The use of layered recycled aggregate concrete barriers in targeting urban noise

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Abstract

Transportation noise has become an increasing major issue of modern urban life and at the same time the financial, environmental and social consequences of construction and demolition waste, especially concrete waste, have become less tolerated by the community.

The Infrastructure Service Management Research Group (ISMRG) at Swinburne University of Technology investigated the use of selected recycled and reclaimed (washed) concrete aggregate in the production of sound barriers. Three prototype barriers were manufactured using both recycled and reclaimed aggregate. The resulting barriers consist of either two or three layers that provide structural adequacy and enable the barrier to restrict sound transmission and absorb transportation noise.

Impedance tube and reverberation chamber test results of the barrier material indicate satisfactory acoustic performance of the barriers in the low and mid frequency range and excellent sound absorbency at frequencies above 1,000 Hz. Strength and durability test results of recycled and reclaimed aggregate concrete meet specified requirements.

The paper also presents an assessment of the acoustic performance of the acoustic barriers as a means to attenuate road traffic noise, as a means of reducing reverberation and providing sound absorption in transformer rooms, as a means of reducing noise coming out of traffic tunnels and as a means of lessening of noise from railway tracks.

Keywords: concrete waste, recycled and reclaimed aggregate, transportation noise, sound transmission loss, sound absorption, sound barriers, pre-cast concrete panels.
1 Introduction

1.1 Concrete waste

There are numerous example of the successful reuse of recycled concrete waste as an alternative aggregate in road construction, one being the Formula 1 racetrack in Melbourne. Selected aggregate has now been used for the production of ‘green’ concrete for numerous infrastructure projects in Melbourne including the 60L building in Carlton. The concrete used in this project was made from reclaimed and recycled aggregate, supplementary cementitous materials and recycled water. The total replacement materials in the 25 MPa concrete accounted for 94% and in the 32 and 40 MPa concrete accounted for 35% total weight of materials.

In Victoria in the period 2001 - 2002, 1 million tonnes of concrete demolition waste were recovered and recycled [1]. Construction concrete waste in its plastic state is now treated at some concrete manufacture plants. It is estimated that one concrete plant alone with concrete reclaim facilities produces and reuse approximately 8,000 tonnes of reclaimed aggregate annually [2]. Water used in the reclaim facilities is recycled water and all the slurry and reclaimed aggregate used in new concrete. Typical use of reclaimed slurry is 4% of total water and reclaimed aggregate 5% of coarse aggregate portion in concrete of compressive strength of up to 32 MPa [2]. This approach reduces transport of waste to the landfills or concrete recycling plants. The environmental benefits associated with reclaiming concrete waste results in reduction of energy use for transport, virgin material extraction as well as reduces demand for landfill space.

1.2 Transportation noise

An urban population in the modern cities is constantly exposed to excessive noise due to an increase in large-scale transport facilities including motorways and railways. The noise levels in the urban transport infrastructure vary significantly depending mainly on a type, volume and speed of the source generating transportation noise. The increased noise level is also a function of a distance between the noise source and the receiver. The urban population’s response to the noise also varies with diverse level of annoyance and other effects on humans including effect on health and effect on day and night activities.

Nelson [3] identifies the Sound Pressure Level (SPL) of 65 dB(A) as the absolute upper acceptable limit tolerable by the community. However, the noise generated by the transportation infrastructure is much higher than the acceptable limit of 65 dB(A). An average road traffic noise generated by the heavy vehicles exceeds 73 dB(A) [85 dB] at the low frequency range (up to 200 Hz) and at the mid-frequency range (between 200 and 500 Hz). It exceeds 76 dB(A) [80 dB] in the frequency range between 500 Hz and 2,000 Hz. The light vehicle road traffic noise levels are lower than heavy vehicle noise by approximately 9 dB at the
corresponding frequencies. Figure 1 shows typical noise spectra for a free flow of a light and heavy vehicles [3].

![Graph](image)

**Figure 1**: Typical noise spectra for free flowing light and heavy vehicles traffic.

An intensity of road traffic noise is predominantly a function of the volume of traffic as well as a type and proportion of vehicle types in the traffic flow. The sound pressure level generated by vehicles is a function of an engine and exhaust emitted noise, which is amplified by the noise from a tire-surface interaction. The tire-surface noise contribution is predominant at the frequencies above 1,000 Hz.

To address excessive transportation noise in urban environment the noise levels of newly constructed transportation infrastructure must comply with the specified limits. The most stringent requirements on transportation noise reaching residents alongside transport infrastructure are in countries such as the Netherlands and Denmark where the day noise level is limited to 55 dB(A) [4]. In Australia, the Victorian State Road Authority, Vicroads sets the 63 dB(A) as the limit for newly constructed roads and 68 dB(A) for existing roads [5].

Transportation noise control techniques include re-routing transportation infrastructure away from the residential areas, reduction of generated noise by the source, control of the noise pathway or protection of the receiver.

Typically noise barriers, both sound reflective and absorptive, have been used to control transportation noise. In Victoria reflective barriers made from concrete, timber or plastic are usually installed alongside busy arterial roads. Kotzen [4] states that in Europe there is a tendency to use absorptive barriers that acoustically soften the environment as well as allowing a reduction of the height of the barrier or reducing buffer zone width to achieve required noise reduction. Day [6] proposes a general guide to illustrate the benefits of using absorptive barriers over the reflective type barriers. For example, to reduce a noise level to 60 dB(A) a 3 meter high absorptive barrier or 4 meter high reflective barrier would be required. He indicates that the buffer zone reduction of approximately
50 meters can be achieved by substituting a 4 meter high reflective barrier with an absorptive barrier.

### 1.3 Tunnel noise

There are two distinctive subdivisions of noise related to tunnels viz., a build-up of reverberant noise within the tunnel and noise at the mouth of a tunnel. Wu and Kittlinger [7] indicated that a noise level within the tunnels due to the build-up of reverberation sound is at least 8 dB(A) higher than the noise in a free field. Woehner [8] states that for the same traffic stream the noise level at the mouth of the tunnel is higher by 6 to 9 dB(A) than that of a free field. The noise level tends to be constant over the tunnel portal.

Albeit there is an increase of noise level at the tunnel portals, Kotzen [4] states that cut and covers openings and tunnel and road enclosures provide the most effective acoustic and visual solution to urban transportation noise effects. A cut and cover opening either with open louvers or solid covers offers a range of possibilities to mitigate transportation noise. The control of noise related to tunnels, using cut and covers, and enclosures is relatively easier than those of open roads. For example, Nelson [3] indicates that noise reduction of up to 10dB(A) can be achieved by depressing a road by 5 m below ground in a cut 15 m wide with vertical reflective walls. The cut and cover also creates a shadow zone at and above the cut edge ground level. By further substituting reflective vertical walls with absorptive ones SPL at a distance of 25 meters from the cut edge 10 meters above ground can be reduced by approximately 8 dB(A).

Woehner [8] states that if the rigid reflective walls within the tunnels were replaced with the absorptive lining, this would contribute to an SPL reduction of at least 4 dB(A). Lining the inside of tunnel mouth for at least two tunnel’s diameters with absorptive material and approximately 100 meters from the tunnel portal can reduce noise level by at least 8 dB(A) at the tunnel portal.

### 2 Swinburne Acoustic Barrier

The Swinburne Acoustic Barrier (SAB) is a pre-cast concrete ‘sandwich’ barrier consisting of two or three distinctive layers. In the 2-layer design a structural backing layer acts as a structural support for the barrier and the porous layer acts as a sound absorbing layer. In the 3-layer design a third outer layer, which is perforated has been introduced. Besides perforations, the outer layer can be also coloured or variety of patterns can be applied. The presence of the third layer not only enhances the visual appearance of the barrier but also changes acoustic characteristics of the SAB.

The overall thickness of the 2-layer design is 150 mm whereas the 3-layer design is approximately 160 mm thick. Relative thickness of structural and porous layers depends on the targeted noise frequency and can be changed by varying concrete mix proportions. For optimum compressive strength and durability it is recommended that the structural layer thickness be from 60 to 90 mm.
3 Methodology

Although both mechanical and acoustic properties of the Swinburne Acoustic Barriers are of equal importance in this paper, an acoustic performance only of SAB will be reported. The authors reported on the testing of mechanical properties of concrete used for production of SAB in a number of papers [9, 10]. The authors’ recommendation is that the concrete made from the selected recycled concrete aggregate has adequate compressive strength and durability and can be used in pre-cast concrete panels of the compressive strength of up to 40 MPa including acoustic barriers.

Two distinct properties of an acoustic material are usually of concern, the Sound Transmission Loss (STL), which is a measure of insulation ability of a material, and Sound Absorption Coefficient, which is a measure of an amount of sound energy absorbed by a material. The STL was estimated using current published data on solid concrete panels of various thicknesses and the mass law.

Experimental work adopted in this project, included determination of Sound Absorption Coefficient of the Swinburne Acoustic Barrier. The Sound Absorption Coefficient was measured using two experimental methods, the impedance tube method (AS 1935 – 1998), and the reverberation room method (AS 1045 – 1988). Two sets of impedance tube samples were tested. The first set consisted of three specimens with the same thickness of porous layer of 70 mm (denoted as A samples). One of the samples was a 2-layer specimen, the two remaining specimens consisted of three layers with two various amount of perforation viz. 24% and 8% in the outer layer. The second set also consisted of three specimens (one 2-layer design and two 3-layer design with 24% and 8% perforation of the outer layer) all with the same thickness of porous layer of 90 mm (denoted as B samples). Table 1 presents impedance tube specimens.

### Table 1: Impedance tube samples.

<table>
<thead>
<tr>
<th>Barrier type</th>
<th>No</th>
<th>Thickness [mm]</th>
<th>Outer layer</th>
<th>Perforation [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-layer</td>
<td>A1</td>
<td>80</td>
<td>70</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td>80</td>
<td>70</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>A3</td>
<td>80</td>
<td>70</td>
<td>13</td>
</tr>
<tr>
<td>3-layer</td>
<td>B</td>
<td>60</td>
<td>90</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>B1</td>
<td>60</td>
<td>90</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>60</td>
<td>90</td>
<td>13</td>
</tr>
</tbody>
</table>

Three rectangular pre-cast concrete panels of 4m x 1m x 0.15m thick each were manufactured at the local pre-cast concrete yard. The panels were of the 2-layer design and were cast in two layer operation with the structural backing layer cast from concrete made from 20 mm graded reclaimed concrete aggregate and porous layer cast from concrete made from 14/10 mm recycled
concrete aggregate. The thickness of the structural baking layer was 110 mm and the porous layer was 40 mm. The thickness of the porous layer was arbitrarily chosen, as the main purpose of this stage of the project was to test the production process in an industrial setting. Table 2 shows the features of the 2-layer design SAB panels.

Table 2: SAB 2-layer design panels characteristic.

<table>
<thead>
<tr>
<th>Panel weight per 1 m²</th>
<th>Structural backing thickness</th>
<th>Porous layer thickness</th>
<th>Air channels in porous layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>[kg]</td>
<td>[mm]</td>
<td>[mm]</td>
<td>[%]</td>
</tr>
<tr>
<td>330</td>
<td>110</td>
<td>40</td>
<td>~20</td>
</tr>
</tbody>
</table>

To determine the Sound Absorption Coefficient of the 3-layer design an outer layer made from plasterboard was used. The plasterboard was perforated with the 9 mm in diameter holes, which accounted for 24% of the total area. The perforated plasterboard was pressed into the porous layer to mimic the 3-layer design panels.

4 Acoustic performance of the Swinburne Acoustic Barriers

4.1 Sound Transmission Loss (STL)

The STL of SAB was calculated using the mass law. Figure 2 shows predicted STL of the barrier. Conservative estimate of STL ranges from 33 dB at low frequencies to 64 dB at 2,000 Hz. The high STL of the Swinburne Acoustic Barrier combined with the sound absorption make it suitable for the use in reducing noise impacts from generator and transformer rooms, as inclosing walls to the gas turbine power stations and suburban factories.

![Figure 2: Sound transmission loss of SAB vs. frequency.](image)
4.2 Sound absorption coefficient

The impedance tube test results of the 70mm porous layer thickness sample series shown good sound absorbency of the 2-layer design with the peak frequencies at 400 Hz and 1,600 Hz. The effect of applying the outer perforated layer is the shift of the peak frequency to the lower frequencies, which is of particular interest in targeting the road traffic noise. Figure 3 shows impedance tube results.

Figure 3: Impedance tube results of 70 mm porous layer SAB samples.

The impedance tube results of the 90 mm porous layer thickness sample series follow similar pattern to the 70mm samples with the peak frequency for absorption at 400 Hz and 1,250 Hz. The use of perforated outer layer shifts the peak frequency for absorption to 200 and 250 Hz. The results indicate clearly
that sound absorbency is related to the thickness of the porous layer and that the peak frequency can be modelled by the use of the perforated outer layer.

The reverberation room test results show satisfactory sound absorbency of the 2-layer design in a low and mid frequency range and absorbency of sound frequencies above 1,000 Hz. It is evident that the application of the outer perforated layer improves SAB’s sound absorbency in the mid frequency range. Figure 4 presents Sound Absorption Coefficient of the SAB measured in a reverberation room. Figure 5 presents the estimated noise level outside the windows of a train. The upper graph shows the noise level with totally reflective tunnel walls and roof. Note that the noise is dominated by high frequencies from around 630 Hz to 4 kHz where the SAB is effective. At these frequencies an SAB lined tunnel has negligible reverberation; with only direct sound transmission being effective so that an approach to the open air noise level is achieved. The modelled noise levels shown in the figure are simply based and should be taken as indicative as structure-borne sound through the carriage structure and other effects have been ignored.

Figure 5: Effectiveness of SAB in tunnel application.

5 Discussion

The Swinburne Acoustic Barrier panels with a compressive strength of 40 MPa made in a controlled pre-cast concrete process creates another use for selected recycled and reclaimed concrete aggregate. Besides the concrete waste utilization in SAB, the added benefit of sound absorbency of the barriers can soften acoustically the urban environment and effectively reduce effects of transportation noise on residences alongside urban arterial roads and railways.

The estimated noise reduction due to sound absorbing properties of SAB inside a suburban factory where the inclosing standard pre-cast concrete walls
are substituted with the 2-layer design Swinburne panels is approximately 7 dB on top of the transmission loss of approximately 40 dB through the panel. Swinburne Acoustic Barrier effectively absorbs sound energy in the frequency range between 500 and 2,000 Hz which is characteristic of transportation noise especially road and rail traffic. The use of SAB as noise barriers alongside urban arterial roads can result in a reduction of height (up to 1 m) of the barrier or reduction of the size of the buffer zone (up to 50 m) to achieve specified noise attenuation. Significant SPL reduction can be achieved in road and rail tunnels where SAB is used in lining the tunnel walls. Modelled SPL reduction in a train tunnel lined with Swinburne Acoustic Barrier was higher by up to 15 dB(A) when compared with standard tunnel with concrete walls.

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References