ICSV13 - Vienna
The Thirteenth International Congress on Sound and Vibration
Vienna, Austria, July 2-6, 2006

# SOUND BARRIERS AND ENVIRONMENTAL IMPACT STUDIES

Jorge P. Arenas[1]

[1]Institute of Acoustics, Universidad Austral de Chile,
PO Box 567, Valdivia, Chile
jparenas@uach.cl

## Abstract

In particular, noise barriers are a commonly used measure to reduce the high levels of environmental noise produced by the traffic on highways. When developing environmental impact studies for highways, it appears that construction of barriers is the main alternative used for the reduction of noise, although quiet road surfaces, insulation of properties or use of tunnels have also been used for this purpose. In the design of a barrier all of the relevant environmental, engineering and safety requirements have to be considered. However, in addition to mitigate the impact of a highway, a barrier will become part of the landscape and neighbourhoods. Therefore, particular consideration has to be taken to assure a positive public reaction from both residents adjacent to barriers and drivers. In this paper a review of some fundamentals of environmental impact studies will first be considered. Then, the use of environmental barriers as mitigation measures will be presented. Finally, some concepts for the design, economics, materials, construction details, aesthetic, and durability will be discussed.

## INTRODUCTION

The public, increasingly well-informed about the problem of excessive noise, is taking actions on the development of new transport infrastructure projects and improvement to existing infrastructure. Many countries have implemented environmental impact assessment procedures. As a result, the construction of a sound barrier is a common measure which an agency will take to mitigate potentially significant noise impacts. A sound barrier, equally, will become part of the surrounding landscape and the barrier itself could be a cause of impact for both the road user and those who live alongside the road. Then, the design of a sound barrier involves achieving a balance between meeting the needs of noise reduction and minimizing its intrusion on the local environment.

Basically, this paper discusses the details involved when using sound barriers in environmental impact studies.

Eds.: J. Eberhardsteiner, H.A. Mang, H. Waubke

## ENVIRONMENTAL IMPACT STUDIES

Evidently, due to the increasing of both automotive park and trade, the construction of highways has been widely expanded during the last decades all over the world. The construction of a highway, however, is a complex process, often disruptive and environmentally controversial, which produces noise impact on the natural and social environment.

It is well known that, in some cases, litigation arises from environmental groups who want to block a project or from parties who feel that the assessment overstates the risks to the environment to the detriment of economic interests. This can be explained because transportation systems are always of immense significance to the shape, form, and liveability of communities. Therefore, a challenge for transportation practitioners will be to recognize that the collaborative planning process with the community does not have to begin only after allegations, conflict, posturing, and brinkmanship occur. Similarly, initiating a collaborative planning process does not require extraordinary resources or leadership at the very highest levels of government.

In general, there is typically a three to five-year decision-making process required before any major transportation project can be built. It ensures that issues affecting the community and the environment are identified and considered before making a final decision. Because of the complexity of the environment and the many ways any one project might impinge upon it, the authors of an environmental impact study usually represent many areas of expertise and may include biologists, sociologists, economists, and engineers.

In the thirty years since its inception, Environmental Impact Assessment (EIA), a procedure for appraising the environmental implications of a decision to enact legislation, to implement policies and plans, or to initiate development projects, has become a widely accepted tool in environmental management. Formally, environmental impact assessment (EIA) is a policy and management tool for both planning and decision-making. EIA has been adopted in many countries with different degrees of enthusiasm, where it has evolved to varying levels of sophistication[1].

EIA assists to identify, predict, and evaluate the foreseeable environmental consequences of proposed development projects, plans, and policies. The outcome of an EIA study assists the decision maker and the general public to determine whether a project should be implemented and in what form. EIA does not make decisions, but it is essential for those who do.

Environmental assessment (EA) refers to an understanding of the present status of environmental impacts and a study of how to manage them. An Environmental Impact Statement (EIS) is the final step of an EIA/EA exercise where the conclusions of the assessment are put out in a communicable form to the concerned developer or authority. There is thus a distinction between the terms EIA, EA, and EIS.

An EIS reports the analysis of the impact that a proposed development, for example the construction of a highway, will have on the natural and social environment. It includes assessment of long- and short-term effects on the physical environment, such as air, water, and noise pollution, as well as effects on employment, living standards, local services, and aesthetics[1].

The EIS process is conducted by local and government agencies. In the US, the National Environmental Policy Act (NEPA) of 1969[1], as well as many state and local laws enacted during the late 1960s and early 1970s mandate that these EIS be completed before major development projects can begin. NEPA has given a federal dimension to land-use planning which existed in only rudimentary form prior to 1970 and has created a situation where decisions on major federal activities can only be taken with foreknowledge of their likely environmental consequences. The influence of these federal measures can be gauged from the rapidity with which they have been echoed in state and local statutes. Other industrialized countries have since implemented EIA procedures. Canada, Australia, the Netherlands and Japan, for example, adopted legislation in 1973, 1974, 1981 and 1984, respectively. In July 1985 the European Community (EC) adopted a directive making EAs mandatory for certain categories of projects after nearly a decade of deliberation[1].

In the US, NEPA requires that an EIS include: 1) A community involvement process, 2) A clear statement of the transportation needs within the corridor, 3) An analysis of all reasonable transportation alternatives that address these needs, and 4) Study and full disclosure of impacts on communities and environmental resources. Then, an EIS follows a process outlined by NEPA. It is designed to ensure that reasonable transportation alternatives are considered, that community input plays a key role, and that the environmental and community impacts are fully disclosed. The complete process usually includes nine stages:

a) *Community involvement*: A community involvement process warrants that residents, businesses, and others have an opportunity to participate.

b) *Scoping*: The team solicits issues and concerns from various agencies, the community, and others.

c) *Purpose and Need*: Using the input from scoping and data gathering, a purpose and need statement is developed. It serves as the basis for the alternative development, screening and environmental evaluation.

d) *Criteria*: Working with the community, agencies, and other stakeholders, criteria are developed to determine how the transportation alternatives are evaluated.

e) *Alternative development*: Various sources will be used to develop a full range of alternatives, including previous and current proposals, as well as new ideas from the community and stakeholders.

f) *Screening*: A three-step screening process will evaluate the full range of packages that are reasonable and meet the purpose and need.

g) *Draft EIS* (DEIS) evaluation: The first official document issued during the process, the DEIS includes a detailed analysis of the social, environmental, and economic impacts of the alternatives. Comments will be received after it is issued.

h) *Final EIS* (FEIS): After incorporating and addressing public and agency comment, additional analysis is conducted and preferred alternatives are considered.

i) *Record of Decision* (ROD): After receiving public and agency comment and

[1] The National Environmental Policy Act (NEPA) was signed into law on January 1, 1970, although formally implemented in 1978 by the Council on Environmental Quality (CEQ). To date, the only change in the NEPA regulations occurred on May 27, 1986, when CEQ amended Section 1502.22 of its regulations.

providing responses, a document formalizing the official decision on the preferred alternative is issued.

From an environmentalist point of view, an EA should follow the steps described and summarized in Table 1.

*Table 1: Steps of an environmental impact assessment (EIA)*

| Step | Include |
|---|---|
| Describe the proposed subject as well as the options | • description of the entire project<br>• such things as parking, drainage, sound barriers, etc.<br>• options proposed. |
| Describe the existing environment | • detailed description of the current condition of the area on which the proposed project will occur<br>• baseline measurements<br>• what kind of vegetation and wild life inhabit the area. |
| Select the impact indicators to be used (depends on the subject: noise pollution, air pollution, water pollution, etc.) | • definition of dangerous conditions for humans and/or wildlife<br>• damage to existing structures due to noise, vibrations, etc. |
| Predict the nature and the extent of the environmental effects | • definition of cause of the possible environmental problems<br>• description if the impact only affect the land and/or a small group of animals and plants or if the project will impact a large population of plants and animals. |
| Identify the relevant human concerns | • financial impact on the community<br>• health risks involved<br>• damage to personal property, etc. |
| Assess the significance of the impacts | • who and what will be affected by the construction. |
| Incorporate appropriate mitigating and abatement measures into the project plan | • how can the project be altered or reduced so as to have a less severe impact on the environment<br>• recommendations and possible alternative options. |
| Identify the environmental costs and benefits of the project to the community | • all the possible positive issues of project<br>• comparison of economic benefits of the project to overall impact. |
| Report on the assessment | • Environmental Statement.<br>• the final recommendation: go with the original plan or it follows an alternate plan (based on the comparison of community financial gain and impact on environment). |

## Scoping and baseline studies

Scoping and baseline studies are activities that are undertaken at early stages in an environmental impact assessment (EIA) and the success of an EIA will depend largely upon how well they are conducted. Scoping refers to the process of identifying a number of priority issues to be addressed by an EIA. Baseline studies are designed to provide information on the issues and questions raised during the scoping exercise. This stage of EIA requires an initial assessment of the risk to sensitive receptors and, if shown to be necessary by the level of risk, a more detailed assessment of the impact should be undertaken.

Table 2 outlines potential reasons for undertaking assessment work, although there can obviously be a degree of overlap and ultimately there will be a large element of site–specificity in whatever action is taken.

*Table 2: Potential reasons for undertaking assessment work in EIA.*

| Potential reason | Assessment work |
|---|---|
| Related to the effect on sensitive receivers | • assessment of harm potential (possibly as part of a complaint investigation), estimating the likelihood of complaints arising or grounds for reasonable cause for annoyance<br>• assessment of absolute noise levels<br>• investigation of the nature and degree of tonal, impulsive or other features of the noise emitted from a source |
| Predictive | • assessing the impact of a new activity or changes to an activity or the addition of abatement equipment |
| Determining trends | • regular long-term monitoring strategy to look at trends, or short samples over a long period, i.e. increase or decrease with time (unlikely to be continuous monitoring, but more likely to be sample or check monitoring at a specific number of times or days a year). |
| Determination of compliance with permit conditions | • extent and frequency of any alleged or actual breaches and the circumstances relating to those breaches. |
| Risk assessment/environmental impact assessment: | • to support a permit application a statement of the noise impact of a site and associated history will be required. Additionally, the application will have to demonstrate that best available technique has been achieved, or how it is to be achieved<br>• to provide background information for setting appropriate conditions<br>• to respond to a permit condition requiring additional information<br>• to ascertain the level of control required or achieved, as a result of actions taken. |

During scoping the public has an important role in providing input on what issues should be addressed in an EIS. The public can participate in the process by attending hearings or public meetings and by submitting comments directly to the lead agency.

An important part of the EIA relies in the determination of the current conditions, i.e. the background noise. The measurement and evaluation of noise is covered in a number of standards. These give guidance on a wide range of related topics including equipment types, calibration, measurement techniques and locations and also the interpretation of data. Wherever possible a recognized method should be followed as closely as possible[2].

## Detailed Mitigation and Enhancement Plans

If the EA determines that the environmental consequences of a proposed project may be significant, an EIS is prepared. An EIS is a more detailed evaluation of the proposed action and alternatives. Then, the EIS may address measures which an agency will take to reduce (mitigate) potentially significant impacts, such as the noise impact. It is important that key participants sign a carefully worded, detailed, and precise plan to mitigate community impacts, which defines commitments, roles, and responsibilities.

There have been experiences in the world that consider certain impacts of the highway construction and operation that are related to cultural heritage. This is the case of the Queensland Government in Australia[3], which has been very conscious of the significance of the land to the descendents of local indigenous people. This has resulted in the development of cultural heritage studies of the proposed routes in order to include this information in EISs. Other examples can be found in South and North America, where some aboriginal cultural heritage acts must be consulted when proposing a new project, which can result in special mitigation and enhancement measures to ensure respect, preservation and maintenance of aboriginal cultural heritage.

The occupier of a property may also claim monetary compensation for any loss in value of the property caused by the presence of the road (in UK this is ruled by the "Land Compensation Act"). In addition, properties affected by the new roads may in extreme cases be acquired at the discretion of the highway authority where mitigation cannot prevent living conditions becoming intolerable either during construction or after the road is opened[4].

Evidently, sound barriers are a widely used mitigation measure in an EIS when the construction of a highway is planned. The rest of this paper will focus on this particular mitigation measure.

## SOUND BARRIERS AS A MITIGATION MEASURE

As discussed previously, a new road can have a profound effect on the quality of life for residents in its vicinity. In addition to the noise, dust and fumes caused by traffic, the road may restrict access to local facilities and obstruct views of the surroundings. Then, the design of a new road involves achieving a balance between meeting the needs of traffic and minimizing its intrusion on the local environment. Routes which pass close to residential property need to be assessed for the effects of road traffic noise and visual intrusion. Table 3 presents several ways to control road traffic noise.

*Table 3: Measures to mitigate the impact of traffic noise.*

| Mitigation method | Limitation of method |
|---|---|
| Distancing the road so far away that the noise received it minimal | The alignment of the road is dictated by many factors which may make it impossible to achieve noise attenuation by distance alone |
| Placing the road in cutting | Engineering factors or vertical alignment may rule out cuttings in certain locations |
| Constructing a sound barrier (fence, wall or earth mound) which impedes the transmission of noise | Barriers can deprive occupants of views previously enjoyed |
| Containment at source (e.g. by constructing the road in a tunnel, or by using noise reducing road surfaces) | Tunnels are often too expensive to be a realistic option, and noise reducing road surfaces are at present relatively expansive to construct the maintain |
| Insulation at reception point (e.g. by provision of secondary glazing) | Insulation does not screen occupants from adverse visual affects or from noise when they are outside the house |

From Table 3, it is evident why sound barriers are widely used to mitigate the traffic noise and why they are usually termed environmental barriers. An environmental barrier is one that combines the function of a visual screen and a noise barrier to protect residential, recreational and other vulnerable areas alongside a road. Earth mounds, fences or walls are common ways to implement an environmental barrier.

### Human impact of barriers

Although barriers can mitigate the effects of traffic noise and visual intrusion in the immediate vicinity of a road, they themselves may have a significant visual impact. An environmental barrier will become part of the surrounding landscape and the barrier itself could be a cause of impact for both the road user and those who live alongside the road. Experience in several countries has indicated that residents living behind a high noise barrier quickly forget the former high noise levels, and instead become dissatisfied with the loss of view which was once enjoyed. Therefore, the need for barriers should be considered at the initial route planning stage, taking into account the effects on people living alongside the traffic corridor, incorporating solutions to mitigate adverse effects.

Most of the residents near a barrier seem to feel that highway noise barriers effectively reduce traffic noise and that the benefits of barriers far outweigh the disadvantages of barriers. Some studies have shown that public reaction to highway noise barriers appears to be positive[5,6]. However, specific reactions vary widely. Residents adjacent to barriers have reported that conversations in households are easier, sleeping conditions are better, the environment is more relaxing, windows are opened more often, and yards are used more in the summer. In addition, residents perceived indirect benefits, such as increased privacy, cleaner air, improved views, a sense of ruralness, and healthier lawns. Negative reactions from residents have included a restriction of view, a feeling of confinement, a loss of air circulation, a loss of sunlight and lighting, and poor maintenance of the barrier.

On the other hand, motorists have sometimes complained of a loss of view or scenic vistas and a feeling of being “walled in” when travelling adjacent to barriers. High barriers substantially conceal the view of existing landmarks from the road, but they also conceal visual clutter, which might otherwise distract the attention of drivers. It is recommended that the appearance of barriers should be designed to avoid monotony (the need to provide drivers with visual relief street furniture). Surveys of drivers in the Netherlands have indicated that a view which is unchanging for 30 seconds is monotonous[4]. This suggests that changes in design of barrier face every 800 meters are desirable for long barriers adjacent to a high-speed road. Varying the form and materials will add visual interest and avoid the monotony of a uniform barrier solution. From design point of view, the appearance of barriers has to be aimed in terms of aesthetic concepts, well know in architecture, such as proportion, order, rhythm, harmony, and contrast. In addition, a barrier which alludes to the locality hidden behind it will help motorists avoid boredom or disorientation.

On the other hand, barriers will in most cases be set back from the road edge by the need for verges, hard shoulders and other clearances; while this reduces their acoustic efficiency, it prevents them creating a visually oppressive “canyon” effect on either side of the road.

Sometimes, the use of transparent barriers is indicated as a measure to reduce visual impact. However, a low sun shining through transparent barriers can also distract motorists by causing a flickering light. In some countries, the long shadows created by barriers in winter may cause ice and snow to remain in patches, which will have implications for safety and maintenance costs[4].

Noise barriers should reflect the character of their surroundings or the local neighbourhood as much as possible to be acceptable to local residents. It is then always recommended to preserve aesthetic views and scenic vistas. The visual character of noise barriers in relationship to their environmental setting should be carefully considered. For example, a tall barrier near a one-story, single family, detached residential area can have a negative visual effect. Visual intrusion is an adverse effect which can properly be mitigated by the use of earth mounds and planting, in particular in rural areas. Here, an earth mound is an obvious solution to noise pollution because it can be made to fit in with the landscape more naturally than any vertical structure, especially as it can support planting which greatly improves its appearance in most rural contexts. In other words, the soft “natural” outline of an earth mound in conjunction with planting is likely to be more attractive both to local residents and to road users. In general, it is recommended to locate a noise barrier approximately four times its height from residences and to provide landscaping near the barrier to avoid visual dominance and reduce visual impact[6].

## DESIGN OF ENVIRONMENTAL BARRIERS

### Sound attenuation required

The mitigation measures required to reduce the impact of a planned highway are part of the outcomes of an EIS. Therefore, if environmental barriers are recommended, the first step in designing a sound barrier will be the calculation of its noise attenuation. This calculation is usually done by means of a model which can be either theoretical, empirical, or a combination of both.

As in the diffraction of light waves, when the sound reaches a listener by an indirect path over a barrier, there is a shadow zone and a bright zone. However, the diffracted wave coming from the top edge of the barrier affects a small transition region close to the shadow zone by interfering with the direct wave[7]. In 1957 Keller proposed the geometric theory of diffraction (GTD) for barriers, which has been employed in the formulation of many different physical problems[8]. This geometrical theory of diffraction leads to relatively simple formulas, which combine the practicability of Kirchhoff’s approximations with the greater accuracy of the Sommerfeld-type solutions and can be generalized to treat diffraction by three-dimensional objects of any smooth shape[9].

However, from a practical point of view, most of the applications of the physical and geometrical theory had been difficult to use due to the complexity of the analysis, which does not permit fast calculation for design purposes. Because of this, several algorithms, charts and plots have been developed from time to time, as the one proposed by Redfearn in 1940[10].

Maekawa[11] presented a chart based on the physical theory of diffraction and also numerous experimental results. His chart gave values of attenuation versus the dimensionless Fresnel number defined as $N = \pm 2d/l$, where $d$ is called the path length difference. The ± is used to indicate the corresponding zone, such that $N$ is positive in the shadow zone and negative in the bright zone.

The oldest theories were established for point or coherent line sources. However, the sound radiated from a highway is composed for several incoherent moving sources (vehicles of different types). It has been shown[7] that when a noise source approximates to an incoherent line source (stream of traffic) then the insertion loss is about 5 dB lower than the one calculated for a point source. From field results it has also been observed that earth berms (mounds of earth) produce about 3 dB more attenuation than walls of the same height. Then, predicted barrier attenuation values will always be approximations.

In 1971 Kurze and Anderson reported a seminal study that presented one algorithm widely used today[12]. This algorithm was obtained by comparing the experimental results of Rathe and Redfearn[13,14] and the geometric theory of diffraction. They modified the results of previous work and obtained an analytical-empirical equation known as the Kurze-Anderson algorithm given by

$$IL_{KA} = 5 + 20\log\frac{\sqrt{2pN}}{\tanh\sqrt{2pN}}\,. \tag{1}$$

where $IL_{KA}$ is the barrier insertion loss (the difference of the sound pressure levels at the receiving point with and without the screen present). Equation (1) gives good results in practice for $N > 0$ and it shows good agreement with the experimental results obtained by Maekawa, for values of attenuation up to 24 dB. Equation (1) has been the starting point to define most of the barrier design algorithms used today to mitigate the impact of noise from highways.

It is important to notice that all the theories of diffraction have been developed assuming that the transmission loss of the barrier material is sufficiently large that transmission through the barrier can be ignored. As a general rule, when the barrier surface density exceeds 20 kg/m$^2$, the transmitted sound through the barrier can be ignored and then the diffraction sets the limit on the noise reduction that may be achieved. Nevertheless, in some countries, the legislation requires a sample of barrier to be tested in accordance with the local standard for sound insulation of partitions in buildings.

Attenuation other than resulting from wave divergence is called excess attenuation. Noise reduction due to a barrier is considered as a reduction to be added to other reductions due to such effects as spherical spreading, attenuation by absorption in the air, wind and temperature gradients, presence of grass and trees, etc. Therefore, it is common to refer to the excess attenuation by a barrier instead of insertion loss of barriers.

If a barrier is finite in length (as the barriers used indoors) flanking (noise travelling around the ends of the barrier) will reduce the attenuation. In highway applications, it is recommended that the minimum angle of view that should be screened to avoid flanking is 160$^o$. This means that to effectively reduce the noise coming around its ends, a barrier should be at least eight times as long as the distance from the home or receiver to the barrier.

For a barrier finite in length, parallel to a highway and located between the highway and the observer, as shown in Fig. 1, the approximate A-weighted attenuation in dB is given by[15]

$$A = 10\log\left( \frac{1}{b_2 - b_1} \int_{b_1}^{b_2} 10^{A(b)/10}\, db \right), \tag{2}$$

where $b$ is the angular position of the source from a perpendicular drawn from the observer to the highway, and $A(b)$ is a function based on Eq. (1), that depends on different Fresnel numbers and corrections for earth berm. Expressions for $A(b)$ can be found in reference[16]. We notice that for an infinite barrier, $b_1 = -p/2$ and $b_2 = p/2$.

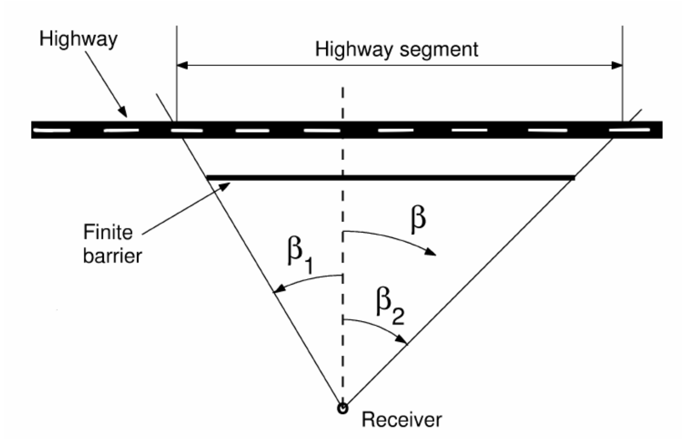


*Figure 1: Top view of the finite barrier parallel to a highway*

The noise attenuation of a finite barrier calculated by Eq. (2) includes just the segment of incoherent source line that the receiver cannot see. Then, the contribution to the total noise of the segments not covered by the barrier should be estimated accordingly[17].

It is possible to calculate Eq. (2) for each frequency band. However, to save time, an effective radiating frequency of 550 Hz is, in general, used as representative of a normalized A-weighted noise spectrum for traffic over 50 km/h[18,19]. Thus, the Fresnel number can be evaluated as $N = 3.21 \times d$. Under this assumption, the A-weighted barrier attenuation in dB for an infinite freestanding wall, as a function of $d$, is shown in Fig. 2[17]. Here we can observe that the maximum attenuation that can be afforded by a practical sound barrier is 20dB.

On the other hand, wind distorts the sound waves as they propagate so the performance of a sound barrier can be degraded. The action of wind on an environmental barrier depends on its exposure relative to the surrounding topography. The basic wind speed appropriate to the area varies with latitude and longitude, but is significantly modified by local features. In addition, weather conditions and the changes in interaction with the ground surface can increasingly negate the benefits of barriers at distances over 100 metres. Figure 3 shows that the insertion loss of a barrier can be reduced as much as 10 dB for certain frequencies, for wind velocity of 4 m/s.

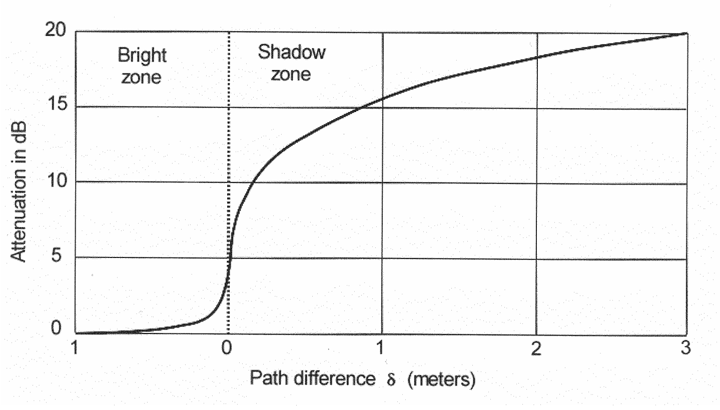


*Figure 2: A-weighted attenuation for traffic noise as a function of path difference*

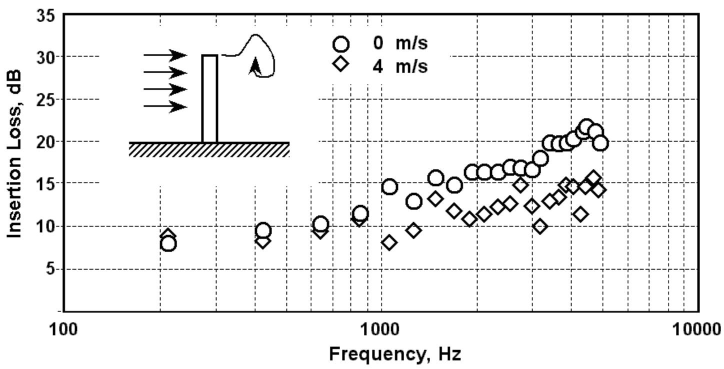


*Figure 3: Effect of wind on the performance of a sound barrier*

Of course, in calculating the attenuation of a barrier or a set of barriers, non-parallel effects, barrier thickness, ground reflections, and the presence of multiple barriers should be considered[16]. These details have been discussed in several references[17,20–25].

### *Computational aid*

There are a number of commercially available software programs to help in designing barriers. Most programs are designed to predict the noise levels produced by sources such as factories, industrial facilities, highways, railways, etc. Their use is widely accepted in EIS when the solution of problems of high geometrical complexity is required. The programs are, in general, able to compute the sound level contours, insertion loss contours, and level difference contours. Some of these programs implement governmental approved models to predict traffic noise as well as more specialized enhancements (for instance, ISO9613[26] is the basis for many computer-based modelling packages). However, it is important to make sure that the model on which the software is based is relevant to the specific case under investigation. Then, problems involving diffraction by building rows, trees zone, parallel-barrier degradation for barriers or retaining walls that flank a roadway are possible to solve.

Some of the programs can make work much easier in that they incorporate vehicle noise emission databases. In general, the results predicted by these programs agree quite well with experimental results when the models have been calibrated to field measurements. Thus, predictions calculated with a program that does not state which standard it is based on, or the margin of error, should always be treated with prudence[2].

## Improving the performance of barriers

In certain applications it may be necessary to enhance the attenuation provided by a single barrier without increasing its height. One example of this would be the need to increase a barrier's effectiveness without further reducing the view for residents living alongside a road that would be caused by use of a higher barrier. All the studies show that the use of some kind of element over the top of the barrier or the modification of its profile will change the original diffracted sound field[27]. In some cases this alternative can produce a significant improvement of the attenuation.

Theoretical and experimental studies on diffracting-edge modifications include T- and Y-shaped barriers[28–30], multiple-edge barriers[31], and tubular caps and interference devices placed on top of barriers[32–34]. Full-scale tests of the acoustic performance of new designs of traffic noise barriers have been reported by Watts et al[35]. Such modifications may increase the wind loading on the barrier slightly, but probably by less than would occur if the barrier was made taller to achieve the same acoustic benefit. The effect of a cap on wind loading is unknown and consideration of the effect of water and snow on the exposed surface would also need to be investigated. On the other hand, the use of resonators as a mean to absorb sound energy on the top of a barrier could be limited in practice due to the effect of wind.

Other options to improve the performance of a barrier are the use of modular forms of absorbing barriers[36], absorbent edges[37], and by developing random profiles of different heights and widths, depending on the acoustic wavelength that has to be taken into account[38].

However, these alternatives are still under research and, sometimes, it is difficult to compare the results between different studies since the barrier heights, source position, receiver position and ground conditions are all different.

## Materials and costs

A good design has to take into account that a barrier should require minimal maintenance other than cleaning or repair of damage for many years. A service life of 40 years is desirable, with no major maintenance required for 20 years. Therefore, attention should be paid to the selection of materials used in the construction of barriers, in particular for areas subject to extreme weather conditions. Noise barriers can be constructed from earth, concrete, masonry, wood, metal, plastic, and other materials or combination of materials[39]. A report showed that until 1998 most barriers built in the US have been made from concrete or masonry block, range from 3-5 meters in height, and slightly more than one percent have been constructed with absorptive materials[40]. Figure 12 presents a comparison of the types of material used to construct barriers in the US.

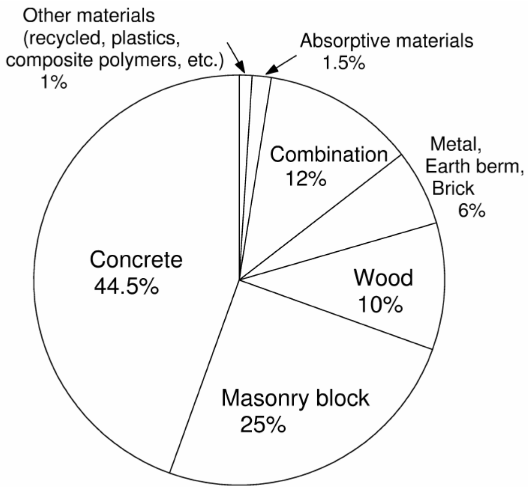


*Figure 4: Types of material used to construct barriers in the US (until 1998).*

Evidently, concrete or masonry walls require little or no maintenance during the service life, but transparent sections need frequent cleaning and might well need replacing after some time. Potential problems with birds flying into transparent barriers may be reduced by either using tinted material or by superimposing a pattern of thin opaque stripes. In some countries, transparent barriers should pass a test which limits the size and shape of fragments produced when a sample is shattered. Vandalism may also be a material factor. Laminated safety glass has the advantage that fly posters can be removed easily and that it also tends not to accumulate static electricity which would attract dirt. Polycarbonate may become opalescent over time as it can absorb water, especially at exposed edges. Some modern commercial barriers have special treatments that can repel graffiti.

The durability of sound absorbing materials for highway noise barriers has been discussed by some authors[41].

Often it is necessary to provide access from the protected side for maintenance purposes and for pedestrians or cyclists, which render a barrier vulnerable to vandalism. In addition, it may be advisable to avoid the use of flammable materials in some fire risk areas and, in general, it may be appropriate to install fire-breaks to limit the spread of fire[42]. When plants are selected for use in conjunction with a barrier they should generally be of hardy species (native plantings are preferable) which require a low level of maintenance.

A designer should seek detailed information for a specific project in order to estimate the cost of barrier construction and maintenance. This is particularly important when cost effectiveness is a must for positive decision on the construction of a barrier, since in some countries governmental agencies and individual homeowners sometimes share the costs of noise barriers.

Although barriers up to 10 metres in height have been used in some countries, structural constraints normally limit the maximum height of simple fence type barriers to about 5 metres; the cost of higher structures escalates rapidly and alternative or supplementary methods of noise control should be considered.

A broad indication of the relative costs, for a selection of typical forms of construction at a standard height of 3 meters, is shown in Table 4.

*Table 4: Construction and maintenance cost of different barriers (adapted from* [4]).

| **Barrier Type** | **Assumed features of design** | **Factors of maintenance** | **Relative cost of construction** | **Relative cost of maintenance** |
|---|---|---|---|---|
| Earth Mound | - agricultural land price, landscape planting excluded<br>- local source of fill assumed | - grass cutting, planting maintenance | Very Low | Fairly Low |
| Timber Screen | - designed in accordance with current standards | - inspection/repair, periodic treatment | Low | Low |
| Concrete Screen | - precast pier, beams and panels | - inspection/repair, periodic cleaning | Fairly Low | Very Low |
| Brickwork/ Masonry Wall | - standard facing brick | - inspection/repair, periodic cleaning/repainting | Moderate | Very Low |
| Plastic/ planted system | - plastic building ‘blocks’ (planters) | - inspection/repair, periodic cleaning, planting maintenance, irrigation | Moderate | Moderate |
| Metal Panels | - plastic coated metal panels with steel supports | - inspection/repair, repainting/treatment<br>- tighten bolts, check earthling | Moderate | Fairly Low |
| Absorbent Panels | - perforated (absorbent) metal panels with rock wool infill | - inspection/repair, periodic cleaning | Moderate | Fairly Low |
| Transparent Panels | - steel piers, etched glass panels | - inspection/repair, regular cleaning/treatment | Fairly High | Fairly High |
| Crib Wall (concrete or timber) | - proprietary system or purpose designed<br>- high labour costs, agricultural land price | - inspection/repair | Very High | Low |

Some additional aspects of the design of a barrier that need to be considered are the force caused by wind, aerodynamic forces caused by passing vehicles, the possibility of impact by errant vehicles, earthquakes, noise leaking through any gaps between elements or at the supports, and the effect of snow being thrown against the face of the barrier by clearing equipment. The in-situ determination of the insertion loss of outdoor noise barriers is also described by an ISO standard[43].

## SUMMARY

The main objective of this paper was to stress that in the design of a barrier there is a large number of relevant environmental, engineering and safety requirements that have to be considered, when a sound barrier is included in an EIS. Once the assessment work is complete and mitigation measures have been put into place, such as the use of sound barriers, ongoing monitoring, maintenance and feedback arrangements are vital to sustained improvement. In this paper, although EIA and EIS were discussed mainly with respect to noise components, it should be noticed, however, that similar considerations relate equally to other environmental issues.

## REFERENCES

[1] P. Wathern, Environmental Impact Assessment: Theory and Practice, Routledge (1992).
[2] Environmental Agency, Horizontal Guidance for Noise: Part 2 - Noise Assessment and Control, Integrated Pollution Prevention and Control, Bristol (2002).
[3] Queensland Government, Department of Main Roads, Environmental Assessment of Tugun Bypass Project, Nerang Qld (2004).
[4] Highways Agency, Design guide for environmental barriers, Chapter 10, Section 5 in Design manual for roads and bridges, Part 1, HA65/94, London (1994).
[5] M.E. Nilsson and B. Berglund, Noise annoyance and activity disturbance before and after the erection of a roadside noise barrier, *J. Acoust. Soc. Am*. **119**, 2178-2188 (2006).
[6] US Department of Transportation, Keeping the noise down: Highway traffic noise barriers, Publication No FHWA-EP-01-004, Federal Highway Administration, Washington, DC (2001).
[7] U.J. Kurze and L.L. Beranek, Sound propagation outdoors, Chapter 7 in Noise and Vibration Control, edited by L.L. Beranek, McGraw-Hill, New York (1971).
[8] J.B. Keller, The geometrical theory of diffraction, *J. Opt. Soc. Am*. **52**, 116-130 (1962).
[9] U.J. Kurze, Noise reduction by barriers, *J. Acoust. Soc. Am*. **55**, 504-518 (1974).
[10] R.S. Redfearn, Some acoustical source-observer problems, *Phil. Mag. J. Sci*. **30**, 223-236 (1940).
[11] Z. Maekawa, Noise reduction by screens, *Applied Acoustics* **1**, 157-173 (1968).
[12] U.J. Kurze and G.S. Anderson, Sound attenuation by barriers, *Applied Acoustics* **4**, 35-53 (1971).
[13] E.J. Rathe, Note on two common problems of sound propagation, *J. Sound and Vib.* **10**, 472-479 (1969).
[14] R.S. Redfearn, Some acoustical source-observer problems, *Phil. Mag. J. Sci*. **30**, 223-236 (1940).
[15] T.M. Barry and J. Reagan, FHWA Highway traffic noise prediction model, Report No FHWA-RD-77-108, Washington, DC, Federal Highway Administration (1978).
[16] J.P. Arenas, Use of barriers, Chapter 54 in Handbook of Noise and Vibration Control (Ed. M.J. Crocker), John Wiley and Sons, New York (2006).
[17] C.W. Menge, C.F. Rossano, G.S. Anderson and C.J. Bajdek, FHWA Traffic noise model–Technical Manual, Report No FHWA-PD-96-010, Washington, DC, Federal Highway Administration (1998).
[18] J. Pfretzschner, F. Simon, C. de la Colina and A. Moreno, A rating index for estimating insertion loss of noise barriers under traffic noise conditions, *Acustica* **82**, 504-508 (1996).
[19] F. Simon, J. Pfretzschner, C. de la Colina and A. Moreno, Ground influence on the definition of single rating index for noise barrier protection, *J. Acoust. Soc. Am*. **104**, 232-236 (1998).

[20] Department of Transport and Welsh Office, Calculation of road traffic noise, HMSO, London (1988).
[21] T.F.W. Embleton, J.E. Piercy and G.A. Daigle, Effective flow resistivity of ground surfaces determined by acoustical measurements, *J. Acoust. Soc. Am*. **74**, 1239-1244 (1983).
[22] C.I. Chessell, Propagation of noise along a finite impedance boundary, *J. Acoust. Soc. Am*. **62**, 825-834 (1977).
[23] B.A. DeJong, A. Moerkerken and J.D. van der Toorn, Propagation of sound over grassland and over an earth barrier, *J. Sound and Vib*. **86**, 23-46 (1983).
[24] K. Fujiwara, Y. Ando and Z. Maekawa, Noise control by barriers–Part 1: noise reduction by a thick barrier, *Applied Acoustics* **10**, 147-159 (1977).
[25] R.N. Foss, Noise barrier screen measurements: Double-barriers, Research Program Report 24.3, Olympia, WA, Washington State Highway Commission (1976).
[26] ISO 9613-2, Acoustics – Attenuation of sound during propagation outdoors, Part 2: General method of calculation (1996).
[27] J.P. Arenas and A.M. Monsalve, Modification of the diffracted sound field by some noise barrier edge design, *Int. Journal of Acoustics and Vibration* **6**, 76-82 (2001).
[28] D.C. Hothersall, D.H. Crombie and S.N. Chandler-Wilde, The performance of T-Profile and associated noise barriers, *Applied Acoustics* **32**, 269-287 (1991).
[29] D.N. May and M.M. Osman, The performance of sound absorptive, reflective and T-profile noise barriers in Toronto, *J. Sound and Vib*. **71**, 67-71 (1980).
[30] R.J. Alfredson and X. Du, Special shapes and treatment for noise barriers, Proceedings of Internoise 95, Newport Beach, CA, 381-384 (1995).
[31] D.H. Crombie, D.C. Hothersall and S.N. Chandler-Wilde, Multiple-edge noise barriers, *Applied Acoustics* **44**, 353-367 (1995).
[32] K. Fujiwara and N. Furuta, Sound shielding efficiency of a barrier with a cylinder at the edge, *Noise Control Engineering J*. **37**, 5-11 (1991).
[33] K. Iida, Y. Kondoh and Y. Okado, Research on a device for reducing noise, in Transport Research Record 983, National Research Council, Washington, DC, 51-54 (1984).
[34] M. Möser and R. Volz, Improvement of sound barriers using headpieces with finite acoustic impedance, *J. Acoust. Soc. Am*. **106**, 3049-3060 (1999).
[35] G.R. Watts, D.H. Crombie and D.C. Hothersall, Acoustic performance of new designs of traffic noise barriers: full scale tests, *J. Sound and Vib*. **177**, 289-305 (1994).
[36] F.J. Fahy, D.G. Ramble, J.G. Walker and M. Sigiura, Development of a novel modular form of sound absorbent facing for traffic noise barriers, *Applied Acoustics* **44**, 39-51 (1995).
[37] A.D. Rawlins, Diffraction of sound by a rigid screen with a soft or perfectly absorbing edge, *J. Sound and Vib*. **45**, 53-67 (1976).
[38] S.S.T. Ho, I.J. Busch-Vishniac and D.T. Blackstock, Noise reduction by a barrier having a random edge profile, *J. Acoust. Soc. Am*. **101**, Pt.1, 2669-2676 (1997).
[39] B. Kotzen and C. English, Environmental noise barriers–A guide to their acoustic and visual design, E&FN Spon, London (1999).
[40] US Department of Transportation, Highway traffic noise barrier construction trends, Federal Highway Administration, Office of Natural Environment, Noise Team, Washington, DC (2000).
[41] A. Behar and D.N. May, Durability of sound absorbing materials for highway noise barriers, *J. Sound and Vib*. **71,** 33-54 (1980).
[42] Highways Agency, Environmental barriers: Technical requirements, Chapter 10, Section 5 in Design manual for roads and bridges, Part 2, HA66/95, London (1995).
[43] ISO 10847, Acoustics – In-situ determination of insertion loss of outdoor noise barriers of all types (1997).