Analysis and Control of Bridge Expansion Joint Croaking Noise

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1. INTRODUCTION

Large bridges require expansion joints to accommodate thermal expansion and contraction as well as movements induced by seismic events. Virtually all expansion joints create additional noise over and above that due to normal tire-pavement interaction. Many joints create "slapping", "banging" or "booming" sounds from the impact of tires on the leading edges of the joints. Another type of expansion joint noise arises from the sequential impact of rolling tires on series of transverse joint elements (bars, tubes) – the familiar "cattle guard" effect. This noise is tonal and its pitch varies directly with vehicle speed.

In response to community concerns, Wakefield Acoustics Ltd. has investigated expansion joint noise at two new bridges in B.C. While of very different constructions, these two expansion joints produced similar sounds, variously described as a "croaking frog" or a giant "zipper". The first bridge utilizes Mageba "modular expansion joints" (Figure 1), which feature a series of transverse "lamella" beams (I-beams) with v-shaped rubber seals between them to keep water and debris out the sliding joint mechanism below. The second joint (Figure 2) is produced by Alba and features a "saw-toothed" rolling surface constructed from rubber-encased steel strips which expand and contract like accordion bellows.

2. INITIAL FIELD MEASUREMENTS

Initial measurements conducted close to one of the Mageba Modular Expansion Joints using a Larson-Davis 2800 Real Time Analyzer revealed that the characteristic frequency of the "croaking sound", while not constant, fell within a limited range centred on the 630 Hz. one-third octave band (Marriner & Wakefield, 2011). The frequency did not vary directly with vehicle speed so that this was not the cattle guard effect. While the intensity of the croaking noise varied with vehicle type and speed, virtually all light vehicles made the noise, while heavy trucks, tended not to.

3. JAPANESE RESEARCH

Researchers in Japan (K. A. Ravshanovich et al) investigated modular expansion joint noise and created a full-size replica of a modular expansion joint in a test compound. They postulated that the croaking noise was created when pulses of air are injected into the joint cavities by tires rolling over the gaps between lamella beams. While not identifying the precise source mechanism behind the croaking noise they found that the sound (again centred around 630 Hz.) was substantially suppressed when "rubber fillings" were inserted into the cavities bounded by the joint seals and the lamella beams. The specific nature of the "rubber fillings" was not described nor was such information subsequently obtainable. An experimental investigation was therefore required to identify an optimal noise suppression material.

4. JOINT INSERT EXPERIMENTS

An initial experiment involved filling the cavities of one modular expansion joint with 2 mm diameter crumb rubber from recycled tires. Crumbs of this size have been shown (Asdrubali et al, 2008) to have optimal sound absorption capabilities at 630 Hz. One third-octave and narrow band spectra of croaking noise were obtained on the bridge deck directly adjacent to the expansion joints, both before and after, the crumb rubber was inserted. By averaging spectra from many vehicle pass-bys, the crumb rubber was found to have reduced the maximum band-limited (400 to 900 Hz.) noise levels created during these very brief noise events by approximately 3.2 dB. The crumb rubber had then dissipated just over 50% of the joint noise energy. While a significant noise reduction, it was not sufficient to resolve the community noise issue.

A similar 3 dB noise reduction effect was attained when closed-cell foam rubber strips were glued between the lamella beams flanges leaving the v-shaped cavities below empty. Here part of the observed noise reduction may have resulted from the closed-cell foam strips acting to reduce the intensity of pressure pulses entering the joint cavities.

5. SOUND ABSORPTION TESTS

To find a more effective joint insert material, eight different open and closed-cell foam rubbers as well as other porous materials were tested to determine their sound absorption coefficients. The tests were conducted at UBC's Department of Mechanical Engineering using the impedance tube method under the direction of Dr. Murray Hodgson. The best combination of high sound absorption capacity and good physical properties was found to be provided by a fibrous "geotextile" material developed for use in soil/slope stabilization. At 50 mm thick, the geotextile had a sound absorption coefficient of 0.85 at 630 Hz. and, because of its intended use, was suitable for prolonged exposure to the elements.

6. ADDITIONAL FIELD EXPERIMENTS

To provide a long-term solution to the joint noise issue, the joint cavities were first filled with geotextile material and then "capped" with strips of 6 mm thick solid neoprene rubber, The caps, which were bonded to the flanges of the lamella beams keep the geotextile material in place and exclude water and debris from the joint.

When measured on the bridge deck, these geotextile and neoprene inserts were found to reduce the maximum band-limited noise levels by an average of 10.3 dB compared to the levels from the untreated joint - corresponding to roughly a halving of the subjective loudness of the croaking noise. Since this noise reduction was achieved at the source, similar reductions were anticipated at the quite distant (700 m) residences most bothered by the noise. Digital sound recordings made before and after the geotextile joint treatment using a B&K Type 2250 portable analyzer confirmed this expected outcome.

Figure 1. Mageba Modular Expansion Joint

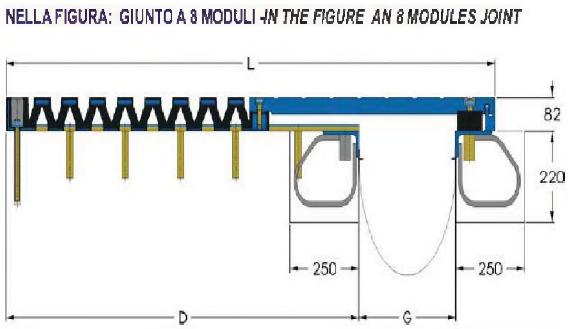

Figure 2. Alba Expansion Joint (cross section)

7. CROAKING NOISE MECHANISM

7.1 Helmholtz Resonator Theory

Initially it was suspected that the croaking noise was due to an acoustic resonance involving the compliance of both the volume of air in the joint cavities and the compliance of the rubber joints seals. However, when the Alba expansion joint, which has no lamella beams or rubber seals, was seen to produce a very similar noise, it became apparent that the compliance of mechanical joint components themselves had little influence on the observed resonant frequency. The standard equation for the frequency of a Helmholtz resonator could then be used in an attempt to confirm the source mechanism.

The classic Helmholtz resonator is a spherical volume connected to the outside air by an opening with or without a "neck". Such resonators can be used to absorb sound at frequencies close to resonance. However. if excited by a pulse of air pressure, as when one slaps the top of a empty bottle, sound energy at the resonant frequency is radiated to the outside world. In the classic Helmholtz resonator, the air volume in the sphere, or bottle, provides the compliance element while the "slug" of air in the resonator's neck provides the mass or inertance. If no physical neck is present, a short air column on either side of the opening (i.e., end correction) will provide the acoustical inertance. end correction length is related to the radius of opening.

Figure 3 shows a vehicle tire rolling over the gap beType equation here.tween two adjacent lamella beams within a modular expansion joint. As the tire rolls over each successive gap, a semi-enclosed volume of air is temporarily created between the tire tread above and the v-shaped rubber surface, lamella beam edges and the joint seals, then act as "necks" on either side of the resonator volume.

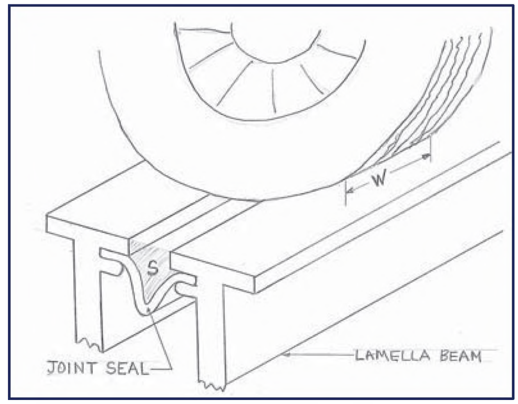

Figure 3. Modular Expansion Joint with Tire

The natural frequency of a Helmholtz resonator (Kinsler and Frey, 1950) is given by:

$$f = \frac{c}{2\pi}\left(\frac{S}{lV}\right)^{1/2} \text{ Hz.} \qquad \text{Equation 1}$$

If the area of the resonator's openings, or necks, is "S" and the typical width of a light vehicle tire is "W", then the resonator cavity volume "V" is:

$$V = SW \qquad \text{Equation 2}$$

The effective length of the neck "l" is equal to the actual neck length, (here zero), plus two end corrections, "Δl", assumed (Kinsler and Frey, 1950) to be approximately 0.85a, where "a" is the equivalent radius of the neck opening. In this case, "a" is roughly 24 mm. Substituting for V from Equation 2 into Equation 1, we obtain:

$$f = \frac{c}{2\pi}\left(\frac{1}{lW}\right)^{1/2} \text{ Hz.} \qquad \text{Equation 3}$$

Solving Equation 3 with c = 345 m/sec, l = 41 mm and W = 180 mm, we obtain a Helmholtz frequency of 635 Hz.

8. CONCLUSIONS

While the Helmholtz frequency varies with assumed tire width and effective resonator neck length, the excellent agreement between the predicted resonance frequency and the central value obtained from many croaking noise events, confirms the mechanism behind this unusual noise. The two joint types, while very different in design, create similar croaking frequencies because this frequency is primarily a function of tire width. The effectiveness of the geotextile inserts is attributed to a combination of sound absorption in the cavity and vibration damping of the rubber seals.

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