measurements at 10 m of distance and heights of 0.2 m and 4 m from the receiving point into a database [21].

Setting up the conditions of noise prediction

In this study, the types of vehicles that generate noise pollution are classified into: Category 1 (mid-size cars), Category 2 (full-size cars with 2 axes) and Category 3 (full-size cars with more than 4 axes). The computation conditions of each sound power level are described in Table 1 and each power level has been calculated as the hourly average noise level. Vehicle categorization in Korea is set as 12 types by the Ministry of Land, Infrastructure and Transport according to the number of axis, width of wheels and distance between left and right wheels, whereas the Korea Expressway Corporation re-categorizes the 12 types according to the number of axis, width of wheels and distance between left and right wheels into 5 and calculates each noise level. Although the domestic standards consider the number of axis in the vehicle, Nord 2000 uses combination of the number of axis and weight.

Meanwhile, noise sources with different sizes of reflection noise by directions, although they are based on an identical sound source, are referred to as directivity noise sources. Sound directivity models have been developed through foreign standard models and individual research projects. Members of the EU especially possess customized models for their domestic conditions through long-term research. Tables 2-4 show how representative sound directivity models such as Nord 2000 harmonize and calculate the directivity.

	Vehicle number	Vehicle speed
Category 1	1000 cars/h	100 km/h
Category 2	20 cars/h	100 km/h
Category 3	10 cars/h	100 km/h

Table 1: Computation conditions of sound power level.

	Height	Frequency range	Directivity
Source 1	0.01 m	1,600 – 10,000 Hz	-5 + 7 abs(cos(φ))
Source 2	0.15 m	1,600 – 10,000 Hz	-5 + 7 abs(cos(φ))
Source 3	0.30 m	1,600 – 10,000 Hz	-5 + 7 abs(cos(φ))

Table 2: Horizontal directivity of sedans (Nord 2000).

	Height	Frequency range	Directivity
Source 1	0.01 m	1,600 – 10,000 Hz	-5 + 7 abs(cos(φ))
Source 2	0.15 m	1,600 – 10,000 Hz	-5 + 7 abs(cos(φ))
Source 3	0.30 m	1,600 – 10,000 Hz	-5 + 7 abs(cos(φ))

Table 3: Horizontal directivity of full-size cars (Nord 2000).

	Height	Frequency range	Directivity
Source 1	0.01 m	f ≤ 1250 Hz , f ≥ 8000 Hz 1,600 Hz ≤ f ≤ 6,300 Hz	0 $-1.5 + 2.5abs(\cos(\phi))\sqrt{\cos(\psi)}$
Source 2	0.30 m		0
Source 3	0.75 m	$(1.546(\frac{\pi}{2} - \phi)^2 + 0.22(\frac{\pi}{2} - \phi) + 0.6)\sqrt{\cos(\psi)}$	

Table 4: Automobile Directivity Model of Harmonize.

Heights of noise sources (Source 1, 2, 3) that appear in Tables 2-4 refer to the heights of noise sources that are emitted from the road, usually used in mathematical models. Although they vary according to the vehicle categorization and the types of models employed, the lowest sound source means the friction noise between tires and the road surface and the mid-height sound source means engine noise in case of small cars, whereas it means exhaustion noise for full-size cars. The highest sound source, on the other hand, would mean engine noise for small cars and exhaustion noise for full-size cars. These are not absolute in any terms and can differ from model to model.

The directivity of Nord 2000 cannot calculate the vertical directivity and since it is in conflict, in terms of the height of noise sources, with Sound Plan 7.2, the directivity in this research has been calculated based on the Harmonize model. According to the vehicle categorization provided in Table 1, the noise levels for each frequency based on the heights of sound source (directivity heights of the Harmonize model) have been calculated for the simulation and

Table 5 shows the results. Noise level has also been calculated via Sound Plan 7.2, a noise prediction program. Each simulation has been based on the ray-tracing method.

Conditions for predictions of noise level by lanes

Figure 1 is a prediction of noise delivery distribution when a noise level of 63 Hz is emitted from each lane toward a 5 m tall flat-type noise barrier. To set up the prediction conditions, we have assumed a situation as Figure 1, where a noise of 63 Hz is emitted from each lane while there exists a flat-type noise barrier with a height of 5 m. As seen in Figure 1c to 1f, it has been forecasted that the noise emitted from the first lane on the barrier side and the opposite side have not been much influenced by the noise barrier. This is probably because the noise source and the reflective body are quite far apart that the reflection noise is almost undetectable due to distance attenuation. Moreover, as Figure 1a depicts, it has been predicted that the influence of noise barriers will be exaggerated when noise occurs from the third lane on the noise barrier side. A possible reason might be that when the distance between the noise source and the noise barrier is too close, it will be almost similar to a case of direct noise.

The conditions for the simulation will be most similar to the reality when the prediction is based on all the lanes, making the 6-lane road the standard. But when conducting the simulation prediction, we have selected the second lane on the noise barrier side as the basic condition for noise prediction, to best depict the prediction results.

Research subject: Forms of noise barriers

This project aims to consider the reduction effects of the reflection noise according to the forms of noise barriers. To this end, the study will follow the format of a comparative analysis on the reflection noise between the existing flat-type noise barrier and wing-type (Figure 2a), zigzag (Figure 2b), and curved (Figure 2c) noise barriers.

The design factors for each form will include: first, for the wing-

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	Height	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	Overall
S1	0.01 m	77.39	77.49	77.69	78.59	82.99	80.29	80.19	81.79	89.05
S2	0.3 m	70.23	70.33	70.53	71.43	75.83	73.13	73.03	74.63	81.89

Table 5: Calculated sound power level (dB).

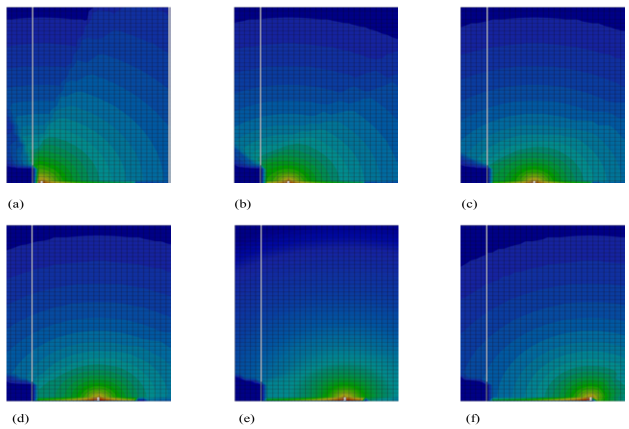

Figure 1: Delivery of noise from noise barriers by lanes (63 Hz). (a) First lane on the noise barrier side; (b) Second lane on the noise barrier side; (c) Third lane on the noise barrier side; (d) First lane on the opposite side; (e) Second lane on the opposite side; (f) third lane on the opposite side.

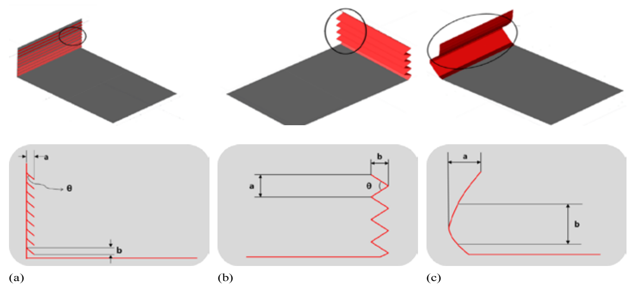

Figure 2: Design factors and forms of the noise barrier.(a)Vane-type; (b) Zigzag-type; (c) Curve-type.

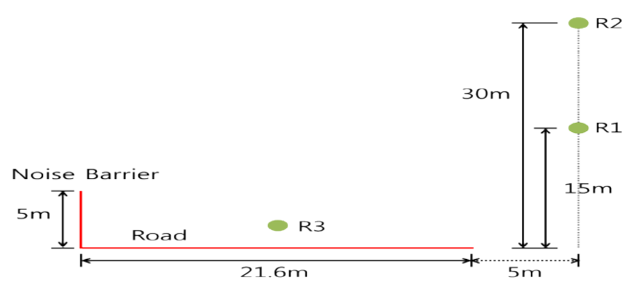

Figure 3: Location map of comparison point about noise level.

type noise barrier, the depth of the wing (a), the height of the wing (b) causing the difference of the installation angle of the wing (θ); secondly for zigzag forms, the width of the panel (a), height of the zigzag shape (b) causing various zigzag shapes by the installation angle of (θ); last but not least, for curved types, the width (a) and height of the curved peak (b), in order to evaluate the reduction effects of the reflection noise according to the values of each design factor. Besides, the reflection

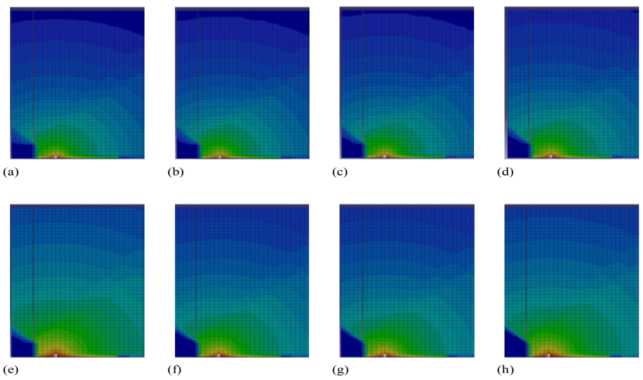

Figure 4: Diffusion of reflection noise from flat-type noise barriers by frequency. (a) 65 Hz; (b) 125 Hz; (c) 250 Hz; (d) 500 Hz; (e) 1,000 Hz; (f) 2,000 Hz; (g) 4,000 Hz; (h) 8,000 Hz.

noise is measured by frequency, with values of 65 Hz, 125 Hz, 250 Hz, 500 Hz, 1,000 Hz, 2,000 Hz, 4,000 Hz and 8,000 Hz.

In case of common residential housings, because noise levels are normally measured in a unit of 5 floors, we conducted the experiments of measuring the reflection noise at 15 m (R1), a usual height for a 5-story building and at 30 m (R2) that is level with usual 10th floors on the opposite side of the noise barrier. Additionally, to check whether the noise level increases at the inside of the road (R3) compared to the flat-type noise barrier, the noise level was measured at 2 m above from the middle of the road (Figure 3).

Results and Discussions

Reduction effects of reflection noise on flat-type noise barriers

To evaluate the reduction effects of reflection noise by shapes of the noise barriers, we first reviewed that of the flat-type noise barriers that is widely used nowadays. The reduction effect has been calculated by frequency, as Figure 4 illustrates. Although the diffusion direction of the reflection noise slightly differs from one frequency to another, the values mostly tend to diffuse towards the diagonally opposite direction from the noise barrier. Besides, we can see that the distribution of the left and right sound rays follow an uneven pattern from the borders of the diffusion direction of the reflection noise.

Table 6 is a prediction of noise levels at points R1, R2 and R3. First, the predicted reflection noise at R1, 15 m high and opposite from the noise barrier, was 59.79 dB. At R2, a point 15 m higher than R1, the prediction value decreased by 4 dB to score 55.6 dB. On the other hands, at R3, 2 m above the middle of the road and the closest to the noise source, it was predicted to reach 71.1 dB.

Reduction effects of reflection noise on wing-type noise barriers

The experiment conditions and results for the wing-type noise barriers are presented in Table 7. To go over the results, with W-1, the smallest values of a, b and θ, the predicted noise level at R1 was 57.5 dB, presenting a high reduction effect of reflection noise than flat-type noise barriers by 2.2 dB. At R2 and R3, however, the reflection

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Prediction measuring point	Predicted noise level (dB)
R1 (15 m)	59.7
R2 (30 m)	55.6
R3 (Middle of the road, 2 m)	71.1

Table 6: Predictions of reflection noise from flat-type noise barriers.

Sample No.	a (m)	b (m)	θ (deg.)	R1 (dBA)	R2 (dBA)	R3 (dBA)
W-1	0.4	0.64	39	57.5	55.9	71.1
W-2	0.5	0.71	45	59.2	55.9	71.4
W-3	0.7	0.86	54	59.8	55.4	71.3

Table 7: Predictions of noise level of wing-type noise barriers.

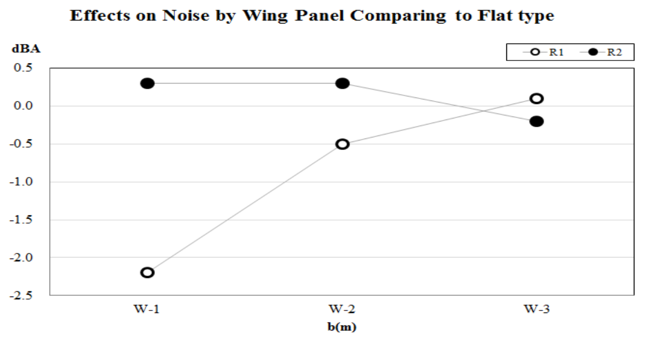

Figure 5: Amount of noise reduction of wing-type noise barriers compared to flat-type.

noise seems to increase or remain the same compared to flat-type noise barriers. In case of W-2, the prediction at R1 was 59.2 dB, slightly lower than flat-type noise barriers, and the reflection noise actually showed higher values at R2 and R3 than flat-type barriers. With the largest a, b and θ values, W-3 appeared to display predicted noise levels at R1, R2 and R3 as 59.8, 55.4, and 71.3 dB, suggesting an increase of 0.1~0.2 dB or a slight decrease compared to flat-type noise barriers. Figure 5 is a graph that signifies the reduction amounts of wing-type noise barriers in comparison with flat-type barriers and it clearly shows that the reflection noise of W-1 suggests the highest reduction effect.

Taking into account its special forms, it was expected that wing-type noise barriers will have a reduction effect of reflection noise than flat-type noise barriers, but the prediction results suggest a different finding. Especially with wing-type noise barriers, we have expected the diffusion of noise toward the diagonal opposite direction will be suppressed, resulting in an increase of noise level at R3 and consequently decrease the reflection noise at R1 and R2. But, the actual results suggest that the noise level at R3 will slightly increase than flat-type noise barriers and a moderate degree of reduction effect of reflection noise can be observed at R1. At R2, however, the noise level is predicted to increase or slightly decrease regardless of the measuring conditions, leading us to conclude that after all, the reduction effects of reflection noise with wing-type noise barriers can only be limited to the lower part.

Reduction effects of reflection noise on zigzag noise barriers

Table 8 summarizes the results by the measuring conditions of zigzag noise barriers. And the reduction value by zigzag panel comparing to the flat panel was shown in Table 9 and Figure 6. The values of R3 are shown in Figure 6. The main reduction effects of the zigzag noise barriers were identified in R1. With Z-3 and Z-4, where values of a and b are equal predicted -2.2 dBA that the reduction value is maximum compared to flat-type noise barriers. But considering the noise at high receiver (R2), the condition of Z-3 would be poor to select. Besides, as we can see from the results, to obtain the reflection noise at both R1 and R2, the condition of Z-1 would be recommended.

Similar to the wing-type case, it was highly expected that zigzag noise barriers could display a reduction effect of reflection noise since the sound source would hit the inside of the zigzag panels, but the predictions depict a quite different picture. Especially, it was predicted that the noise would be reflected towards the opposite side rather than the inside with zigzag noise barriers so that the reflection noise will increase at R2 no matter what the measuring conditions are. Therefore, since R2 equals the 10^{th} floor of a common residential building where the reflection noise will increase, zigzag noise barriers can only be installed in regions with low-level buildings and facilities.

Using the general linear model, the predicted noise of zigzag panel by the factors a and b was figured out as the following equation with the coefficients [22].

$$Noise_{zigzag},\ R_1 = 58.42 - 0.150*a_{0.5} - 0.567*b_{0.5} + 1.083*b_{0.8} + 0.500*a_{0.5}*b_{0.5} + 0.250*a_{0.5}*b_{0.8}$$
$$Noise_{zigzag},\ R_2 = 55.90 - 0.333*a_{0.5} - 0.250*b_{0.5} - 0.250*b_{0.8} + 0.283*a_{0.5}*b_{0.5} - 0.317*a_{0.5}*b_{0.8}$$

Where $a_{0.5}$ is the value for 0.5 m of a, $b_{0.5}$ is that of 0.5 of b and $b_{0.8}$ is that of 0.8. The values of the parameters a and b were adapted from the sigma-restricted model.

Sample No.	a (m)	b (m)	R1 (dBA)	R2 (dBA)	R3 (dBA)
Z-1	1	0.5	58.2	55.4	71.0
Z-2	1	0.8	59.1	56.0	69.4
Z-3	1	1	57.5	56.4	71.5
Z-4	0.5	0.5	57.5	55.9	71.2
Z-5	0.5	0.8	59.9	55.3	70.7
Z-6	0.5	1	58.3	56.4	71.8

Table 8: Noise at R1, R2 and R3 by Zigzag Panel Comparing to Flat Type.

Sample No.	a (m)	b (m)	R1 (dBA)	R2 (dBA)	R3 (dBA)	Reduction Effects
Z-1	1	0.5	-1.5	-0.2	-0.1	R1, R2, R3
Z-2	1	0.8	-0.6	0.4	-1.7	R1, R3
Z-3	1	1	-2.2	0.8	0.4	R1
Z-4	0.5	0.5	-2.2	0.3	0.2	R1
Z-5	0.5	0.8	0.2	-0.3	-0.3	R2, R3
Z-6	0.5	1	-1.4	0.8	0.7	R1

Table 9: Effects on Noise by Zigzag Panel Comparing to Flat Type.

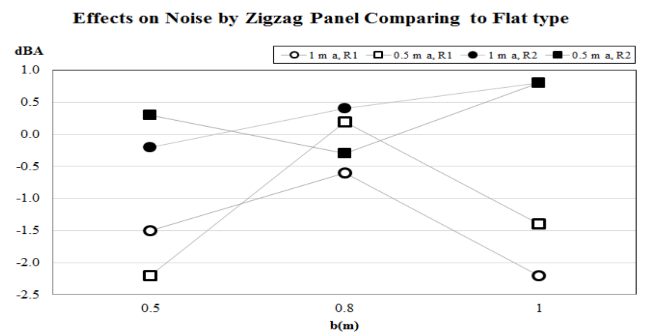

Figure 6: Amount of noise reduction of zigzag noise barriers compared to flat-type.

Citation: Lee J, Kim J, Park T, Chang S, Kim I (2015) Reduction Effects of Shaped Noise Barrier for Reflected Sound. J Civil Environ Eng 5: 171. doi:10.4172/2165-784X.1000171

Reduction effects of reflection noise on curved noise barriers

The experiment summary for curved noise barriers is shown under Table 10. And the reduction value comparing to the flat panel was shown Table 11 and Figure 7. The R3 values are depicted in Figure 7. The main reduction effects at R1, R2 were separated by the 'a' value. When the value of 2 m used, there were the reduction effects on R1. But at R1, there was considerable effect on the conditions of 1.5 m of 'a' value such as C-7, C-8, C-9 and, C-10. With C-4, C-5, C-9 and C-10 where the b values were 3 m and 4 m, the predicted noise level had the reduction effects on both R1 and R2 than the flat-type noise barriers. By increasing the value of b, the reduction effects of reflection noise at R1 increased as well. Particularly at R2, the increase of noise level occurred when the curved peak was lower. The results suggest, as the value for the curved peak gets larger, the reflection noise decreases. This seems to stem from the angle where the noise is reflected with curved panels.

Considering the form of curved noise barriers, we have expected that the curves on the barriers will diminish the noise delivered to the very top of the barriers and reflect the noise delivered to the side off to the inside of the roads displaying a high level of reduction effect. But, the actual experiment suggests that as the height of the curved peak gets smaller, the noise level at R1 decreases than flat-type noise. As a result, if we design the height of the curved peak to be long, the reduction effect would not be limited to only the lower parts as the wing-type and zigzag noise barriers, but become applicable to all levels of the facilities.

Sample No.	a (m)	b (m)	R1 (dBA)	R2 (dBA)	R3 (dBA)
C-1	1	1	59.6	56.5	71.4
C-2	1	2	59.9	54.7	71.2
C-3	1	2.5	59.8	55.2	70.9
C-4	1	3	59.0	54.9	70.8
C-5	1	4	59.0	55.1	70.7
C-6	1.5	1	60.5	55.7	70.7
C-7	1.5	2	59.3	57.2	70.7
C-8	1.5	2.5	58.5	57.5	70.7
C-9	1.5	3	58.6	55.0	70.8
C-10	1.5	4	58.4	55.1	71.1

Table 10: Noise at R1, R2 and R3 by Curved Panel Comparing to Flat Type.

Sample No.	a (m)	b (m)	R1 (dBA)	R2 (dBA)	R3 (dBA)	Reduction Effects
C-1	1	1	-0.1	0.9	0.3	R1
C-2	1	2	0.2	-0.9	0.1	R2
C-3	1	2.5	0.2	-0.4	-0.2	R2, R3
C-4	1	3	-0.7	-0.7	-0.3	R1, R2, R3
C-5	1	4	-0.7	-0.5	-0.4	R1, R2, R3
C-6	1.5	1	0.9	0.1	-0.4	R3
C-7	1.5	2	-0.3	1.6	-0.4	R1, R3
C-8	1.5	2.5	-1.2	1.9	-0.4	R1, R3
C-9	1.5	3	-1.1	-0.6	-0.3	R1, R2, R3
C-10	1.5	4	-1.2	-0.5	0.0	R1, R2

Table 11: Effects on Noise by Curved Panel Comparing to Flat Type.

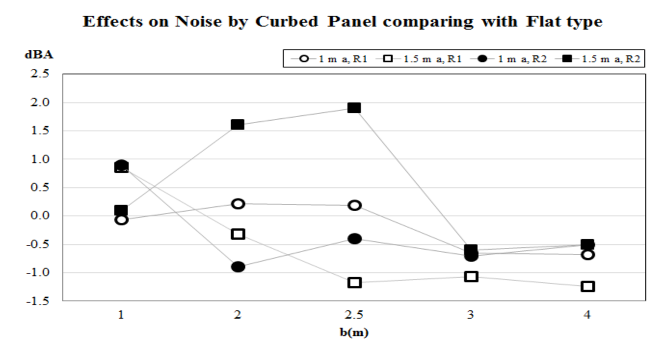

Figure 7: Amount of noise reduction of curved noise barriers compared to flat-type.

Using the general linear model, the predicted noise of curved panel by the factors of a and b was figured out as the following equation with the coefficients [22].

$$Noise_{curved,}R_1 = 59.29 - 0.050*a_{1.0} + 0.510*b_{1.0} + 0.210*b_{2.0} + 0.010*_{2.5} - 0.240*b_{3.0} - 0.050*a_{1.0}*b_{1.0} - 0.050*a_{1.0}*b_{2.0} + 0.050*a_{1.0}*b_{2.5}$$

$$Noise_{curved,}R_2 = 55.75 + 0.110*a_{1.0} + 0.600*b_{1.0} - 0.150*b_{2.0} - 0.05*b_{2.5} - 0.500*b_{3.0} - 0.160*a_{1.0}*b_{1.0} + 0.290*a_{1.0}*b_{2.0} + 0.190*a_{1.0}*b_{2.5} - 0.360a_{1.0}*b_{3.0}$$

Where a_i is the value for i m of a and b_j is j m of b. The values of the parameters for a and b were adapted as the sigma-restricted model.

Conclusions

In this study, the reduction effects of reflection noise caused by noise barriers is evaluated based on analysis of wing, zigzag and curved type forms and by comparing with the normal flat-type panels. Experiment conducted by inserting the noise source from the second lane on the noise barrier side, slightly increased or decreased the reduction effect in R2 and R3. But, point R1 showed a maximum positive prediction of 2.2 dB reduction effect. For the three shapes of soundproof panels, the main results could be concluded as follows.

- Wing type, the smaller the size of wing, the reduction effect is improved at R1, whereas it slightly decreased at R2.

- Zigzag type, the wider the angle between two panels, the reduction effect is improved at R1 and R2. At 45^0, the reduction extent has the maximum value of 2.2 dB, however the effect at R2 is decreased.

- Curved type, a gentle slope has shown an improved effect at R1 and R2. On the contrary, it has shown irregularity at R1 and R2 with a steep slope.

Although W-1, Z-3 and Z-4 are effective forms of noise barrier at R1, considering the overall effects, including R2 and R3, curved C-9 noise barrier is the best choice for diminishing reflection noise. Further research that clarifies the design factors of the curved noise barriers is necessary. When a curved noise barrier is installed at a downtown region where the amount of traffic is increasing from day to day, it is believed to lessen any noise pollution or damages due to the reflection noise.

The study is restricted to prediction of reflection noise from nominal model, as described in the results and discussion parts. Hereafter, it will be necessary to construct a quantitative method of estimating reduction effects by the designing factors corresponding to the shapes.

Acknowledgment

This work is supported by the Korea Institute of Civil Engineering and Building Technology, KICT, of Korean Government number 2015-0152.

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