Modular Bridge Joints – Reduction of noise emissions by use of Helmholtz Absorber

Eric J. Ancich, Project Manager, Bridge Technology Section, Roads & Traffic Authority of NSW, PO Box 558 Blacktown 2148, Australia. E-mail: Eric_Ancich@rta.nsw.gov.au

Stephen C. Brown, Associate, Richard Heggie Associates Pty Ltd, PO Box 176 Lane Cove 1595, Australia. E-mail: steve.brown@heggies.com.au

SYNOPSIS

Modular bridge expansion joints are widely used throughout the world for the provision of controlled thermal expansion and contraction in bridges. Modular Bridge Joint Systems (MBJS) are considered to be the most modern design of waterproof bridge expansion joint currently available. It was known that an environmental noise nuisance occurred as motor vehicle wheels passed over the joint but the mechanism for the generation of the noise nuisance was not previously known.

Observation suggested that the noise generation mechanism involved possibly both parts of the bridge structure and the joint itself as it was unlikely that there was sufficient acoustic power in the simple tyre impact to explain the persistence of the noise in the surrounding environment. Engineering measurements were undertaken at Georges River (Tom Ugly's) Bridge and the analysis of these measurements indicated that an environmental noise nuisance resulted from the interaction of vibration of the modular bridge expansion joint with acoustic resonances produced within the void space of the abutment below the joint. A number of engineering methods of noise abatement were considered or investigated before a Helmholtz Absorber installation was adopted.

"Before" and "After" noise measurement results show a significant decrease of low frequency noise due to the Helmholtz Absorber installation. The benefit is most obvious in the frequency range of 50 to 200 Hz which encompasses all the natural vibration modes. The noise reduction provided by the Helmholtz Absorber installation is of the order of 10 dBA which is equivalent to a halving of the perceived loudness.

1 INTRODUCTION

Whilst the use of expansion joints is common practice in bridge construction, modular bridge expansion joints are designed to accommodate large longitudinal expansion and contraction movements of bridge superstructures. In addition to supporting wheel loads, a properly designed modular joint will prevent rainwater and road debris from entering into the underlying superstructure and substructure.

Modular bridge expansion joints are subjected to more load cycles than other superstructure elements, but the load types, magnitudes and fatigue-stress ranges that are applied to these joints are not well defined [Dexter *et al* (1)].

Modular bridge expansion joints are generally described as single or multiple support bar designs. In the single support bar design, the support bar (beam parallel to the direction of traffic) supports all the centre beams (beams transverse to the direction of traffic). In the multiple support bar design, multiple support bars individually support each centre beam. **Figures 1 & 2** show typical single support bar and welded multiple support bar MBEJ's respectively.

The MBEJ installed into the Western abutment of Anzac Bridge is, in fact, a hybrid design having pairs of support bars in series across the full width of the joint. Each pair of support bars is attached to alternate groups of four centre beams [i.e. Centre beams 1, 3, 5 & 7 are attached to support bar #1 (and the other odd numbered support bars) and centre beams 2, 4, 6 & 8 attached to support bar #2 (and the other even numbered support bars)]. The support bar pairs are spaced at 2.25m centres across the full width of the bridge resulting in a total of 24 support bars (2 x 12).

The MBEJ installed into the southbound carriageway of the bridge over the Georges River at Tom Ugly's Point is a typical multiple support bar design as shown in **Figure 2**.

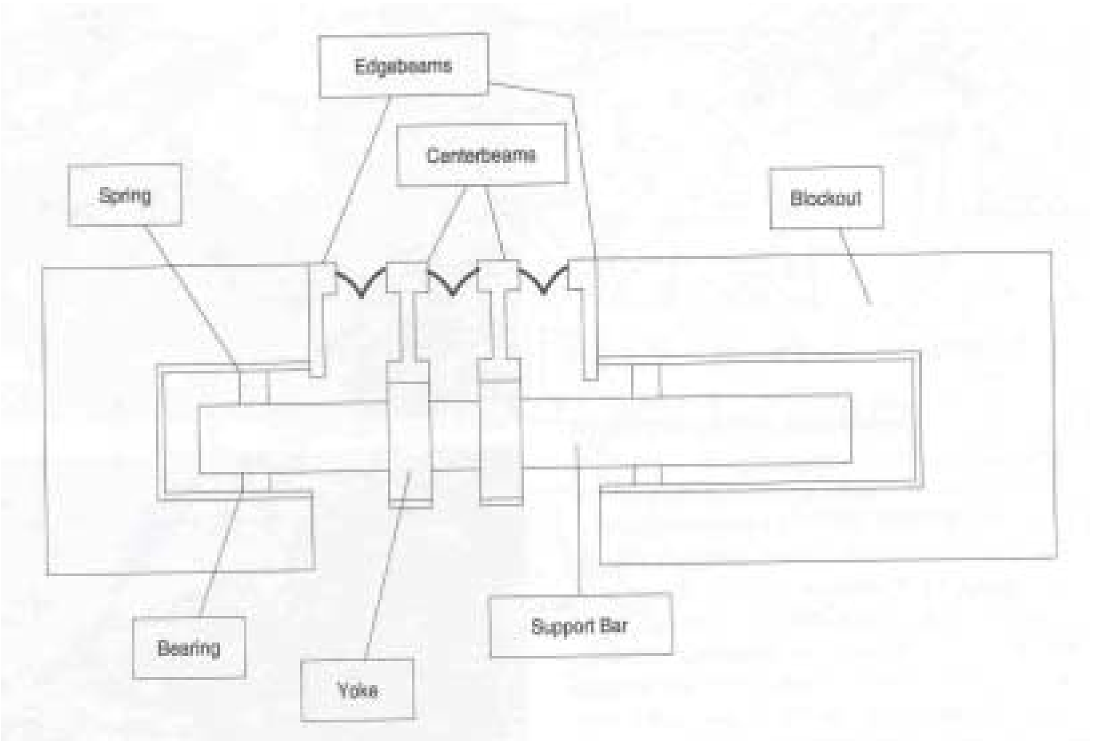

Figure 1: Typical Single Support Bar Design MBEJ

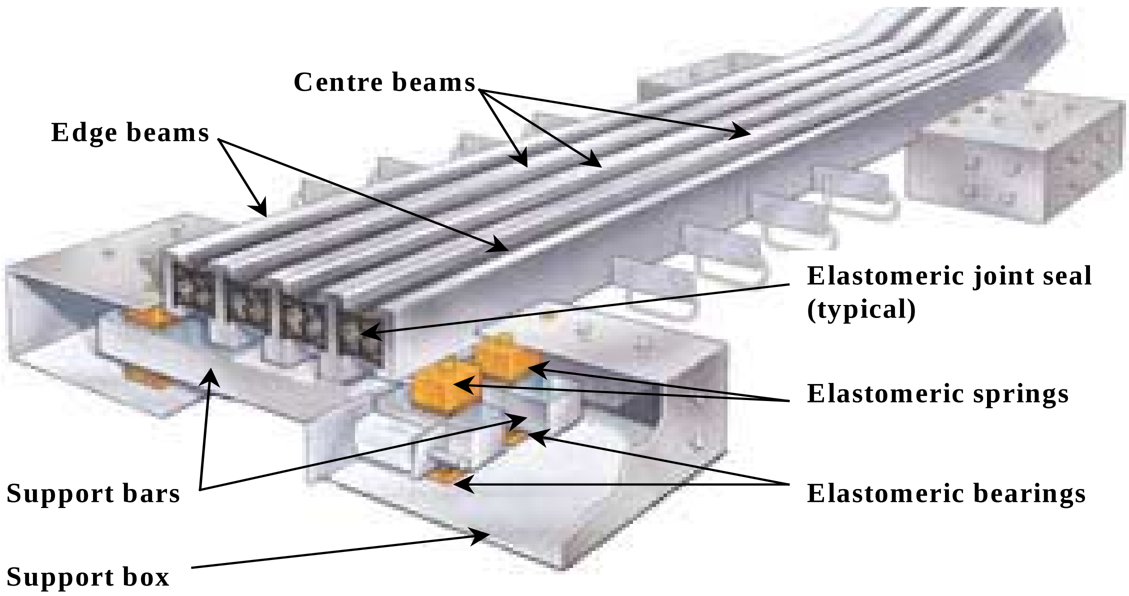

Figure 2: Typical Multiple Support Bar Design MBEJ

It is known that an environmental noise nuisance occurs as motor vehicle wheels pass over the joint but the mechanism for the generation of the noise nuisance is not widely known although Barnard & Cuninghame (2) do identify the role of acoustic resonances. A study was undertaken to determine how the noise nuisance originates and is subsequently propagated into the surrounding environment [Ancich (3)].

Modular bridge expansion joints built into the Georges River (Tom Ugly's) Bridge and Anzac Bridge were selected for the study due to their proximity and ease of access. Engineering measurements were made under operational conditions to determine how the noise nuisance originates and is subsequently propagated into the surrounding environment.

2 MODULAR BRIDGE EXPANSION JOINTS & ENVIRONMENTAL NOISE

There was evidence from environmental noise nuisance complaints received by the RTA that the sound produced by the impact of a motor vehicle tyre with modular bridge expansion joints was audible at least 500 metres from the bridge in a semi-rural environment. This observation suggests that the noise generation mechanism involves possibly both parts of the bridge structure and the joint itself as it is unlikely that there is sufficient acoustic power in the simple tyre impact to explain the persistence of the noise in the surrounding environment.

The hypothesis was developed by Ancich (3) that tyre impacts vibrationally excite modular bridge expansion joints thereby producing noise that is amplified within the bridge superstructure (due to resonance) and then propagated into the surrounding environment.

3 MEASUREMENT PROCEDURE

To test the hypothesis, simultaneous noise and vibration measurements, at the Georges River (Tom Ugly's) and Anzac Bridges, were recorded and analysed. Vibration data were obtained from an accelerometer attached to a transverse beam (centre beam) of the modular bridge expansion joint receiving primary wheel load impacts. Noise data were obtained from a precision Sound Level Meter located inside the void space within the bridge abutment beneath the modular bridge expansion joint and at external locations.

The simultaneous noise and vibration data were recorded using a DAT recorder and subsequently analysed using a dual channel FFT analyser.

4 RESULTS & DISCUSSION

Measurements were initially made at the Georges River (Tom Ugly's) Bridge and the narrow band frequency analysis of the vibration data indicated the presence of a small number of discrete frequencies generally in the range 50-150 Hz.

It was believed that these frequencies were likely to be the vertical and/or horizontal bending frequencies for the transverse beams (tyre contacting) of the modular expansion joint.
Figure 3 shows the ensemble average (50) of wheel load impacts on a transverse beam when viewed in the frequency domain. Examination of Figure 3 reveals the presence of three dominant peaks in the frequency spectrum (70 Hz, 82 Hz & 90 Hz). Consequently, simple natural frequency calculations (using MicroStran®) were undertaken and **Table 1** shows the measured and calculated vibration frequencies.

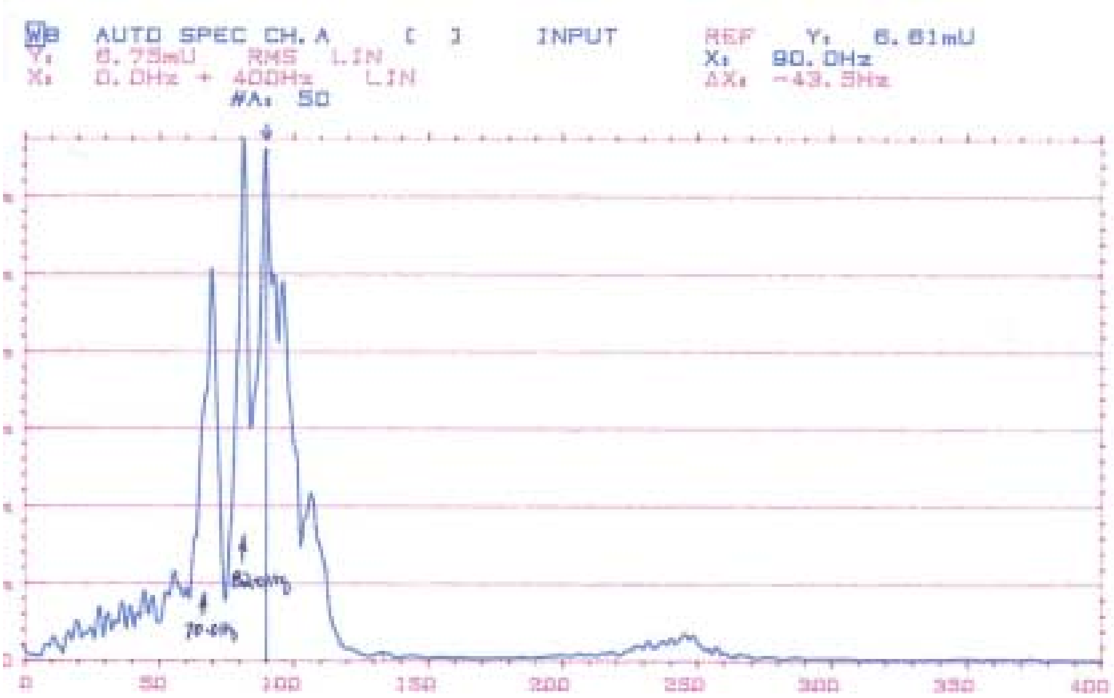

Figure 3: Transverse Beam Vibration Spectrum – Tom Ugly's Bridge

Table 1: Calculated and Measured Natural Frequencies - Georges River (Tom Ugly's) Bridge

Measured Frequency, Hz	Calculated Frequency, Hz[2]	Calculated Vibration Mode[1]
70	67.11	Vertical (1)
82	80.06, 80.78, 81.72, 82.91, 83.37, 83.45, 87.78, 88.97	Horizontal (4), Horizontal (2), Horizontal (3), Horizontal (5), Vertical (2 & 6), Vertical (1 & 4), Horizontal (4), Vertical (2 & 5)
90	88.97, 91.21, 97.36	Vertical (2 & 5), Horizontal (3), Vertical (3, 5 & 7)

Notes: (1) As the precise boundary conditions for the Georges River (Tom Ugly's) Bridge joint are not known, some assumptions were made. The Mode numbers associated with the various frequencies reflect the range of assumptions.

(2) Calculated frequencies are considered correct ± 10% due to assumption uncertainties.

Table 1 indicates a high degree of correlation between the calculated natural frequencies and the three dominant frequencies (70 Hz, 82 Hz & 90 Hz) measured at the Georges River (Tom Ugly's) Bridge.

A possible explanation for the high environmental noise nuisance is acoustic coupling between vibration of the modular joint and room acoustic modes inside the void space within the bridge abutment beneath the modular joint. This possible explanation was tested by calculating the frequencies of the various room acoustic modes encompassed by the vibration frequencies of interest [Beranek (4)]. This comparison is shown as **Table 2**.

Figure 4 shows the acoustic excitation spectrum from measurements undertaken inside the void space within the bridge abutment beneath the modular bridge expansion joint. Examination of Figure 2 reveals the presence of two dominant peaks in the noise frequency spectrum (76 Hz & 82 Hz) and similar or matching frequencies also appear in **Figure 3** and **Table 2**.

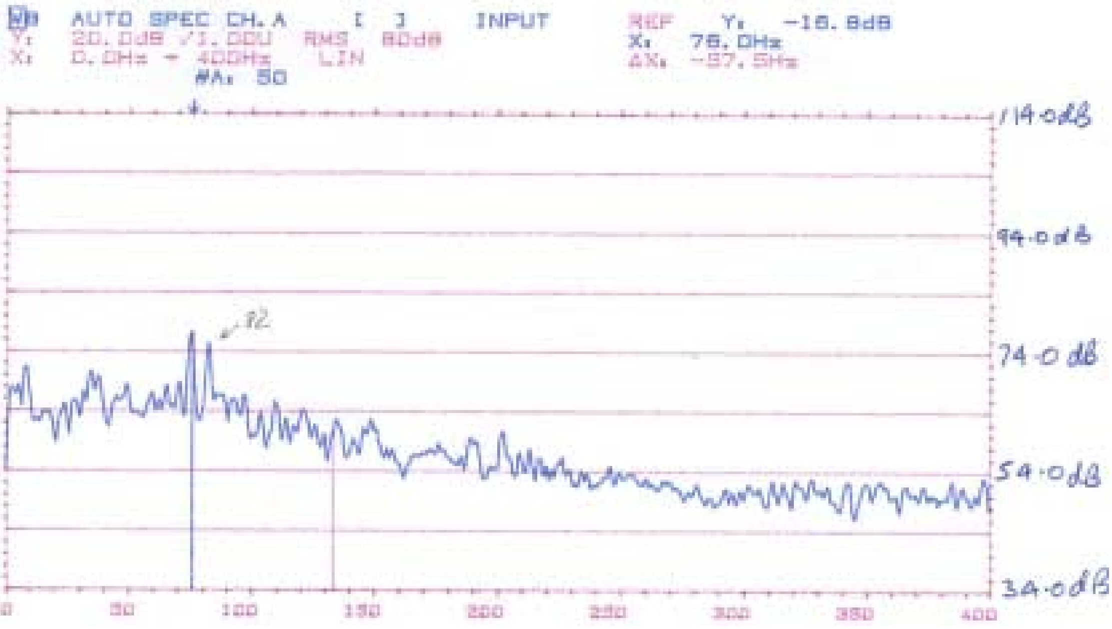

Figure 4: Acoustic Excitation Spectrum – Tom Ugly's Bridge

Table 2: Calculated Room Acoustic Modal Frequencies compared with Measured Vibration Frequencies - Georges River (Tom Ugly's) Bridge

Measured Frequency, Hz		**Calculated Frequency, Hz[1]**	**Calculated Acoustic Mode**
Noise	**Vibration**		
N.A	N.A	11.09	Transverse (1)
76	70	74.14	Vertical (1)
82	82	81.9	Vertical (1)
N.A	90	148.3; 163.8	Vertical (2)

Notes: (1) Calculation of multiple frequencies for some acoustic modes arises from varying dimensions within the void space.

Similar measurements to those undertaken at Georges River (Tom Ugly's) Bridge were repeated at the Anzac Bridge. **Figure 5** shows the corresponding ensemble average (30) of wheel load impacts on a transverse beam when viewed in the frequency domain. Examination of Figure 3 reveals the presence of six dominant peaks in the frequency spectrum (57 Hz, 65 Hz, 70.5 Hz, 84 Hz, 122 Hz & 189 Hz).

Consequently, simple natural frequency calculations (using MicroStran®) were undertaken and **Table 3** shows the measured and calculated vibration frequencies.

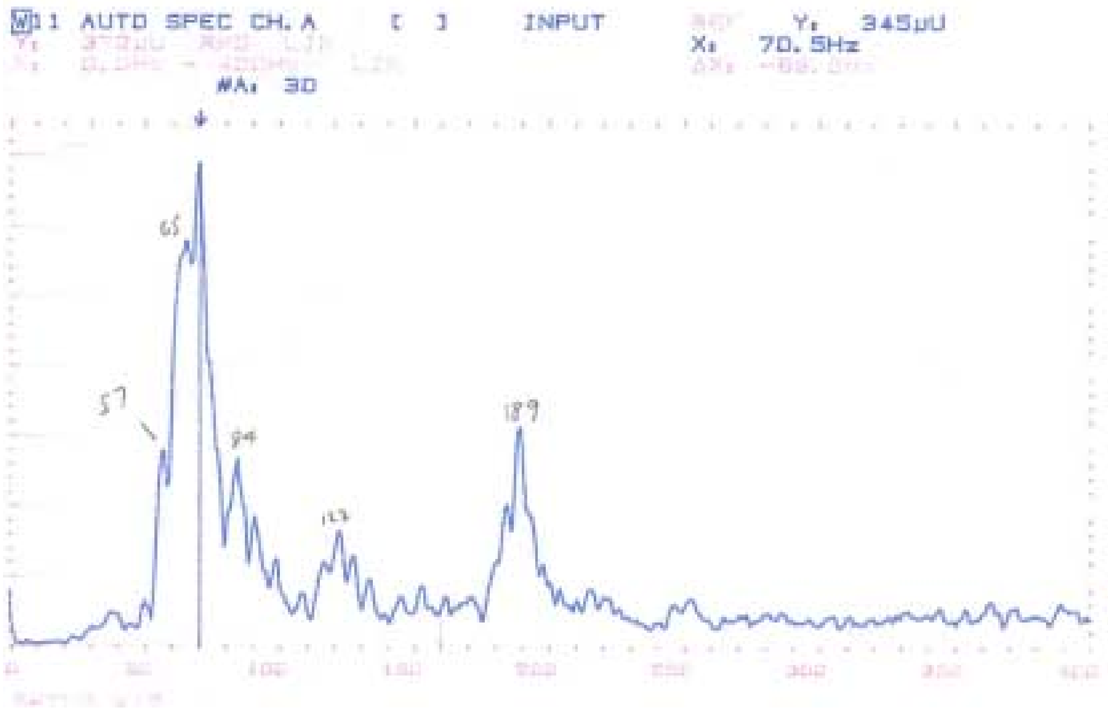

Figure 5: Transverse Beam Vibration Spectrum – Anzac Bridge

Table 3: Calculated and Measured Natural Frequencies (Anzac Bridge)

Measured Frequency, Hz	Calculated Frequency, Hz[2]	Calculated Vibration Mode[1]
57	34.49	Horizontal (1)
65	N.A	N.A
70.5	N.A	N.A
84	91.25, 94.94, 99.38	Vertical (2 & 3), Horizontal (4)
122	103.38, 108.42, 111.21, 118.75, 119.02, 124.27	Horizontal (5), Vertical (6), Horizontal (7), Vertical (8), Horizontal (9), Vertical (10)
189	N.A	N.A

Notes: (1) As the precise boundary conditions for the Anzac Bridge joint are not known, some assumptions were made. The Mode numbers associated with the various frequencies reflect the range of assumptions.

(2) Calculated frequencies are considered correct ± 10% due to assumption uncertainties.

Table 4: Calculated Room Acoustic Modal Frequencies compared with Measured Vibration Frequencies (Anzac Bridge)

Measured Frequency, Hz	**Calculated Frequency, Hz[1]**	**Calculated Acoustic Mode**
N.A	19.0	Transverse (3)
57	45.3, 47.8, 53.8	Axial (1), Vertical (1), Axial (1)
65	63.7	Vertical (1)
70.5	71.7	Vertical (1)
84	86.0	Vertical (1)
122	127.4, 135.8, 143.3	Vertical (2), Axial (3), Vertical (3)
189	172.0, 191.1	Vertical (2), Axial (2) & Vertical (3)

Notes: (1) Calculation of multiple frequencies for some acoustic modes arises from varying dimensions within the void space.

5 NOISE ABATEMENT OPTIONS

Martner (5) reports the results of noise measurements of a number of different types of bridge expansion joints, including modular bridge expansion joints. Whilst he indicates that the installation of an acoustic enclosure beneath the expansion joint was very effective, it is not clear whether the enclosure was used with the modular design.

The analysis of measurements supported the hypothesis that an environmental noise nuisance resulted from the interaction of vibration of the modular bridge expansion joint with acoustic resonances produced inside the void space below the joint. The reverberant nature of the void space was considered to be the reason for the apparent amplification of the low frequency sound pressure within the void space. As true standing waves do not propagate, this highly reactive (long reverberation time characteristic) of the void is not apparent in the far field. Due to acoustic absorption (limited) in the void, some of this sound energy is absorbed within the void and some is radiated to the environment through openings. The build-up of acoustic energy is then radiated into the environment.

It was considered that effective noise abatement could be undertaken by:

- Modifying the dynamic behaviour of the joint to shift the natural frequencies so that they no longer co-incide with acoustic resonances. This option included the trial use of tuned mass dampers.
- Providing acoustic absorption and limited screening, adjacent to the joint, to reduce noise propagation.

- Modifying the acoustic absorption properties of the void space to eliminate or reduce the incidence of acoustic resonances.

The above strategies represent both “new construction” and “retro-fit” options. However, their efficacy and cost-effectiveness is still to be established by engineering measurement

A preliminary noise abatement trial was attempted at Georges River (Tom Ugly’s) Bridge on 20 June 2000 by lining the floor of the void space within the bridge abutment beneath the modular joint with rockwool insulation batts. The batts were raised 75mm (nom.) above the concrete floor to improve the absorption at low frequencies. The principal outcome of this trial was the apparent reduction in extraneous noise that became evident in the Coherence Function analysis of the simultaneous noise and vibration measurements.

There were initial plans to design and test Option 1. However, this option was ultimately not pursued. Although tuned mass dampers (TMD) would likely provide an effective noise reduction, these devices were not strongly advocated due to the high number of natural modes present and hence a high number of TMD’s needing to be fitted and tuned [Jones (6)]. An alternative to the TMD concept would be the use of broadband damping coupled mass absorbers.

The probable disadvantage of this approach being the requirement for a significant mass attachment to each centre beam.

Due to resonances within the void space, the use of acoustic absorption and limited screening, adjacent to the joint was not considered practical. Consequently, only Option 3 was investigated. This investigation was undertaken using two different approaches. Firstly, the simple addition of acoustic absorption into the void space was tested.

Noise measurements were conducted on 4 May 2001 at which time trial acoustical absorption material had been installed over the floor of the void below the expansion joint. The absorption was arranged in a 100 mm thick layer over the floor area of the void and raised 75 mm (nominally) above the floor surface (to optimise low frequency sound absorption).

Whilst the above deck (Locations 1 and 2 – Figure 3) and the side (Location 3) measurements show no significant change in the noise spectra, Locations 4 and 5 show a significant increase in the low frequency bands when the trial absorption was removed.

As the measurements at Location 5 (from within the void space) are the result of sound pressure due to both propagating sound energy as well as non-propagating standing waves, the results at Location 4 provide a better indication of the effect on the emitted (propagating) noise. The second approach involved the construction of a Helmholtz Absorber within the void space. The internal dimensions of the Helmholtz chambers were calculated to co-incide with the dominant acoustic frequencies.

The Helmholtz Absorber panels were designed to target the critical frequencies shown in **Table 5**.

Table 5: Helmholtz Absorber Modules Target Frequencies

Segment	**Design Centre Frequency of Helmholtz Absorber, Hz**					
	1	2	3	4	5	6
Frequency (Hz)	64	80	90	105	110	120

The "Before" and "After" noise measurement results are provided graphically as **Figure 6**. It is clear from these measurement results that Location 4 (Refer Figure 8) shows a significant decrease of low frequency noise due to the Helmholtz Absorber installation. The benefit is most obvious in the frequency range of 50 to 200Hz. which encompasses all the natural vibration modes. The noise reduction provided by the Helmholtz Absorber installation is of the order of 10 dBA.

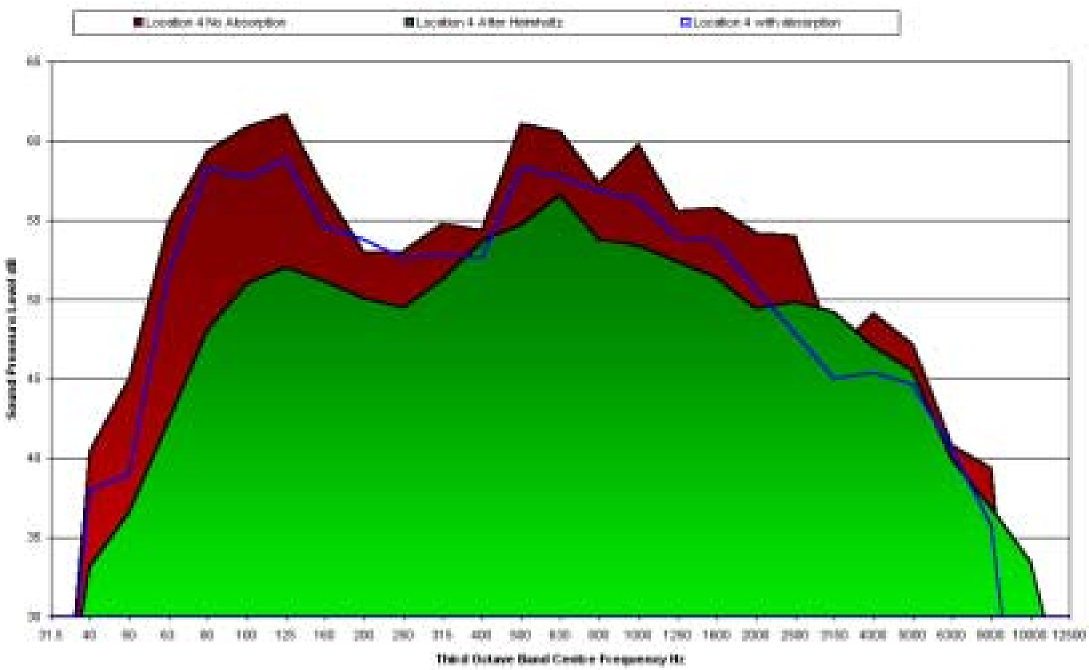

Figure 6: RMS Average Third Octave Band Noise Spectra at Location 4

Figure 6 shows a comparison of RMS average ⅓ octave band noise spectra at Location 4 before and after the Helmholtz absorber installation. Also shown are the ⅓ octave band noise spectra with floor absorption only, for comparison.

These results clearly demonstrate the effectiveness of the Helmholtz absorber modules in the target range of 60Hz to 160Hz.

Figure 7 shows the installed absorber modules.

Figure 7: Helmholtz Absorber

6 NOISE MEASUREMENT LOCATIONS

Noise measurements were conducted at several locations in the vicinity of the expansion joint. **Figure 8** shows a site plan with noise measurement locations indicated.

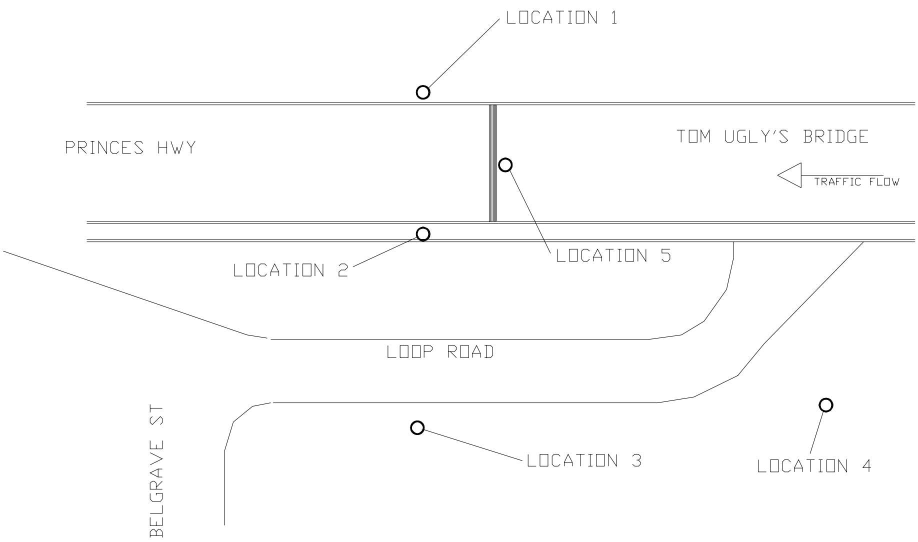

Figure 8: Site Plan Showing Noise Measurement Locations

7 CONCLUSION

Noise and vibration measurements have been undertaken at Anzac and Georges River (Tom Ugly's) Bridges. The analysis of these measurements supported the hypothesis that an environmental noise nuisance results from the interaction of vibration of the modular bridge expansion joint with acoustic resonances produced inside the void space below the joint.

The trial addition of acoustic absorption batts into the void space of Tom Ugly's Bridge was considered to be only marginally effective for noise control and was not pursued. However, the installed Helmholtz Absorber at Tom Ugly's Bridge has reduced the modular expansion joint induced low frequency "booming" noise emissions by up to 10 dB. The character of the noise emission from the underside of the bridge deck would no longer be classified as tonal and hence the likelihood of modular expansion joint related noise complaints has been significantly reduced.

The use of Helmholtz Absorbers at other bridges with modular expansion joints is considered to be viable as an engineering method of noise control.

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