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# Vibration attenuation at rail joints through under sleeper pads

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## Abstract

Modern railway tracks require electrification to power the trains and signaling systems to detect near real-time location of trains on railway networks. Such systems require the rail to carry and return the residual electricity back to substation, while enable signals to transfer within a track circuit. This track circuit requires rail joints to divide and insulate each loop of the circuit. Such the rail joints often generate impact transient dynamics to track systems. This paper presents the filed investigation into the vibration attenuation characteristic of under sleeper pads (USPs), which are the component installed under the concrete sleepers generally to improve railway track resilience. The field trial is aimed at mitigating rail joint impacts in a heavy haul track under mixed traffics. 'Big Data', obtained from both the track inspection vehicle and the sensors installed on tracks, demonstrate that track surface quality (top) of the section was improved after the track reconstruction. Fourier analysis results showed that the track surface (or vertical deviation) tends to deform at larger displacement amplitude and resonates at a lower wavelength of track roughness. Interestingly, the operational pass-by vibration measurements show that the USPs has resulted in an increased vibration of both rail and sleeper with USPs. Although the studies have found that the sleepers with USPs tend to have lesser flexures, the field data also confirms that a railway track with USPs could experience a large amplitude vibration, especially when excited by a high-frequency impact force. These dynamic behaviours imply that the use of soft to moderate USP could potentially induce dilation of ballast whilst the use of hard USP may reduce sleeper-ballast friction. In the end, these could then weaken lateral track stability over time.

Peer-review under responsibility of the scientific committee of the International conference on Transportation Geotechnics and Geoecology

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## 1. Introduction

Ballasted railway tracks are popularly built for traditional suburban and urban rail networks globally. Its benefits include low capital investment, high resilience, high maintainability and constructability, high level of vibration absorption and so on. There are two groups of track components: superstructure and substructure. Superstructure components include rail, fastening system, sleeper, under sleeper pad, ballast and ballast mat; while substructure counterparts are subballast, formation, geotextiles and foundation. Under sleeper pads (USP) are resilient pads installed on the soffit of sleepers as an attachment to provide additional track resiliency between the sleepers and ballast. Fig. 1 shows a typical cross section of the ballasted railway track with under sleeper pad. In recent years, USP has been used widely and heavily in central Europe such as in Austria, Czech Republic and Germany. Additionally, several counties have carried out pilot trials such as in Sweden, Australia, and China. USP is made of polyurethane elastomer with a foam structure including encapsulated air voids. Three common objectives for installing USP are to moderate track stiffness; to reduce ground vibrations; and to reduce ballast breakage. USPs could reduce track stiffness in special areas such as turnout systems (switches and crossings) or tracks on bridge viaducts. The vibration of sleepers could also be isolated by the USP so that the ballast and formation are uncoupled from the wheel/rail interaction, reducing the ground vibrations affecting surrounding buildings and structures. The reduced ballast damage is accomplished by a reduction of contact pressure, and thus wears, in the sleeper/ballast interface. A more uniform load distribution is achieved by the use of USP, resulting in the reduction of the contact pressure and the smaller variations of support stiffness along the track. An application of USPs in Australia was initially trailed back in 1980s on open plain tracks. The outcome showed little improvement at the time whilst the delamination and degradation of the USP material were the key negative issues found in the field [1-6].

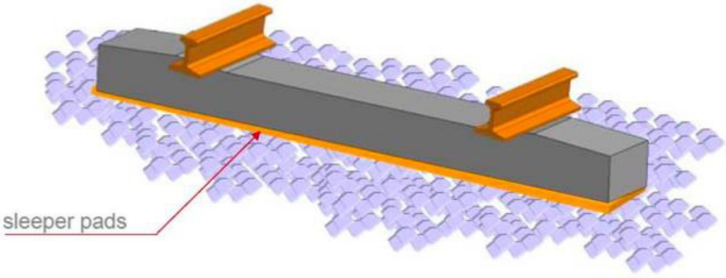


Fig. 1. Under sleeper pads [7].

**Nomenclature**

| | |
|---|---|
| $2\alpha$ | Total joint angle or equivalent dip angle (radian) |
| $C_t$ | Equivalent track damping (kNs/m) |
| $K_t$ | Equivalent track stiffness (MN/m) |
| $M_t$ | Equivalent track mass (kg) |
| $P_0$ | Static vehicle wheel force (kN) |
| $P_2$ | Dynamic vertical force (kN) |
| $M_u$ | Vehicle unsprung mass per wheel (kg) |
| $v$ | Train velocity (m/s) |
| UBM | Under ballast mat |
| USP | Under sleeper pad |

In recent years, the performance of the USPs has been improved through the outcomes from the test results in central Europe and in Austria, which show a promising quality and durability of USPs. Note that contradict outcome has been reported by Trafikverkets (Swedish Transport Administration). After several years of field tests, Trafikverkets reported that there has been no or very little influence of USPs on track quality improvement [8]. However, the utilisation of USPs is not significant globally. Recently, a leaflet for engineering guideline for USPs has been introduced by International Union of Railway (UIC). It is found that most of the tests on the leaflet were mostly benchmarked with tests in Europe. Most of the USP usages were mainly based on trial conditions and its performance does not have a long track history record. Many theoretical studies and some field trials in Austria and France suggest that the added resiliency by USPs will attenuate impact and excessive vibration. Consequently, it is worthwhile to trial such technology in problematic areas, for example at locations with rail surface defects, dipped joints, spark erosions, or other discontinuities in rail running surface [7]. In fact, there has never been a field trail to evaluate USP performance on short-wavelength track defects. Accordingly, a test plan for USPs has been introduced in New South Wales, Australia in order to attenuate impact vibrations at dipped rails/welds and at a glue insulated joint (GIJ) with spark erosion. Similar to other resilient mats, the USP stiffness has been designed to accommodate the differences in track properties and operational parameters [9-12].

The emphasis of USP development has been initially placed on the ballasted tracks for highspeed trains where they induce high dynamic forces onto the track. The ballast could be damaged and densified by this impulsive force. So it is necessary to introduce additional elasticity in the highspeed track, but on the other hand the rail deflection should be controlled to avoid rail breaking. In general, the elasticity can be inserted between rail and sleeper (e.g. rail pads, elastomeric pads), or between base plate and sleeper, or between sleeper and ballast (i.e. USP), or between ballast and subgrade (i.e. ballast mat, shock mat). It is important to note that special care must be taken about the contribution of the elasticity to these single parts because trade-off effects may incur. In Europe, it has been reported that the under sleeper pads (USP) in high speed tracks yield an effective solution combining technical and economic efficiency. Table 1 displays a classification of the USP stiffness introduced by UIC [13].

This study focuses on the consideration of using the under sleeper pads (USPs) in order to suppress vibration at rail joints. It involves the standard and specification reviews, literature review of the performance of USPs, and field data measurements. The outcome of this study will help track engineer applying the USPS in concrete sleepers and bearers at a critical location where is prone to excessive impact and vibration such as insulated joints, in-bearers, rail surface defect locations, turnout crossings and so on.

Table 1. Under sleeper pads.

| USP | Stiffness | In practice |
|---|---|---|
| Stiff | $0.25\ \text{N/mm}^3 < c_{stat} \leq 0.35\ \text{N/mm}^3$ | (heavy rail) |
| Medium stiff | $0.15\ \text{N/mm}^3 < c_{stat} \leq 0.25\ \text{N/mm}^3$ | (light rail) |
| Soft | $0.10\ \text{N/mm}^3 < c_{stat} \leq 0.15\ \text{N/mm}^3$ | (not commonly use) |
| Very soft | $c_{stat} \leq 0.10\ \text{N/mm}^3$ | (not commonly use) |

## 2. Dynamic Force at Rail Joints

The problem related to dynamic impact forces due to dipped welds and spark erosions at glued insulated joints have considerably increased the demand for additional track maintenance and become a main cause undermining public safety and operational reliability. For example, the unplanned maintenance tasks cost railway authorities significantly, e.g. £200m annually in the U.K. The wheel that transverses such dipped geometry (e.g. bad weld alignment or spark erosion at GIJ) will impart the substantial dynamic transient forces as illustrated in Fig. 2. The dynamic content that is associated to structural damage is often called $P_2$. This force should be minimized or suppressed to extend the longevity of railway tracks. On this ground, USPs have been designed for impact vibration suppression at either rail joints or glue insulated joints in this field study. It should be noted that the USPs have similar service life as the sleepers do (about 50 years). Equivalent dip angle can also be measured and used in the $P_2$ prediction formula [14-18]:

Fig. 2. Wheel-rail trajectory over a dipped rail joint.

$$P_2 = P_0 + 2\alpha v \left[\frac{M_U}{M_U+M_T}\right]^{\frac{1}{2}} \left[1 - \frac{\pi C_t}{4\sqrt{K_t(M_U+M_T)}}\right] [K_t M_U]^{\frac{1}{2}} \tag{1}$$

## 3. Field Test

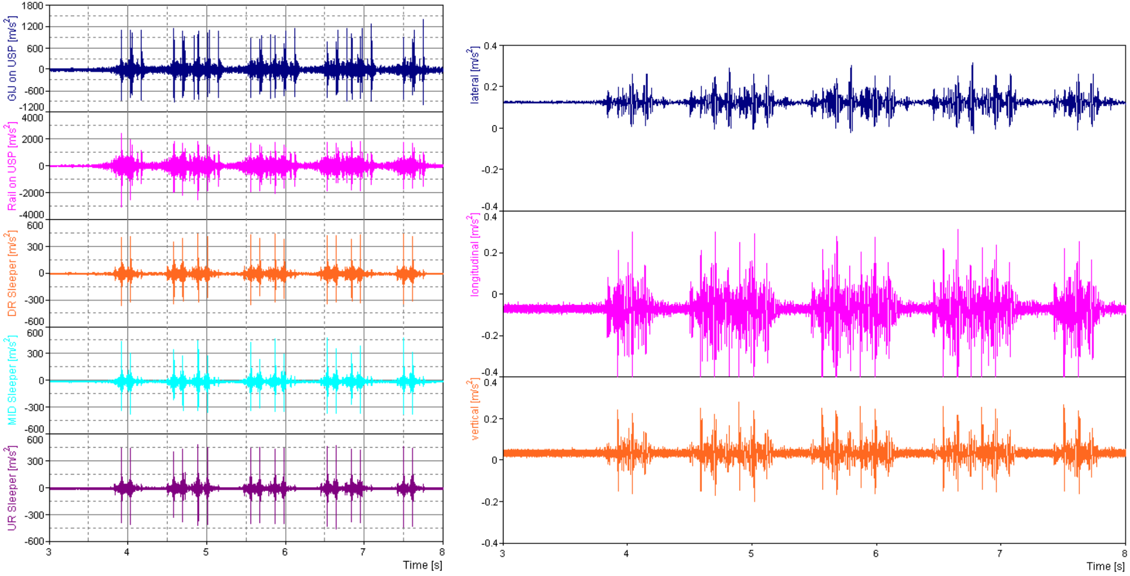
The USPs with moderate stiffness have been chosen so that they could suppress impact vibration without a special requirement for track stiffness transitions. The dimension of the USPs was selected based on the local track stiffness, maintainability and constructability. Based on a finite element analysis of track deformation [7, 19-22], six sleepers in and six sleepers out of the joints need to be fitted with USPs to improve the ride condition over the irregular joint geometry, as well as to provide itself the track stiffness ramp moderation. In this field test, the USPs were kindly supplied by Getzner [23]. The USPs (SLB 2210 10mm thick) has been installed on concrete sleepers using arodite adhesion (see Fig. 3). A location at Austimer (Illawarra Line in NSW Australia) was selected as the test site and the USPs were installed on track late 2011.

Fig. 3. Field test installation.

## 4. Field Measurement Results

The vibration measurements have been carried out after 6 months under revenue services [10]. Fig. 4 shows the measurement instrumentation at the test sites. Two locations were investigated: at the interface between USP and ordinary tracks; and at the GIJs. The measurement campaigns have been carried out to investigate the parametric effects on dynamic track behaviour such as train speeds, rail joint condition, sleeper and ballast contact, etc. In this paper, the vibration due to a passenger shuttle train running pass by is analysed to demonstrate track vibration attenuation. The train was travelling up direction and Fig. 5 displays the vibration signals of track components. In the measurement, we can observe that the vibrations of track components with USPs tend to be higher than those without USPs. The vibration suppression through under sleeper pads can be demonstrated in Fig. 5. It is found that USPs could significantly attenuate transient waves but at a cost of higher sleeper and rail vibrations.

Fig. 4. Field measurements.



a) rail and sleeper vibrations

b) ballast vibrations (at 300mm under sleeper surface)

Fig. 5. Vibration attenuation through under sleeper pads.

## 5. Conclusion

Under sleeper pads (USPs) are a new insertion component installed under the concrete sleepers generally to improve railway track resilience. Positive outcomes from the initial field tests in Europe have motivated the use of USPs around the world. It is important to note that the component has commonly been used for certain applications, mainly to moderate track stiffness in special locations such as turnouts, crossings, and level crossing. On this ground, the use of USPs to attenuate track vibration at rail joints is presented here. Based on the operational pass-by vibration records, it is found that the USPs has resulted in an increased vibration of both rail and sleeper with USPs. The field data also confirms that a railway track with USPs could experience a large amplitude vibration, especially when excited by a high-frequency impact force. These results imply that the use of USPs to alleviate dynamics onto track substructure is a trade-off measure that could increase noise radiations of other track components and cause excessive ballast dilation, resulting weakening track lateral resistance. Also, stiff USPs may not be effective in ground-borne vibration mitigation if the soil itself can be dynamically amplified by ground excitations.

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