ICSV14
Cairns • Australia
9-12 July, 2007

14th International Congress on Sound & Vibration

ACOUSTIC PROPERTIES OF SOUND BARRIERS

Mihai BUGARU[1], Raluca DALE[1]

[1] Department of Mechanics, University POLITEHNICA of Bucharest
Bucharest, ROMANIA
bugarum@yahoo.com

Abstract

The purpose of this study was to optimize the acoustic properties of sound barriers for traffic noise applications. For a correct assessment of the noise produced by road vehicles, it is necessary to know every detail about the noise source. The main difficulty in the prediction of road traffic noise levels is the great variation in source conditions. First of all, the road vehicle type may vary from scooters and mopeds to various types of passenger cars to various types of trucks. Secondly, the characteristics of the road surface are of great influence on the tyre/road noise production. Finally, the noise produced by a single vehicle on a specific road surface is dependent on driving behavior and meteorological conditions.

1. INTRODUCTION

Mechanical equipment such as cooling towers, rooftop units and exhaust fans are commonly located outdoors. In addition, there is an increasing trend to placing additional mechanical equipment outdoors. Unacceptable noise from electrical or mechanical equipment, whether located indoors or outdoors, may be strong enough to be transmitted to neighbor locations. Three broad types of natural effects influence the sound transmission paths: distance effects, terrain and vegetation effects, and atmospheric effects. In addition, structures such as barriers and buildings influence the transmission of sound to the neighbor positions.

2. STATE OF THE ART

From the source to the receiver, noise changes both in level and frequency spectrum. The most obvious is the decrease in noise as the *distance from the source* increases. The manner in which noise reduces with distance depends on the following important factors: geometric spreading from point and line sources; ground absorption; atmospheric effects and refraction; shielding by natural and manmade features, noise barriers, diffraction, and reflection. Sound from a small-localized source (approximating a "point" source) radiates uniformly outward as it travels away from the source in a spherical pattern. The sound level attenuates or drops-off at a rate of 6 dBA for each doubling of the distance (6 dBA/DD). This decrease, due to the geometric spreading of the energy over an ever-increasing area, is referred to as the *inverse square law*. Doubling the distance increases each unit area, represented by squares with sides "**a**" in figure 1, from $\mathbf{a^2}$ to $\mathbf{4a^2}$**.** Since the same amount of energy passes through both squares, the energy per unit area at 2D is reduced 4 times from that at distance D. Thus, for a point source the energy per unit area is inversely proportional to the square of the distance. Taking 10 log(1/4) results in a 6 dBA reduction (for each doubling of distance). This is the point source attenuation rate for geometric spreading.

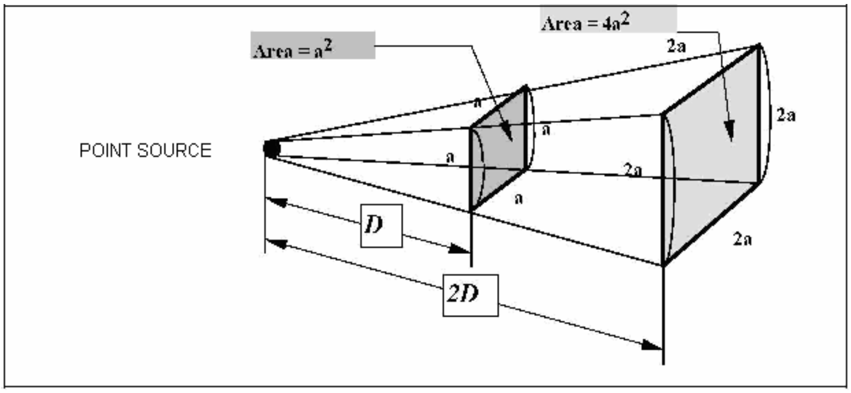

Figure1. Point Source Propagation (Spherical Spreading)

As can be seen in figure 2, based on the inverse square law the change in noise level between any two distances due to the spherical spreading can be found from:

$$dBA_2 = dBA_1 + 10\,log\left[(D_1 / D_2)\right]^2 = dBA_1 + 20\,log\left(D_1 / D_2\right) \qquad (1)$$

where: dBA_1 is the noise level at distance D_1; dBA_2 is the noise level at distance D_2.

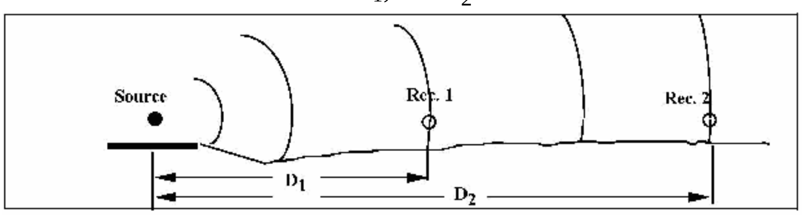

Figure2. Change in Noise Level with Distance due to Spherical Spreading

However, highway traffic noise is not a single, stationary point source of sound. The movement of the vehicles makes the source of the sound appear to emanate from a line (line source) rather than a point when viewed over some time interval (see figure 3). This results in cylindrical spreading rather than the spherical spreading of a point source. Since the change in surface area of a cylinder only increase by two times for each doubling of the radius instead of the four times associated with spheres, the change in sound level is 3 dBA per doubling of distance. The change in noise levels for a line source at any two different distances due to the cylindrical spreading becomes:

$$dBA_2 = dBA_1 + 10\,log\left(D_1 / D_2\right) \qquad (2)$$

where: dBA_1 is the noise level at distance D_1, and conventionally the known noise level; dBA_2 is the noise level at distance D_2, and conventionally the unknown noise level.

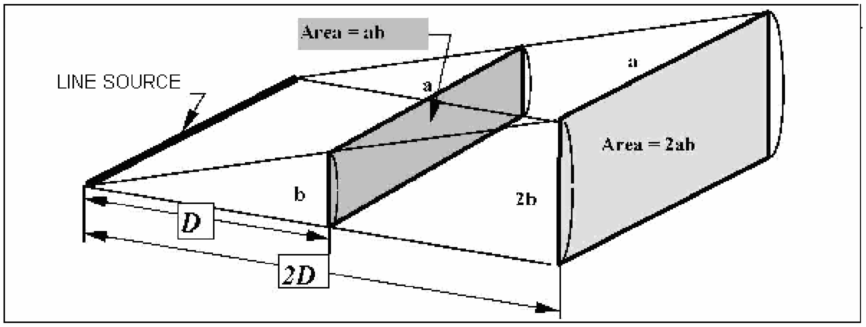

Figure3. Line Source Propagation (Cylindrical Spreading)

Most often, the noise path between the highway and the observer is very close to the ground. Noise attenuation from *ground absorption* and reflective wave canceling adds to the attenuation due to geometric spreading. Traditionally, the access attenuation has also been expressed in terms of attenuation per doubling of distance. This approximation is done for simplification only, and for distances of less than 60 m prediction results based on this scheme are sufficiently accurate. The sum of the geometric spreading attenuation and the excess ground attenuation is referred to as the *attenuation rate, or drop-off rate.* For distances of 60 m or greater the approximation causes excessive inaccuracies in predictions. The amount of excess ground attenuation depends on the height of the noise path and the characteristics of the intervening ground or site. In practice, this excess ground attenuation may vary from nothing to 8-10 dBA or more per doubling of distance. In fact, it varies as the noise path height changes from the source to the receiver and also changes with vehicle type since the source heights are different. The complexity of terrain is another factor that influences the propagation of sound by potentially increasing the number of ground reflections. Only the most sophisticated computer model(s) can properly account for the interaction of sound waves near the ground. In the mean time, for the sake of simplicity two site types are currently used in traffic noise models: *Hard Sites* -these are sites with a reflective surface between the source and the receiver such as parking lots or smooth bodies of water. No excess ground attenuation is assumed for these sites and the changes in noise levels with distance (drop-off rate) is simply the geometric spreading of the line source or 3 dBA/DD (6dBA/DD for a point source); *Soft Sites* - these sites have an absorptive ground surface such as soft dirt, grass or scattered bushes and trees. An excess ground attenuation value of 1.5 dBA/DD is normally assumed. When added to the geometric spreading results in an overall drop-off rate of 4.5 dBA/DD for a line source (7.5 dBA/DD for a point source).
The combined distance attenuation of noise due to geometric spreading and ground absorption in the above simplistic scheme can be generalized with the following formula:

$$dBA_2 = dBA_1 + 10\,log\left(D_1 / D_2\right)^{1+\alpha} \qquad \text{(Line source)} \tag{3}$$

$$dBA_2 = dBA_1 + 10\,log\left(D_1 / D_2\right)^{2+\alpha} \qquad \text{(Point source)} \tag{4}$$

where: **α** is a site parameter, which takes on the value of zero for a *hard site* and 0.5 for a *soft site.* A large object in the path between a noise source and a receiver can significantly attenuate noise levels at that receiver. The amount of attenuation provided by this “shielding” depends on the size of the object, and frequencies of the noise levels. *Natural terrain* features, such as hills and dense woods, as well as manmade features, such as buildings and walls can significantly alter noise levels. Walls are often specifically used to reduce noise.
Research has shown that *atmospheric conditions* can have a profound effect on noise levels within 60 m from a highway. Wind has shown to be the single most important meteorological

factor within approximately 150 m, while vertical air temperature gradients are more important over longer distances. Other factors such as air temperature and humidity, and turbulence, also have significant effects.

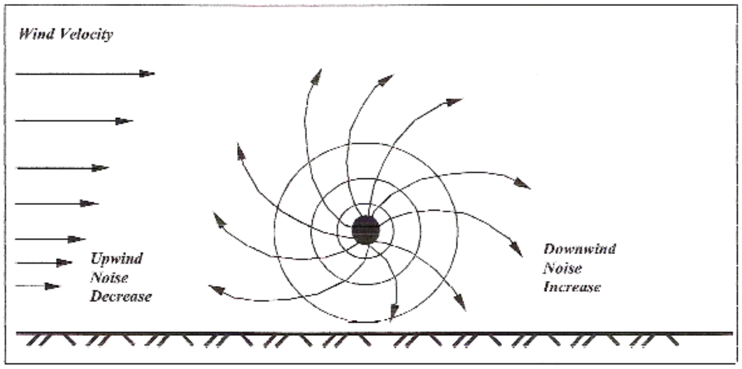

Figure4. Wind Effects on Noise Levels

The effects of the wind on noise are mostly confined to noise paths to the ground. The reason for this is the *wind shear* phenomenon. Wind shear is caused by the slowing down of wind in the vicinity of a ground plane due to friction. As the surface roughness of the ground increases, so does the friction between the ground and the air moving over it. As the wind slows down with decreasing heights, it creates a sound velocity gradient (due to differential movement of the medium) with respect to the ground. This velocity gradient tends to bend sound waves downward in the same direction of the wind and upward in the opposite direction. The process, called *refraction*, creates a **noise "shadow"** (reduction) **upwind** from the source and a **noise "concentration"** (increase) **downwind** from the source. Figure 4 shows the effects of wind on noise. *Wind effects* on noise levels along a highway are very much dependent on wind angle, receiver distance and site characteristics. A 10 km/h cross wind can increase noise levels at 75 m by about 3 dBA downwind, and reduce noise by about the same amount upwind. Present policies and standards ignore the effects of wind on noise levels. Unless winds are specifically mentioned, noise levels are always assumed to be for zero winds. Noise analyses are also always made for zero wind conditions. Wind also has another effect on noise measurements. Wind "rumble" caused by friction between air and a microphone of a sound level meter can contaminate noise measurements even if a windscreen is placed over the microphone. *Wind turbulence* has a scattering effect on noise levels, which is difficult to predict at this time. It appears, however, that turbulence has the greatest effect on noise levels near the source.

Figure 5 shows the effects of *temperature gradients* on noise levels. Normally, air temperature decreases with height above the ground. This is called the normal lapse rate, which for dry air is about - 1^{o} C/100 m. Since the speed of sound decreases as air temperature decreases, the resulting temperature gradient creates a sound velocity gradient with height. Slower speeds of sound higher above the ground tend to refract sound waves upward in the same manner as wind shear does upwind from the source. The result is a decrease in noise. Under certain stable atmospheric conditions, however, temperature profiles are inverted, or temperatures increase with height either from the ground up, or at some altitude above the ground. This inversion results in speeds of sound that temporarily increase with altitude, causing noise refraction similar to that caused by wind shear downwind from a noise source. Both ground and elevated temperature inversions have the effect of propagating noise with less than the usual attenuation rates, and therefore increase noise. The effects of vertical temperature gradients are more important over longer distances. *Wet pavement* results in an increase in tire noise and a corresponding increase in frequencies of noise at the source. Since the propagation of noise is frequency dependent, rain may also affect distance attenuation rates. On the other hand, traffic generally slows down during rain, decreasing noise levels and lowering frequencies. When wet, different pavement types interact differently with tires than when they are dry. These factors make it very difficult to predict noise levels during rain. Hence, no noise measurements or predictions are made for rainy conditions. Noise abatement criteria and standards do not address rain.

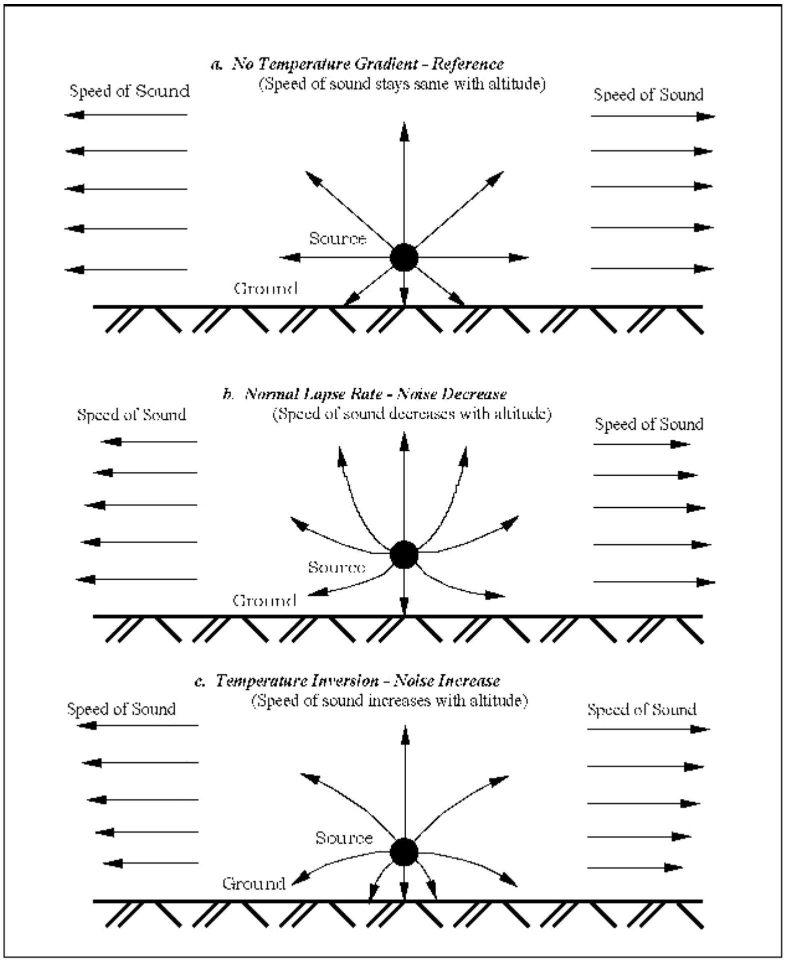

Figure5. Effects of Temperature Gradients on Noise

3. RESULTS

To analyze for wind and frequency effects was used a punctual source located to 4m in front of the barrier and 70 cm. above the ground. The simulation made for pure tones of 200 and 500 Hz. The wind had a negative effect on the sound barrier in the higher frequency, shear refraction effect. The results of the simulations are presented in figures 6, 7 and 8. The results presented in figure 6, 7 and 8 were obtained for a 500 Hz source.

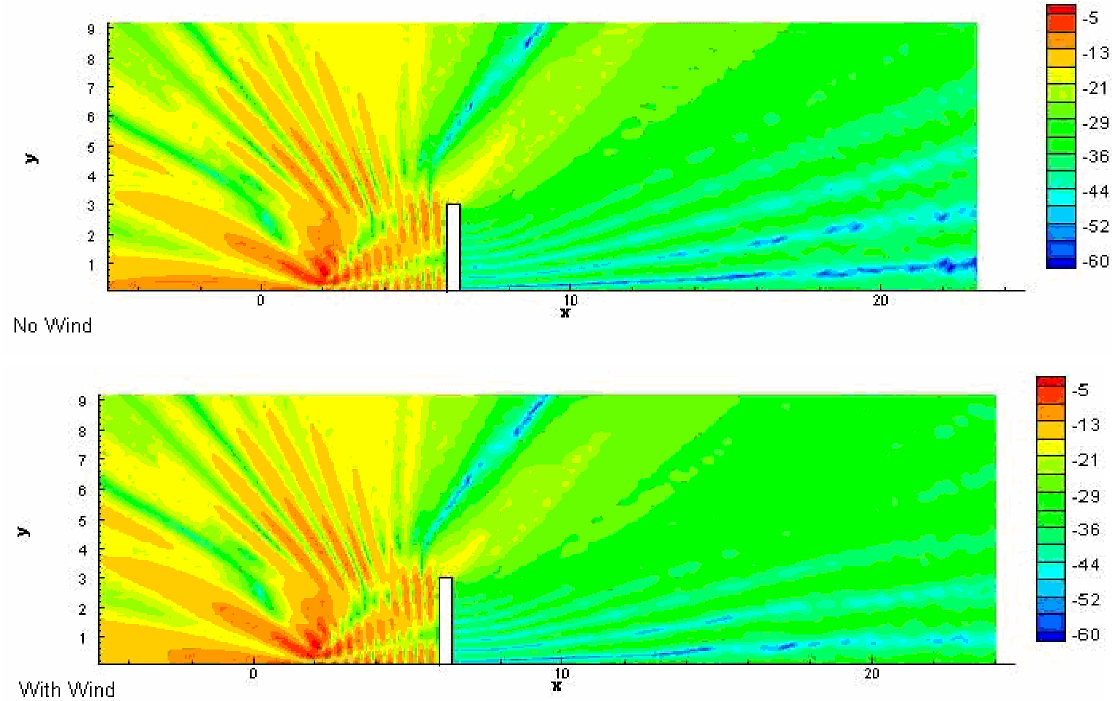

Figure6. Sound Pressure level (relative to the maximum amplitude on the grid)

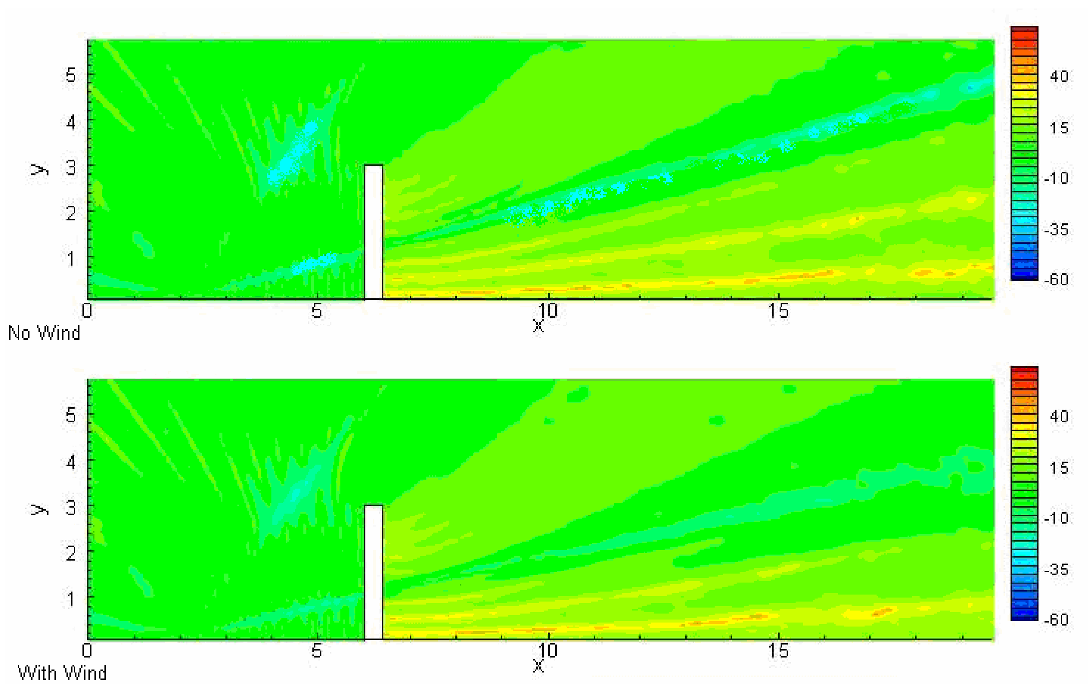

Figure7. Insertion Loss (IL)

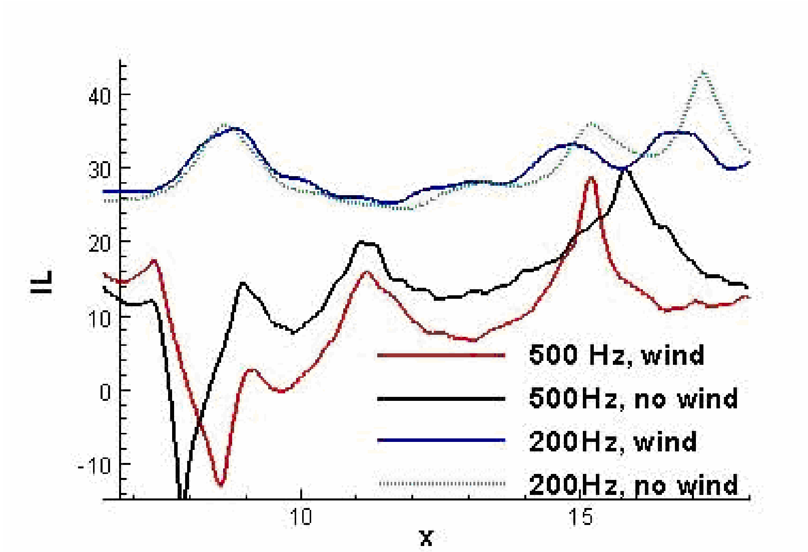

Figure8. Insertion Loss at height of 1.65 m

4. CONCLUSIONS

The results of this study have established that the technique is sensitive enough to demonstrate differences between other acoustics barrier. Depending upon the barrier type, the current apparatus may require upgrading with a more powerful loudspeaker to improve the signal-to-noise ratio. This may be particularly important when noise from adjacent traffic is high. Further measurements are required to look at the effects on screening performance at angles of incidence other than normal incidence. The effects of wind on performance could also be examined by taking further measurements under a greater range of wind speeds.

REFERENCES

[1] M. Bugaru, N. Enescu, R. Stanila, O. Vasile, “Reflection and absorption acoustic properties of finite length acoustical barriers, *Proceedings of the Twelfth International Congress on Sound and Vibration* (ICSV12), 11-14 July 2005, Lisbon, Portugal.

[2] M. Bugaru, R. Stanila, O. Vasile, “Vibration analysis of beams with general boundary conditions traversed by a moving force”, *Proceedings of the AVSM2005*, 10-12 September 2005, Timisoara, Romania.

[3] J.R. Harssal, K. Zaveri, *Acoustic Noise Measurements*, Bruel & Kjaer, 1988.

[4] U.J. Kurze, “Noise reduction by barriers”, *Journal of the Acoustical Society of America* **97,** 937-1007 (1974).

[5] *Technical Assessment of the Effectiveness of Noise Walls*, Final Report **-** Noise/News International, a quarterly news magazine published by I-INCE and INCE/USA, Volume **7**, Number **3**, September 1999.

[6] *LSE Noise Barrier Wall System* **-** Material Specifications, General – Sound Fighter Systems, LLC.

[7] *Highway Traffic Noise Barriers at a Glance* – U.S. Department of Transportation, Federal Highway Administrations.