Technical Noise Supplement

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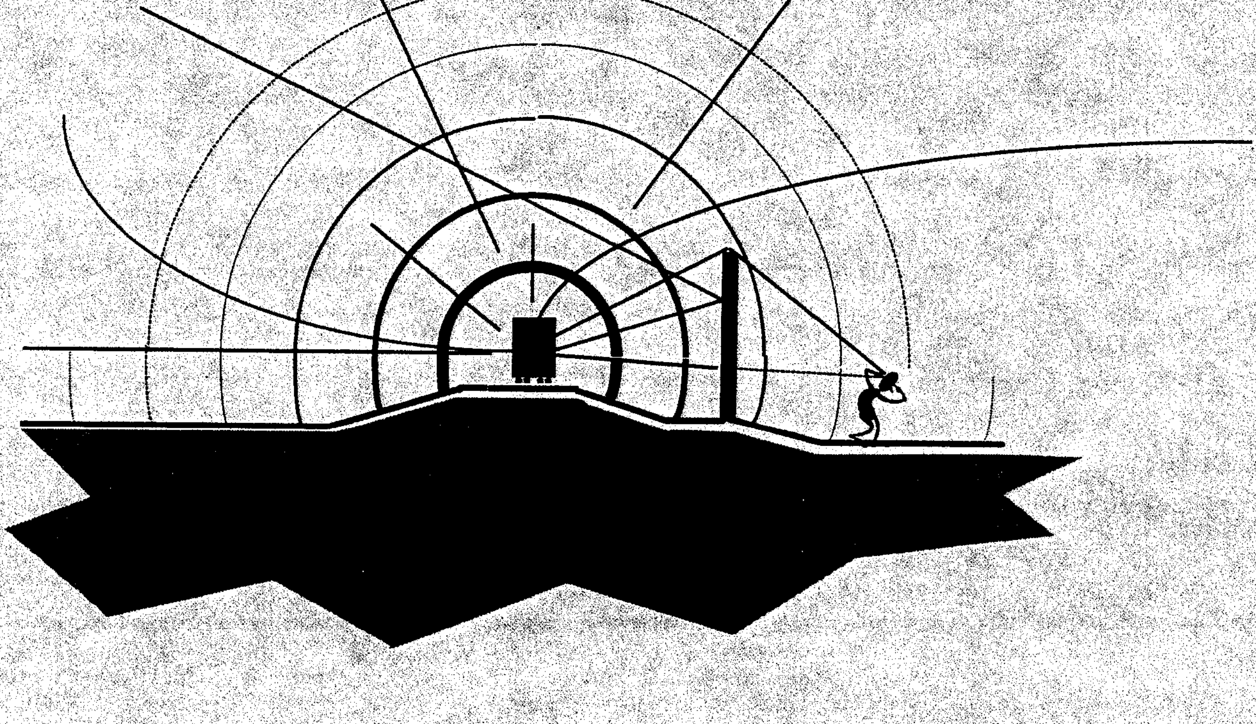
A Technical Supplement To The Traffic Noise Analysis Protocol



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Environmental Program
Environmental Engineering-
Noise, Air Quality, and Hazardous Waste Management Office

Pink noise, in contrast, is defined as having the same amplitude for each octave band (or third-octave band), rather than for each frequency interval. Its octave or third-octave band spectrum is truly a straight, “level” line over the entire audible spectrum. Pink noise generators are therefore conveniently used to calibrate octave or third-octave band analyzers.

Both white and pink noise sound somewhat like the static heard from a radio that is not tuned to a particular station.

N-2140 Sound Propagation

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:

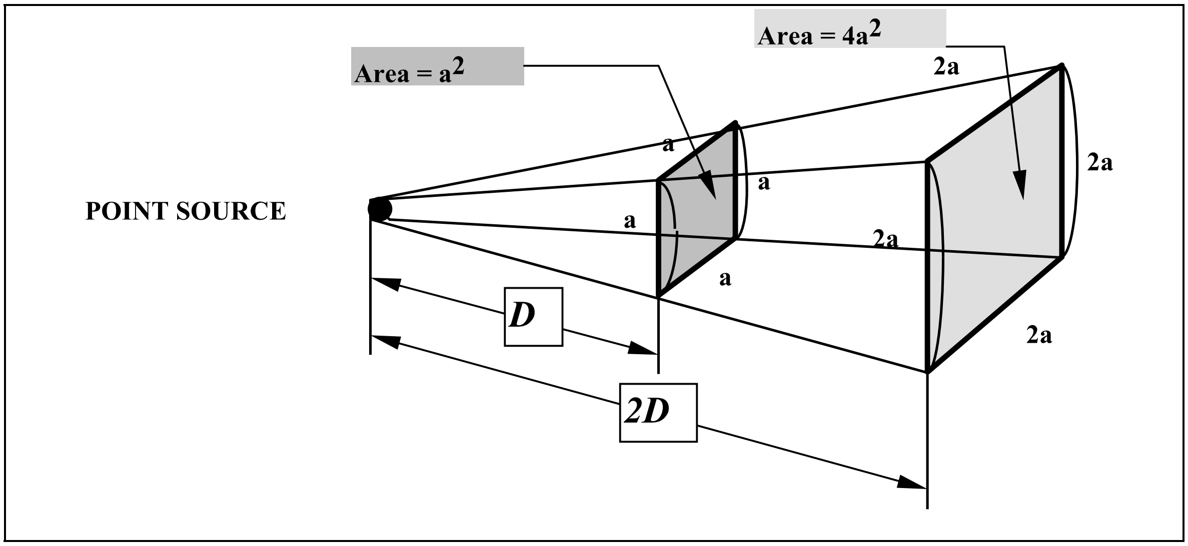
- Geometric Spreading from Point and Line Sources
- Ground Absorption
- Atmospheric Effects and Refraction
- Shielding by Natural and Manmade Features, Noise Barriers, Diffraction, and Reflection

N-2141 Geometric Spreading from Point and Line Sources

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 N-2141.1, 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 $\log_{10}$ (1/4) results in a 6 dBA reduction (for each doubling of distance). This is the point source attenuation rate for geometric spreading.

Figure N-2141.1 Point Source Propagation (Spherical Spreading)



As can be seen in Figure N-2141.2, based on the inverse square law the change in noise level between any two distances due to the spherical spreading can be found from:

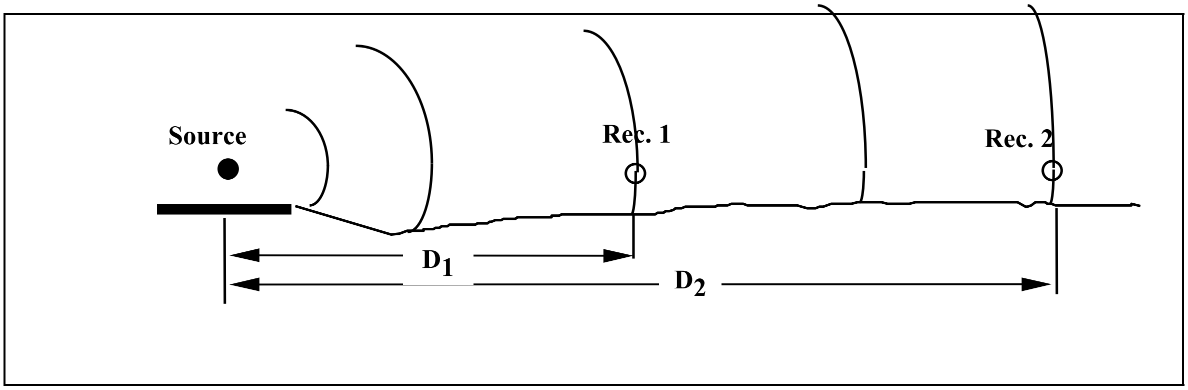
$$dBA_2 = dBA_1 + 10\ Log_{10}\ [(D_1/D_2)]^2 =$$

$$= dBA_1 + 20\ Log_{10}\ (D_1/D_2) \qquad \text{(eq. N-2141.1)}$$

Where:

dBA_1 is the noise level at distance D_1, and
dBA_2 is the noise level at distance D_2

Figure N-2141.2 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 N-2141.3). This results in cylindrical spreading rather than the spherical spreading of a point source.

Since the change in surface area of a cylinder only increases 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:

$$\mathbf{dBA_2 = dBA_1 + 10\ Log_{10}\ (D_1/D_2)} \qquad \textbf{(eq. N-2141.2)}$$

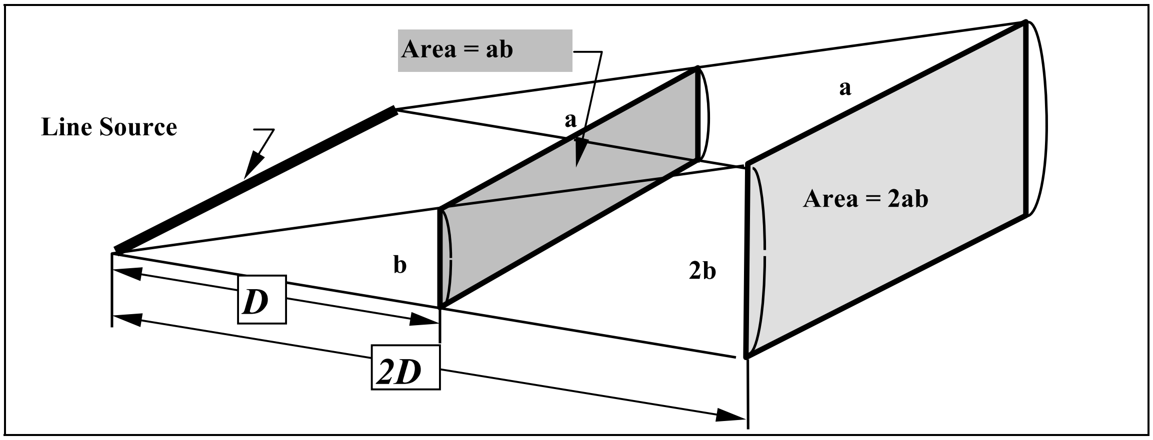
Where:

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

Note: the expression 10 Log_{10} (D_1/D_2) is negative when D_2 is greater than D_1, positive when D_1 is greater than D_2, and the equation therefore automatically accounts for the receiver being farther out or closer in with respect to the source (Log_{10} of a number less than 1 gives a negative result; Log_{10} of a number greater than 1 is positive, and Log_{10} (1) = 0).

Figure N-2141.3 Line Source Propagation (Cylindrical Spreading)



N-2142 Ground Absorption

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 (200 feet) prediction results based on this scheme are sufficiently accurate. The sum of the geometric spreading attenuation and the excess ground attenuation (if any) is referred to as the *attenuation rate,*

Temperature and humidity - Molecular absorption in air also reduces noise levels with distance. Although this process only accounts for about 1 dBA per 300 m (1000 ft) under average conditions of traffic noise in California, the process can cause significant longer range effects. Air temperature, and humidity affect molecular absorption differently depending on the frequency spectrum, and can vary significantly over long distances, in a complex manner.

Rain. **-** 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.

N-2144 Shielding by Natural and Man-made Features, Noise Barriers, Diffraction, and Reflection

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.

***Trees and Vegetation* -** For a vegetative strip to have a noticeable effect on noise levels it must be dense and wide. A stand of trees with a height that extends at least 5 m (16 ft) abve the line of sight between source and receiver, must be at least 30 m (100 ft) wide and dense enough to completely obstruct a visual path to the source to attenuate traffic noise by 5 dBA. The effects appear to be cumulative, i.e. a 60 m (200 ft) wide stand of trees would reduce noise by an additional 5 dBA. However, the limit is generally a total reduction of 10 dBA. The reason for the 10 dBA limit for any type of vegetation is that sound waves passing over the tree tops (“sky waves”) are frequently refracted back to the surface, due to downward atmospheric refraction caused by wind, temperature gradients, and turbulence.

***Landscaping* -** Caltrans research has shown that ordinary landscaping along a highway accounts for less than 1 dBA reduction. Claims of increases in noise due to removal of vegetation along highways are mostly spurred by the sudden visibility of the traffic source.

There is evidence of the psychological "out of sight, out of mind" effect of vegetation on noise.

Buildings - Depending on the site geometry, the first row of houses or buildings next to a highway may shield the second and successive rows. This is often the case where the facility is at-grade or depressed. The amount of noise reduction varies with house or buildig sizes, spacing of houses or buildings, and site geometry. Generally, for an at-grade facility in an average residential area where the first row houses cover at least 40% of total area (i.e. no more than 60% spacing) , the reduction provided by the first row is reasonably assumed at 3 dBA, and 1.5 dBA for each additional row. For example, behind the first row we may expect a 3 dBA noise reduction, behind the second row 4.5 dBA, third row 6 dBA, etc. For houses or buildings “packed” tightly, (covering about 65-90% of the area, with 10-35% open space), the first row provides about 5 dBA reduction. Successive rows still reduce 1.5 dBA per row. Once again, and for the reason mentioned in the above vegetation discussion, the limit is 10 dBA. For these assumptions to be true, the first row of houses or buidings must be equal to or higher than the second row, which should be equal to or higher than the third row, etc.

Noise Barriers - Although technically any natural or man-made feature between source and receiver that reduces noise is a noise barrier, the term is generally reserved for either a wall or a berm that is specifically constructed for that purpose. The acoustical design of noise barriers is covered in sections N-4000 (Traffic Noise Model) and N-6000 (Acoustical Barrier Design Considerations). However, it is appropriate at this time to introduce the acoustical concepts associated with noise barriers. These principles loosely apply to any obstacle between source and receiver.

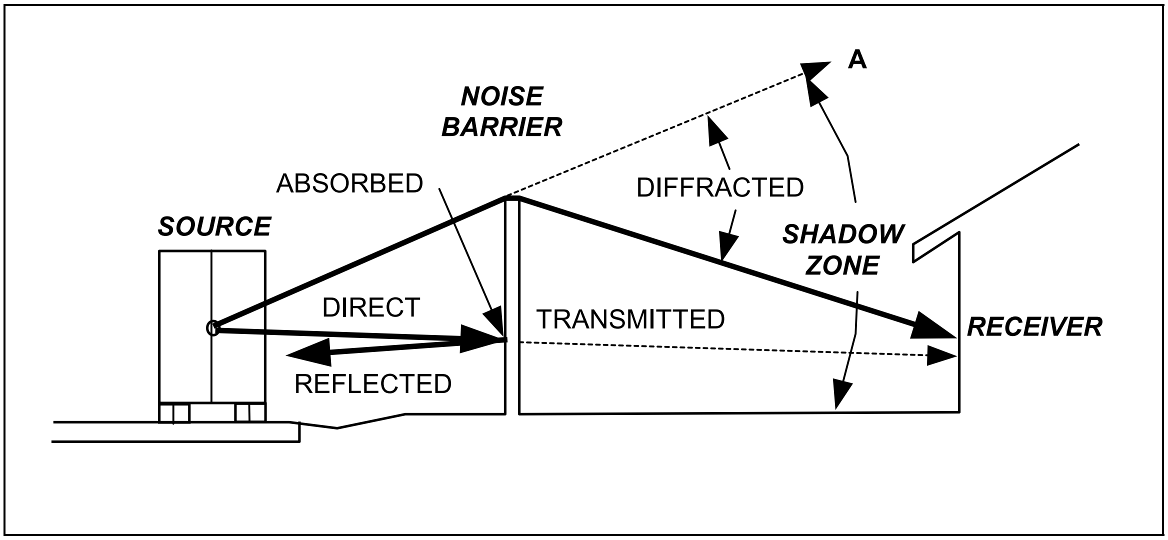
Referring to Figure N-2144.1, when a noise barrier is inserted between a noise source and receiver, the *direct* noise path along the line of sight between the two is interrupted. Some of the acoustical energy will be *transmitted* through the barrier material and continue to the source, albeit at a reduced level. The amount of this reduction depends on the material’s mass and rigidity, and is called the Transmission Loss.

The Transmission Loss (TL) is expressed in dB and its mathematical expression is:

$$\mathbf{TL = 10\log_{10}(E_f/E_b)} \qquad \textbf{(eq. N-2144.1)}$$

where: E_f = the relative noise energy immediately in front (source side) of the barrier
E_b = The relative noise energy immediately behind the barrier (receiver side)

Figure N-2144.1 - Alteration of Sound Paths After Inserting a Noise Barrier Between Source and Receiver.



Note that E_f and E_b are relative energies, i.e. energies with reference to the energy of 0 dB (see section N-2134). As relative energies they may be expressed as any ratio (fractional or percentage) that represents their relationship. For instance if 1 percent of the noise energy striking the barrier is transmitted, TL = $10\log_{10}(100/1)$= 20 dBA. Most noise barriers have TL's of 30 dBA or more. This means that only 0.1 percent of the noise energy is transmitted.

The remaining direct noise (usually close to 100 percent) is either partially or entirely *absorbed* by the noise barrier material (if sound absorptive), and/or partially or entirely *reflected* (if the barrier material is sound reflective). Whether the barrier is reflective or absorptive depends on its ability to absorb sound energy. A smooth hard barrier surface such as masonry or concrete is considered to be almost perfectly reflective, i.e.almost all the sound striking the barrier is reflected back toward the source and beyond. A barrier surface material that is porous with many voids is said to be absorptive, i.e. little or no sound is reflected back. The amount of energy absorbed by a barrier surface material is expressed as an absorption coefficient α, which has a value ranging from 0 (100% reflective) to 1 (100% absorptive). A perfect reflective barrier (α=0) will reflect back virtually all the noise energy (assuming a transmission loss of 30 dBA or greater) towards the opposite side of a highway. If we ignore the difference in path length between the direct and reflected noise paths to the opposite (unprotected) side of a highway, the maximum expected increase in noise will be 3 dBA.

If we wish to calculate the noise increase due to a partially absorptive wall we may use eq. N-2144.1. E_f in this case is still the noise energy striking the barrier, but E_b now becomes the energy reflected back. For example, a barrier material with an α of 0.6 absorbs 60% of the direct noise energy and reflects back 40%. To calculate the increase in noise on the opposite side of the highway in this situation the energy loss from the transformation of the total noise striking the barrier to the reflected noise energy component is $10\log_{10}(100/40)=$ 4 dBA. In other words, the energy loss of the reflection is 4 dBA. If the direct noise level of the source at a receiver on the opposite side of the highway is 65 dBA, the reflective component (ignoring the difference in distances traveled) will be 61 dBA. The total noise level at the receiver is the sum of 65 and 61 dBA, or slightly less than 66.5 dBA. The reflected noise caused an increase of 1.5 dBA at the receiver.

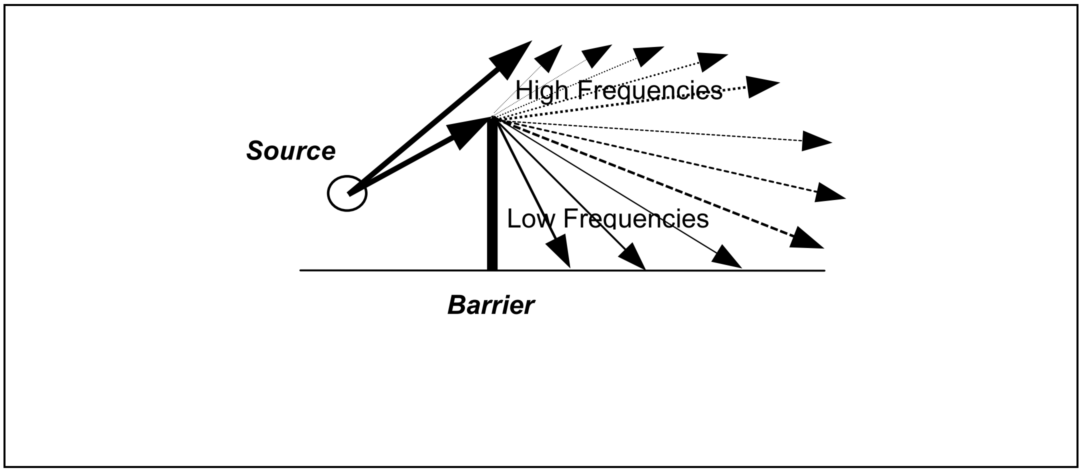
Referring back to Figure N-2144.1, we have discussed the *direct*, *transmitted*, *absorbed*, and *reflected* noise paths. These represent all the variations of the direct noise path due to the insertion of the barrier. Of those, only the transmitted noise reaches the receiver behind the barrier. There is, however, one more path, which turns out to be the most imported one, that reaches the receiver. The noise path that before the barrier insertion was directed towards "A" is *diffracted* downward towards the receiver after the barrier insertion.

In general, *diffraction* is characteristic of all wave phenomena (including light, water, and sound waves). It can best be described as the "bending" of waves around objects . The amount of diffraction depends on the wavelength and the size of the object. Low frequency waves with long wavelengths approaching the size of the object, are easily diffracted. Higher frequencies with short wavelengths in relation to the size of the object, are not as easily diffracted. This explains why light, with its very short wavelengths casts shadows with fairly sharp, well defined edges between light and dark. Sound waves also "cast a shadow" when they strike an object. However, because of their much longer wavelengths (by at least a half dozen or so orders of magnitude) the "noise shadows" are not very well defined and amount to a noise reduction, rather than an absence of noise.

Because noise consists of many different frequencies that diffract by different amounts, it seems reasonable to expect that the greater the angle of diffraction is, the more frequencies will be attenuated. In Figure N-2144.1, beginning with the top of the shadow zone and going down to the ground surface, the higher frequencies will be attenuated first, then the middle frequencies and finally the lower ones. Notice that the top of the shadow zone is defined by the extension of a straight line from the noise source (in this case represented at the noise centroid as a point source) to the top fo the barrier. The diffraction angle is defined by the top of the shadow zone and the line from the top of the barrier to the receiver. Thus, the position of the source relative to the top of the barrier determines the extent of the shadow zone and the diffraction angle to the receiver. Similarly, the receiver location relative to the top of the barrier is also important in determinig the diffraction angle.

From the previous discussion, three conclusions are clear. First, the diffraction phenomenon depends on three critical locations, that of the source, the top of barrier, and the reciver. Second, for a given source, top of barrier and receiver configuration, a barrier is more effective in attenuating higher frequencies than lower frequencies (see Figure N-2144.2). Third, the greater the angle of diffraction, the greater the noise attenuation is.

Figure N-2144.2 - Diffraction of Sound Waves



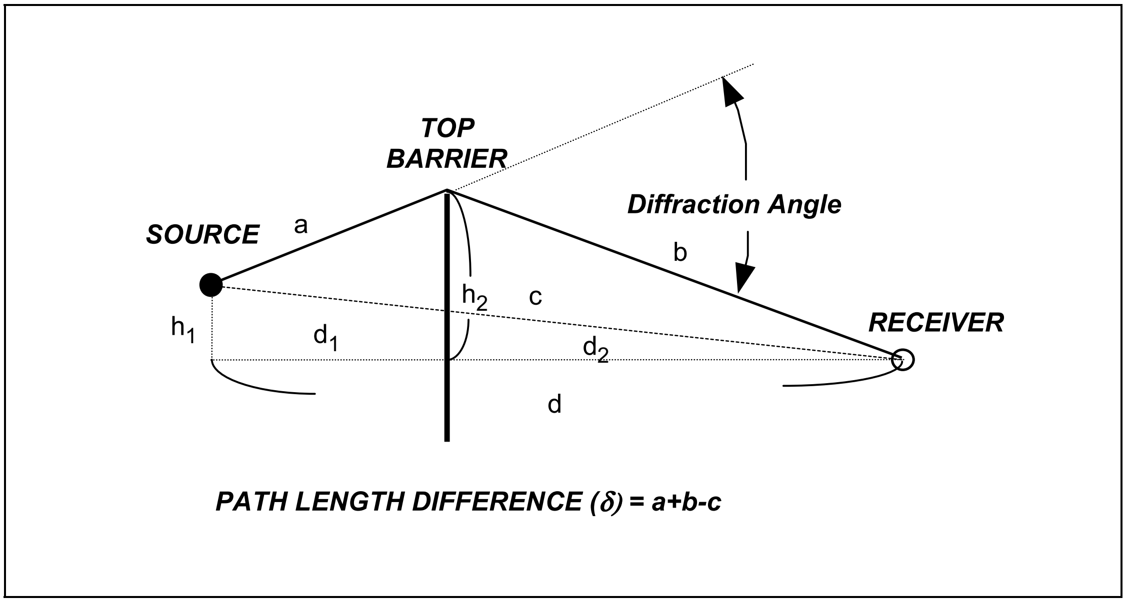
The angle of diffraction is also related to the path length difference (δ) between the direct noise and the diffracted noise. Figure N-2144.3 illustrates the concept of path length difference. A closer examination of this illustration reveals that as the diffraction angle becomes greater, so does δ. The path length difference is defined as δ = a+b-c. If the horizontal distances from source to receiver and source to barrier, and also the differences in elevation between source, top barrier and receiver are known, a,b, and c can readily be calculated. Assuming that the source in Figure N-2144.3 is a point source, a, b, and c are calculated as follows:

$$a = \sqrt{[d_1^2 + (h_2 - h_1)^2]}$$

$$b = \sqrt{(d_2^2 + h_2^2)}$$

$$c = \sqrt{(d^2 + h_1^2)}$$

Figure N-2144.3 - Path Length Difference Between Direct and Diffracted Noise Paths.



Highway noise prediction models use δ in the barrier attenuation calculations. Section N-5500 covers the subject in greater detail. However, it is appropriate to include the most basic relationship between δ and barrier attenuation by way of the so-called <u>*Fresnel Number*</u> (N_0). If the source is a line source (such as highway traffic) and the barrier is infinitely long, there are an infinite amount of path length differences. The path length difference (δ_0)at the perpendicular line to the barrier is then of interest.

Mathematically, N_0 is defined as:

$$\mathbf{N_0 = 2(\delta_0/\lambda)} \qquad \textbf{(eq. N-2144.2)}$$

where: N_0 = Fresnel Number determined along the perpendicular line between source and receiver (i.e. barrier must be perpendicular to the direct noise path)

δ_0 = δ measured along the perpendicular line to the barrier

λ = wavelength of the sound radiated by the source.

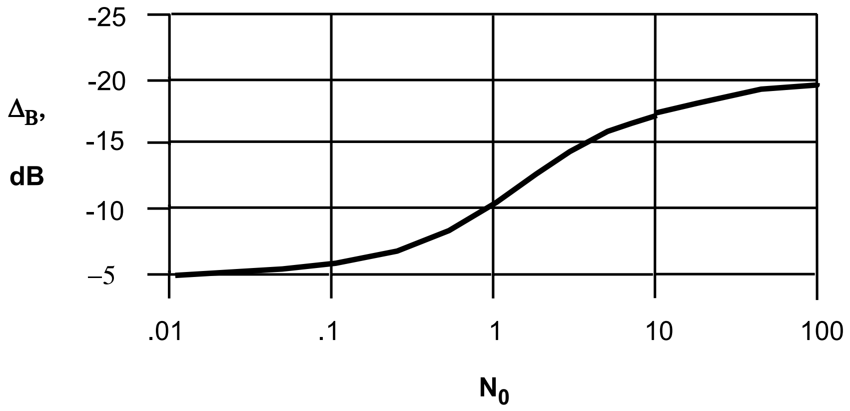
According to eq. N-2131.1, $\lambda = c/f$, and we may rewrite eq. N-2144.2:

$$\mathbf{N_0 = 2(f\delta_0/c)} \qquad \textbf{(eq. N-2144.3)}$$

where: f = the frequency of the sound radiated by the source
c = the speed of sound

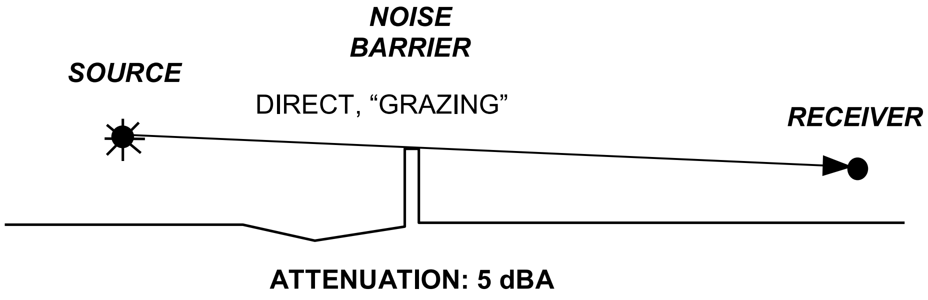
Note that the above equations relate δ_0 to N_0. If one increases, so does the other, and barrier attenuation increases as well. Similarly, if the frequency increases, so will N_0, and barrier attenuation. Figure N-2144.4 shows the barrier attenuation Δ_B for an infinitely long barrier, as a function of 550 Hz (typical "average" for traffic).

Figure N-2144.4 - Barrier Attenuation (Δ_B) vs Fresnel Number (N_0), for Infinitely Long Barriers



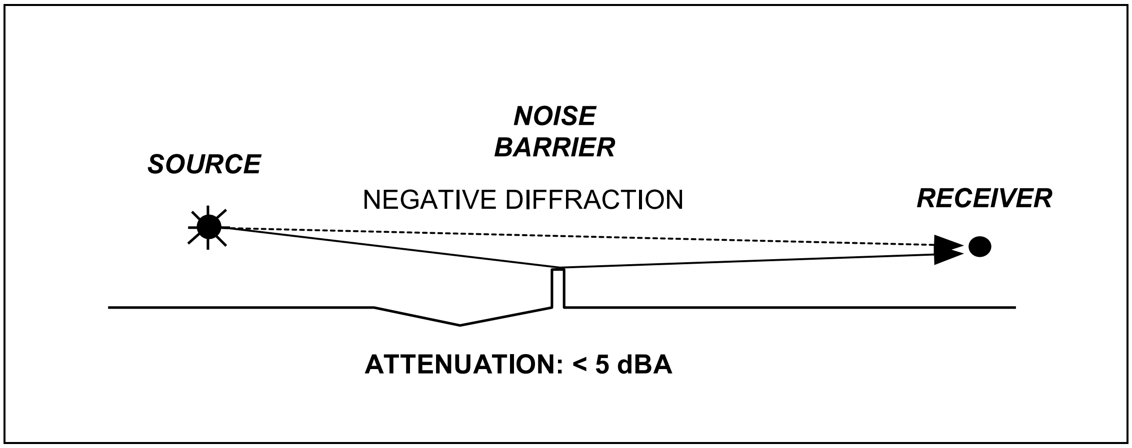
There are several "rules of thumb" for noise barriers and their capability of attenuating traffic noise. Figure N-2144.5 illustrates a special case where the top of the barrier is just high enough to "graze" the direct noise path, or line of sight between source and receiver. In such an instance the noise barrier provides 5 dBA attenuation.

Figure N-2144.5 - Direct Noise Path "Grazing" Top Barrier Results in 5 dBA Attenuation



Another situation, where the direct noise path is not interrupted but still close to the barrier, will provide some noise attenuation. Such "negative diffraction" (with an associated "negative path length difference and "negative Fresnel Number") generally occurs when the direct noise path is within 1.5 m (5 ft) above the top of barrier for the average traffic source and receiver distances encountered in near highway noise environments. The noise attenuation provided by this situation is between 0 - 5 dBA: 5 dBA when the noise path approaches the grazing point and near 0 dBA when it clears the top of barrier by approximately 1.5 m (5 ft) or more.

Figure N-2144.6 - "Negative Diffraction" Provides Some Noise Attenuation



The aforementioned principles of barriers loosely apply to terrain features (such as berms, low ridges, as well as other significant manmade features). The principles will be discussed in greater detail in sections N-5500 and N-6000.

N-2200 EFFECTS OF NOISE; NOISE DESCRIPTORS

N-2210 Human Reaction to Sound

People react to sound in a variety of ways. For example, rock music may be pleasant to some people while for others it may be annoying, constitute a health hazard and/or disrupt activities. Human tolerance to noise depends on a variety of acoustical characteristics of the source, as well as environmental characteristcs. These factors are briefly discussed below:

1. *Level, variability in level (dynamic range), duration, frequency spectrums and time patterns of noise*. Exposures to very high noise levels can damage hearing. A high level is more objectionable than a low level noise, and intermittent truck peak noise levels are more objectionable than the continuous level of fan noise. Humans have better hearing sensitivities in the high frequency region than in the low. This is reflected in the A-scale (section N-2136) which de-emphasizes the low frequency