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Sustainable superstructure with Under Sleeper Pads

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Abstract

With the help of Under Sleeper Pads (USP) a further step towards a sustainable, and durable superstructure in railway engineering can be achieved. The development of USP within the classic components used in the construction of permanent ways can bring defined elasticity into the track. They are installed on the bottom surface of the sleeper and thereby increase the degree of vertical elasticity in the track superstructure. The objective is to transmit the loads from the vehicles through the rails, rail fasteners and the sleepers into the superstructure and the subgrade in the smoothest, safest and most evenly distributed manner possible. With the use of USP not only the bending line of the rail is activated and the load is distributed to more sleepers but also the contact area of the sleepers with the ballast is widely increased – and vibrations can be mitigated. A normal concrete sleeper shows a contact area of around 2-8% of the sleeper's bottom area towards the ballast meanwhile the use of polyurethane USP show up to 35 % contact area. Therefore, next to other positive effects, ballast wear will be reduced in a great manner and looking on the sustainability and life cycle analysis the tamping cycles can be reduced up to 2.5 times. Looking back on more than 25 years of USP in track, turnouts and transition zones for ballast protection, improved track stability or vibration isolation, a vast number of projects are evaluated and the long term benefits can be seen in tracks all over the world.
With the ongoing development of new materials and improvements of the existing products the technology of Under Sleeper Pads is up-to-date and ready to react on upcoming challenges.

Keywords: railroad infrastructure, Under Sleeper Pads, polyurethane, track quality, track alignment, vibration reduction, railway superstructure, life cycle costs, reduced maintenance.

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1. Introduction

Looking at hotspots in the railway superstructure they seem to be alike all over the world. As an innovative company, Getzner Werkstoffe is using this information to create products to solve these problems. Especially with economic growth and increasing wealth the need to transport goods and passengers on railways increases rapidly across the globe. To compensate these developments, railway lines are being upgraded to higher axle loads and the frequency of running trains is enhanced.

2. Maintenance as a hint for development

With the introduction of elasto-plastic materials for Under Sleeper Pads (USP) the superstructure is more even, and therefore the force excitation of passing trains can be reduced, even with higher axle loads. The track panel itself is "floating" in the track superstructure. Without USP, 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 vibrates more and more, thereby also increasing emissions of vibration and noise. By tamping and adjusting, the superstructure must be returned into its original position. The timespan of this deterioration is largely dependent on the initial quality of the track superstructure, Veit et al. (2011). The more worn a superstructure gets the more often a realignment has to take place. Next to this repositioning of the track, the wear of the ballast has to be checked and from time to time replaced, since worn ballast accelerates the deterioration. 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 the railway track edges nearer to achieving this goal.

3. Elasto-plasticity as an innovative approach

Having the feedback of railway operators, that removed unpadded concrete sleepers show only a small contact area to the ballast, and as its result the ballast wear is high, the arrangement of USP 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 or EVA (Ethylen Vinyl Acetat) padding, up to 35% with elasto-plastic polyurethane (PUR) USP) and thereby also avoiding excessive ballast contact pressures. The enlarged ballast contact area and the more even bedding, lead to an increased stability of the ballast bed, less track settlement and reduced wear of significant track components. Investigations have proven these effects since 2001 all over the globe, Schilder (2007). With the elasto-plastic material properties the USP gets integrated in the load distribution path of the track superstructure. The bending line of the rail is activated and therefore the loads can be distributed to a greater number of sleepers.

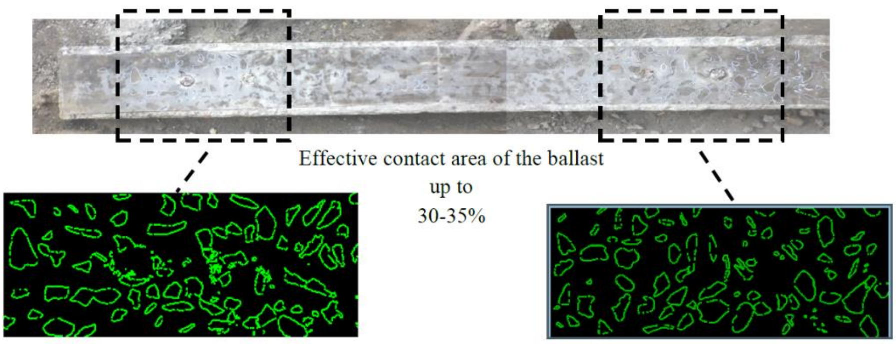

Fig. 1 Digital contact area analysis on a concrete sleeper with elasto-plastic polyurethane USP removed from a heavy haul track in service (porescan method)

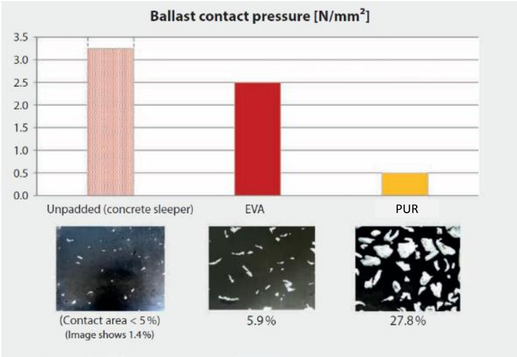

Fig. 2 Mean ballast contact pressures under the concrete block representing the sleeper. Comparison between a concrete sleeper without pads, with EVA pads and with PUR pads. The principal influence reducing the ballast contact pressure is the greater contact area

4. Increased track stability

If trying to increase the track stability one approach is to increase the lateral track resistance (LTR[†]). Next to other positive effects the track can compensate higher longitudinal rail stresses resulting in a smaller lateral track movement mainly in curves. Especially when installing continuously welded track these lateral movements have to be considered. When installing welded track in curves the needed LTR of the track and therefore of the sleeper is appraised by the superstructure regulations, based on in track and laboratory measurements. If this value is not to be reached with the sleeper itself additional measures have to be taken into account. Some of them like safety caps do not only have high acquisition and installation costs but do also need to be serviced and retightened from time to time especially after tamping. With the installation of elasto-plastic polyurethane USP there are no such problems. In addition to the contact area itself the material property allows the ballast to be embedded within the USP and a bigger construct is created consisting of USP and the top ballast layer and the sleeper can interlock with the ballast bed. With these possibilities to enlarge the contact area of the sleeper bottom to the ballast and the fact that 45-50% of the LTR is resulting in sleeper bottom friction with the ballast it is possible to increase the LTR by 17% just with installing elasto-plastic USP and as a result using the interlocking of the ballast itself, Pospischil (2015). This interlocking effect in these high numbers can only be reached by the special Getzner polyurethane recipe. Other USP made of e.g. rubber granulate shows less effective behavior, Iliev (2012).

Knowing a USP is not only specified by its static bedding modulus but especially by its elasto-plastic material behavior Getzner Werkstoffe created the Elasto-Plastic Material Index (EPM-Index). It presents a single value by adapting a constant force for several hours to a USP-specimen resting on a geometric-base-plate (GBP). After relief of the pressure the recovery of the specimen is recorded. The material can thereby be specified by its time relevant (elastic) and a time independent (plastic) behavior. The higher the EPM-Index the higher the plasticity and the contact area.

5. Test-tracks prove the system

The positive effect of installing USP made of Sylomer® or Sylodyn® has been validated on various sections of test track in different countries, Loy et al (2013). For comparative purposes, individual sections were equipped with further-developed PUR USP. Test sections were also set up without USP in order to establish the differences in the tracks' long-term behavior. Precision levelling was used to record the tracks' settlement behavior. Fig. 4 shows examples of mean settlement curves. In this example, the trends were already clearly recognizable after 377 days. The mean track settlement reached a value of 7.5 mm in the zone with pads. In the track without sleeper pads, by contrast, the track settlement already reached a mean value of 12.5 mm. That meant the settlement of the classical ballasted track was more than 65% greater than in the zone with USP, which certainly reflects the experience from other locations where such pads had been used – despite the relatively short observation period.

[†] The LTR is the value of the force needed to move the sleeper itself for 2 mm lateral to the track. Although for nowadays Finite Element Method calculation the development of force is more important.

The test sections of track in which sleeper pads were installed displayed a much more homogeneous quality of track geometry, which can even be recognised with the naked eye in certain circumstances.
In a padded line with ballast, the formation of voids is almost entirely avoided. This fact in particular shows that padded concrete sleepers have a significantly better position behavior. 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, Auer (2011). Deviation in the track quality is significantly lower in padded sections than in unpadded sections. These properties have led to the USP bringing about a significant improvement in the traditional ballasted track. Current research of new PUR USP showed a LTR increase of 100% in newly laid USP-track compared to unpadded 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 USP´s are used as standard in new track and turnout installations.

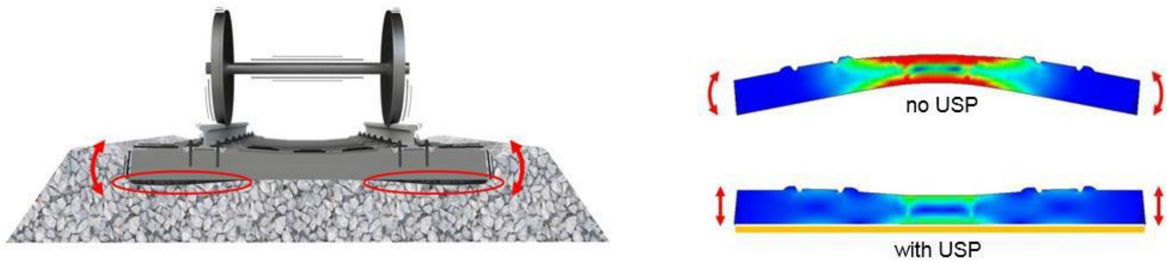

Fig. 3 Void formation only under unpadded concrete sleepers. Such voids are avoided by using under-sleeper pads, which makes load transfer more even

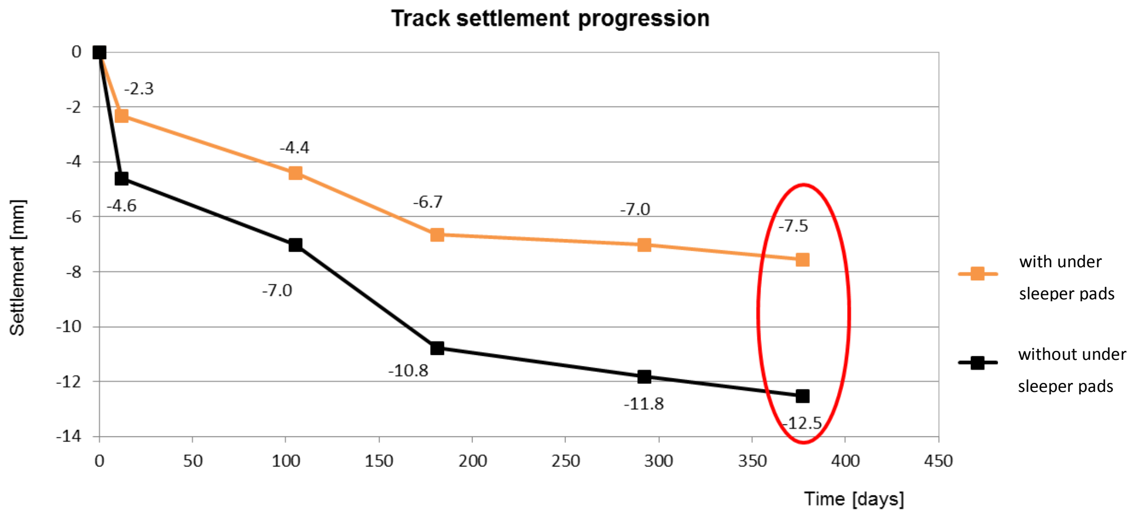

Fig. 4 Mean settlement over time with and without under sleeper pads after a test period of 377 days

6. Vibration mitigation using Getzner USP

Next to the above described benefits of USP regarding track stability or life cycle costs the fast growing population needs protection from vibrations, causing noise. A railway line with an improved, long-term track bed behavior due to USP emits less secondary noise and fewer vibrations thanks to the trains running more smoothly. The use of highly elastic materials can significantly reduce emissions to the 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 much lower than the 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. With a dynamic stiffness that can be accurately adjusted for any application, USP can be used to their desired potential for track vibration insulation. As a rule, the higher the dynamic efficacy of the chosen PUR, the greater the vibration protection performance.

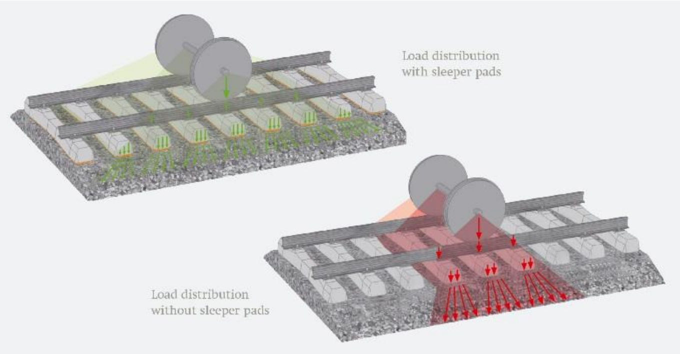

Fig. 5 Improved load distribution with and without sleeper pads

7. Recent measurements

Recent measurements done by the "Wroclaw University of Technology, Faculty of Civil Engineering Department of Bridges and Railways" investigated the vibration mitigation of Getzner USP in Krakow, Poland. As described above two sections were compared, both having the same soil and superstructure age and loads since they are positioned next to each other without influencing one another. For the frequency range above 32 Hz there is a reduction of vibration in the track with USP occurs, compared to the track without USP. Frequencies above 40 Hz to 200 Hz are mainly responsible for the secondary airborne noise in adjacent buildings.
To point out some results: Vibrations around 50 Hz to 63 Hz reach a level of 80 dB without USP, whereas with USP the level is reduced to less than 69 dB, for a train speed of 70 km/h. To clarify these results the insertion loss is determined (difference between section 1 and section 2). With the help of the insertion loss the vibration damping effect, measured in decibel (dB) can be expressed. If the values are positive, a reduction of vibrations is detected and an improvement of the track superstructure is verified.

The dominant one-octave band of passing trains can be found around 63 Hz, Garburg (2007). The used USP show an insertion loss of 11.6 dB. For ease of understanding, a 10 dB improvement already corresponds to an insulation rate, or a vibration reduction of 69%. Even in the area of the natural frequency, very little resonance amplification can be seen. These findings, especially the relevant values around 63 Hz, prove the fundamental suitability of USP for reducing vibration and secondary airborne noise, Kwiatkowska et al. (2017).

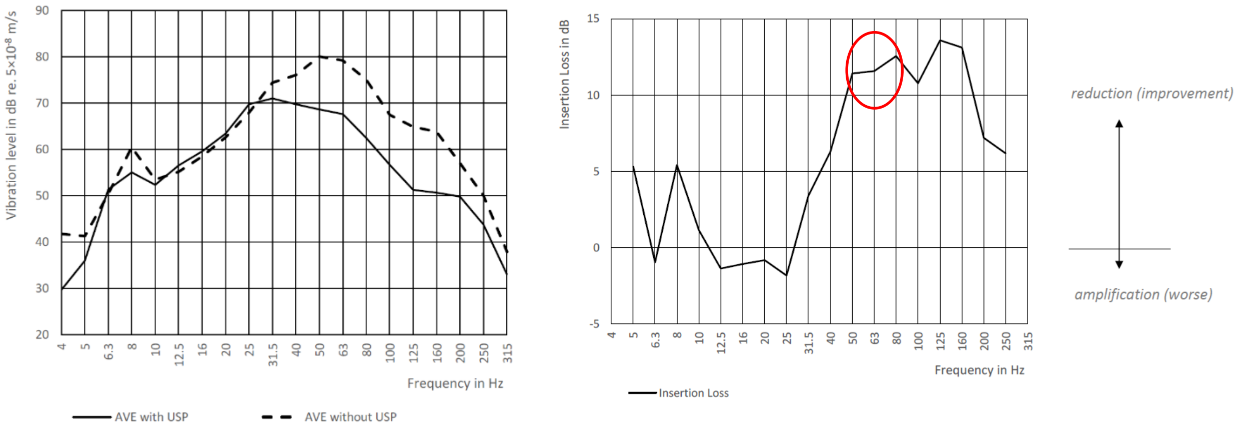

Fig. 6 (a) Average vibration levels Section 1 without USP compared to section 2 with USP (b) Insertion loss for Getzner USP measured in Krakow

8. Summary

The use of USP can increase the elasticity of track superstructure with relatively low investment costs. At the same time the ballast, which is a latent source of track instability, is stabilized, as individual ballast rocks can be embedded in the surface layer of elasto-plastic USP. With this embedment the lateral track resistance is increased and continuously welded tracks can be implemented in tighter curves without additional structures like safety caps or else. Loads on the superstructure are reduced by a more homogeneous mounting of the sleepers and track stability is improved in a way that tamping intervals can be more than doubled[‡]. With in-track measurements in Krakow, Poland an average insertion loss of 11.6 dB could be measured, corresponding to a vibration reduction of 74%. Indicators and first in track tests show that, new USP that are currently under development will be able to double the LTR and thereby raise the track stability to a new level.

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[‡] A long time study (WINS) in the Austrian Federal Railway System ÖBB showed an increase of the tamping cycles by a factor of 2.75, Marschnig (2010).