Reduction of Vibration Emissions and Secondary Airborne Noise with Under-Sleeper Pads – Effectiveness and Experiences

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Summary

In the railway superstructure under-sleeper pads are primarily used for ballast protection and to improve the track quality. They increase the contact area between concrete sleepers and the top ballast layer, reduce the formation of hollowness beneath sleepers and lower superstructure settlements. But elastic under-sleeper pads can also represent a cost-effective way to reduce the transmission of vibration and structure-borne noise. Therefore the formation of a vibratory system is responsible. Both effects, improvement of the track quality and formation of a vibratory system, have an impact on the measured insertion loss which is discussed in this article. Derived therefrom the challenges of a computational prognosis of the vibration mitigation effect is described. In light of experience gained in projects carried out with under-sleeper pads for vibration reduction, the achieved results are presented by way of examples.

1 Introduction

Moving trains cause mechanical vibrations from the wheel/rail contact. These vibrations (emission) are carried through the subsoil (transmission) in the form of waves and are often perceived as disruptive at the receiving location (immission). When these effects can be felt by humans, they are considered to be vibrations. As a result the quality of life for residents may be negatively affected to a considerable degree, particularly if the vibrations increase in the occupied rooms because of the effect of resonance or if secondary airborne noise arises as a result of higher frequency parts of the vibrations. The secondary airborne noise is mostly perceived as a muffled rumbling sound. This sound may be masked by the primary airborne noise arising from outside. Noise and vibrations are an omnipresent, undesired side effect of our mobility. Suitable measures must therefore be taken to preserve and enhance quality of life, particularly in fast-growing conurbations. It is well known that it is most effective to concentrate on reducing disruptive vibrations directly at the source of the emission.

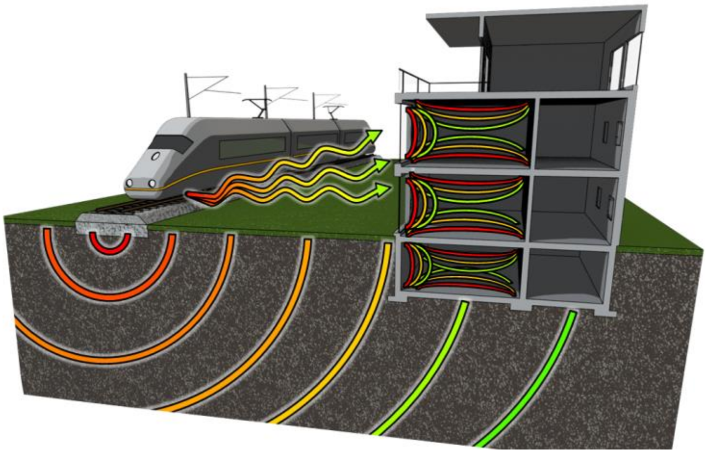


Figure 1: Transmission of vibrations in the area around railway lines

2 High-Quality Superstructure Systems based on Evenness and Resilience

The more even the railway superstructure, the lower the force excitation when a train passes. The track panel itself is "floating" in the track superstructure. Repeated dynamic loads lead to changes in the track geometry over time, which leads to additional acceleration of the wheelsets. The forces generated alter the track bed quality. Hollow areas below the sleepers and signs of wear on the wheel and rail surface, both of which arise over time, increase these processes as well as being the result of them. The system swings more and more, thereby also increasing the emissions. By tamping and adjusting, the superstructure must be returned back to its original position. The length of time this deterioration takes is largely dependent on the initial quality of the track superstructure [1]. The creation of the conditions necessary for a good, durable line that is as inherently stable as possible should therefore be the primary goal when installing new track. In this context, evenness and resilience are important starting points for a high-quality superstructure system. Through the defined arrangement of elastic elements, such as under-sleeper pads, the railway track edges nearer to achieving this goal.

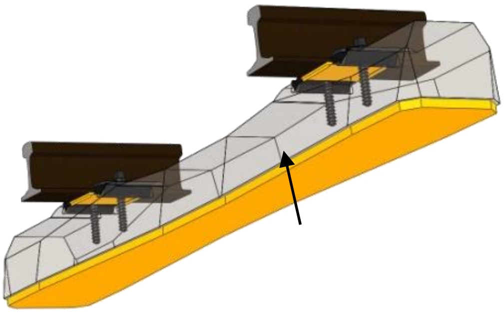


Figure 2: Under-sleeper pad beneath a concrete sleeper

3 Increased Contact Area Using Under-Sleeper Pads

Arranging the under-sleeper pads under the concrete sleepers prevents a hard impression directly on the ballast. The upper-most layer of ballast can bed into the padding material, increasing the contact area (from 2-8% without padding, to 30-35% with padding) and thereby also avoiding excessive contact pressures. The larger ballast contact area and more even bedding lead to increased stability of the ballast bed, less track settlement and reduced wear to significant track components.

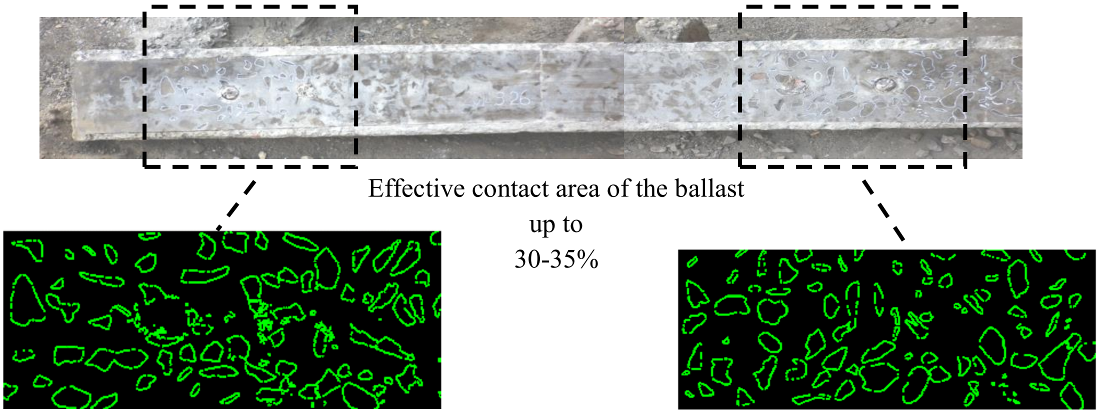


Figure 3: Digital contact area analysis on a concrete sleeper with PU under-sleeper pad removed from a track in service (pore scan method)

As laboratory tests and track measurements show, the lateral resistance of padded sleepers is consistently higher than that of conventional concrete sleepers. With under-sleeper pads, which permit comparably deeper bedding-in of the ballast stones due to their specific material properties, resulting in a larger area of contact ratio, a further increase in lateral resistance was measured [2]. In a padded line with ballast, the formation of voids is almost entirely avoided. This fact in particular shows that the padded concrete sleepers have a significantly better position behaviour. For example, while fairly strongly pronounced voids arose over time between the undersides of the sleepers and the ballast bed in 7 out of 10 unpadded concrete sleepers in the Austrian Federal Railways' network, no void formation could be detected in the measured sections with padding [3]. Deviation in the track quality is significantly lower in padded sections than in unpadded sections. These properties have led to the under-sleeper pads bringing about a significant improvement in the traditional ballasted track. Not least because of this, padded sleepers have become established as the standard form of construction in the Austrian Federal Railways' network. In the mainline network today, concrete sleepers with under-sleeper pads are used as standard in new track and turnout installations.

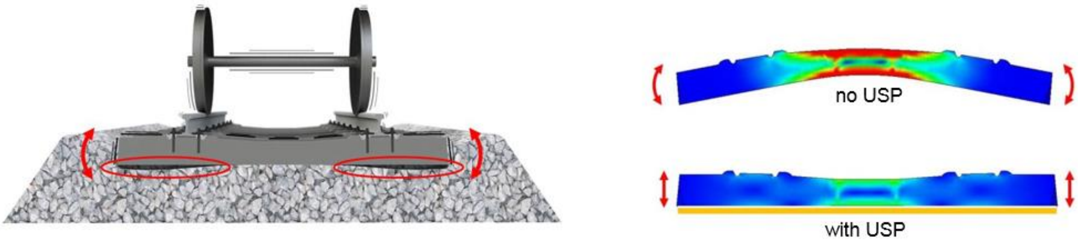


Figure 4: Void formation only under unpadded concrete sleepers. Such voids are avoided by using under-sleeper pads, which makes load transfer more even

4 Vibration Isolation Using Sylomer® and Sylodyn®

The quality of the railway superstructure has a considerable influence on the occurrence of vibrations. A railway line with improved, long-term track bed behaviour due to under-sleeper pads emits less noise and fewer vibrations thanks to the trains running more smoothly. The use of highly elastic materials can significantly reduce emissions to the surrounding environment by making use of the physical principle of mass force compensation for vibration isolation. The effectiveness of elastic components in the railway superstructure is dependent on variables such as mass, stiffness and damping. A vibratory system is formed, the natural frequency of which is ideally far lower than the insulating excitation frequency, based on the operating principle of a single/multi degree of freedom system. The materials Sylomer® and Sylodyn® have proven themselves as essential elastic components for the reduction of emissions. Depending on the requirements, these materials can be provided with a more or less pronounced damping property, especially for avoiding excessively high resonance peaks in the natural frequency. With a dynamic stiffness that can be accurately adjusted for any application, under-sleeper pads can be used to their desired potential for track vibration insulation. As a rule, the higher the dynamic efficacy of the chosen polyurethane material (PU), the greater the vibration protection performance.

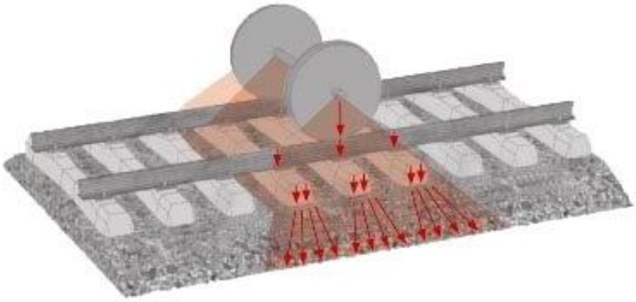


Figure 5: The load transfer in the railway superstructure can be improved significantly with high-quality elastic elements,

5 Insertion loss measurements prove the efficiency

The frequency-dependent vibration-reducing effect of elastic elements is quantified by the insertion loss in accordance with standard DIN V 45673-4 [4]. The insertion loss describes the relative effect of a mitigation measure compared with a reference situation. It shows, for example, how the structure-borne noise changes if under-sleeper pads are installed. Ideally, all other emission influences remain constant here, i.e. the same vehicle, the same speed and identical track roughness, etc. are considered. As the elastic element influences the railway system as a whole, the frequency-dependent insertion loss may vary with other track superstructure properties, other subsoils and/or other vehicle fittings. Figure 6 shows a series of measured insertion losses on different railway lines with various types of under-sleeper pads made from polyurethane material.

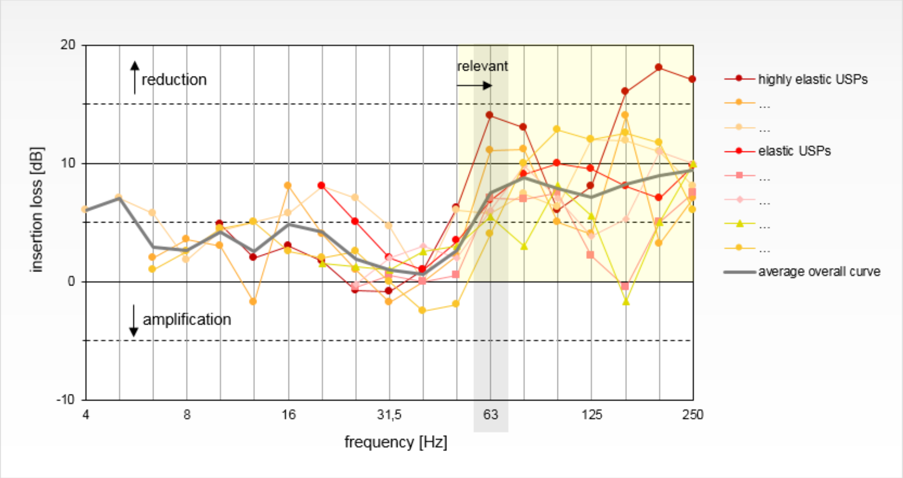


Figure 6: Measured insertion losses with various elastic or highly elastic under-sleeper pads made of Sylomer® and Sylodyn®

As can be seen from the measured insertion losses, the natural frequencies of the superstructures with sleeper pads generally lie between 30 - 40 Hz. In the range relevant for emitted structure-borne noise, above 50 Hz (secondary airborne noise constitutes the decisive criterion here), the damping efficiency ranges between approx. 4 - 14 dB (63 Hz) across all types of sleeper pads. With regular elastic padding, 4 - 7 dB are attainable values. Compared with this, there are the highly elastic under-sleeper pads, which should be considered particularly in conjunction with structure-borne noise insulation. They demonstrate the potential of the technology in an exemplary manner: with a ballasted track optimised acoustically in this way, maximum damping efficiencies of 11 - 14 dB (63 Hz) can be achieved. The measurements prove these types of under-sleeper pads significantly exceeded expectations. For ease of understanding: 10 dB already corresponds to an insulation rate (reduction) of 69%. With frequencies below 50 Hz there is hardly any amplification (-1 to -3 dB), whilst below 25 Hz a further damping efficiency of up to 8 dB is apparent. This is probably largely due to the improved bedding of the sleepers in the ballast bed (fully embedded, no sleepers lying on top of voids) and the enhanced superstructure/vehicle interactions. A reduced damping efficiency occurs in some cases at 100 - 160 Hz ("two degrees of freedom system" with soft rail pads). Nevertheless, there is almost always a positive effect (reduction). The above findings should be sufficient to prove the fundamental suitability of under-sleeper pads for vibration isolation. However, selecting the correct product is vital. This applies both to under-sleeper pads on open tracks and those in tunnels.

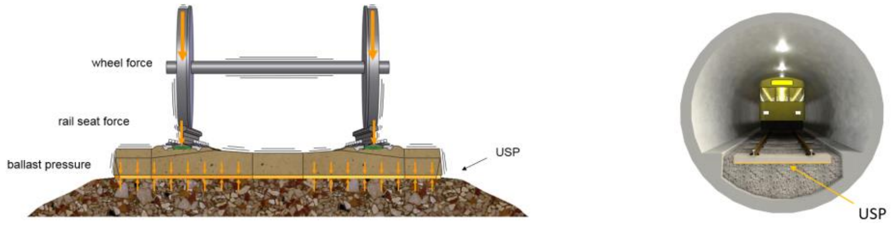


Figure 7: Integrating under-sleeper pads in the load transfer path of the superstructure

6 Forecasting the Vibration-Damping Effect

The findings from track measurements (Figure 6) show the frequency-dependent effect of under-sleeper pads. One relatively simple option for mathematically forecasting such a vibration-mitigating effect is the impedance model [4, 5, 6]. Originally designed for under-ballast mats, this model can, in principle, also be used for calculations involving under-sleeper pads. Here the insertion loss also indicates the ratio of the vibration velocity amplitudes in the ground, without elastic components, to the amplitudes in the ground with elastic components installed. In addition to the spring impedance of the elastic material, the terminating impedance of the subsoil is taken into account – with a softer subgrade in the frequency range > 125 Hz this can typically lead to a falling curve with a decreased effect in the one-third octave band spectrum (cf. Figure 8: Impedance model - left-hand diagram). A possible reduction in the damping efficiency at 100 - 160 Hz with the existing soft rail pads could not be shown using this model. Similarly, the positive impact frequently determined in the measurements for the frequency range < 25 Hz, due to the improved track bed with padded sleepers, could not be seen.

One possibility for better reflecting the behaviour measured in the track with a forecast model would be to use a "semi-empirical" approach. A model partly based on empirical values using three ranges could more closely describe the reality (cf. Figure 8: ‘Semi-empirical’ approach - right-hand diagram, Range 1: Offset for improved track bed quality. Range 2: Analytical model considering the alleviative influence of soft rail pads. Range 3: Optional declining curve taking into account the alleviative influence of the subgrade). It must be noted that use of such an empirical calculation method may, under certain circumstances, require more in-situ measurements, in order to enable more accurate statements in future concerning the mode of operation of under-sleeper pads with regard to vibration isolation. This is intended merely to provide food for thought here, however it is highly probable that the accuracy of a forecast concerning under-sleeper pads could be improved by using empirical data.

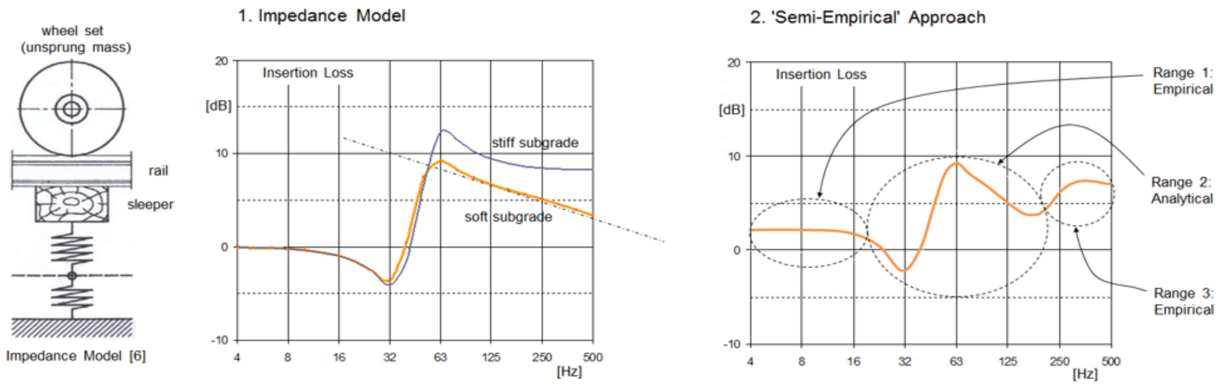


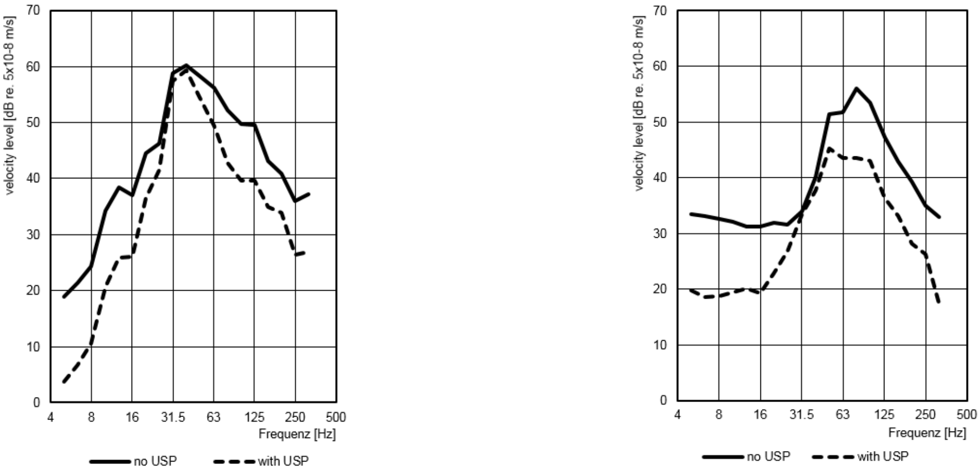
Figure 8: Model approaches for forecasting the insertion loss of under-sleeper pads

7 Project Example: Tunnel

The following example reveals the results of a vibration insulation renovation project for a railway tunnel in Germany [7]. The reason for retrofitting elastic padded sleepers was the high level of secondary airborne noise in the buildings above the tunnel. Numerous complaints from residents led to a law suit, as a result of which measures to improve the situation had to be implemented. Due to the comparatively high demands and resulting high costs of retrofitting under-ballast mats, the decision was made to opt for a much simpler solution: replacing the unpadded sleepers with padded sleepers. This alternative was also significantly cheaper. Highly effective under-sleeper pads made of Sylodyn® of type SLN1010G from Getzner Werkstoffe were used. To test the effectiveness, measurements were taken in the tunnel and in a building above the structure (first floor). The figure below shows the measured one-third octave band spectra with and without under-sleeper pads, and the associated insertion loss factor:

One-third octave band velocity level at the tunnel wall with and without under-sleeper pads:

One-third octave band velocity level in the building with and without under-sleeper pads:



Insertion loss factor at the tunnel wall:

Insertion loss factor in the building:

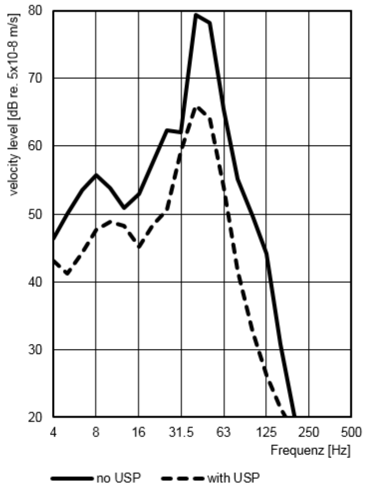
Figure 9: Measured one-third octave band velocity level with and without under-sleeper pad, type SLN1010G, as well as the associated insertion loss factors as difference spectra

The analysis of all the results shows a vibration-mitigating effect of between 5 dB and 10 dB above a frequency of > 40 Hz [7] both in the tunnel and in the building after padded sleepers were installed. There is a reduction in the damping efficiency in the natural frequency range in accordance with vibration theory, however a reinforcing effect does not occur. The suitability of the under-sleeper pad in reducing secondary airborne noise and vibrations has been proven in this renovation project in both the tunnel and inside the building.

8 Project Example: Open Track

The following example shows an extract of the results of investigations into the vibration-damping effect of under-sleeper pads on an open track in Denmark [8]. In this project, highly effective under-sleeper pads made of Sylodyn® of type SLN1010G from Getzner Werkstoffe were used. In order to quantify the mode of operation of the under-sleeper pad, measurements were performed 7.5 m away from the track. The values shown below were originally calculated as acceleration levels, however they have been converted to velocity levels in order to standardise the diagrams. The figure below shows the measured one-third octave band spectra with and without under-sleeper pads, and the associated insertion loss factor:

One-third octave band velocity level 7.5 m from the
track with and without under-sleeper pads:



Insertion loss factor
7.5 m from the track:

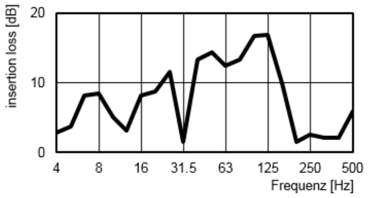


Figure 10: Measured one-third octave band velocity level with and without under-sleeper pad, type SLN1010G, as well as the associated insertion loss factor as a difference spectrum

Based on the measured data for this project, it was determined that the measures implemented produced a vibration-mitigating effect of approximately 13.5 dB in the dominant frequency bands. The reduction in damping efficiency in the natural frequency range is clearly visible as expected, however there remains a positive effect (reduction) without the feared break with a reinforcing effect.

9 Latest Developments in Under-Sleeper Pads

Nowadays, under-sleeper pads that are predominantly used to improve the track bed and protect the track ballast consist of a resistant material with a viscoplastic property that has a positive effect on the way the ballast is embedded. On the other hand, sleeper pads that are primarily used for vibration insulation require a softer, dynamically highly elastic material with low damping properties.

As the explanations show, both approaches are necessary for effective vibration protection. Therefore, a combination of different materials may be used in order to reduce the occurrence of the disruptive vibrations by means of a stable and secure track bed geometry, whilst also reducing the transmission of annoying vibrations using the physical principle of vibration isolation. Figure 11 shows an under-sleeper pad in a sandwich arrangement with multiple functional layers. The soft and acoustically highly effective resilient layer made from Sylodyn® is protectively embedded between a polyamide connecting medium ("mechanical adhesion" mesh) for

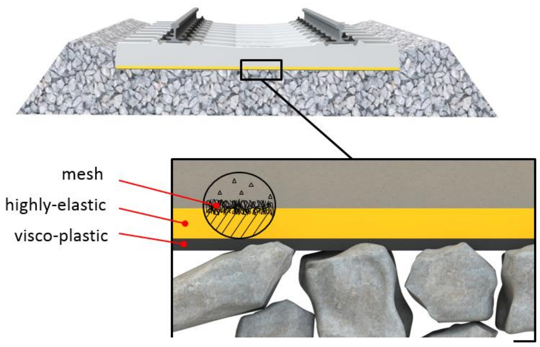


Figure 11: USP multiple functional layers

the sleeper concrete side and a viscoplastic layer for the ballast side. This separation of functions covers multiple aspects and can therefore also cater to combined requirements.

Current development approaches show that it is possible to combine elastic and plastic properties in one material. They form the basis for the latest generation of PU under-sleeper pads. Positive results from various tests performed as part of ongoing research and development already confirm the advanced performance of this material. The demand for optimised innovations that meet market requirements can thus be satisfied with this solution.

Figure 12: The elastic and plastic material properties of under-sleeper pads combined: forecasted and desired ballast impressions immediately after removal (left) and three weeks later - complete restoration (right)

10 Summary and Conclusion

Railway traffic generates mechanical vibrations, due to the interaction between the rail vehicle and the track, which are transmitted either as structure-borne noise through the ground or as airborne noise. Based on the current understanding of the topic, suitable under-sleeper pads made from Sylomer® or Sylodyn® can be used to reduce the vibrations within the frequency range relevant to structure-borne noise by more than 10 dB. To date, a negative impact on primary airborne noise has not been established. Technically sophisticated under-sleeper pads can represent a cost-effective improvement to the traditional ballasted track, however the choice of material used is of vital importance here. PU under-sleeper pads, which combine both elastic and plastic properties, represent the latest generation of innovations in this area.

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