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3pNSb3. A review of road traffic barriers for low frequency noise
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Australia relies heavily on road transport due to its large area and low population density in many parts of the country. Trucks and heavy vehicles are commonly used for road freight. In addition to their normal vehicle brakes, heavy vehicles are typically fitted with release engine brakes which operate by causing the engine to act as a compressor when braking. Compression braking generates a distinct low frequency rumble that can be heard at large distances and is a major source of community annoyance reaction against the heavy vehicle industry. Noise from compression brakes is an on-going cause of complaint from many Australian residents, particularly in rural areas and at night-time. Noise barriers can be used to reduce the spread of general traffic noise and their effectiveness is determined by many factors. This paper presents a review of barriers optimised for road traffic noise, with a view to selecting barriers that may be more effective at reducing the low frequency and modulation characteristics in the noise from compression brakes.

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INTRODUCTION

Road traffic noise is one of the major environmental problems in urban areas. The increase in the number of vehicles in cities and towns is gradually degrading the environmental quality of urban spaces (Rajakumara and Mahalinge, 2008). The primary impact of transportation noise is related to annoyance and not to other effects such as hearing damage (Samuels, 2006). As public awareness and action has increased, measures have been implemented to reduce traffic noise in the development of new roads and improvement of current infrastructure (Arenas, 2008).

In addition to general, or bulk, traffic noise, another main source of annoyance is the identifiable noise within the general traffic noise such as from the supplementary brake mechanisms required by heavy vehicles. Service brakes can easily overheat and fail on overload vehicles travelling downhill. To overcome this, heavy vehicle manufacturers install supplementary braking devices to decrease vehicle speed on steep descents (NTC, 2007). There are different types of supplementary braking systems (also known as secondary retarders) including engine compression brakes, exhaust brakes, hydraulic retarders, electromagnetic retarders and regenerative brakes. Each type of supplementary brakes emits a different type of noise. For instance, a rumble or whine is associated with an exhaust brake and a hydraulic retarder, respectively. Engine compression brakes are often associated with a characteristic low frequency bark or rumble. Although different types of noises emerge, the distinctive low frequency rumble of the engine compression brakes is often the main source of community complaints in residential areas (NTC, 2007).

In Australia, the most common type among the secondary retarders is the engine compression brake. Reliable efficient operation which reduces the maintenance costs, low weight and long service life are the main reasons for the popularity of engine compression brakes (Austroads, 1993). Thus it is anticipated that other forms of the secondary retarder will not replace the engine compression brake in the short term. Whilst the noise levels from engine compression brakes are unlikely to affect health and well-being, this noise is an on-going cause of complaint from many Australian residents, particularly in rural areas and at night-time. The Australian National Transport Commission (NTC) is a body whose function is to develop, monitor, and maintain regulatory and operational reforms relating to road transport, rail transport, and inter-modal transport. In 2007, NTC reported that excessive noise from engine brakes is the major source of community complaint against the heavy vehicle industry (NTC, 2007). Complaints about noise from engine brakes are usually about the ‘bark’ of the noise rather than the overall volume. Studies were conducted in order to identify the characteristics of engine brake noise that makes it so annoying to the community (Sonus, 2003). The pulsing effect, or modulation, of the noise from engine brakes was found to be the primary cause of annoyance from compression brake noise. A suitable noise descriptor for engine brake noise that correlates well with community annoyance was then developed, called the modulated Root Mean Square (RMS). The NTC approved an in-service standard for engine brake noise with a modulated RMS value of 3 (NTC, 2007).

Different treatments for engine brake noise have been suggested and include control at the source using a well-designed muffler and driver techniques. There is currently no muffler commercially available for specific attenuation of noise due to engine compression braking. Whilst it is expected that a properly designed muffler would significantly reduce noise from engine brakes, mufflers deteriorate with time and require maintenance or replacement to maintain effectiveness. Driver education programs can reduce engine brake noise by encouraging driving at constant speed, reducing the use of engine brakes in residential areas, and ensuring that the condition of the muffler and exhaust system are well maintained (RTA, 2003). This education can be supplemented with advisory signage to warn drivers to not use their engine brakes in built-up residential areas (Heggies, 2006).

A further noise control method between the source and receiver is the design of a noise barrier which is effective at attenuation of the low frequency noise from heavy vehicle engine brake noise. This paper reviews the performance of noise barriers for road traffic noise and the frequency ranges at which the various barrier designs are most efficient. The future work to be undertaken by the authors for reduction of engine compression brake noise is discussed.

NOISE BARRIER DESIGNS

Noise barriers are commonly used to reduce noise in the vicinity of roads. In the presence of a barrier, noise at a receiver location from a source is due to two sound pathways: diffracted waves at the top edge of a barrier and the transmitted pathway through the barrier. Barriers are usually built with solid materials. Since the transmitted sound is very low, the barrier performance is limited by the diffracted sound which is highly dependent on source frequency as well as the relative source and receiver positions and the barrier height.

The acoustic performance of a noise barrier is generally quantified by its insertion loss, which is the difference between the sound level at a receiver position, with and without the barrier. Based on diffraction
theory, there is a relationship between the strength of the diffracted field and wavelength (Guo and Pan, 1998). Noise barriers are more effective at high frequencies than at low frequencies, which presents problems since traffic noise mainly occurs at low frequencies (Melnyk et al., 2009). The simplest way to control low frequency noise is to increase the height of the noise barrier. However, aesthetic problems, cost and safety reasons usually prevent the transportation authorities from erecting very high barriers (May and Osman, 1980).

As the diffraction path between the source and receiver is related to height, there have been numerous studies on the screen height and width to reduce the level of noise in the area behind the barrier, known as the shadow zone (Maekawa, 1968). Since different top edges of a barrier will modify the diffracted waves, various barrier shapes have been investigated in an attempt to achieve the same performance as high straight barriers. The shapes for the tops have included T-shaped, Y-shaped, arrow, cylindrical, multiple and random edge configurations (May and Osman, 1980). Figure 2 presents some of the noise barrier design investigated in different studies. The addition of small extra panels on a vertical barrier was found to increase the effectiveness of the barrier, thus reducing the height compared to a single straight barrier for the same performance (Crombie et al., 1995; Watts, 1996a). Other studies found that the T-shaped edge provide higher insertion loss compared to their simple rigid shapes (Parnell et al., 2010). The slope of the top part of a noise barrier has also been shown to provide an improved performance, with the greatest attenuation of low frequency sound for a slope of 120° (Venckus et al., 2012). Although for most barrier designs shown in Fig. 1 higher insertions losses were observed, it was shown that the random edge profile barrier does not perform as well as a conventional noise barrier at low frequencies (Ho et al., 1997; Parnell et al., 2010).

The use of reactive top surfaces comprised of wells of different depths have also been recently investigated. Monazzam et al. (2010) showed that adding a diffuser on the top of a 3 m high T-shape barrier, as shown in Fig. 2, resulted in greater attenuation compared to an equivalent height of a T-shaped barrier. Although reactive top surfaces are very frequency selective depending on the design frequency of the diffuser, it is possible to improve the barrier efficiency at low frequencies. Using perforated sheets within the diffuser can shift the effectiveness of the barrier to lower frequencies (Naderzadreh et al., 2011). The design of noise barriers with varying cross-section have been optimized using genetic algorithms, however this greatly increases the cost of the barrier (Grubeša et al., 2012).

![FIGURE 1. Noise barrier designs: (a) random edge barrier (Parnell et al., 2010), (b) cylinder shaped (c) T-shaped (d) arrow shaped, (e) Y-shaped, (f) inclined shape, (g) curved shape](image1)

![FIGURE 2. Application of a diffuser on the top side of a T-shape noise barrier (Monazzam et al., 2010)](image2)

The addition of absorptive material to either the top of the barrier or to the side facing the highway generally improves the efficiency of the noise barrier (Watts, 1996a). Absorption treatments can also improve noise barrier performance when the transmission energy through the barrier is high or when multiple reflections are presented (Ming, 2005). Ishizuka and Fujiwara (2004) investigated the effect of different surfaces for noise barriers, corresponding to a rigid surface with a normalized surface admittance of 0, an absorbing surface with a
normalized surface admittance of 1, and a soft surface using a value of $10^6$ for the normalized surface admittance. They showed that the performance of a soft 3 m high T-shaped barrier was similar to that for a 10 m high plain barrier. One of the main constraints of absorptive materials is their high cost. They are also vulnerable to particles from the traffic flow and natural precipitation, such as water, which results in a reduction of performance (Fahy et al., 1995). Behar and May (1980) stated that there are three cases involving the use of sound absorbing materials: installing the material freely without a backing, installing the material on a hard surface without an air gap, and installing the material on a hard surface with an air gap. In the first case, acoustic energy is absorbed better at high frequencies; the second case has a mid-frequency range performance; in the last case, the performance at low frequencies can be improved by increasing the air gap.

Parallel noise barriers are often used when residential areas are on both sides of a highway, resulting in reflections between the parallel screens. The reduction in multiple reflections between parallel barriers can be achieved by tilting the side panels by $10^\circ$ (Crombie et al. 1995) or using absorptive material (Watts, 1996b; May and Osman, 1980).

**DESRIPTORS FOR ROAD TRAFFIC AND ENGINE BRAKE NOISE**

To appropriately design and select a noise barrier as the control solution for road traffic noise, it is necessary to establish a relationship between the barrier performance and descriptors of road traffic noise. Commonly used descriptors for road traffic noise include the Traffic Noise Index (TNI), Noise Pollution Level (NPL), $L_{eq}$ (equivalent continuous sound level) and $L_{10}$ (sound level exceeded for 10% of the time period). These are all based on the A-weighted noise level and take into account the time variation of the noise.

The effectiveness of a noise barrier is generally evaluated by its insertion loss based on the sound pressure level before and after installation. The A-weighted standard traffic noise spectrum (BS EN 1793-3) may be applied to make some corrections for insertion loss at 1/3 octave band frequencies (Watts et al., 2004; Oldham and Egan, 2011; Defrance and Jean, 2003). Only frequencies from 100 Hz to 4 kHz are usually considered due to long computational times for high frequency calculations and the pronounced peak in the traffic noise spectrum of BS EN 1793-3 at 1 kHz.

In the case of engine compression brake noise, the frequency range used to assess the effectiveness of noise barriers should be extended to lower frequencies. Furthermore, it is not only the low frequency characteristics but the intermittent noise events which need to be considered (Fidell and Horonjeff, 1981). Nilsson et al. (2007, 2008) showed that the A-weighted sound pressure level was not a useful indicator for road traffic noise with considerable low frequency noise. Annoyance of road traffic noise with low frequency characteristics may be more suitably described using the Zwickert sound level or a low-frequency corrected sound pressure level.

Sonus (2003) reported that there are few reports in the literature that go beyond using a traditional maximum noise level to describe noise from engine brakes. They also discovered that the modulation of engine brake noise was the cause of annoyance. The standard A-weighted decibel scale measures volume or loudness, but does not capture the pulses or variation from engine brake noise. With no internationally accepted measure for annoyance caused by engine brakes, the NTC (2007) commissioned a comprehensive research project to identify a noise descriptor that correlates community annoyance with noise from engine brakes. A descriptor called modulated Root Mean Square (RMS) was developed and found to be the best noise descriptor that correlates community annoyance with noise from engine brakes. Measurement and signal processing to obtain the modulated RMS of engine brake noise is undertaken in the following manner. A microphone is positioned at a height equal to that of the exhaust outlets of heavy vehicles (nominally at a height of 3.5 metres) and located at a distance of 7.5 metres from the centre of the measurement lane. The microphone location must also be at least 15 metres from any wall, building or other reflecting surface. The noise transmission path is required to be unobstructed for the full length of the minimum recording period of 5 seconds of the vehicle drive by. For the measurements to be valid, ambient and wind noise levels should be below 50 dB(A). The A-weighted sound pressure level captured with a time constant of 5 milliseconds is clipped such that any levels below 60 dB are maintained at exactly 60 dB. The sound level is then filtered by a 6th order 5 Hz to 80 Hz band-pass Butterworth filter in order to remove any steady state noise, such that only noise modulations which fall within the pass-band remain. The output of the filtering process is then exponentially time-averaged with a time constant of 300 milliseconds. The peak value of the result is the modulated RMS of the engine braking noise.

One of the methods for collecting the RMS values of engine brakes is usage of a specific equipment called a Noise Camera Analysis System that can be set up at the roadside to allow automatic recording of engine brake noise (ARL, 2012). The noise camera comprises of three main components corresponding to (i) the noise processing unit and microphone, (ii) the camera processing unit and two video cameras, and (iii) the controller software (Klos, 2006). The noise camera has a nominal flat frequency response from 5 Hz to 15 kHz and is suitable for collecting large amounts of engine brake noise recordings. Parnell and Dowdell (2007) present modulated RMS values of engine brake signals collected with a noise camera. Figure 3 shows the relationship between RMS values and annoyance.
Two main locations for reducing the noise from engine brakes are at the source and in the transmission path. To control the noise at the source, implementation of a muffler is a possible solution. However, there are no mufflers commercially available for reduction of engine compression brake noise. To control noise in the transmission path, an effective noise barrier is required and the challenges in achieving this for engine brake noise are multiple. A further challenge is that the source height for heavy vehicle engines and exhausts are respectively set at 1.5 m and 3.6 m. This results in the necessity of very high barriers for effective performance, which is not usually a practical solution in urban and suburban situations. It is possible to decrease the height of a noise barrier while still achieving effective noise reduction by modifying its shape. However, not all shapes will lead to improved performance at low frequencies. Diffusers with perforated sheets on the top side of a barrier show potential but need further investigation.

Engine compression brake noise of heavy vehicles is identified as an annoyance by communities and the current methods employed are clearly ineffective. There is scope for further research to identify and develop cost effective means for reducing the problem. The opportunities to reduce this noise with the use of a suitably designed muffler and/or with the use of a barrier to attenuate low frequency modulating engine brake noise will be investigated by the authors in the near future.

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REFERENCES


