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ACOUSTIC BARRIER FOR TRANSFORMER NOISE

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Abstract

In this paper, an acoustic barrier is employed for solving the environmental problem imposed by transformer humming noise on nearby communities. A SoundPlan model was created to quantify the noise emission and to optimise the design for maximizing the barrier performance. Based on the requirements and limitations in the substation of interest, the acoustic barrier is designed consisting of absorptive and tonal sections. *In-situ* measurements have been taken to assess the barrier performance. Both predicted and measured results demonstrate that the acoustic barrier is an effective measure for mitigating transformer humming noise emission.

1. INTRODUCTION

The humming noise emitted from electric power transformers constitutes a serious environmental problem to nearby community. Because of its tonal component it causes greater annoyance than other noise at the same level. In some countries such as Australia, a 5.0dB penalty is added to the measured noise levels to account for the additional annoyance caused by the tonal noise for transformers as part of the noise management for transformer substations and terminals. Effective control of transformer humming noise has long been the objectives of the utility industry. Theoretically different noise control methods are available. In practice, however, the choice of noise control methods will be limited depending on the cost, effectiveness and feasibility.

Acoustical barriers are the most common noise control measures. They have been used for the noise mitigation of transportation systems such as highways, railways, airports and so on. Recently a novel designed tonal noise barrier has been successfully applied to mitigate tonal noise from a gearbox substation in a mining site[1]. In this paper, an acoustic barrier is applied to reduce transformer humming noise emission from a substation. A SoundPlan model was created to quantify the humming noise emission and to optimize the barrier design for maximizing the barrier performance. Based on the requirements and limitations in the substation of interest, the acoustic barrier was designed consisting of two sections: absorptive section and tonal section. *In-situ* measurements were taken before and after the installation of acoustic barrier to assess the barrier performance and to compare the effectiveness between absorptive and tonal barriers.

2. TRANSFORMER SUBSTATION AND ITS NOISE EMISSION

The transformer substation of interest is located in an urban suburb. The closest residences are about 50m away (crossing a road) from the northern substation boundary, as shown in Figure 1 below. The boundaries to the east, south and west of the substation adjoin a golf course, which acts as a buffer zone for other residential areas adjoining the golf course. The substation has three transformers in service, and the transformers sit outdoors in line from south to north half metre above the ground.

Figure 1. Aerial view of the transformer substation of interest and its surrounding area.

Several field measurements were taken during calm nights from 10:00pm to 1:00am to characterize the noise emission from the transformers and to evaluate the extent of noise impact on the closest residences. There are two busy roads nearby where cars and motorcycles still drive along even after midnights (though very intermittently). Care has been taken during the measurements to minimize the impact of traffic noise by recording the data during intervals when little traffic noise could be heard. However, it was not possible to totally eliminate traffic noise from recordings, and so inset noise.

Figure 2 presents a typical third octave frequency band noise spectrum measured at 5.0m away from a transformer surface. It can be seen that the noise emission can be represented by the components at 100Hz, 200Hz, 315Hz and 400Hz. The neglect of other frequency components does not result in a notable difference (less than 0.3dB) in the overall A-weighted noise level.

Figure 3 presents a typical third octave frequency band noise spectrum measured at a closest residential location. The noise is dominated by the components at 100Hz and 200Hz. The A-weighted noise component at 800Hz, 1.0kHz and 1.25kHz has similar level as that at 315Hz and 400Hz. The sum of A-weighted noise components at 100Hz, 200Hz, 315Hz and 400Hz is 2.1dB lower than the overall A-weighted noise level. Narrow frequency band results indicated that peaks can be hardly seen at harmonic frequencies of 500Hz, 600Hz, 700Hz and above. It is believed that in Figure 3 the noise components at frequencies above 500Hz were corrupted by traffic and insect noise. This is supported by the modelling results, where the measured values at frequencies above 500Hz are much higher than the predicted ones.

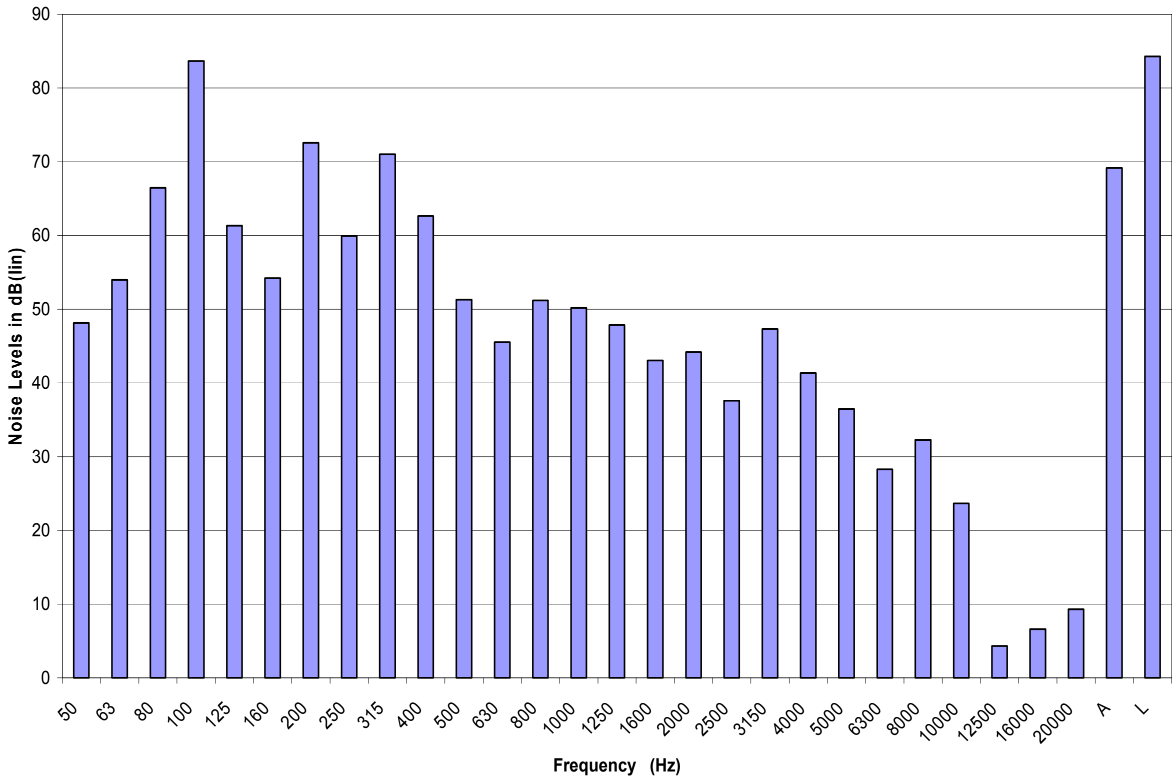

Figure 2. Measured noise level in dB(lin) at a position 5m away from transformer wall.

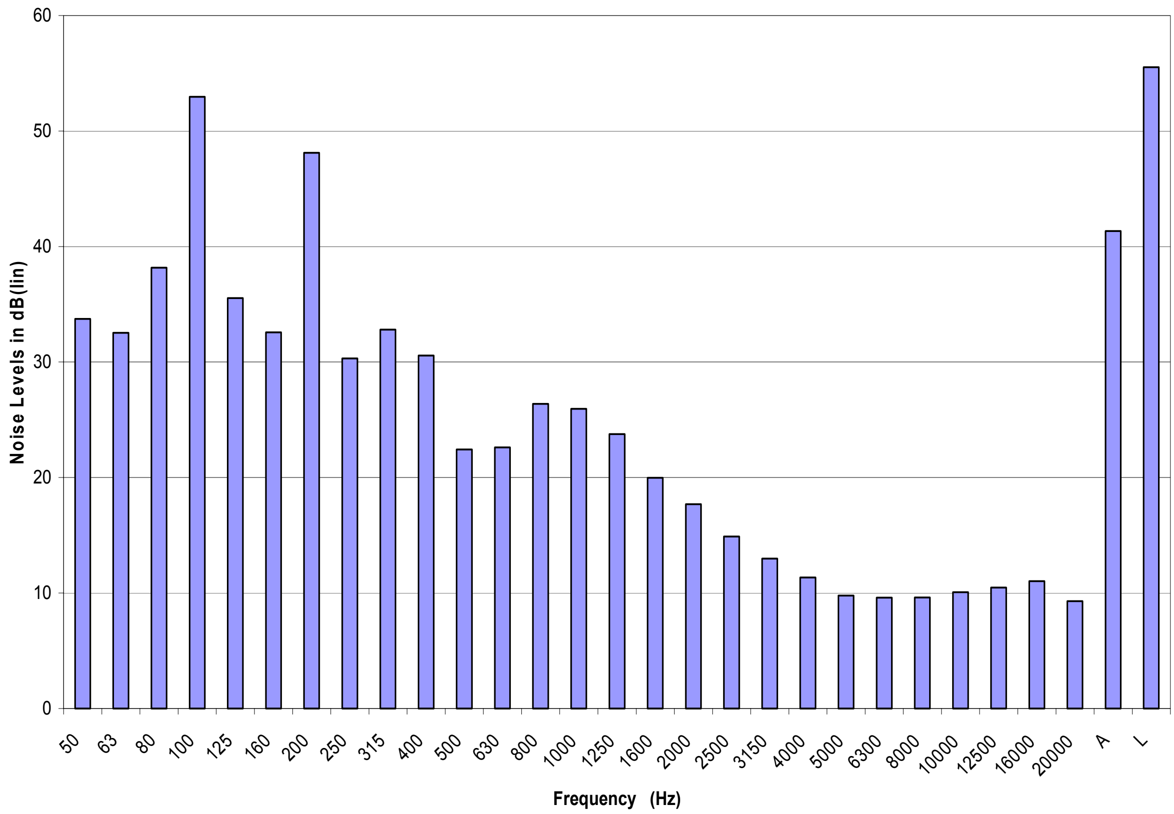

Figure 3. Measured noise level in dB(lin) at a closest residential location.

Figures 2 and 3 indicate that the humming noise for a transformer and its propagation can be adequately represented by the 1/3rd octave band components at 100Hz, 200Hz, 315Hz and 400Hz.

3. ACOUSTIC BARRIERS

The aim of this project is to reduce the transformer humming noise emission so that the noise levels at the closest residences are below the assigned noise levels, imposed under the Western Australia Environmental Protection (Noise) Regulations 1997.

Noise control measures for the substation have the following requirements:

- do not interfere with existing transformer structures and cables;
- have little impact on the transformer maintenance, ie, maintenance personal can easily assess the transformers and associated equipment.
- do not have heat build-up problem; and
- should be cost effective.

Based on the above requirements, acoustic barriers were proposed, as shown in Figure 4 on the right. Two types of barriers were designed:

- Absorptive barrier (black line) consisting of a thin base panel (outer skin), sound absorption layer and perforated inner surface.
- Tonal noise barrier (blue lines) consisting of a base panel (outer skin), sound absorption layer and profiled inner surface, as described in Reference [1].

The tonal noise barrier is designed based on the principle of the Helmholtz resonator to give better sound absorption at tonal frequencies.

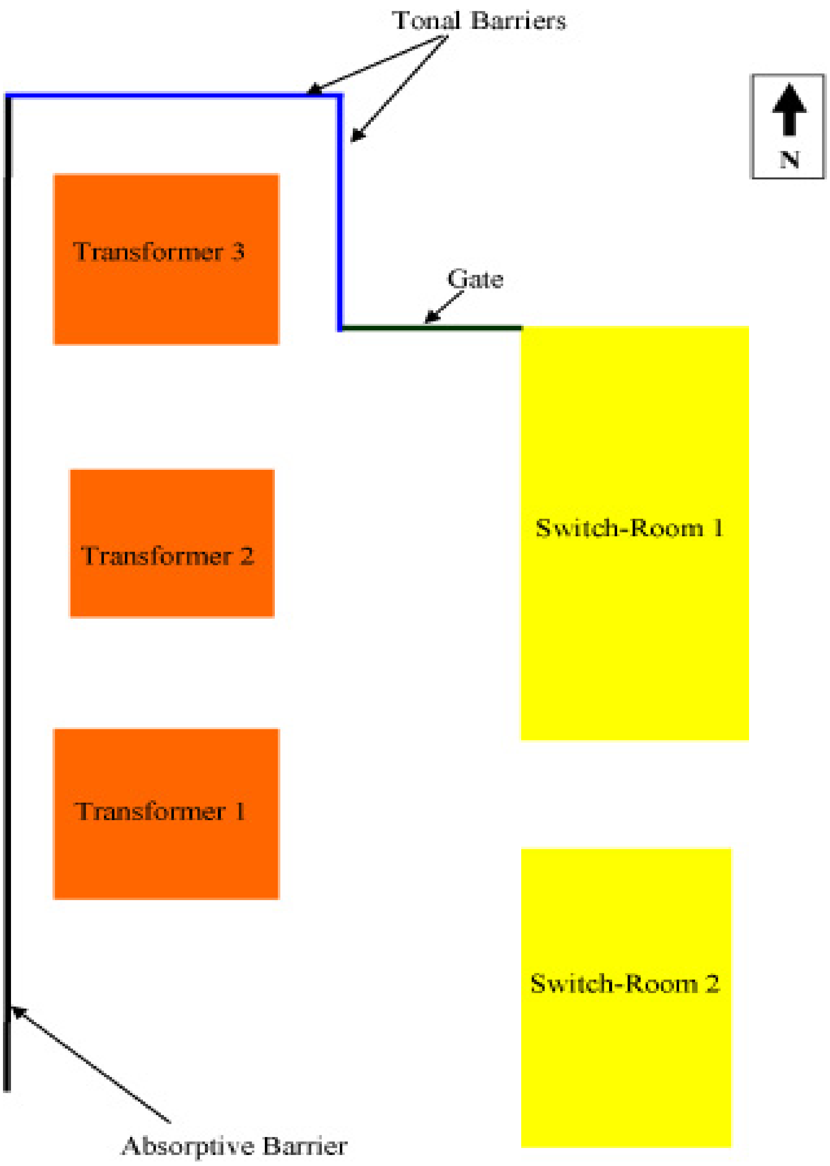

Figure 4. Plan view of the acoustic barriers.

4. PERFORMANCE ASSESSMENTS

4.1 SoundPlan Modelling

An acoustic model has been created using SoundPlan 6.2 program developed by SoundPLAN LLC (implementing the CONCAWE prediction algorithm). The model was used to optimise the design for maximizing the barrier performance and to characterize the transformer humming noise propagation. Each transformer is modelled as a rectangular box source with 5 radiating surfaces. The bottom surface of the box is blocked and sits 0.5m above the ground. The sound power level density of each transformer wall surface was estimated from the *in-situ* measurements around the transformers.

Acoustic modelling has been undertaken for both worst-case day and night time meteorological conditions, which are suggested by the EPA (*WA Environmental Protection Act 1986*) Guidance note No 8 for assessing noise impact from new developments as the upper limit of the meteorological conditions investigated. For each of these conditions, seven operation scenarios have been considered:

- All the transformers are operating;
- Any two of the transformers are operating; and
- Only one of the transformers is operating.

The acoustic model has been calibrated based on the night-time spot measurements along the substation boundary and at the closest residential locations before the acoustic barriers were installed. The level difference between predicted (for calm night) and measured A-weighted noise levels varies from -2.7dB to +2.9dB at positions along the boundary and from -2.0dB to +3.7dB at the closest residential locations.

Table 1 below gives the predicted overall noise reduction levels in dB(A) for different operating scenarios under calm and worst-case night-time operating conditions. This table indicates that the noise reduction level depends on the operation conditions and residential locations. Wind speed has little effect on the noise reduction levels. The acoustic barrier can significantly reduce the humming noise levels at all of the closest residential locations and are most effective for suppressing humming noise emission from transformer T3.

Table 1. Predicted calm/worst-case night-time noise reduction levels in dB(A)

Closest Residences	All Operated		T1 Only		T2 Only		T3 Only	
	Calm	Worst-case	Calm	Worst-case	Calm	Worst-case	Calm	Worst-case
R1	7.0	7.0	4.3	4.3	7.3	7.5	9.7	9.6
R2	6.1	6.1	3.7	3.8	5.8	5.9	9.6	9.7
R3	6.1	6.2	4.9	4.9	5.1	5.2	9.7	9.7
R4	6.4	6.5	6.2	6.2	4.8	4.9	9.8	9.9
R5	7.9	8.0	8.3	8.3	7.0	7.0	9.3	9.4
R6	8.0	8.4	8.5	9.4	7.1	7.2	8.7	8.8
R7	7.1	8.7	6.2	10.0	7.2	7.3	9.0	9.0
R8	7.5	7.6	7.1	7.1	7.3	7.4	8.8	8.7
R9	7.1	8.3	6.4	8.9	7.1	7.3	8.7	8.7
R10	8.0	8.3	9.1	9.5	6.7	6.9	8.7	8.8
R11	5.3	6.7	5.8	6.0	4.3	7.2	6.9	7.1

4.2 *In-situ* Measurements

Apart from modelling, the barrier performance was also assessed based on the *in-situ* measurements, which were taken at the closest residential locations during calm nights between 10:00pm to 1:00am for different operation scenarios before and after the installation of acoustic barriers. Though care was taken during the measurements, the impact of traffic and insect noises can not be totally eliminated in the *in-situ* measured data. To minimize the impact of traffic and insect noises, as stated in section 2, the measured transformer humming noise was represented by the recorded one third octave band components at 100Hz, 200Hz, 315Hz and 400Hz.

Figure 5 below presents the measured overall A-weighted noise reduction levels (the sum of measured one third octave band components at 100Hz, 200Hz, 315Hz and 400Hz) at positions along a line extended from the east tonal barrier section (along the entrance from south to north). The 0m is located at a line extended from the north tonal barrier section. It can be seen that the noise reduction level generally decreases with distance.

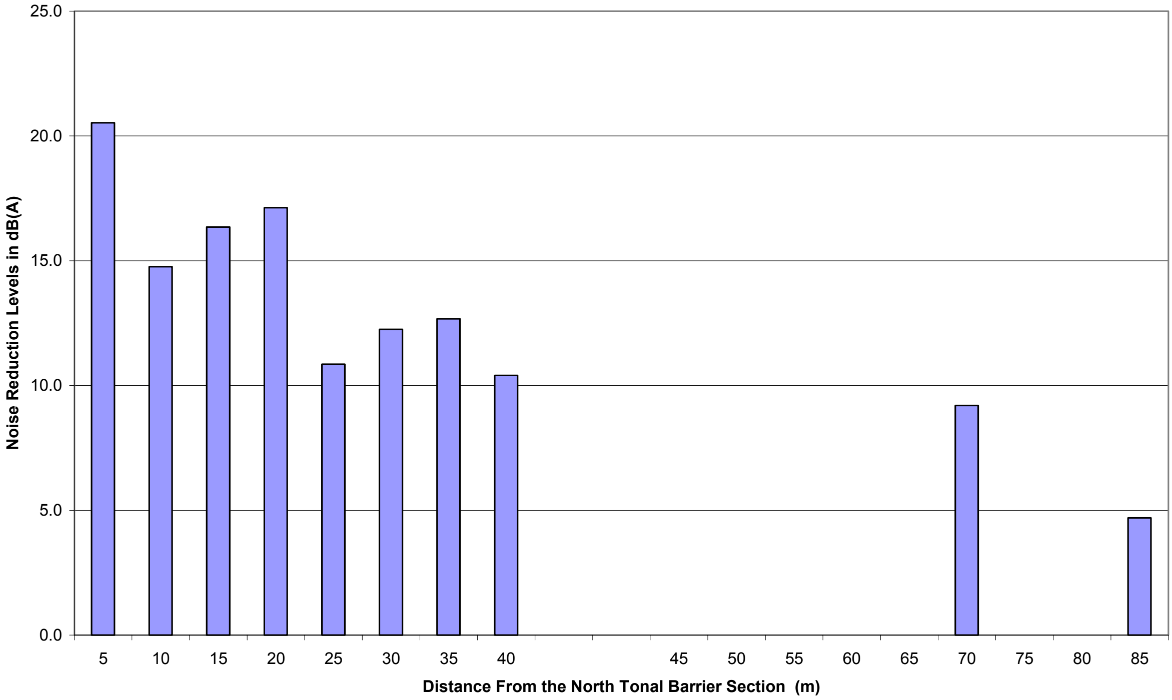

Figure 5. Measured A-weighted noise reduction levels when transformer T3 was operating.

Table 2 on the next page gives the measured A-weighted overall noise reduction levels during calm nights at the closest residential locations. Noise reduction level at R1 is not presented for the full operation conditions because the measured noise level after the installation of acoustic barriers was corrupted by traffic/inset noise (the measured noise levels at 80Hz and 125Hz are higher than that at 100Hz) and cannot be used for the calculations. Generally the small values of noise reduction levels result from the low noise levels measured before the installation of acoustic barriers. Some of the measured noise reduction levels in table 2 significantly depart from their predicted values shown in table 1. The reason could be because:

- background noise cannot be removed from the measured data,

- the operation conditions such as loading are different (the measurements were taken in different nights and the transformer loading may be different)
- the accuracy of the SoundPlan (CONCAWE) prediction algorithm, which was developed based on empirical formulae, is not suitable, and/or
- the actual meteorological conditions were different from the input parameters for SoundPlan Program such as ground type, temperature, relative humidity, wind-speed and Pasquill stability category.

However, both the predicted and measured results do indicate that acoustic barrier is an effective measure for reducing environmental noise problems imposed by transformer humming noise on nearby communities.

Table 2. Measured calm night-time noise reduction levels in dB(A)

Closest Residences	**Name of the Operating Transformer**			
	All	**T1 Only**	**T2 Only**	**T3 Only**
R1		4.8	7.0	5.2
R2	0.9	2.9	6.2	3.6
R3	14.8	6.9	10.6	4.7
R4	10.8	9.8	8.0	9.2
R5	11.6	8.8	3.2	3.9
R6	2.4	7.8	4.6	4.5
R7	2.6	11.4	7.3	5.0
R8	5.9	7.3	7.0	4.1
R9	7.4	5.1	7.4	5.0
R10	15.6	14.8	5.1	6.9
R11	0.2	6.0	4.9	2.1

Measurements were also taken *in-situ* to assess the efficiency of the tonal noise barrier by comparing the results measured before and after the tonal noise barrier sections, shown in Figure 4, were replaced by absorptive barriers. Table 3 below presents a comparison of the measured noise reduction levels and their level differences at the closest residential locations

Table 3. Comparison of noise reduction levels in dB(A) measured during a calm night

Closest Residences	**Noise Reduction Levels in dB(A)**		
	With absorptive noise barrier	**With tonal noise barrier**	**Difference**
R1	3.4	5.2	1.8
R2	3.1	3.6	0.5
R3	2.4	4.7	2.3
R4	7.8	9.2	1.4
R5	2.7	3.9	1.2
R6	3.1	4.5	1.4
R7	4.3	5.0	0.7
R8	-0.6	4.1	4.7
R9	3.9	5.0	1.1
R10	4.7	6.9	2.2
R11	-1.4	2.1	3.5

when transformer T3 was operating during a calm night. It can be seen that the tonal noise barrier provides a higher noise reduction level than absorptive barrier at all of closest residential locations, resulting in positive level differences. The results shown in table 3 demonstrate that the tonal noise barrier has a marginally better performance over the absorptive barrier at all of the closest residences.

5. CONCLUSIONS

The acoustic barrier is applied to mitigate transformer humming noise, and its performance has been assessed based on modelling (implementing the SoundPlan (CONCAWE) prediction algorithm) and *in-situ* measurements. Both predicted and measured results demonstrate that an acoustic barrier is an effective measure for reducing transformer humming noise emission towards nearby communities. In comparison, the tonal noise barrier has a marginally better performance over the absorptive barrier for reducing transformer humming noise emission.

Acknowledgments

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REFERENCES

[1] RS Ming, “Acoustical barrier for tonal noises”, *Applied Acoustics* **66**, 1074-1087 (2005).