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Mitigating vibration using under-sleeper pads

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Mitigating vibration using under-sleeper pads

Installation of concrete sleepers fitted with Sylomer pads.

ADDED BENEFITS Primarily used to improve the stability and life of ballasted track, under-sleeper pads have been found to provide a cost-effective way of reducing the transmission of ground-borne noise and vibration.

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Under-sleeper pads are primarily used to improve the structure of ballasted track, helping to maintain an even surface, improve the grip between ballast and concrete sleepers and avoid the development of hollow areas underneath the sleepers. However, ongoing research suggests that these pads can also offer an economical way to mitigate problems of structure-borne noise and vibration.

Noise and vibration are an inevitable but unwelcome side effect of our mobility. A moving train causes mechanical vibration from wheel/rail contact, which is transmitted through the subsoil. This can be very annoying for residents in properties alongside the line. The problem can be aggravated if the vibration is increased by resonance within the buildings, or if structure-borne noise arises as a result of higher-frequency vibration. Secondary airborne noise emitted by the structures can often be heard as a muffled rumble inside the buildings. This sound is sometimes enhanced by the primary airborne noise on open track (Fig 1).

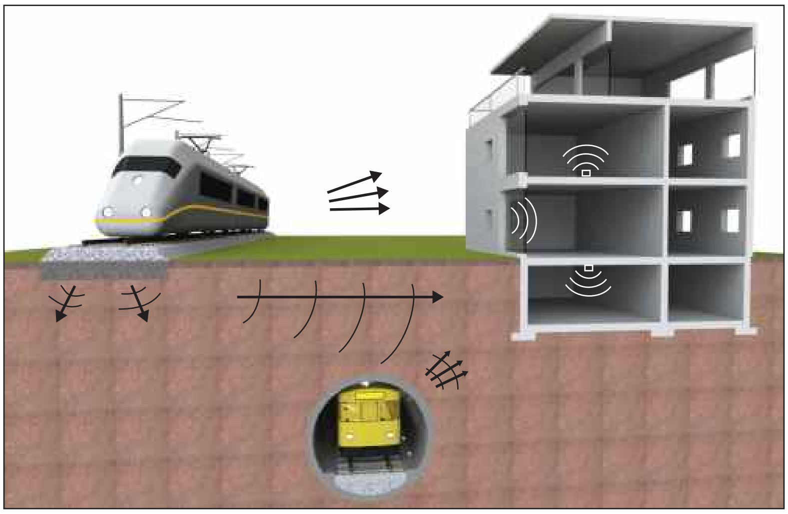
Tackle the source

Where it is considered necessary to reduce the impact of noise and vibration, particularly in urban areas, it is widely accepted that it is most effective to concentrate on reducing vibration at the point of emission.

The quality of the railway superstructure has a considerable influence on the generation of vibration. The more even the structure, the lower the excitation when a train passes. In a conventional ballasted trackform, the track itself is 'floating', and repeated static and dynamic loads result in changes to the geometry over time. These deviations lead in turn to additional acceleration of the wheelsets, and the resulting forces further alter the quality of the track bed. Over time, hollow areas appear below the sleepers (Fig 2) and the rail surface wears, which further increase the rate of change. As the system swings more and more, emissions increase, until the structure is returned to its original geometry by lining and tamping.

The time taken for this deterioration process is largely dependent on the initial quality of the track so establishing as good and stable a structure as possible should be the primary objective when laying track. Elastic elements such as under-sleeper pads can be a valuable contributor to a high-quality structure, ensuring evenness and resilience in the trackform.

In recent years, various European railways have been adopting USPs, mainly as a way to improve trackbed geometry and protect the ballast. Adding an elastic layer under concrete



Right: Fig 1. Transmission of vibration in the area around railway lines.

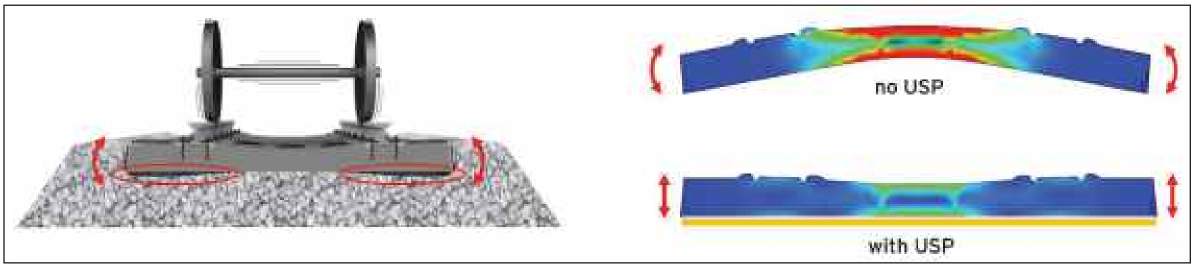


Fig 2. Hollow area formation is reduced by under-sleeper pads, thanks to more consistent deflection of the concrete sleepers.

sleepers avoids a hard interface with the ballast, allowing the stones to bed into the padding material. This increases the surface area and avoids excessive contact forces, leading to increased stability, less settlement and reduced wear of the track components (RG 1.11 p42). Studies by the Technical University of München showed that pads with a bigger contact area offer a further increase in lateral resistance[1].

Tests by Austrian Federal Railways found that the use of USPs almost completely eliminated the formation of hollow areas under the sleepers[2]. Deviations in track geometry were significantly reduced where pads were used, and ÖBB therefore adopted them as standard for all new main line track and turnouts.

Vibration insulation

As well as reducing noise and vibration by providing a smoother trackbed, the highly elastic materials can also reduce emissions significantly thanks to their physical insulation properties.

The efficiency of an elastic component is mainly dependent on the mass, stiffness, and damping factors. Ideally, the natural frequency of the resulting vibratory system should be far lower than the insulating excitation frequency. As elastic components, the polyurethane materials Sylomer and Sylodyn have been found effective in reducing emissions. Depending on local requirements, under-sleeper pads made of such materials can be provided with a more or less pronounced damping component by adjusting the dynamic stiffness, in order to reduce excessive peaks or resonance in the vicinity of the natural frequency. As a rule, the higher the dynamic efficiency achieved through the choice of material, the greater the vibration protection.

The vibration reduction of elastic elements is quantified in terms of the insertion loss[3]. This describes the relative effect of a mitigation measure against a reference situation. For example, it could show how the 1/3 octave band spectrum of structure-borne noise would change if USPs were installed, assuming all other influences remain constant, for example the same vehicle, speed and rail roughness. As the elastic element influences the system as a whole, the frequency-dependent insertion loss could vary with other properties of the track, subgrade and/or vehicles.

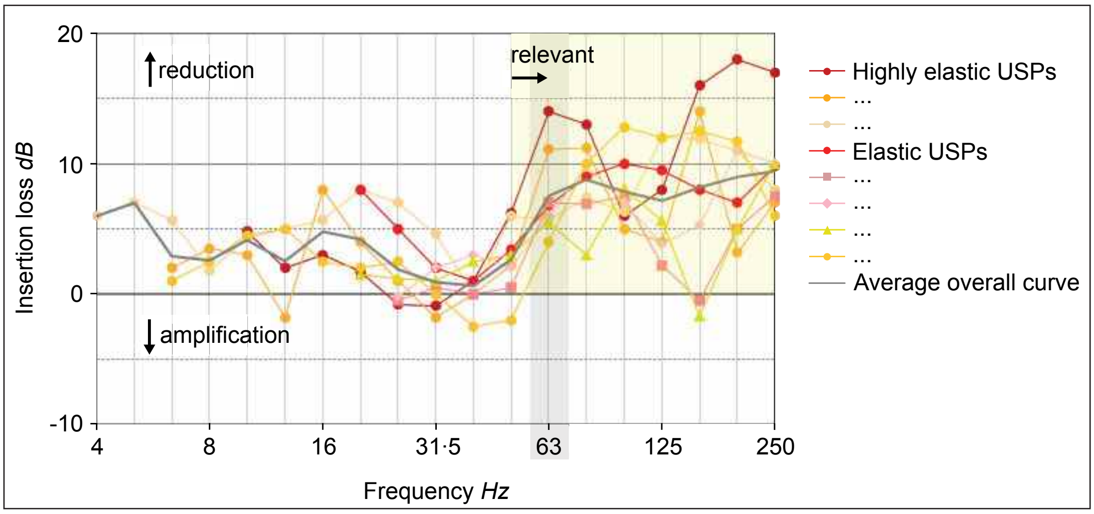
Fig 3 shows a series of insertion loss curves measured on different lines with various types of polyurethane under-sleeper pads. The natural frequencies of the superstructures with USPs generally lie between 30 Hz and 40 Hz. In the relevant range for emitted structure-borne noise and secondary airborne noise, above 50 Hz the insulation efficiency varies between 4 dB and 14 dB at 63 Hz across all types of pad.

Values of 4 dB to 7 dB are attainable with regular elastic pads. But to address structure-borne noise it is worth considering highly-elastic pads, which can achieve insulation efficiencies of 11 dB to 14 dB with an acoustically-optimised superstructure. Multiple measurements found that the performance of these types of pad significantly exceeded expectations. For ease of understanding, a 10 dB improvement corresponds to an insulation rate, or a reduction in vibration, of 69%.

With frequencies below 50 Hz, there is hardly any amplification, whilst below 25 Hz a further reduction of up to 8 dB is apparent. This is probably due mainly to the better bedding of the sleepers in the ballast.

Vibration insulation theory leads us to expect a lowered efficiency at some point due to the influence of softer rail pads, and this can be found between 100 Hz and 160 Hz. Nevertheless, the reduction almost always remains positive, without the risk of amplification which had been feared.

These findings prove the fundamental suitability of USPs for reducing vibration and secondary airborne noise, but selecting the right



Left: Fig 3. Measured insertion loss with various types of under-sleeper pads.

Below: Fig 4. Use of under-sleeper pads in the ballast structure of a single-bore tunnel.

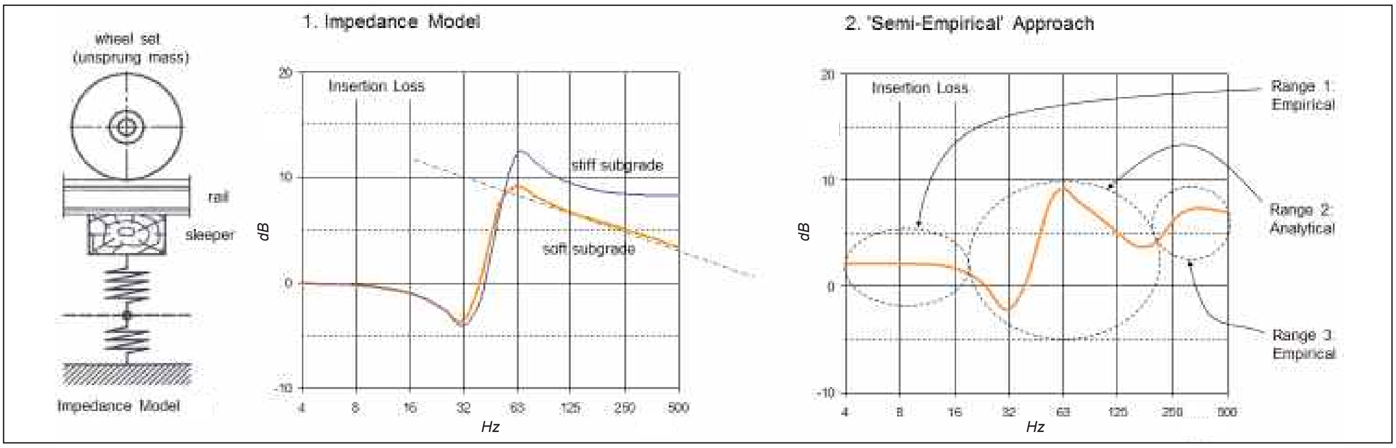


Fig 5. Model approaches for forecasting the insertion loss of under-sleeper pads. In the semi-empirical approach (right), Range 1 shows the offset for improved trackbed quality; Range 2 considers the alleviative influence of soft rail pads; and Range 3 shows an optional declining curve taking account of the decreasing influence of the subgrade.

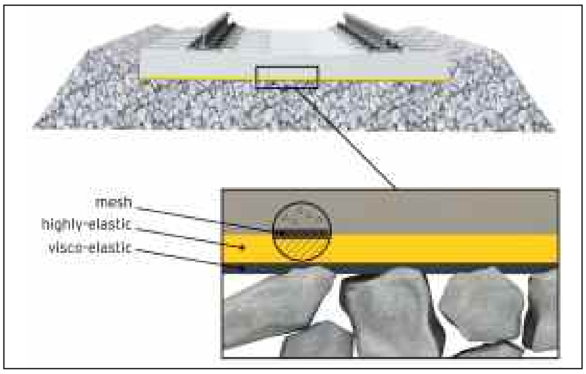
pads for the local application is vital, both on open tracks and in tunnels (Fig 4).

Modelling performance

The measurements in Fig 3 show that the effect of USPs is frequency-dependent. One relatively simple option to forecast the vibration mitigation performance mathematically is to use an impedance model[3,4,5]. Originally designed for ballast mats, this can in principle also be used for calculations involving under-sleeper pads. The insertion loss indicates the ratio of the vibration velocity amplitudes in the ground for track without elastic components to those when such components are installed.

In addition to the spring impedance of the elastic material, the terminating impedance of the subgrade is taken into account. With a softer subgrade in the frequency range greater than 125 Hz this can typically lead to a declining curve with a decreased effect in the 1/3 octave band spectrum, as shown on the left in Fig 5. The possible reduction in the insulation efficiency in the 100 Hz to 160 Hz range with soft rail pads is not seen. Nor does the model show the positive changes measured in the frequency range below 25 Hz thanks to the improved trackbed.

Fig 6. A sandwich under-sleeper pad using different materials to provide multiple functional layers.



Another approach for better forecasting of track behaviour might be to adopt a 'semi-empirical' model using multiple ranges (Fig 5, right). However, this has yet to be explored fully, and an empirical model may require more site measurements for calibration.

Primary airborne noise

Measurements suggest that the use of USPs has no significant impact on the emission of primary airborne noise. Although a short-term increase amounting to a maximum of 5 dB within the frequency range 50 Hz to 100 Hz must be expected following installation, this is offset by a reduction of up to 5 dB in the higher frequency spectrum above 100 Hz[6].

These comparisons use a new track without USP as a reference, and it should be borne in mind that the geometry of that track will deteriorate more quickly, which could lead to a significant increase in airborne noise. For example, rails with short-pitch corrugation may result in an increase of more than 15 dB in noise levels when a train passes. Given the improved long-term quality of track offered by the use of USPs, the short-term impact on primary airborne noise appears negligible, although further investigation is needed.

Improved pads

Under-sleeper pads that are predominantly used to improve trackbed geometry ideally consist of a resistant material with a visco-plastic property. This allows the ballast stones to become properly embedded, even if the pads are very stiff. On the other hand, pads used primarily for vibration insulation require a softer, dynamically highly-elastic material with low damping properties.

Ideally, both approaches are necessary for effective vibration protection. A combination of different materials could be used to reduce the creation of disruptive vibration by ensuring a stable geometry, and reducing the transmission of vibration at the same time using the physical insulation principles. Fig 6 shows such a sandwich pad arrangement. The soft and acoustically highly-effective elastic layer made from Sylodyn is embedded between a mechanical adhesion mesh next to the concrete sleeper and a visco-plastic layer on the ballast side. This separates the various functions in order to cater for the differing requirements.

Our research suggests that appropriate under-sleeper pads can be used to reduce vibration within the frequency range relevant to structure-borne noise by more than 10 dB. Nevertheless, we have not established any significant impact on primary airborne noise. Technically-optimised pads offer an economic improvement for vibration protection in traditional track structures, but the choice of material is of vital importance. The initial results from using under-sleeper pads to mitigate vibration have been very promising, and research into this application is continuing.

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