Assets4Rail – Quantifying and mitigating rumbling on steel railway bridges

Steel railway bridges present a noise protection challenge. Advances in combating noise have increasingly highlighted the locally high noise emissions from these bridges. Marketable mitigation measures need to be developed. One measure is the bridge dampers that are being researched as part of the Assets4Rail project and are proving themselves in practice.

Thilo Hanisch, M.Sc.
Research assistant at the chair of rail vehicles at the Technische Universität Berlin
hanisch@tu-berlin.de

Dr.-Ing. Christoph Gramowski
Head of Research and Development, Schrey & Veit GmbH
Christoph.gramowski@sundv.de

Marian Ralbovsky, PhD
Scientist
AIT Austrian Institute of Technology GmbH
marian.ralbovsky@ait.ac.at

Dr.-Ing. Armando Carrillo Zanuy
Secretary General, EURNEX e.V.
acarrillo@eurnex.eu

Prof. Dr.-Ing. Markus Hecht
Head of the chair of rail vehicles at the Technische Universität Berlin
markus.hecht@tu-berlin.de

1. Introduction and presentation of Assets4Rail

Rumbling generated when trains cross steel railway bridges can be a nuisance for those living nearby. That is why these bridges are a special target for noise reduction measures. The Assets4Rail project is assessing, among other things, both a bridge noise monitoring system and a typical reduction measure: the bridge damper. This is the focus of research by such institutions as Schrey & Veit GmbH (S&V), the Technische Universität Berlin (TUB) chair of rail vehicles and the Austrian Institute of Technology GmbH (AIT).

Assets4Rail is a three-year Shift2Rail open call project with total financing of about 3 million EUR and 19 partners (Fig. 1) headed by Eurecat with EURNEX as technical coordinator. The Assets4Rail project adheres to the objectives of the Shift2Rail Master Plan Innovation Program 3 (IP3) ("Cost-efficient and reliable infrastructure"), which is intended to allow the development of a number of cutting-edge, system-specific vehicle-side and rail-side measurement and monitoring devices.

These devices collect and deliver railway system condition data (for infrastructure and rolling stock).

The information collected by these devices is processed to generate relevant infrastructure-related maintenance information that supports asset management decisions. The biggest challenge for the Assets4Rail project with respect to infrastructure was identifying the specific monitoring and modernization solutions for bridges and tunnels.

The project delivers the following specifics:

1: Assets4Rail Consortium

Source: EURNEX

- Analysis technology for detecting defects in railway tunnel substructure;
- Methods of cleaning long tunnel drainage pipes without disrupting traffic;
- Bridge and tunnel information modelling systems;
- Algorithms for the bridge information module;
- Touchless measuring technology for detecting and monitoring noise emissions when trains cross bridges and development of noise mitigation measures to greatly reduce noise emissions.

This last is the focus of the following sections. Bridge rumbling will first be introduced, followed by a description of bridge dampers. Finally, the results of field testing will be presented.

2: Bridge dampers Source: TUB/S&V

2. Bridge rumbling

Bridge rumbling is airborne noise emitted when a train crosses a bridge. This airborne sound is low-frequent due to the bridge construction and arises in addition to the higher frequent rolling noise, which those living nearby find a great nuisance.

Bridge rumbling is usually primarily a problem with steel railway bridges, especially those with a plate girder design and a superstructure with directly fastened track (open track). [1]

Because the sleepers are directly fastened on the bridge construction, the structure-borne sound waves, excited by the wheel-rail contact, are transferred almost undamped into the bridge structure, where they propagate. If bridge component natural frequencies are in the excitation frequency range, there is usually very strong vibration and bridge wave emissions in the absence of component damping. The airborne noise thus emitted is directly dependent on component vibration velocity. The frequency range given as critical for bridge rumbling is 40 Hz to 100 Hz. Generally, bridge rumbling can be up to 500 Hz. [1, 2].

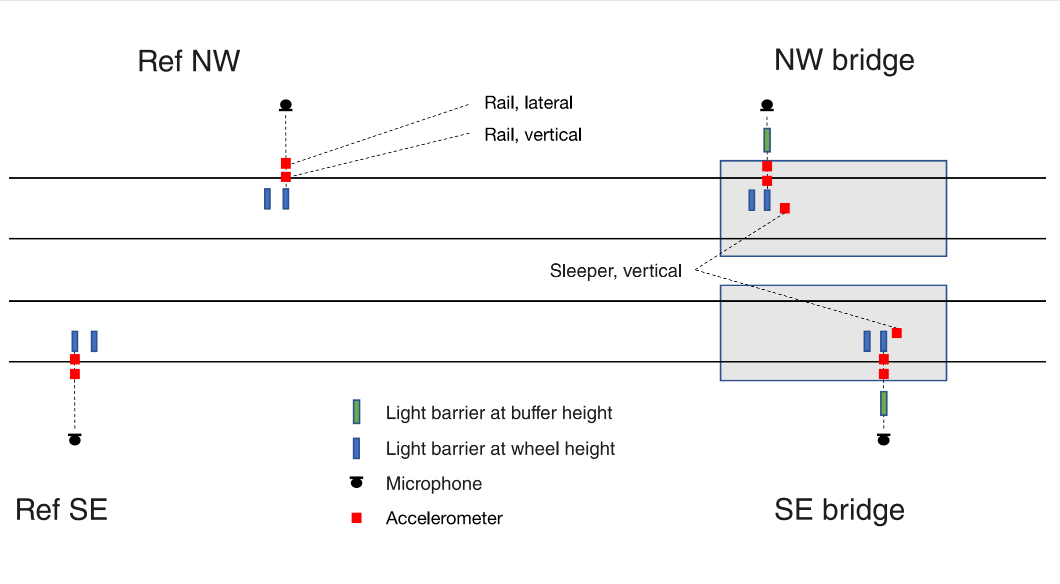
Because of the possible dominant low-frequency components, no frequency-weighting is applied in bridge acoustic analysis (called Z frequency-weighting, where Z stands for "zero"). For steel bridges with directly fastened track, sound pressure levels of more than 10 dB(Z) compared to those of plain track can be determined. That is why these bridges are a special target for noise mitigation measures.

Classical noise mitigation measures like noise barriers and soundproof windows work well for plain track, but not for bridge rumbling [1]. In the past, various innovative bridge noise mitigation measures have therefore been assessed, including as part of Germany's "Konjunkturpaket II" employment and stability program [3]. Possible measures include installing (1) Under-ballast mat, (2) Resilient Rail Fastening Systems, (3) slab track systems, (4) Under-Sleeper Pads, (5) damping foils, or (6) bridge dampers. Measures (1) to (4) increase decoupling of track and bridge construction, while damping sheets and bridge dampers reduce vibration and thus airborne noise emission directly at the associated bridge components [4]. The bridge damper analysed here has advantages over Measures (1) to (5), and those advantages are discussed below.

3. Bridge dampers

The functional principle of bridge dampers is the targeted absorption of kinetic energy of the vibration processes in the bridge structure. The dampers use the "coordinated vibration absorber" principle: Vibrating masses are adapted to the individual vibration of the bridge structure. The relevant vibration frequency and direction and the necessary vibration mass is determined (see Section 4) and a design that will work in practice is implemented. Thus optimally

3: Bridges equipped with bridge dampers (top: SE bridge, bottom: NW bridge) Source: TUB



4: Sketch of the measuring set-up on the line

Source: TUB

coordinated damping can be determined and implemented for any bridge type.

In previous applications, a design involving bending beams fixed on one side has proven effective. It leads to a compact construction, allowing simple fixing with just four screws (Fig. 2).

As part of Konjunkturpaket II, bridge dampers were installed in 15 bridges in the Deutsche Bahn network in 2010/2011 [3].

Both the acoustic measurement results and the design implementation produced valuable experience that can now be used for serial application. The good condition of these bridge dampers can still be seen today in Berlin, Hamburg, and Peine. As part of the Assets4Rail project, bridge dampers are installed in two more bridges (see Section 4).

The construction of the bridge is not changed by the installation of a bridge damper, which merely involves additional components being mounted on the bridge. This means that the structural load capacity analyses for existing structures remain valid. Applications thus far have shown that the additional mass per 20 m of bridge length is only about 1 t. The bridges therefore retain their full capacities.

Measures (1) to (4) for countering bridge rumbling (see previous section) requires work directly on the superstructure.

If bridge dampers are used, this extensive work, including the necessary line closures, can be dispensed with because the dampers can be installed from the road / field instead of from the track. Temporary work scaffolding or cherry picker cars have proven effective as well.

Another advantage is that the bridge web plate remains largely visible because the bridge dampers cover only a small area (unlike damping foils). This allows corrosion inspections to continue normally.

But bridge dampers are currently not a recognized measure within the meaning of Schall 03 (Guideline for the Calculation of Sound Emissions from Railways) [5], which makes the relevant conformity tests necessary. The bridge noise monitoring system that was tested in Pressig with bridge dampers can be used here.

4. Reduced noise for two bridges in Pressig

As part of Assets4Rail, a search was made in Germany for suitable steel railway bridges to be fitted with the bridge noise monitoring system [6] and the bridge damper [7]. A variety of criteria were used. Pronounced bridge rumbling was especially important, and the track and the area around the measuring points were to exhibit favourable conditions for acoustic measurements.

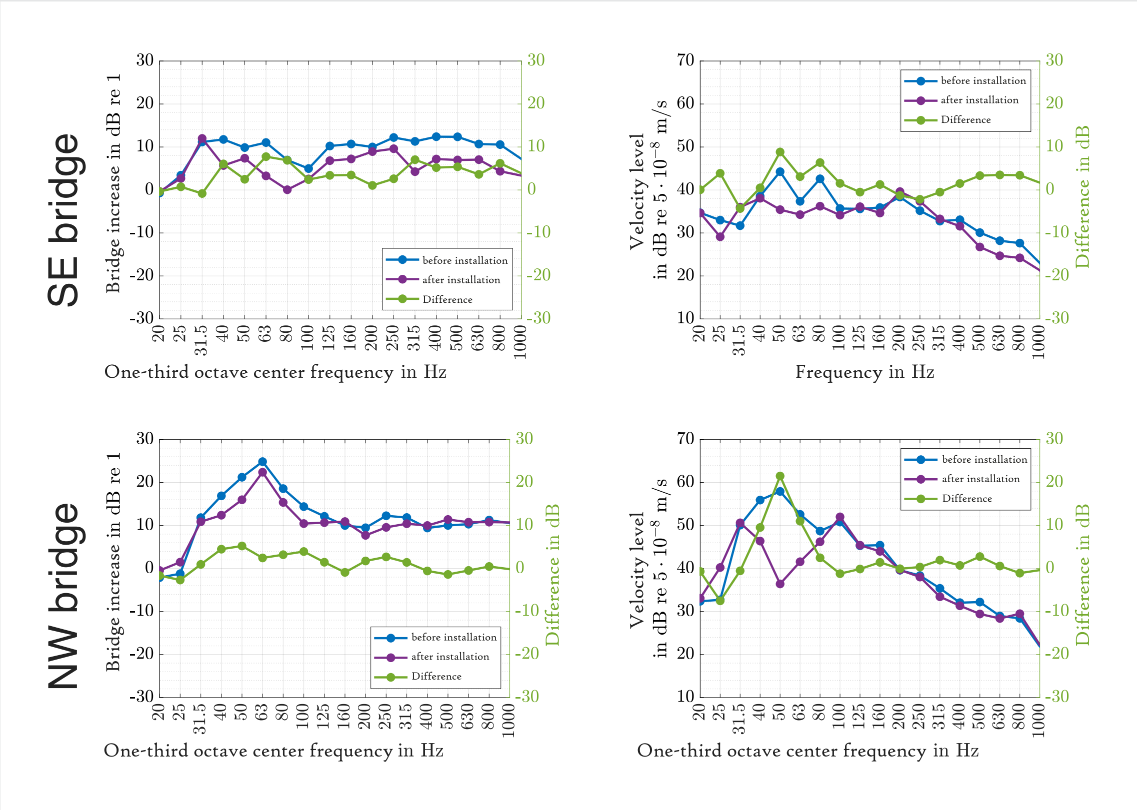
This means that acoustic environment requirements and the background noise level according to ISO 3095 [8] have to be adhered to as much as possible. The track has to be free of visible surface defects.

Other selection criteria included high frequency of passengers and, ideally, freight trains, all with, ideally, a constant speed.

Two steel bridges in Pressig, Bavaria provided two immediately adjacent superstructures that largely met these requirements. Both bridges were single-track railway bridges of the "Franconian Forest Railway" crossing the Tettau River.

The northwest (NW) bridge (built in 1902) is riveted plate girder bridge, while the southeast (SW) bridge (1962) is a welded plate girder bridge, each with directly fastened track (see Fig. 3). Both bridges are about 20 m long, and the two are not structurally connected. The web plates measure about 2 m x 2 m x 0.012 m for the NW bridge and about 4 m x 2 m x 0.012 m for the SE bridge. Both web plate types are reinforced. The only criterion not met completely was that of constant speed for regional trains. This was due to the proximity to the Pressig-Rothenkirchen station. [9]

Bridge noise monitoring system development followed the DB Systemtechnik GmbH requirements for innovative measure conformity tests [3, Annex 2]. The tests consisted of airborne noise and structure-borne noise measurements at the bridge and at a reference point (Ref) on the plain track and were performed in Pressig by TUB. For airborne noise measurements, microphones are positioned at a distance of 7.5 m / 25 m to the track center and 1,2 m and 3,5 m above the top of rail. The local conditions did not allow the measurement in 25 m distance. The measuring position was selected so that it was between 1/3 and 1/2 of the bridge span. For the refer-



5: Bridge correction factor (left column) and velocity level of an example structure-borne noise sensor (right) for both bridges before and after bridge damper installation (train speed 90 to 100 km/h)

Source: TUB

ence point, the track conditions for measurement at constant speed according to ISO 3095 were to be adhered to as much as possible. The bridge airborne noise results L^{Bridge}_{Zeq,T_p} and the corresponding reference point $L^{Reference}_{Zeq,T_p}$, each in the form of a equivalent continuous sound pressure level of a train passing, are used to calculate the so-called bridge correction factor using:

$$K_{BR} = L^{Bridge}_{Zeq,T_p} - L^{Reference}_{Zeq,T_p}$$

The bridge correction factor can be determined for individual frequency ranges and as a total level. [3]

The structure-borne noise measurements call for measurement positions on the track in the lateral and vertical directions and the sleeper in the vertical direction.

Structure-borne noise measurements were also performed on the web plates. Light barriers are used to determine the train speed from the beginning of the train to its end.

The duration of the measurement in each case is at least the time of train passage (Tp). The measurement set-up for the measurement campaigns is shown in Fig. 4.

As trains passed, AIT performed experimental modal analysis and used a laser Doppler vibrometer (LDV) to perform structure-borne noise measurements on the web plates.

The experimental modal analysis determines the web plates' natural modes and frequencies and modal mass and damping – all necessary input parameters for the bridge damper design. An important advantage of the LDV is its touchless measurement, which allows the vibration behaviour of even hard-to-reach web plates to be analysed remotely.

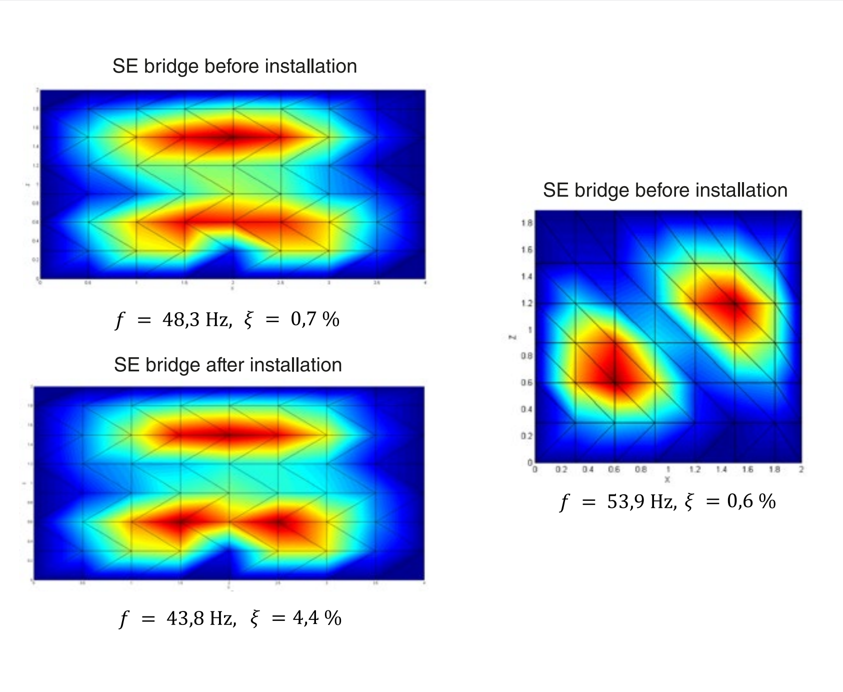
So far, two measurement campaigns have been implemented in Pressig. The first was in October 2019 and determined bridge rumbling and web plate vibrational properties. On the basis of this information, S&V designed and applied customized bridge dampers. In September 2020, control measurements to quantify insertion loss were taken. For both measurement campaigns, TUB also determined track roughness at all four measuring points. Year-on-year comparisons to the assumed wheel roughness showed negligible change.

The results of the two measurement campaigns are shown together. The explanations are limited to Talent 2 regional trains from Bombardier Transportation.

In 2019, before bridge damper installation, about 70 regional trains were measured per direction; in 2020, after installation, 100 were measured.

Before bridge damper installation, both bridges exhibited pronounced to very pronounced bridge rumbling (blue curves, left column, Fig. 5). The bridge correction factor, summing the one-third octave frequency range of 20 Hz to 250 Hz, is about 9 dB for the SW bridge and a 16 dB for the NW bridge. For both bridges, the one-third octave ranges from 31.5 Hz to 80 Hz were noticeable. The right column shows the vibration velocity level for an acceleration sensor on the web plate for each bridge as an example. For the SE bridge, there are two clear peaks in the 50 Hz and 80 Hz one-third octave ranges. The NW bridge's web plates have a much higher velocity level, especially between 31.5 Hz and 63 Hz, with a maximum at 50 Hz.

Fig. 6 to the left shows the result of the experimental modal analysis with the example of a natural mode for a SE bridge web plate with the associated natural frequency f and modal damping ξ (top is



6: Examples of natural web plate modes with natural frequency and modal damping before and after bridge damper installation. The natural modes are shown as absolute values of low (blue) and high (red) amplitudes Source: AIT

before and bottom after bridge damper installation).

Fig. 6 (right) shows the example of a measured natural mode for the NW bridge before the bridge damper was installed. It clearly shows the stiffening effect of the diagonal.

For the SE bridge damper, these results and the experimental modal analysis, which included natural frequencies at 48 Hz and 76 Hz, were used to develop two-level bridge dampers. These dampers were configured to be effective at these two natural frequencies. For the NW bridge, a single-level bridge damper was designed to reduce web plate vibration at the noticeable natural frequency of 55 Hz and did so effectively.

The measured results after bridge damper installation show that bridge rumbling was reduced for both bridges. In all, the bridge increase in the frequency range of 20 Hz to 250 Hz was reduced by about 3 dB(Z).

The velocity level reduction for the SE bridge is similar, and for the NW bridge it is 6 dB.

An examination of the modal analysis examples shows that the natural modes identified after bridge damper installation are similar to those before. There are some significant frequency shifts, but there is also a significant rise in modal damping. A few natural modes could not be reproduced after the bridge damper was installed.

5. Further work

In addition to this field analysis, research on bridge dampers was performed on a test rig within this project and in the In2Track2 partner project. Vibrational properties were analysed for the bridge damper alone and in combination with a plate [10, 11].

6. Summary and outlook

Assets4Rail has shown that bridge dampers can be an effective reduction measure for combating bridge rumbling.

The bridge increase was reduced by up to 3 dB(Z). The refined bridge noise monitoring system was used to verify this reduction.

One more measurement campaign in Pressig is planned before the end of the project, but only for the NW bridge and the associated reference point. A refined bridge damper is to be tested and analysed there. The objective is to further reduce the high bridge increase values for 63 Hz and improve noise reduction.

The Rete Ferroviaria Italiana (RFI) is going to demonstrate the bridge noise monitoring system on a bridge in Italy.

Acknowledgements

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