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Under sleeper pads: field investigation of their role in detrimental impact mitigation

Sakdirat Kaewunruen

University of Birmingham, sakdirat@hotmail.com

Alex M. Remennikov

University of Wollongong, alexrem@uow.edu.au

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Abstract

Under sleeper pads (USPs) are the component installed under the concrete sleepers generally to improve railway track resilience. Initial development in Europe, particularly in Austria, has encouraged the adoption of the component around the world. In practice, the component has commonly been used in certain applications, mainly to moderate track stiffness in special locations such as turnouts, crossings, and level crossing. In heavy haul operation, the heavier wagons result in sturdier bogie structures, higher unsprung mass, and then higher level of wheel-rail interaction forces. Accordingly, the application of USPs to mitigate detrimental impact load consequence on track structure is presented in this paper. A field trial aimed at mitigating rail joint impacts using the USPs with a thickness of 10mm and bedding modulus of 0.2 N/mm³ has been conducted in NSW Australia since October 2011. It was found that the track structure and its heavy-duty components were designed to cater heavy load burden of 30t axle load with rail pad stiffness of 800 MN/m (HDPE pads). '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 resiliency of 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 behaviours imply that the use of USPs to alleviate the impact force onto track substructure is a trade-off measure that could aggravate noise radiation due to track components.

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UNDER SLEEPER PADS: FIELD INVESTIGATION OF THEIR ROLE IN DETRIMENTAL IMPACT MITIGATION

Sakdirat Kaewunruen¹ and Alex M. Remennikov²

¹ Birmingham Centre for Railway Research and Education, School of Civil Engineering
The University of Birmingham, Edgbaston, B15 2TT UK
e-mail: s.kaewunruen@bham.ac.uk

² School of Civil, Mining, and Environmental Engineering
University of Wollongong, Northfield Ave, Wollongong, NSW 2522 Australia
e-mail: alexrem@uow.edu.au

KEYWORDS: Under sleeper pads; Track components; Railway infrastructure; Rail joints; Impact vibration; Suppression

ABSTRACT

Under sleeper pads (USPs) are the component installed under the concrete sleepers generally to improve railway track resilience. Initial development in Europe, particularly in Austria, has encouraged the adoption of the component around the world. In practice, the component has commonly been used in certain applications, mainly to moderate track stiffness in special locations such as turnouts, crossings, and level crossing. In heavy haul operation, the heavier wagons result in sturdier bogie structures, higher unsprung mass, and then higher level of wheel-rail interaction forces. Accordingly, the application of USPs to mitigate detrimental impact load consequence on track structure is presented in this paper. A field trial aimed at mitigating rail joint impacts using the USPs with a thickness of 10mm and bedding modulus of 0.2 N/mm^3 has been conducted in NSW Australia since October 2011. It was found that the track structure and its heavy-duty components were designed to cater heavy load burden of 30t axle load with rail pad stiffness of 800 MN/m (HDPE pads). '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 resiliency of 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 behaviours imply that the use of USPs to alleviate the impact force onto track substructure is a trade-off measure that could aggravate noise radiation due to track components.

INTRODUCTION

Under sleeper pads (USP) are resilient pads attached to the soffit of sleepers to provide resiliency between the sleepers and ballast. Figure 1 shows a typical cross section of the ballasted railway track with under sleeper pad. In recent years, USP has been used heavily in central Europe. USP is made of polyurethane elastomer with a foam structure including encapsulated air voids. Two common objectives for installing USP are to reduce ground vibrations and to reduce ballast breakage. The vibration of sleepers could 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].

In recent years, the performance of the USPs has been improved. The test results in central Europe and in Austria show a promising quality and durability of USPs. However, the utilisation of USPs is not significant. At present, there is no unified engineering specification for USPs, except for Austria. It is also found that most of the tests were mostly benchmarked with the concrete sleepers and track properties in Europe. Reportedly, most of the USP usages are mainly based on trial conditions only and its performance does not have a long track 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].

Accordingly, a new application of USP has recently 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 can be designed to accommodate the differences in track properties and operational parameters [8-11].

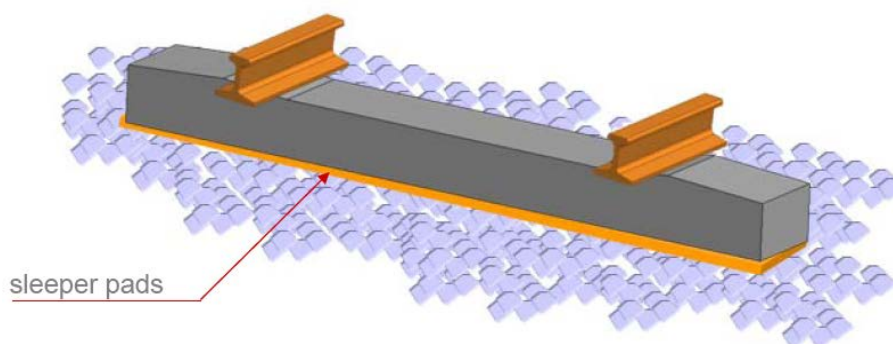


Figure 1: Under sleeper pad

The USP development has been initially focussed on the ballasted tracks for high speed 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 high speed 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.



Figure 2: Gluing System using adhesion (courtesy: DelkorRail)

The USPs developed by Getzner, are made of foamed polyurethane with high mechanical stability. They cover the bottom side of the sleeper and this method saves costs and the resilient material is placed exclusively onto the loaded area where it is used. There are two methods of gluing systems. In the past, the pads were glued onto the sleepers (see Figure 2). However, it was reported that this method sometimes leads to technical problems. Another method of gluing is to attach the pad to sleeper during the production process of the sleeper (concrete setting period). A special steel grid, which is attached to the pad, is embedded in fresh concrete. This provides high-resistance connection between sleeper and pad with longer time stability. The padded sleepers (as shown in Figure 3) can be handled in construction and maintenance activities in a usual way. This could save time and importantly cost. In addition, the under sleeper pads could be used in either slab tracks and ballasted tracks.



Figure 3: Padded sleeper (courtesy: DelkorRail)



Figure 4: USP with indentations (courtesy: RailCorp)

This technical investigation focuses on the consideration of using the under sleeper pads (USPs) in order to increase resiliency for impact vibration mitigation. This study involves the standard and specification reviews, literature review of the performance of USPs, and field data measurements. This study is aimed at 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.

ENGINEERING PERFORMANCE

The bottom part of the USPs is usually subjected to the high angular stress and strain from granular ballast. The resiliency of USPs reduces the angular stress and allows the ballast to bite in, resulting in a higher friction between ballast and sleeper, as illustrated in Figure 4. Subsequently, lateral track resistance can be improved and the risk of track buckling or misalignment due to heat, breaking, pulling and longitudinal train forces can be reduced. The elastic resilience yields a more uniform global track deformation under loads and then it increases the pressure distribution area of track support layers, as shown in Figure 5 [12]. The ballast pressure could therefore be reduced more than 10-25%.

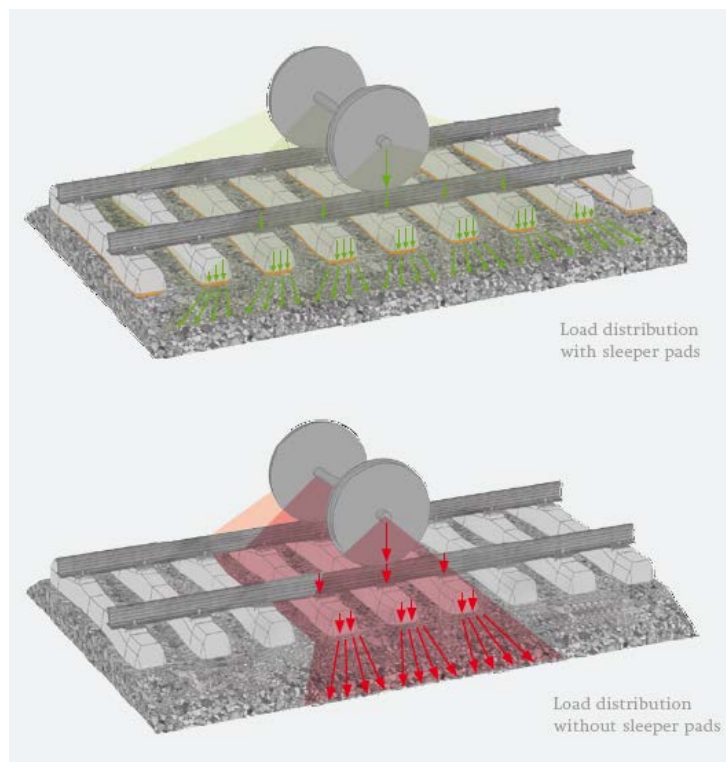


Figure 5: Pressure distribution with USP [12]

The advantages of using under sleeper pads in ballasted tracks include:

- Vibration isolation
- Protection of ballast
- Stabilisation of track geometry
- Reduction of rail corrugation
- Adjustment of track stiffness.

A classification of the USP stiffness has been introduced by UIC [13] as follows:

USP	Stiffness
Stiff	$0.25 \text{ N/mm}^3 < c_{\text{stat}} \leq 0.35 \text{ N/mm}^3$
Medium stiff	$0.15 \text{ N/mm}^3 < c_{\text{stat}} \leq 0.25 \text{ N/mm}^3$
Soft	$0.10 \text{ N/mm}^3 < c_{\text{stat}} \leq 0.15 \text{ N/mm}^3$
Very soft	$c_{\text{stat}} \leq 0.10 \text{ N/mm}^3$

INTERNATIONAL EXPERIENCE

According to a critical literature review and rail industry data, USPs have been developed and manufactured in Europe. Currently, there is somewhat limited information for practitioners to design and use the components in railway tracks. Its utilisations are based mostly on a conditional approval for trials.

Usage in Austria:

Since 1994, Austrian Federal Railway (OBB) has implemented four trial locations, e.g. Nuziders, Hieflau, Riedau, and Neusiedl. The USPs were used in either tangent or curved tracks on embankments. It was claimed to help reduce rail corrugations (see Figure 6), to absorb vibration, and to get less track settlement.

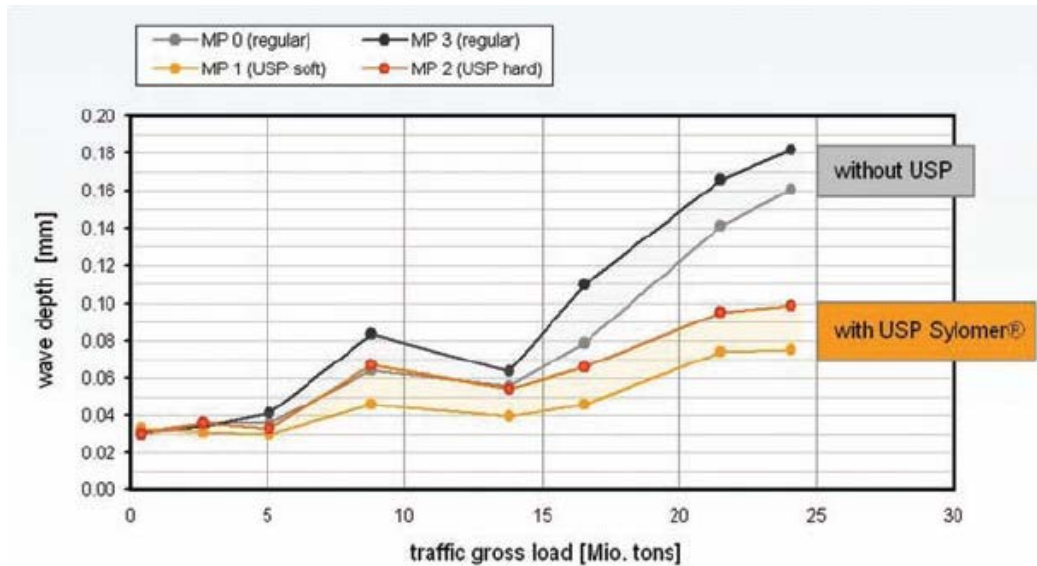


Figure 6: Rail corrugation amplitude reduction (Getzner, 2014)

Usage in Denmark:

The use of USPs in Denmark was limited to tangent tracks in cutting in 1996. The aim was to isolate excessive vibration from tracks to rock cutting. The trial of USPs was implemented on the 6.6 km track section in Copenhagen, by Oresund Consortium.

Usage in Germany:

A trial track at Waghausen has adopted the USPs in track by German Railways (DB AG) since August 1996. This track has been built for operating high speed trains. The aim of this trial on a 200 m track section on embankment was to suppress noise and vibration.

Usage in Korea:

In 1998, Korean National Railways has applied the USPs for impact reduction on a bridge. This trial was implemented on a 460 m long ballast top bridge.

Usage in Norway:

Since 1990, three trial locations in Hotel Plaza (384 m), Gronland Torq (444 m), and Sandvika (260 m) have been implemented the USPs in order to isolate the vibrations, by Norwegian Federal Railways. Two of them are in underground tunnels and the other is at a train station.

Up to date, most of the current uses of USPs are only in trial phase. Although there is no specific engineering standard, the use of USPs has become popular in Europe because the negative effect could be avoided by considering the suitable track structures and locations. UIC (International Union of Railway) has introduced a draft of recommendations for the use of the under sleeper pads based on the positive results tested in European railways. The main fields of recommendations by UIC [13] are:

Applications	Main Line with normal platform ($c_{stat} = 0.1 \text{ N/mm}^3$)*	Main Line with hard platform ($c_{stat} = 0.3 \text{ N/mm}^3$)*
Improve track quality	$c_{stat} \pm 15\%$	$c_{stat} \pm 20\%$
Reduce long pitch corrugation; Reduce ground borne vibration	$c_{stat} \pm 10\%$	$c_{stat} \pm 20\%$
Transition zone	$c_{stat} \pm 7\%$	$c_{stat} \pm 10\%$

* c_{stat} is static bed modulus

IMPACT MITIGATION AT RAIL JOINTS

In this field trial, the USPs were glued to existing sleepers or bearers. Its depth of about 8-10 mm additional to the sleeper depth allows the tamping machine to operate as usual. The USP characteristics have been designed and the component material was chosen so that the track stability is not undermined. The USPs have shown strong benefits in impact and vibration mitigation for railway tracks. In RailCorp network (New South Wales, Australia), the problem related to 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. The wheel that transverses such dipped geometry (e.g. bad weld alignment or spark erosion at GIJ) will impart the substantial impact forces as illustrated in Figure 7. On this ground, USPs have been designed for impact mitigation at either rail joints or glue insulated joints in this field study. It should be noted that the USPs can last as much as the sleepers do (about 50 years in Australia).

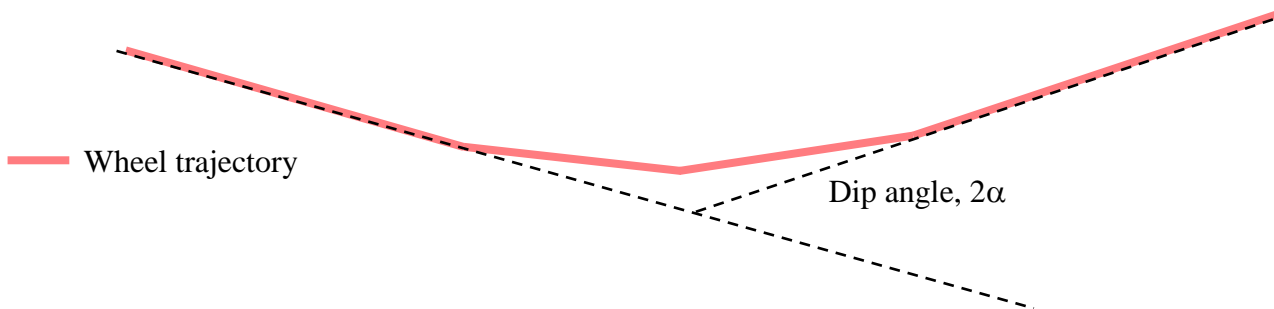


Figure 7: Wheel trajectory over dipped rail geometry

Equivalent dip angle can also be predicted and later used in the P_2 prediction formula [14-18]:

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

where

- P_2 = Dynamic vertical force (kN)
- P_0 = Vehicle static wheel load (kN)
- M_u = Vehicle unstrung mass per wheel (kg)
- 2α = Total joint angle or equivalent dip angle (rad)
- v = Vehicle velocity (m/s)
- K_t = Equivalent track stiffness (MN/m)
- C_t = Equivalent track damping (kNs/m)
- M_t = Equivalent track mass (kg)

Some plain track parameters can be used as follows:

Track Class	Max P2 force Locomotives (KN)	Max P2 force other rolling stock (KN)	Equivalent Track Stiffness Kt (MN/m)	Equivalent Track Damping Ct (kNs/m)	Equivalent Track Mass Mt (kg)
1	295	230	110	52.5	135
2	230	230	100	48	117

The USPs with moderate stiffness have been chosen so that they could suppress impact vibration without a requirement for track stiffness transitions. The dimension of the USPs is selected based on the track stiffness, maintainability and constructability. Based on a finite element analysis of track deformation (Kaewunruen, 2010), 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 a stiffness ramp moderation. In this trial, the USPs was supplied by Getzner. The USPs (SLB 2210 10mm thick) has been installed on concrete sleepers using arodite adhesion (see Figure 8). A location at Austimer (Illawarra Line in NSW Australia) was selected as the test site and the USPs were installed on track in October 2011 (see Figure 9).



Figure 8: Newly glued USPs



Figure 9: Installation of USPs at GIJs

TRACK GEOMETRIC PERFORMANCE

Track patrol vehicle (AK Car) has recorded the condition of track in this section over the years as part of track condition monitoring. Figure 10 shows the track condition or quality of track parameters. It is found that overall track geometric parameters have been improved after the USP installation and the track reconstruction in October 2011.

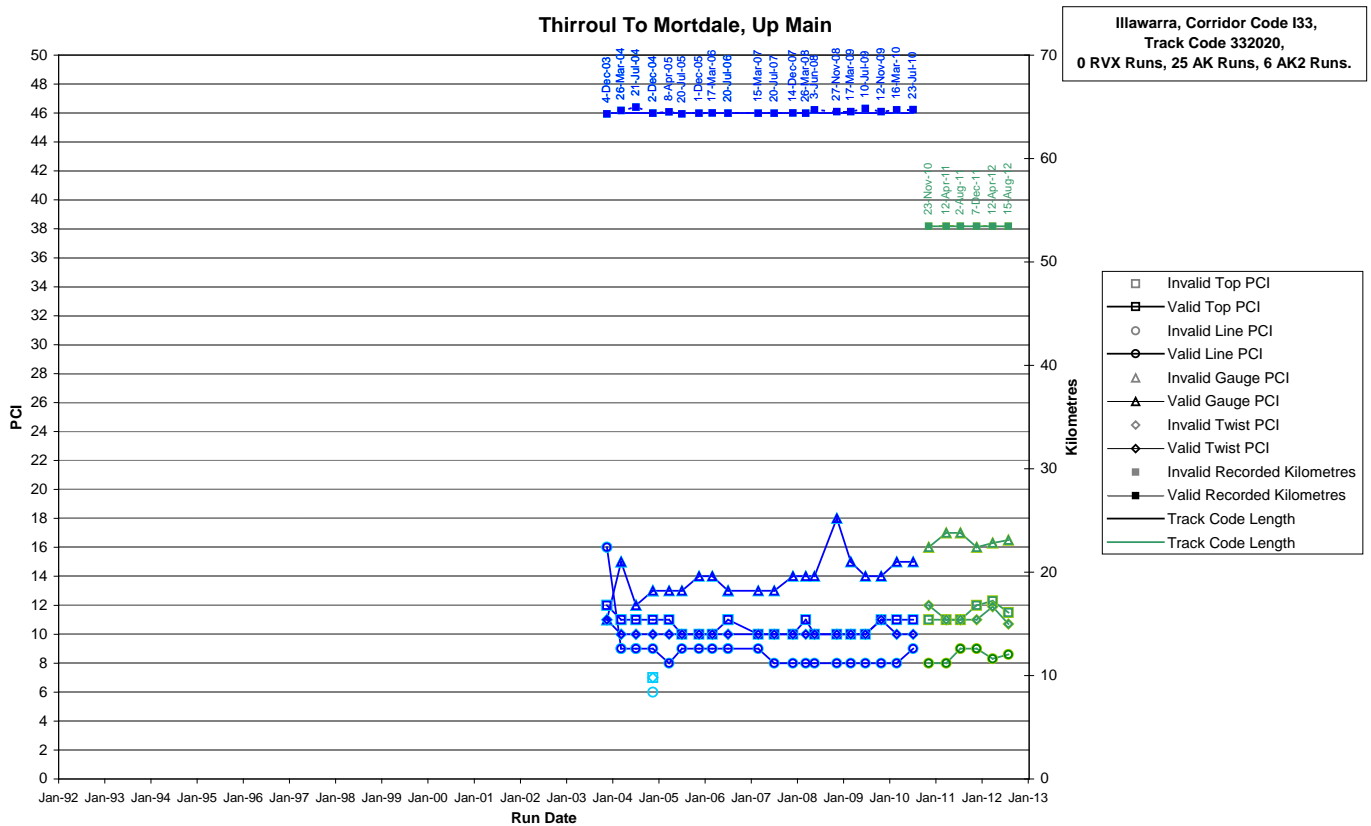
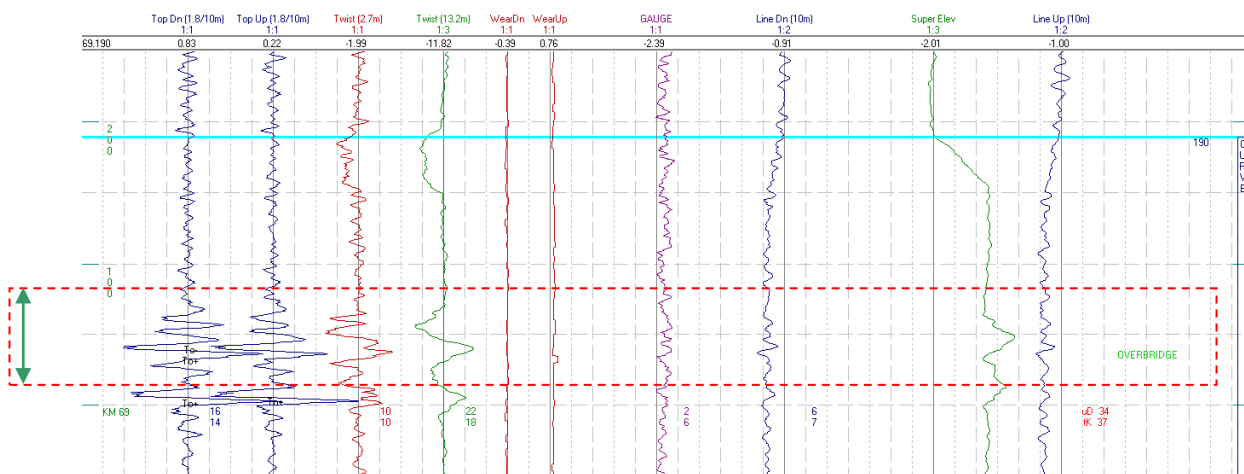


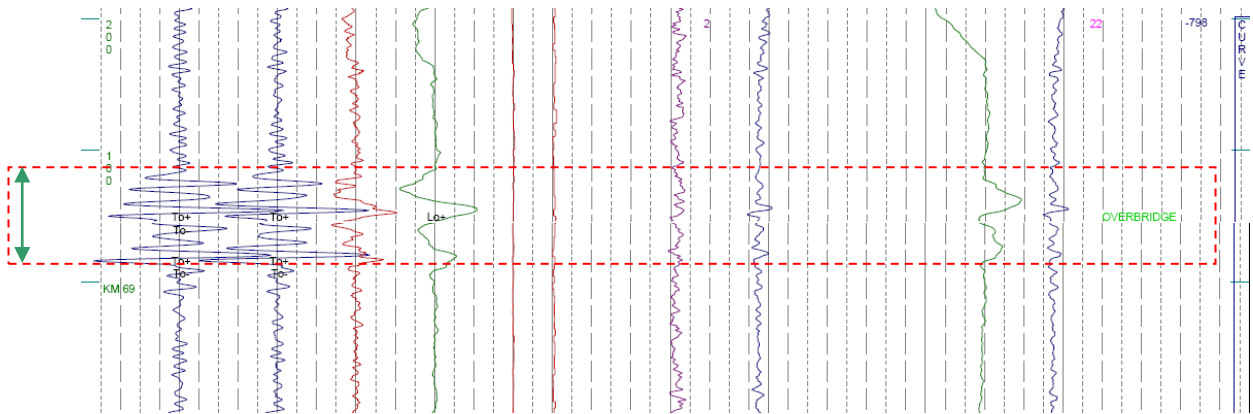
Figure 10: Track condition index Up Illawarra Main

The AK Car geometry data has been collected in order to re-affirm the recorded location of tracks as shown in Figure 11. It is noticeable that the geometry indicators show a promising performance after the renewal of the tracks. The track location records are found to be consistent (max 5-10m different). To gain consistency, Top 1.8/10m and Line 10m will be focused [19]. It is noticeable from Figure 11 that the top and line of the track section has been improved after the track reconstruction.

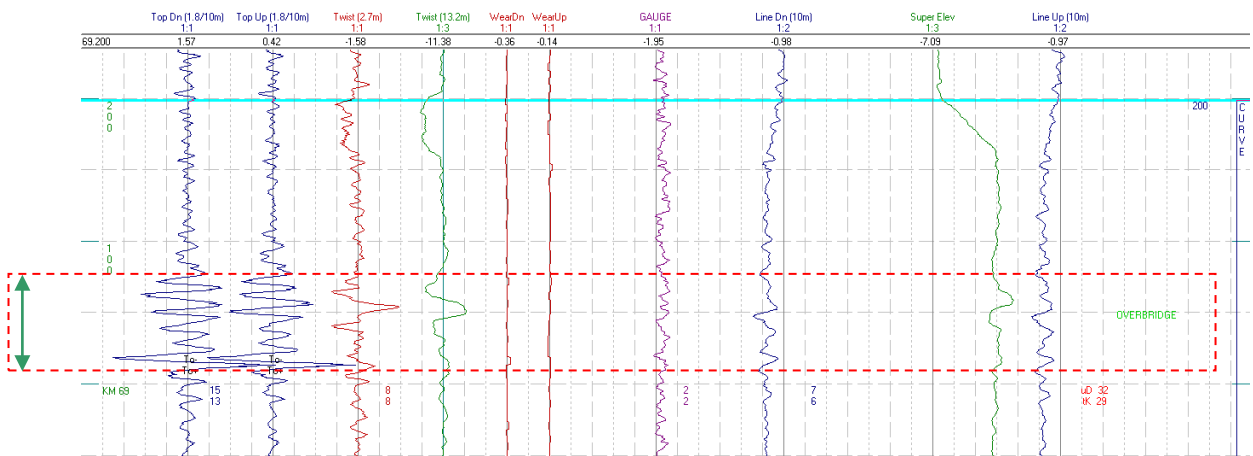


a) Record on 23 Nov 2010 at km69.064 (just before renewal)

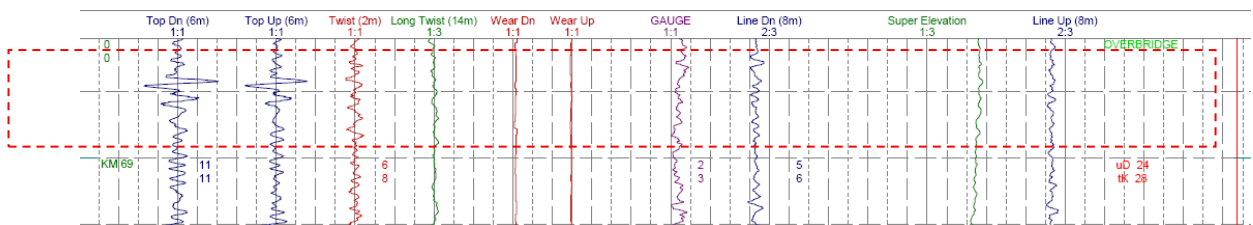
Figure 11: AK Car geometry data



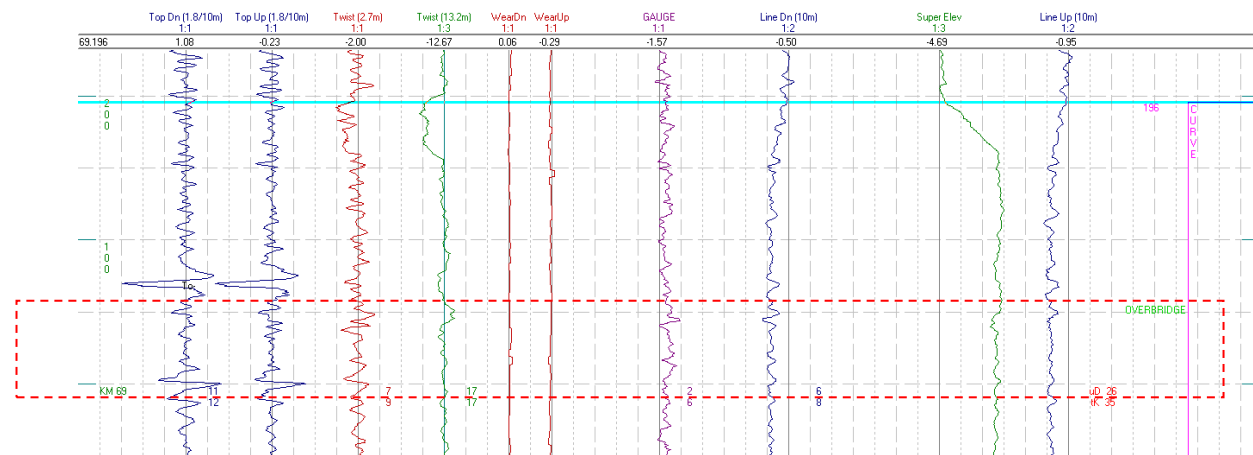
b) Record on 12 Apr 2011 at km69.064 (just before renewal)



c) Record on 02 Aug 2011 at km69.064 (just before renewal)

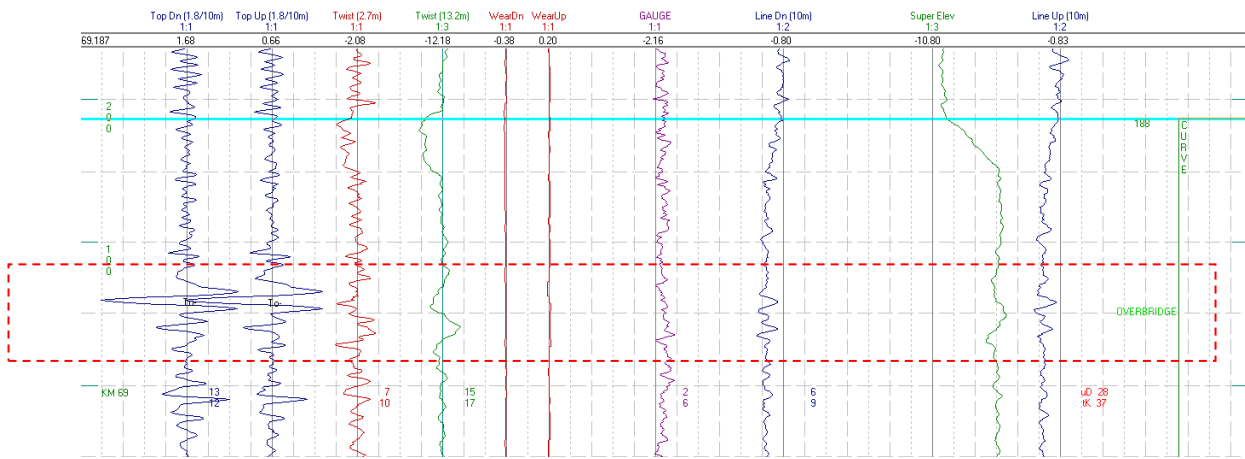


d) Record on 07 Dec 2011 at km69.064 (after renewal)

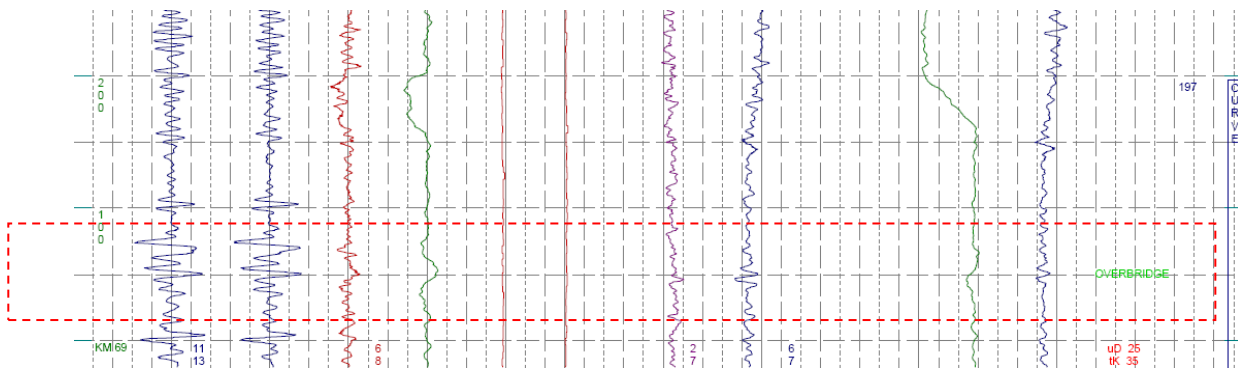


e) Record on 12 April 2012 at km69.064 (after renewal)

Figure 11: AK Car geometry data



f) Record on 15 Aug 2012 at km69.064 (after renewal)



g) Record on 12 Dec 2012 at km69.064 (after renewal)

Figure 11: AK Car geometry data

FIELD CONDITION MONITORING

The visual inspections were first carried out in May 2012 in conjunction with the vibration measurement. It was also found that there was no sign of ballast pulverisation or breakage in the area as shown in Figures 12 and 13. In comparison, Figure 14 suggests some soffit abrasion of concrete sleepers without USPs.



Figure 12: General condition of the USP track

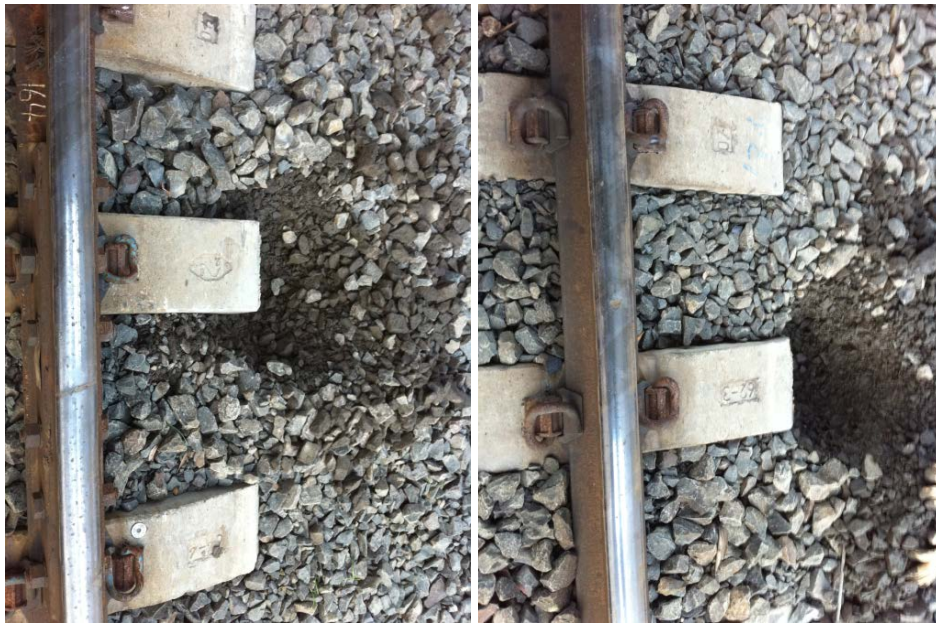


Figure 13: USP and ballast inspection



Figure 14: Abraded sleeper soffit (location adjacent to the test site)

FIELD MEASUREMENTS

The vibration measurements were carried out in early May 2012. Figures 15 and 16 show the measurement plan and instrumentation at the test sites. Two locations were investigated: at the interface between USP and ordinary tracks; and at the GIJs.

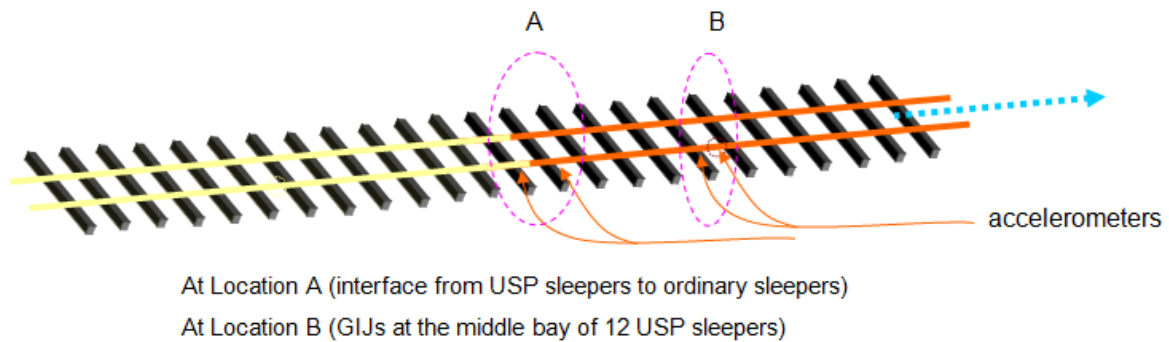


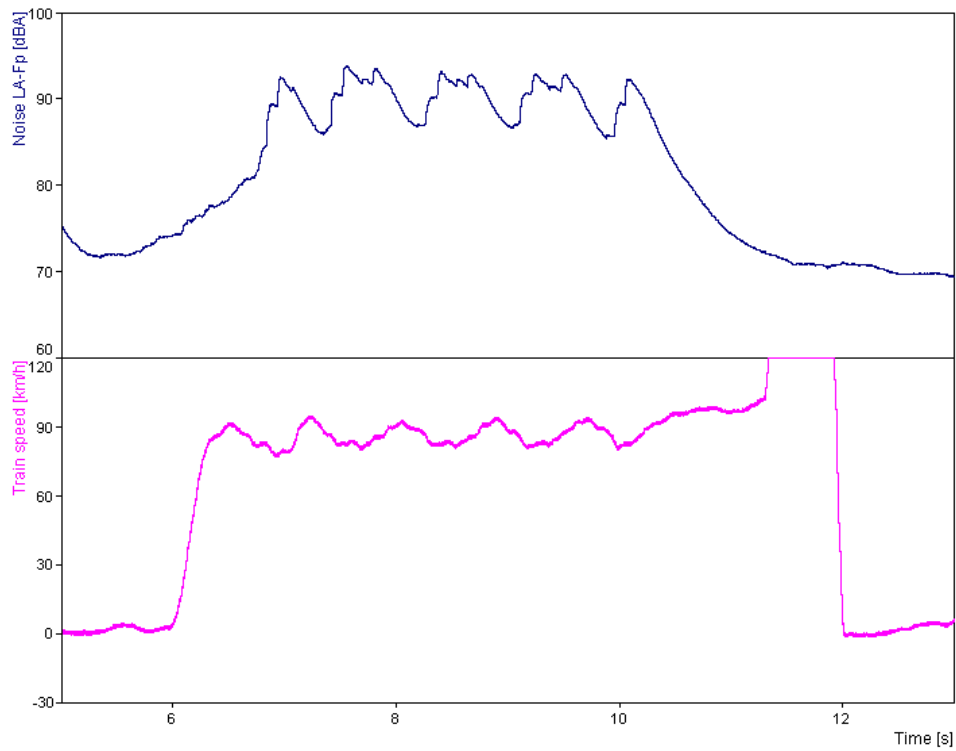
Figure 15: Acceleration measurements for a site



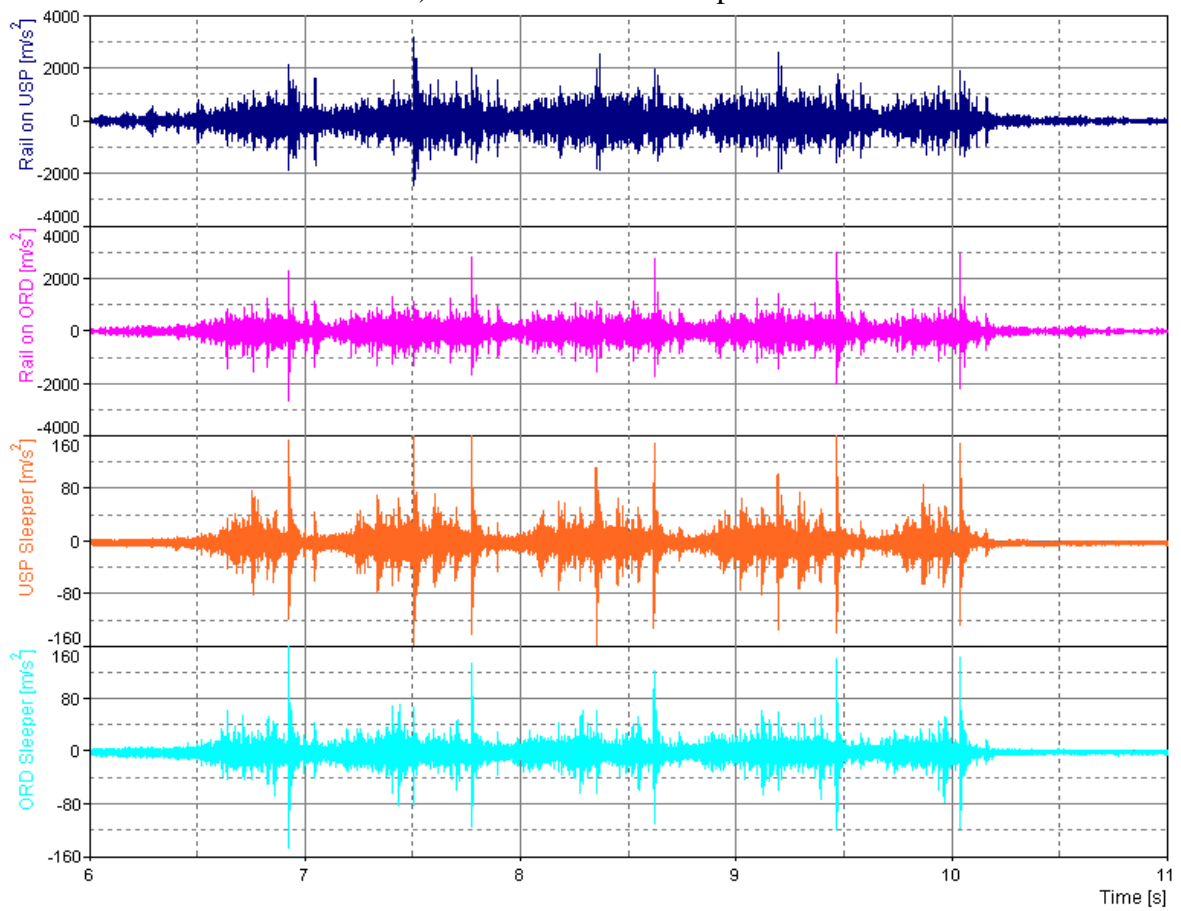
Figure 16: Instrumentations at the test site (accelerometers, deflectometers, speed radars, microphone array, high-speed camera)

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 (Oscar – File No 6) running pass by is used to demonstrate track dynamics. The train was travelling up direction on the Illawarra Main and Figure 17 display the vibration data of track components.

Figure 17 and other data [8] show that in general, the vibrations of track components with USPs tend to be higher than those without USPs. The speed effect is clearly pronounced on the impact vibration: as the speed increases, the vibration increases. Interestingly, the sleeper vibrations at Location B are observed to be at similar phases between the mid span's and the rail seats' sleeper vibrations - implying a lesser dynamic flexural bending moment when USPs are used in a track.

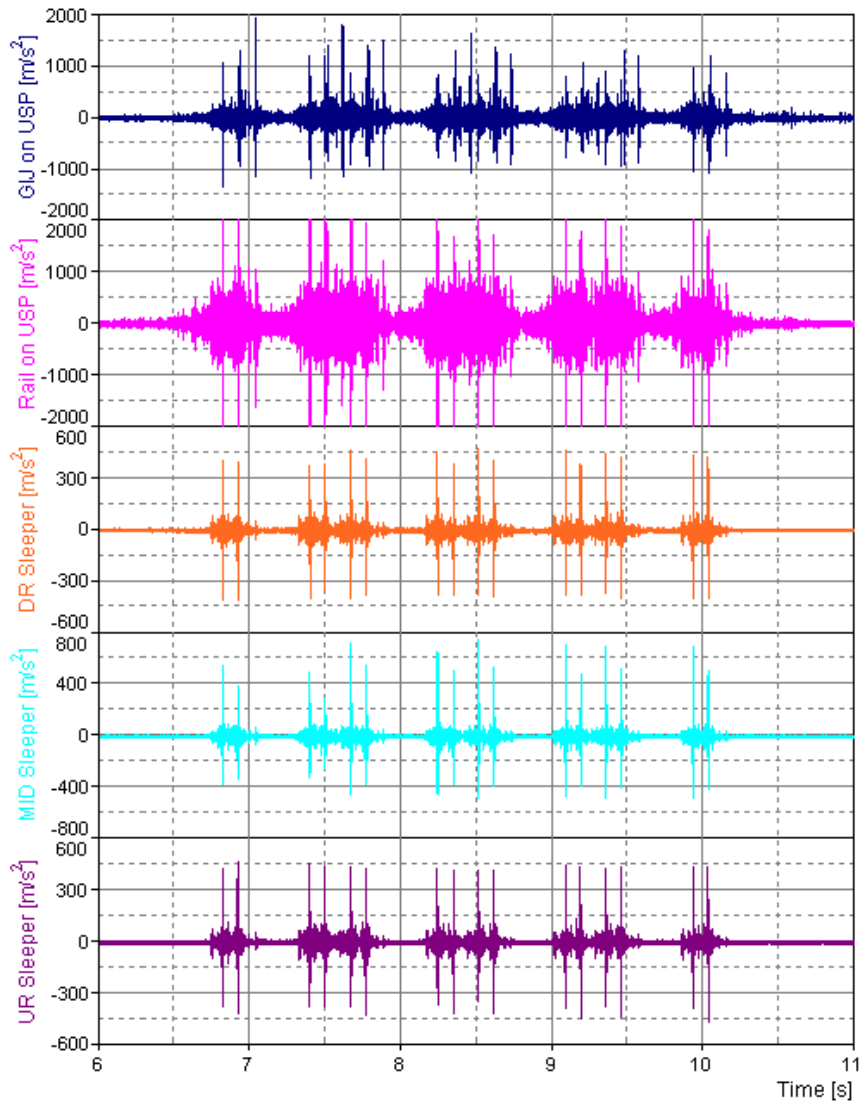


a) noise level and train speed

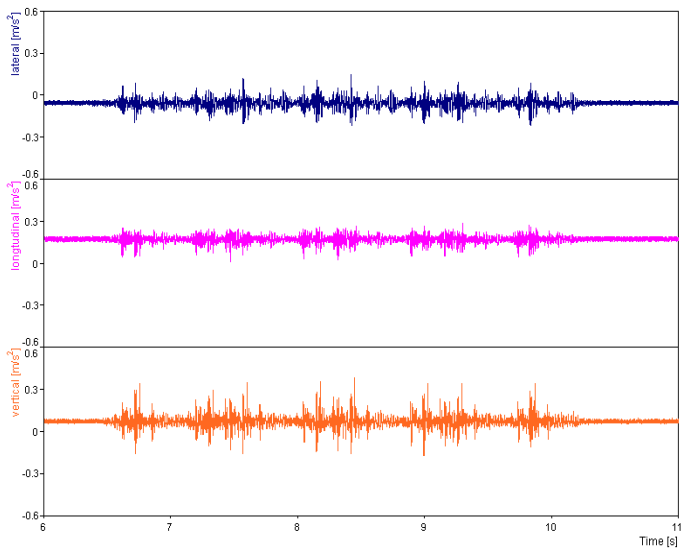


b) vibrations at location A

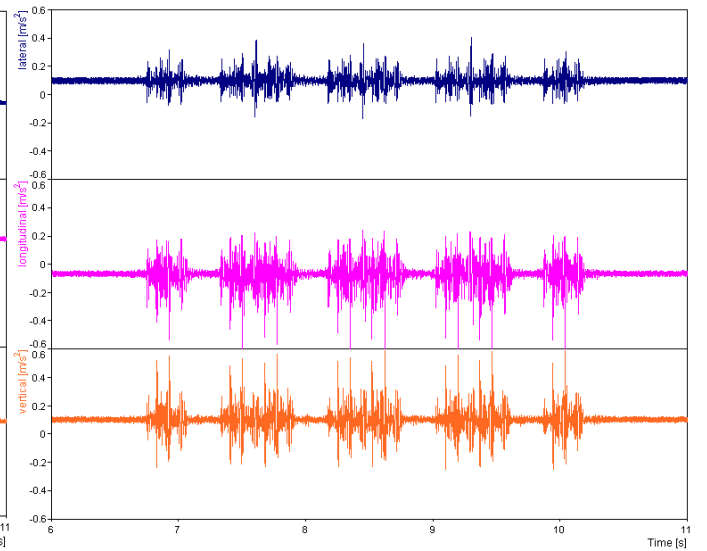
Figure 17: Passenger shuttle train - Oscar (File No 6)



c) vibrations at location B



d) ballast vibration at A



e) ballast vibration at B

Figure 17: Passenger shuttle train - Oscar (File No 6)

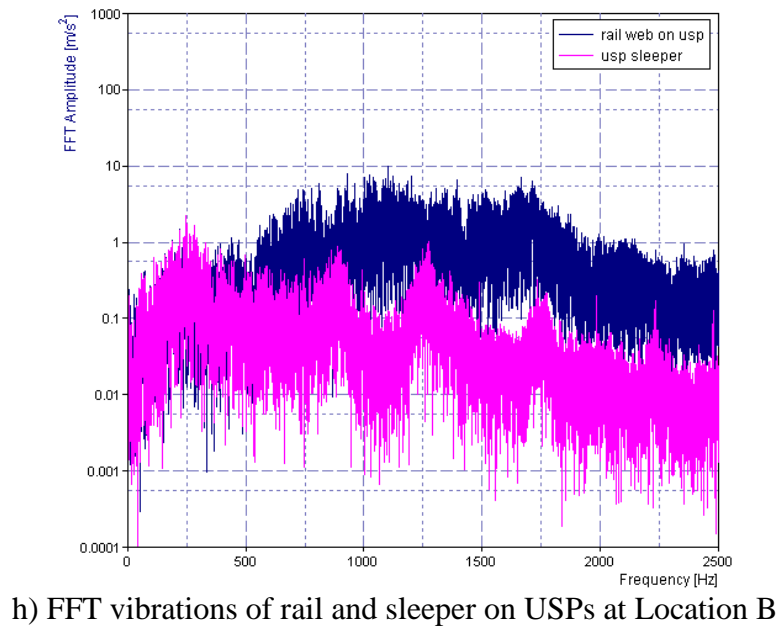
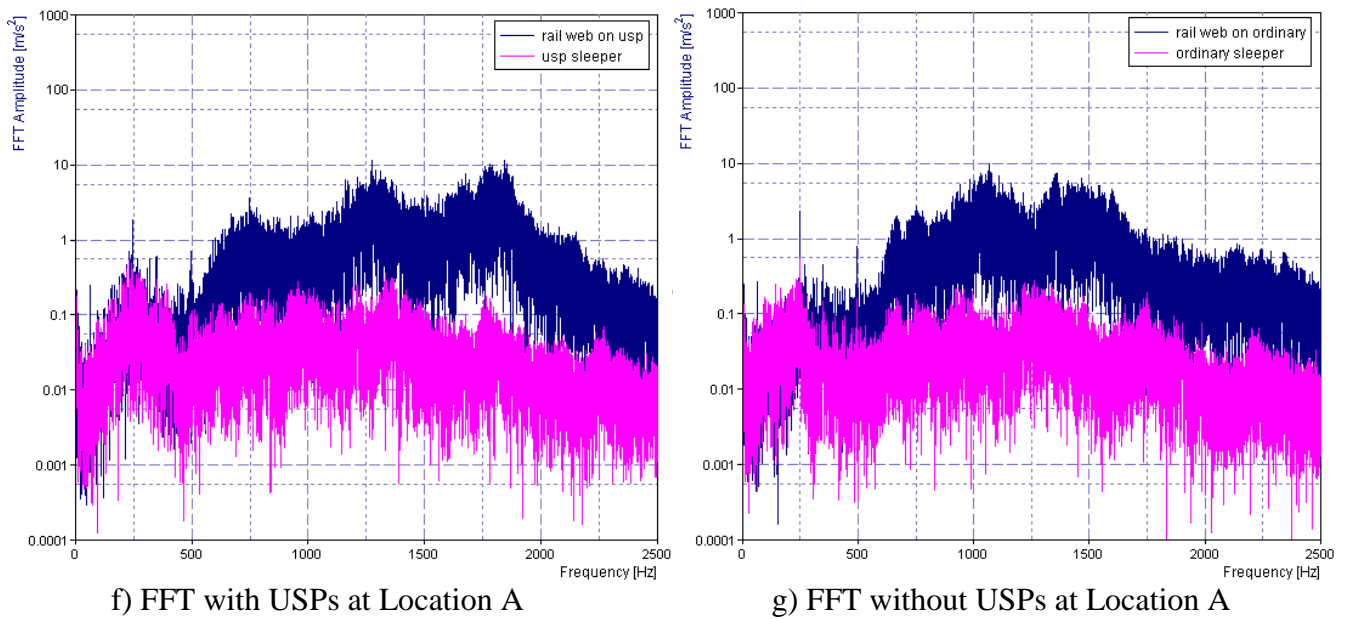


Figure 17: Passenger shuttle train - Oscar (File No 6)

Considering the FFT vibration data in Figures 17(f, g, h), it is quite clear that at most frequency bands, the rail (supported by USPs) tends to vibrate at a larger amplitude compared with the track without USPs. It is noticeable that the rail resonance changes at Location A (stiffness interface). It is found at Location A that the rail resonances shift to a higher frequency when supported by USPs and the amplitude of vibrations at low frequency band decreases, when compared with those without USPs [20].

CONCLUSIONS

Under sleeper pads (USPs) are the component installed under the concrete sleepers generally to improve railway track resilience. Initial development in Europe, particularly in Austria, has encouraged the adoption of the component around the world. In practice, the component has commonly been used in certain applications, mainly to moderate track stiffness in special locations such as turnouts, crossings, and level crossing. Accordingly, the application of USPs to mitigate detrimental impact load consequence on track structure is presented in this paper. The desktop study of AK Car records and inspection data were conducted in conjunction with visual inspection and vibration measurements at the trial site at Austinmer in NSW Australia.

A field trial aimed at mitigating rail joint impacts using the USPs with a thickness of 10mm and bedding modulus of 0.2 N/mm^3 has been conducted in NSW Australia since October 2011. It was found that the track structure and its heavy-duty components were designed to cater heavy load burden of 30t axle load with rail pad stiffness of 800 MN/m (HDPE pads). The visual inspection in conjunction with the review of the dynamic measurements confirms that the track with USPs maintain structural and dynamic integrity. The track with USP is stable and in a very good condition after over a year under mixed traffics and potential impact sources (GIJs and a rail surface defect). There is neither sign of ballast breakage under the USP sleepers nor any ballast pulverisation surrounding USP sleepers. The dynamic effect of train speeds on track components is more pronounced than that of axle loads in a broad range of frequencies. However, sleeper vibrations at a low frequency band can be highly influenced by axle loads (pronounced by freight trains).

Interestingly, the operational pass-by vibration measurements show that the resiliency of 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 behaviours imply that the use of USPs to alleviate the impact force onto track substructure is a trade-off measure that could aggravate noise radiation due to track components. If the impulse frequency (by impact sources such as joints, wheel flats, etc.) triggers resonance of track and formation, it is likely that, in some cases, the USPs may not be effective in ground-borne vibration suppression, especially when the soil structure itself can dynamically amplify ground excitations, e.g. Bangkok clay.

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