2008-5435/11/32-43-48
INTERNATIONAL JOURNAL OF OCCUPATIONAL HYGIENE

IJOH 3: 43-48, 2011

ORIGINAL ARTICLE

Numerical Analysis of the Efficiency of Different Median Barrier Models in the Presence of a Plain Roadside Noise Barrier

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Received February 4, 2011; Revised May 17, 2011; Accepted May 30, 2011

This paper is available on-line at *http://ijoh.tums.ac.ir*

ABSTRACT

Roadside noise barrier as the noise control solution is extensively applied to reduce noise pollution. Median barrier like roadside barriers can make insertion loss at the receiver's area making a shadow zone behind the screen. However, the performance of roadside barrier can be affected by erecting a median barrier. Mainly a median barrier is considered as an extra structure to decrease the cross median crashes at highways. The aim of this study was to investigate the effectiveness of some treatments such as absorbent material and diffusers on various median barriers shapes. A 2D boundary element method was used to analyze the designed median barrier effects. Application of grass on the top surface of median barriers with even cap was more effective than those median barriers that had uneven cap. Utilizing Primitive Root Diffuser (PRD) and Quadratic Residue Diffuser (QRD) on the stem surface of median barrier has high efficiency due to cancel outing multiple reflection effects between roadside barrier and median barrier by 2.2 to 2.7 dB (A), while no improvement could be seen at median barriers with QRD and PRD tops. Finally, it can be stated that the performance of most median barriers were increased using the reactive surfaces on the stem sides of the barrier, while the top surface treatment was not very effective in this kind of screens.

Keywords: *Median barrier, Boundary element method, Absorbent material, Diffusive devices*

INTRODUCTION

In most countries, especially in sensitive areas, noise barriers are used to decline the noise pollution interference and disturbance effects on sleep and also to increase the quality of conservation. Noise barrier are dense structures that can decrease the amount of received sound to receiver depending on the distance between source and receiver. Performance of noise barriers are known at high frequencies while traffic noise with its inconvenient sound is occurred at low and mid frequencies. In last decades, most researches has shown the efficiency of noise control applying various noise barriers [1-2]. Survey on profiled barriers, application of absorbent materials and verification of common diffusers such as Primitive Root Diffuser and Quadratic Residue Diffuser are three different methods that are used in noise barrier investigations [3-7]. The applied shapes were T-shape, Arrow shape, pear shape, curved; brackets attached, branched barriers, etc.

Median barriers [8-9] and parallel noise barriers [10-11] like single noise barriers were the subject of many researches. Erection of a median barrier along with a 3 m single roadside barrier, which can be known as a type

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Table 1. Design model names and corresponding configurations

Models	Median barrier	Roadside barrier	Flow resistivity (kg/(s·m2))	Well width, w (cm)	Sequence	Design frequency, Fr (kHz)	(N)	Diffuser	Description
I	-	I	infinity	-	-	-	-	-	-
HAWI	HA	I	2500	-	-	-	-	-	Fibrous material with a thickness of 10 cm
TAWI	TA	I	2500	-	-	-	-	-	Fibrous material with a thickness of 10 cm
AAWI	AA	I	2500	-	-	-	-	-	$\theta = 60$ Fibrous material with a thickness of 10 cm
YAWI	YA	I	2500	-	-	-	-	-	$\theta = 60$ Fibrous material with a thickness of 10 cm
ZAWI	ZA	I	2500	-	-	-	-	-	$\theta = 60$ Fibrous material with a thickness of 10 cm
VAWI	VA	I	2500	-	-	-	-	-	$\theta = 80$ Fibrous material with a thickness of 10 cm
RAWI	RA	I	2500	-	-	-	-	-	$\theta = 80$ Fibrous material with a thickness of 10 cm
UAWI	UA	I	2500	-	-	-	-	-	Fibrous material with a thickness of 30 cm
UPSWI	UPS	I	infinity	14	[3 2 6 4 5 1]	0.4	6	PRD	Diffuser on the stem surface
UPTWI	UPT	I	infinity	14	[3 2 6 4 5 1]	0.4	6	PRD	Diffuser on the top surface
UQSWI	UQS	I	infinity	12	[0 1 4 2 2 4 1]	0.4	7	QRD	Diffuser on the stem surface
UQTWI	UQT	I	infinity	12	[0 1 4 2 2 4 1]	0.4	7	QRD	Diffuser on the top surface

of parallel noise barriers, were also investigated [12]. Various shapes were tested to decline the negative efficiency of a plain median barrier. It was shown that sloped barriers with 10 degree compared with other profiled barriers have better efficiency.

This study aimed to investigate the efficiency of diffusers and absorbent material on different median barriers. The present study is continuation of our previous study [12] and it is assumed that the performance of the median noise barriers will increase applying diffuses and absorbent materials.

MATERIAL AND METHODS

Prediction Methods

A numerical modeling method can be used to estimate the efficiency of median noise barriers. The 2D boundary element method (BEM) as an effective and accurate method for predicting the insertion loss of barriers of complex shapes was used [5, 13-14]. In this method, the insertion loss at different frequencies is predicted by the following equation:

$$IL = -20 \log 10 \left| \frac{p_b}{p_g} \right| \text{ dB},$$

Where p_b is sound pressure at the receiver with presence of the both barrier and the rigid ground, p_g is sound pressure at the receiver only with the presence of the rigid ground. Detailed descriptions of this method can be found in [7, 15].

In all studied barriers, the sound source is located near ground at coordinate (5, 0.02) to reduce the interference between the source and its ground image. To represent typical distances of high speed traffic on single and double carriageway roads adjacent to roadside barriers where rolling noise predominates, the distance from the source to the centre line of the barrier is chosen at 5 m [5].

The empirical formulae of Delany and Bazley [16] were used to calculate the characteristic impedance of absorptive materials. As grass with flow resistivity of 2500 (kg/(s·m2)) has been found to be more effective than the fibrous material with flow resistivity of 20000 (kg/(s·m2)), this type of treatment has been preferred to be used in the barrier examinations [8].

As it was shown in many roadside barrier investigations, two common Schroeder diffusers; QRD and PRD, have dramatic effects when they were installed on the top surface of barrier [6-7]. Improvement of such structures was also observed in single median barriers [8]. The wells of diffuser reduce specular sound reflection scattering the incident sound energy into a wide range of directions. The impedance of the wells was calculated from the method indicated by [17]. For all of diffuser model types, the fin thickness between wells was assumed to be negligible where the viscous and thermal effects in the wells were taken in account.

To give accurate results especially at high frequencies, the dimension of element was 8 mm which was less than 1/10 of the shortest tested wavelength [12]. The acoustic pressure with and without considering the noise barrier at 1/3 octave band between 50 and 4,000 Hz is predicted at different receiver positions.

Median and Roadside Barrier Configurations

The design of barrier models used in the simulations is shown in Fig. 1. The overall height of all median barriers is fixed at 1 m [9]. Median barrier were divided

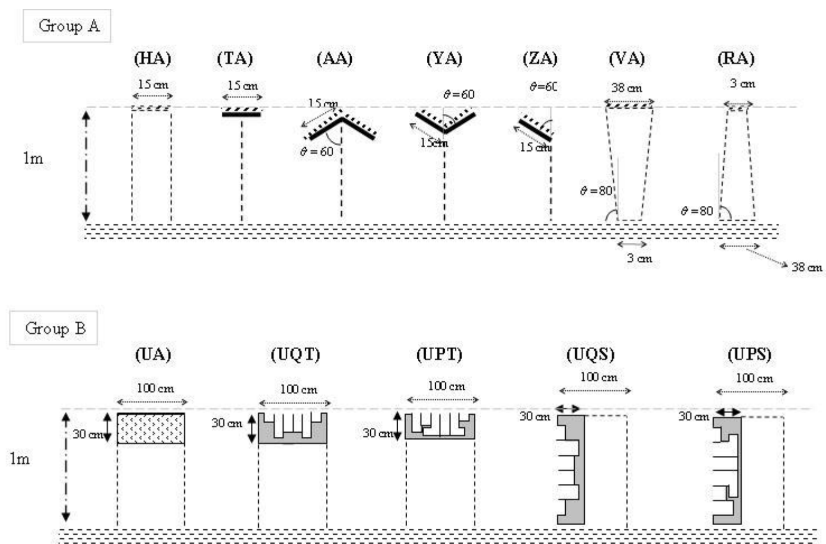

Fig 1. Side view of designed median barrier models

into two groups where the stem thickness of barrier group A and group B were 0.03 and 1 m, respectively.

The length of caps for the relevant shapes is 15 cm and the angle of sloped barriers is 10 degree [18]. The top surfaces of barriers group A were covered by grass with a thickness of 10 cm. PR and QR diffusers were also installed on the top and lateral surfaces of barriers group B. The thickness of grass in barrier model UA was set at 30 cm to have a precise comparison with other barriers in group B. As it was stated in pervious paper [12] a plain median barrier decreases the performance of a roadside barrier where different shapes were designed to decline this negative efficiency. This study was extended to look at more treatments. Median barriers are covered with either diffuser or absorbent material when they are erected parallel to a 3 m roadside barrier with distance of 20m (Fig. 2). Table 1 shows the characteristics of tested median barrier models. For instance, model UPSWI corresponds to a plain U shape median barrier treating with PRD on the stem surface, which is erected along with a roadside barrier.

RESULTS

Absorptive Effect

The performance of barrier model HAWI was compared with its equivalent rigid barrier in Fig. 3. Slight insertion loss improvement of barrier model HAWI was seen at most frequencies utilizing absorbent elements, while the low efficiency at frequency 1250 and 2500 was due to the constructive effect of incident and reflective waves. In other words, utilizing absorbent material just on the top surface of median barrier cannot remove the deconstructive and constructive effects of incident and reflected waves between the two parallel surfaces.

The amount of improvement of barrier model "TAWI" compared to its equivalent rigid barrier was shown in Fig. 4. The performance of barrier model TAWI was more considerable at frequencies 250 and 1250 Hz. In comparison with Fig. 3, it was found that the absorptive cap of T shape barrier not only eliminate the negative effect at frequency 250 Hz, but also made considerable effect. The high performance of this model at low frequencies as the label of traffic sound makes this barrier to be more applicable [5].

The calculated spectra of insertion loss of barrier models AAWI, YAWI and ZAWI compared with their equivalent rigid one are shown in Fig. 5. The trend in all these barriers is almost the same where the efficiency of barrier model YAWI was better than barrier model ZAWI at most frequencies due to an extra absorptive edge. Frequency selectivity at some frequencies is only because of constructive and deconstructive effect of incident and reflective waves in which is altered by the wavelength and median barrier dimensions.

Table 2. Comparison of the A-weighted mean insertion loss of different median barrier models along with their equivalent rigid barrier at 15 receivers

Group A				Group B			
Models	IL	Equivalent	Δ IL	Models	IL	Equivalent	Δ IL
HAWI	14.9	14.79	0.15	UWI (ref)	14.9	14.9	0
AAWI	15.8	15.96	-0.13	UAWI	15.4	14.9	0.51
RAWI	16.2	16.15	0.07	UQTWI	14.7	14.9	-0.11
TAWI	14.9	14.72	0.15	UPTWI	14.8	14.9	-0.09
VAWI	16.2	16.12	0.09	UQSWI	17	14.9	2.164
YAWI	15.4	15.46	-0.01	UPSWI	17.5	14.9	2.682
ZAWI	15.3	15.29	-0.02				

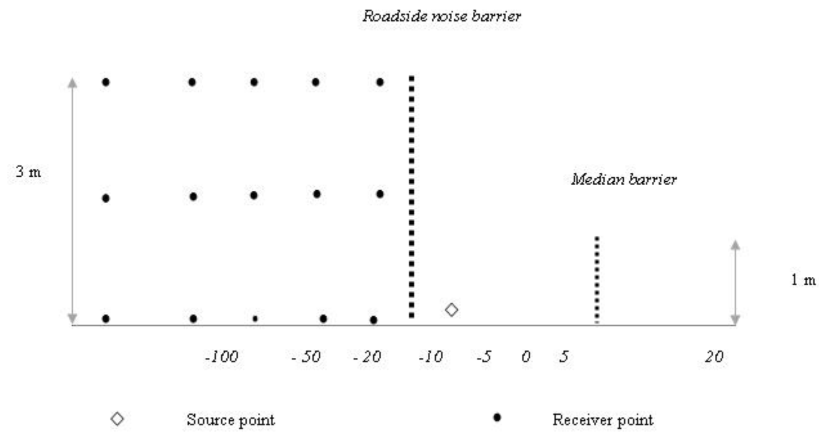

Fig 2. Schematic set up of the roadside barrier (barrier model I) along with median barrier (barrier model HA) labeled model HAWI (Source and receivers locations are also included)

Grass was also applied on the top surface of sloped median barriers. The comparison results of two inclined median barrier; called VAWI and RAWI, relative to their equivalent rigid barrier was presented in Fig. 6. Sloped barriers with 10 degrees compared with other profiled barriers have better efficiency [12]. The only negative effect of barrier model RAWI was seen at frequencies 2000 and 4000 Hz. Barrier model VAWI was tilted toward the roadside barrier while barrier model RAWI has the converse condition. Directing the incident wave upward by barrier model RAWI decrease the extra reflections from roadside barrier. Barrier model VAWI directs the incident wave toward ground in which leads to more reflections. However, more absorbent surface on top surface of barrier VAWI compared to barrier model RAWI cancel out the effects of multiple reflections on the top surface and helps to be an effective model.

Increase in height and thickness of a barrier plays a significant role in insertion loss improvement. Insertion loss difference between barrier models UAWI and UWI was shown in Fig. 7. The performance trend of this barrier was similar to barrier model HAWI due to their similar structure. However, the constructive and deconstructive effects in barrier model UAWI make higher peaks and troughs as a result of the great width (e.g. at frequencies 1250 and 2500 Hz).

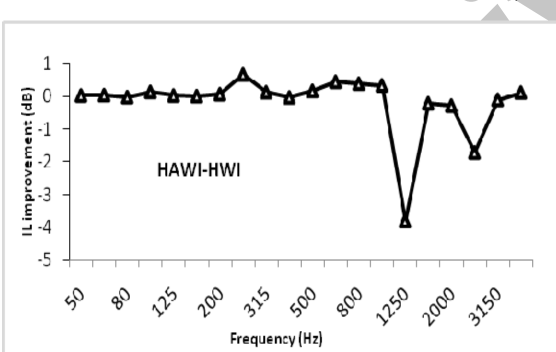

Fig 3. Insertion loss improvement of barrier model HAWI compared to its equivalent rigid barrier at the receiver position (-50, 0)

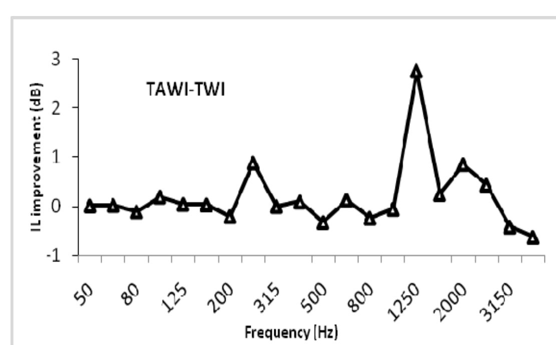

Fig 4. Insertion loss improvement of barrier model TAWI compared to its equivalent rigid barrier at the receiver position (-50, 0)

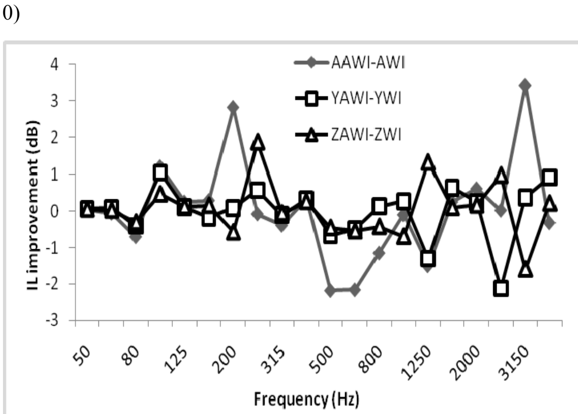

Fig 5. Insertion loss improvement of barrier models AAWI, YAWI and ZAWI compared to their equivalent rigid barrier at the receiver position (-50, 0)

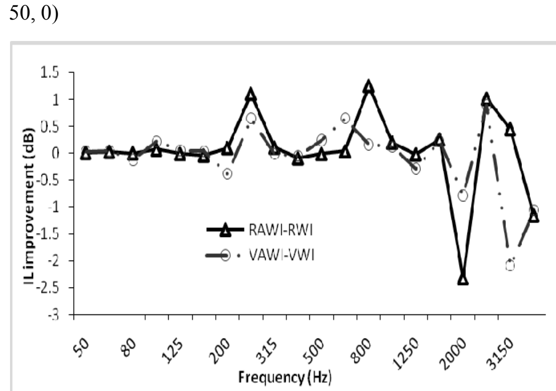

Fig 6. Insertion loss improvement of barrier models RAWI and VAWI compared to their equivalent rigid barrier at the receiver position (-50, 0)

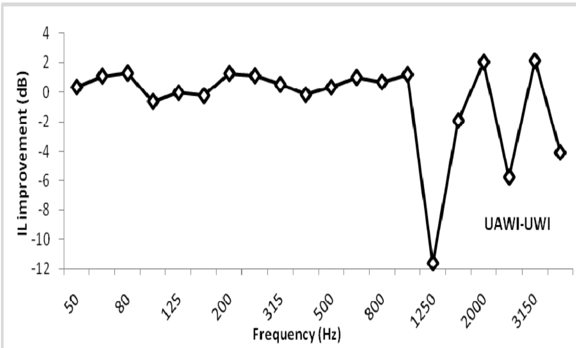

Fig 7. Insertion loss improvement of barrier model UAWI compared to their equivalent rigid barrier at the receiver position (-50, 0)

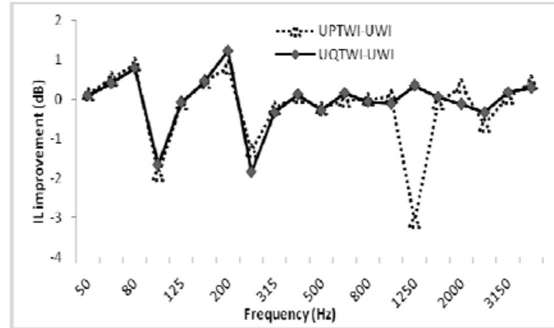

Fig 8. Insertion loss improvement of barrier models UQTWI and UPTWI compared to their equivalent rigid barrier at the receiver position (-50, 0)

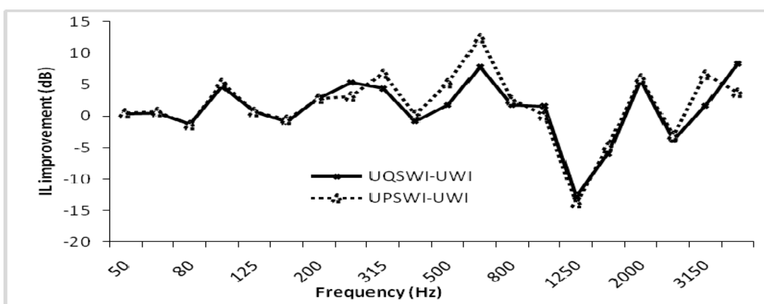

Fig 9. Insertion loss improvement of barrier models UQSWI and UPSWI compared to their equivalent rigid barrier at the receiver position (-50, 0)

Diffuser Effect

The acoustic performance of a plain median barrier employing designed QRD and PRD on the top and lateral surface was shown in Fig 8 and 9. As it was expected, the diffusive median barriers are highly frequency selective in which is in agreement with previous studies [10-11].

As one can clearly see from Fig.8, the performance of barrier models UQTWI and UPTWI is only higher at some limited frequencies. The effects of both diffusers were higher at frequencies lower than 100 Hz in which can have positive effect on the whole performance of these barriers. Since the incident wave from roadside barrier was redirected upwards no significant cancellation will be happened.

The diffusers were also installed on the roadside face of the plain median barriers (Fig. 9). The performance of these two models was higher than that of the two previous diffusive models. Although the trend of barrier models UPSWI and UQSWI were the same at entire frequencies, the amount of improvement of barrier model UPSWI were higher at some frequencies. More sequences of PR diffuser, which causes more impendence changes on the lateral surface, provides higher overall performances in barrier model UPSWI. It should be also noted that at the receiver (-50, 0), the barrier model "UPSWI" enhances the A-weighted insertion loss of the equivalent plain median barrier by 3.09 dB (A), while the barrier model "UQSWI" only improves the A-weighted insertion loss of the equivalent rigid median barrier at the above mentioned receiver point by 2.56 dB (A).

Broadband Insertion Loss

Table 2 shows the broadband insertion loss predictions over a range of receiver positions using an A-weighted traffic noise spectrum in 1/3-octave band from 50 to 4000 Hz [19]. The fifteen receivers were located at -5, -10, -20, -50 and -100 m from the centre line of the barrier on the ground and at 1.5 and 3 m above the rigid ground.

Each barrier either in group A or group B was compared with its equivalent rigid barrier. In group A, the A-weighted mean insertion loss of median barriers with absorptive flat top surface was higher than the equivalent rigid barrier. However, median barriers with uneven cap could not make such positive effect. The highest improvement was seen at median barrier models HAWI and TAWI by 0.15 dB (A).

In median barriers of group B, installing diffusers on the top surface of barrier model UWI couldn't make any improvements. However, utilizing PR and QR diffusers on the lateral surface significantly increase the performance of median barrier where its acoustic performance is higher than an equivalent absorptive median barrier; barrier model UAWI. Although most of studies stated that application of PR and QR diffuser on the top surface of barrier can improve the mean insertion loss [8, 20], in the case of a median barrier along with a roadside barrier such effect could not be seen and it is better to use such devices on the stem surface. Elimination of reflection effect was the reason for the positive effect of the barrier models with diffusive stem. It should also note that employing grass on the top surface is much better than using diffuser on the top surface of median barrier. Comparison between median barriers with diffusive stem has shown that if the diffuser sequence was reformed from QR to the PR diffusers, higher insertion loss can be achieved as a result of its depths that produced more resonance frequencies [6].

DISCUSSION

When a single median barrier with out roadside barrier was erected at highway the condition was much differed. Using reactive surfaces (QRD and PRD) on the top surface of barriers can increase the overall A-weighted insertion loss while employing reactive surfaces on the source side of a barrier's stem produces lower efficiency and can even produce a negative value in PRD barrier [8]. As diffusers on the top surface redirect the sound waves upwards, in the case of a single median barrier such devices are effective. However, when a median barrier is installed parallel to roadside barrier, the upwards incident waves from median barrier are combined with the incident or reflected waves from roadside barrier and then negative effect is occurred. Thus it is better to use diffuser on the stem surface than top surface of median barriers. In other words, for top diffusive surface construction effect between incident and reflected waves from the median and roadside barriers were higher than deconstructive effect.

Comparison between a narrow plain median barrier (barrier model HWI) and a wide plain median barrier (barrier model UWI) has shown that the amount of improvement when the thickness of barrier model HWI was increased from 15 cm to 100 cm was same as when absorbent material (grass) with a thickness of 10 cm was used on the top surface. Thus, change in structure and geometry of barrier can make similar effects to that barrier covered by absorbent material. This result confirms the survey of [15] who claimed the performance of the soft 3 m high T-shaped barrier performed the same as a 10 m high plain barrier.

CONCLUSION

The acoustic performance of various median barriers treated with absorbent material and diffuser was predicted using a two-dimensional boundary element model. Broadband insertion loss, weighted with a standard traffic noise spectrum, was also investigated over a range of representative receiver positions using A-weighted traffic noise spectrum in 1/3-octave band from 50 to 4000 Hz. Each median barrier was compared with its equivalent rigid barrier. It was found that employing grass on top surface of those barriers that have even top surface was more efficient than using on those structures that have not such condition.

Application of PRD and QRD on the stem surface of median barrier can cancel the negative effects of incident waves from roadside barrier. That is why the performance of such devices was higher than when they are installed on the top surface.

ACKNOWLEDGEMENTS

This research was funded and supported by Tehran University of Medical Science; grant no.8707. The authors declare that there is no conflict of interests.

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