Optimized T-Shape and Y-Shape Inclined Sound Barriers for Railway Noise Mitigation

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Performance of T-shape and Y-shape inclined noise barriers in railway noise mitigation is studied in this paper. Control of the noise attenuation and sound-map behind two conventional barriers is performed by optimal adjusting their inclination angle. Logarithmic averaging of the noise attenuation in different heights is adopted to be the objective function. A numerical model is constructed and the Steepest Descent Method (SDM) is adopted as the optimization algorithm. Validly of the modeling and solution procedure is verified by use of experimental results. Field measurements are performed and the frequency responses of different trains are loaded into the model. Optimal inclination angel is subsequently obtained for each configuration. It is found that the inclination angle can play a significant role in noise mitigation level remarkably in high elevation back regions.

1. INTRODUCTION

Influence of the noise and vibration on people is an issue of concern nowadays for communities around different transportation systems. Owing to the simplicity and efficiency, application of sound barriers in mitigation of noise is one of the main solutions to prevent noise pollution around transportation systems. Throughout the past few decades, different aspects of optimal sound barriers have been subjected to intense research. Liu et al. tested and analyzed the noise reduction effect for different heights and distances of sound barriers [1]. Buret studied diffraction of sound due to moving sources by barriers and ground discontinuities [2]. Piechowicz investigated the sound wave diffraction at the edge of a sound barrier. To test and determination of inherent characteristics of noise barrier sound diffraction, he described the method of testing by using maximum length sequences [3]. A field experiment was performed by Chen et al. [4] at Wuhan-Guangzhou high-speed railway to study the train-induced environment noise and noise mitigation performance of the sound barriers.

Effect of the inclination of a noise barrier on the reflected noise produced by road traffic was studied by Engström [6]. Sungho Mun et al. [7] presented a novel method to design a noise barrier by global optimizing of a simulated annealing (SA) algorithm. They focused on reducing construction cost and material by minimizing the barrier dimension for controlling the traffic noise. Active noise barriers were experimentally investigated in low-frequency range by Chen et al [10]. Koussa et al. [12] experimentally and numerically evaluated the acoustical efficiency of low height gabions barriers.

Okubo et al. [8] investigated sound diffraction behind a modified barrier by use of scaled-model experiments. They examined efficiency of the edge-modified barrier for noise shielding. Baulac et al. [9] optimized T-shape noise barriers acoustical efficiency by adding walls on top of the barrier. They focused on optimizing the barrier edge profile to minimize the propagated noise behind the barrier. Grubeša et al. [11] focused on the barrier cross-section optimization. They used 2D and 3D Boundary Element Method (BEM) for modeling and assumed acoustical

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efficiency and economic feasibility to be simultaneous objectives in optimization. Acoustical performance of various noise barriers with diverse shapes was studied by Watts et al. [14-15]. Multiple edge, T-shape and double-parallel barriers were taken into account and the noise attenuation behind each barrier was examined.

Scale-model experiments were conducted by Hothersall et al. [13] to evaluate performance of different railway noise barriers. Van Leeuwen [16] investigated 14 models to predict the noise attenuation by placing barrier alongside a railway track. He compared all models together and employed 15 source locations to predict the noise attenuation. Baulac et al. [17] optimized the cap size, shape and surface impedance of multiple-edge barriers by use of Nelder-Mead optimization algorithm.

Developing of simple, easy-to-install and cost effective barriers is still a research interest for many researchers and engineers. The objective in this paper is to control the noise attenuation and sound-map behind two conventional barriers i.e. T-shape and Y-shape walls by adjusting their inclination angle. As another new concept, we seek an optimized barrier to attenuate the railway noise effectively and simultaneously in different heights. The main contribution of this paper is to find optimized inclination angle for different combinations of barrier height, distance between source and barrier, specific edge length of barrier and barrier edge disruption angle. SOUNDPLAN software is employed to model different cases and the Steepest Descent Method (SDM) is applied for the optimization procedure. A MATLAB code is provided to link the SOUNDPLAN and the SDM algorithm. In order to validate the modeling and solution procedure, performance of a typical partial sound barrier is experimentally examined in noise mitigation of moving sound sources. Effect of the barrier inclination angle in different frequencies is studied on the noise attenuation and noise map behind the barrier. Optimized inclination angle of the T-shape and Y-shape barrier installation is obtained for different practical configurations. A sensitivity analysis is carried out to find out how deviations about the optimal design can influence the barrier performance.

2. PROBLEM DEFINITION AND MODEL VALIDATION

Noise attenuation efficiency is always a function of geometric correlation between the source, barrier, and receiver and also frequency and type of the sound source. Different configurations, geometry and physical parameters in our problem are schematically illustrated in Figure 1. Four receivers in different elevations are targeted in this study. The objective here is to find the optimal inclination angle of T-shape and Y-shape barrier to achieve maximum noise attenuation behind the sound barrier at 4 receiver locations. Noise source is placed at 0.5 m above ground and receivers are in 0.5 m, 3.5 m, 6 m and 10 m above ground.

A logarithmic average value of noise attenuation is taken into account. The optimization algorithm is constructed based on the Steepest Descent Method. The objective here is a function of distance between barrier and track (a), length of barrier edge (L), height of barrier (H), barrier edge disruption angle (α) and barrier inclination angle (β).

$$\text{Objective function} = F(a, L, H, \alpha, \beta)$$

The constraints for optimization follow the limitation of structure and track gabarit.

In order to validate the model and solution procedure, performance of a typical sound barrier is experimentally examined in noise mitigation against a

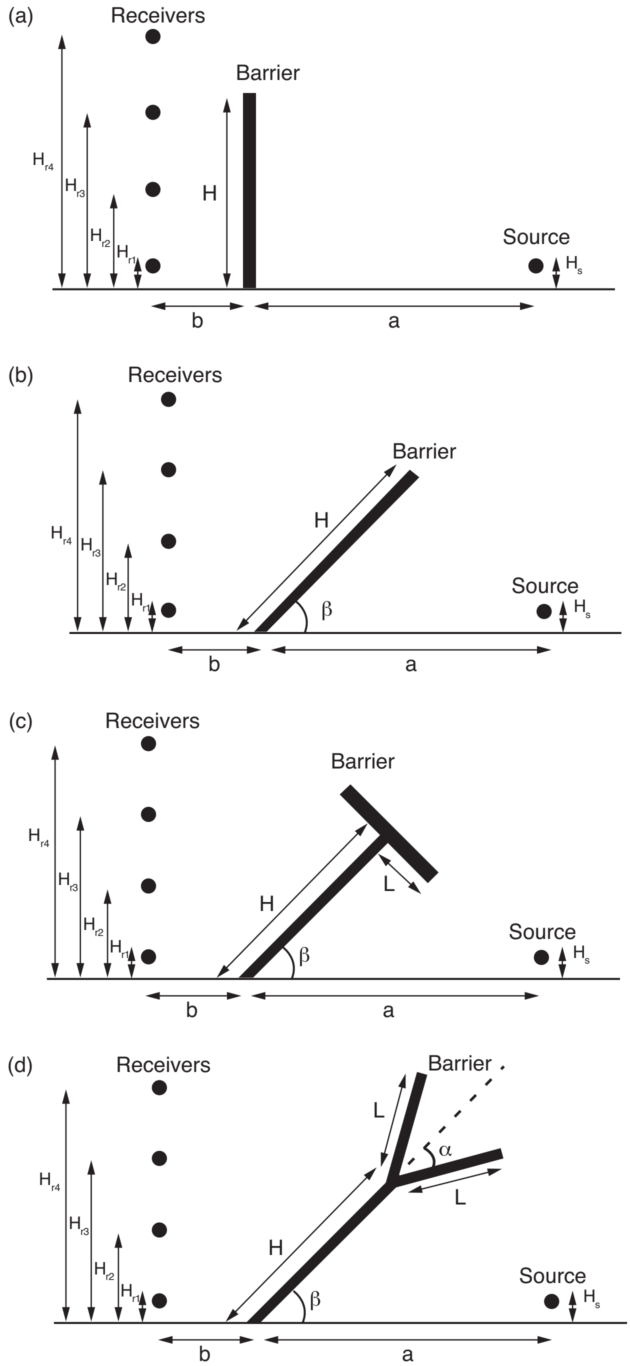

Figure 1. Configuration of the source-barrier-receiver system (a) vertical barrier (b) inclined barrier (c) inclined T-shape barrier (d) inclined Y-shape barrier.

moving sound source. Desired sound signals with specific frequencies are generated by SpectraLAB software. The test setup is illustrated in Figure 2. To achieve different Fresnel numbers, the barrier is placed at 110 cm, 125 cm and 140 cm distances from the moving sound source when it generates sound signals in various frequencies. The measured sound pressure level is transferred from time domain to frequency domain using Fast Fourier Transform method (FFT). The 3D frequency-time-SPL surface is demonstrated in Figure 3. This figure shows ensemble measurement results in different time shots in frequency domain and illustrates that the dominant frequency remains stationary around 500 Hz in that case study. The test parameters are listed in Table1.

a and *b* denote distance between the

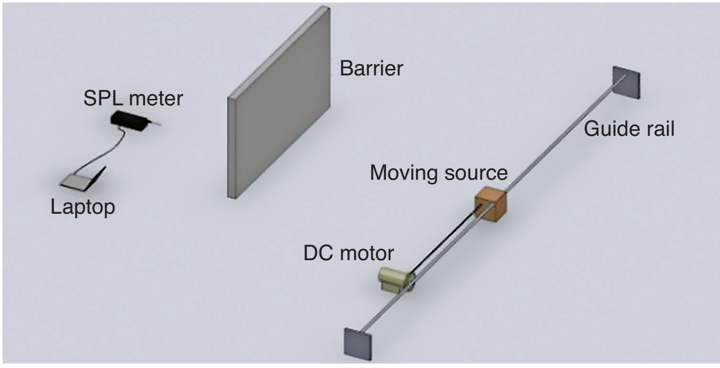

Figure 2. *Test setup.*

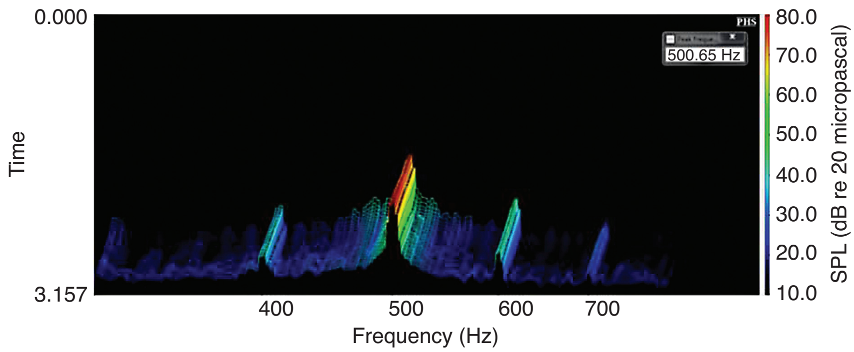

Figure 3. *3D surface of Time-Frequency-SPL.*

Table 1. *Test parameters.*

a **(cm)**	140	125	110	
b **(cm)**	70	85	100	
f **(Hz)**	500	1000	1500	2000
Speed (m/s)	1.5	1.8	2.35	

barrier and source and receiver respectively. The simulation is conducted in SOUNDPLAN which works based on the ray tracing technique. The source is modeled by a mono-frequency point moving along a straight line with three different speeds. According to the table, 36 tests have been conducted with 4 different frequencies, 3 barrier locations, and 3 various speeds. Considering four different frequencies (500 Hz, 1000 Hz, 1500 Hz and 2000 Hz), Sound pressure levels are measured for different moving source speeds. The corresponding results are illustrated in Figure 4 for the cases with and without barrier.

Noise barrier reflective attenuation depends to geometric configuration of the source, barrier, receiver and the frequency of sound source. Value of such noise attenuation is addressed by the Kurze & Anderson formula

$$A_b = 20\log\left(\frac{\sqrt{2\pi N}}{\mathrm{tgh}\sqrt{2\pi N}}\right) + 5$$

In which, N represents Fresnel number defined by:

$$c(z) = c_0 +$$

λ is the wave length of the propagated sound and δ denotes the effective length between source and receiver.

SOUNDPLAN software is employed to model different sound barriers and noise attenuation caused by

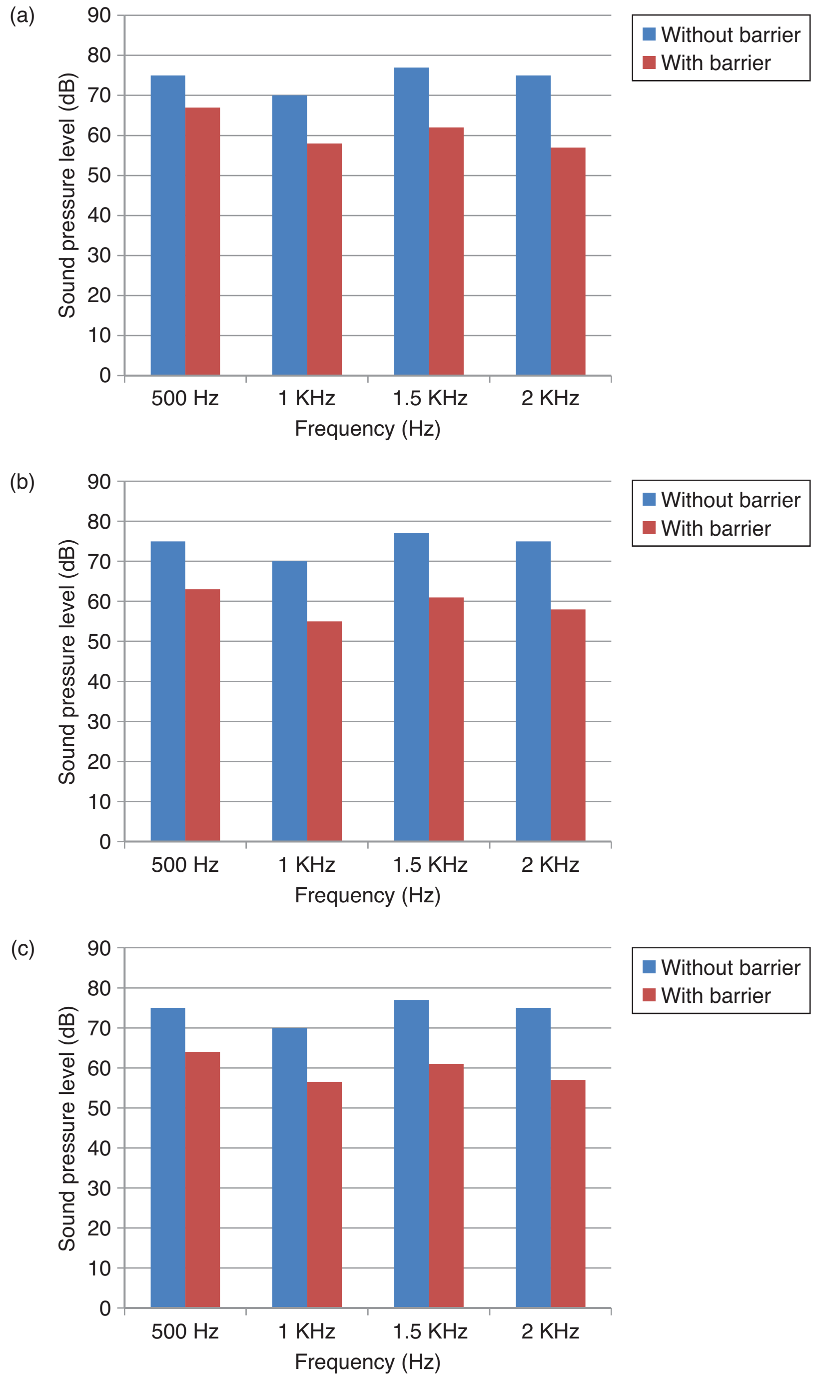

Figure 4. Sound pressure level (a) v=1.5 m/s, (b) v=1.8 m/s, (c) v=2.35m/s.

each barrier configuration is investigated. Noise reduction levels are compared in Figure 5 with those obtained by SOUNDPLAN, experimental test and Kurze & Anderson formula [18]. It is seen that K&A formula could be only valid for stationary sound sources. A very good correlation is observed between the numerical and experimental results in different Fresnel numbers.

3. PARAMETRIC STUDY

Distance between source and receiver line is assumed to be 17 m and distance between source and sound barrier changes from 4 m to 13 m and the height of the barrier is assumed to be 7 m. Barrier average attenuation level in different distance of the sound source and inclination angle (β) is illustrated in Figure 6. Based on the Iranian Railway Standard, distance between railway

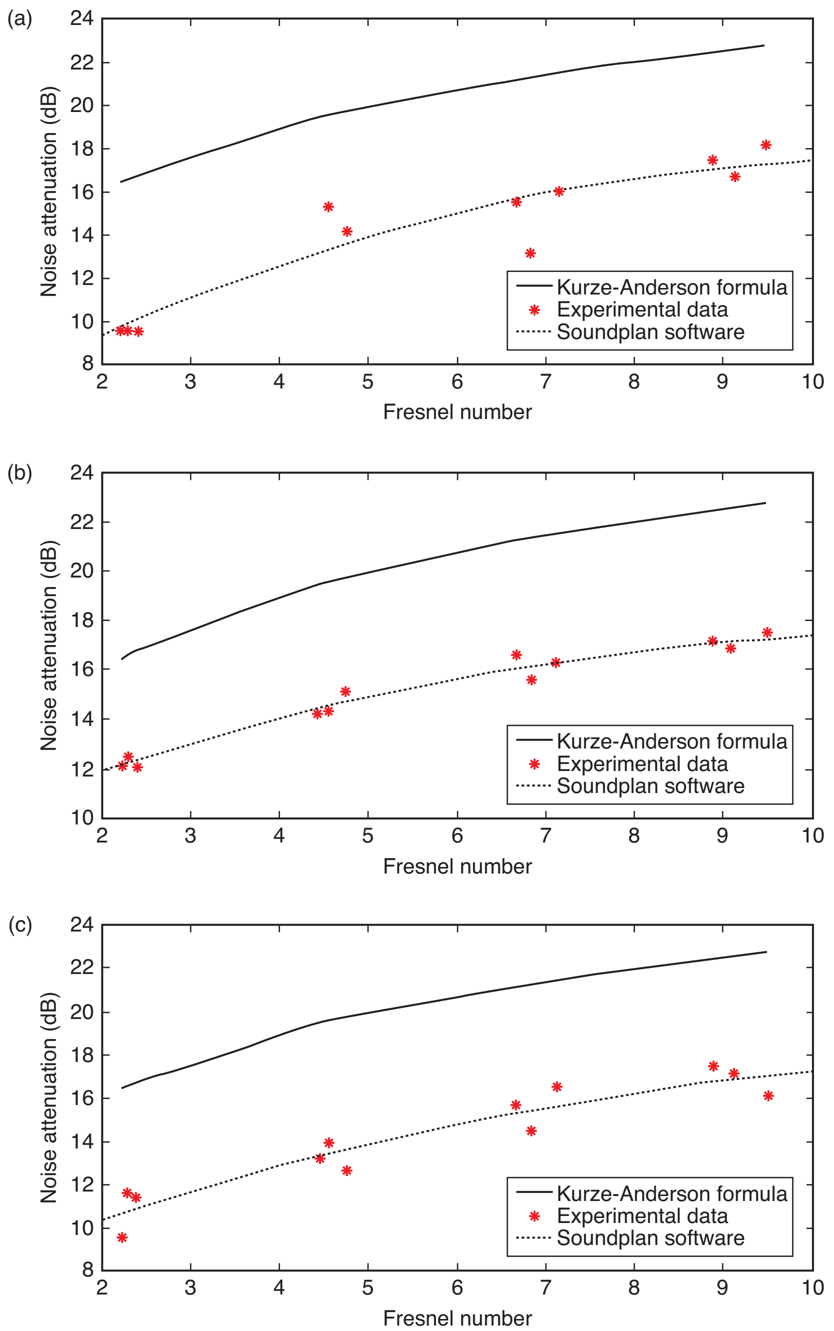

Figure 5. Noise reduction level against Fresnel number (a) v = 1.5 m/s (b) v = 1.8 m/s (c) v = 2.35 m/s.

track and buildings must be at least 17 m. Also, according to maximum height of barrier and minimum inclination angle (β), minimum distance between source and barrier should be 4m. Also the optimal zones are localized in a border region when we increase α from 0 to 90 degree.

It is also seen that, close to the sound barrier, the barrier attenuation is increased by decreasing its inclination angle but in regions far from the sound barrier, the barrier attenuation increased by increasing the inclination angle. In other hand, for any distinct configuration, there exists an optimum value for inclination angle.

In order to eliminate the effect of the receiver height, a multi-objective optimization is conducted so that the receivers at the four different heights simultaneously take their minimum sound level. For this purpose logarithmic average of the SPL are

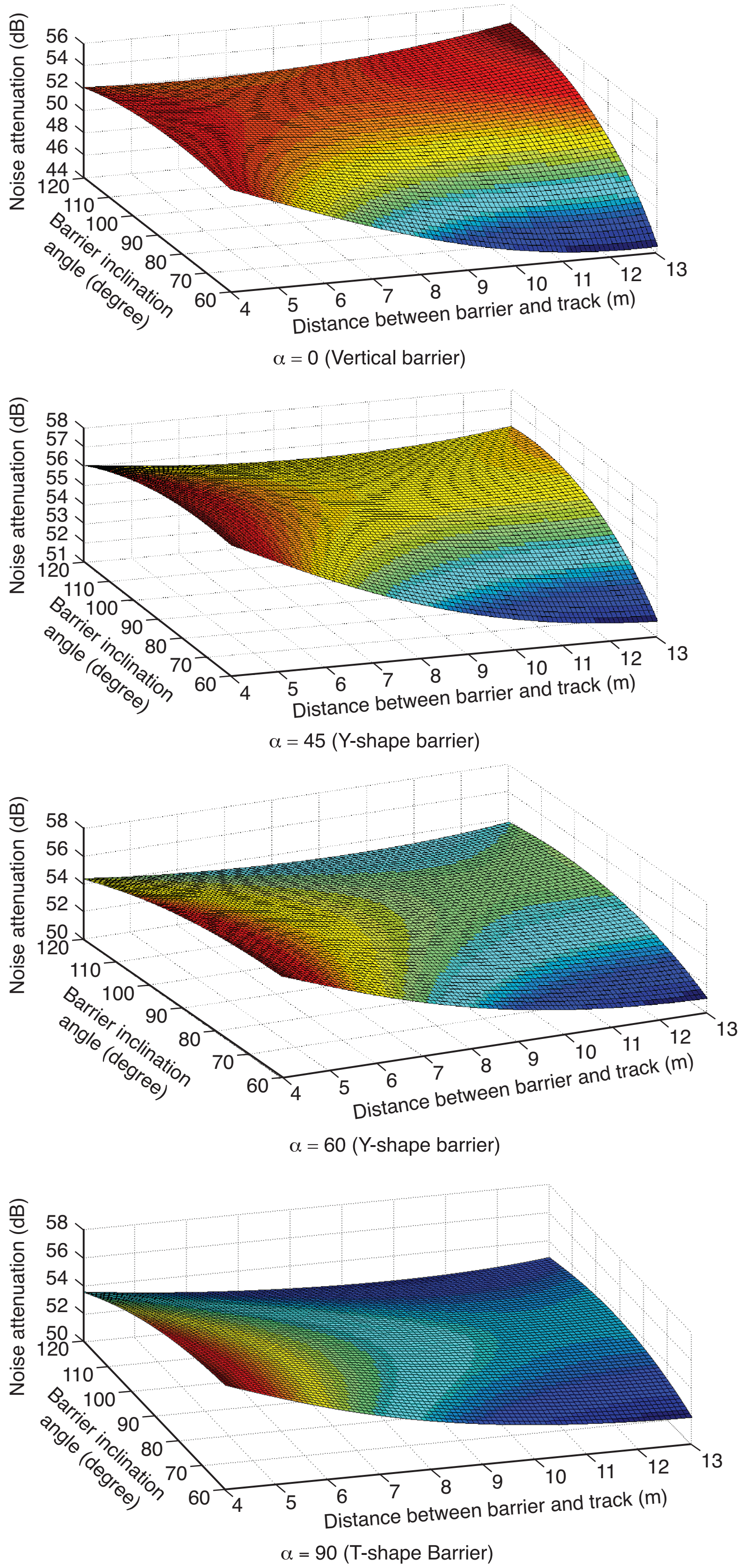

Figure 6. Barrier attenuation in different distance of sound source and inclination angle.

taken to be the cost function. The Steepest Descent Method applied for optimization procedure. This method is based on moving along gradient of the objective function by regulating the speed of convergence. It is found that a

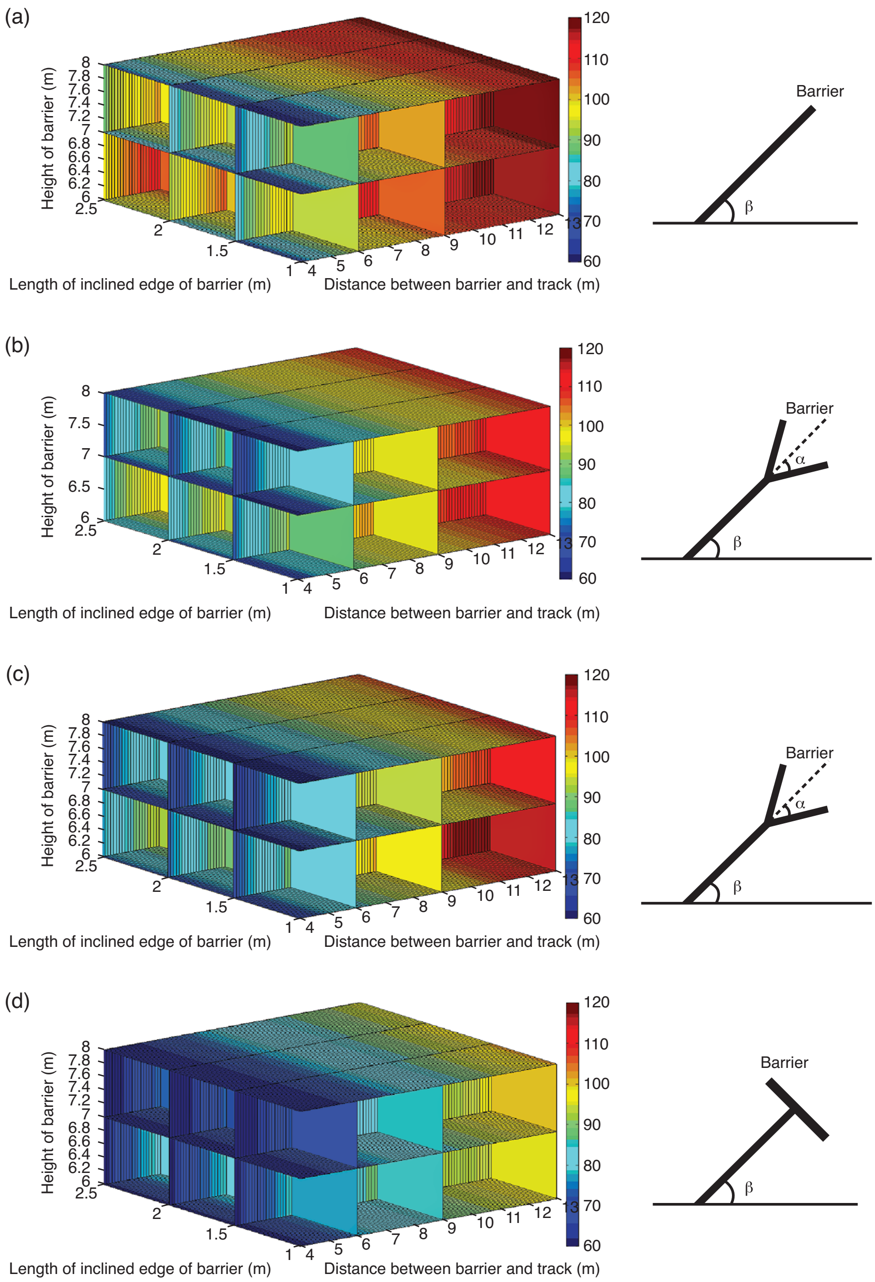

Figure 7. Optimal inclination angle of barrier (Simultaneous 4 receivers at 0.5 m, 3 m, 6 m and 10 m heights) (a) α=0 (b) α=45° (c) α=60° (d) α=90°.

maximum attenuation can be obtained in a specific value of the inclination angle, height of barrier, distance between barrier and source and barrier edge disruption angle (α). The optimum inclination angles for different geometric configurations are shown in Figure 7.

It is seen that the optimal inclination angle increases when the distance between barrier and sound source and also the length of the barrier edge increase. It is found that for a case having constant length of barrier edge, the inclination angle increases by increasing the distance between barrier and sound source and decreases by increasing the height of barrier. For a specific distance between sound source and barrier, an increase in the length of barrier edge leads to larger inclination angle. It is also found that the inclination angle decreases by increasing the barrier edge disruption angle (α).

Sound measurement has been conducted for different types of running trains at different operational speeds.

Table 2. Different types of running trains at different operational speeds.

Case	Locomotive Type	Speed (Km/h)		Case	Locomotive Type	Speed (Km/h)	
Case 1	GT26CW	90		Case 2	GT26CW	50	
Case 3	Siemens (ER24PC)	80		Case 4	Subwa Train(CRV-DKZ3)	65 (accelerating)	
Case 5	IRICO Rail Bus	45		Case 6	GT26CW	65	

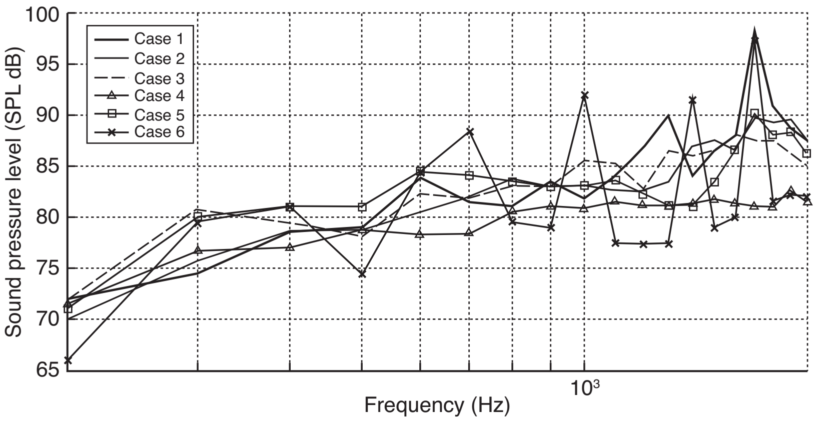

Figure 8. SPL for different locomotives at different operational speed.

The frequency-spectrums as illustrated in Figure 8 are taken as the input data in the optimization procedure.

SOUNDPLAN software is employed in modeling and noise mapping. For a real barrier of 5 m height in south Tehran, when the sound source is 4.5 m far from the railway track, the optimized barrier inclination angle is found to be 20º. The noise level maps are shown in Figure 9.

In another case study, the T-shape barrier was modeled in SOUNDPLAN. The height of T-shape barrier is assumed to be 7 m and the length of barrier edge 2 m. According to the numerical results, the optimal inclination angle of T-shape barrier (β) was found to be 70º in this case. The noise maps of the T-shape barrier with different inclination angle are shown in Fig 10. Differentiation between the optimal barrier inclination angle and the alternate non-optimal barriers are shown in Figure 11. It is shown that the inclination angle can play a significant role in noise mitigation level remarkably in high elevations. Up to 7

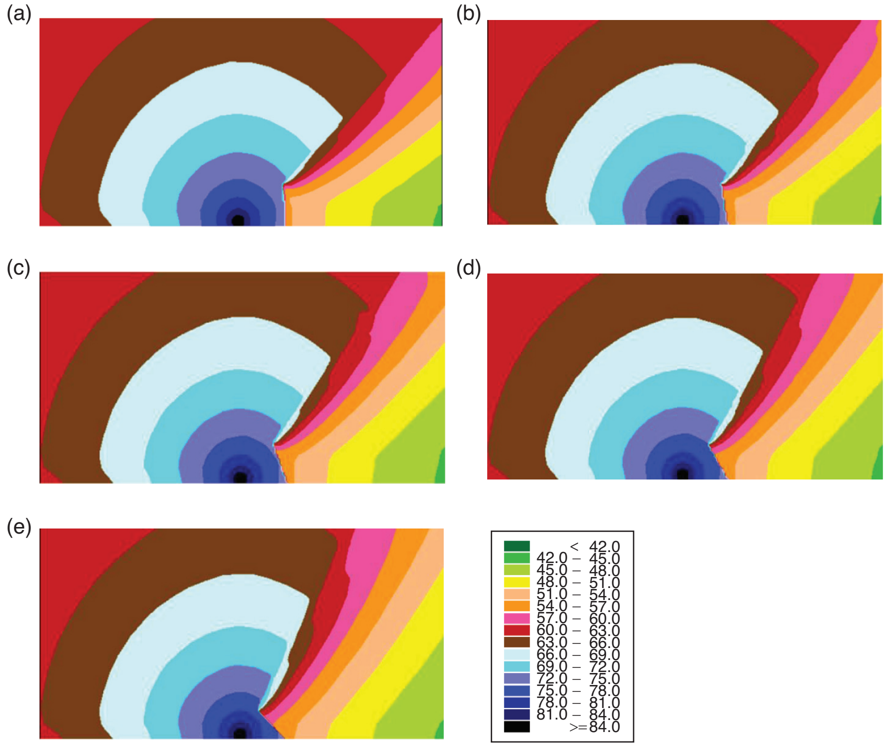

Figure 9. Noise map metro train with a (a) vertical barrier (b) barrier of 10° inclination (c) barrier of 20° inclination(d) barrier of 30° inclination (e) barrier of 45° inclination.

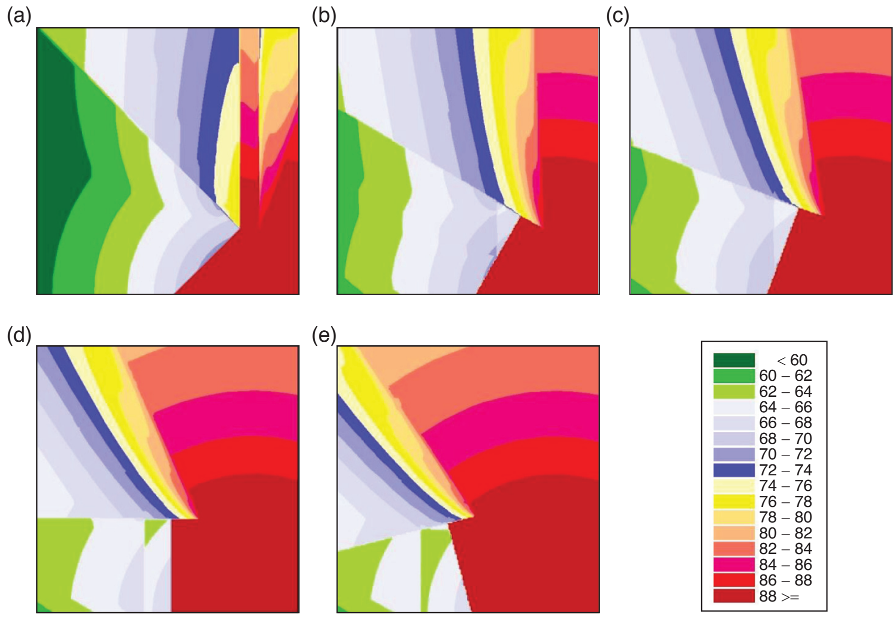

Figure 10. Noise map for different inclination angle of barrier (β) (a) 45° inclined T-shape barrier (b) 60° inclined T-shape barrier (c) 70° inclined T-shape barrier (d) 90° inclined T-shape barrier (e) 105° inclined T-shape barrier.

dBA excessive noise reduction may be imposed in receivers of 10 m height above ground.

Boundary Element Method (BEM) and Soundplan software predict different results for the region near the barrier but there is a good agreement between the results of far field determined by these methods. The near field region is characterized by the following condition [19]

$$kr << 1$$

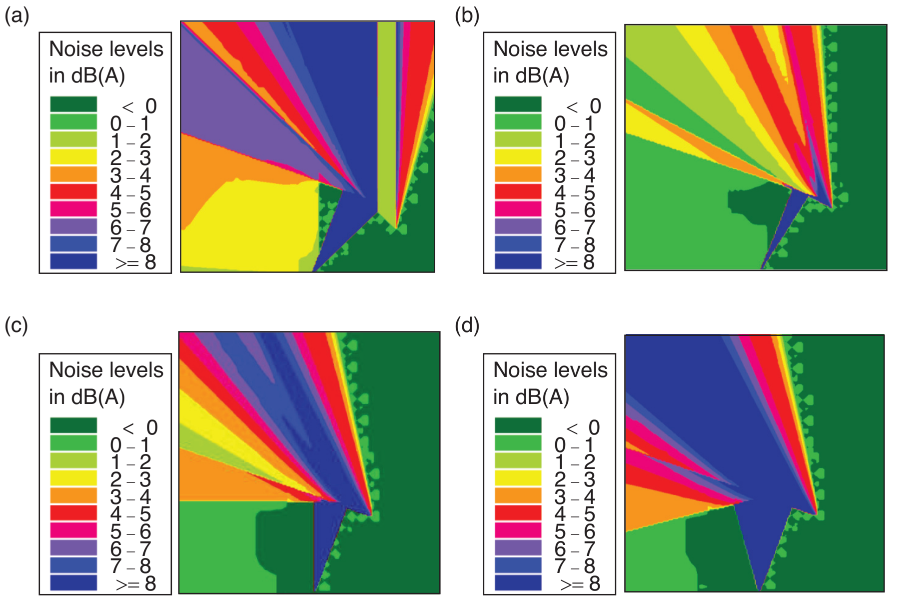

Figure 11. Noise level differentiation maps with respect to optimal angle of 70° (a) 45° inclined T-shape barrier; (b) 60°; (c) 90°; (d) 105°.

Table 3. Optimal values of inclination angle (h=8 m).

	α = 0				α = 45°			
a (m)	L=1	L=1.5	L=2	L=2.5	L=1	L=1.5	L=2	L=2.5
4	60	60	62	67	60	62	74	82
6	80	80	83	85	82	88	93	97
8	91	91	93	95	95	99	103	106
10	99	99	100	101	104	107	110	111
12	106	106	106	106	115	115	116	116
	α = 60°				α = 90°			
a (m)	L=1	L=1.5	L=2	L=2.5	L=1	L=1.5	L=2	L=2.5
4	60	60	60	60	60	60	60	60
6	74	77	79	81	67	68	69	69
8	86	88	90	91	79	79	79	79
10	95	96	96	97	87	86	86	85
12	105	103	103	102	97	93	91	90

where k is the wave number and r is the distance from the source. The near field region for a signal of frequency, 500Hz, is recognized at distance of 0.108m from the barrier which is too much in this research. The region considered in this paper is at least 2 m away from the barrier.

In order to check and compare the results of our study with those obtained by the BEM, a case of vertical barrier with 3 m and 4 m height near the railway track [20] is taken into account. The same situation has been simulated by SOUNDPLAN software and average insertion loss for 400 points behind the sound barrier has been calculated. Results of the two different methods are listed in Table 4. A maximum range of difference between 1.2 to 1.6 dB is observed. It is verified that although the ray-tracing-software ignores the wave characteristics of sound but it is reasonably reliable within the range of applications in our study. The corresponding noise maps with and without barrier 5 m far from the track are shown in figure 12.

According to the current literature, accuracy of the ray tracing method is

Table 4. Average calculated insertion loss by the BEM and SOUNDPLAN.

Wall type	Vertical (3 m height)		Vertical (4 m height)	
Source Distance	BEM [20]	This Study	BEM [20]	This Study
2.5 m	18.7	17.7	21.5	20.3
5.0 m	16.8	15.8	19.3	17.9
10.0 m	14.8	13.6	17.7	16.3

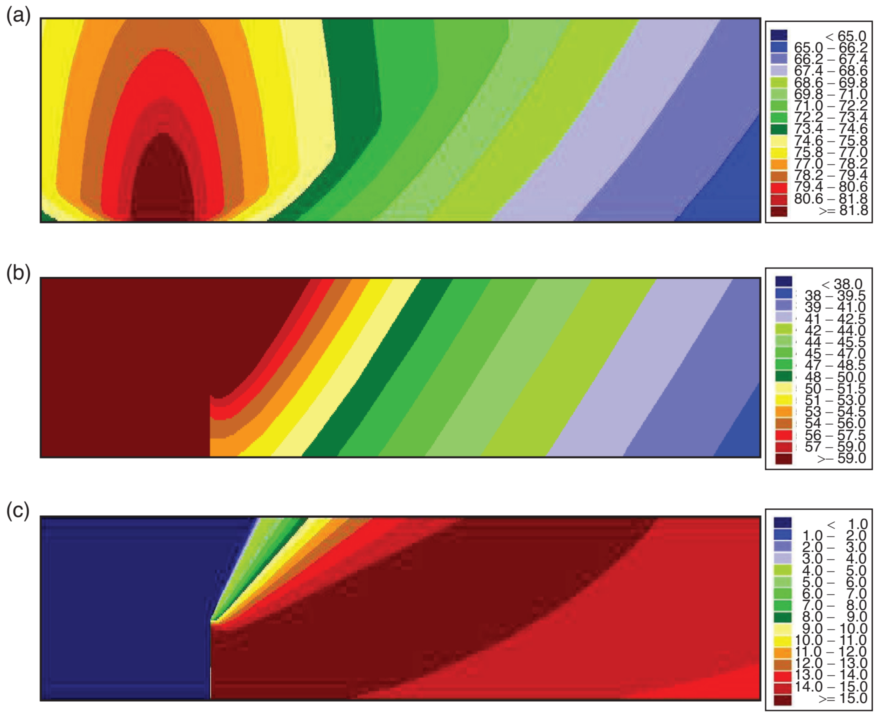

Figure 12. Noise map of railway (a) Without sound barrier (b) With sound barrier (c) Noise level differentiation.

not fully satisfactory in the near field especially in case of unconventional top edges or in the presence of complicated added devices. It is worth to note that the main focus in this paper is the optimization procedure and the employed acoustic model holds validity for such standard case studies.

4. CONCLUSIONS

Performance of T-shape and Y-shape inclined noise barriers in railway noise mitigation was studied in this paper. By use of the Steepest Descent Method, an optimized value of the inclination angle was obtained to achieve multi-point maximum noise mitigation. It was found that the inclination angle can play a significant role in noise mitigation level remarkably in high elevation positions. Validly of the modeling and solution procedure was confirmed by use of experimental results. Field measurements were also performed and the SPL spectrums of different trains were analyzed. Optimum inclination angles were presented and tabled as a practical design sheet for diverse geometric configurations. It was shown that any deviation with respect to the optimal configuration can result in excessive noise level particularly in higher elevations.

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25% OF DUBLINERS EXPERIENCE NOISE POLLUTION

Almost 25pc of Dubliners are living and sleeping with very high noise pollution, and the capital's most expensive addresses are some of the noisiest spots in the city. According to Dublin City Council (DCC) research 127,000 people are living with "undesirable" noise levels, out of a population of about 527,000. At the moment Ireland has no official limits or values on noise or air pollution, but for the purpose of their research DCC said that anything over 55 decibels in the city at night and anything over 70 decibels during the day was "undesirable." The highest night time sound levels were recorded around busy roads both in and out of the city on the north and south sides. During the daytime just over 53pc of Dubliners are exposed to sound levels from traffic sources below 55 decibels, and around 69pc of the capital's population are subjected to night time noise levels of below 50 decibels. But only 5pc of Dubliners are exposed to daytime sound levels of 70 decibels.

CAA'S RECOMMENDATIONS ON AIRCRAFT NOISE

The UK Civil Aviation Authority (CAA) has published a series of recommendations to help drive improvements in the way the aviation industry manages aircraft noise. More people in the UK are affected by aviation noise than any other country in Europe. With the Airports Commission currently considering proposals for increasing the UK's aviation capacity, the CAA is clear that the industry will not be able to grow unless it first tackles its noise and other environmental impacts more effectively. To help drive improvements from the industry, the CAA has published Managing Aviation Noise, a document setting out a series of recommendations to help reduce, mitigate and compensate communities for aviation noise. The recommendations cover changes airports and airlines could make now, as well as improvements policy-makers and industry could make ahead of any future increases in capacity. There is a strong focus on making sure airports work with their local communities more closely, as well as operational changes and ideas for incentivising airlines to reduce the noise impact of their flights. Key recommendations for the aviation industry include: • Airports and airlines should ensure that operational approaches to mitigate noise are incentivised and adopted wherever feasible. The CAA will work with industry to consider, trial and promote novel operational approaches to noise minimisation. • When looking to expand, airports should do more to ensure local residents see benefits from additional capacity - whether through funding community schemes, direct payments, or tax breaks. • Airports seeking expansion should significantly increase spending on noise. mitigation schemes to get closer to international competitors - including full insulation for those most affected. • Airlines should focus on noise performance when purchasing new aircraft. • Airports should structure their landing charges to incentivise airlines to operate cleaner, quieter flights.

IT'S THE NOISE, NOT THE COOKING

The 2014 Zagat Boston Restaurants Survey found restaurant noise level to be the number-one irritant about dining out, more irksome than service and price, according to online survey results. Over 70 percent of those surveyed avoid restaurants that are too loud. The results were similar in New York City, as well as nationally. About 8,500 persons participated in the Boston survey.