Field tests Nottwil (March-May 2022)

Introduction

A limited series of the novel damping railpads is produced by Semperit (static stiffness 244 kN/mm, thickness 7 mm). Around 300 pieces are installed in a straight railway section of 100m for comparison measurements of the noise and vibration from regular train pass-by's. The test section is part of the northern track (lake side), between the masts at km 72.830 and 72.930. The pads were installed in the night of 17-18 March 2022 by SBB.

The track structure is representative for the Swiss railways, using a ballasted track with concrete sleepers (type B91 with hard under-sleeper pads) and Ws14 (SKL 14), System W 14 clamps. The maximum speed on the track is 160km/h. The existing railpads, hard EVA pads commonly used by SBB (static stiffness 1400 kN/mm, thickness 7 mm), are kept in place in the other sections of the track which are used for reference measurements.

In 2019, 42868 passenger trains and 2419 freight trains were counted. This amounts to a loading of around 40000 tonnes per day.

The location in Nottwil was chosen because of easy access to the tracks, which had been shown during similar tests of railpads by a different supplier. The north side of the tracks is accessible via a footpath, and faces open fields which ensures reliable noise measurements.

In addition to the dynamic tests, the rail roughness was measured on each testing day. They showed no significant differences between the two sections.

Figure 1: Installation of the Semperit railpads on 18 March 2022

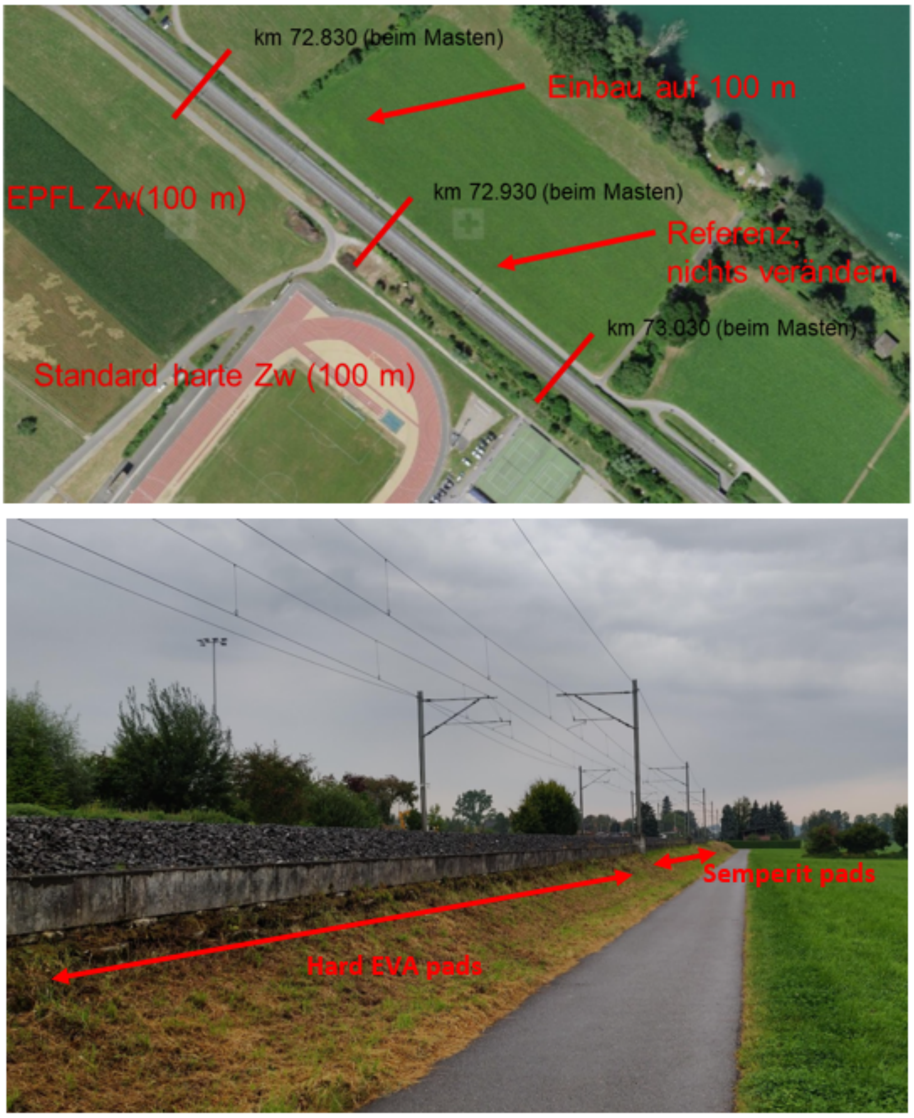

Figure 2: Situation plan of the test sections, showing the environment and the height of the tracks above the walking path

Measurements and setup

The goal of the field test is to compare the effect of damping railpads and standard hard rail pads on (i) the dynamics of the free track, (ii) the track vibrations during pass-by, and (iii) the pass-by noise. Two cross-sections are identically equipped with accelerometers and a microphone. In order to measure the three effects under consideration, the setup is as shown in Figure 3

Measurements were done in 2022 on

- March 17 **(day 1)** baseline, before changing the pads, all measurements,
- March 18 **(day 2)** directly after changing the pads, all measurements,
- April 12 **(day 3)** TDR and pass-by noise, and
- May 16 **(day 4)** pass-by noise.

The equipment used was as follows:

1. The free-track dynamics are quantified by the point mobility and track decay rate (TDR) according to standard EN 15461:2008. Therefore, two accelerometers (PCB M352C68 with sensitivity 100mV/g) are placed vertically (bottom of the rail) and laterally (outer side of the rail head) at sleeper-midspan. The location of the sensors is more or less in the middle of the 100 m sections, around 3 m away from the

nearest mast. The sensors are screwed into a threaded plate, connected magnetically to the rail. A PCB 86B03 impact hammer with a steel instrumented tip and mass extension was used for the vertical and lateral excitation. At least 10 impacts were used for vertical and lateral excitation, respectively, at the locations described by the norm. The average third-octave band spectra of the accelerometer responses and the transfer functions were calculated in Matlab using the standard function **poctave**.

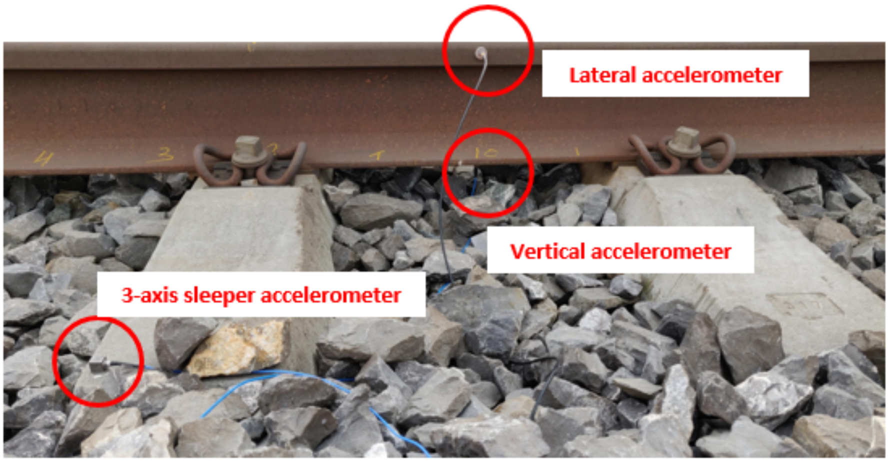

Figure 3: Placement of the sensors in each measurement section. There are two rail accelerometers, a triax sleeper accelerometer, and a microphone.

2. The pass-by vibrations are measured on the rail (PCB M352C18 with sensitivity 10mV/g) and on the sleeper (triaxial sensor PCB 356A11 with sensitivity 10mV/g). The location of the sensors is identical to the ones for the free-track measurements. The spectra of the accelerations are calculated by the standard Matlab function **poctave**.
3. An IEPE membrane microphone (B&K 4189, sensitivity 50mV/Pa) is placed according to standard EN ISO 3095:2013, 7.5 m removed from the track axis, and 1.20 m above the rail head, and at the location of the accelerometers. The microphones were placed north of the track, to avoid noise propagation over ballast. The LAeq values were calculated choosing an appropriate time window as described in the standard. First, the A-weighted third-octave spectra of the pass-by signals are calculated by the standard Matlab function **poctave**. The LAeq level is then calculated as the sum of the third-octave spectral values.

   The microphones are calibrated before and after the measurements on each day, showing a drift smaller than 1%.

   The ground effect has a potentially important influence, since the railway banks are not equally high at both sections and the travelled path over ballast and grass is different. The effect of the placement of the microphones was additionally calibrated on days 3 and 4 using a loudspeaker emitting pink noise. The loudspeaker was placed identically on both measurement sections, mid-span between two sleepers.

Figure 4: Placement of the loudspeaker during pass-by.

All 12 channels were recorded by a NI DAQ card (PXIe-4499, 24 bits) with 16 synchronous recording channels. The measurement was triggered by the vertical rail accelerometer in the Semperit section (first arrival of the trains) with a sufficiently long pre-trigger to ensure recording of the entire pass-by signal. Only pass-by measurements of good quality were used, measurements with a simultaneous train on the opposite track were removed.

Measurement results

Overview of trains

During daytime, the track is mainly used for passenger traffic, especially for IR, RE, and S connections. To compare the two types of pads measurement days 2, 3 and 4 are used. Measurement day 1, before exchanging the hard and new pads, is used as a baseline measurement to ensure both sections are identical.

Over the three days, 101 pass-by measurements could be used for analysis: 33 on day 2, 35 on day 3, and 33 on day 4. More in detail, there were 33 IR trains, 18 RE trains, 34 S trains, and 14 miscellaneous trains (mainly freight trains and service trains). RE and S trains usually have an integrated locomotive of the type RABe521. IR trains have locomotives of the types Re460 or RABe526, depending on the connection.

Typical speeds are 140 km/h for IR trains, 120 km/h for S trains, and 125 km/h for RE trains.

RABe526 Re460 RABe521

Figure 5: Three most used train types on the test section.

Point mobility

The mobility of the free track is measured as the transfer function of the impact force to the acceleration, and is in the following results given as accelerance in $m/s^2/N$.

Figure 6 shows the vertical and lateral transfer functions in both sections. The blue lines represent the point mobility, i.e. the transfer function measured at the location of the hammer impact. The position numbers refer to the impact locations according to the TDR measurement standard. Position 10 is over a sleeper, 1.5 m removed from the sensor location. Position 28 is the furthest impact point, 39.6 m away from the sensor position and midspan between two sleepers.

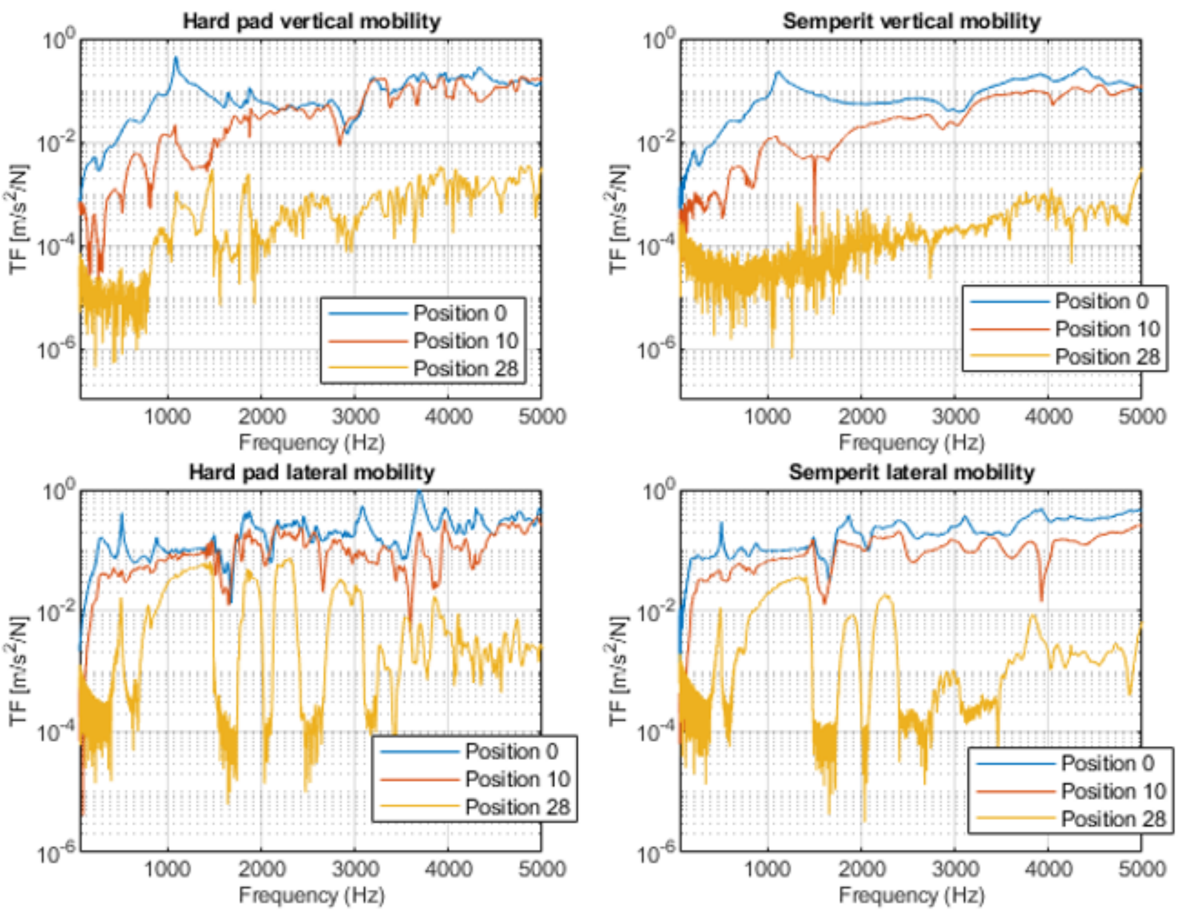

Figure 6: Vertical and lateral rail mobilities at various measurement points. The difference between the two sections can clearly be seen for faraway impacts (Position 28).

Two conclusions are obvious from the graphs

1. The damping pads reduce sharp vibration modes from the mobility, both for vertical and lateral motion. The main pin-pin peaks (1100 Hz for vertical and 500 Hz for lateral vibration) become lower and wider in the case of damping rail pads. The obvious peaks at higher frequencies almost disappear when damping pads are used.
   The pin-pin damping effect is clearly visible for vertical vibrations, but even at lower frequencies the lateral motion's amplitude is reduced.
2. At larger distances (position 28), the damping pads reduce the vertical motion to the sensor's noise floor over the entire frequency range, whereas the acoustically relevant vibrations between 1 and 2 kHz are still propagating in case of the hard rail pads. It is commonly known that lateral vibrations propagate further, which the measurements confirm. The distinct minima, so-called band gaps, in the transfer

function are induced by the periodicity of the rail supports. Once again, the damping pads clearly reduce the transmission at higher frequencies (>1500 Hz).

Track decay rate

For standard materials with low viscous damping, the track decay rate decreases with the pads' stiffness. Very soft pads therefore don't reach the legal minimal requirements for TDR.

The rail pads with high damping lead to a higher vertical TDR. The high damping is clearly reflected in less pronounced dips of the sleeper modes (300-800 Hz) and pin-pin mode. At higher frequencies, the roll-off is less steep, in turn leading to higher TDR values.

The lateral TDR is much more influenced by high-frequency modal effects, resulting in sharp peaks and valleys. Once again, these narrow-band effects are less pronounced when damping rail pads are used.

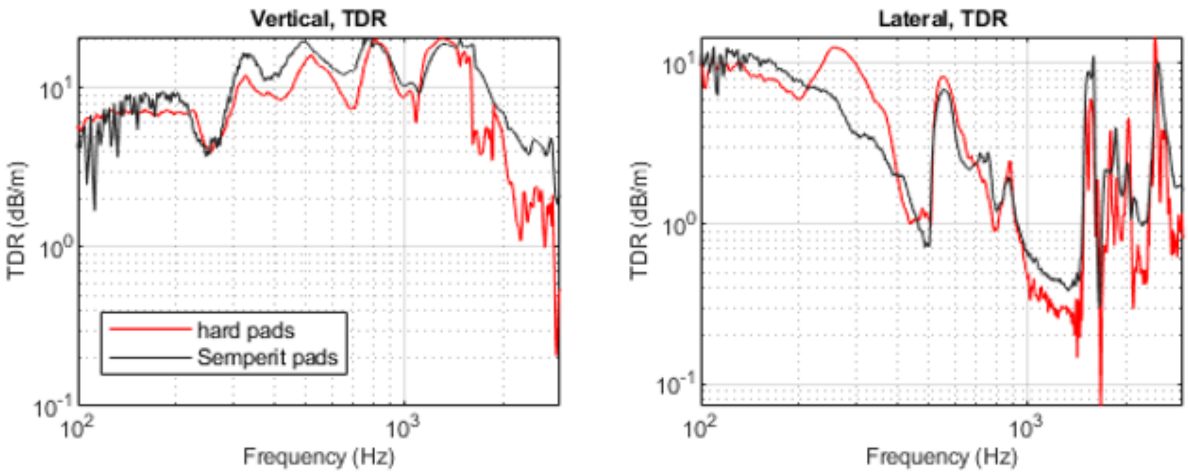

Figure 7: Narrow-band TDR spectra comparing the section with hard EVA pads and new Semperit pads.

The third-octave representation of the results shows an even clearer trend. Damping pads are superior in terms of TDR over the entire frequency range 200 – 5000 Hz. For lateral vibrations, the TDR of hard pads is slightly higher below 700 Hz. At higher frequencies, the TDR of damping pads is higher. The damping pads' geometry and materials were chosen for optimal vertical performance.

As an illustration, a section with experimental soft pads was measured as well. They are not used on the SBB network because they do not match the official requirements in terms of stiffness and thickness. The curves show a clear decrease of TDR due to the low pad stiffness and inadequate damping.

The measurements on day 2 and 3 allow a comparison of the performance as a function of the rail temperature. Day 2 was cool and shady, with a rail temperature of 12°C, day 3 was warm and sunny with a rail temperature of 32°C. The TDR at frequencies above 600 Hz is hardly affected by the temperature. At lower frequencies the TDR slightly decreases with increasing temperature. This is probably due to a reduced stiffness and/or damping of the pads.

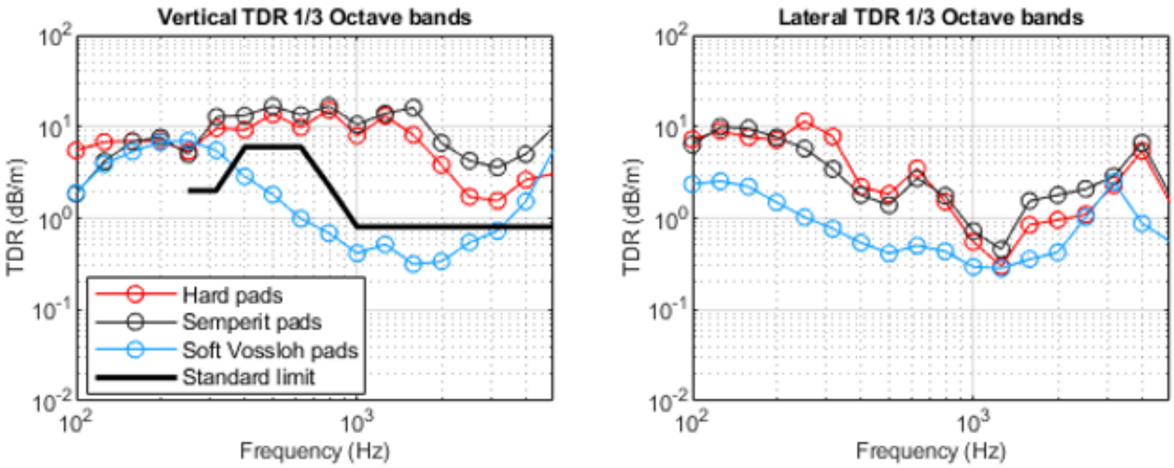

Figure 8: Third-octave TDR of three sections with hard, soft, and new Semperit pads. The damping Semperit pads lead to a higher TDR despite the fact that they're softer.

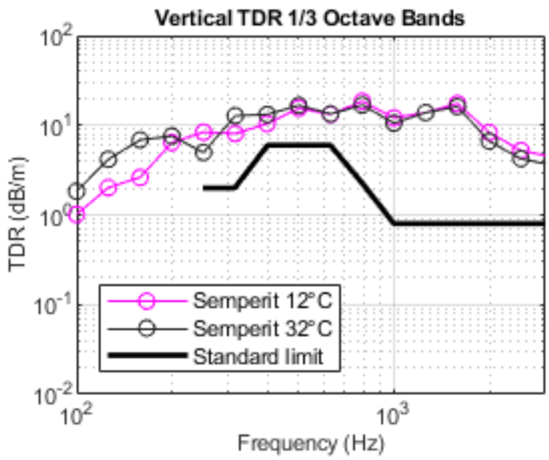

Figure 9: Influence of rail temperature on the Semperit section TDR.

Rail and sleeper vibration

The rail pads play an important role on the track dynamics, both the sleeper and the rail. Whereas the rail is mainly responsible for noise emission, the sleeper vibrations affect the ballast degradation. However, sleeper modes at higher frequencies (300-1000 Hz) have a direct influence on the TDR and indirectly also on the noise emission.

The spectra of the vertical rail vibrations during pass-by, averaged over all trains on a particular day, shown in Figure 10 are almost identical before the exchange of the rail pads on day 1. After the exchange, the rails vibrate significantly less in the frequency range starting at 700 Hz, where the acceleration is reduced by a factor 2. This has a direct effect on the noise emission. Although the train wheels' vibrations might not be smaller, the emission of the rails is smaller which should reduce the overall noise emission.

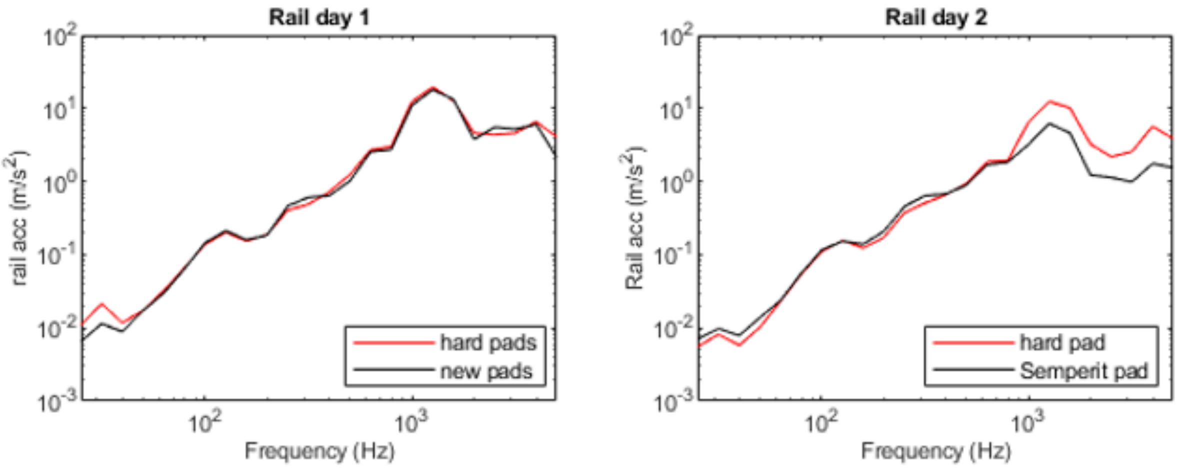

Figure 10: Average spectra of all trains for vertical railway acceleration in both test sections on day 1 (before replacing the hard pads) and day 2 (with new Semperit pads).

A similar trend can be seen in the sleeper vibration. On day 1, there is an offset between the vertical sleeper vibrations. This can be the result of the ballast bed, with different properties under each sleeper. However, a clear reduction of the vertical sleeper vibration can be seen on day 2, starting at 400 Hz. The low frequency range, which is important for the ballast degradation is hard to assess using the current setup, due to the uncertainty of the baseline measurement for identical pads on day 1. A measurement of multiple sleepers within the same section might resolve this issue.

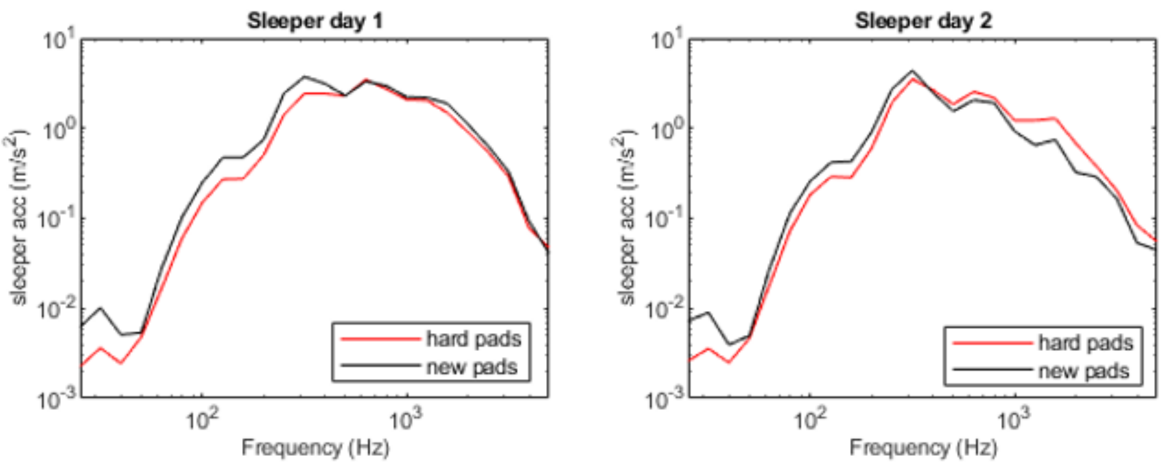

Figure 11: Average spectra of all trains for vertical sleeper acceleration in both test sections on day 1 (before replacing the hard pads) and day 2 (with new Semperit pads).

Noise radiation

The pass-by measurements were performed on three different days, on a variety of train types with different speeds. All these variables can lead to a changing LAeq, so special care has to be taken to claim the effect of the changed rail pads.

Background noise measurement

The background noise (not A-weighted) was measured on all four days. The results show a general noise level below 40dB at frequencies over 100 Hz. Slight differences between the two measurement sections (A1 = hard pads, A2 = Semperit pads) are due to occurences such as passing bikes or remote tractors.

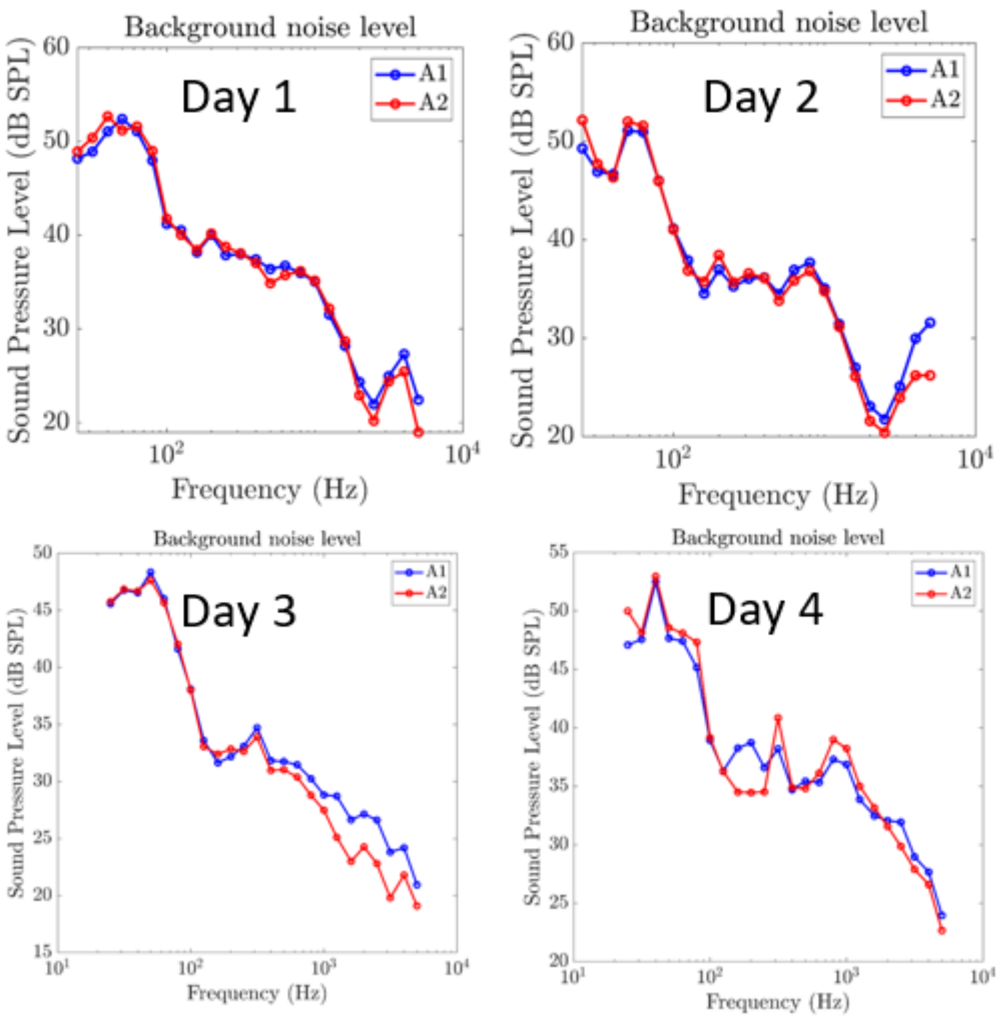

Figure 12: Background noise spectra for all measurement days.

Correction for ground effect and microphone positioning

Different propagation conditions (grass, ballast, nearby trees or other reflectors) can influence the measured SPL at the measurement position. Additionally, a misalignment of the microphones can introduce additional measurement error. On measurement days 3 and 4, the microphones are therefore additionally calibrated using a loudspeaker placed in the middle of the track and emitting pink noise. This shows an almost negligible difference on day 3 and a 1dB offset between both sections on day 4.

The calibration was not done on measurement days 1 and 2. Instead, the SPLs were supposed to be equal on day 1, with hard rail pads on both sections. The average spectrum of all trains was used to correct the measurements of day 2.

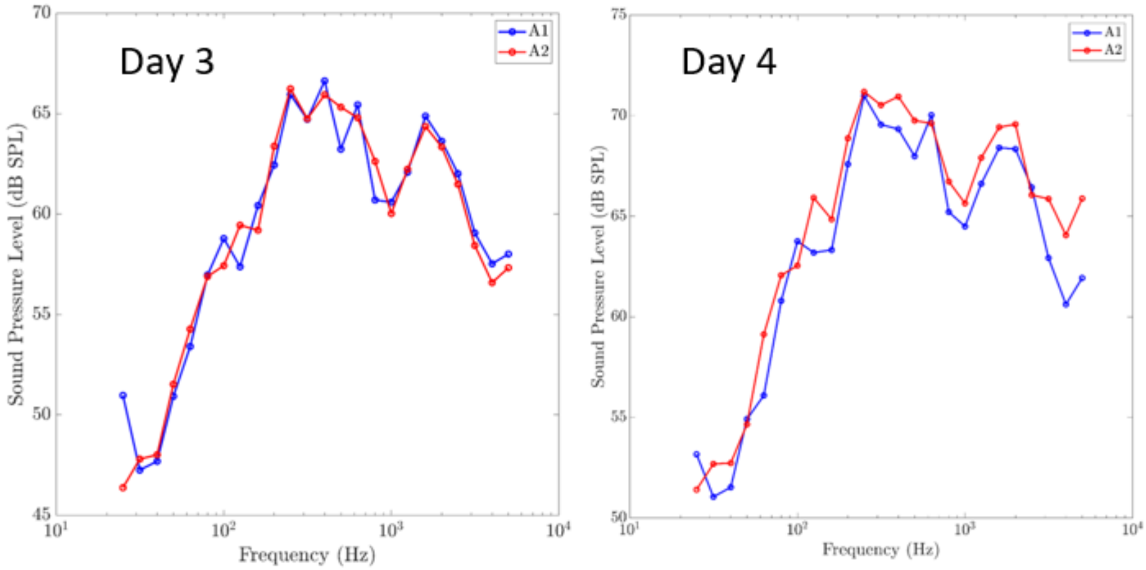

Figure 13: Pink noise calibration spectra for both sections. On day 3, both section microphones are almost identical. For day 4, a correction is needed for the offset.

SPL spectra of various train types

We present the third octave band spectra of IR, S and RE trains for day 3, since they don't require any correction and the measurements give direct insight into the effect of the rail pads. The non-weighted spectra show the average of the trains (14 IR, 6 RE and 11 S). The blue curves represent the section with hard pads, the red curves the section with Semperit pads.

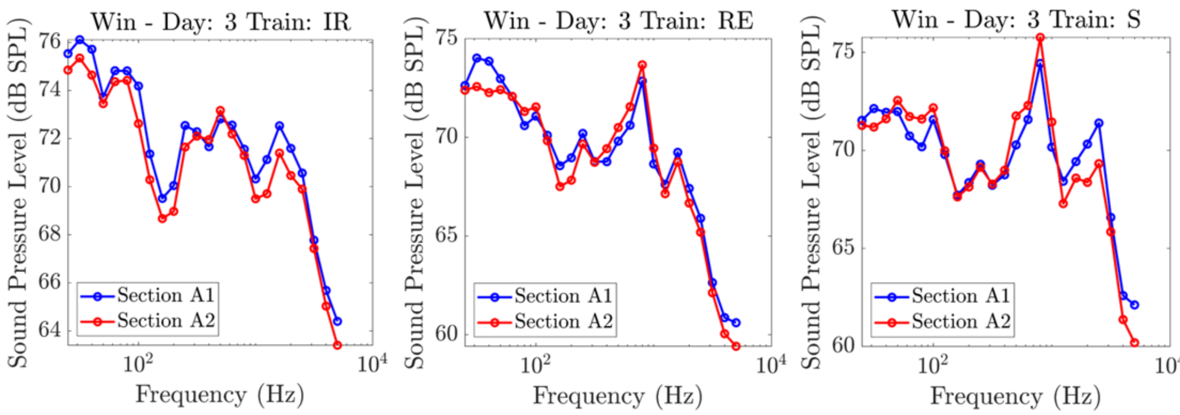

Figure 14: Spectra of the pass-by noise emissions (average of all trains on day 3). The spectra are not A-weighted.

For IR trains, generally the fastest trains on this track, with separate locomotives, the SPL is lower over the entire frequency range. The SPL of S trains is considerably lower starting at 700 Hz, the frequency range where the damping of the pads becomes very high. The RE trains show similar SPL levels over the entire frequency range, but a smaller number of these trains was measured.

From the average spectra, we can deduce that the softer Semperit pads do not lead to an increase in SPL. Moreover, the low-frequency range in which they sometimes show a small increase in SPL is filtered out when using an A-weighting filter.

LAeq levels of the train pass-by measurements

As a final assessment of the new pads, we present an analysis of the LAeq values to deliver a one-number qualification of the tested pads. To do this, several variables that potentially influence the noise emission are includeded in a multivariate analysis model performed in R:

- Connection type (IR, S, RE, IC, …)
- Train speed
- Measurement day
- Rail pad

A first insight into the effect of the pads is given in Figure 15 showing a plot of the LAeq values in both sections. Each point represents a pass-by. The black line is showing equal LAeq values in both sections. The points below this black line are pass-by measurements with a lower noise emission in the Semperit pad section. The majority of the trains lies below the black line.

The boxplots of LAeq's in both sections also shows a reduction of the median value in the section with Semperit pads compared to hard pads. However, the spreading is much larger than the difference in medians. Important for the interpretation of the boxplots is the fact that both samples are not independent. A loud train in the section with hard pads will also be loud in the section with Semperit pads, due to its speed or the train type. The spread of the box plots should therefore not be seen as a statistical error on the median value.

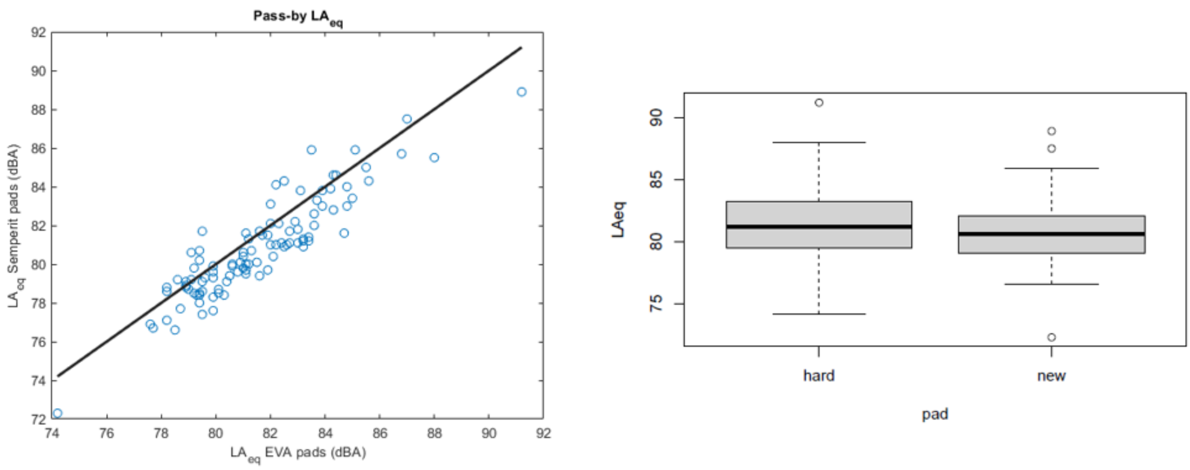

Figure 15: Left: Comparison of the LAeq levels of 101 pass-by measurements, comparing the level in both sections. The black line represents equal levels. Points below the black line represent trains with lower noise emission in the Semperit pad section. Right: Box plot of the LAeq noise emissions in both sections, showing a reduction of the median in the section with new Semperit pads.

A multivariate analysis creates a model including the four important parameters, and is then able to isolate the role of a single influencing factor (in our case, the rail pad). This approach is necessary to exclude potential bias from e.g. different measurement conditions on different days and train type.

Using this model, the effect of using the new pads can be quantified. It shows a reduction of 0.73dB over all measurements, with an error of 0.11dB. The t-value is therefore 6.77, showing that the Semperit pads are significantly more silent ($p<0.0001$) than the hard EVA pads.

Overall conclusion

1. Semperit produced 350 rail pads with desired stiffness and damping properties. They meet the SBB requirements in terms of stiffness and geometry. The pads were tested according to the standards for safety.
2. The pads are significantly softer than standard hard EVA pads, over the entire frequency range. The viscous damping is much higher.
3. The pads' design was fully based on numerical and analytical simulations to predict their behaviour. No iteration steps in the design were necessary to improve their dynamic properties such as vertical TDR.
4. The pads behave as predicted by the models and by lab tests. They were tested for stiffness and fatigue according to the standards. Moreover, the noise emission was tested in the lab on a 3-sleeper section and the TDR was measured on an 18-sleeper ballasted test track. The field tests confirm the models and lab measurements.
5. The Semperit pads reduce free rail mobility and increase the TDR compared to hard EVA pads. The rail and sleeper vibration is reduced, but more measurements are needed to investigate low-frequency vibrations of the sleepers. The LAeq noise emission during pass-by on the Semperit pad section is on average (101 trains) reduced by 0.73 dB with very high statistical significance.