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Environmentally Friendly Sound Absorbing Noise Barrier Made from Concrete Waste - Further Developments

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Abstract: This paper reports on the second phase of a research project aimed at the development of an environmentally friendly noise barrier for urban freeways, also known as KMAK [1]. The concrete barrier, which has some unique capabilities to mitigate transportation noise, is made from recycled concrete (RC) aggregate and industrial by-products such as fly ash and reclaimed water. The current developmental work expands on a research project that resulted in a two-layer (2L) concrete barrier. Two prototypes of the 2L barrier were produced, followed by extensive acoustic testing and a number of simulations where standard timber and/or concrete barriers were substituted with KMAK barrier [2]. Current research investigates a variety of architectural finishes applied to the original KMAK barrier with the aim of improving its visual appearance and also fine-tuning its acoustic performance. The new three-layer (3L) barrier optimizes sound absorption in a frequency range characteristic similar to that of transportation noise, especially road traffic noise. Three major aspects related to the development of architectural finishes were considered; environmentally responsible materials, surface features, and production methods. The findings of the current investigation demonstrate that there is a positive correlation between surface features, percentage of perforation as well as depth of the architectural layer, and increased potential of the 3L barrier to mitigate transportation noise. On average, the addition of perforated architectural finish contributes to a 20% increase in sound absorption. The preliminary results also show that the sound absorbency of the 3L barrier can be better controlled and tuned to specific noise frequency than the 2L type. The visual appearance has been significantly improved with the addition of the architectural finish, which makes the barrier an attractive, feasible, and viable alternative to road barriers made from standard concrete or timber.

***Key words**: Concrete waste; Noise barrier; Road traffic noise.*

Introduction

The noise level generated on urban roads can be excessive and has a negative impact on the urban environment. Typical noise spectra from heavy (HV) and light vehicle (LV) traffic on open graded asphalt (OGA) road are presented in Fig. 1. The sound pressure level (SPL) resulting from HV traffic on standard, dense asphalt roads is even higher and well exceeds 80dB(A) at a frequency of approximately 800Hz. Sandberg [3] argues that traffic noise due to tyre-road interaction is modal in nature and a dominant SPL peak occurs in a wide frequency range between 700 and 1,300Hz. Further, an occurrence of such peak at specific frequency depends on a number of factors related to vehicles and road infrastructure, for example, the type of tyre and surface texture of the road. Similar noise characteristics are displayed by mixed traffic where the frequency range at which the peak occurs narrows to 800 - 1,250Hz. The peak can sometimes occur at lower or higher frequency, depending on a number of additional factors such as vehicle speed, engine noise, pipe noise, etc.

Sandberg [3], states that porous surface, similar to the OGA, not only reduces traffic noise level but also shifts the peak frequency from about 1,000Hz to a frequency range between 600 and 800Hz.

In Victoria, the State Road Authority, VicRoads, has implemented a number of integrated measures aiming at the reduction of adverse effects of road traffic noise in urban environments on affected residents. One of such measures is an increased use of open graded asphalt which reduces the SPL at a road surface by approximately 3dB(A). However, the use of sound barriers is still necessary, as the difference between noise level at source (road traffic) and the permissible levels in residential areas is well in excess of 15dB(A). In Victoria, the limit of 63dB(A) $L_{10(18hr)}$ set for SPL in residential areas is impractical to control unless barriers are installed. The $L_{10(18hr)}$ is the noise level descriptor defining the noise level exceeded 10% over the time period of 18 hours. The type of barriers employed in order to attenuate noise depends on a number of factors, including, land configuration, buffer zone between the road and affected residents as well as their capital cost [4].

In general, the use of reflective barriers is preferred as the life cycle analysis is not always deployed, and also because specifications for absorptive barriers are prohibitive to meet at reasonable cost. For example, the VicRoads standard sets the minimum sound absorption of this type of barriers of 82% of incident noise, in the frequency range between 125 and 2,000Hz. The noise reduction coefficient (NRC) of such barrier has to exceed 0.85 [4].

Experimental Work

The two major objectives of current research are to improve (1) acoustic performance and (2) visual appearance of KMAK barrier. The experimental work devised in order to meet these objectives has been divided into three concurrent phases:

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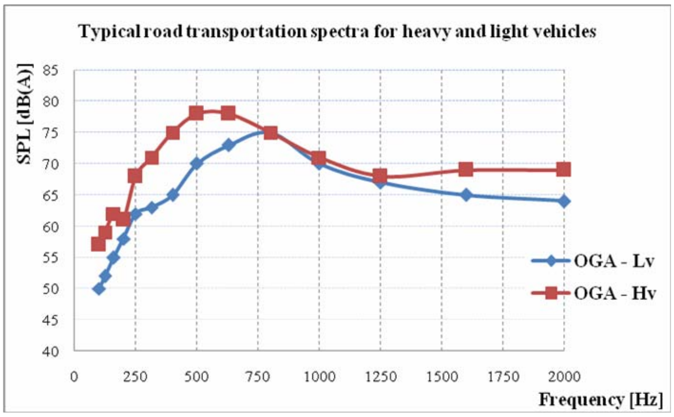


Fig. 1. Typical Traffic Noise Spectra on OGA Road (VicRoads).

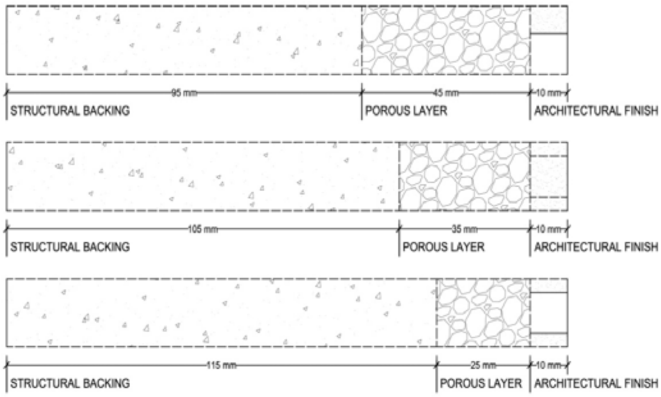


Fig. 2. Cross-Sections of Impedance Tube Samples.

- Material - improvements to recycled aggregate (RA) concrete used in the 2L (two-layered) barrier and development of an environmentally responsible material for the architectural layer in the 3L (three-layered) barrier;
- Production - optimization of production method; and
- Acoustics and visual appearance - fine-tuning of acoustic performance.

The visual appearance of the 2L KMAK barrier, especially the rough surface of the barrier's side facing traffic noise was considered as its only major negative feature when it was evaluated by road authorities, landscape architects, investors, and potential clients. There was a concern that the rough appearance may not be well perceived by motorists using urban freeways equipped with such noise barriers [5, 6].

An addition of a third layer was deemed as one of the most plausible solutions. A number of patterns, with different surface features and perforations, imprinted into this architectural layer were investigated. The patterns ranged from a smooth-perforated finish to corrugated or recessed-flat finishes. The various designs were subjected to basic cost-benefit analyses where the ease of manufacturing, cost of the final product, aesthetics, and overall barrier's sound absorptions were the major evaluation criteria.

The methodology employed in order to enhance the 3L KMAK barrier's acoustic performance consisted of the following steps:

- preparing and testing a variety of samples using the AS1935 impedance tube method [7];
- computer simulation and selecting one pattern to be imprinted into a prototype barrier;
- producing a casting mould for the architectural layer;
- developing a light-weight material for architectural layer which enhances sound absorption and be visually attractive;
- manufacturing a prototype barrier in a commercial setting; and
- testing sound absorption of the prototype ($12\ m^2$ in area) in a reverberation chamber in accordance with the AS1045 method [8].

The light-weight material used in the architectural finish is based on ordinary Portland cement (OPC) and uses a very fine fraction of recycled concrete (RC) aggregate. The manufacturing process of the 3L barrier was tested in a commercial setting and two sets of prototype barrier were cast. An innovative, cost effective method of applying pattern, and perforation to the surface of architectural finish was also developed and tested.

This paper only reports on the results and methodology employed in improving visual appearance and acoustic performance of the barrier.

Sound Absorption by Impedance Tube Method

The samples used in the impedance tube experimentation were divided in the 2L and 3L compositions. The 2L samples consisted of a structural backing layer made from normal density RA concrete and a porous layer made from no-fines RA concrete. Porous layers of three different thicknesses were investigated; 25, 35, and 45 *mm*. In the 3L samples suite, one of the six different architectural finishes was added to each of the 2L compositions. Fig. 2 presents cross-sections of the 3L samples.

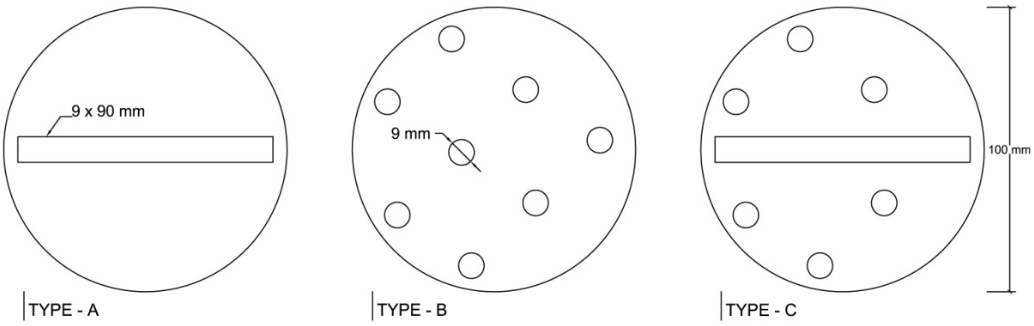
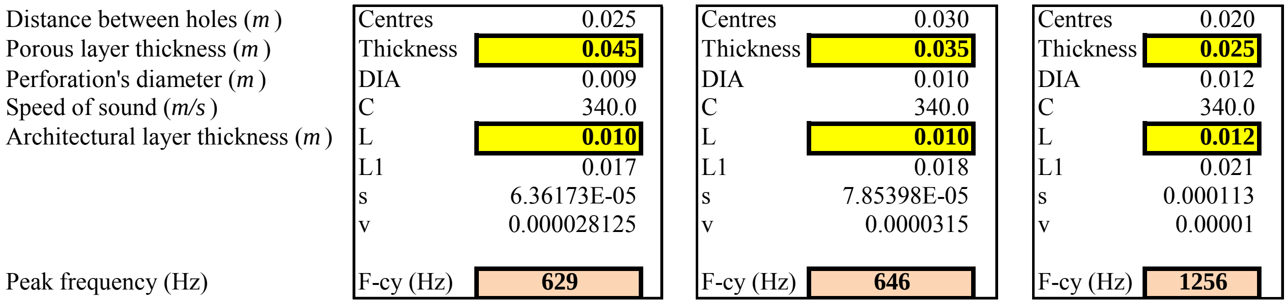


Fig. 3. Patterns of Architectural Finishes.



Distance between holes (*m*)	Centres	0.025	Centres	0.030	Centres	0.020
Porous layer thickness (*m*)	Thickness	**0.045**	Thickness	**0.035**	Thickness	**0.025**
Perforation's diameter (*m*)	DIA	0.009	DIA	0.010	DIA	0.012
Speed of sound (*m/s*)	C	340.0	C	340.0	C	340.0
Architectural layer thickness (*m*)	L	**0.010**	L	**0.010**	L	**0.012**
	L1	0.017	L1	0.018	L1	0.021
	s	6.36173E-05	s	7.85398E-05	s	0.000113
	v	0.000028125	v	0.0000315	v	0.00001
Peak frequency (Hz)	F-cy (Hz)	**629**	F-cy (Hz)	**646**	F-cy (Hz)	**1256**

Fig. 4. Calculated Peak Resonant Frequencies Using Helmholtz Resonance Function (Note that the L1, s, and v: Intermediate Coefficients in the Calculations of the Peak Frequency).

Table 1. Basic Parameters of Various Patterns in the Architectural Finish.

	A - group		B - group		C - group	
	A1	A2	B1	B2	C1	C2
Perforations (%)	8	14	8	14	8	14
Pattern	Grooves		Holes		Holes & Grooves	
Size	9 × 90*mm* Length		9*mm* Diameter		50% Holes + 50% Grooves	

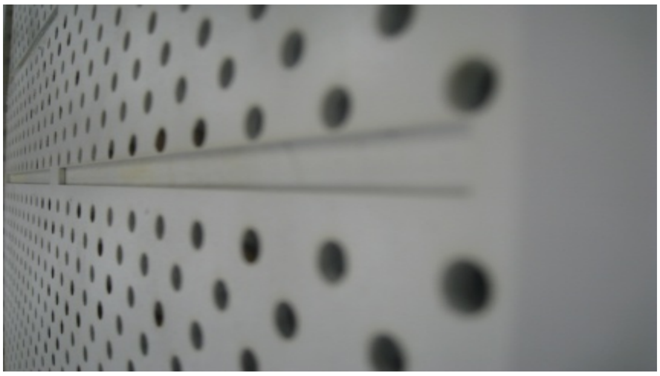


Fig. 5. Traffic Facing Side of the 3L KMAK.

A number of finishes with varying surface shape and features were investigated and categorized in three groups. The A-group consists of grooves; the B-group of holes; and the C-group of a combination of grooves and holes. Fig. 3 presents the three basic perforation patterns.

Previous study on the correlation between porous layer thickness and percentage of circular perforations in the architectural layer suggested a workable range of perforation between 8 and 25% [9]. Based on previous research data and computer simulations impedance tube samples with the two 8 and 14% perforation of the architectural layer, were prepared and tested. For the barrier's prototype the 14% perforation was deemed to provide best balance between structural and acoustic performance. Parameters of the six most feasible architectural finishes are presented in Table 1.

Computer Simulation and Selection of Optimum Pattern

Simple computer simulation based on the Helmholtz resonance principles was used to determine the optimum parameters of the architectural finish layer. The thickness of the layer was one of the variables used in the fine-tuning of the sound absorption of the 3L barrier. The simulation indicated the optimum thickness of 10*mm*, which was consequently applied to impedance tube samples and to the prototype barrier. Fig. 4 demonstrates the simulation's variables, amongst others, the thickness of porous layers (e.g. 45 *mm*), thickness of architectural finish, and resulting peak frequency.

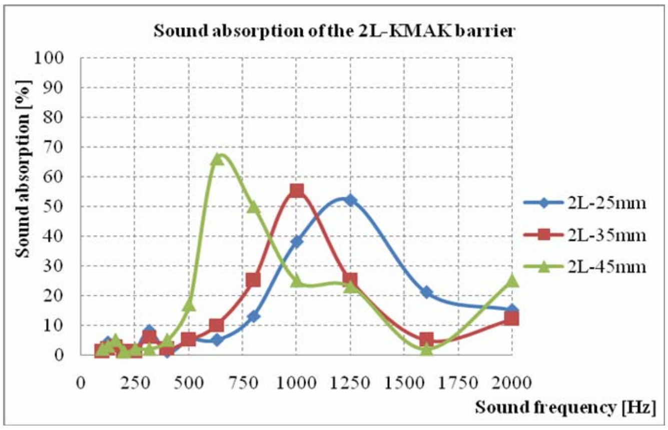


Fig. 6. Sound Absorption of Two-Layered Samples Measured in Impedance Tube.

Production Process

To optimize the manufacturing process and maintain low production cost, a simple roller device to imprint patterns and perforations was developed. The process, which deviates slightly from a common industry practice, was modified to allow a replacement of a standard casting mould. The three layers were placed consecutively one on top each other with a final one-way passage of the roller over the architectural finish. Fig. 5 presents an impression of the finish used to prepare the mould.

Production of the 3L barrier's prototype was divided into three stages, of four panels each. The panel size is 1.2 × 1.2*m* with the overall thickness of 150 *mm*. Process analysis, material sampling, and testing allow progressive improvements to the design and production process. A set of eight panels produced is ready to be transported and tested in a reverberation chamber.

Results

In this paper only impedance tube test results are presented and analyzed in relation to roads traffic noise. Current results confirm that of previous study into volume of voids in porous layer (function of layer thickness and aggregate size) and sound absorption of 2L

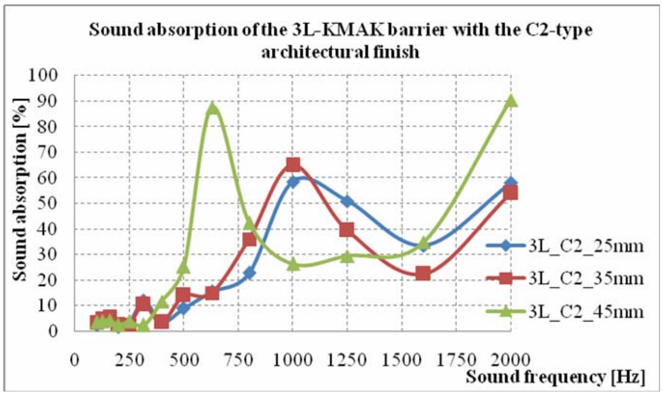


Fig. 7. Sound Absorption of Three-Layered Samples with C2-type Architectural Finish.

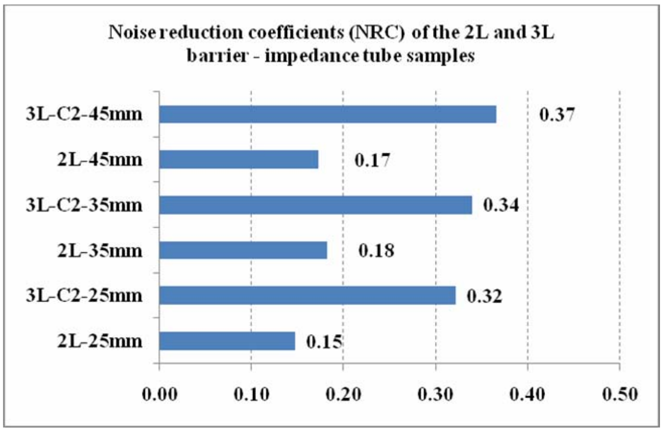


Fig. 8. NRC of Two and Three-Layered Samples Derived from Impedance Tube Testing.


(a) (b)

Fig. 9. The (a) 2L and (b) 3L KMAK Prototype Barriers.

samples [2, 10].

There is positive correlation between layer thickness and sound absorbance. On average, samples with a porous layer thickness of 45*mm* (2L-45mm), absorb on average 68% of incident sound at a peak frequency of 600Hz, with overall absorption of 40% in a frequency range between 125 and 2,000Hz. Similarly 2L-35mm samples' average sound absorption is 56% at 1,000Hz and the 2L samples with the porous layer thickness of 25*mm* absorbs 52% at a peak frequency oscillating around 1,250Hz. Fig. 6 presents impedance tube results for 2L samples.

The addition of the architectural layer increases sound absorption by approximately 20% and also shifts the peak frequency closer to lower frequencies. Fig. 7 presents sound absorption characteristics of the 3L samples with grooves-and-holes type of perforation.

It should also be noted that measured peak frequencies of sound absorption for 3L samples confirm that of the calculated ones, within an average tolerance margin of 11%. For example the calculated peak frequency of 3L_C2_45mm samples is 629 Hz, which is the same as the measured frequency.

Calculated NRCs for the two and three-layered samples show a familiar trend of increasing its potential to absorb sound as the thickness of porous layer increases (see Fig. 8). The results also show that addition of the architectural layer increases the NRC by 100% from 0.17 for 2L samples to 0.34 for the 3L samples.

The visual appearance of the barrier has radically changed from a rough surface of no-fines concrete to a smooth, pattern perforated surface of an architectural finish. In addition a use of oxides was investigated to increase a range of possible colors of the light-weight material used in the architectural finish. Figs. 9(a) and 9(b) present the 2L and 3L KMAK prototypes.

Conclusions

The results clearly demonstrate that the acoustic characteristics of the two and three-layered KMAK barrier indicate that the peak frequency occurs in the frequency range between 600 and 1,000Hz, which coincides with the predominant frequencies of traffic noise. Consequently it is well suited to mitigate road traffic noise with the dominant SPL in the frequency range between 700 and 1,200Hz.

The simple manufacturing process and the use of recycled and/or reclaimed materials make the alternative barrier viable to standard concrete or timber barrier. The added benefit of sound absorbance would also allow reduction in the barrier's height and consequently reduce material usage [2].

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