# Noise nuisance caused by movable bridges

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**Summary**

The Netherlands is a densely populated country with a lot of waterways. The road network therefor contains a lot of bridges. Some of these are movable steel bridges. Especially these movable steel bridges recently caused a rise in the complaints on road traffic noise annoyance. The reason for the increased noise annoyance is partly related to the increased amount of heavy traffic driving on relatively old bridges. Remarkably, however, that more often complaints arise after reconstruction work on the bridge or on the adjacent road surface. Reducing the noise emission of one part may highlight the remaining noise emission of the other and therefor increase the annoyance. We have recently investigated several movable bridges with respect to their noise and vibration behavior. There are a lot of insights obtained in these studies with regard to the assessment of the bridge, the causes of the noise annoyance, and the possible solutions. This article shares some recent insights on the annoyance of steel movable bridges and some potential solutions are given. Additionally some improvements to the measurement protocol are proposed.

## 1. Introduction

In the Netherlands, noise nuisance caused by road traffic is being addressed on a large scale. The most used measure is the application of silent road surfaces. This solves the problem in most places, but in other places the noise cannot be reduced to the desired levels. In some situations the noise nuisance even increases after the application of a silent road surface. Steel expansion joint between roads and bridges are a well-known example of this problem [1]. The noise emitted by the expansion joints wasn't noticeable because of the noisy road surface on site before the application of the new and silent surface. When it becomes noticeable, the noise causes (extra) nuisance. Applying isolation on the outside walls of buildings, or building an acoustical barrier results in similar complaints: the high frequency noise emitted by road surface/tires is better shielded, but the low frequency noise (LFN) emitted by the joint stands out more and is experienced as more disturbing.

In the last few years this problem has more increasingly been experienced in movable bridges. Especially in the water rich provinces, provincial roads are constantly being interrupted by bridges. Now that the application of silent road surfaces on the provincial road network is becoming more and more common, problems arise with LFN emitted by movable bridges. Residents are filing more complaints every year. The last couple of years, M+P researched the noise and vibration aspects of different bridges. This article describes the extra nuisance caused by these bridges, mentions an assessment method and points to ideas for reducing the noise sources.

### 1.1. A typical situation

In a lot of situations where the problem occurs, dwellings are situated near the movable bridge and the water (figure 1). The mostly low frequency joint noise which is emitted by the bridges underside, can easily reach the dwellings by reflecting on the water surface. The mostly high frequency road surface/tyre noise is partly shielded by the bridge top surface.

Figure 1. Example of a common situation where a provincial road in the middle of a water rich village is interrupted by a bascule bridge

## 2. The bridge as a noise source

Steel movable bridges are often a really efficient low frequency noise emitter. Noise emission was not taken into account during the design process because the bridges where calculated to carry the load of considerably less traffic then they are nowadays. In a lot of cases the expansion joint between the 'shore' and the bridge deck has been shaped in a way that an opening existed between them. Because of this opening, tires slam onto the bridge deck which results in a very efficient excitation of the bridge deck. Existing old bridges are very light and can easily be excitated by heavy trucks. The bridge deck forms an excellent speaker and together with the reverberation room underneath the bridge low frequency noise will be emitted very efficiently. This 'drumming' noise can easily identified at a distance and has a typical low frequency characteristic, in which every passing truck axle can be identified.

The coarse wear layer on the bridge deck also causes increased noise levels and nuisance. Especially when the road surfaces adjacent to the bridge are silent pavements. The construction of the moving part of the bridge itself can cause additional noise problems. After replacing the moving part of the bridge, the noise emitted by the bridge can change so significantly, that nearby residents start complaining immediately. It is very important to take acoustic aspects into account during the design process of the moving part.

## 3. Rules and regulations

The Dutch laws (Wet geluidhinder) and regulations (Reken- en meetvoorschrift geluid 2012) [2] do not take into account the (extra) noise emission caused by (movable)bridges and their joints. For the law, the road is considered as a continuous and constant noise source over its length. In situations where only the road surfaces adjacent to the bridge are renewed, there is no 'hard' requirement for the road surface of the bridge.

However, in order to assure "correct spatial planning" it is very important to think of acoustical aspects when (re)constructing a movable bridge. A link can be made with the requirements that are set on the expansion joints in the national highway network by the responsible authorities of the National Public Works and Water Management Office [3]. These requirements depend on the road surface adjacent to the expansion joint. The more quiet the surface is, the more quiet the joint has to be. In routes where the asphalt is replaced by a more silent variant, there will also be more stringent requirements for the joint. If necessary, these have to be replaced by less noisy variant. A movable bridge can also be seen as a very special expansion joint. Besides the noise emitted by the joint itself, the emission by the bridge deck also plays a large role. The measuring protocol for joints is however aimed at measuring peak noise levels. When measuring movable bridges another method is necessary to be able to correctly identify noise emitted by joints and bridge deck emissions.

Following multiple complaints filed at the National Public Works and Water Management Office in 2011, Movares consultants conducted research on noise emitted by movable bridges. This resulted in a 'design and measurement protocol' in which a 'correction' for bridges can be calculated [4]. This 'bridge correction' (Cw1 and Cw2) is defined as 'the increase of noise emitted by road traffic caused by the presence of a bridge' and need to be established by measurements on site (figure 2). Establishing the bridge correction serves multiple purposes. It is especially useful when replacing a bridge or adapting an existing bridge and comparing the before and after scenario's. The correction can also be added to noise calculation models, so the effect of the bridge can be determined on the immission levels in the environment. Finally the method introduces an objective dose measurement for the increase of nuisance in the environment.


Figure 2. Overview of several measurement positions necessary to determine the bridge correction conform the measurement protocol from the National Public Works and Water Management Office (1= reference point besides the road; 2= point above the bridge; 3 = point below the bridge; 4= immission point in the direct environment)

## 4. Practical experiences of measuring movable bridges

Whenever noise complaints arise, the first step is often to measure noise levels on immission points at nearby dwellings. The low frequent part of the noise caused by the bridge can be made clearly visible by showing the sound spectrum in a graph (figurer 3). The low frequency noise becomes even more obvious when using the C-weighted spectrum instead of the A-weighted spectrum. A simple way to determine the amount of low frequency noise with a hand held sound level meter is by taking the difference between the A- and C-weighted sound levels. At all the bridges where there were measurements because of nuisance caused by low frequency noise, the LC-LA measurement confirmed the validity of the complaints. Measuring immission levels isn't always easy in practice. Especially low frequency noise levels are dependent on the position, meteorological conditions (wind) reflecting water surfaces and back ground noises.

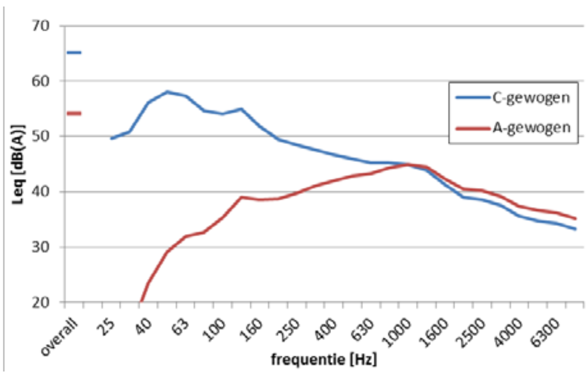


Figure 3. Example of an immission spectrum recorded at a 100 meters from a bascule bridge and the influence of the frequency weighing. The dominant frequency shifts from 1000 Hz to 50Hz.

A next step is to research the bridge itself. E.g. by determining the bridge correction conform the protocol of the National Public Works and Water Management Office [4]. Determining the correction for the top side of the bridge deck (Cw1) and the bottom side of the bridge deck (Cw2) of a bridge is easy enough. In specific situations, when there are twin decks installed, a custom solution might be required. Measurement positions and noise levels are in most cases easy to determine. A challenge could be to plan the measurement of heavy trafficked bridges. Measurement equipment has to deal both with road and waterway transport as well as with the opening of the bridge. The result of the measurements (Cw1 and Cw2) describes the acoustical characteristics of the bascule bridge, on the base of a 15 minute LAeq. This LAeq is determined by the difference between the levels of the reference and bridge locations. Figure 4 shows an example of the Cw1 and Cw2 correction factors of a bascule bridge. This 'acoustic drawing' of the bridge is very useful when comparing old and new situations.

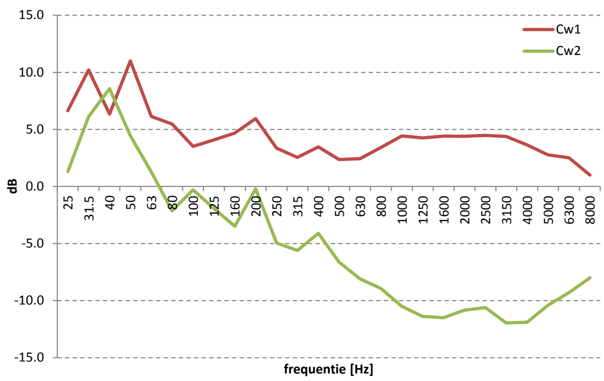


Figure 4. Example of the bridge correction factors above (Cw1) and below the same bridge (Cw2)

The third step is entering the bridge correction factors into a model. With this model the increase of the noise levels in the environment caused by the bridge can be calculated. The benefit of using a model as opposed to measuring everything on site is that an "infinite" number of immission points can be added and assessed. The increase of A-weighted noise levels is often very small: 0~1 dB. This small difference doesn't correlate with the increase of nuisance experienced by nearby residents. This can be explained partly by the fact that the model is only valid for frequencies of 63

Hz and higher, while a significant part of the low frequency noise emitted consists of frequencies below the 63 Hz band. More important are the use of A-weighting, the $L_{Aeq}$ dose and the fact that the noise levels are experienced indoor, while these are measured outdoor. All these factors cause a discrepancy between what people experience and the official dose measure unit.

## 5. Possibilities for noise reduction

If the noise nuisance of the bridge is to be reduced, several noise reducing measures can be taken. For an optimal solution it is essential to understand and list the sound generating mechanism. If that sound generating mechanism is understood, targeted reduction measures can be proposed and balanced with other constructive constraints. The sound generating mechanism of a bridge can often be split in the following sub systems:

- Impact; the geometry of the expansion joint determines the impact with which the truck tyre ‘slams’ against the bridge. A broad perpendicular joint gives a high force; a tight or angled joint gives a low force.
- Input impedance; The mechanical impedance of the edge of the bridge determines the amount of energy the bridge consumes from the slamming truck tyre. A rigid concrete edge accepts little energy transfer; a flexible steel plated edge consumes a high amount of energy.
- Vibration transfer; The mass, damping and stiffness of the bridge determine how much the rest of the bridge parts will vibrate; A bridge with a bolted wooden deck reacts differently from a welded steel construction.
- Radiation efficiency; the stiffness shape and surroundings of the bridge determine how efficient the energy of vibrating bridge plates is transferred into radiated sound. Solid plates radiate more efficient than air vented gratings, although they could be designed to carry the same load.

A broad range of specialized measurement and calculation tools is available for the investigation and optimization of the sound radiation of bridges. FEM, BEM, SEA models may be complemented by various forms of modal analysis, transfer path analysis of sound source localization.

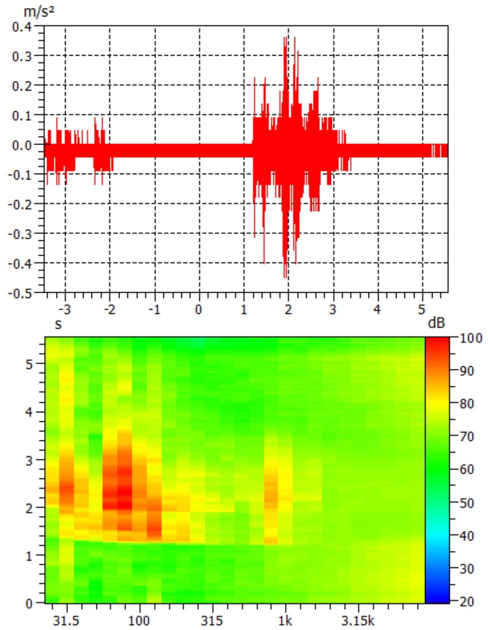


Figure 5. Example of a multi channel synchronised vibration and sound analysis, with multiple analysis options. A vibration signal as function of time (top) and the Campbell diagram of a sound measurement. Both during the passage of a truck.

## 6. Effect of reduction measures

Figure 6 gives an example of measurements, before and after reconstruction of the bridge. In the old situation people complained about a beating noise. This could be explained by the low frequency noise radiation of the deck. The overall sound level of the new bridge has been reduced by only 1,5 dB(A). But the spectral comparison of the measurements before and after reconstruction clearly shows that low frequency sound has been reduced by more than 10 dB. The noise nuisance of the neighbors has been reduced drastically.

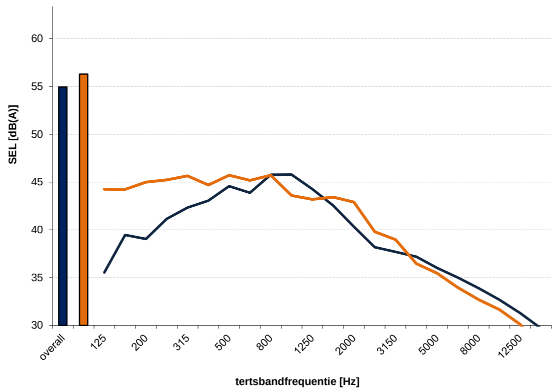


Figure 6. Difference in SEL spectrum and sound level before (orange) and after (blue) reconstruction of the bridge.

## 7. Conclusions

More silent is not always better. Unfortunately this applies increasingly for the application of traditional traffic noise measures around steel movable bridges. Low noise road surfaces, noise barriers and façade insulation reduce mainly the high frequency content of the noise. Therefor the low frequency noise from the bridge attracts more attention and yields to raising annoyance.

The raise in traffic noise due to the bridge is mostly limited to around 1 dB if it is measured in A-weighted sound levels. But in the sound spectrum the raise is often more than 10 dB in the lower frequency range. If measured in C-weighted sound levels the raise is often much higher. Therefor the difference $L_C$-$L_A$ is a quick indicator for the increased annoyance due to low frequency noise radiated by the bridge.

The vibrating bridge deck, often in combination with an unfavorable expansion joint, is the most prominent cause of the increased low frequency noise. If the bridge is reconstructed, it should be considered to take into account the acoustic requirements. A good understanding of the noise generating mechanisms and the options for noise reduction are important to enable parties to come to a low noise design in conjunction with the other constructive requirements.

## References

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