Analysis of highway reflection noise reduction using transparent noise barrier types

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ABSTRACT

Transparent type noise barrier is a desirable facility since it provides a secure view to drivers and passengers. However, reflection from this type of barrier could annoy dwellers on the sides of the road. To reduce reflection noise by transparent type barrier, modification can be made to the shapes on the front side and hence get effects by distortion of sound transmission. To achieve this, we have conducted simulation by which the effects of patterned screens of noise barrier on high-ways were investigated. The reduction effects of reflected sounds were evaluated for swelling, swelling with curved, rectangular and V-shaped screen type barriers, compared to the planar panel. The emitting noise was generated by 6-lane road and the patterned noise barriers had shown the reduction effects, especially in swelling and swelling with curved type for middle height dwellers, and the V-shaped screen type for higher elevation dweller. The swelling-type showed a decrease of 0.7~1.2 dB, performing the best diminution effect among the tested noise barriers.

Keywords: Curved-Type, Noise Barrier, Panel shape, Reflection noise, Sound Insulation Performance, Swelling-type

1. Introduction

Along with the rapid urbanization rate of Korea, various traffic pollutions took place within the last half-century. Especially, traffic noise damage by cars and trains has caused serious civil appeals and disputes. The environmental standards for noise in the Basic Environmental Law notes are stated to be 65~70 and 55~60 Leq dBA in day (06:00~22:00) and night time (22:00~06:00), respectively. But, according to the Report on Conditions of Environmental Noise in Major cities of Korea, the noise exceeds over 7~10 Leq dB, especially in overpopulated cities such as Seoul [1].

As effective plan to control undesirable noise from highway, there are several methods to apply, which fall under one or combination of source emission reduction, improving highway design and land use control mechanisms [2, 3]. The former two approaches face various potential troubles, such as alteration of circumstances in highway, design of vehicles and detailed understanding of noise generating conditions.

Noise barrier, on the other hand as an effective method to control the traffic noise, has been used for decades to reduce noise from highway which affected nearby residents [4]. This facility has

been installed by predicting the propagation characteristics of traffic noise generated from the road. There are sound-absorbing noise, reflective noise and combined noise barrier types. In case of sound-absorbing noise barriers, the soundproof effect is extraordinary since sound-absorbing materials are used and these are usually installed in residential areas and highways in the downtown region [5, 6]. The visual obstruction, however, exerts a negative image as materials such as aluminum and galvanized sheet iron are mainly used. Combined noise barriers do merge sound-absorbing and reflective noise barriers to simultaneously decrease the noise absorption and insulation, and are usually installed in vicinities that require partial visibility. A representative example of reflective noise barriers would be a transparent noise barrier, which are mostly used in places that require view, right of light and lighting. Because these noise barriers can optimize their unique transparency as much as possible to secure enjoying the scenery, the demand for their installation is particularly increasing.

There are a lot of studies made on the perception of noise barrier attenuation considering aesthetic to personal preference [7-9]. These studies reported that the constituent materials external design changes make people respond to attenuating noise. Such aesthetic design could make a role to reduce an upset about road

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noise. But the residents dwelling near the highway perceive just noise in priority and not the visual effects.

Actually, the front design of noise barrier gives just not only aesthetic effects but also propagation of noise as sound power. Hayek has conducted analytical modeling on the transmission of noise reflecting from various shapes of noise barriers [10]. The mathematical theories offer a significant basis in calculating the noise that occurs in the field. He presented the propagation models of typical configurations, such as single, double and wedge wall, mainly based on Geometrical Theory of Diffraction (GTD).

On the rapid development of information technique, many models based on computing process about noise prospect have emerged. In 2001, Steele presented a critical review of the traffic noise prediction models on electric computing [11]. FHWA Traffic Noise Prediction Model, FHWA Traffic Noise Model, CoRTN, RLS90, MITHRA, STL-86 and ASJ-1993 were well compared in algorithm and propagation characteristics. Recently, Garg et al. followed former comparison works to come up with an update [12]. On their study, they considered newly developed models, such as HARMONOISE, Son Road model, NMPD-Routes-2008 and NORD2000. Among these four models, HARMONOISE and NORD2000 have the directivity which defines the directional head of sound source. In this study we have chosen NORD2000, since it offers abundant directivity index and frequency data; hence, adding various technical attributes which we face in various road conditions. Besides, NORD2000 makes possible to package the external built-in software, such as Virtual Lab and 3D CAD program, by which real-like circumstance can be prepared.

Meanwhile, materials such as Polycarbonate (PC), Polymethylmethacrylate (PMMA) and glass are used in transparent noise barriers. Based on their characteristics, since transparent noise barriers control noise by reflection, multiple noise damages can be caused to the opposite side. Despite the various strengths of transparent noise barriers, such as securing view, a weakness lies in the limited areas available for installation. However, there is a constant increase in requests to install transparent noise barriers that are absolutely advantageous in terms of view and lighting effects although the stated short comings are well known. In consequence, damages caused by noise reflected from the transparent noise barriers are likely to increase in the future, unless otherwise mechanisms to control the reflected noises are devised.

Saif et al. made a comparison of the cases in which single and parallel tilting noise barriers were set by varying the number of panels on the front [13]. Then, they found out the optimal setting condition for attenuation of noise. So by considering shapes and adjusting the designing factors of the front of noise barrier, it was possible to find the optimal factor for designing the facility. Even though the attenuation effects can be calculated, under complex field conditions, computation involving simulations will simplify things.

In this study, considering the various front designing factors, the optimal shape and condition were investigated using computing simulation. In our previous research work [1], we have demonstrated the effects of various shaped panels, such as wing, zigzag and curved form on reflected noise. From the simulation results of NORD2000, each shape showed significant effects on opposite

site with optimized designing factors. This study also involves evaluation of the attenuation effects of reflection noise; however, by considering different types of screen noise barriers, instead of the soundproof panel shapes. Hence, the objective of the current study is to assess and come up with an alternative method to diminish the reflection noise.

2. Materials and Methods

2.1. Noise Prediction Model

In this research, Nord 2000, which has been applied to road traffic noise calculations since revised in 2005-2006, was employed [14-17]. The methodology adopted for the noise barrier prediction using Nord 2000 has been described in our previous work [1].

Nord 2000 gives a more sophisticated classification of mid-size cars and full-size cars of 2 axis, 3 or more than 4 axis compared to other similar noise prediction models, such as CRTN, RLS90, and NMPB. Besides, the octave analysis which offers 25~10,000 Hz with 1/3 octave band is much wider than comparable models. Hence, Nord 2000 was selected as it provides relatively full information in noise prediction. The basic sound source model given by the following relation was used in this research.

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

where: $L_{E,10_m}$ = noise level at more than 10 m sway from noise source [dB]

d = measurement distance

w = axle width of the venhicle

(if no ∞ or mation cars = 1.5 m, trucks = 2.5 m)

h_r = height of the microphone

$\Delta\alpha$ = $\angle$ of ular sector coverint the | of integration[rad]

$$C(v) = L_w - L_{E,10_m} \quad (2)$$

$$L_w = L_{E,10_m} + C(50) + 10 \log \left(\frac{v}{50} \right) \quad (3)$$

To calculate the noise level, Nord 2000 applies the data measured where the distance between the road and the receiving point ranges from 7.5 m~15 m and the height is 0.2 m and 4 m above the ground level to refer the input set value of noise level such as $L_{E,10_m}$. Eq. (1) is 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 as in Eq. (2) and Eq. (3) indicates how to calculate L_w (sound power levels by frequency) according to the change of car speeds, by using Eq. (1) and (2). The standard speed is 50 km/h 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.

2.2. Setting up the Conditions of Noise Prediction

Here, the type of vehicles that generate noise pollution are categorized into mid-size cars (Category 1), full-size cars with 2 axis (Category 2) and full-size cars with more than 4 axis (Category 3). Table 1 presents the computation conditions of each sound power levels which has been calculated as the hourly average noise level. Based on the number of axis, width of wheels, and distance between left and right wheels, Ministry of Land, Infrastructure and Transport of Korea categorized Vehicles into 12 types, whereas the Korea Expressway Corporation re-categorizes the 12 types into 5 and determines each noise level. Nord 2000 uses a combination of the number of axis and the weight, unlike the domestic standards, which consider the number of axis in the vehicle.

On the other hand, Table 2 and Table 3 show how representative sound directivity models such as Nord 2000 calculate the directivity. Directivity noise sources are those noises which are based on an identical sound source, however different sizes of reflection noise by directions. 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.

Heights of noise sources (Source 1, 2, 3) that appear in Table 2 and Table 3 refer to the heights of noise sources that are emitted from the road, often 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 exhaust noise for full-size cars. The highest sound source, on the other hand, would mean engine noise for small cars and exhaust noise for full-size cars. These are not absolute in any terms and can differ from models to models.

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 SoundPlan 7.2, the prediction program used in this study, 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 4 shows the results. Noise level has also been calculated via SoundPlan 7.2, a noise prediction program. Each simulation has been based on the ray-tracing method.

2.3. Conditions for Predictions of Noise Level by Lanes

Fig. 1 shows a prediction of noise delivery distribution when a noise level of 63 Hz is emitted from each lane towards a 5 m tall flat-type noise barrier. From items (c) to (f) of the figure, it has been forecasted that the noise emitted from the 1st lane on the barrier side and the opposite side have not been much influenced by the noise barrier. This is probably because, the noise barrier is quite far from the source that the reflection noise is almost undetectable, i.e., it is attenuated by the distance. Moreover, as Fig. 1 (a) depicts, it has been predicted that the influence of noise barriers will be exaggerated when noise occurs from the 3rd 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 2nd lane on the noise barrier side as the basic condition for noise prediction, to best depict the prediction results.

Table 1. Computation Conditions of Sound Power Level

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

Table 2. Horizontal Directivity of Mid and Full-Size Cars (Nord 2000)

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

Table 3. Automobile Directivity Model of Harmonize

	Height (m)	Frequency range (Hz)	Directivity
Source 1	0.01	$f \leq 1250 \text{ Hz}, f \geq 8000$	0
		$1,600 \text{ Hz} \leq f \leq 6,300$	$-1.5 + 2.5 \text{abs}(\cos(\varphi)) \sqrt{\cos(\Psi)}$
Source 2	0.30	-	0
Source 3	0.75	$\left(1.546\left(\frac{\pi}{2} - \varphi\right)^3 - 1.425\left(\frac{\pi}{2} - \varphi\right)^2 + 0.22\left(\frac{\pi}{2} - \varphi\right) + 0.6\right) \sqrt{\cos(\Psi)}$	

Table 4. Calculated Sound Power Level (dB)

	Height (m)	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	Overall
S1	0.01	77.39	77.49	77.69	78.59	82.99	80.29	80.19	81.79	89.05
S2	0.3	70.23	70.33	70.53	71.43	75.83	73.13	73.03	74.63	81.89
S3	0.75	73.14	73.24	73.44	74.34	78.74	76.04	75.94	77.54	84.8

Fig. 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.

2.4. Research Subject: Forms of Noise Barriers

This research aims to review the reduction effects of the reflection noise according to the shapes of the 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 swelling-type (Fig. 2(a)), swelling + curved-type (Fig. 2(b)), and screen-type (Fig. 2(c)) noise barriers.

The design factors for each form will include: first, for the swelling-type noise barrier, the depth of the swelling (a); secondly for swelling + curved forms, the width of the curve (a) and height of the curved peak (b) and; last but not least, for screen types, the shape of the screen (rectangular and triangular (V-shape)) in order to evaluate the diminution effects of the reflection noise according to the values of each design factor. Also, the reflection noise is measured by frequency, ranging from 65 Hz, 125 Hz, 250 Hz, 500 Hz, 1,000 Hz, 2,000 Hz, and 4,000 Hz to 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 2m above the middle of the road (Fig. 3).

The points of receiver are decided as follows. Ordinarily, noise is assessed at every 5 stories for analysis of environmental case in Korea. So, 15 m and 30 m were set to receiver points for middle and high point for residents, respectively. And in Enforcement Decree or the architecture law in Korea, it is set that the residences were located 6 m from the end of the road. Besides, in the standard notice of Ministry of Environment, the receiver should be placed 1 m by side from the noise barrier. So the distance of receiver of this study was set to be 5 m from the end of road (R1, R2). Adding to this, to assess the generated noise in the middle of the road, R3 as a receiver was set as Fig. 3.

Fig. 2. Design factors and forms of the noise barrier. (a) Swelling type; (b) swelling + curved type; (c) screen type.

Fig. 3. Location map of comparison point about noise level.

Table 5. Predictions of Reflection Noise from Flat-Type Noise Barriers

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

3. Results and Discussion

3.1. Diminution Effects of Reflection Noise on Flat-type Noise Barriers

To evaluate the diminution effects of reflection noise by shapes

of the noise barriers, we first reviewed that of the flat-type noise barriers which are being widely used nowadays. The diminution effect has been calculated by frequency, as shown in Fig. 4. As shown in the figure, 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. Also, 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 5 describes 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 59.7 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.

3.2. Diminution Effects of Reflection Noise on Swelling-Type Noise Barriers

The experiment conditions and results for the swelling-type noise barriers are shown in Table 6. To go over the results, in cases of B-2 and B-3 where the depth of swelling (a) were 20 and 30 cm, the predicted noise level at R1 were 58.6 and 58.5 dB, showing a decrease of 1.1~1.2 dB in reflection noise. But at R2 and R3, the reflection noise either increased or remained the same. With B-1 where the value of 10 cm, the noise level was predicted as 59 dB at R1, showing a 0.7 dB diminution effect. But at R2 and R3, unlike B-2 and B-3, the measures were identical at R2 and decreased 0.1 dB at R3. Fig. 5 provides an understanding of the noise variation compared to flat-type noise barriers. Because the effects at R3 were insignificant, their values were omitted.

Fig. 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.

Table 6. Predictions of Reflection Noise from Swelling-Type Noise Barriers (attenuation/increment to plane)

Measuring Conditions		Noise level from each receiving point (dB)		
Models	Depth of the swelling (a)	R1 (15 m)	R2 (30 m)	R3 (middle of the road)
B-1	10 cm	-0.7	0.0	-0.1
B-2	20 cm	-1.1	+0.3	0.0
B-3	30 cm	-1.2	+0.5	0.2

Taking into account its special forms, it was expected that swelling-type noise barriers would display a high diminution effect of reflection noise than flat-type noise barriers. Because swelling-type noise barriers symbolize the swellings of an anechoic chamber, we have expected the sound source to hit the swellings on the inside parts of the noise barrier; however, the prediction results showed a different finding. Actually, the predictions illustrated that although the reflection noise decreased at R1, it was increased at R2. Therefore, swelling-type noise barriers can be installed only in regions with low-level buildings and facilities.

3.3. Diminution Effects of Reflection Noise on Swelling + Curved-Type Noise Barriers

Swelling + curved-type noise barriers are a noise barrier type that combined a curved panel on the swelling-type noise barriers discussed under 3.2. Table 7 summarizes the measuring conditions and results of the present type. At R1 and R3, the predictions were 59.1 and 70.8 dB, showing a diminution effect of reflection noise of 0.6 and 0.3 dB, compared to flat-type noise barriers. Fig. 5 shows the noise variation in comparison with flat-type noise barriers and a slight increase was detected at R2.

Fig. 5. Amount of noise reduction of swelling-type and swelling + curve-type noise barriers compared to flat-type.

The curves on the noise barriers induced a screening effect to diminish the noise that was delivered to the very top of the barrier and the swellings reflected the noise delivered to the side, off to the inside due to scattering effect, thus leading us to expect a diminution effect of reflection noise. But the actual results suggested that at R1 and R3, although the reflection noise was predicted to decrease, it increased at R2. Therefore, swelling + curved-type noise barriers also can be installed only in regions with low-level buildings and facilities.

3.4. Diminution Effects of Reflection Noise on Screen-Type Noise Barriers

The experiment summary for screen-type noise barriers is shown in Table 8. With rectangular screen-type noise barriers, we have varied the measuring points as shown in Fig. 6 to predict the noise variation according to each point source, because when setting up the sound source during the simulation process, it appeared as a group of point sources for every unit distance (1 m). For Rec-1, we placed the measuring points on the borders of the asperity and embedded areas as Fig. 6(a) and for Rec-2, on the center of the embedded area as in Fig. 6(b).

The prediction results suggested that the noise levels at R1 and R3 in every conditions would lead to higher or similar level of reflection noise. R2 in case of rectangular noise barriers also displayed increased measurements of reflection noise in all conditions. For V-1 cases, the predicted noise level at R2 is 55.1 dB, a 0.5 dB decrease than flat-type barriers. At R1 and R3, 60.2 and 71.6 dB, respectively, were predicted, showing an increase of 0.5 dB. Fig. 7 shows the noise variation of screen-type noise barriers compared to flat-type barriers. Being insignificant at R3, their values were also omitted. Here, we can see that the diminution effects of reflection noise for screen-type noise barriers are either less powerful or even negative.

Considering the form of screen-type noise barriers, we have

Table 7. Predictions of Noise Level of Swelling + Curved-Type Noise Barriers (attenuation/increment to plane)

Model	Measuring conditions			Noise level from each receiving point (dB)		
	a (m)	b (m)	Depth of swelling (cm)	R1 (15m)	R2 (30m)	R3 (middle of the road)
B-4	1	4	10	-0.6	+0.4	-0.3

Fig. 6. Predicted position of screen-type noise barriers.

Table 8. Predictions of Noise Level of Screen-Type Noise Barriers (attenuation/increment to plane)

Measuring conditions		Noise level from each receiving point (dB)		
Model	Characteristics of screen	R1 (15 m)	R2 (30 m)	R3 (middle of the road)
Rec-1	Rectangular - borders	+0.1	+0.6	+0.2
Rec-2	Rectangular - embedded	+0.1	+1.1	+0.3
Rec-3	Rectangular - asperity	0.0	0.0	0.0
V-1	Triangular (V-shape)	+0.5	-0.5	+0.5

Fig. 7. Amount of noise variation of swelling + curved-type noise barriers compared to flat-type.

expected that the inside of the screen on the barriers will reflect the noise to display a higher level of diminution effect than flat-type barriers. Especially the measurements at the asperity parts of the rectangular and the triangular noise barriers increased the reflection noise, thus leading us to conclude that the applicability of screen-type noise barriers is lower than other types of barriers (Table 8).

4. Conclusions

This study predicted and analyzed the diminution effects of reflection noise of transparent noise barriers by considering forms of swelling-type, swelling + curved-type and screen-type barriers, compared to normal flat-type panels. By designing the noise barriers by shape and running the prediction program by inserting the noise source on the 2nd lane to the noise barrier side among the 6 lanes, the reflection noise slightly decreased or increased in all noise barriers. At R1, especially in the cases of the screen-type noise barriers, it was predicted that no diminution effect were to occur in all conditions. However, the swelling-type showed a decrease of 0.7~1.2 dB at R1, performing the best diminution effect among the tested noise barriers. Compared to other forms of noise barriers, the swelling-type is thought to be the most suitable in diminishing the reflection noise but since a slight increase was predicted at R2, further research is necessary, based on a more sophisticated categorization of related design factors. Moreover, because swellings are difficult to produce and the size of the modules were smaller than other panels, it seems difficult

to install swelling-type noise barriers. If these problems are solved, its applicable region would not be limited as other types of noise barriers. When a swelling-type noise barrier is installed at a downtown region where the amount of traffic is increasing every day, it will both secure visibility through the transparent walls and diminish any noise pollution or damages due to the reflection noise. Moreover, when decorated with more shapes and design, noise barriers will contain a visual attraction than a flat-type one and thus will alleviate any psychological impressions related to noise, other than the unique physical soundproofing functions of the soundproof panels.

The simulation results have a limitation to assess the noise on circumstance in accuracy to realism. But as a prearranged plan in large-scale installation of noise barrier, it is recommendable to pass through this process. Several researchers presented a psychological effect on personal reception of noise just by change of aesthetic condition. So with these effects, real reduction effects of designing front-shape could be a significant technology in installation of noise-countermeasures facility.

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