Recent Developments in the Design and Performance of Road Traffic Noise Barriers

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Abstract

The present paper deals with some recent developments in the design and performance of roadside barriers that are applied as a means of controlling road traffic noise. It is a review paper that is based on the outcomes of literature and information searches undertaken for and on behalf of the Roads and Traffic Authority of NSW. Some interesting, ongoing developments in the design and performance of traffic noise barriers have been identified. In particular, three types of innovative barrier designs were identified that appear to offer the potential for increased attenuation without the need for substantial increases in barrier height. Each of these developments is considered in some detail in the paper and recommendations are made for the possibility of pursuing them further.

Introduction

Roadside barriers represent an important means of controlling the noise generated by road traffic. As well documented in both Roads and Traffic Authority of NSW (RTA) (1991) and Road Directorate of Denmark (RDD 1991), there is a wide range of barrier types and designs available and in service at present in Australia and in many other developed nations. Currently, barriers used in urban/suburban areas are typically 2 to 3m in height, and these can achieve attenuations up to around 10 dBA. However exceeding this and obtaining, say, 15 dBA is extremely difficult and, for practical purposes, generally not possible. To do so requires very tall barriers in the order of 8m. It is generally accepted that barrier attenuation increases with barrier height according to a deterministic function that is reasonably well understood. However, the cost of barriers increases dramatically with the attenuation provided and similarly with barrier height.

Advances in barrier design to improve attenuation performance have been slowly made in recent years. The present paper documents the outcomes of literature and information searches undertaken to determine current developments in the design and performance of traffic noise barriers. The work reported herein was conducted under contract to the Asset Performance Technology Branch of RTA.

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Existing Roadside Barrier Technology

The application of roadside barriers for traffic noise control represents a well established technique that has found wide application within Australia and throughout the developed world (RTA 1991, RDD 1991). Based on the pioneering work of Maekawa (1968) and Kurze (1974), the technology revolves around some relatively simple algorithms that describe the combined effects of sound transmission loss through a barrier in conjunction with the diffraction of sound over (and in some cases around) the barrier. In terms of roadside barrier design, the most common application of this technology hitherto in Australia has been via the calculation procedure set out in UK DoT (1988). This well-known procedure puts barrier attenuation as a function of the path length difference between the diffracted wave path (over the barrier) and the direct wave path from source to receiver.

Some enhancements to this basic type of technology have been reported recently (Hansen and Burroughs 1998, Herman et al 1998, Clairbois et al 1998). A considerable Research and Development effort in the area of traffic noise propagation and the effects of barriers on this

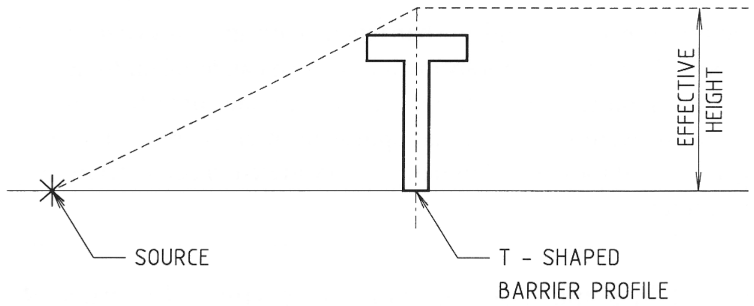

Figure 1. Effective height of a barrier. [Sketch based on Hothersall (1991) as reproduced in Watts (1992)]

propagation was recently conducted in the USA. This work was performed within the overall program of developing the new US Department of Transportation, Federal Highway Administration (FHWA) Traffic Noise Model (TNM) (Menge et al 1998, Menge et al 1996).A significant limitation with all these developments is that applying their outcomes to achieve high levels of traffic noise attenuation generally involves the adoption of tall, imposing barriers. Typically such barriers are expensive (they are primarily governed structurally by wind load considerations), unsightly and difficult to construct and maintain. Overcoming these problems leads to the consideration of technological developments which now follow. Generally the concept behind this new technology is to achieve an increase in attenuation without an increase in barrier height.

Current Technological Developments

Barriers with Novel Shaped Cappings

Simple Shapes

Barriers of this type incorporate various capping arrangements which come in a range of design formats. Watts (1992) and Hothersall (1992) explain the features of such barriers and the attenuation performance they are purported to provide. The original examples of these barriers had a uniform capping fitted such that the cross sectional shape of the barrier typically became like a T, as illustrated in Figure 1. The increased attenuation produced by such a barrier is due to the increased effective height, again as shown in Figure 1. Several variants of this design have appeared, common examples of which are the so-called multiple edged barriers sketched in Figure 2. Crombie et al (1988), Hajek and Blaney (1984), Hasebe (1988), Iida et al (1984) and Watts (1992) have all studied

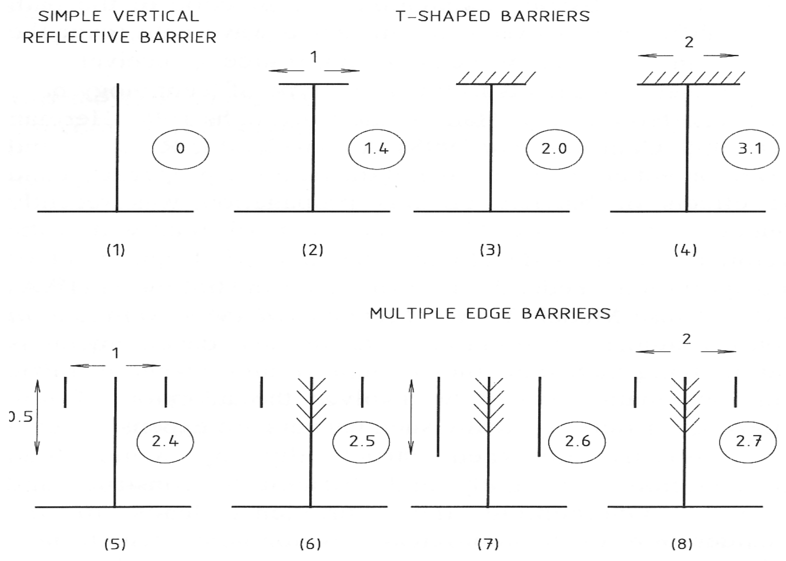

Figure 2. Various barrier capping arrangements. [Sketch based on Watts (1992)]

the performance of several of these barrier types and the consensus of all this work is that they can deliver small but useful increases in attenuation of around 2 to 3 dB, compared to conventional barriers.

More Complex Shapes

Sophisticated and complex numerical modelling methods, along with scale modelling techniques (Jean 1998, Hutchins et al 1984A and 1984B, Hothersall et al 1998) have evolved to facilitate the study of barriers with alternative shaped cappings. Some quite complex capping shapes have appeared recently (Fujiwara et al 1998, Shima et al 1996, Shima et al 1998), an example of which is shown in Figure 3. According to Amram and Masson (1992), these complex shapes are configured on the basis of their capability to create a destructive interference sound field around the top of the barrier, thereby producing increased attenuation. Amram and Masson (1992) suggested that attenuation increases in the order of 3 to 5 dBA are possible with such barriers. This finding is confirmed in the results of Shima et al (1998), Watts et al (1994), Watts (1996) and Watts and Morgan (1996).

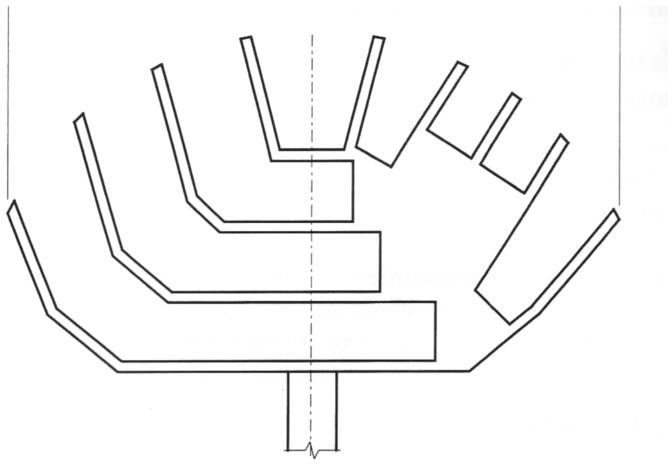

Figure 3. Cross-section of alternative capping arrangement. [Sketch based on Fujiwara *et al* (1998)]

Absorbing Edge Barriers

Absorbing edge barriers achieve a gain in attenuation by the attachment of a sound absorbing device on the top edge of the barrier. At its simplest this involves use of a barrier of curved cross sectional shape (Pierce et al 1986) and could typically take the form of an earth mound covered in soft vegetation. They indicated that, in theory, small increases in attenuation of the order of around 1 or 2 dB are possible with this technique.

More recently there has been some work reported on the use of absorptive cylinders to provide the absorbing edge (Fujiwara 1989, Yamamoto et al 1989 and Fujiwara and Furuta 1991). The type of barriers resulting from this concept is similar to that of Figure 3, with the device shown in Figure 3 replaced with an absorptive cylinder along the top of the barrier. The theoretical analysis of the behaviour of such a barrier is most complex and difficult and requires higher order numerical simulation techniques. It seems that the increases in attenuation attributed to barriers of this particular type arise from enhancing the capacity of the barrier to reduce the sound diffracted over the top of the barrier. Field tests reported by Fujiwara and Furuta (1991) suggest that the increased attenuation from such barriers is in the order of 2 to 3 dBA.

While these results are indeed encouraging, more work seems necessary to produce a satisfactory, serviceable engineering design for the absorptive cylinder units. Several types have been trialed experimentally and a design for a perforated metallic type has been suggested (Fujiwara and Furuta 1991). A more recent design involves a device with a cross sectional shape said to be like a mushroom (Yamamoto 1998). Again this device gave about 2 dB improvement in attenuation compared to a conventional barrier. Further work on barriers fitted with absorptive cylinders would therefore appear to be warranted.

Longitudinal Profiled Edge Barriers

Early Technology

Wirt (1979) originally suggested that improvements in barrier performance could be obtained by application of a longitudinal profile to the top edge of a barrier. The theory behind this suggestion also involves the creation of a destructive interference sound field. Wirt investigated this theory via laboratory based scale model tests on both flat topped and pointed sawtooth top profiles that were known as "Thnadners". In Figure 4 these two "Thnadner" shapes have been sketched. The results of Wirt's tests were that improvements in attenuation in the range 1.5 to 4.0 dBA were obtained with the profiled barriers.

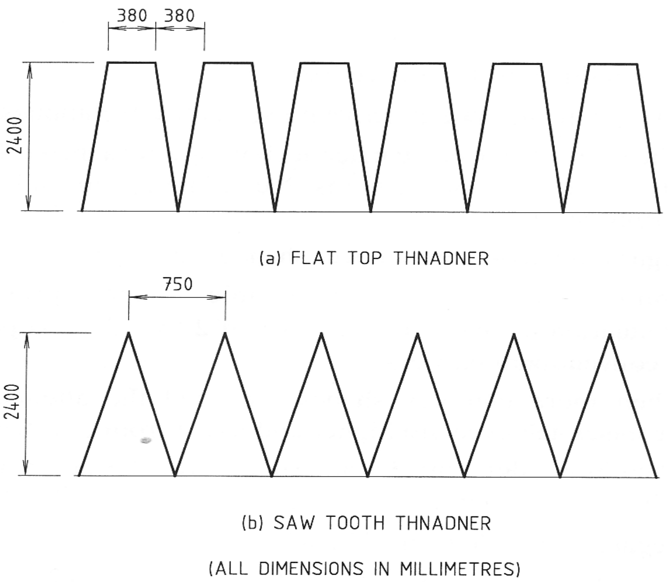

Figure 4. "Thnadner" designs. [Sketch based on Wirt (1979)]

Subsequently, similar laboratory model studies of "Thnadner" style barriers were undertaken independently by May and Osman (1980) and by Hutchins et al (1984). Both these studies contradicted the Wirt conclusions and indicated that the "Thnadner" barriers exhibited poorer performance than conventional barriers of the same height. The advanced theoretical analyses and laboratory studies of Maekawa and Osaki (1986) also supported this view.

Technical debate about these differing conclusions focused on the nature of the scale modelling processes and, in particular, how ground absorption effects were included in the experiments. It has been suggested as a result of these debates that full scale field tests would be required to resolve the situation to an adequate degree of scientific rigour (Watts 1992). To date it would not appear that any such experimentation has been undertaken.

Random Edge Barriers

More recently Ho et al 1995A, Ho et al 1995B, Ohm et al 1997, Ho et al 1997, Rosenberg and Busch-Vishiniac 1997, and Menounou et al 1998 have been investigating similar types of barriers where the profile applied to the top edge is random in shape.

The theoretical concept here involves the manner in which sound is diffracted over the top of a barrier.

In the case of a straight topped barrier this particular theory assigns the noise source (that is the road traffic) as a straight line source comprising a long string of highly correlated point sources. Consequently the coherence of the sound diffracted over the barrier acts to set an upper limit on the attenuation performance of the straight edged barrier.

To overcome this problem the theory suggests that the barrier be redesigned so as to interfere with the coherence of the diffracted sound, thereby increasing the attenuation performance of the barrier. One way of achieving this is to replace the straight edge top of the barrier with a random edge profile.

This theory has been embodied into a "Directive Line Source Model" (Menounou et al 1998) to predict the diffraction behaviour of sound over barriers with straight and random profiled edges.

This model has been shown to perform well in extensive laboratory based evaluation trials (Menounou et al 1998, Rosenberg and Busch-Vishniac 1997). One particular finding of their work was that the performance of random profiled barriers increased as the profile became more pronounced or "jagged".

An example of their random edge profiles is drawn in figure 5, while some typical laboratory performance results appear in Figure 6. The profile demonstrates a reasonable degree of randomness as might be expected. However the experimental results show two clear findings

- The insertion loss (attenuation) produced by random edged barriers exceeds that of conventional barriers at the higher frequencies.
- However the insertion loss of random edged barriers is less than that of conventional barriers at the lower frequencies.

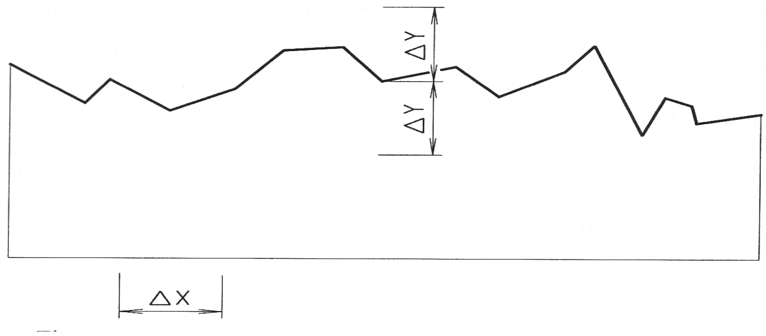

Figure 5. A random edge profile. [Sketch based on Ho *et al*

It would appear that the transitional frequency that separates the above two ranges of performance is around 5000 to 7000 Hz and this seems to vary with the distance of the receiver from the barrier. This is not a particularly good outcome as far as road traffic noise is concerned as the majority of the acoustic energy generated by road traffic is in the range 50 to 5000 Hz (Samuels 1982). Ho et al (1997) indicated that they intended to work further on understanding an overcoming this problem. At the time of writing this paper, no further information on the progress of this work was available.

What may now be concluded is that the concept of random edged barriers is at an early stage of development. A theory has been developed and a laboratory based scientific investigation of this theory has shown some promising results. Further work is clearly required to understand and resolve the poor performance of such barriers over the frequency range in which road traffic noise sits. While such work might be partly laboratory based, serious consideration should be given to incorporating full scale field tests, in concert with similar recommendations made by Ho et al (1997).

Barriers Incorporating Active Control Techniques

Recently, some attempts have been made to apply active noise control technology to the design and operation of traffic noise barriers. Again, this has involved the fitment of devices to the top edge of a barrier.

Examples of the analytical techniques associated with these types of barriers may be found in Fujiwara and Hothersall (1996), Guo and Pan (1997 and 1998), Ise et al (1991), Omoto and Fujiwara (1991 and 1993) and in Ise and Tachibana (1998). While the reported performance of barriers using active control vary a little, the overall results are consistently that such barriers provide increases in attenuation of around 5 to 10 dB compared to conventional barriers. Duhamel (1998) and Duhamel et al (1998), for example, demonstrated such performance potential via an outdoor experiment utilising stationary

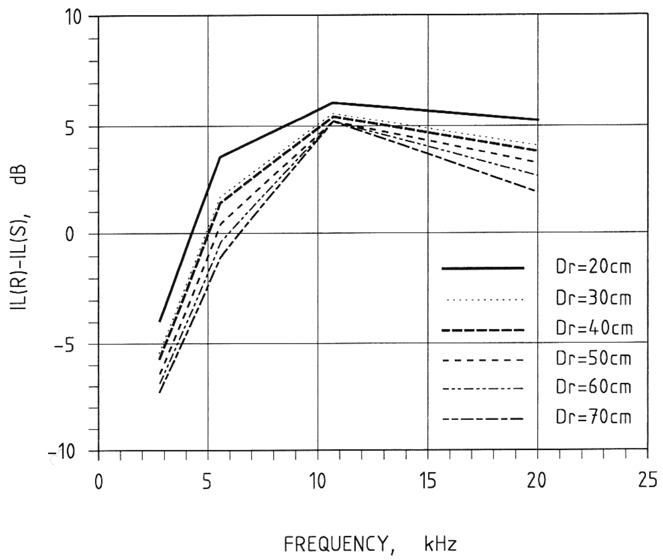

Figure 6. Performance of random edge barrier compared to a conventional barrier. [Sketch approximating that of Ho *et al* (1997)]

noise sources.

Ohnishi et al (1998) have been developing an active noise control device, known as an Acoustical Soft Edge (ASE), that is attached to the top edge of a barrier and incorporated into an active control system. A series of these devices is fitted to the barrier, where each device is controlled individually and may be tuned to specific frequency ranges. There are some limitations to the frequency range possible for a particular ASE device and these limitations are related to the physical size of the device.

The devices investigated by Ohnishi et al (1998) operated from about 100 Hz to around 1000 Hz which is particularly appropriate as far as traffic noise is concerned. They undertook a series of theoretical studies comparing the performance of ASE devices of various shapes against that of a conventional barrier. Overall they concluded that their active control devices improved barrier attenuation by 3 to 5 dB within the 100 to 1000 Hz frequency range and this must be regarded as a considerable achievement. As yet, however neither field nor laboratory trials have been conducted on these devices. So doing may well prove to be technically challenging indeed, given that traffic noise is essentially comprised of many time varying, moving, extended sources.

Consequently, it may be concluded that the techniques of active noise control as applied to barriers appear promising but are presently at an early stage of development. It would seem that they may be applied in the frequency range within which traffic noise occurs.

While considerable developments in the theory surrounding this technology have been made, these do not yet appear to have been explored further via empirical based investigations. Such investigations would appear to be warranted.

Conclusions and Recommendations

Conclusions

On the basis of what appears in the present paper, the following conclusions have been drawn.

1. Technological developments are being made in the design shape and configuration of road traffic noise barriers. These developments have resulted in three types of innovations.

- Barriers with alternative shaped cappings
- Longitudinal profiled edge barriers
- Barriers incorporating active noise control techniques

2. Application of current barrier technology to achieve high levels of attenuation requires the adoption of tall and imposing barriers.

3. In regard to barriers with alternative shaped cappings

- Application of relatively simple shapes provides attenuation increases in the order of 2 to 3 dB compared to conventional barriers.
- When more complex shapes are used the attenuation increases

achieved are higher and range from 3 to 5 dB.
- Absorbing edge barriers appear to have the potential to deliver attenuation increases of 2 to 3 dB.

4. In regard to profiled edge barriers

- Early designs known as "Thnadners" have been shown to have inferior attenuation performance compared to conventional barriers.
- Random edge barriers investigated via laboratory studies in the USA have demonstrated enhanced performance at higher frequencies but reduced performance at lower frequencies. The transitional frequency involved here is around 5000 to 7000 Hz which suggests that in their current format these particular type of barriers are not yet suited to traffic noise applications where the acoustic energy lies primarily in the 50 to 5000 Hz range.

5. In regard to barriers using active noise control

- Application of active noise control techniques to traffic noise barrier applications is at a very early stage of development
- These techniques have been demonstrated to have the potential to enhance barrier attenuation performance by possibly 5 to 10 dB.
- The techniques can be applied within the 50 to 5000 Hz frequency range of road traffic noise.

Recommendations

What is contained in the body of the present paper along with the above conclusions leads to the following recommendations for further work in the field.

1. Pursuing the design and development of barriers with novel shaped cappings would seem to be worthwhile.

2. Random edge barriers clearly require a considerable research and development effort before they could be deemed suitable for traffic noise applications. Should such work proceed, it is recommended that it should have particular emphasis on an empirical evaluation approach.

3. Barriers utilising active noise control technology also require a substantial technological program to achieve practical, engineered applications.

Acknowledgement

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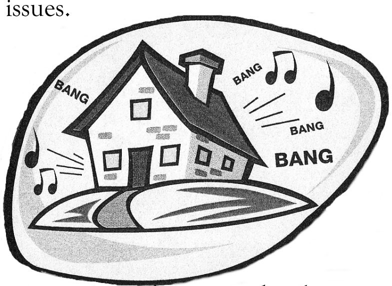
Manukau City Addresses Noise

Manukau City Council have recently issued a brochure called “Noise Control in our Streets”.

Subtitled “Dealing with Excessive Noise Issues in Your Neighbourhood”, the leaflet gives a good overview of what residents can and can’t do about noise issues.



Beginning with a reminder that there is no set level which constitutes excessive noise, the discussion leads on to practical suggestions on being a good neighbour.

If that doesn’t work for you, there is advice on who to complain to, and what happens when you complain.

For more information, visit www.manukau.govt.nz

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