Reduction of Impact Noise of Trams on a Major Bridge

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Summary
As part of a recent renovation of the Erasmus bridge in Rotterdam, improvements were made to reduce impact noise caused by trams passing a series of rail joints. The bridge includes several different sections including a bascule bridge and is in an inner city location with new adjacent apartment buildings. At request of public transport company RET, TNO investigated the noise situation and proposed a number of noise control solutions in close cooperation with RET and the engineering department of the city of Rotterdam. This paper describes how the noise sources were identified and ranked by monitoring, how diagnostic measurements and analyses were performed to select and evaluate the most suitable noise control measures, and the achieved noise reduction. The main solutions included moving rail joints and introducing new joint types, local stiffening of sensitive bridge deck parts and improved elastic support of the rails.

PACS no. 43.50.Lj, 43.40.Kd

1. Introduction

With the construction of a new multi-storey residential and office building near the Erasmus bridge in Rotterdam, the need arose to reduce impact noise from trams passing rail joints on the bascule bridge and the adjacent bridge sections. As general maintenance of the tram tracks and their support systems on the bridge was planned in 2014, the opportunity was given to combine this renovation work with noise control measures without major changes to the bridge structure.

At request of public transport company RET, TNO investigated the noise situation and proposed a number of noise control solutions [1] in close cooperation with RET and the engineering department of the city of Rotterdam. This paper describes how the noise sources were identified and ranked by monitoring, how diagnostic measurements and analyses were performed to select and evaluate the most suitable noise control measures, and the achieved noise reduction.

2. Situation and description of the bridge

The Erasmus bridge spans the New Maas River in Rotterdam with a total length of 802 meters. It includes a large suspension bridge and at the south end, a fixed steel bridge followed by a movable bascule bridge and a fixed steel-concrete bridge towards the bank. The bridge carries a dual carriageway with four lanes of road traffic and two tram lines with more than 600 tram crossings each day. The new multi-storey building completed in 2014 called "De Rotterdam" is at its closest point about 120 meters from the centre of the bascule bridge. Each track has five rail joints, 2 either side of the bascule bridge and 3 to allow for expansion or movement relative to other bridge sections. These joints are a source of varying levels of impact noise each time a tram passes. A schematic side view is shown in Figure I. Photos showing the view from the building and the bridge structure are shown in Figures II-IV.

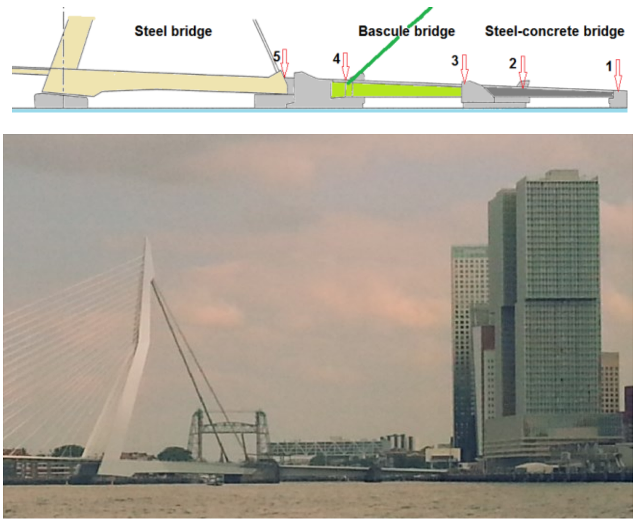

Figure I: Schematic view and photo of the South section of the Erasmus bridge with rail joints numbered and indicated by arrows. "De Rotterdam" building is on the right. Photo: C. de Mooij

Figure II: View from noise monitoring position on 7th floor balcony of "De Rotterdam", with a tram passing joint 4 to 5.

Figure III: Open bascule bridge, northward view, showing main bearing girders and bridge deck with stiffening profiles.

Figure IV: Open bascule bridge with protruding rails. 'De Rotterdam' building is visible on the right.

The rail cross-section along this stretch of track varies near each joint, to allow for the varying support structure which must also provide flexibility at the joints of the bascule bridge. The rail joints were initially all splice joints with different types of support (see Figure V), potentially generating structure-borne noise which is transmitted into the bridge structure.

Most of the track beyond the joints was embedded vignol rail with a cork rubber runner and cast rubber embedding, positioned between steel side walls (far right in Figure V).

Figure V: Rail joint 4 with from left to right: suspension support, seating support, 2 clamp supports with railpads and far right, embedded rail. The rail on the left moves with the bascule bridge and 'lands' on the seating support which is on a concrete base..

3. Key questions

At the outset, the following key questions were formulated:
a) What are current noise levels at the building façade, and what reduction is required?
b) Which rail joints contribute most?
c) What is the cause of the highest excitation levels and which bridge parts radiate the most sound?
d) Which noise control measures are feasible and effective, and what is their potential reduction?
e) After implementation, what is the achieved noise reduction?
Questions a) and b) were addressed in the reference measurement, c) and d) by diagnostic measurements and analysis, and e) by a final measurement after completion of the modifications.

4. Characteristics of the bridge noise

The noise generated by trams crossing the bridge includes both rolling noise and impact noise with strongly varying levels, depending on the wheel condition, tram speed, and wheel-rail interaction particularly at the rail joints. The impact noise was generally stronger than the rolling noise and was the main point of focus. In addition, variable background noise including road traffic, occasional sirens, ship horns and other source were also present, complicating the task of measuring the noise in a representative manner.
Tram speeds vary around 20-45 km/h. The spread in impact noise is similar to that expected due to speed variation, in the order of 10 dB.

5. Reference measurement

A reference measurement was performed to quantify the noise levels in the initial situation.
As the noise levels were known to be highly variable, noise monitoring was performed during several days so as to obtain a representative result. Measurements were taken both at a receiver point on the new building (see Figure II), a balcony on the seventh floor at 120 m from the bascule bridge, and on the bridge itself, both along the tracks and underneath the bridge. The target quantities for noise reduction were the L_{pAFmax} noise level and the L_{DEN} noise level. The L_{DEN} level due to trams is harder to measure as it is more easily contaminated by variable background noise sources, especially once the bridge noise is reduced. Time signals and level histories were registered of a large number of pass-bys, which were also processed just for the duration of the tram movement, so as to minimize the contribution of other sources. This allowed to determine the L_{DEN} level mainly due to the trams. 24 hour level histories of the sound pressure level at the façade are shown in Figure VI for a single day before and after modifications. These include all the other sound sources. Levels of 64 dB L_{DEN} including all sources contained 62 dB L_{DEN} due to trams. A reduction of 3 dB or more in the L_{DEN} due to the trams was sought. For the maximum noise levels a larger reduction of 10-15 dB(A) of the highest peaks was sought, as they are more critical for annoyance and sleep disturbance.

Multiple level histories of tram pass-bys scaled to fit the joint positions are shown in Figure VII, including the average levels and single standard deviation. These show the relative importance of individual joints and the characteristic spread in noise levels. Joints 2/3 and 4 have the highest levels.

As the variation in maximum noise levels was significant, also normal probability distributions were determined for each joint, showing not only the average maximum levels, but also the probability of high levels occurring. These curves are set out in figure VIII for northbound trams, both for the reference situation and after modifications.

6. Diagnostic measurements

Diagnostic measurements were performed to support the analysis of noise control measures. The following was measured:
- rail deflection during pass-by including video registration; rail deflections of up to 16 mm near joints 3 and 4 were found, indicating wear or play in rail supports;
- position of impacts from time signal analysis of rail vibration; time signal analysis revealed that noise impacts could originate not only from the rail joint gaps but also potentially from the rail seating and other flexible supports at joints 3 and 4, which may generate impact forces under load. Once an impact force generates vibrations in the rail, these can be transmitted to the bridge deck via the different types of rail support (see Figure V);
- structure-borne sound transmission through the rail supports and the bridge structure; the vibration isolation of the rail supports was found to take effect from above 125-250 Hz; the deck stiffeners have a stronger sound radiation than the bridge deck itself or the main bearing girders, above 100 Hz. This is illustrated in Figure IX;
- spectral ranking of the sound pressure contribution around each rail joint (see Figure X). An indication of the spectral ranking of each joint was obtained by analyzing successive parts of the time signals from the pass-by.

7. Selection of noise control measures

A number of noise control measures was selected based on practical feasibility, taking into consideration that major structural modifications were not possible. The final list included:
- Renewal of worn rails and rail support and fastener systems (foreseen in any case);
- Shifting of rail joints towards a solid base (joint 5);
- Applying diagonal joints on added mass, for joints 1, 2 and 5;
- Stiffening and mass addition to deck parts on the bascule bridge deck near rail joints 3 and 4 together with added continuous elastic support.

These modifications are illustrated in Figures XI and XII.

The stiffener configurations were analysed using calculation models to obtain optimal design in terms of size, weight and noise reduction. The input mobility, which determines the injected vibration energy, and thereby the structure-borne noise, was calculated for different stiffener configurations using fundamental mobility formulas from [2]. The bascule bridge deck has a complex inhomogeneous stiffener structure and is relatively thin near the edge of the bridge.

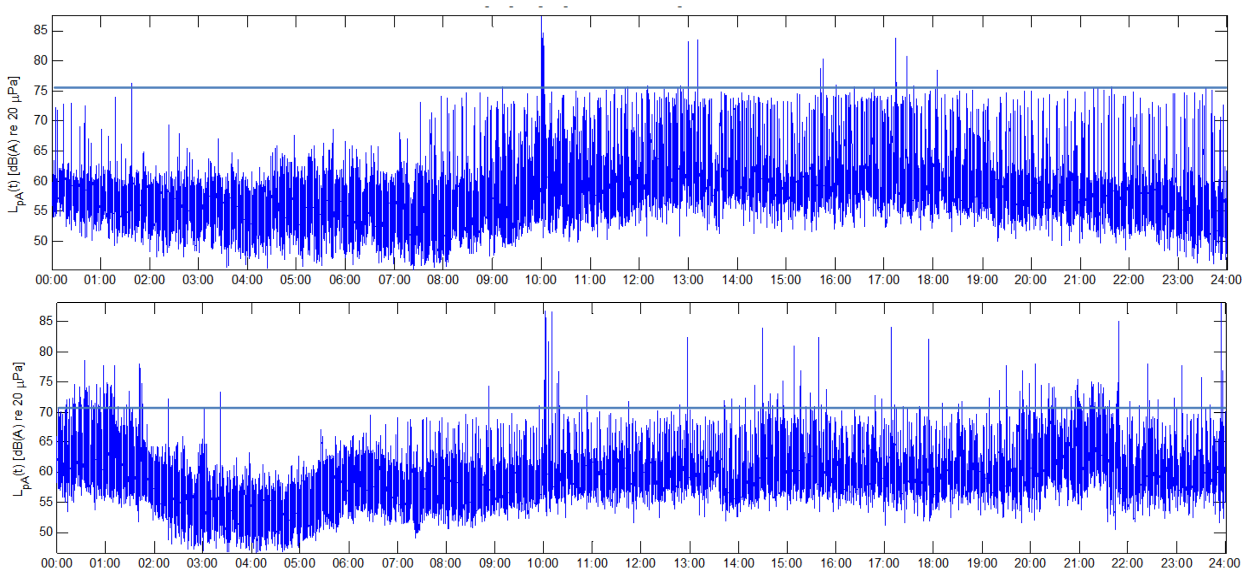

Figure VI: Level history of the A-weighted sound pressure level measured at the building façade over a 24 hour period, before (above), and after modifications (below). Horizontal lines indicate typical impact noise levels.

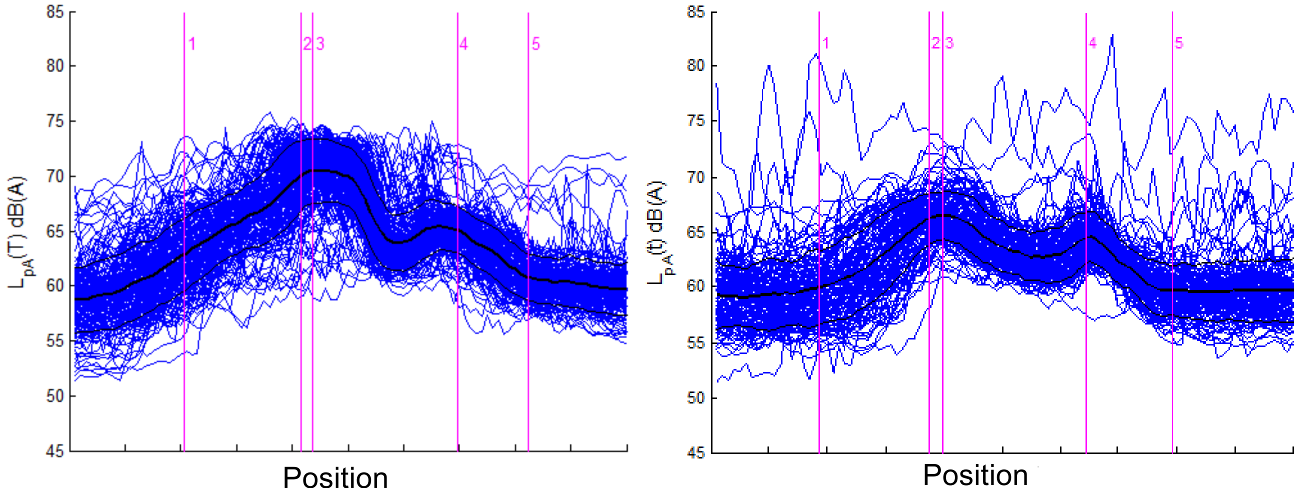

Figure VII: A-weighted sound level histories of tram pass-bys measured at the building façade, scaled to the position of the rail joints (numbered). Left: reference measurement, 369 pass-bys, right: after modifications, 135 pass-bys, both for southbound trams. Black lines indicate the average level history and plus/minus a single standard deviation.

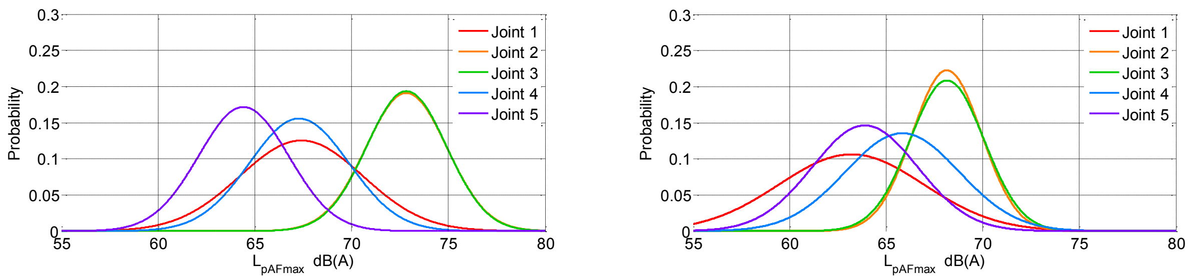

Figure VIII: Estimated normal probability distribution curves of measured L_{pAFmax} levels for each rail joint, before (left) and after the modifications (right), for northbound trams.

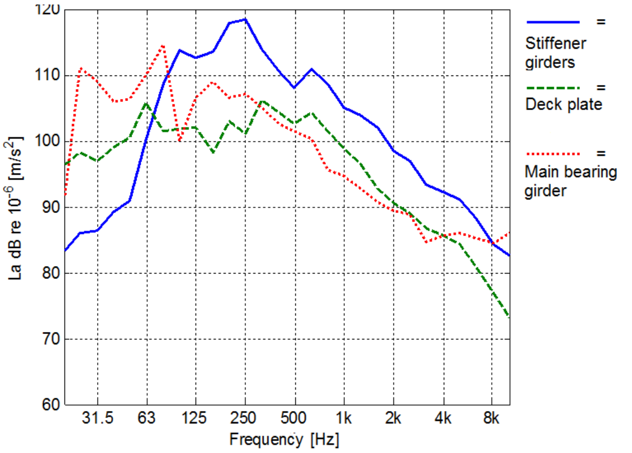

Figure IX: Structural vibration third octave spectra during a tram pass-by at joint 4, on stiffening profile, deck and main bearing girder (all visible in Figure 3).

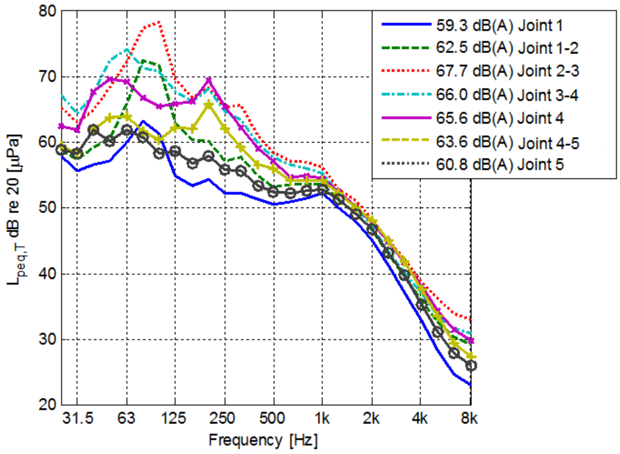

Figure X: Sound pressure third octave spectra at building façade, around each rail joint, average over 4 tram pass-bys southbound.

Figure XI: Noise control measures during track renovation. Top left: Diagonal rail joint based in concrete; top right: added mass and stiffness at joint 4; Below : added stiffeners at joint 4, left without rails, right with rails and cork rubber embedding and seatings for bascule bridge rails.

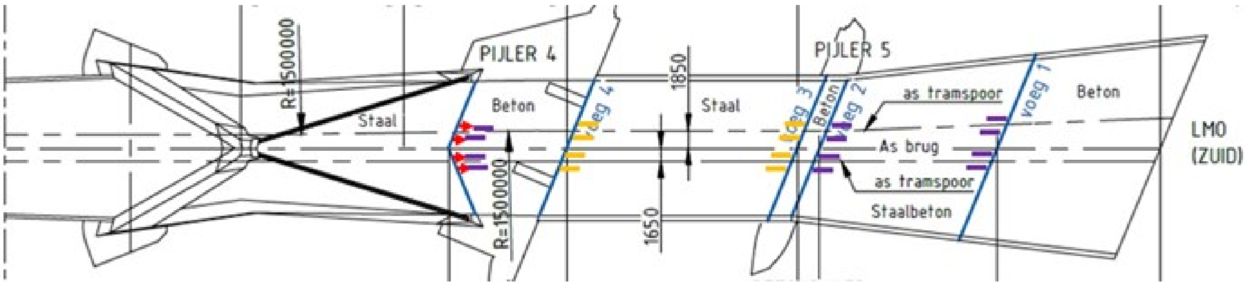

Figure XII: Top view of bridge section with modifications indicated: → = shifted joint, \ = deck stiffening and cork rubber support, \ = diagonal rail joint with cork rubber support and concrete base.

Damping of the stiffener profiles underneath the bridge deck would also be an effective measure, as these are relatively lightly damped and contribute significantly to the noise, but this was not considered practical due to weight and safety considerations.

8. Measured effect

The effect of the modifications was measured according to the same procedure as the reference measurement [3], 4 months after the bridge renovation was completed. Approximately 5 dB reduction was found in the average maximum noise levels (see figures VI,VII,VIII). The probability of high noise levels at the rail joints has been significantly reduced: the chance of levels above 70 dB(A) has been reduced from 91% to 17%. Also the spread in impact noise has decreased. An overall noise reduction of around 3 dB, from 62 dB to 59 dB was found in the L_{DEN} level due to trams at the building façade.

Local inhabitants have reported a significant improvement in the noise.

9. Conclusions

Rail joint impact noise from trams on the Erasmus bridge in Rotterdam has been reduced significantly by several noise control measures. These included track renewal, moving of joints, use of diagonal joints, local deck stiffening and mass increase, and additional continuous elastic rail support near rail joints. 3 dB noise reduction in the L_{DEN} level due to trams was achieved. Impact noise was reduced by 5 dB and occurrence of excessive peak levels was significantly reduced.

Acknowledgement

This project was funded by the Public Transport Company of Rotterdam, RET, whose support is gratefully acknowledged. Thanks are also due to RET and the City of Rotterdam Engineering department for their close cooperation during the engineering process.

References

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