Selection of state highway bridge expansion joints in noise sensitive areas

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ABSTRACT

Noise generated by vehicles passing over expansion joints has not been a significant factor in the selection of joint types for most existing state highway bridges in New Zealand. In response to concerns raised by residents living near a proposed new bridge in Wellington, the NZ Transport Agency commissioned research into noise from existing bridge joints on the state highway network to gain a better understanding of design and selection parameters. The research primarily used vehicle mounted noise and vibration transducers to obtain comparative data for a relatively large number of existing joints. Even for the same joint types significant variability in noise generated was found, meaning no clear ranking of different joint types could be established from the data. The installation and maintenance quality of the road surface and joint appears to be a significant factor in noise generated. Finger joints were found to provide consistent performance with noise towards the lower end of the range measured. Modular joints without surface treatment generated high noise levels. This paper sets out the methodology used for the measurement of bridge expansion joint noise and summarises the key findings from the research.

Keywords: bridges, expansion joints, noise I-INCE Classification: 11.7.1, 13.2

1. INTRODUCTION

Many state highway bridge expansion joints in New Zealand are at least partly removed from noise sensitive areas such as housing. Bridges and associated joints are usually immediately above water or other roads, and the footprint of embankments and slip lanes can create separation between joints and the nearest houses. In these cases, while cars and trucks traversing joints may cause noise heard inside the vehicles there is a relatively limited effect experienced in the wider environment. However, the same is not always true for bridges in dense urban environments.

When the NZ Transport Agency was investigating a new urban state highway bridge in Wellington, local residents adjacent to the proposed bridge raised concerns over potential noise from vehicles passing over expansion joints. Consequently, the Transport Agency commissioned research to determine factors affecting noise generated by joints currently used in New Zealand, and to establish options available to minimise noise from new bridge joints in noise sensitive areas. Existing literature was reviewed and an extensive measurement programme was conducted primarily using instrumentation mounted on a vehicle (1).

1.1 Joint types

Bridge expansion joints are used to accommodate horizontal/longitudinal and to a lesser degree vertical movements within bridge structures. The main guidance on expansion joints relates to this primary structural function, with a key factor being the range of movement that can be accommodated by different joint types (2,3,4).

In New Zealand, over half the existing state highway bridges do not have expansion joints. Of the remaining bridges the most common joints are simple air gaps and bitumen filled gaps, followed by sliding steel plates. There is then a variety of rubber extrusions/seals in use. Modular and finger joints are only present on a small number of existing bridges, but finger joints have been more commonly used on recent projects with large viaducts/bridges. Environmental noise is not known to have been a significant factor in the selection of any existing expansion joints.

1.2 Joint noise

Internationally, there have been numerous previous studies and research into noise from vehicles passing over expansion joints. These include development of methods to treat both the top surface (5) and cavity underneath joints (6) to reduce noise levels. However, the focus of research is often on noise from larger joints, such as modular joints, and the literature does not provide comparative data for the range of expansion joint types commonly used in New Zealand.

2. MEASUREMENT SYSTEM

Previous investigations into expansion joint noise have generally used measurement methods based on those developed for road surface noise, such as statistical pass-by (7), close proximity (5) and on-board sound intensity (8). Statistical pass-by type measurements beside a bridge appear to be favoured in most studies as that allows the contribution of noise radiated from below the joint/bridge to be included. A disadvantage of this approach is that significant time is required at each measurement site and access can be difficult. Some of the recent expansion joints installed in New Zealand, that were desired to be included in the current study, are on roads with high traffic volumes and no access to the side of the bridges for measurements. Night-time lane closures to enable road-side measurements were not considered practical within the time constraints for this research. Therefore a vehicle mounted measurement system was used.

There are currently no close proximity trailers or on-board sound intensity equipment in New Zealand. To enable measurements of expansion joint noise to be undertaken quickly, a bespoke measurement system was made by fitting a microphone and an accelerometer to a car. The vehicle selected was a Toyota Aurion, which has independent rear suspension, and the transducers were mounted by the left rear wheel. A single data acquisition system (IOtech LogBook/360) was used to record the sound and vibration signals, along with other information.

2.1 Transducers

A mini condenser microphone was installed in close proximity behind the rear left wheel of the test vehicle, in the lateral centre of the tyre. The microphone was located as close as considered practical to the road without damaging the equipment. All noise levels presented in this paper relate to this specific measurement position, and have not been correlated to levels experienced in the wider environment near bridges. Only the relative performance of joints has been assessed.

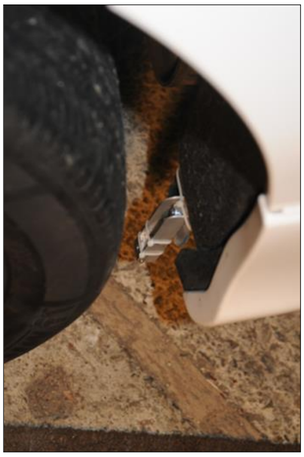

Figure 1 – Microphone mounting behind left rear wheel

Vibration measurements were made with a triaxial accelerometer fitted to the left rear suspension arm of the test vehicle. In broad terms both the noise and vibration data resulted in similar comparisons of the different joint types. Figure 2 shows the relationship between noise (L_{AFmax}) and vibration (vertical acceleration) for all joints measured in this study, including a best fit line indicating a weak correlation of increasing noise with increasing vibration. While both noise and vibration are generated from the force as the tyre passes over the joint, the weak correlation is likely to be due to factors such as the specific tyre of the test vehicle. For clarity only noise data is presented in the remainder of this paper.

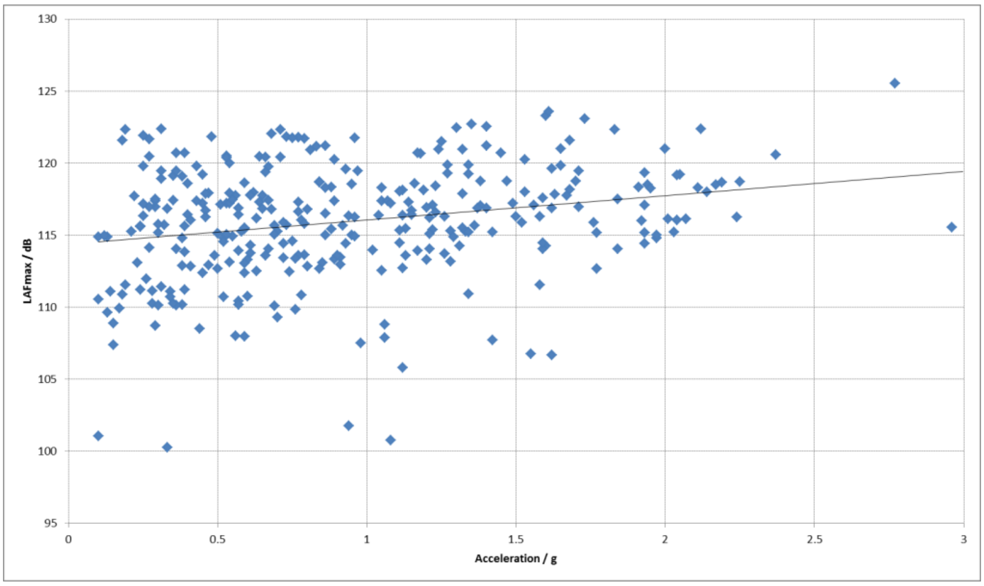

Figure 2 – Comparison of noise and vibration data for expansion joints

2.2 Ancilliary equipment

In addition to the noise and vibration transducers, the vehicle was fitted with a GPS unit, a manual event marker and two digital video cameras. The equipment operator in the vehicle pressed a button each time the rear wheels passed over a joint. This marker together with the GPS data was used to manually identify each expansion joint event in the noise and vibration data, and relate it to an entry in the national database of state highway bridges. While the system was designed for this process to be undertaken efficiently, it still required significant time to accurately locate each joint/event in the noise data and correlate that with the joint type in the bridge database.

Two cameras were used, one forward facing to assist locating the vehicle if required, and one facing down at the road to the side of the vehicle. It was intended that the side camera would provide clear images of each joint traversed. The camera was a GoProTM Hero 3 Black Edition with a recording resolution of 1080 ×720 pixels at 120 frames per second. Unfortunately this system did not result in useful pictures, with lighting conditions having a significant effect on the quality. An example image with two adjacent joints is shown in Figure 3. As these images were not suitable, library images taken during the annual pavement condition survey were used as required.

Figure 3 – Example image from side mounted camera

2.3 Analysis

Data was analysed in MATLAB for a 1 second period around each joint event. Various time and frequency weightings were assessed. Comparing frequency weightings, Figure 4 shows a joint event that is obscured in the unweighted data but is more pronounced in the A-weighted data. A disadvantage of the temporary measurement system used is contamination of noise data that occurred from wind and other extraneous noise. This system noise is partly suppressed by the A-weighting, and the resulting levels are appropriate to illustrate overall trends between joints. With respect to time weightings, it was found that using a fast weighting gave marginally better differentiation between joints than a slow weighting, and therefore results are presented here in terms of the L_{AFmax}.

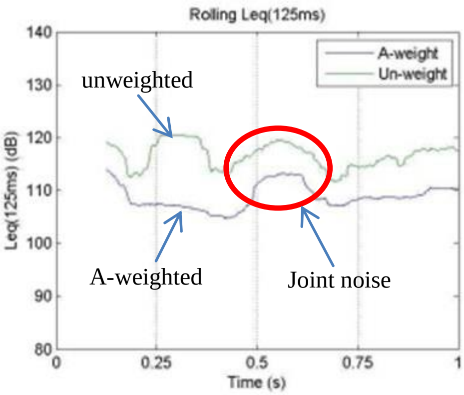

Figure 4 – Comparison of A-weighted and unweighted noise data

2.4 Repeatability

For some of the expansion joints the test vehicle made multiple pass-bys, and this data has been used to examine the repeatability of the measurement system. Table 1 shows the differences in measured L_{AFmax} values for two traverses of five joints on one particular bridge. The joints on this bridge are recorded as being rubber seals with vertical steel plates. For each of these joints, apart from joint 5, the two pass-bys give results within 1 dB. A number of factors may have influenced the change in level measured for joint 5, such as the exact lateral position of the test vehicle on the road.

Table 1 – Difference in L_{AFmax} for two pass-bys

Joint number	L_{AFmax} difference
1	0.6 dB
2	0.0 dB
3	0.9 dB
4	0.7 dB
5	4.2 dB

Further analysis for all joints where there were multiple pass-bys is summarised in Figure 5. The difference in L_{AFmax} was determined for each multiple pass-by of the same joint, and then the average differences for each joint type were calculated. For all joint types the average difference between multiple pass-bys of the same joint was 3.1 dB L_{AFmax}, with a standard deviation of 1.3 dB. As discussed below, differences appear not to be attributed to the test vehicle speed, and the exact causes remain unknown. Given the limitations in the repeatability of the test method, conclusions drawn from the data only relate to overall trends. Reliance has not been placed on a single sample or measurement of any specific joint.

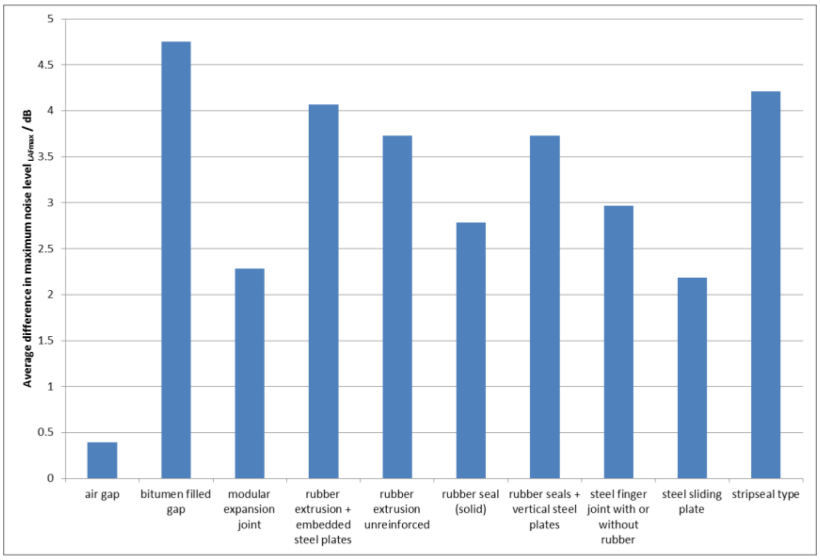

Figure 5 – Average differences in L_{AFmax} between pass-bys

The test vehicle was driven at a target speed of 80 km/h, although the actual speed varied slightly. The effect of speed variations was examined for two pass-bys over a bridge with 5 joints. Figure 6 shows the L_{AFmax} values plotted against speed for the 5 joints and two pass-bys. Each line on the graph connects the measurements for one of the 5 joints. There is no consistent relationship between speed as L_{AFmax} values both increase and decrease with increasing speed over this range. The L_{AFmax} values for the two pass-bys with the greatest variation in speed (79 to 85 km/h) are within 1 dB. From this data it appears that minor variations from the target speed of 80 km/h are not significant. Data has not been obtained at other speeds to confirm the variation in expansion joint noise over the range of state highway speed limits from 50 km/h to 100 km/h.

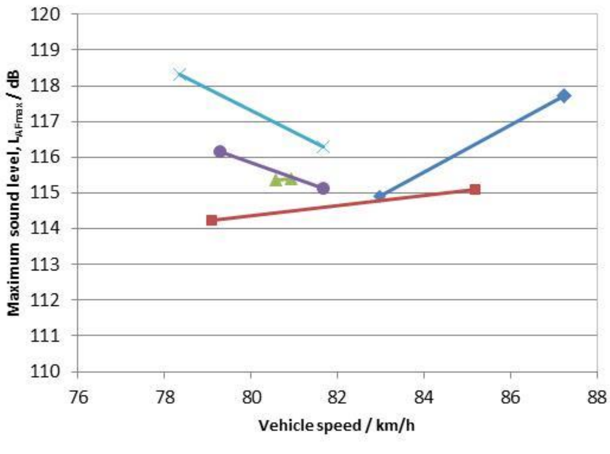

Figure 6 – Changes in L_{AFmax} with test vehicle speed

3. RESULTS

Measurements were made in three areas of New Zealand (Auckland, Wellington and Tauranga), which were selected to provide a range of expansion joint types within practical driving circuits, and in particular including some recently installed joints. The numbers of each type of joint measured are shown in Figure 7. A total 320 measurements were made for 197 expansion joints on 63 bridges, including multiple pass-bys on some joints. Figure 8 shows the average and range of L_{AFmax} values measured for each joint type.

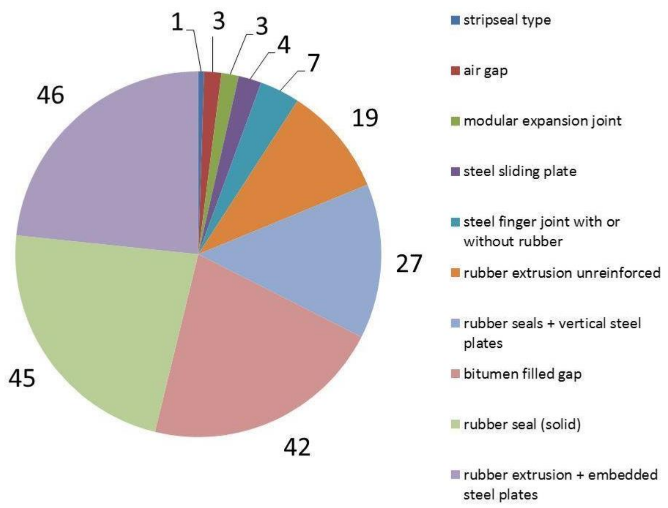

Figure 7 – Number of each joint type measured

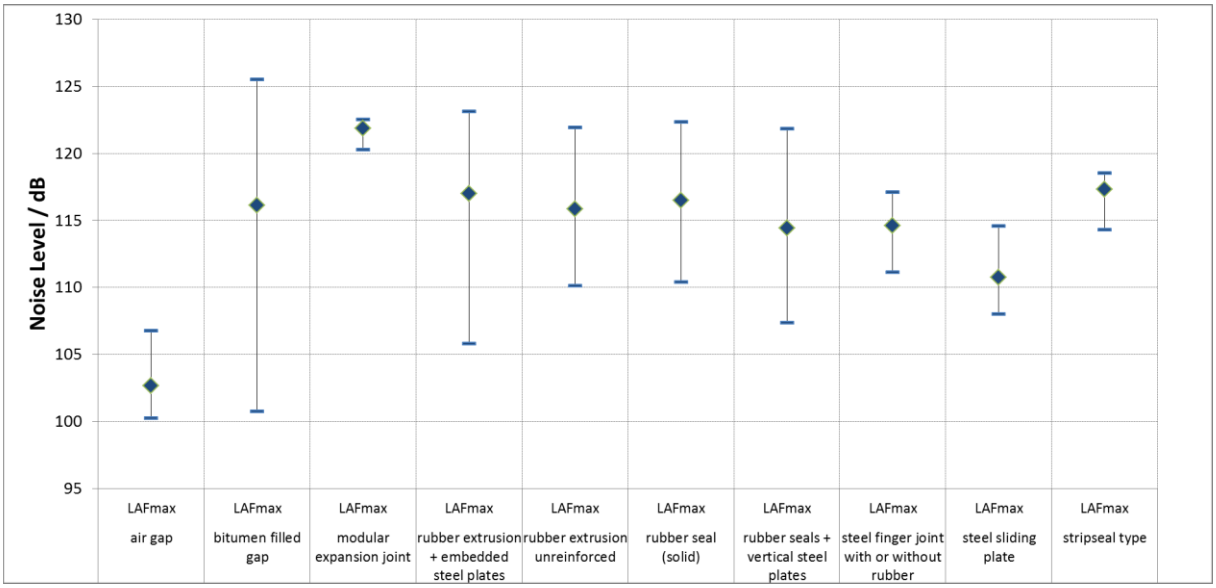

Figure 8 – Range of L_{AFmax} values for each joint type

The L_{AFmax} data varies significantly for some joint types, although the greatest variations are where there are more measurements for a particular joint type. In addition to effects of the measurement system, the variation may be due to different ages of joints, and the quality of the installation and road surface interface with the joint. There are also potential variances from different designs of joint having the same classification in the bridge database, and the database only recording one joint type for each bridge, when in some cases there are multiple joint types on the same bridge. The following observations are made from the ranges of measured levels:

- the variation in noise for specific joint types are often greater than the variations between joint types,
- there are examples of most joint types having noise and vibration at the lower end of the range, and
- there is no clear ranking of all joint types on the basis of this data.

From this data it appears that installation quality, including any subsequent road surface reseals around the joint, may be an important factor in achieving low noise levels. The literature indicates that finger joints should perform well, but this is not immediately apparent from these measurements. However, while not the quietest, the L_{AFmax} values for the seven steel finger joints are towards the lower end of the range measured. Also, some of the other joint types which are quieter do not actually have a physical joint in the road surface, as shown in Figure 9 for one of the air gap joints. The two modular joints measured were amongst the worst performing, which could be expected as they do not have surface plates.

Figure 9 – Asphalt surface covering a joint

4. CONCLUSIONS

A vehicle mounted measurement system has been used to measure noise and vibration from a large number of bridge expansion joints in a short timeframe. The noise experienced by people in the vicinity of bridges will be different from the noise measured by the test vehicle, but the system provides a tool to compare the relative performance of different joint types.

The measurements have shown there to be significant variations in noise and vibration from the same joint types, greater than the variations between different joint types. Installation and maintenance quality is likely to be a key factor in noise generation. The data has not enabled a clear ranking of joint types in terms of noise. As could be expected, the joints with the lowest noise levels are those that have a continuous surface over the joint. Only a small number of finger joints were measured, but these have a consistent performance towards the lower end of the range. Two modular joints without surface plates generated relatively high noise levels.

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REFERENCES

1. Opus Research, URS New Zealand. State highway bridge expansion joint noise. 2014. Available from: http://acoustics.nzta.govt.nz/resources/research-reports
2. NZ Transport Agency. Bridge manual, SP/M/022, Third edition. Wellington, NZ: NZ Transport Agency. 2013.
3. Austroads. Design Rules for Bridge Bearings and Expansion Joints, AP-R405-12. Sydney, Australia: Austroads. 2012.
4. Highways Agency. Expansion Joints for Use in Highway Bridge Decks, BD 33/94. Dorking, UK: Highways Agency. 1994.
5. Glaeser K-P, Schwalbe G, Zöller M. Mitigation the noise emissions of vehicles travelling over bridge expansion joints. Proc. Inter-Noise 2011, Osaka, Japan. 2011.
6. Ancich EJ, Brown SC. Engineering methods of noise control for modular bridge expansion joints. Acoustics Australia. 2004;32(3):101-107.
7. van Vliet WJ, van Loon R. Road traffic noise of expansion joints. Proc. Inter-Noise 2011, Osaka, Japan. 2011.
8. Donavan P, Rymer B. An investigation of noise generation of seismic expansion joints for highway structures. Proc. Inter-Noise 2011, Osaka, Japan. 2011.