



Guidelines on Design of Noise Barriers



Environmental Protection Department



Highways Department

Government of the Hong Kong SAR

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1. Introduction

This booklet provides guidelines in the detailed design of roadside noise barriers including vertical & crank-top barriers, semi-enclosures, full enclosures and deck over. These roadside noise barriers are in general termed as Direct Technical Remedies. Their locations, dimensions, types and shapes are normally determined and defined in statutory Environmental Impact Assessment (EIA) studies or other non-statutory Noise Impact Assessment (NIA) studies etc.

This booklet intends to cover various aspects at the detailed design stage including determination of acoustic properties of noise barriers like transmission loss, material selection, some important tips at design and construction stages. However, it is not the intention of this booklet to cover calculation methodologies as these would have been dealt with during EIA and NIA studies.

Design engineers are reminded that during detailed design stage, sufficient space should be allowed for the erection of noise barriers. Without sufficient space, design options for noise barrier will be limited. As laid down in the WBTC 19/98 and 19/98A, the noise barrier design proposal should be submitted to ACABAS for consideration of its aesthetic acceptability.

Also, the reader is advised to make reference to the relevant design manuals currently adopted such as “Structures Design Manual, Highways Department, Government of the HKSAR” and “Transport Planning and Design Manual, Transport Department, Government of the HKSAR”.

2. Design Considerations

The primary function of noise barriers is to shield receivers from excessive noise generated by road traffic. While the onus of mitigating road traffic noise lies with the road projects, noise barriers are considered the most reasonable noise mitigation measures available.

Many factors need to be considered in the detailed design of noise barriers. First of all, barriers must be acoustically adequate. They must reduce the noise as identified in the EIA and NIA studies. A proper design of noise barriers would need due considerations from both acoustic and non-acoustic aspects. Acoustical design considerations include barrier material, barrier locations, dimensions and shapes. However, they are not the only requirements leading to proper design of noise barriers.

A second set of design considerations, collectively labeled as non-acoustical design considerations, is equally important. As is often the case, the solution of one problem (in this case noise), may cause other problems such as unsafe conditions, visual blight, maintenance difficulties, lack of maintenance access due to improper barrier design and air pollution in the case of full enclosures or deck over. With proper attention to maintainability, structural integrity, safety, aesthetics, and other non-acoustical factors, these potential negative effects of noise barriers can be reduced, avoided, or even reversed.

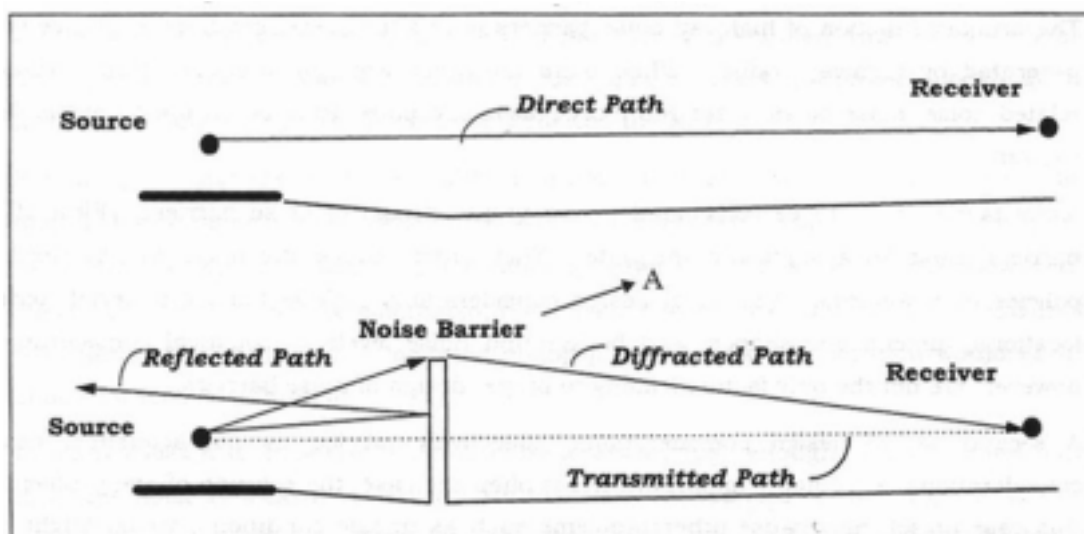
2.1 Acoustical Design Considerations

The material, location, dimensions, and shapes of noise barriers can affect the acoustical performance.

Figure 2.1.1 is a simplified sketch showing what happens to road traffic noise when a noise barrier is placed between the source (vehicle) and receiver. The original straight line path from the source to the receiver is now interrupted by the noise barrier. Depending on the noise barrier material and surface treatment, a portion of the original noise energy is reflected or scattered back towards the source. Other portions are absorbed by the material of the noise barrier, transmitted through the noise barrier, or diffracted at the top edge of the noise barrier.

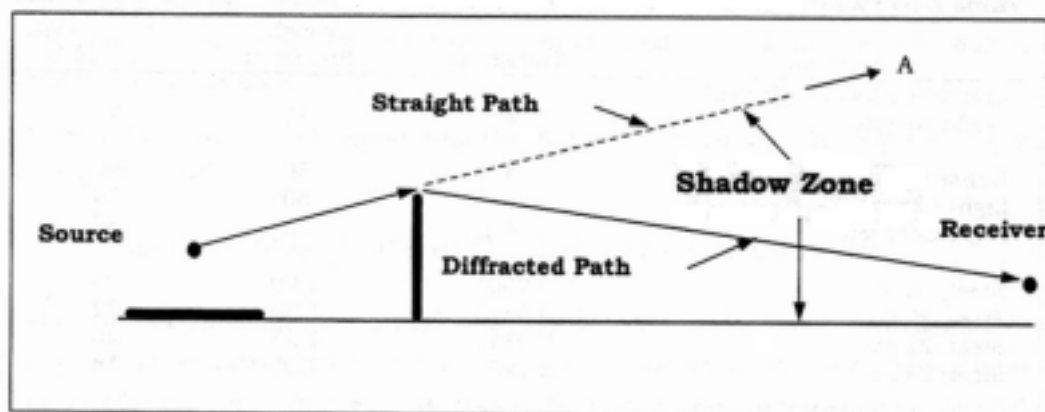
The transmitted noise, however, continues on to the receiver with a “loss” of acoustical energy (acoustical energy redirected and some converted into heat). The common logarithm of energy ratios of the noise in front of the barrier and behind the barrier, expressed in decibels (dB), is called the Transmission Loss (TL). The TL of a barrier depends on the barrier material (mainly its weight), and the frequency spectrum of the noise source.

Figure 2.1.1 Alteration of Noise Paths by a Noise Barrier



The transmitted noise is not the only noise from the source reaching the receiver. The straight line noise path from the source to the top of the barrier, originally destined in the direction of A without the barrier, now is diffracted downward towards the receiver (Figure 2.1.2). This process also results in a “loss” of acoustical energy.

Figure 2.1.2 Barrier Diffraction



The receiver is thus exposed to the transmitted and diffracted noise. Whereas the transmitted noise only depends on barrier material properties, the diffracted noise depends on the location, shape, and dimensions of the barriers.

Where there are noise sensitive receivers on the opposite side of the road, absorptive type noise barriers, either alone or in combination with reflective type, could be used to avoid causing reflection of noise to these receivers. The same may also be required for barriers along the medium barrier in the case of a dual carriageway. In case where this is required, the lower portion of at least 2 to 3 meters should be of absorptive materials.

Sometimes enclosures may be required. If the enclosure is extended to cover the footway(s) as well, attention should be paid to the reverberation noise inside the enclosure. To reduce

the noise disturbance on the pedestrians, it is recommended to limit the reverberation time inside the enclosure. Though there is no specific noise level standard applicable here, the general guideline to address reverberation noise is to specify the reverberation time at 500 Hertz to no more than 2 seconds.

2.2 Transmission Loss of Various Barrier Materials

All materials permit sound energy to pass through, although in varying degrees depending on the material and the frequency of sound. The attenuation of sound passing through a material is referred to as Transmission Loss (TL).

For a barrier to be fully effective the amount of sound energy passing through it must be significantly less than that passing over the top (or around the edge). When noise levels of two sources L_A and L_B are added, a difference between them larger than 10 dB adds less than 0.5 dB to the higher level.

For example: $L_A = 70$ dB $L_B = 60$ dB

$$\begin{aligned} L_{A+B} &= 10 \times \log_{10} [\log_{10}^{-1}(70/10) + \log_{10}^{-1}(60/10)] \\ &= 70.4 \text{ dB} \end{aligned}$$

Thus, if the portion of sound transmitted through the barrier is 10 dB lower than that which goes over the barrier, the overall sound received is essentially determined by the energy travelling over the barrier.

For acoustical purposes, any material may be used for a barrier between a noise source and a noise receiver as long as it has a TL of at least 10 dB(A) greater than the desired noise reduction (i.e. Insertion Loss (IL) determined in the EIA or NIA studies). This ensures that the only noise path to be considered in the acoustical design of a noise barrier is the diffracted noise path, i.e. the path over (or around) the barrier.

For example, if a noise barrier is designed to reduce the noise level at a receiver by 8 dB(A), the TL of the barrier must be at least 18 dB(A). The transmitted noise may then be ignored, because the diffracted noise is at least 10 dB(A) greater and hence the noise propagation path must be over the barrier.

Table 2.2.1 gives approximate TL values for some common materials, tested for typical A-weighted traffic noise frequency spectra. They may be used as a rough guide in acoustical design of noise barriers. For accurate values, consult material test reports prepared by accredited laboratories.

Table 2.2.1

Material	Thickness mm	Surface Density kg/m ²	Transmission Loss* (TL) dB
Polycarbonate	8 – 12	10 – 14	30 – 33
Acrylic	15	18	32
[Poly-Methyl-Meta-Acrylate (PMMA)]			
Concrete Block 200x200x400 light weight	200	151	34
Dense concrete	100	244	40
Light concrete	150	244	39
Light concrete	100	161	36
Brick	150	288	40
Steel, 18 ga	1.27	9.8	25
Steel, 20 ga	0.95	7.3	22
Steel, 22 ga	0.79	6.1	20
Steel, 24 ga	0.64	4.9	18
Aluminium Sheet	1.59	4.4	23
Aluminium Sheet	3.18	8.8	25
Aluminium Sheet	6.35	17.1	27
Wood	25	18	21
Plywood	13	8.3	20
Plywood	25	16.1	23
Absorptive panels with polyester film backed by metal sheet	50 – 125	20 – 30	30 – 47

* Values assuming no openings or gaps in the barriers

In terms of noise reduction, the maximum value that can be achieved theoretically is 20 dB(A) for thin screens (walls) and 23 dB(A) for berms. A material that has a TL of 33 dB(A) or greater would therefore always be adequate for a noise barrier in any situation.

Small adjustments in surface density to reach a preferred material gauge or a preferred construction thickness do not greatly affect the TL.

Similar to the practice in other countries, a material surface density of 10 kg/m² is typically sufficient but this should be reviewed on a case-by-case basis to meet the requirements of the project.

2.3 Reduction in Noise Barrier Performance due to Holes, Slits or Gaps

Sound “leaks”, due to holes, slits, cracks or gaps through or beneath a noise barrier, can seriously reduce the barrier performance, and should be avoided. Any gaps represent segments of the barrier with zero Transmission Loss; that is, the gap can be considered to transmit 100% of the energy incident on it. Therefore, extra efforts should be spent at design and construction stages to avoid holes, slits or gaps, either with the adjoining panels, along the bottom edge or gaps for road traffic signs, lighting poles, fire hydrants, construction joints or expansion joints. See Figure 2.3.1 for examples.

While site specific situation warrants provision of gaps like necessary opening of maintenance doors in a very long barrier or provision of access into special areas, special attention should be paid to provide overlapping of barriers etc. (also see section 4.5). In such cases, the sound transmission loss of the barrier is reduced by the amounts shown in Table 2.3.1 for various percentages of the barrier area comprising leaks.

If the noise barrier TL were reduced by at most 3 dB, the overall barrier performance will be reduced by at most 1 dB(A). It may be seen from Table 2.3.1 that the percent area occupied by leaks ranges from at most 1.5% of the total area for situations where the minimum TL requirement is 10 dB, to nearly zero for situations where the required barrier TL exceeds 20 dB. Thus, the significance of leaks increases dramatically where a high amount of noise barrier attenuation is needed.

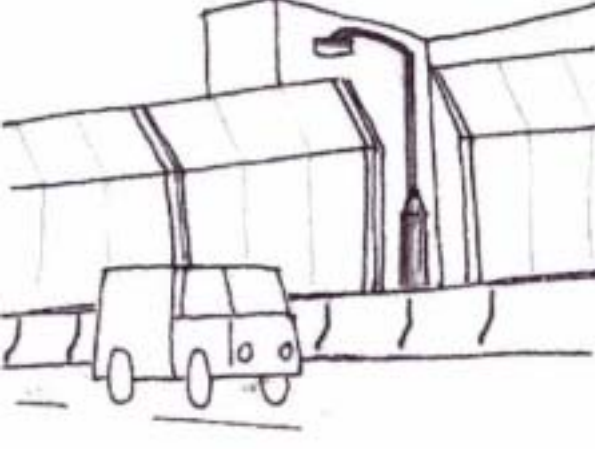
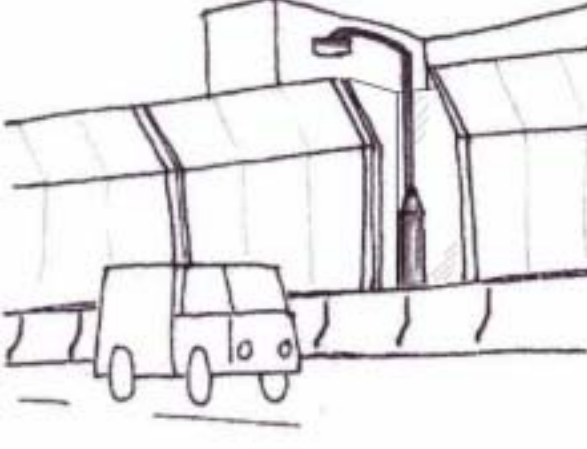

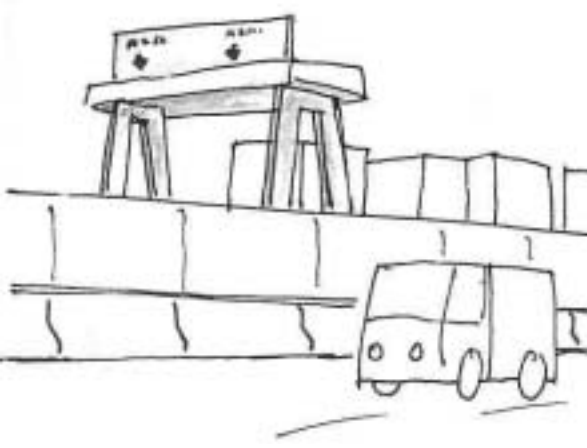
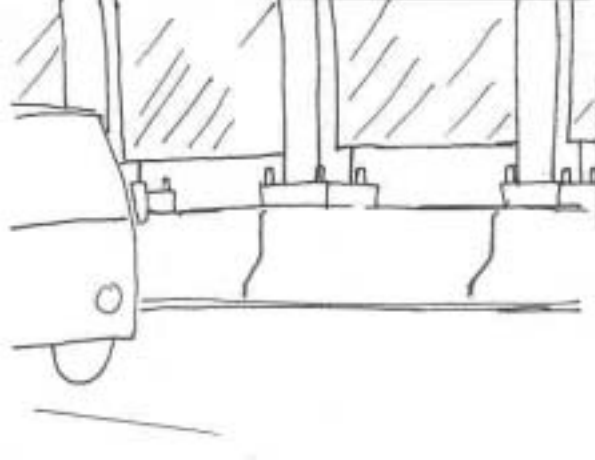
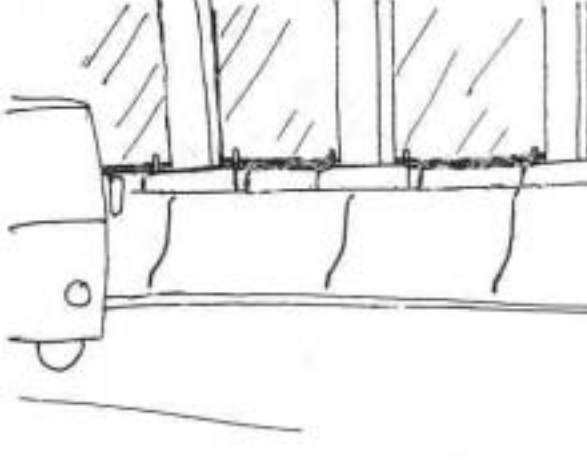
For noise barriers made of concrete, or other “planks”, the planks must be tongue-and-grooved, carefully lapped, or extremely well butted, to ensure a good air seal at joints. “Alternating boards”, planks mounted on alternate sides of horizontal supports, should not be used.

Table 2.3.1 Reduction in Transmission Loss due to Leaks

% area occupied by leaks	Transmission Loss without leaks at 500 Hz			
	10 dB*	15 dB*	20 dB*	25 dB*
	↓ reduction in transmission loss, dB ↓			
50	10+	15+	20+	25+
25	10	15	20	25
13	8	12	17	22
6	5	10	14	19
3	4	7	11	16
1.5	2	5	9	13
0.78	1	3	6	10
0.39	1	2	4	8
0.20	0	1	3	5
0.10	0	1	1	4
0.05	0	0	1	2

* Required transmission loss for the proposed barriers

Figure 2.3.1 Examples of Gaps

DON'T	DO
	
▲ Gap at lamp post	▲ Recess formed at lamp post
	
▲ Gap at gantry sign	▲ Barrier continues at gantry sign
	
▲ Gap at bottom edge	▲ Gap at bottom edge filled with concrete and sealant

Therefore, to avoid reduction in acoustic performance of noise barriers, recess should be formed along the barrier to accommodate the street furniture as far as possible. See Figure 2.3.2. However, if this is not possible for whatever reason, an integrated design of the noise barrier may be required to accommodate the street furniture. In case where space (headroom and side clearance) sight line and maintenance are permissible, traffic signs may be integrated with the noise barrier.

Figure 2.3.2 Recess for Emergency Telephone



2.4 Barrier Shapes

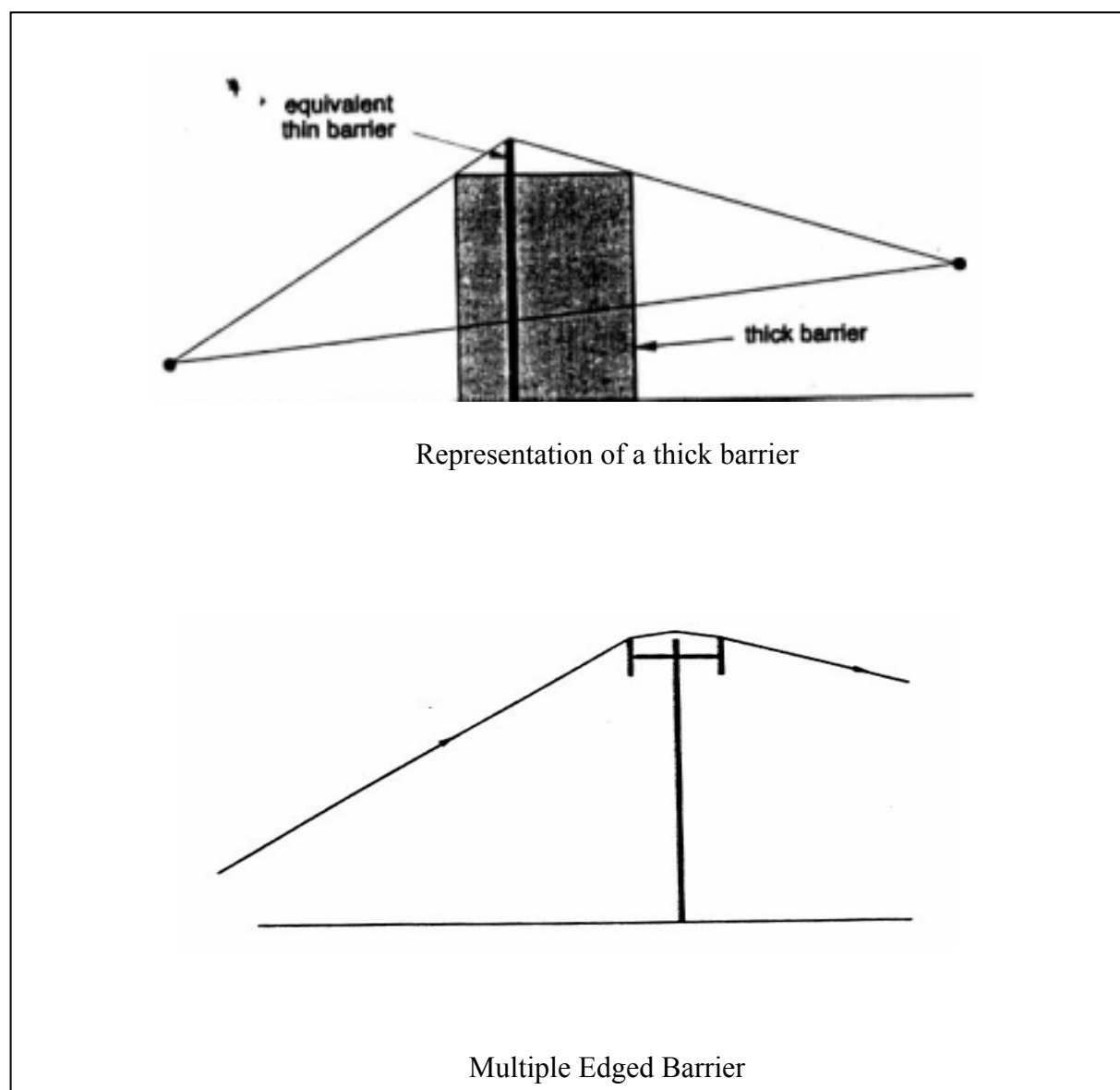
Calculation of Road Traffic Noise (CRTN), the methodology used in predicting road traffic noise in Hong Kong, assumes that a barrier has insignificant thickness, but diffraction over the top edge of a barrier is affected by its cross section. It may be appropriate to use an equivalent effective height for barriers which are very wide such as buildings. This can be estimated from the geometry as shown in Figure 2.4.1. Barriers with cross sections having corners and curved shapes are not as effective at reducing noise as those with sharp edges. Wedge shapes with internal angles greater than 90° and rounded shapes are least effective. It may therefore be advantageous to use an acoustic screen on the top of a mound, to increase its effectiveness.

The effectiveness of a thin barrier of given height may be increased by bringing the diffracting edge nearer to the source of noise - thus increasing the path difference. Where a tall barrier is placed near to the carriageway, tilting the upper section towards the source can provide

additional benefit. Increasing the number of diffracting edges can also improve attenuation considerably.

In most cases it will be relatively expensive to provide more than one barrier, however, by attaching short side panels to a barrier so that there are several edges at the same level may increase the number of diffracting edges (see Figure 2.4.1). Full scale trials with a triple edged barrier have shown benefits of as much as 3 dB(A) in certain circumstances. 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.

Figure 2.4.1 Thick Barrier and Multiple Edged Barrier



Barriers do not necessarily have to be of constant height - it may be cost effective to increase the height in the vicinity of isolated noise sensitive receivers and to reduce it between them. Some computer programs can optimise the profile of a barrier to screen such properties efficiently. Varying the height of the barrier may also help to alleviate the monotonous

appearance of long lengths of barrier and may lessen the visual impact of the barrier as well.

While the position (relative to the carriageway) and height of the barrier have been fixed in the EIA study, the outlook is still open to the designer to refine. It is very often that only limited space is allowed at planning stage for noise barrier erection which not only imposes restriction on the choice of noise barrier design but also makes it impossible to soften the structure with landscape planting. If necessary, the designer should explore the feasibility of increasing the space required for the erection of noise barrier.

2.5 Choice of Material

In general, roadside noise barriers could be divided into the following categories:-

- Reflective type – transparent and non-transparent
- Absorptive type – sound absorbent materials and possible finishes of absorptive panels
- Earth landscaped mound and retaining structures
- Mixed type – a combination of the above types

One of the key features in all structures is the material ultimately chosen. Despite the above categorization, the materials could largely be categorized as reflective and absorptive. The determination whether reflective or absorptive or the combination of both are already done in the EIA or NIA studies. In general the following could be used :

- Steel (painted, galvanized, stainless)
- Aluminium
- Polycarbonate or acrylic sheets
- Concrete, brick or glass fibre reinforced concrete (GRC)
- Proprietary-made acoustic panels
- Landscaped earth berm

An acoustic panel is typically made up of a perforated cover sheet enclosing noise absorptive material (mineral wool or fiberglass inside and wrapped up with polyester film). An absorptive GRC noise barrier relies on noise absorptive material inside the GRC surface grill for noise absorption.

Each of these materials will have its special advantages and disadvantages and it is dependent upon the nature and requirement of a specific project to determine the suitability. As a general rule, the following should be noted :

- Except for absorptive GRC composites, acoustic panels and earth berms, all other materials to various degree reflect sound (i.e. reflective) to premises on the opposite side of the receiver to be protected;
- Metallic and transparent material can produce “glare” effects at certain incident angles;
- The appropriate surface treatment of polycarbonate must be chosen to avoid weathering, ultra-violet attack and consequent loss of transparency; and

- Non-transparent materials such as steel, aluminium and concrete normally require greater efforts in surface treatment to soften the visual impact.

2.6 Barrier Materials

The following sections give a brief introduction to various materials that could be used for the construction of noise barriers. The design of and the materials used in noise barriers shall be selected to ensure that factors such as aging/corrosion resistance, stone impact resistance, colour resistance and fire resistance etc. can satisfy the requirements specified in noise barrier standard ZTV-Lsw 88.

2.6.1 Concrete

Concrete is used in various ways in the construction of noise barriers. Precast planks slotted into H shaped uprights provide a rapid means of construction and can be easily repaired. One form of proprietary concrete noise barrier is constructed from linked precast panels set at varying angles so as to obviate the need for separate post supports. Concrete noise barriers benefit from low-maintenance, but prefabricated noise barriers are relatively expensive. Special designed surface features can be beneficially employed to reflect sound at a desired angle, away from noise sensitive receivers. On a highway contract involving other concrete structures it may be economical to use in-situ concrete to construct noise barriers. Concrete noise barriers are usually sufficiently robust to withstand vehicle impact damage, but an untensioned corrugated beam barrier may be needed to prevent excessive damage to vehicles if the surface finish is heavily textured. Alternatively, concrete profile barriers could be used to form the lower portion of a noise barrier. For structural design of concrete profile barriers, please refer to Highways Department's Standard Drawings No. H2101A and H2102 to H2107.

2.6.2 Alternative Materials

A variety of materials can be used in barriers including glass, acrylic and other synthetic materials, hollow sheet metal box sections and porous concrete. Landscaped barrier systems, including living barriers of willow or similar woody plants may also be aesthetically attractive.

2.6.3 Metal

Metal noise barriers can be painted or coated in a wide range of colours. Steel is commonly used for supports. Sheet metal can be formed into lightweight hollow sections, which may contain fibreboard or mineral wool absorbent materials. A number of profiled barrier systems, comprising horizontal panels spanning between galvanized steel posts, are commercially available. The metal sheeting on one side may be perforated to allow noise to interact with absorbent material within, and the corrugated profile provides structural rigidity. Aluminium is often used in proprietary systems because of its high strength to weight ratio; large panels may be easily erected with fewer supports (up to 5-meter spans).

2.6.4 Transparent Materials

Transparent materials allow light to properties or areas which would otherwise be placed in the shadow of the barriers. At the top of a noise barrier, transparency (i.e. by using transparent panels) will reduce the visual impact of tall noise barriers and tinted material may enhance the appearance. “Windows” (i.e. incorporation of transparent panels at eye level of the noise barrier) may allow road users to orientate themselves by providing views of the surrounding area. But designers should be aware of the oblique and narrow angle of view from the driving position and of the obscuring effect of supporting structures. 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.

Transparent materials are noise reflecting and their use might therefore be restricted where reverberation would cause problems. Transparent panels may need to be protected from impact by errant vehicles. Consideration should also be given to the use of laminates, toughened glass, embedded mesh or other systems in order to control the spread of fragments in the event of damage.

Some transparent panels can become semi-opaque relatively quickly, either through superficial or material deterioration. It may be appropriate to make some allowance for this in specifying requirements. Grit can abrade surfaces - plastics are more vulnerable to this than glass. Maintenance requirements and expected life need to be considered when the use of transparent materials is proposed. There are products on the market that claim to be self-cleansing. The adoption of these materials should be considered to reduce the need of maintenance.

Vandalism may also be a material factor. Laminated safety glass has the advantage that 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.

2.6.5 Plastics

Apart from their use in transparent panels, plastics have also been used in absorbent panels and for supporting planted systems. Plastics may be coloured as required, but colour may bleach in strong sunlight. Susceptibility to bleaching can be tested in a weatherometer. Plastics are prone to damage from fire and vandalism and some, e.g. polyethylene, become brittle after prolonged exposure to sunlight.

2.6.6 Recycled Materials

An increasing number of products are available which claim to be “environmentally friendly” by incorporating various recycled materials in their manufacture. Examples are: recycled plastics in supporting structures, waste materials from industrial processes in absorbers, sections of old tyres as planters, domestic waste transformed into compost. There may be limitations in the suitability of recycled products. The use of mixed scrap and surplus may affect choice of colour; eliminating contamination and reprocessing reclaimed materials will add to costs. It is important to establish whether the recycled product is comparable with new material and to ensure it will not tend to degrade more quickly.

2.6.7 Sound Absorbent Materials

Tests in a reverberation chamber (BS 3638 or similar) will produce a frequency response curve. It is desirable for absorption coefficients to be better than 0.8 at frequencies which are significant in the traffic noise spectrum. In general, the peak traffic noise frequencies lie between 500 - 1500 Hz. In some cases, tests may indicate absorption coefficients larger than 1. Although theoretically impossible, this can occur with highly absorbent materials where the shape of the product differs markedly from the ideal of a flat sheet. Some products are strongly tuned to prevent reverberation of low frequencies (100 - 300Hz). These are unlikely to prove useful in connection with high speed roads, but may be appropriate in urban centres where heavy vehicles will be stationary at junctions and accelerating in low gear.

Acoustic requirements should be specified for the whole noise barrier structure (including panels and supporting structure) and allowance should be made for a proportion of reflective supporting elements. An overall performance rating may be quoted for products, obtained by combining sound absorption coefficients in a similar manner to that described above for insulation performance.

Sound absorbent material may be fixed to a backing structure such as a framework of timber or steel, or the surface of a solid wall. Sound absorbent panels are often based on noise absorbent products developed for use in industrial environments and may be available in a range of colours. The aesthetic aspects including shape, colour and surface texture should be considered.

The case for using absorbent barriers in specific situations must be argued on the basis of their cost effectiveness, but where a high quality finish is already required, the additional cost of similar absorbent panels may not be excessive. The geometry of sound reflections may also permit the use of the absorbent material to be limited to that part of the surface where it will be most effective. Materials placed close to the carriageway can quickly become dirty and clogged with pollutants.

2.7 Earth Berms and Retaining Structures

If a road construction contract would otherwise have surplus material, landscaped berms can be provided at negligible cost; at the same time the inevitable impact on the surrounding area of hauling the surplus material off site can be avoided. The design of berms should be compatible with the local landscape character and topography. The surplus material may only be suitable for gentle slopes and large quantities may be needed to achieve a significant amount of screening. Long roadside slopes are visually attractive but acoustically inefficient and increase landtake, which is always a constraint in Hong Kong. On the protected side, gentle slopes may serve other design objectives such as returning landscaped areas to agriculture.

Where insufficient land is available to construct earth berms high enough with natural slopes, geotextile reinforcement may be used to steepen slopes, but at the risk of being visually incompatible. Alternatively, retaining methods such as reinforced and anchored earth construction, gabions, concrete or timber cribs, and other proprietary support systems may be used to support the traffic face with advantage.

2.8 Non-acoustical Considerations

While standard guidelines on ventilation, lighting, visual impact and drainage requirement specifically for noise enclosure are not available, the designers are recommended to principally specify that agreements on requirements from Electrical & Mechanical Services Department, Lighting Division of Highways Department, Landscape Unit of Highways Department, Structures Division of Highways Department and Drainage Services Department should be sought.

Some other important issues including fire fighting and emergency access requirements for road users as well as nearby residents should have already been considered during EIA or NIA. Nevertheless, designers should not overlook these during detailed design stage.

2.8.1 Safety/Vehicle Impact

Whenever there is a likelihood of a noise barrier being struck by an errant vehicle, for example, when it is closer than 4.5 m from the carriageway, it should be protected from the impact of errant vehicles by a vehicle restraint system. Untensioned corrugated beam barrier or concrete profile barrier should be installed between it and the hard shoulder/kerb or carriageway on roads where speeds of 70 km/h or more are permitted.

The criteria for the provision of untensioned corrugated beam barrier and clearance required behind it for the various categories of untensioned corrugated beam barrier are given in the Highways Department Standard Drawings No. HH2128 and HH2129. The requirements for the horizontal clearance from a carriageway to an obstruction including any railing barrier are given in TPD Volume 2 Table 3.5.2.1 (copy attached at Annex A for reference).

Alternatively, where space is limited, say less than 1.5m, untensioned corrugated beam barrier or concrete profile barrier can be integrated with the noise barrier.

Where noise barriers are required to be installed on bridge structures, these should only be combined with a parapet if the assembly has been designed to accept the consequences of vehicle impact. Materials and finishes for attached noise barriers need to allow for the considerable distortions of metal parapets under impact. A freestanding noise barrier vulnerable to vehicular impact should be located behind vehicle parapet with adequate clearance for it to deflect upon impact.

The risk associated with noise barriers on flyovers falling onto vehicle/pedestrian paths upon impact by vehicles should also be considered in the design. Additional catching devices such as laminated panels or panels with embedded filaments or mesh should be provided as appropriate. Further requirements are set out in the “Particular Specification for Noise Barrier” published by Highways Department, February 2001.

2.8.2 Fire Resistance and Emergency Access

Noise barriers, particular transparent type, are subjected to fire hazards. In the case of noise barriers whose elements, whilst having the fire retardant properties as required, are nevertheless combustible, either the posts must be non-combustible and function as a fire barrier, or a length of at least 4 metre made of non-combustible elements shall be inserted in every 100 metres of noise barrier. Emergency access/exit points are also required for

roadside barriers and barriers erected along the central reserve to assist evacuation. Attention should be paid to the design of these doors so as to avoid sound leakage and these doors should be kept closed under normal circumstances. (Also see section 4.5.) Advice from relevant authority should be sought on the frequency of these emergency access/exit points. If necessary, a risk assessment should be conducted to evaluate the anticipated risk associated with the noise enclosure.

2.8.3 Lighting Considerations

Lighting inside noise enclosures should be uniform and should avoid glare and flicker effects whilst the switch-on time of artificial lighting during daytime should be minimized. The Lighting Division of the Highways Department, the “Final Report of the Noise Enclosure Lighting – Engineering Study” and/or the “Public Lighting Design Manual” should be consulted / referred to as appropriate for the design of lighting conditions inside noise enclosures.

2.8.4 Maintenance Considerations

Chapter 4 would give a full and detail account of maintenance considerations.

2.8.5 Installation

The contract drawings should show methods of fixing noise barriers to structures, which ensure that gaps below the bottom edge of the barrier are avoided.

The drawings should also show the position and height of the noise barrier and where applicable, the position of gates, also the fittings required and the proposals for treatment at gaps to maintain the acoustic attenuation. The length and position of noise barriers behind any gap should ensure that there is adequate deviation of the noise path from the carriageway to any sensitive receiver being protected by the noise barrier. It should be noted that additional width may be required on embankments to install panels behind the barrier line where gaps are required.

3. Aesthetical Aspect

According to the Environmental Impact Assessment Ordinance (EIAO), direct technical remedy should be given wherever practicable to remedy or compensate for adverse noise conditions brought about by a new road scheme. The form of direct technical remedy represents any form of direct screening, which includes e.g. earth mounding, barriers and enclosures, that can be incorporated into the road design.

This Guidelines intend to provide guidance on how the aesthetical impact brought by the roadside barriers could be minimised by the appropriate choice of the form and materials used.

3.1 Overview

There is no dispute that the roadside barriers erected would protect residents living next to roads from excessive traffic noise. However, the roadside barriers itself could also affect the aesthetical perception of both road users and residents. In a broad sense, a new road scheme changes the visual quality of the area through which it runs as perceived by the people who live and visit the area. This is partly due to presence of the road and its structures and mainly because the road is man-made, and its alignments, materials, signs, lighting and traffic can be out of character with the rest of the landscape. Thus the amount of visual intrusion of a road is dependent on the quality and type of landscape through which it runs.

The visual impact of roadside barriers on adjoining communities, as well as on the motorists is a major consideration in the design of roadside barriers. A tall roadside barrier placed close to the low rises could have severe visual effect as a tall barrier creates unwanted shadows and blocks panoramic views. On the motorist side of the barriers the emphasis should be on the overall form of the barrier, its colour and texture. Small details will not be noticed at normal highway speeds. However, the emphasis should be on avoiding a tunnel effect through various forms, and visual treatment. Landscaping can be used effectively to accomplish this. It is always the challenge to design an aesthetically pleasant roadside barrier that can protect residents in the vicinity.

3.2 Elements to be Considered

3.2.1 Architectural

The appearance of barriers would be governed by the choice of the “form”, which can be regarded as “the broadly perceived shape of an object”. In view of the linear nature of the noise barrier, simple plan vertical shape appears to be monotonous and creates a wall effect. The visual quality can be enriched through manipulation of the linear form, such as segmentation, curving and articulation of the surface texture and colour.

The overall appearance of barriers could be further articulated through applying of architectural concepts such as rhythm, proportion, order, harmony and contrast (not in any priority order). Such considerations are particularly useful where tall or extensive lengths of barriers are required in urban areas and where it may be desirable to break down the scale of an otherwise monolithic feature by using combination of contrasting materials. In laymen term, the five concepts could generally be interpreted as: -

Figure 3.2.1a Rhythm: *To repeat the forms in a sequential manner*



Figure 3.2.1b Proportion: *To compare in size or number of 2 or more components in the vicinity*

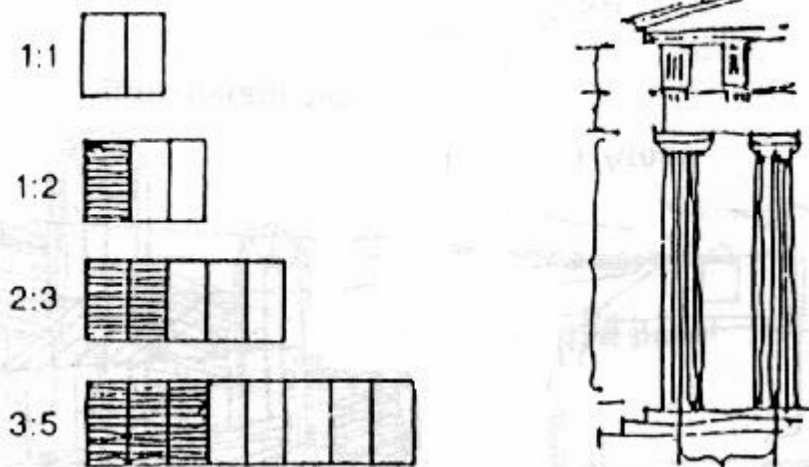


Figure 3.2.1c Order: *To arrange the components in a systematic, logical or controlled manner*

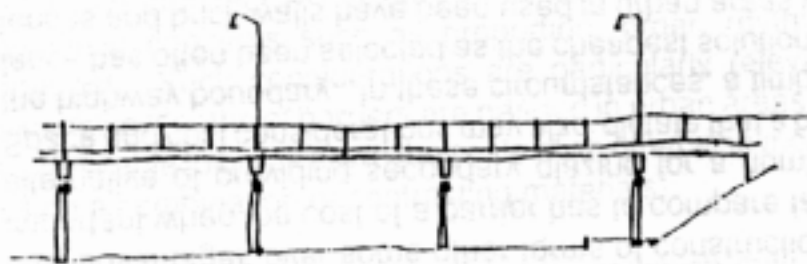
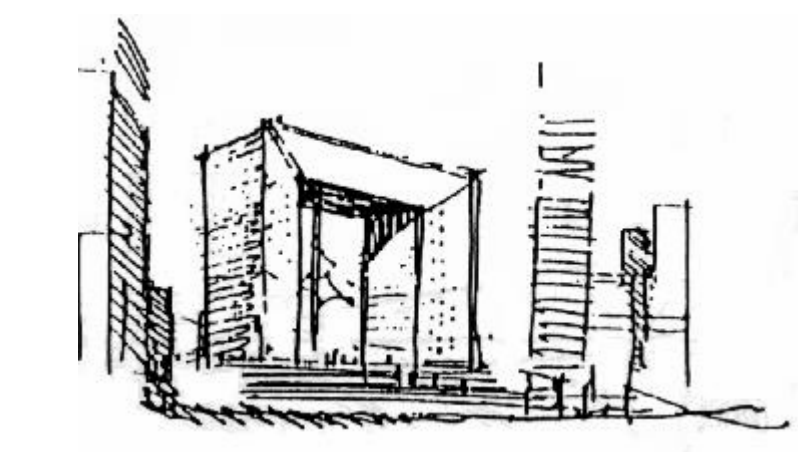


Figure 3.2.1d Harmony: To put the components in an agreeably proportional or ordered composition



Figure 3.2.1e Contrast: To put in adjacency the strikingly different forms, colours or textures



To reduce the visual impacts of barriers, it is often useful to design the solution appropriate to their locality. The linear barriers could either be broken down, for examples, by using alternative solid and transparent panels, by using colour variations or plantation to soften the sharp edges of barriers. Therefore, designed solutions are preferable than mass produced barrier systems.

3.2.2 Visual Impact

Barriers would no doubt affect the aesthetic perception of road users and people living there which to certain degree termed as visual impact. The fundamental is to design the barriers with appropriate scale and character compatible and matches with the local environment. If it is not possible to design a barrier that blends into the local environment, the aim should be to reflect some of its features such as materials, colours, textures and shapes, in a form of barriers which has aesthetic appeal, without being dominant in the field of view. Sometimes, transparent panels may be used to lighten the overall impact, either to create "windows" which partially restore views, or along the top section of a barriers to reduce its apparent height.

Figure 3.2.2 Barriers which have Aesthetic Appeal



3.2.3 Compatibility with Local Features

To some extent, local residents would tend to accept the barriers which have relationship with its surroundings and are compatible with the appearance of the adjacent neighbourhood.

As a general rule, the character of the neighbourhood should be looked into to provide a checklist of its distinguish elements. For example in the urban context, the design of a barrier needs to capture something of the neighbourhood, such as the prevalence of a particular material or style in buildings; for a leafy suburb a barrier incorporating planting might blend in more readily. Alternatively, the design of a barrier in the vicinity of a local point such a group of high rise blocks might best echo the visual dominance of that image. For the rural and new town situation, it is preferable to have a 'natural' form to harmonise the local vicinity. The use of earthworks and planting should be developed to create a visual impression which seems to preserve the rural.

Figure 3.2.3 Barriers Compatible with their Surroundings



3.2.4 Coordination with Road Furniture

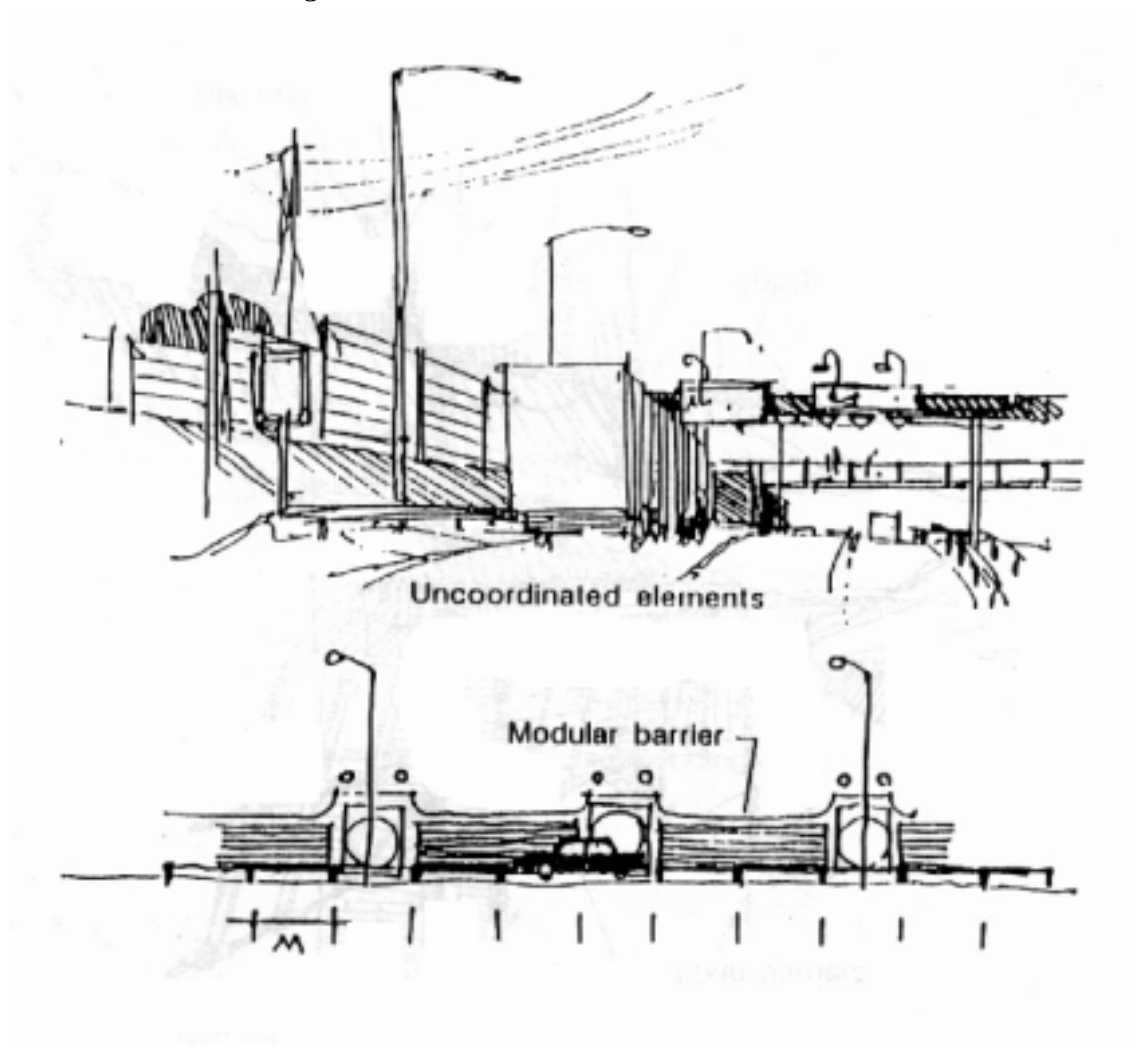
In general, priority of design should be given to the protected side since the purpose of a barrier is to protect the environment enjoyed by the people. However, the design of barriers must take into account the visual effects of the traffic sides, recognising their role as a backdrop to the motorists' view of the road.

Efforts would always be spent in the design of roads and bridges to ensure that their visual impact is acceptable. However, the visual unity is often spoiled by uncoordinated elements such as road signs, lighting columns, gantries, safety fences and parapets. The design of a roadside barrier should complement the engineering design of the road and therefore needs to be developed as part of an overall concept. Consideration of visual impact early on in the design process will help designers to avoid unnecessary conflicts. The designer should also

take note of the compatibility of the rhythm of various elements along the road to determine the suitable module for the barrier.

There are several advantages to be gained from identifying a suitable module for a barrier that will help to coordinate it with other elements. As well as being cost effective in terms of installation and maintenance, the repetition of units can create a sense of order and harmony which is conducive to road safety.

Figure 3.2.4 Coordination with Street Furniture



3.2.5 The Protected Side

A barrier can drastically change the outlook for residents, who in addition to a loss of view, may also suffer loss of daylight. A barrier is experienced by the residents as a feature which perhaps dominates the space, and such impact would remain unchanged unlike the impact of variable traffic volumes. A designer can provide a barrier which minimises this potential intrusion by using attractive materials which display in plan and elevation. Planting incorporated within the barrier design will soften its overall impact by imparting a more natural character and relieving the monotony of a horizontal skyline.

3.2.6 The Road Users' Side

The road user experiences a length of barrier for a very short space of time and will nearly always view the design at an oblique angle. The road user in general will perceive only a broad impression of the design, its pattern of colour and its contrast with the surroundings. The driver in particular will absorb a very limited amount of visual information because of vehicle speed and concern for other traffic on the road.

Barriers over 3 metres high substantially conceal the view of existing landmarks from the road, but they can also conceal visual clutter which might otherwise distract the attention of drivers. Where barriers are needed over considerable lengths in urban and semi-urban areas, their appearance should be designed to avoid monotony. Features which create a monotonous appearance are the unrelieved face of a barrier constructed from a single material, and a stark and unvaried horizontal top. Surveys of drivers in Holland have indicated that a view which is unchanging for 30 seconds is monotonous; this suggests that changes in design every half mile, or approximately 800 meters, are desirable for long barriers adjacent to a high speed road.

Variation in the type of barrier, changes in its longitudinal profile, and transparent panels over structures, will all act as visual signposts helping drivers to recognise where they are along the route. Changes should be introduced at natural "break points" and care should be taken to ensure that barriers complement or even enhance the road users' broad picture of the road.

3.2.7 The Impact of Tall Barriers

In urban areas in particular the Hong Kong situation, a straight barrier is often called to protect the high rises next to roads. However, tall barriers tend to be out of scale and proportion to its surrounding and associated structure. The resulting vertical surface may in fact be visually more incompatible with an urban environment. A careful study of the areas requiring protection should be carried out to determine whether the barriers would be acceptable as a dominant feature in the protected area, or whether they should be subordinate to the existing townscape elements. It is always useful to include breaking down the scale of the barrier structures to fit the scale and character of the surroundings, as evidenced by the size and the appearance of the adjoining buildings and their component parts.

The scale of the barrier can be reduced by providing alternative solid and transparent panels and together with the introduction of set back or recessed panels, or by the arrangement of elements on the facade of the barrier, so that these component parts (such as the structural frame and the infill panels) would harmonise with the pattern of the surroundings. The sensitive choice of colours will also help to integrate the barrier with its setting. In some areas the barrier could take the form of a facade, as a new feature designed to enhance the character of townscape.

In some cases, cantilever barrier is built instead of a very tall barrier. The cantilever barrier is one which cantilevers out towards and above the roads. Visually, it could minimise the impact as it would reduce the overall barrier height. However, a substantial section of materials must be avoiding to protrude over the carriageway of the road. From residents' point of view, the cantilever barrier could diminish the impact on the viewer from outside because the top part curves away from the viewers and hence appears lighter. The top section should also be avoided to be seen as too substantive. Some good design could blend the cantilever with the scenic surroundings.

Figure 3.2.7 Examples of Curved Barriers



3.2.8 Use of Transparent Barriers

Where a barrier is required to provide noise protection to properties in close proximity to the highway there are likely to be adverse effects due to the loss of view, loss of daylight, and enclosure effects. The loss in the quality of the view and the need for light will need to be assessed for each property affected by a tall barrier alongside the road, and the design of the barrier should be adjusted to mitigate these adverse effects. Measures to be considered include the incorporation of transparent panels coordinated with the windows of properties behind the barrier.

Transparent barriers can also be used as a more general means of reducing the prominence of the barrier as perceived both from the protected side and from the new road. A reduction in impact can be achieved by incorporating transparent panels at regular intervals along the barrier, or by glazing the top part of the barrier (typically one third of the height to reduce its apparent height and dominance. For some cases, specific pattern may be added onto the transparent panels to avoid blindly birds' collision.

Figure 3.2.8 Barriers with Transparent Panels



3.2.9 Use of Colour

Many barrier systems comprise acoustic panels which can be produced in a range of colours. It is of general consensus that the appearance of a barrier can be toned down to help it merge with its surroundings, or made to stand out as a striking and highly visible addition to the environment by the use of colour. In general, cooler blue / grey shades at the top of a barrier and warmer brown green earth colours near to the ground would help to reduce the monotonous looking. This variation in colour tends to reduce the apparent height of a tall barrier at the roadside. Colour graduation may be less effective at some distance, where the barrier appears in silhouette.

The local setting for the barrier should determine whether it is appropriate to add a splash of colour to an otherwise drab scene. The use of bright colours to create a feature should be careful. They are most effective when restricted to key parts of the barrier, for example, to emphasise its structural form. Large areas of strong colour on a barrier can result in an unpleasantly bright rather than attractive appearance.

Figure 3.2.9 Colour Graduation



3.2.10 Use of Vegetation

Planting can often be used to soften and enhance the appearance of a barrier, providing variation from season and in different daylight conditions. Vegetation which overtops a barrier will relieve the stark horizontal line which otherwise draws attention to it, so reducing the intrusion on its surroundings, but care must be taken to make use of species which will blend into the natural landscape.

Figure 3.2.10 Examples of Vegetated Barriers



3.2.11 Modifications to Barrier Designs

Small variations in the alignment of the barrier, such as stepping or zig-zags, may have only a marginal effect on noise attenuation, and so they can be used to create a more attractive design, particularly on the protected side. They can also assist the establishment of planting to soften the appearance of the barrier.

Figure 3.2.11 Zig-zags Barrier



3.3 Approach

The following principles should form the basis of the first considerations for barrier designs: -

- a) Barrier appearance should be considered initially from the view point of those living alongside the road. Barriers should as far as possible reflect the characters of the local neighbourhood and should preserve or even enhance the quality of the environment for local residents.
- b) As far as possible, barriers should be designed so that it is not apparent to the road users or to those who live alongside road that there is actually a barrier there.
- c) Barriers from the motorists' view point should reflect the character of the locality through which the road passes in order to provide a sense of place. However, if extensive lengthy barriers are necessary, the designer should apply appropriate design concepts to add visual interest in order to avoid a monotonous appearance.

In general, the size of barriers will largely be determined by requirements for noise attenuation. Considerations of structural stability, safety and maintenance will also influence their appearance. However, this still leave a considerable amount of freedom to vary the form and finish to reflect the character of the neighbourhood through which the road passes. The use of materials and structural forms appropriate to the adjacent landscape and the application of architectural principles to the design of barriers will reduce their visual impacts.

3.4 Experience of Adopting Different Forms of Mitigation Measures in Local Context

3.4.1 Straight Solid Barriers

Concrete or other solid materials could be used for short barriers. To reduce the visual

impact, features or patterns could be added on the surface of barriers.

Figure 3.4.1 Examples of Straight Solid Barriers



3.4.2 Straight Barriers with Transparent Panel

For very tall barriers, it is useful to have transparent panels at top to reduce the visual impact.

Figure 3.4.2 Straight Barriers with Transparent Panels



3.4.3 Barriers with Combination of Transparent Panels and Solid Panels

A combination of transparent and solid panel would lighten the visual impact and at the same time maintain the attractiveness by using colourful panels.



Figure 3.4.3 Transparent and Solid Panels

3.4.4 Semi-enclosure

To minimise visual impact, transparent panel should be considered on both sides.



Figure 3.4.4 Transparent Panel in Semi-enclosure

3.4.5 Earth Mound

An earth mound is an obvious solution to noise pollution in country side 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. The amount of space which an earth mound requires is a major constraint as it requires more land than vertical barriers.

Figure 3.4.5 Example of Barrier Sitting on top of an Earth Mound



3.4.6 Vegetated Barriers

A number of 'green barrier' systems have been developed which use living plant material in conjunction with soil-filled supporting structures up to 4m high. In most cases, these need careful maintenance including irrigation in dry weather. If planting fails through lack of water or disease, the barriers lose their visual appeal and may not be easily restored. In the longer term, well-established living barriers may need to be rebuilt if the planted material causes the supporting structure to deteriorate. Any consideration of this type of barrier should take into account of the appropriateness of the planted species to the locality and to their maintenance requirements.

Particular attention should be paid on the safety issue for carrying out maintenance works to vegetation adjacent to an expressway. Designers should consult and agree with Transport Department, Police, Highways Department and the landscape maintenance party early at the design stage on a particular arrangement for future maintenance.

Figure 3.4.6 Vegetated Barrier



4. Maintenance

4.1 Design Consideration

Noise barriers should be designed so that they require minimal maintenance other than cleaning. Concrete or masonry walls require little or no maintenance during the desirable service life of 40 years, but transparent sections need frequent cleaning and might well need replacing during their service life. Careful design can prevent the need for on-site modifications or other damage during construction that might considerably reduce the life of noise barriers. For example, hammering of panels for fitting into place could cause damage and should be prohibited. Therefore, design should be done carefully with due consideration of the practicability in construction. Plastic panels should incorporate resistance to the effects of ultra-violet light. Surfaces and joints should not include dirt or moisture traps or other details liable to cause rust staining. The effects of weathering on colour and of rainwash on accumulated surface grime should also be considered.

It may be necessary to provide access from the protected side for maintenance purposes and where there is a right of way for pedestrians or cyclists. This may render a barrier vulnerable to vandalism and the choice of form and materials should take this factor into account. It may be appropriate for pedestrian and cycle paths to be lit; where painted surfaces are required, polyamide based finishes will enable easier removal of graffiti. Materials for noise barriers should possess good fire retardant properties and comply with the “Particular Specification for Noise Barrier” published by Highways Department, February 2001. Though there is no specific requirement of service life, noise barrier material manufacturer is, however, required to guarantee for at least 10 years on properties such as colour resistance, stone impact resistance, aging and corrosion resistance, light transmission, fire retardant properties etc.

4.2 Materials and Detailing

In order to minimise the need for maintenance, attention should be paid to the selection of materials used in the construction of noise barriers. The quality of materials used should be appropriate to the location. For example, barriers built in relatively inaccessible locations or in areas likely to be subject to extreme weather conditions will need more durable components than those which can be more easily maintained or are in relatively sheltered positions. Care should be taken over design details in order to eliminate possible moisture traps which would encourage rot or chemical attack. Alloy and metal fittings should be carefully selected to avoid differences in electrochemical potential which would accelerate corrosion. Plants selected for use in conjunction with a noise barrier should generally be of hardy species which require a low level of maintenance.

4.3 Cleaning

With the passage of time, barrier surfaces may become stained by contaminants such as water-splash from the road surface, airborne grime, bird droppings, honeydew or sap from overhanging trees. Concrete or masonry noise barriers may not need cleaning in certain locations as the surfaces would be washed by rain water and their textured finish may control staining. Flat surfaces, however, will require regular cleaning as contamination will be more apparent and will detract from the appearance of the barrier. High pressure water jets mounted on purpose built tankers, or hand washing with brushes and low pressure water are suitable treatments.

The frequency of cleaning required will depend on the degree of contamination that occurs. Water splash contamination can be reduced by distancing the barrier from the edge of the carriageway, although this will have the drawback of reducing its effectiveness in attenuating the road traffic noise. Effective road surface drainage will also reduce splash effects by preventing puddles from forming. Bird dropping staining can be controlled by the use of design details or chemical repellents that deter birds from perching on the barrier. A very thin wire at a height of about 50mm along the top edge of the barrier will help to prevent birds resting, thus control bird droppings. Trees and other overhanging vegetation may need trimming or cutting back to prevent abrasion and marking of the barrier. Transparent noise barriers will need to be cleaned more frequently than other types because they will show any contamination more readily or surface treatments can be used. Proprietary-made self-cleansing panels could also be considered where its use is justified.

Purpose-made vehicles fitted with water tanks, hoses, brushes and access platforms would reduce the cost of cleaning barriers but long lengths of barrier will be required to justify the necessary investment. In the short term, access platforms can be used to reach the far sides of barriers in order to carry out cleaning and other maintenance. Noise barriers erected near to the carriageway may require lane closures during maintenance; traffic management will be especially important for access to any barriers in the central reserve. Their use is not encouraged, but zero maintenance barriers (self cleaning, impact resistant) would be appropriate in this location.

Similarly, it would be difficult to clean the outside of noise barriers erected on high level structures, as such zero maintenance barriers should be used.

4.4 Other Maintenance Tasks

In addition to cleaning, other maintenance tasks include :

- a) Tightening joints and fixings after initial construction. This should take place at the end of the construction maintenance period.
- b) Painting or treatment of metal surfaces. This requirement can be reduced by using anodized aluminium, galvanized or weathering steel. But colours may need to be refreshed periodically if they are an important element in the design.
- c) Periodic maintenance of planting - weeding, replacement of failed plants and, if necessary, watering to secure the proper establishment of the vegetation in the initial period, followed by periodic thinning, or pruning as necessary. (Barriers composed

of living material retaining earth require a more intensive management regime.)

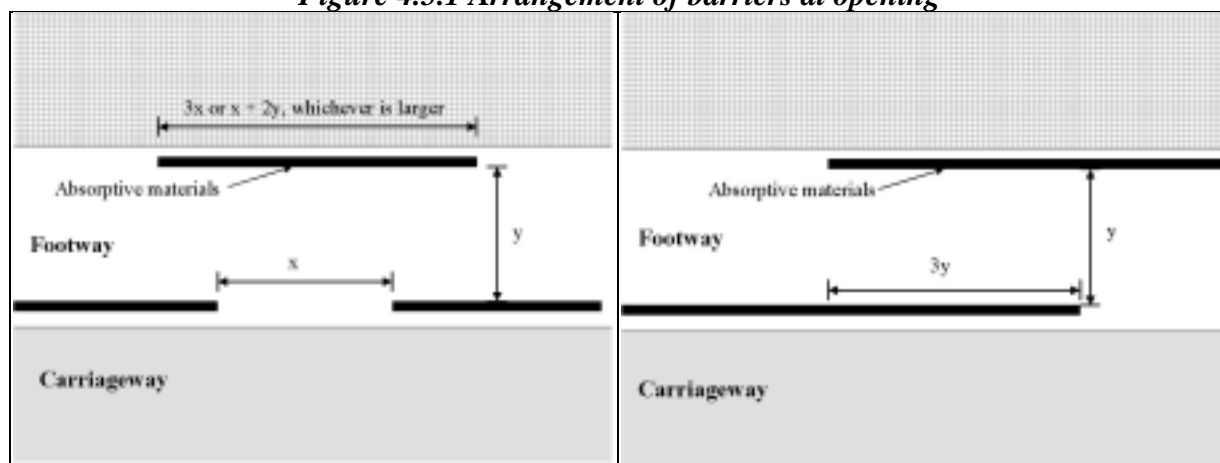
4.5 Access

The need for future maintenance should be taken into account when deciding on the form of a noise barrier. Where it will need to be inspected from time to time, screen planting should be placed with sufficient space to permit easy access. Doors or gaps should be provided at reasonable intervals to give access to either side of the barrier. Frequent access will be needed to clean both sides of a transparent noise barrier - on bridges and viaducts this might necessitate the use of specialized equipment. Working area will be required for erecting platform or parking of vehicle with hydraulic lifting platform that can reach both sides of the noise barrier for the carrying out of maintenance works.

Gates or gaps should be provided at about 200m intervals to provide access for the maintenance of both the noise barrier and any planting behind the noise barrier. Where possible these access points should be located to provide access to any traffic control and communications equipment.

Where access point is to be provided for pedestrian but doors are not practical, then, another section of parallel barrier should be provided in front of the access point to avoid degrading of the acoustic performance. One face of this barrier should be provided with absorptive materials to avoid multiple reflections between parallel barriers. The length of this additional barrier should be at least several times of the width of the gap/opening ($3x$) or as a rough guide, $x + 2y$, where x is the width of the gap and y is the spacing of the two barriers, whichever is larger. See the figure below for different arrangements at the opening. The exact length required should be worked out during detail design stage having considered standard acoustical principles and practices.

Figure 4.5.1 Arrangement of barriers at opening



5. Checklist

The following are some of the points which should be considered when the Contractor's design is checked :

- (i) The intensity for wind load and calculations for acoustic performance.
- (ii) The quality of the materials proposed to be incorporated in the barrier, particularly those, if any, that are not included in the Material Specifications.
- (iii) That the structural grades of materials used are in accordance with those quoted in the calculations.
- (iv) The supply, transportation and storage of noise barrier materials. Workmanship, particularly any pre-installation treatment required and the method of fixing.
- (v) That the acoustic properties are maintained by the avoidance of gaps, including gaps due to shrinkage or thermal movement.
- (vi) Easy replacement of parts following accidental or wilful damage.
- (vii) Security of components and nature of materials used to discourage wilful damage.
- (viii) Maintenance access is provided at appropriate location.

5.1 Checklist of Significant Issues

<u>Issues</u>	<u>Consideration</u>
A. Effectiveness	A1. Is there any opening or gap that would reduce the Transmission Loss? A2. Is there any residual noise impact at the noise sensitive receivers? A3. Will the presence of the structure reflect sound excessively? A4. Is the size and alignment optimized for maximum noise benefit?
B. Structural Integrity	B1. Can the design withstand design loading conditions? B2. Is the probability of fallen parts from the structure minimized by design (e.g. by provision of catching or locking device to prevent fallen parts?
C. Compatibility with	C1. Has visual impact been softened?

<u>Issues</u>	<u>Consideration</u>
the Environment	<p>C2. Is the design compatible with the characteristics of its immediate environs?</p> <p>C3. Can the structure be designed to create a positive identity for the neighbourhood?</p> <p>C4. Is there space allowed for landscape planting?</p> <p>C5. Is the module of the noise barrier compatible with rhythm of other elements such as street lighting along the road or unit length of parapet of elevated structure?</p>
D. Maintenance	<p>D1. Is the material capable of providing a pleasant visual impression by regular maintenance?</p> <p>D2. Is the design such that it facilitates maintenance, either by machine or by manual labour?</p> <p>D3. How often will replacement of parts be necessary?</p> <p>D4. Is there any special requirement for access?</p> <p>D5. Has a practicable arrangement been agreed with all relevant parties for carrying out maintenance works to vegetated barriers?</p>
E. Safety	<p>E1. Will the structure become a hazard upon a crash, or a fire by breaking into splinters or by producing toxic fumes?</p> <p>E2. Is the design safe on traffic engineering grounds?</p> <p>E3. Will the structure obstruct fire engine/emergency access?</p> <p>E4. Has head-light glare been minimized?</p>
F. Ventilation	<p>F1. If the structure is an enclosure (or semi-enclosure), has the capability of natural (or forced) ventilation been checked?</p> <p>F2. If the structure is intended to serve other purposes, has the ventilation load been taken into account?</p> <p>F3. Is there sufficient space between the noise barrier and the building to enable natural/sufficient ventilation of the lower floors of the building behind the noise barrier?</p>
G. Lighting	<p>G1. If the structure is an enclosure, has openings been</p>

<u>Issues</u>	<u>Consideration</u>
	provided at sidewalls and/or roof to allow daylight penetration in order to save energy cost?
	G2. What would be the operation hours of artificial lighting and has it been taken into account in the design?
	G3. If the structure is a vertical noise barrier, has recess or adequate space behind or in front of the barrier been allowed for the installation and maintenance of road lighting column?
	G4. If the structure has a cantilever arm, will it affect the road lighting system?
H. Installation	H1. Is a light weight construction preferred?
	H2. Will the method of installation bring about the least amount of traffic congestion?

6. Bibliography / References

- 6.1 The Highways Agency (1994) *Design Manual for Roads and Bridges*, Volume 10, Environmental Design, Section 5, Environmental Barriers, Part 1, Design Guide for Environmental Barriers, HMSO, London.
- 6.2 The Highways Agency (1995) *Design Manual for Roads and Bridges*, Volume 10, Environmental Design, Section 5, Environmental Barriers, Part 2, Environmental Barriers: Technical Requirements, HMSO, London.
- 6.3 The Highways Agency (1994) *Manual of Contract Documents for Highway Works* Volume 1 Specification for Highway Works Series 2500 Special Structures
- 6.4 U.S. Department of Transportation Federal Highway Administration (1976) *A Guide to Visual Quality in Noise Barrier Design*
- 6.5 California Department of Transportation (1997) *Technical Noise Supplement* 1st Draft
- 6.6 Benz Kotzen and Colin English (1998) *Environmental Noise Barriers: A Guide to their Acoustic and Visual Design*, E & FN Spon, London
- 6.7 David C Hothersall and Richard J Salter (1977) *Transport and the Environment*, Crosby Lockwood Staples, London
- 6.8 Ian Sharland (1986) *Woods Practical Guide to Noise Control*, Woods of Colchester Limited
- 6.9 Environmental Protection Department, *Application of Screening Structure to Abate Noise from Surface Transportation*, Environmental Protection Department, Hong Kong
- 6.10 Environmental Protection Department (2000) *Housing Design to Abate Traffic Noise in Hong Kong*, Environmental Protection Department, Hong Kong
- 6.11 Environmental Protection Department (2001) *Screening Structures and Building Designs against Transportation Noise in Hong Kong*, Environmental Protection Department, Hong Kong
- 6.12 Hong Kong Government (1991) *Environmental Guidelines for Planning in Hong Kong*, an Extract from the Hong Kong Planning Standards & Guidelines
- 6.13 Hong Kong Government (1997) *Environmental Impact Assessment Ordinance*
- 6.14 Hong Kong Government (1997) *Technical Memorandum on Environmental Impact Assessment Process*
- 6.15 Highways Department (2001) *Particular Specification for Noise Barriers*, Highways Department, Hong Kong
- 6.16 Highways Department (2002) *Final Report of the Noise Enclosure Lighting – Engineering Study*, Highways Department, Hong Kong