Noise from bridge expansion joints – Evaluation considerations and possible reduction measures

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ABSTRACT: Considering the considerable impact that noise from bridge expansion joints can have on local residential communities, particularly at night, and the problems that resulting complaints may present for bridge owners, it is sometimes necessary to evaluate noise from existing expansion joints, or from proposed or already implemented solutions. This paper explores the general issue of noise from bridge expansion joints, with discussion of causes/sources and possible solutions. Principles of evaluation of noise and of the benefit offered by noise-reduction measures are also discussed.

1 INTRODUCTION

The noise that will be generated by traffic in crossing a road bridge's expansion joints is often not a primary concern during the expansion joint selection process, when issues such as movement capacity, durability and installation seem more important, but it is not an issue that should be overlooked – as can be attested by engineers and bridge owners that have had to deal with unhappy residents' organizations following the use near residential areas of expansion joints that are not quiet enough under traffic. Fortunately, most types of expansion joint in common use today can be considered "quiet" as a rule – assuming well designed and fabricated, properly installed and in good condition. In general, joints that provide continuous support to the wheels of overpassing vehicles – such as mat joints, flexible plug joints and finger-type expansion joints – fall into that category, since their designs minimize the kinds of impacts and vibrations that cause noise. However, joint types that do not provide continuous support to vehicle wheels – such as standard single-gap joints and modular joints – can generate significant noise due to the impacts and vibrations that arise under traffic.

Of course, these types of joint have much to offer for the various benefits they offer, some of them unique. For instance, the most technologically advanced modular joints available today (Figure 1) offer the ability to accommodate very large movements, combined with exceptional flexibility in terms of tridimensional movements and triaxial rotations (Moor et al, 2016). And single gap joints such as those shown in Figure 2 offer unsurpassed robustness and durability – the one with polymer concrete anchorage having the added advantage of being optimal for installation on an existing structure (Spuler et al, 2013).

Where joints of these types – single gap or modular – are to be used but noise generated by traffic crossing the joints may cause a problem, then it may be necessary to evaluate the noise. It may also be necessary to consider ways of reducing noise accordingly by means of optional features – again, with appropriate evaluation of the benefits offered by potential noise reduction measures. This subject is discussed below with reference to the modular joint, which in effect comprises a series of single gap joints combined together as a single unit.

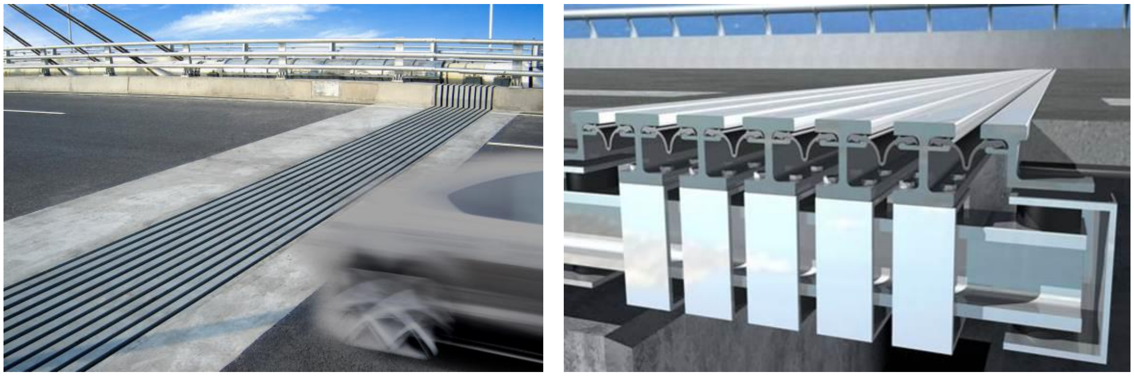

Figure 1. A Tensa-Modular joint on a bridge, and a cross-section image of a joint of the same type.

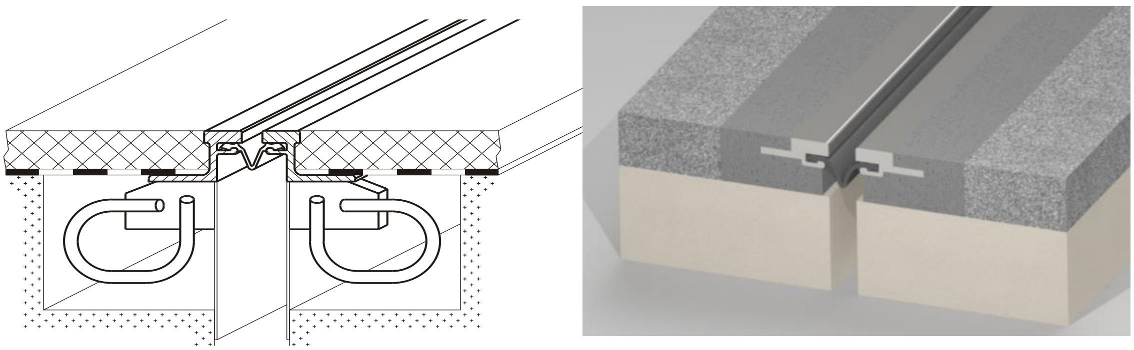

Figure 2. Single gap joints of two types: a Tensa-Grip joint with normal concrete connection (left), and a Tensa-Crete joint with polymer concrete anchorage – ideal for use on existing structures (right)

1.1 *Approaches to combatting noise from bridge expansion joints*

In general, noise from bridge expansion joints (of the modular or single-gap type) is of two principal types – that generated at the driving surface by rubber/steel contact and transmitted directly through the air above the joint's surface, and that resulting from impacts and vibrations passing through the joint and emanating from the joint's underside.

1.1.1 *Noise emitted from joint's surface and transmitted above driving surface*

Noise from modular or single-gap joints may be combatted by adding suitably shaped plates on top of each surface beam, creating a smooth driving surface that provides continuous support to vehicle wheels. These surface plates have protrusions which bridge over the gap's individual gaps, somewhat like the fingers of finger-type expansion joints. The surface plates that may be added to joints of the types shown in Figure 1 and 2, known as "sinus plates" due to their shape which resembles a sine wave, are shown in Figure 3 and considered in Section 4 below. It should be noted that the geometry of these plates typically limits the otherwise excellent ability of these joint types to accommodate transverse and vertical movements, so this potential impact must not be overlooked in the joint's overall design.

1.1.2 *Noise emitting from beneath the joint's surface*

As a vehicle crosses an expansion joint, noise from the vehicle and its contact with the joint also passes right through the joint and is transmitted from the space beneath the joint – most significantly, transversely to the direction of travel, but due to reflection of sound waves, any downward or horizontal emission of noise from this space can have a considerable impact.

Such noise can be addressed by enclosing the space below the joint using mats/membranes or similar that are flexible enough to accommodate the joint's movements and rotations. Such a system can be designed to block the free passage of sound waves away from this space, absorbing much of the noise energy and reducing its intensity. Images of such a solution, developed for the type of modular joint shown in Figure 1, are presented in Figure 4 and considered in Section 5 below.

Figure 3. Expansion joints of the types shown in Figures 1 and 2, equipped with noise-reducing “sinus plate” surfacing – a modular joint (left) and a single-gap joint (right).

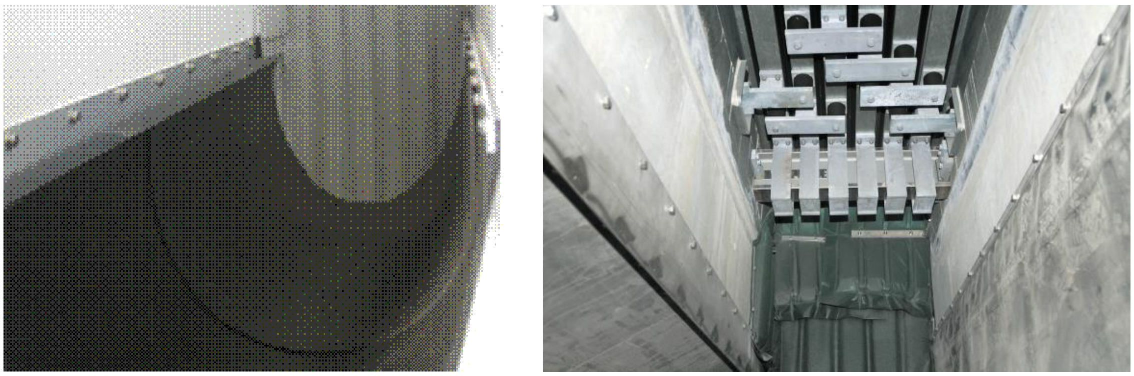

Figure 4. The Robo-Mute noise protection feature encloses the space beneath an expansion joint, trapping and absorbing noise and reducing its impact. It consists of a channel along the length of the joint, which may be disconnected at one side to allow inspections of the joint, as shown on the right, and hanging elements at each end of the channel.

1.2 *Uniqueness of every application and of applicability of test results*

It is important to note that the noise generated at a bridge’s expansion joints, and its impact on the local population, is strongly dependent on a wide range of factors (see Section 2 below). Therefore, the fact that a certain solution was found in testing to reduce noise by a certain number of decibels, for example, does not mean that the same level of noise reduction can be expected on another structure, or even at the same structure under different conditions. Therefore, the results of any testing should be considered only an indication of performance level, and their applicability should be considered for each particular application.

2 FACTORS AFFECTING NOISE LEVELS AND THEIR IMPACT

A large number of factors affect the sound generated by traffic crossing any bridge expansion joint and the impact this noise will have – for example:

- The type, design and quality of the expansion joint; noise can be minimized by selection of a high-quality joint, with a design that minimizes impacts between components and damps vibrations (see Figure 5), and which is fabricated to a high degree of precision.
- The care with which the expansion joint is installed; proper long-term joint performance requires installation without unintended stresses and constraint forces that could result in accelerated wear and impacts between components. The joint type shown in Figure 1, with a rectilinear layout thanks to it “single support bar design” (Figure 5), simplifies installation and thus minimizes such risks.
- The care with which the road surface at each side of the joint is placed, and its condition; a lack of smoothness (e.g. due to rutting) can result in impacts and vibrations which can generate noise. Such noise can be significant, for example, when resulting from impacts on an empty truck that resonates strongly, causing a “boom” sound.

- Varying surfacing at either side of a joint (e.g. asphalt and concrete); this can accentuate the change in sound that occurs as a vehicle crosses the joint.
- The condition of the expansion joint, which depends on its age and on the care and attention devoted to inspection and maintenance activities through its life.
- The presence of relatively loose features such as cover plates.
- The type of bridge structure and its design – in particular, the design of the space in the abutment underneath the joint, and whether or not it would tend to block noise.
- The materials from which the bridge is constructed – e.g. a hollow steel structure will echo and resonate, whereas a solid concrete structure will damp noise.
- The proximity of buildings, especially residential, and the location of these relative to the bridge and expansion joint – is there a clear straight line for noise to travel?
- Local topography – are buildings situated below or above the level of the bridge?
- Level of background noise, since sensitivity to noise is strongly influenced by this.
- Time of day, since noise at night is likely to be far more bothersome than daytime noise.
- Personality and state of mind of the person who hears the noise and might object – since objective data should be valued more than a subjective alternative.

All such factors should be considered when assessing a perceived problem with noise at any particular expansion joint and developing a solution to such a problem.

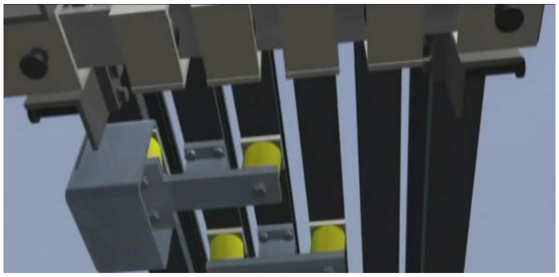
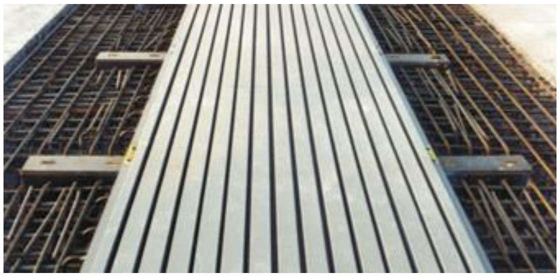

Fig. 5. The design of the modular joint type shown in Figure 1 helps combat noise; its elastic design (left) provides damping and prevents impacts between its structural elements, and its regular, rectilinear layout simplifies installation, minimizing the risk of noise due to sub-optimal installation.

3 EVALUATION OF EFFECTIVENESS/VALUE OF NOISE REDUCTION MEASURES – ALTERNATIVE GENERAL APPROACHES

Where the effectiveness of a solution (a feature or measure) in combatting noise from an expansion joint is being evaluated, or requirements are being specified for a particular project, it might be easy to consider or define this effectiveness as

- the degree to which noise from the joint is reduced, in dB, compared to a joint that does not feature the solution.

However, there is much to be said for defining the effectiveness, alternatively, as

- the degree to which noise from a joint, which features the solution, exceeds the level of other "background noise" from traffic on the road before/after it crosses the joint.

It can be strongly argued that the second of these approaches is considerably more relevant in most cases, because the disturbance level caused by any source of noise depends very strongly on how it stands out from other noises to which the listener has become accustomed. People living near the bridge, while trying to sleep at night, are unlikely to care how much quieter the joint is than it would have been if it did not feature a particular solution – which is, in effect, what is evaluated by the first approach. The first approach also has the flaw that it does not take account of the fact that all expansion joints of any particular type (e.g. modular), without any noise reducing features, do not emit the same level of noise under traffic (e.g. ref. Figure 5). Therefore, although a noise reduction solution may reduce noise significantly, and thus satisfy a requirement based on this approach, the resulting noise level may still be unacceptably high.

Alternatively, a combination of the above approaches may also be considered, evaluating:

- the degree to which the application of the solution to a joint reduces the amount by which noise from the joint exceeds the level of background noise from the road.

These alternative approaches are illustrated, where the availability of data allows, in relation to noise-reducing surfacing in the following section.

4 EVALUATION OF EFFECTIVENESS OF NOISE-REDUCING SURFACING

The effectiveness of "sinus plates" (as described above and shown in Figure 6 below) in combatting noise from Tensa-Modular joints is considered below, using the three approaches proposed above. These comments are brief summaries of detailed evaluations contained in a report by Mageba (2013), which was prepared using data contained in noise measurement reports by specialist consultancy Müller-BBM (1993, 2012).

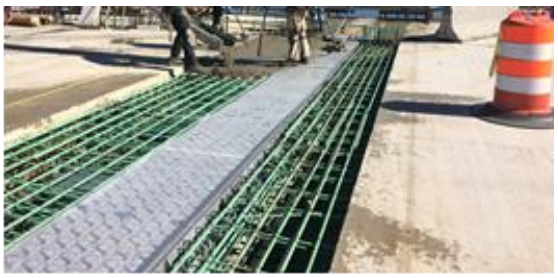

Figure 6. Installation of noise-reduced modular joints of the SR520 West Approach Bridge, Washington.

4.1 *Evaluation of the degree to which noise from the joint is reduced compared to a joint that does not feature the solution*

Using data from measurements of noise from a particular 5-gap modular joint, as installed, both before and after the addition of noise-reducing surfacing (Müller-BBM, 1993), the effectiveness of the surfacing could be evaluated, as follows:

- Noise from a car travelling at 60 km/h was reduced by 14 dB
- Noise from a car travelling at 80 km/h was reduced by 10 dB
- Noise from a car travelling at 120 km/h was reduced by 4 dB
- Noise from a truck travelling at 60 km/h was reduced by 7 dB
- Noise from a truck travelling at 80 km/h was reduced by 3 dB

It is important to note that these values are conservative due to the way in which the testing was conducted – with surfacing simply added to the surface of an existing joint for the purposes of the testing, and with surface plates only applied to the joint's free-moving centerbeams. Therefore, an expansion joint that has been fabricated with surface plates under factory conditions, with full quality control, might be expected to achieve significantly better results – especially since it will have surface plates on the edgebeams as well as the centerbeams.

4.2 *Evaluation of the degree to which noise from a joint, which features the solution, exceeds the level of background noise from the road*

The degree to which noise from a particular Tensa-Modular expansion joint with sinus plates on its surface exceeds the level of "background noise" from traffic at either side of the joint could be evaluated with reference to a noise measurement report relating to a 5-gap joint of that type at the Liesertal Bridge on the A1 autobahn in Germany (Müller-BBM, 2012). That report records measurements of noise at two locations, both at the edge of the highway as shown in Figure 7 – one directly above the joint, and the other at a distance of 30 m away. The data provided in the report was used (Mageba, 2013) to compare average noise levels at the two locations, due to the passing of both trucks and cars, at specified speeds. Six sets of data (each itself an average of four subsets) were combined in producing the table shown in Figure 8, enabling an overall average value for trucks to be calculated, and another for cars.

Figure 7. Measurement of noise at a 5-gap Tensa-Modular joint on the Liesertal Bridge on the A1 autobahn in Germany – directly at the expansion joint (left), and at a distance of 30 m away (right).

	Speed [km/h]	Set of readings	Average noise at edge of road, 30 m from joint [dB(A)]	Average noise at edge of road, directly above joint [dB(A)]	Difference due to distance of 30 m [dB(A)]
Noise due to TRUCKS:					
Table 3	90	VarA	91.4	92.2	0.8
Table 3	90	VarG	90.9	92.4	1.5
				Average difference (dB) =	**1.15**
Noise due to CARS:					
Table 4	90	VarA	84.1	87.4	3.3
Table 4	90	VarG	83.7	87.1	3.4
Table 5	120	VarA	88.0	89.8	1.8
Table 5	120	VarG	87.5	89.4	1.9
				Average difference (dB) =	**2.60**

Figure 8. Comparison of noise levels at two locations at side of carriageway at Liesertal Bridge – directly at expansion joint and at a distance of 30 m away – due to passing of trucks and cars at specified speeds.

This demonstrates that the level of noise from a modular joint of this type, with noise-reducing sinus plates on its surface, is not much higher than the level of noise generated by the regular carriageway, for either heavy or light traffic. In fact, with an average difference of only 1.15 dB(A) recorded for the heavier truck traffic which causes the greatest noise, this provides compelling evidence of the quietness under traffic of this type of joint.

4.3 *Evaluation of the degree to which sinus plates reduce the amount by which noise from the joint exceeds the level of background noise from the road*

As an alternative to the above two approaches, a combination of the two might be considered, based on an evaluation of the degree to which the application of the solution to a joint reduces the amount by which noise from the joint exceeds the level of background noise from the road. By comparing data from the two above-mentioned noise measurement reports by Müller-BBM (1993, 2012), the degree to which noise from an expansion joint exceeds "background noise" from the road near the joint could be estimated – in one case, with the joint featuring noise-reducing sinus plates, and in the other case without. In each case, the values presented in decibels can be converted into simple factors using the equation

$$G_{\mathrm{dB}} = 20 \log_{10} \left(\frac{V_1}{V_0} \right)$$

where G_{dB} represents the gain, or difference between the values V_1 and V_0, in decibels.

Considering truck traffic, for example:

- For a joint without sinus plates, noise at the joint was 4.28 dB louder than 25 m away, representing an increase by a factor of 1.64 (i.e. 64% louder).
- For a joint with sinus plates, noise at the joint was 1.15 dB louder than 30 m away (see Section 3.2.2), representing an increase by a factor of 1.14 (i.e. just 14% louder).

Comparing the two increase factors, it can be seen that the net increase in noise caused by the presence of a joint with sinus plates is just 14%/64% = 22% of the increase caused by a joint without sinus plates. In the same way, a figure of 28% was calculated for car traffic. In other words, the data suggests that the increase in noise from a road due to the presence of a modular joint with sinus plates is just approximately one quarter of the increase that would occur if the joint did not have sinus plates. Again, it should be noted that this estimation is conservative since the noise measurements for the joint with sinus plates were conducted at higher speeds (90 or 120 km/h as opposed to just 80 km/h), and the background noise was measured at a distance of 30 m from the joint (as opposed to just 25 m). Had these factors been equal for all cases, the difference between the two sets of results might be expected to be more pronounced.

5 EVALUATION OF NOISE-REDUCTION EFFECTIVENESS OF ENCAPSULATING SPACE BENEATH EXPANSION JOINTS

The effectiveness/value of the noise-reduction solution described in Section 1.1.2 and shown in Figure 4 above (see also Figure 9 below) – which combats noise emitting from below an expansion joint by enclosing the space beneath the joint using noise-trapping and -absorbing elements – is also demonstrated by Mageba (2013) using data provided by Müller-BBM (2012). This data was based on measurements taken not above the road surface as described previously, but inside the bridge abutment (directly beneath the expansion joint) and beneath the superstructure (next to the abutment), as shown in Figure 8. In summary, the data showed that, in this case, noise directly beneath the joint was reduced by 12 – 13 dB. Outside the abutment, noise levels, and thus also the measured noise-reducing effect of 5 – 8 dB, are lower, due to the insulating effect of the abutment itself – an effect which is strongly dependent on the design of the structure and the materials used in its construction. In this particular case, the bridge structure offers a high degree of sound insulation with the area beneath the expansion joint almost fully enclosed by solid concrete structural elements, as can be seen in Figure 10. Therefore, greater reductions in noise level (closer to the values of 12 – 13 dB measured inside the abutment) might be expected for bridges with more open / less insulating abutment designs.

Figure 9. Noise-reduction system applied to the underside of modular expansion joints of the SR520 West Approach Bridge, Washington.

Figure 10. Measurement of noise under traffic of specified types/speeds, both inside the bridge abutment beneath the expansion joint (left) and outside the abutment beneath the superstructure (right).

6 CONCLUSIONS

Noise from bridge expansion joints of certain types, potentially a source of considerable annoyance to nearby communities, should be properly considered when specifying and using expansion joint solutions in bridge construction and maintenance projects. Different solutions may be appropriate, depending on the likely significance of noise emanating directly from the joint's surface (above the level of the driving surface), or from beneath the joint (within the abutment). In evaluating the likely effectiveness of any proposed solution, a more sophisticated approach than is often taken may be possible. For instance, rather than simply evaluating the degree to which noise from a joint is reduced by a particular solution, compared to a joint that does not feature the solution, it is likely to be far more relevant to affected parties to evaluate the degree to which noise from a joint which features the solution exceeds the level of “background noise” from the road (e.g. just 1.15 dB in the presented example of truck traffic crossing a particular type of modular joint with “sinus plate” noise-reducing surfacing). Another useful approach may be to evaluate the degree to which application of the solution reduces the amount by which noise from the joint exceeds the level of “background noise” from the road (e.g. to just 22% or less for the same presented example). By sensibly determining such evaluation criteria, the effectiveness of the evaluation process during selection of an expansion joint solution for a particular structure can be considerably optimized, reducing the risk of public relations difficulties with residents in a structure's neighborhood.

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