British Columbia

Ministry of Transportation and Highways

NOISE CONTROL EARTH BERMS

Guidelines for the Use of Earth Berms to Control Highway Noise

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Highway Engineering Branch

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Summary

Background

Since 1989, the Ministry of Transportation & Highways of B.C. (MoTH) has had a noise impact mitigation policy which applies to all new or upgraded freeway and expressway projects. This policy is intended to prevent excessive noise impacts at residences and educational facilities and requires that mitigation measures be considered wherever project-related noise increases are predicted to exceed certain limits. Where such mitigation measures are warranted, cost-effective and widely supported by the directly affected community, they are to be carried out. Mitigation measures generally take the form of noise barriers constructed within MoTH right-of-way. Three basic configurations are employed: walls, earth berms or berm/wall combinations. The MoTH policy limits the height of walls to 3 m, but no such limit exists for earth berms or berm/walls. Given their natural appearance and potentially lower costs, earth berms have often been the preferred form of mitigation where space is available.

Since the MoTH noise policy requires that mitigation measures achieve average noise reductions of 5 dBA or more, it is crucial that the relative noise reduction capabilities of the three forms of noise barriers be well understood. While experimental assessments to date have yielded mixed results, some highway noise prediction models assign a noise reduction bonus of 3 dBA to earth berms in recognition of their relatively broad and soft tops. To assess the validity of this "soft top correction" and to explore the effects of adding walls to the tops of earth berms, ***MoTH has funded research by the U.B.C. Mechanical Engineering Department (through the Professional Partnership Program) and Wakefield Acoustics Ltd.***

Results of U.B.C. Scale Modelling of Noise Barrier Performance

Mechanical Engineering graduate student Todd Busch, under the supervision of Dr. Murray Hodgson, developed a 1/31.5 scale model of a highway section in the department's anechoic chamber and tested a large number of noise barrier configurations. The key results of these experiments are listed below. Supplementary comments and interpretations by Wakefield Acoustics Ltd. are intended to assist MoTH staff in appreciating how these findings can be applied in the effective implementation of the Ministry's noise policy. Table S-1 illustrates the optimal forms which noise barriers should take in various situations while Table S-2 demonstrates the appropriate and inappropriate use of landscaping/vegetation near noise barriers.

1. Model earth berms with normal surfaces (i.e., representative of grass over soil) were found to provide ***about 2 dBA less noise reduction than walls of the same height and position.*** The poorer performance of berms is felt to be due to sound waves which strike the berm's inclined front face and are; 1. reflected/scattered towards the crest of the berm, or 2. transformed into "surface" waves at the air/berm interface and then propagate along the berm face, over its crest and into the sound shadow zone behind it.

2. Berms with more gentle slopes (e.g. 3:1 or flatter) will tend to more effective at both reflecting/scattering sound waves towards the berm crest and at fostering surface waves. They therefore may be expected to provide from 0.5 to 1 dBA less noise reduction than steeper (e.g., 1.5:1 and 2:1 slopes) berms of the same height and location.

(Summary, cont'd)

3. The slopes of earth berms consume substantial space, so that berms cannot be built as close to the traffic (the noise source) as can noise walls. Since the performance of a noise barrier improves as it is moved closer to either the noise source or the receiver, this may give walls another performance advantage over earth berms. The magnitude of this advantage varies with source-to-receiver distance and with receiver elevation, but ***it can amount to another 1 to 2 dBA, bringing the total advantage of a wall over an equivalent berm of normal softness to 3 to 4 dBA.***

4. The top profile, or shape of the berm top, does not appear to significantly influence berm performance, with flat-topped and round-topped berms showing only a slight (about 0.5 dBA) advantage over wedge-shaped berms.

5. ***Berms with highly sound absorptive surfaces perform substantially (4 to 5 dBA) better than berms with normally absorptive grassy surfaces.*** This major improvement appears to result from the near total suppression of reflected/scattered sound waves as well as surface waves and from the additional absorption of energy from sound waves passing over the berm's very soft top. Berms with very wide flat tops should then perform better than those with narrower tops.

6. ***It appears then that the so called "soft-top correction" does exist, but only for berms with surfaces substantially more sound absorptive than normal grassy surfaces.*** It remains to be seen whether such surface can be achieved in practice. Some potential may lie in the use of light-weight admixtures such as vermiculite and pearlite or perhaps fine wood chips or bark mulch. The sound absorption capabilities of such materials in combination with soil need to be evaluated.

7. When walls were added to the tops of normal earth berms, rather than being diminished, the overall performance of the resulting berm/walls (for the same total barrier height), was improved by an average of 1.5 dBA for the various height and slope combinations tested. ***It appears that when a wall is used to elevate the barrier top above the berm surface, the berm-reflected/scattered sound waves have a greater tendency to cancel, or at least not reinforce, the direct waves at the top of the barrier. In addition, surface waves are prevented from propagating over the berm crest.***

8. ***Optimal berm/wall performance was observed when the wall comprised less than half the total barrier height.*** For example, a 3 m high, 3:1 sloped berm with a 1 m wall on top gave the largest noise reduction (10.2 dBA) of any <u>normally sound absorpive</u> berm or berm/wall configuration tested.

9. ***Berm/walls then tend to perform better than pure berms of normal softness and similar to, or in some cases better than, pure walls.*** While it may be possible to "tune" berm/walls so as to achieve optimum sound cancellation at the barrier top and hence maximum noise reduction, this would require detailed analysis of site geometry, wall and berm height and berm slope and surface nature.

10. When a 1 m wall was added to the top of a 3 m high berm having a <u>highly sound absorptive</u> surface, the overall barrier performance was reduced slightly from 10.4 to 9.9 dBA - in spite of the total berm/wall height being 1 m greater than the pure berm. ***This indicates that the substantial benefit of applying a very soft surface to a berm is largely duplicated by the placement of a wall on top of a berm so that unfortunately the two effects do not appear to be directly additive.***

11. The presence of vegetation on the face of an earth berm or wall can have minor beneficial effects due to the absorption and scattering of traffic noise, however, on a plantable scale, vegetation does not provide an effective noise barrier. ***However if vegetation is allowed to overtop the crest of a noise barrier, it will cause sound to be scattered down in behind the barrier, thereby reducing its performance, particularly at higher frequencies where the barrier itself is most effective.***

1. Introduction

Background

Since 1989, the Ministry of Transportation & Highways of B.C. (MoTH) has had a noise impact mitigation policy (the revised 1993 version is summarized in Appendix A) which applies to all new or upgraded freeway and expressway projects. It is intended to prevent excessive noise impacts at residences and educational facilities and requires that mitigation measures to be considered wherever project-related noise increases are predicted to exceed certain limits. ***Where such mitigation measures are warranted, cost-effective and widely supported by the directly affected community, they are to be carried out.***

Figure 1.1: Noise Barrier Wall at Victoria's McKenzie Avenue Interchange

Highway project noise impacts can be avoided or minimized through thoughtful alignment selection. Active mitigation measures however, for impacted residences are effectively limited under the policy to the construction of noise barriers within MoTH right-of-way (note; the use of open-graded asphalt, or quiet pavement, is being considered for some projects).

Noise barriers have three basic forms: a wall, earth berm or berm/wall combination. For aesthetic and cost reasons, the policy limits wall heights to 3 m but no such limit exists for earth berms. Given their natural appearance and potentially low costs (where sufficient right-of-way is available), earth berms have often been the preferred form of mitigation.

The three basic types of noise barriers have varying capital costs, maintenance and right-of-way requirements and aesthetic implications, but these factors are readily ascertainable. Their relative acoustic (noise reduction) performance, however, has not been clearly established and some questionable "rules of thumb" have persisted for many years. Since the MoTH policy requires all mitigation measures to provide a minimum traffic noise reduction of 5 A-weighted decibels (dBA) - corresponding to about a 40% reduction in loudness - ***such uncertainty has been the source of some concern.***

To gain a clearer understanding of earth berm performance, the ***Highway Environment Branch of MoTH*** contracted with the ***U.B.C. Department of Mechanical Engineering and Wakefield Acoustics Ltd.*** to conduct a joint research effort. In 1994, the ministry entered a Professional Partnership arrangement with M.A.Sc. candidate Todd Busch to conduct, under the supervision of Dr. Murray Hodgson, acoustic scale-modelling of the traffic noise reduction performance of walls, earth berms and berm/wall combinations. Wakefield Acoustics Ltd. has provided direction and review of the lab research effort, conducted field assessments of existing earth berms and prepared these guidelines.

Intent of the Guidelines

These guidelines are intended for use by project managers, environmental management and roadside development staff, and other MoTH personnel ***who must integrate noise control concerns with the many other highway project design issues.*** They will hopefully be of assistance in:

- appreciating the acoustical strengths and limitations of noise barriers - earth berms in particular - and how these can be exploited to maximize noise reduction performance,
- constructing earth berms and berm/walls which optimize noise reductions while minimizing negative aspects such as capital costs, right-of-way, maintenance and aesthetic impacts.

2. Noise Barrier Fundamentals

Creating a Sound Shadow

Noise barriers work by interrupting the direct, straight-line path between the noise source and the noise receiver positions - thereby creating partial "sound shadows". Unlike light waves, sound waves (due to their relatively long wavelengths) are noticeably "diffracted" or bent, around everyday objects. Therefore while a noise barrier can substantially reduce the intensity of traffic noise reaching a receiver position behind it, it can never, in practice, eliminate the noise. ***Noise reductions may range (see Figure 2.1) from about 5 decibels (dB) where the "line of sight" is just blocked to a practical limit of about 20 dB deep within the "shadow zone".***

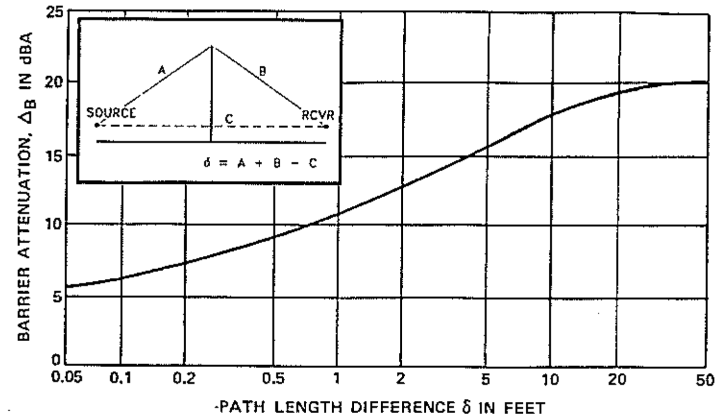


Figure 2.2; Noise Barrier Attenuation as a Function of Path Length Distance

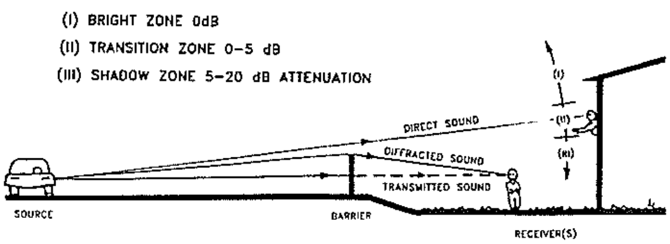


Figure 2.1: Fundamental Noise Barrier Concepts

The amount by which the intensity of sound will be reduced by a barrier is determined by the "**path length difference**" between the direct source-to-receiver path and the diffracted path which sound must follow in going over the top of the barrier. Figure 2.2 shows the relationship between path length difference and barrier attenuation for an infinite line source (i.e. long highway) and an equally long, "knife-edged" barrier such as a thin wall. ***The closer the barrier to either the noise source or receiver, the longer the path length difference and the greater the attenuation*** - attenuation here being the noise reduction achieved by a barrier in the absence of any soft ground effects (see Section 3B).

Basic Noise Barrier Requirements

In addition to having sufficient height and being optimally located (generally the closer to the noise source the better) to substantially interrupt the line of sight from source to receiver, effective noise barriers must satisfy three additional requirements:

- *Barrier Surface Density* - to prevent any significant amount of traffic noise from being transmitted through a noise barrier, its surface density (weight per unit area) should be at least 12 kg/m^2 (2.5 lb/ft^2),
- *Barrier Leakage* - a small amount of open area (cracks, gaps, holes) can be tolerated before noise leakage begins to degrade the overall wall performance. For typical attenuation objectives of 5 to 10 dB, this open area can be up to 2.5% if evenly distributed along the barrier,
- *Horizontal Extent* - a noise barrier must extend horizontally well beyond the limits of the area to be shielded - typically four times the barrier-to-receiver setback distance - or must "wrap around" the receivers at its terminations.

Noise Barrier Types

This section describes the non-acoustical characteristics of the three basic noise barrier types. Their acoustical characteristics will be discussed in Sections 3 and 4.

A. Walls

Noise walls have been the most commonly employed form of highway noise mitigation, both in B.C. and elsewhere. As highway noise barriers, vertical, or near vertical, walls have the following advantages:

- ***minimal right-of-way requirements*** - typically 1 to 2 m including space for concrete roadside barrier where warranted, e.g. wall on shoulder,
- ***minimal or no routine maintenance*** - if adequately protected from vehicle impacts, most commercial noise barrier products (typically precast concrete or steel) require little or no routine maintenance,
- ***wide variety of materials and finishes*** - noise walls may be constructed of many materials (concrete panels and blocks, brick, steel, engineered wood, timber, tempered glass, plastics, recycled tires etc.) with a large variety of textures and finishes.
- ***security*** - noise walls generally preclude the need for highway security fences.

Figure 2.3; A 3 m High Precast Concrete Noise Wall at the McKenzie Interchange Near Victoria

Noise walls have the following disadvantages:

- ***visual impacts*** - the substantial heights and lengths of noise walls may produce undesirable visual impacts and may impart a "feeling of confinement" to adjacent residents and motorists alike. These negative impacts can be "softened" by providing the wall with prominent texture, visual variety and appropriate landscaping,
- ***sound reflective*** - most noise wall materials are acoustically hard and hence reflect almost all the sound energy that impinges on them. Unless the walls are either tilted or sound absorptive, this may result in somewhat increased noise exposures on the opposite side of the highway, or, where there are walls on both sides, in mutually-reduced barrier performance,
- ***capital costs*** - noise walls are relatively expensive, ranging (at 3 m high, installed) from about $300 per running metre for basic reflective precast concrete or corrugated steel walls to $700 per metre for some propriety sound absorptive walls or planted "green" walls,
- ***collision protection*** - where noise walls are to be located within the clear zone of a highway, they generally must be protected from vehicle collisions. This may involve the additional cost of CRB at about $100 per metre.

B. Earth Berms

In suburban and rural settings where sufficient right-of-way and fill material are available, earth berms are generally the preferred form of highway noise mitigation. Berms have the following advantages:

- ***visual compatibility*** - the natural appearance of earth berms permits them to blend in with their surroundings. Their sloping sides reduce their perceived height and the feeling of confinement,
- ***reflection avoidance*** - the sloping sides and relatively sound-absorptive surfaces of berms avoid the potentially problematic reflection of traffic noise across the highway.

(Earth Berms, cont'd)

- *potentially lower capital costs* - where right-of-way is available, earth berms will generally cost less than noise walls. Where suitable fill material is available on site, costs for placement and compaction of a 3m high, 2:1 slope berm will range from $100 to $150 per running metre. This may be offset by reduced costs of off-site waste material disposal. The costs of landscaping the roughly 31 m^2 per running metre of 3 m earth berm can vary from $50/m for grass-seeded, unirrigated rural berms to $250/m for intensely planted, irrigated urban berms.

- *collision protection* - depending on posted speed and other highway parameters, earth berms of suitable slope may not need collision protection.

Figure 2.4; An Intensely Planted, 4 m Urban Berm Along the Pat Bay Highway Near Victoria

Earth berms may have the following inherent disadvantages:

- *space requirements* - a 3 m high berm with 2:1 slopes and a 1 m wide top requires 13 m of right-of-way; a 3:1 sloped berm requires 19 m,

- *maintenance requirements* - depending on setting and landscaping treatment, berms may require minimal (grassed or naturally-vegetated rural berms) to considerable (highly planted urban and suburban berms) routine maintenance,

- *security* - berms tend to be climbable and so do not generally act as a highway security barrier.

C. Berm/Wall Combinations

Noise barriers composed of an earth berm topped by a wall present an attractive alternative where some spare right-of-way is available but not enough to accommodate a full-height berm. Being hybrids, berm/walls tend to share, to moderated degrees, many of the advantages and disadvantages of both noise walls and earth berms. ***There are however, some rather unique benefits associated with berm/walls combinations:***

- *aesthetics* - by moderating the height of wall required and visually balancing the wall against the supporting berm, appropriately landscaped berm/wall combinations can provide attractive solutions,

- *reduced costs* - since the costs of noise walls increase quite rapidly with height (particularly above about 2 m), a berm/wall combination barrier will often be less expensive than a noise wall of the same total height,

- *minimized reflection* - potentially problematic noise reflections are minimized since the berm portions are soft and sloped while the upper wall portions tend to be elevated far enough above the highway that most reflected noise is redirected skywards.

Figure 2.5; A 3 m Berm/1.5 m Wall Combination Noise Barrier along Highway 17 in Delta

3. Noise Attenuation Performance of Earth Berms

Historical Perspective

Due to their soft surfaces, earth berms have been considered to provide more noise reduction than walls of equivalent height and position. As a result, some highway noise prediction procedures have applied a "soft-top correction" of 3 dBA. However, scale model studies and field measurements have, over the years, produced mixed results. Several have found walls better than berms, while others have found the opposite or no effect. Further scale model tests using a linear (highway) noise source and including a logical series of walls, berms and berm/wall barriers were required to clarify this and other issues and to gain an understanding of the acoustical phenomena at work.

U.B.C. Scale Model Studies

Barrier model studies at 1/31.5 full scale were conducted in the anechoic (i.e., no sound reflections) chamber at U.B.C.'s Mechanical Engineering laboratories. Frequencies were scaled up 31.5 times so that real-world relationships between sound wavelengths and barrier dimensions were maintained. Tests were carried out to find model materials which, at the scaled-up frequencies, behaved like real-world asphalt, soft ground and reflective barrier surfaces. The very high frequency noise required was produced by a specially-fabricated compressed air jet nozzle.

Figure 3.1; U.B.C. Scale Modelling Facility

Scale Modelling Results

Based on the U.B.C. scale modelling results, the following assertions can be made about the effects of berm parameters such as side slope, top shape and surface treatment on berm noise attenuation performance. Also discussed is the central issue of the relative performance of walls and earth berms.

A. Noise Barrier "Insertion Loss"

When discussing the performance of berms and walls, it is helpful to be familiar with the concept of barrier "insertion loss". This is the net effect of placing a noise barrier between a noise source and receiver. ***The insertion loss of a given barrier at a given receiver position is then the difference between noise levels at the receiver position "with and without" the barrier in place.***

B. "Ground Effect" and Barrier Insertion Loss

The insertion loss of a noise barrier depends on the nature of the ground on which it has been constructed. If the ground surface between highway and receiver position is largely sound reflective, or "acoustically hard", (e.g., concrete, asphalt or hard packed gravel) the barrier's measured insertion loss will be very close to that which would be predicted purely on the basis of highway/barrier/receiver geometry (see Figure 2.2). If, however, the intervening surface is sound absorptive, or "acoustically soft" (e.g., grassy or cultivated fields or wood lands), then it will have been providing some excess noise attenuation, or "ground effect" of its own. When a noise barrier is installed in such a situation, it will, by diverting sound waves away from the ground, cause some or all of this "ground effect" attenuation to be lost. Therefore the insertion loss of a barrier will be smaller over soft ground than over hard ground. ***Since the ground between highway and receiver is more typically "soft", the insertion losses presented herein are the net attenuations to be obtained over soft ground.***

C. Earth Berms versus Walls

The scale model studies have shown the ***insertion losses of earth berms with typical grass-covered surfaces to be about 2 dBA lower than those of equivalent walls.*** This somewhat counter-intuitive result, may be understood when it is realized that while much more sound absorptive than most noise walls, earth berms do not absorb all sound energy which strikes their inclined surfaces. Some is ***reflected and/or scattered towards the berm crest,*** thereby increasing the intensity of sound in this critical zone. In addition, some sound energy is ***transformed into "surface" waves at the air/berm interface*** which then travel along the berm's face and over its crest. Both phenomema (see Figure 3.2) result in more noise reaching the shadow zone behind the berm. In contrast, with a noise wall on flat ground, no inclined surface exists to redirect sound waves while surface waves are blocked by the wall. ***Higher insertion losses are therefore obtained with walls than berms with normal surfaces.***

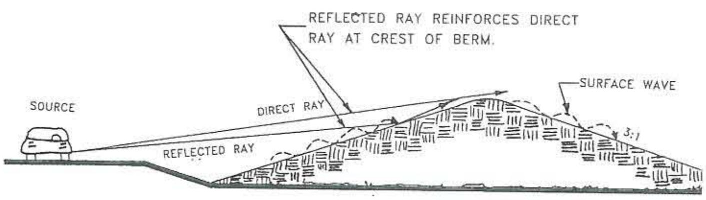


Figure 3.2; Reinforcement of Sound Waves at Berm Crest and Formation of Surface Waves

D. Effects of Berm Slope on Insertion Loss

It is to be expected that the flatter the slopes of an earth berm, the greater the tendency for traffic noise to be redirected towards the berm's crest and the more efficient the formation of surface waves. The model studies have shown that berms with 3:1 slopes do provide less insertion loss those with 1.5:1 and 2:1 slopes. However, significant differences occured only at low frequencies where the berms are least sound absorptive. Effects of berm slope on overall A-weighted insertion loss (relevant to MoTH noise policy) were then found to be less than 0.5 dBA in the 1.5:1 to 3:1 slope range. ***At flatter slopes (to a practical limit of 5:1), this performance decrement might be expected to approach a maximum of 1dBA.***

Therefore, while steeper earth berms were found to provide higher insertion losses, the differences do not appear to be significant, at least at moderate (30 m or less) barrier-to-receiver distances. At larger setback distances, low-frequency traffic noise components gradually become more prevalent so that the superior low-frequency performance of steep berms would be expected to be reflected more noticeably in the overall A-weighted insertion loss.

E. Effects of Earth Berm Top Profile

Since the diffraction, or bending of sound into shadow zone of an earth berm takes place principally at its crest or top, it is reasonable to expect that the shape, or profile of the berm top would influence the degree to which sound is so diffracted. Three scale model top profiles were examined: a wedge or pointed top, flat tops (1 m and 2 m widths) and a round tops (1 m and 2 m diameters). Three berm slopes (1.5:1, 2:1 and 3:1) were used. ***The A-weighted insertion losses of all 15 berm top profile and slope combinations were between 7.1 and 8.0 dBA.***

On average, the flat-topped and round-topped berms showed slightly (about 0.5 dBA) better performance than the wedge shaped berms, but these differences may not be significant. It appears that while flat topped berms should perhaps be avoided - mostly since they may encourage walking on their crests and hence compaction of surface materials - the precise shape of the berm top (i.e. rounded, elliptical or peaked) is not critical assuming the same total berm top elevation.

Figure 3.3; A 4 m High Berm with a 1.5 m Wide Quasi-flat Top, Between Pat Bay Highway and Douglas St. near Victoria

F. *Effects of Berm Surface Absorption*

By covering a 4 m high, 3:1 sloped, wedge-topped scale model berm with a highly sound absorptive layer (felt), its insertion loss was increased by 4.5 dBA. Similarly when a 3 m high, 3:1 sloped, flat-topped berm (2 m top width) was covered with felt, its insertion loss increased by 5.3 dBA. These improvements occurred across a wide range of frequencies and are believed to be due to the essential elimination of sound reflections from the front slopes of the berms as well as the prevention of the formation of surface waves. The somewhat larger improvement seen with the flat-topped berm is likely due to additional absorption of sound as it travels across the 2 m flat top. While at scale model frequencies, the felt layer possessed a degree of acoustical softness (sound absorption) which may not be attainable with real world materials, ***the dramatic improvements observed indicate there is potential for increasing the insertion loss of earth berms by softening their surfaces, particularly the slope facing the highway.***

Acoustical softening of an earth berm could be achieved by increasing the porosity of the fill material used to dress the berm. While we are aware of no real world experiments conducted to assess the acoustic softness of various porous fill materials, some potential candidates would appear to be bark mulch/wood chips, vermiculite and pearlite. The former are often used to dress berms with slopes steeper than 2:1 which are not suited to planting in grass, while the latter two materials are sometimes used as light-weight admixtures in roof gardens or other locations where the weight of ordinary soil is of concern. The addition of such materials (up to about 40% to 50% by volume) would be expected to improve the plant-supporting capacity of the surplus fill materials typically used in earth berms.

Over time the root structure of flowering plants and shrubs planted on the steeper berms would also increase the porosity of the berms' surfaces. The degree to which such natural porosity or the artificially enhanced porosity discussed above will increase the sound absorption capacity of berm slopes and hence the insertion loss of berms, remains to be determined. However, it can be stated that ***any enhancement of the fine-scale porosity of the upper layer of a berm, particularly berms of 3:1 slope or flatter, will increase overall berm insertion loss.***

G. *Effects of Barrier Set Back From Highway*

The comparison (see Section 3 C) between berm and wall scale model insertion loss performance was based on a constant barrier set back distance from the highway. That is, the tops of the walls and berms tested were always at the same distance from the noise source. However, in reality, due to the space requirements of earth berms, the top of a noise wall can usually be located closer to the highway than that of an earth berm or berm/wall combination of the same height. By being closer to the noise source, the wall can create a larger "path length difference" for sound travelling over its top (see Section 2) and therefore can achieve greater insertion loss.

The quantitative effect of this set back advantage will depend on the source to receiver distance and the elevation of the receiver relative to the highway. As an example, Figure 3.4 below shows a 3 m noise wall on the highway shoulder (behind CRB) and a 4 m high, 2:1 sloped earth berm providing the same total barrier height above pavement level. The source to receiver distance is about 30 m. Based strictly on the relative path length differences induced by the wall and berm, the wall is found to provide an additional 1.5 dBA of insertion loss. When this is added to the approximately 2 dBA of inherent insertion loss advantage of walls over typical berms as revealed in the scale model studies, ***it is seen that the total advantage of the noise wall could easily be as much as 3.5 dBA for a typical highway/barrier/receiver configuration.***

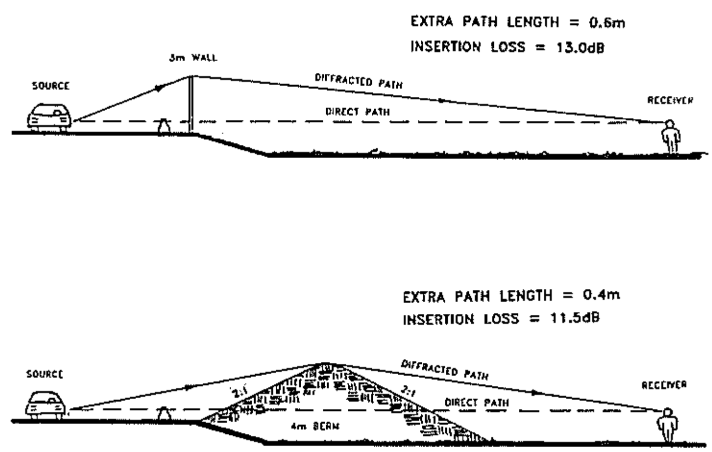


Figure 3.4; Relative Insertion Loss of 3 m Wall and 4 m Berm (3 m above pavement) Based Purely on Path Length Difference.

4. Noise Attenuation Performance of Berm/Walls

Historical Perspective

As discussed in Section 2, noise barriers which combine a wall with an earth berm have aesthetic, height and right-of-way advantages (see Figure 4.1). However, in the past there has been concern that the placement of a noise wall, particularly a low one, on top of an earth berm would destroy the latter's beneficial "soft top" effect and thereby produce only a minor positive, or even a negative, net change in barrier performance. Scale model tests of berm/walls were conducted to assess the validity of this concern, and if validated, to determine the minimum height of wall required to achieve a net improvement in barrier performance.

However, as reported in Section 3, initial scale model tests found that earth berms surfaced with normal highway fill materials provided no net "soft top" benefit and in fact performed less well than pure walls of the same height. ***It was then reasonable to expect that placement of a wall on top of a berm would, for the same total barrier height, increase, rather than decrease, overall barrier insertion loss.***

Figure 4.1; Transition from a Pure Wall to a Pure Berm via a Berm/Wall Combination - Highway 17 near Highway 10, Delta.

Scale Modelling Results

It was noted in Section 3E that the insertion losses of all scale model 4 m high earth berm configurations tested (i.e., wedge, round and flat tops, 1.5:1, 2:1 and 3:1 side slopes) were between 7 and 8 dBA with an average of 7.4 dBA. ***In contrast, the 4 m high berm/wall combinations tested (all with 2 m wide flat tops) had insertions losses ranging from 7.8 to 10.2 dBA with an average of 8.9 dBA.*** To complete the comparison, a 4 m pure wall located at the same position as the berm/walls (see Figure 4.2 below), achieved an insertion loss of 9.1 dBA.

The placement of a wall on top of a berm then appears to prevent the propagation of surface waves over the berm top and also to alter the nature of the interaction between direct sound waves and those reflected from the berm face. For the berm/walls tested, it appears that when the top of the barrier (i.e. the wall top) is elevated above the berm surface, direct and berm-reflected waves tend to cancel, or at least not to reinforce, one another at the top of the barrier to the degree they appear to do with pure berms. ***Berm/walls then tend to perform better than pure berms (by an average of 1.5 dBA) and similar to, and in some cases better than, pure walls of the same total height.***

Figure 4.2; Scale Model Test Setup for 4 m Wall (3 m above Pavement).

Effects of Wall Height and Berm Slope

The largest A-weighted scale-model barrier insertion loss observed (without the use of felt berm surfaces) was 10.2 dBA. This was obtained with a 3 m high, 3:1 sloped berm topped with a 1 m wall. While all walls more than about 1 m high would be expected to effectively block the propagation of surface waves, the above combination of berm slope and wall height appeared (for constant total height of 4 m) to produce the most beneficial interference/cancellation between direct and berm-reflected sound waves. Such interference effects are subtle since they depend on the nature (softness) and slope of the berm surface, the path length difference between direct and reflected waves (function of setback distance and berm and wall heights) and on the frequency of sound considered. Slight variations in any of these parameters can significantly alter overall performance. For example, ***when the optimal 3 m high 3:1 berm/1 m wall combination described above was replaced by a 2 m berm/2 m wall combination, overall insertion loss was decreased from 10.2 to 7.8 dBA.***

While it may then be possible to "tune" a berm/wall to maximize its overall A-weighted insertion loss, this would be a "site-specific task" requiring detailed assessment of site geometry, wall height and berm height, slope and surface characteristics.

Optimal Berm/Wall Configurations

While it is therefore difficult to prescribe definitive rules by which to optimize the performance of a berm/wall under any given situation, the following general conclusions can be drawn, based on the scale modelling results:

1. berm/walls as a group out-perform pure berms and perform as well or slightly better than pure walls,

2. berm/walls appear to perform better when the wall component makes up less than half the total barrier height, e.g. 3 m berm/1 m wall,

3. when the wall is 3 m high and makes up well over half of the barrier height, the berm/wall performs essentially like a pure wall.

Effects of Berm Surface Absorption

The placement of a low wall on top of an earth berm of normal softness, has been seen to increase overall barrier insertion loss performance. ***Similar improvements were not however observed with very soft berms.*** When a 1 m wall was placed on a 3 m high, flat-topped berm with 3:1 side slopes and a surface covered with highly sound absorptive felt, significant improvements were seen at some low frequencies. However, overall A-weighted insertion loss was reduced from 10.4 to 9.9 dBA - this in spite of the berm/wall being 1 m higher than the pure berm. It then appears that earth berm performance can be improved (through the suppression of reinforcing reflected waves as well as surface waves) by either the application of a very soft berm surface or the addition of a wall. ***Since these two measures achieve their performace enhancements in essentially the same way, their effects do not appear to be directly additive.*** There may then be little to be gained from placing a wall of modest height on top of a highly absorptive earth berm, nor from softening the surface of a berm which is already topped with a wall.

Figure 4.3 below shows an earth berm which would be expected to be relatively sound absorptive since it is covered with a thick layer of bark mulch and is quite intensively planted. While its sound absorptivity will increase with time as plantings mature and root systems develop, it is unlikely to ever approach that provided for the scale model berms by the felt layer.

Figure 4.3; A Relatively Sound absorptive Berm Near the McKenzie Interchange, Victoria

5. Effects of Vegetation on Wall and Berm Performance

Vegetation as a Noise Barrier

It is a common misconception that planted vegetation, such as a row of trees or shrubs, can provide an effective barrier against noise. Some extremely dense (and no doubt old) English hedgerows have been shown to provide 2 to 3 dBA of attenuation, while wide belts of mature forest are commonly considered to provide noise reductions of about 5 dBA per 30 m of forest width up to a 10 dBA maximum. However, ***the noise shielding benefits from any vegetation buffer that could practically be planted along a highway would be almost entirely psychological.***

This is not to say that vegetation screens have no value. Where site geometry precludes effective noise shielding with a barrier, or where project noise impacts will exist but do not warrant mitigation, vegetative screens can create "perceived" noise reduction benefits by removing the traffic from view and can generally ameliorate many of the negative proximity effects of highways.

Vegetation as a Sound Absorber

Highway noise barrier walls are typically sound reflective. Their hard, non-porous surfaces absorb little sound, rather they reflect most of it back across the highway. Where such reflections would cause significant noise level increases at other residences, the barriers may need to be tilted or, at considerable extra cost, made highly sound absorptive.

Vegetation planted along the highway side of a noise wall will both absorb and scatter sound waves striking the wall. The sound absorption effectiveness of vegetation in such situations has not in general been quantified but cannot be expected to approach that of proprietary sound absorptive wall products. However, it can be expected that:

- the more dense and continuous the vegetation the greater the absorption, and
- broad-leafed plants will tend to be more effective than conifers of similar size and density.

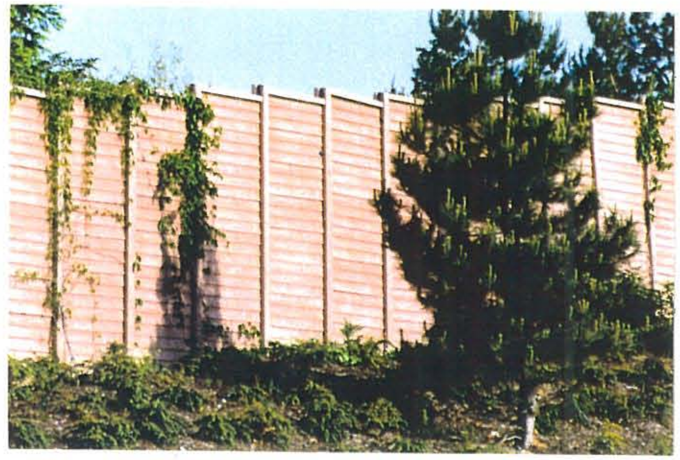


Figure 5.1; Vegetation Begins to Add Sound Absorption to a Wall Surface

Vegetation as a Sound Scatterer

Where vegetation overtops a noise barrier, it will scatter sound (particularly mid and high-frequency sound which is most effectively blocked by the barrier) back down behind the barrier, thereby reducing its overall effectiveness. This capacity for vegetation to scatter and reflect sound is very eveident when driving in an open car along a street overhung with leafy trees.

While the effects of vegation on noise barrier performance are difficult to quantify, the following rules of thumb can be applied:

- the denser the plantings the greater the scattering effect,
- broad-leafed plants tend to scatter sound more effectively than coniferous plants,
- the more the vegetation protrudes above the noise barrier, the worse the effect,
- the closer the vegetation is to the noise barrier, the worse the effect,
- scattering effects are most noticeable outdoors and fairly close to the barrier.

Appropriate Berm Landscaping

There are several forms of landscaping that are appropriate for use on noise berms or near noise walls. These forms will not cause any significant amount of sound to be scattered down behind the berm or wall and will tend to increase the sound absorption capacity of the berm or wall surface.

Grass is certainly one acceptable form of berm landscaping, however, depending on location (rural versus urban/suburban) and climate (arid versus coastal marine) it may require routine mowing and/or watering during the warmer months.

Shrubs and small bushes scattered over grassy or wood chip/bark mulch dressed berm surfaces are acceptable provided the shrubs and bushes do not grow above the crest of the berm. Broad-leafed plants which will grow to more than 1 m in height should not then be planted near the crest of the berm. Figure 5.2 below shows a berm on Highway 17 near Victoria which has been planted in such a manner.

Figure 5.2; A Berm Dressed with Bark Mulch and Planted with Small Bushes and Shrubs

Grassy berms with occasional bushes or trees (preferably conifers) may be acceptable provided the trees are quite widely spaced and not too large - the larger the trees the greater the scattering potential. Shown in Figure 5.3 below is a berm, again near Victoria, with an appropriate scattering of medium-sized conifers.

Figure 5.3; A Grassy Berm with Widely-Spaced Coniferous Trees - McKenzie I/C.

Inappropriate Berm Landscaping

Where the trees and shrubs on a berm are allowed to form a solid wall of vegetation, substantial mid and high-frequency sound scattering will occur. Berm insertion loss at receiver positions behind the berm will gradually, and perhaps imperceptibly, be degraded as the vegetation becomes taller and more dense. Subjectively, the effect of such vegetation scattering, like that of sound leakage through cracks or gaps in a noise wall, is to make traffic noise appear natural in character (i.e. not muffled) as if the berm or wall was not present. Figure 5.4 below shows an over-planted and overgrown berm (on private property) along Highway 17 near Highway 10 in Delta.

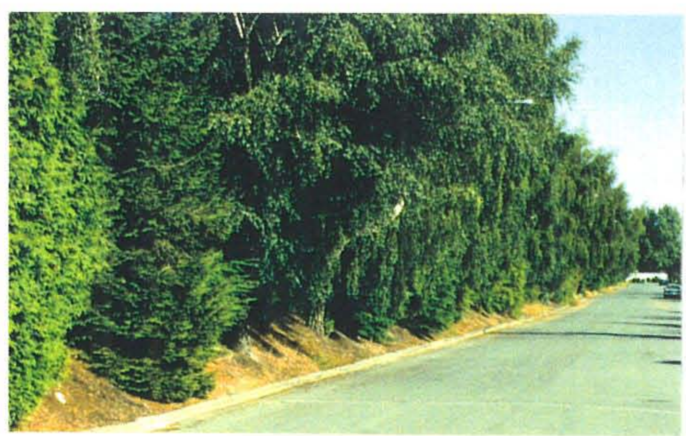
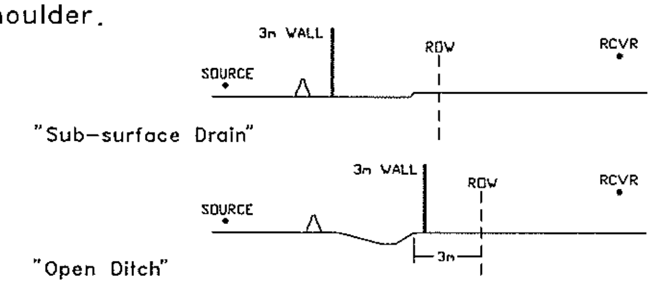
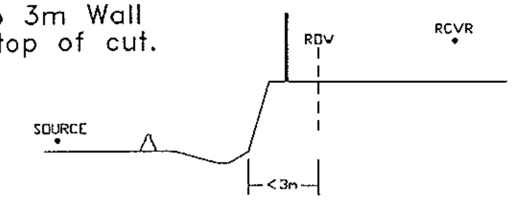
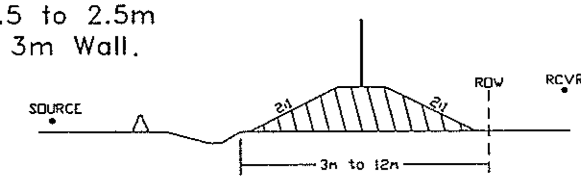
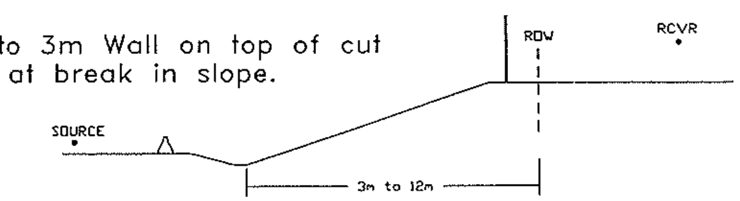
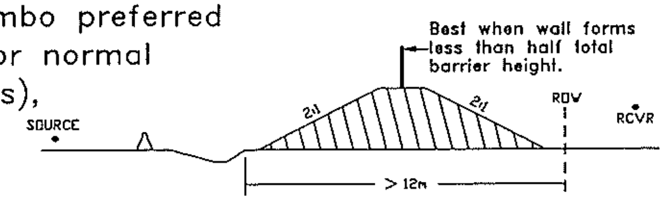
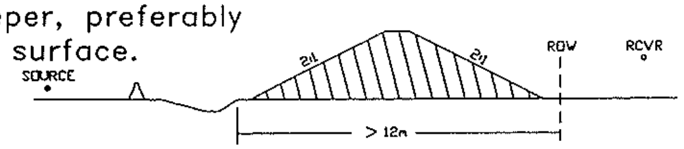
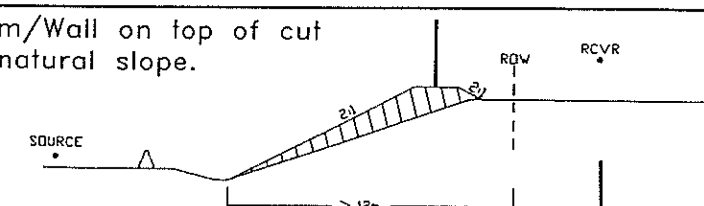
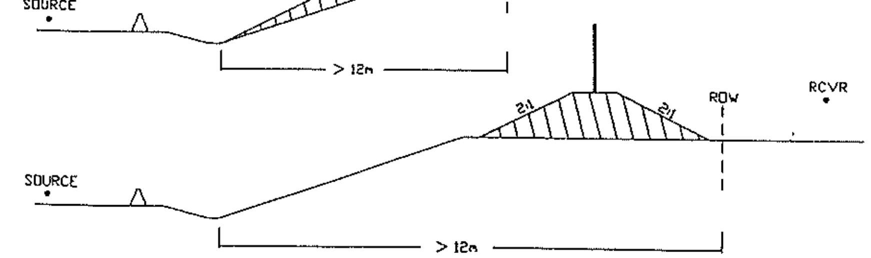


Figure 5.4; An Overgrown Berm - Highway 17, Delta

AVAILABLE RIGHT-OF-WAY[1]	OPTIMAL FORM FOR HIGHWAY NOISE BARRIERS[2]	
	Receiver Near Highway Elevation	**Receiver Well Above Highway Elevation**
Less than 3 m	• 2m to 3m Wall on Shoulder. 	• 2 to 3m Wall on top of cut. 
3 m to 12 m	• Berm/Wall; 0.5 to 2.5m Berm, 1.5 to 3m Wall. 	• 2 to 3m Wall on top of cut or at break in slope. 
More than 12 m	• Berm/Wall combo preferred (particularly for normal Berm surfaces),  • or, Pure Berm 3m or higher 2:1 or steeper, preferably with "soft" surface. 	• Berm/Wall on top of cut or natural slope.  

1. From the edge of travelled way (if sub-surface drainage) or from the outside of ditch if surface drainage.
2. Note, that these represent the most effective barrier configurations in typical situations, but that each situation must be examined in detail to confirm the optimal form(s).

Table S-1; Optimal Forms for Highway Noise Barriers in Various Situations (Right-of-Way Widths and Highway/Receiver Geometries)

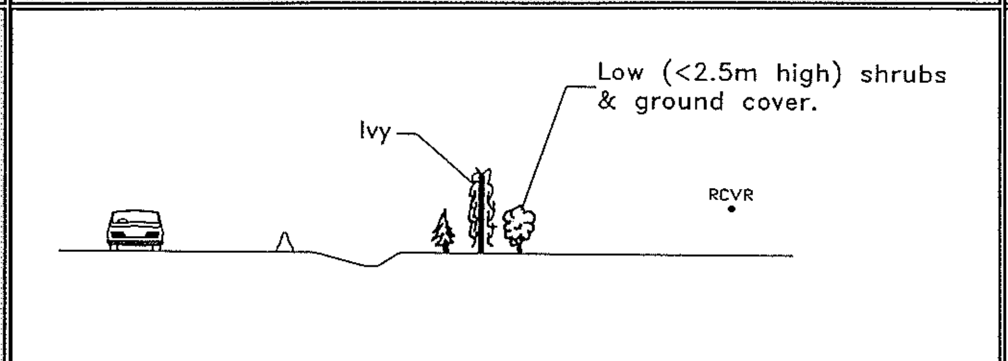
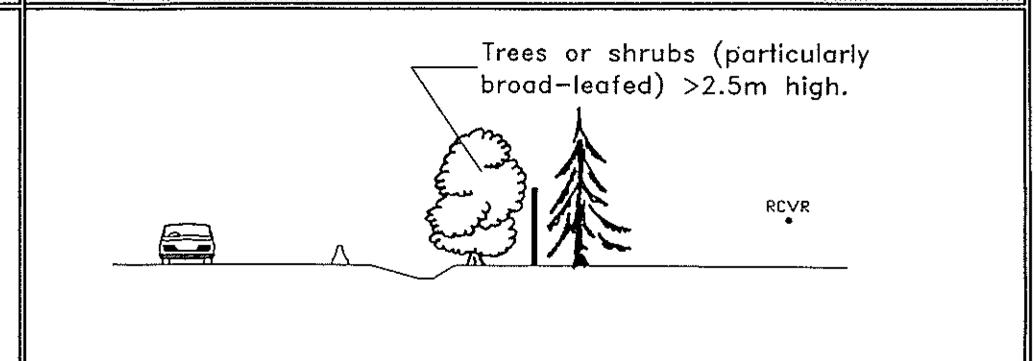
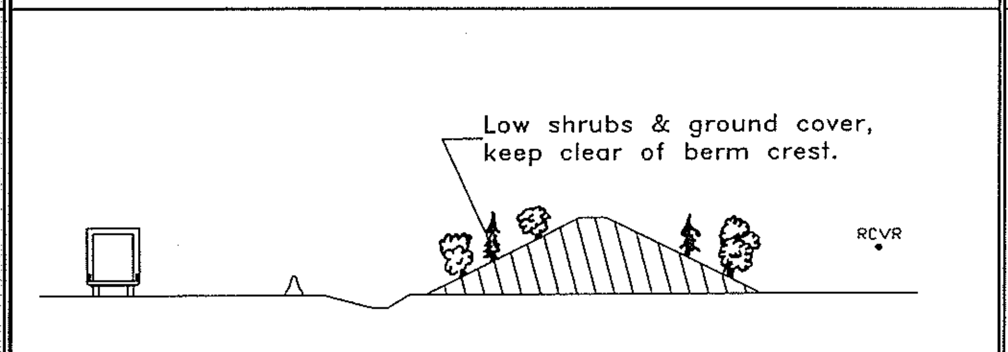
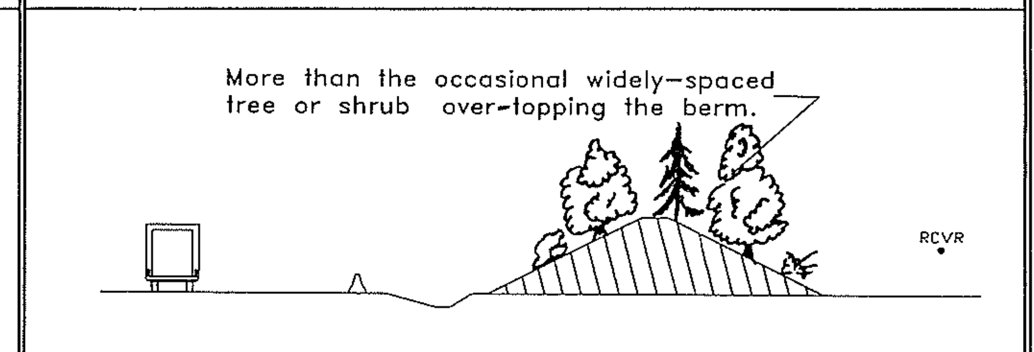
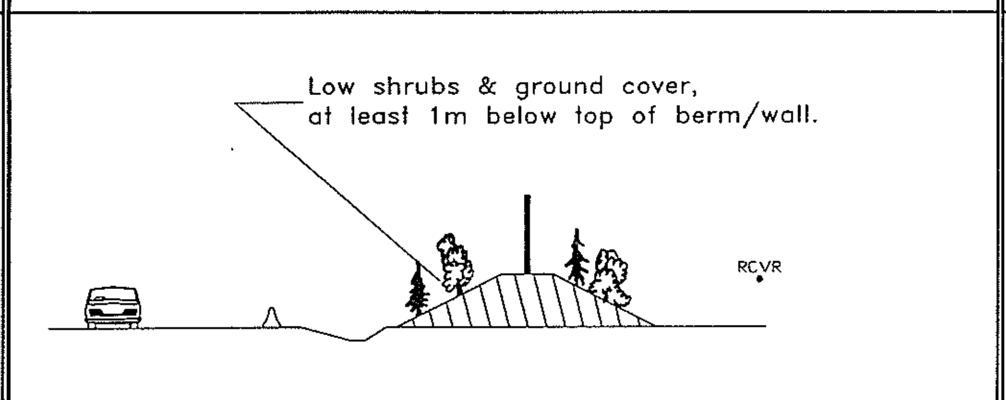
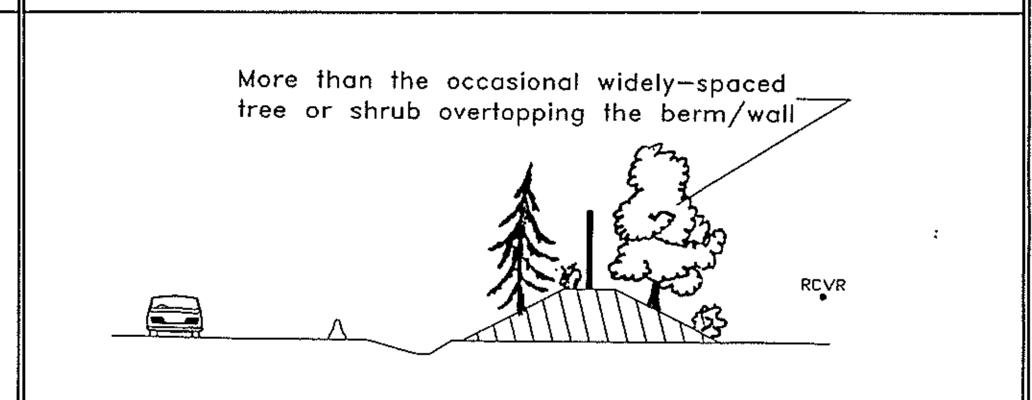
TYPE OF NOISE BARRIER	APPROPRIATE FORMS OF LANDSCAPING	INAPPROPRIATE FORMS OF LANDSCAPING
Noise Walls		
Earth Berms		
Berm/Wall Combinations		

Table S-2; Appropriate and Inappropriate Forms of Vegetation (Landscaping) for use on Earth Berms and Adjacent to Noise Walls

Glossary

Absorption The dissipation of a sound wave's energy upon striking a surface, primarily through the conversion of the motion of air molecules into heat within the surface material.

Attenuation A general term referring to the reduction in noise brought about by a particular noise control measure. Here more specifically referring to the reduction in traffic noise achieved by a barrier in the absence of any soft ground effects.

Avoidance The design and location of a highway to minimize the potential for creation of noise impacts on adjacent sensitive areas.

Bright Zone The area, typically above a noise barrier, which sound may penetrate without being reduced in intensity by the barrier.

dB The abbreviation for "decibel", which is the unit of Sound Pressure Level, or sound level, or more commonly, "noise".

dBA The abbreviation for "A-weighted decibel", which is the unit of Sound Pressure Level when an "A-weighting" has been applied to simulate the response of the human ear to sounds of different frequencies.

Diffraction The tendency of sound waves, which increases with increasing wavelength (decreasing frequency), to bend around solid obstacles.

Frequency That property of sound giving rise to the subjective impression of "pitch" and indicating the rate of fluctuation of sound pressure. Expressed in cycles per second or Hertz (Hz.).

Ground Effect The reduction in the intensity of sound at a distance from a source due to destructive interference (cancellation) between direct and ground-reflected sound waves. Most pronounced over soft ground.

Insertion Loss The net effect of the introduction of a noise barrier between the noise source (e.g. highway) and a given receiver position - including any lost "ground effect".

Intensity The primary property of sound giving rise to the subjective impression of loudness.

Loudness The subjective impression of sound which results primarily from its intensity but also from its frequency and other lesser factors. People typically judge that the loudness of a given sound doubles with each 10 decibel (dB) in its sound level. A 3 dB change in sound level is typically just noticeable while a 5 dB change is readily noticeable.

L_{eq} The abbreviation for "equivalent sound level" or equivalent continuous noise level; i.e., that continuous, steady noise level which over a given time period, would result in the same sound energy exposure as would the actual time-varying community noise level.

L_{eq}(1 hour)	The equivalent continuous noise level during any 1 hour period; when applied to highway noise exposures at educational facilities, the hour should be between 8:30 am and 3:30 pm.
L_{eq}(24)	The equivalent continuous noise level over a 24-hour period; used for measurement of noise exposures at residences and prediction of highway noise exposures.
L_n	The abbreviation for "Exceedance Level", i.e., that noise level which is exceeded for "n" percent of a given monitoring or prediction period.
L_{10}	That noise level which is exceeded for 10% of the measurement or prediction time period - a reasonable representation of the peaks noise levels associated with heavy truck pass-bys on a busy highway.
Mitigation	The reduction of potential highway noise impacts through the construction of roadside noise barriers or, potentially at schools, the enhancement of the sound insulating capabilities of buildings.
Path Length Difference	The extra distance which sound is forced to travel in going over the top of a noise barrier to reach a receiver position. This largely determines the barrier's effectiveness.
Reflected Sound	Sound that is redirected in a fairly coherent and directional fashion after encountering a large-scale surface such as a noise wall or building.
Scattered Sound	Sound that is redirected in quite a random fashion after encountering small-scale obstacles such as the foliage of trees or the facets of rough-textured surfaces.
Shadow Zone	The area, typically behind a noise barrier, which sound can only reach by diffracting over the barrier or by being transmitted through it and where, as a result, noise levels are the reduced due to the barrier's presence.
Sound Pressure Level	Or Sound Level, is the scale most commonly used to express the intensity or "volume" of sound. It is equal to 20 times the common logarithm of the acoustic (or sound) pressure divided by a very small reference pressure. It is expressed in decibels (dB) and in everyday experience may range from about 20 to 120 dB.
Transition Zone	Area near the top of a noise barrier, between the bright zone and the shadow zone, where the barrier's shielding effect is just beginning to be felt.
Transmitted Sound	The sound which reaches a receiver position after passing directly through a noise barrier. If the barrier has sufficient surface density and is free of leakage, then the transmitted sound is negligible.

Appendix A

Ministry of Transportation & Highways of B.C.

REVISED POLICY FOR MITIGATING THE EFFECTS

OF TRAFFIC NOISE

FROM FREEWAYS AND EXPRESSWAYS

SUMMARY

REVISED POLICY FOR MITIGATING THE EFFECTS OF TRAFFIC NOISE FROM FREEWAYS AND EXPRESSWAYS

SUMMARY

NOVEMBER 1993

Province of
British Columbia

Ministry of Transportation
and Highways

HIGHWAY ENVIRONMENT BRANCH

3rd Floor, 940 Blanshard Street
Victoria, B.C.   V8W 3E6

REVISED POLICY FOR

MITIGATING THE EFFECTS OF TRAFFIC NOISE FROM FREEWAYS AND EXPRESSWAYS

Prepared For:

Highway Environment Branch,
Ministry of Transportation & Highways
Victoria, B.C.

Prepared By:

Wakefield Acoustics Ltd.
Victoria, B.C.

1 *Mitigating Noise Impacts of New and Upgraded Freeways and Expressways*

In relation to its mandate to provide new and upgraded highway facilities to supply the province's needs for increased transportation capacity and safety, the B.C. Ministry of Transportation & Highways (MoTH) recognizes that without proper planning, design and control measures, such major improvements to the highway system may be accompanied by excessive noise impacts on adjacent communities. As a result ***the potential community noise impacts of all MoTH projects involving the new construction or substantial upgrading (including alignment changes, new movements or increased numbers of through lanes) of controlled-access highways (freeways and expressways) will be evaluated and mitigation will be carried out where warranted, cost-effective and desired by the majority of the directly-affected community.***

Active mitigation measures will generally be carried out within the MoTH right-of-way and involve the construction of ***roadside noise barrier walls, earth berms or combinations of these elements.***

2 *Avoiding Highway Noise Impacts Through Land Use Controls*

Any effective strategy for minimizing the negative effects of highway noise must include the avoidance of future impacts through the appropriate control of land use along existing and planned highway corridors. Towards this end, the MoTH will promote the adoption - by the appropriate municipal government(s) - of effective land-use controls and/or design requirements for noise sensitive land uses on properties adjacent to existing or planned highway corridors.

3 *Noise Impact Mitigation Criteria and Objective for Residences*

The MoTH noise policy utilizes the widely recognized, sound energy-based community noise descriptor known as the ***24-hour equivalent sound level, or $L_{eq}(24)$*** - with units of decibels (dB). It is acknowledged that noise from highway projects can impact on residential areas either by exceeding threshold $L_{eq}(24)$ levels for significant interference with essential activities like speech communication and sleep, or by substantially increasing community noise levels over pre-project ambient noise levels.

Mitigation will not be considered where predicted $L_{eq}(24)$'s, ten years after project completion, are less than 55 dB. Impact avoidance, however, will be considered in such situations where feasible. ***Mitigation is warranted, and will be carried out where cost-effective, practical and broadly supported by the directly-affected residents, wherever the exterior $L_{eq}(24)$ at the ground floor level of adjacent residences, ten years after project completion, is predicted to be:***

1. <u>from 55 to 65 dB</u> inclusive and exceed pre-project, or ambient, noise levels by a minimum amount which progressively decreases from 10 dB at a pre-project level of 45 dB to 3 dB at a pre-project level of 62 dB (see accompanying graphical representation of policy), or

2. <u>over 65 dB</u> and exceed pre-project noise levels by 3 dB or more.

In order to justify the considerable cost of highway noise mitigation works, ***they must be able to achieve a minimum reduction in project $L_{eq}(24)$ of 5 dB when averaged over the worst-impacted locations - typically the first abutting row of residences.*** Where site topography and highway/noise receiver geometry are favourable, efforts should be made to achieve larger reductions.

4 Noise Impact Mitigation Criterion and Objective for Schools

The primary function of schools and other educational facilities is communication, largely through the spoken word. Excessive levels of intrusive noise within classrooms can interfere with this function by masking or interrupting speech and by distracting the attention of students. ***Highway noise mitigation will be considered - and implemented where cost-effective and practical - for educational facilities where it is projected that, ten years after project completion, daytime (typically 8:30 am to 3:30 pm) traffic noise levels inside classrooms will exceed L_{eq}(1 hour) 47 dB and will have increased by 3 dB or more over pre-project levels.***

Mitigation measures will, where feasible, be carried out within the MoTH right-of-way. Where effective mitigation of classroom noise levels through measures taken within the right-of-way will not be feasible (e.g. for multi-storey schools), consideration will be given to the treatment of the school facade(s). ***Mitigation works must be capable of achieving a minimum 5 dB reduction in L_{eq}(1 hour) within impacted classrooms.***

5 Policy Restrictions

5.1 Development Must Precede MoTH Project Announcement - The ***MOTH will not mitigate highway noise impacts at residences or schools for which planning approvals were not issued by the appropriate municipal authority prior to the first public announcement of the highway project*** or the designation (through gazetting) of the affected lands as potential future highway right-of-way, whichever occurs first. For multi-phased highway projects, the first public announcement is considered to be that which accompanies the initial project phase.

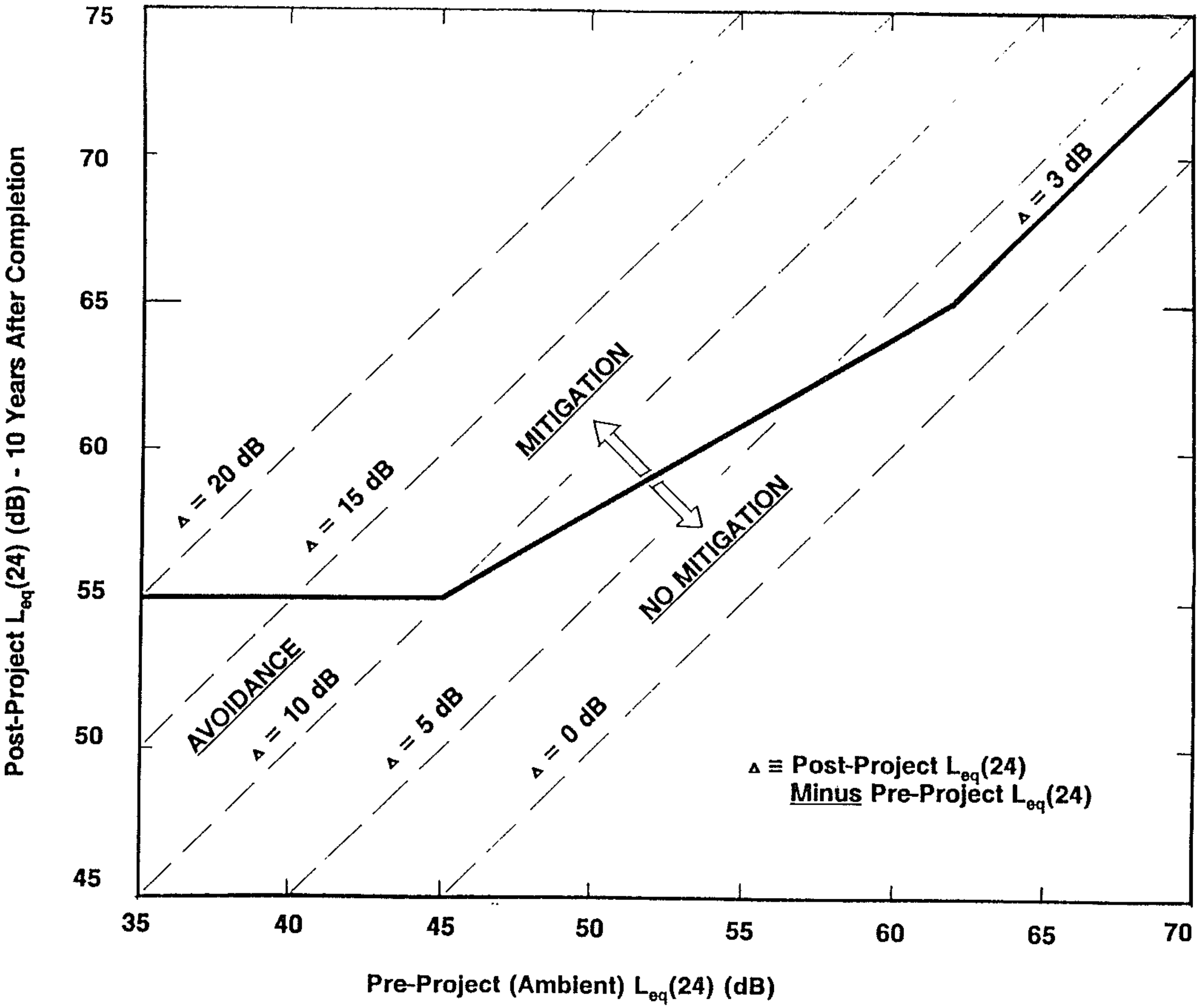
5.2 Height Limitations for Noise Barriers - Earth berms, when used as roadside noise barriers, may be of any reasonable height, subject to soil conditions and the availability of adequate right-of-way and fill materials. However, to limit visual impacts and shading effects and to control costs, which tend to increase rapidly with height, ***vertical or near-vertical barrier walls are limited to 3 m in height.***

5.3 Mitigation Cost Guidelines - Noise mitigation costs and benefits must be rationalized on a project by project basis. However, ***a benchmark maximum cost has been established of $15,000 (1993 dollars) per directly-fronting residential unit.***

5.4 Restriction of Mitigation to Controlled-Access Highways - Because of the importance of preserving local access, pedestrian security and utility services, roadside noise barriers are neither practical nor effective along uncontrolled-access roadways such as arterials or minor highways. ***Mitigation will therefore not be considered for uncontrolled-access roadways,*** with the possible exception of limited areas adjoining intersections/interchanges with controlled-access highways.

5.5 Eligibility of Residences/Schools for Mitigation - There are no restrictions on the eligibility of residences/schools for ***mitigation consideration*** provided policy criteria are met and the developments precede the highway project. More specifically:

- there is no minimum number of residences which must be impacted by project noise,
- there is no specific number of housing rows or highway setback distance within which impacted residences/schools must lie,
- residences/schools which have, as a result of a project, had their setback distances increased, may still be eligible for mitigation.



Pre-Project	Post-Project	Increase
≤ 45	55.0	≥10.0
46	55.6	9.6
47	56.2	9.2
48	56.8	8.8
49	57.4	8.4
50	58.0	8.0
51	58.5	7.5
52	59.1	7.1
53	59.7	6.7
54	60.3	6.3
55	60.9	5.9
56	61.5	5.5
57	62.0	5.0
58	62.6	4.6
59	63.2	4.2
60	63.8	3.8
61	64.4	3.4
62	65.0	3.0
63	66.0	3.0
64	67.0	3.0
65	68.0	3.0
etc...		

Figure 2.1: Graphical Representation of MoTH Noise Policy Criteria for Residences