RAIL ENGINEERING INTERNATIONAL

EDITION 2020
NUMBER 4

Optimising the track bedding stiffness and settlement behaviour at insulated rail joints

Besides turnouts, insulated rail joints are the most frequent cause of track failure. They disturb track homogeneity and cause a local variation in track bedding stiffness, leading to an increase in dynamic loading. Local variations in track bedding stiffness due to turnouts, insulated rail joints, as well as other necessary devices in the track, lead to an increase in maintenance demand and inherent costs. By implementing under-sleeper pads, the track bedding stiffness and settlement behaviour at insulated rail joints can be optimised, which has been confirmed by measurements conducted in the USA and China. Insulated rail joints with an optimised track stiffness yield promising maintenance-related and economic benefits, as also alluded to in this article.

By: Dipl.-Ing. Martin Quirchmair, Development Engineer – Railway Division, Getzner Werkstoffe GmbH, Bürs, Austria; Assoc.-Prof. Dipl.-Ing. Dr.techn. Stefan Marschnig, Associate Professor, Institute for Railway Engineering and Transport Economy, TU Graz, Austria; Dipl.-Ing. Michael Fellinger, University Project Assistant, Institute for Railway Engineering and Transport Economy, TU Graz, Austria; Dr. Harald Loy, Head of R&D – Railway Division, Getzner Werkstoffe GmbH, Bürs & Postdoc Researcher, Intelligent Transport Systems, University of Innsbruck, Austria.

INSULATED RAIL JOINTS: THEIR IMPACT ON TRACK HOMOGENEITY

Signalling technology is an integral part of modern railway networks. Many electrical signals are still transmitted via the rail, with the track vacancy detection system being one of the most important safety technologies (Fig. 1).

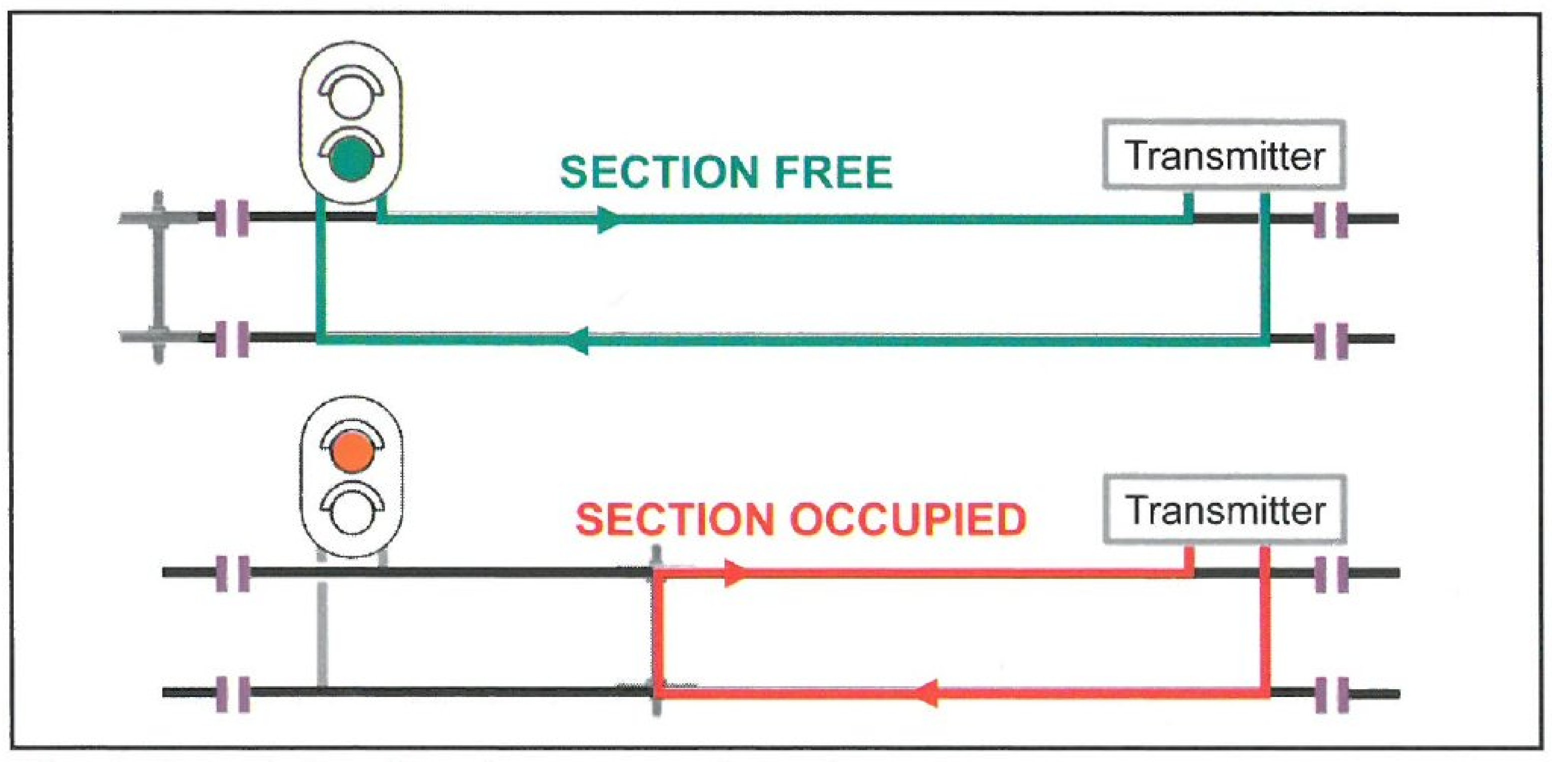

Fig. 1: Principle of track vacancy detection

In order to guarantee the function of track vacancy detection systems, defined sections of track must be electrically separated from one another, which is effected by the adoption of insulated rail joints (Fig. 2). Typically, these are arranged at 1-3 km intervals and can also be found at the beginning and the end of turnouts. The use of insulated rail joints has great benefits in terms of signalling, but this is at the expense of track homogeneity, as their static and dynamic behaviour differs from that of the adjoining track sections.

The ideal track is characterised by a uniform static and dynamic behaviour throughout the entire railway network. The change in track bedding stiffness at insulated rail joints, however, leads to a local increase in dynamic forces, which results in an accelerated wear of the components of the insulated rail joints, as well as a deterioration in track geometry quality in their immediate vicinity. Typical damage that has been observed includes increased metal flow at the rail ends (short circuit), end-post battering, and ballast quality deterioration. The latter causes an increase in rail deflection, which leads to higher mechanical stresses in the insulated rail joint and exacerbates the situation further. All this results in a rise in maintenance demand and inherent costs, both regarding the track and the insulated rail joint itself.

The service life of insulated rail joints depends on the type and intensity of traffic borne. Australian studies have observed a service life of only 50 million load tons for freight traffic, whereas in the USA the figure is around 200 million load tons. This corresponds to an effective service life of only 12-18 months, leading to additional costs of some $10,000 per mile each year.

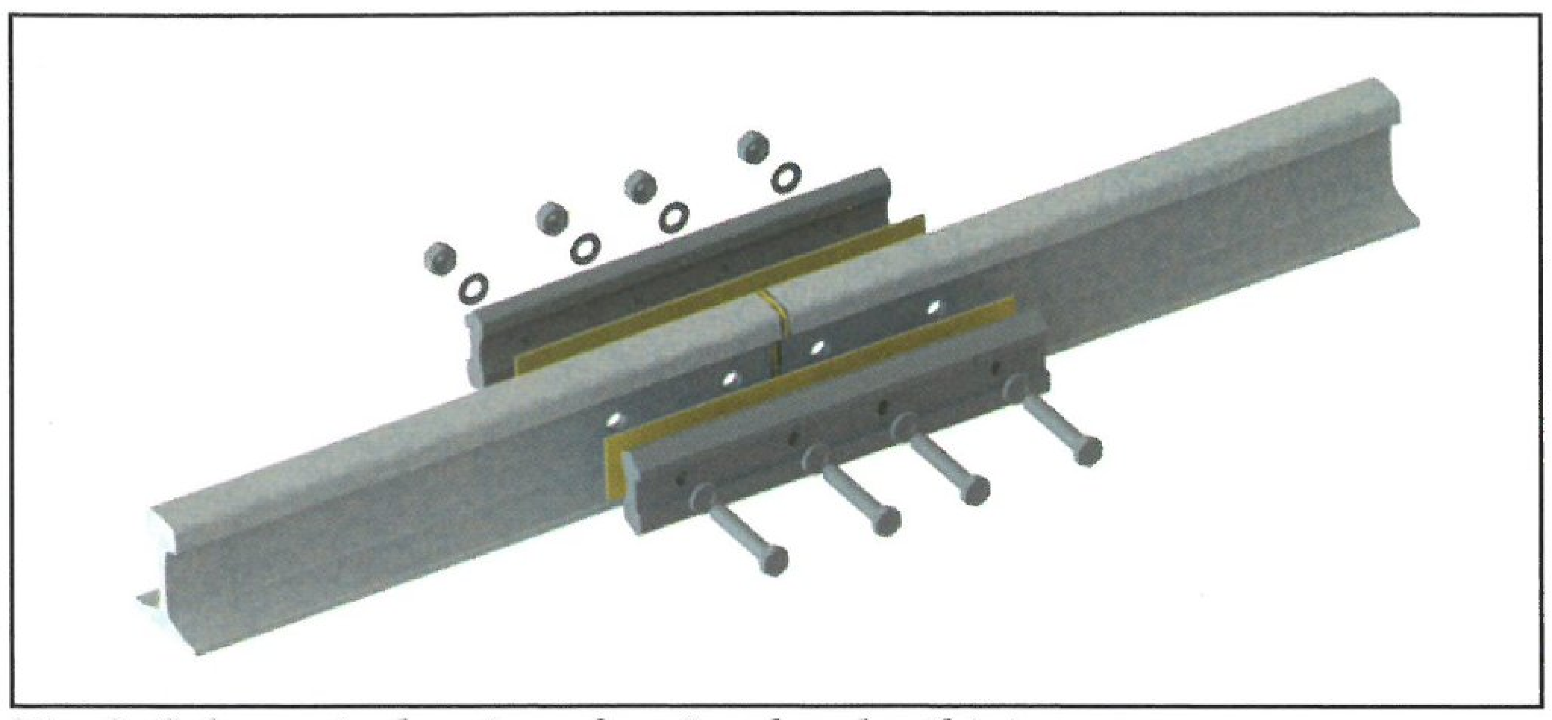

Fig. 2: Schematic drawing of an insulated rail joint

In Europe, Network Rail (UK) is investing £10 million over a two-year period due to defective insulated rail joints [1]. Insulated rail joints have also been identified as a problem area by Austrian Federal Railways (ÖBB). In Austria, they are the most frequent cause of track failure, accounting for approx. 40%, when not taking turnouts into consideration (see also Fig. 3) [2].

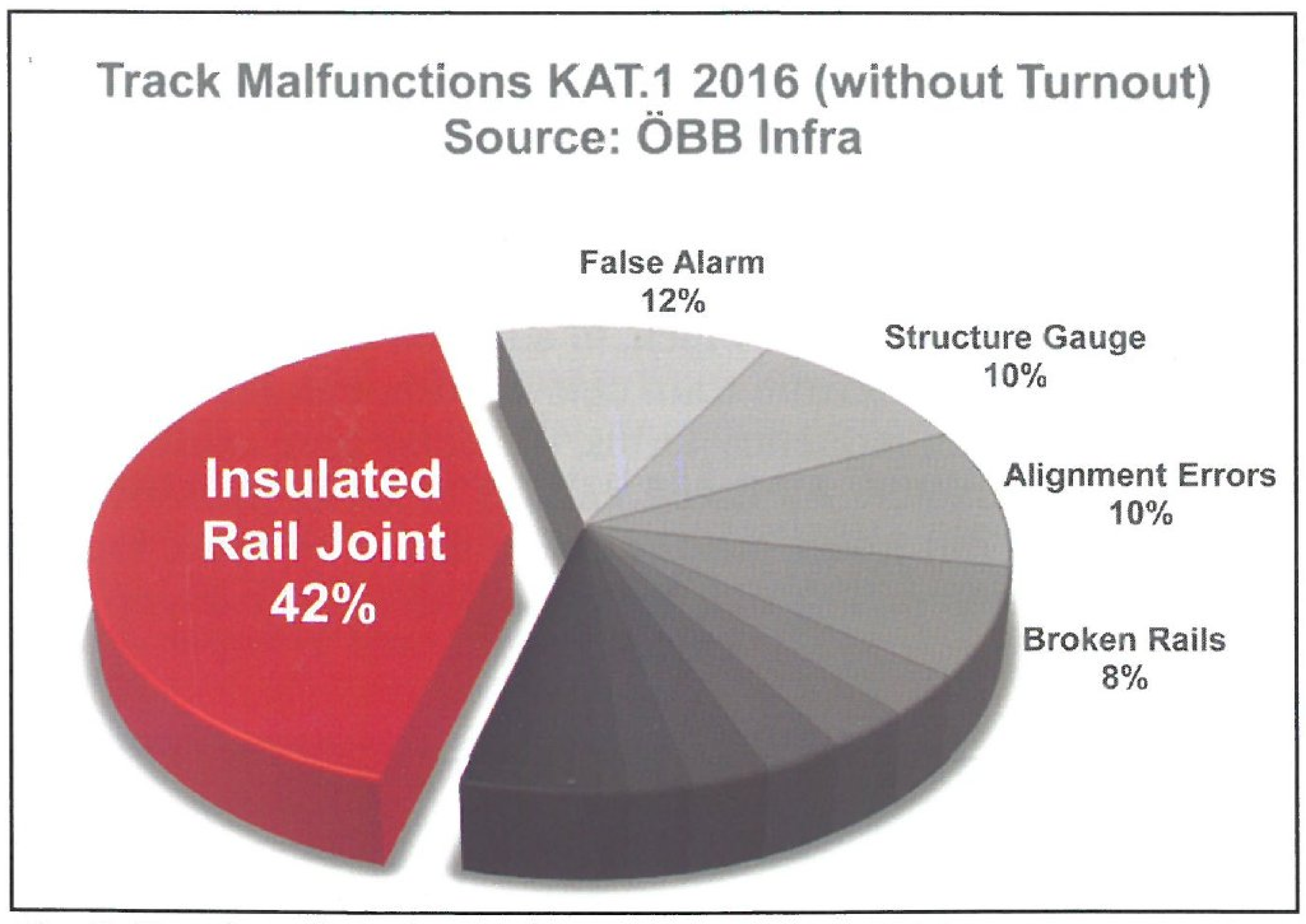

Fig. 3: Kat. 1 track faults (excluding turnouts) in 2016 (Kat.1 corresponds to traffic hindrances, i.e. full closure or speed restrictions) [2]

Maintenance of jointed track – a costly matter

Concerning track maintenance, rail joints are a factor that must not be neglected. Particularly in the case of jointed tracks (in Austria limited to track sections featuring curves with very tight radii; today they are only implemented if the rails cannot be continuously welded due to regulations), "joint upkeep" represents a considerable cost factor. A jointed track in a tight curve has an around five times higher life-cycle cost (LCC) than straight continuous welded rail (CWR) track [3], due to its higher maintenance demand and shorter service life (Fig. 4).

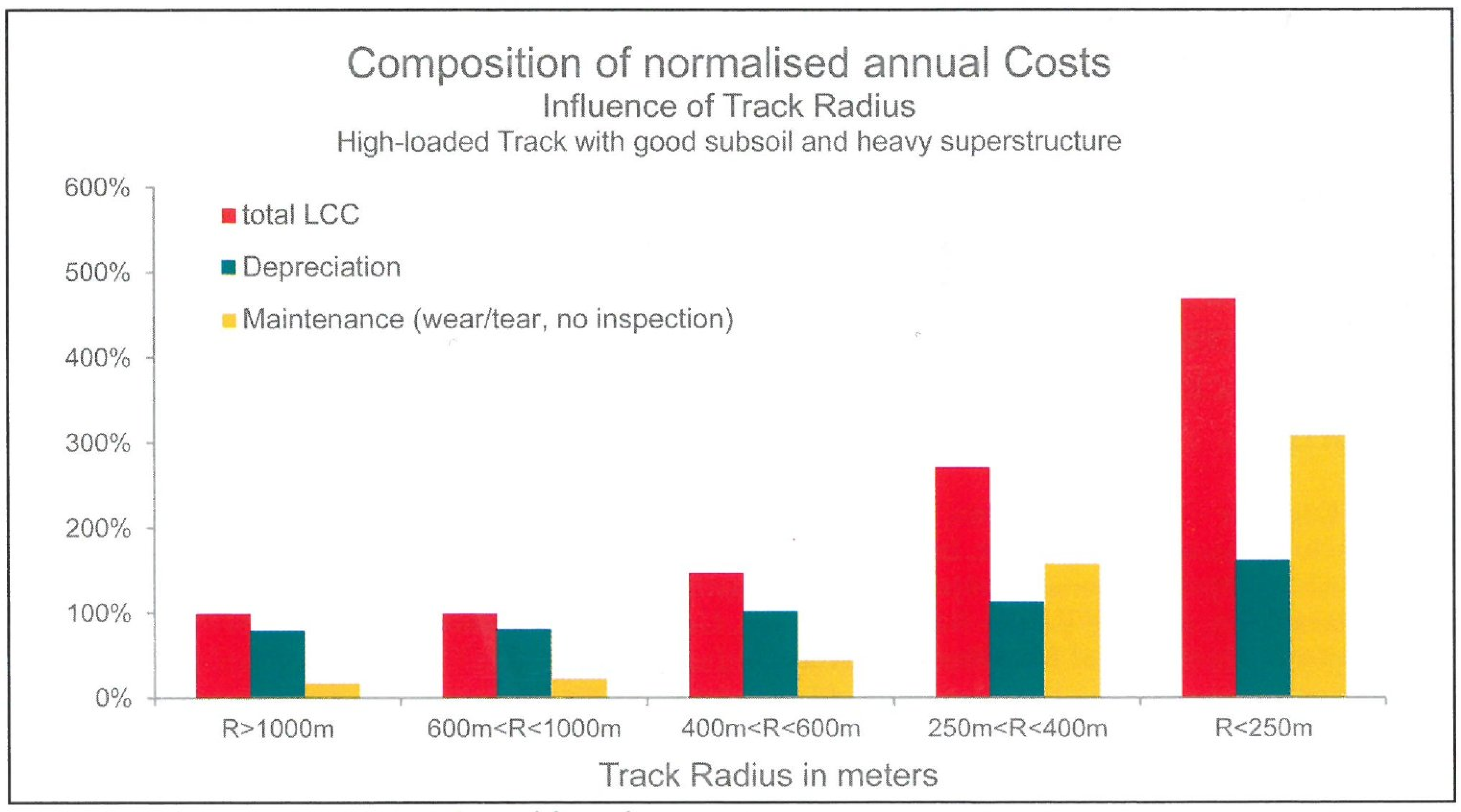

Fig. 4: Influence of track curve radii on life-cycle costs [3]

There is a need for a low-maintenance concept that can provide a more homogeneous dynamic track behaviour at insulated rail joints. This would not only benefit their service life, but also that of other track components in their vicinity in a cost-efficient manner.

A solution for insulated rail joints may well be offered by the implementation of under-sleeper pads that are especially optimised to offer ballast protection and increased track stability – under-sleeper pads are already well known for their potential to improve track geometry in turnouts, transition zones and open track.

The elimination of geometrical defects on the rail surface or necessary work on the fishplates constitutes just one aspect of joint maintenance. A far bigger part of joint maintenance demand is due to the local variations in track bedding stiffness, which lead to an increase in dynamic loading and a resulting disrupted bending line of the rail. These effects amplify the vertical force acting on the ballast bed. This force is a percussive force due to the effects already described, which intensifies the impact on the ballast. The increase in dynamic loading at insulated rail joints not only leads to a deterioration in track geometry quality, but also that of the ballast.

Ballast stones may break or pulverise, subsequently leading to the occurrence of:
— "white spots" (Fig. 5): these can develop into "splash points" in the event of water penetration;
— "mud pumping": in the case that the subsoil is not sufficiently load bearing, the dynamic loading can cause the fine particles to be pumped into the ballast bed from below, resulting in the formation of muddy spots.

These two phenomena cannot be reversed by means of tamping – instead, the ballast has to be replaced, which increases track costs.

If insulated rail joints do not function properly, this will result in traffic disruptions which, in addition to track costs, will lead to costs resulting from train delays. Although the latter are often not shown in monetary terms, the delay time caused is an important parameter. As noted earlier, at ÖBB-Infrastruktur AG, insulated rail joints are the major cause of track failure (some 40%); this means that technological improvements are essential.

Fig. 5: Formation of white spots at an insulated rail joint

By using under-sleeper pads, the stones in the top ballast layer embed themselves in the padding material, impeding their movement, which results in track stability and ensures a durable high track geometry quality. Especially in Austria, their development was highly influenced by fundamental research regarding load distribution within the ballast bed, respectively sleeper-ballast interaction [4], impact of under-sleeper pads [5], and many other scientific studies related to the technical and economic impact of adopting under-sleeper pads.

An optimum adaptation of the static and dynamic track stiffness at insulated rail joints can be achieved by a finely-tuned portfolio of elastomer stiffnesses. FEM modelling allows the most suitable under-sleeper pad design to be selected for a specific insulated rail joint situation, as alluded to in the following.

UNDER-SLEEPER PADS AT INSULATED RAIL JOINTS: PROBLEM-SPECIFIC MODELLING

For several years now, Getzner Werkstoffe GmbH has been using customised calculation models to design complex sections of track, such as turnouts or transition zones. It is therefore a logical step to expand this system expertise also to rail joints, in particular insulated rail joints, in order to select the most suited under-sleeper pad design for a specific situation. The basis of the numeric model is the finite element method (FEM). If track parameters change in a confined space, FEM modelling shows clear advantages over analytical methods.

For the design calculation, it is assumed that the track is new or freshly tamped. Hanging sleepers and other track alignment faults are therefore normally not present in this type of simulation. However, the model is capable to implement them if needed. The approach without track defects is chosen as, ideally, a new track has no imperfections. By adopting this approach, the most suitable under-sleeper pad model can be selected.

Under-sleeper pads made of high-end elastomers can improve track behaviour at insulated rail joints

When a track is new, its behaviour at insulated rail joints is determined by the mechanical properties of the respective rail joint. However, after some time in operation, the first track geometry faults appear, due to increased loading at the point of stiffness variation, and track behaviour becomes dominated by hanging sleepers and ballast quality deterioration (Fig. 6).

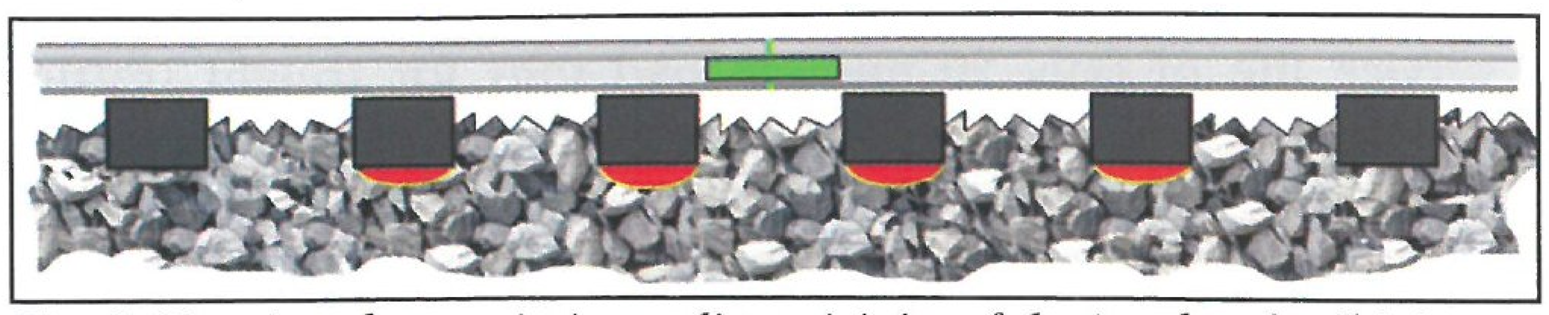

Fig. 6: Hanging sleepers in immediate vicinity of the insulated rail joint

This problem must be tackled on two fronts:

- firstly, the track in-homogeneity must be reduced by lowering the dynamic forces and the ballast contact pressure, in order to protect all track components from wear;
- secondly, ballast movement must be minimised, in order to improve long-term track behaviour.

Under-sleeper pads made of elasto-plastic polyurethane can handle both these tasks, in that FEM calculations have shown that, by implementing under-sleeper pads of this type, dynamic forces at the insulated rail joint in new track conditions and its immediate vicinity can be reduced by a quarter. Ballast contact pressure and ballast movement is reduced, as the stones in the top ballast layer embed themselves in the under-sleeper padding material, resulting in a better long-term track behaviour.

The main parameter that affects ballast contact pressure is the effective ballast contact area of the sleeper: the larger the ballast contact area, the more uniform the load distribution is and, thus, ballast contact pressure decreases.

Ballast contact area enlargement by polyurethane under-sleeper pads

The greatest benefit of adopting polyurethane under-sleeper pads is achieved in the contact area between the ballast and the padded sleeper, i.e. the ballast contact area. Unpadded sleepers typically have a ballast contact area of 3-5%. The contact area can be increased to up to 35% by using elasto-plastic polyurethane under-sleeper pads [6].

Information on the potential of under-sleeper pads as regards ballast contact area size can be obtained from both the track in-situ and in the laboratory. For material comparisons, laboratory measurements have a clear advantage, as irregularities in the ballast can be eliminated and, in practice, removing a sleeper from the track involves a great deal of effort and cost.

Laboratory experiments – material comparisons: polyurethane offers a larger ballast contact area

In order to compare under-sleeper pad materials with one another under laboratory conditions, Getzner uses a method based on the DIN EN 16730:2016 standard [7], which consists of a combination of a quasi-static test and a shortened (one-hour) fatigue test. In this manner, the test can be carried out quickly by testing institutes and yet still provide useful information about the increase in ballast contact area due to elasto-plasticity, which could not be achieved by using a purely quasi-static test.

As can be observed from Fig. 7, materials with nominally identical stiffness (according to DIN 45673-6:2010 [8]) can have significantly different contact areas with the ballast. This affects lateral track resistance (LTR) and, subsequently, track geometry quality [9]. Polyurethane under-sleeper pads show the largest ballast contact area [10].

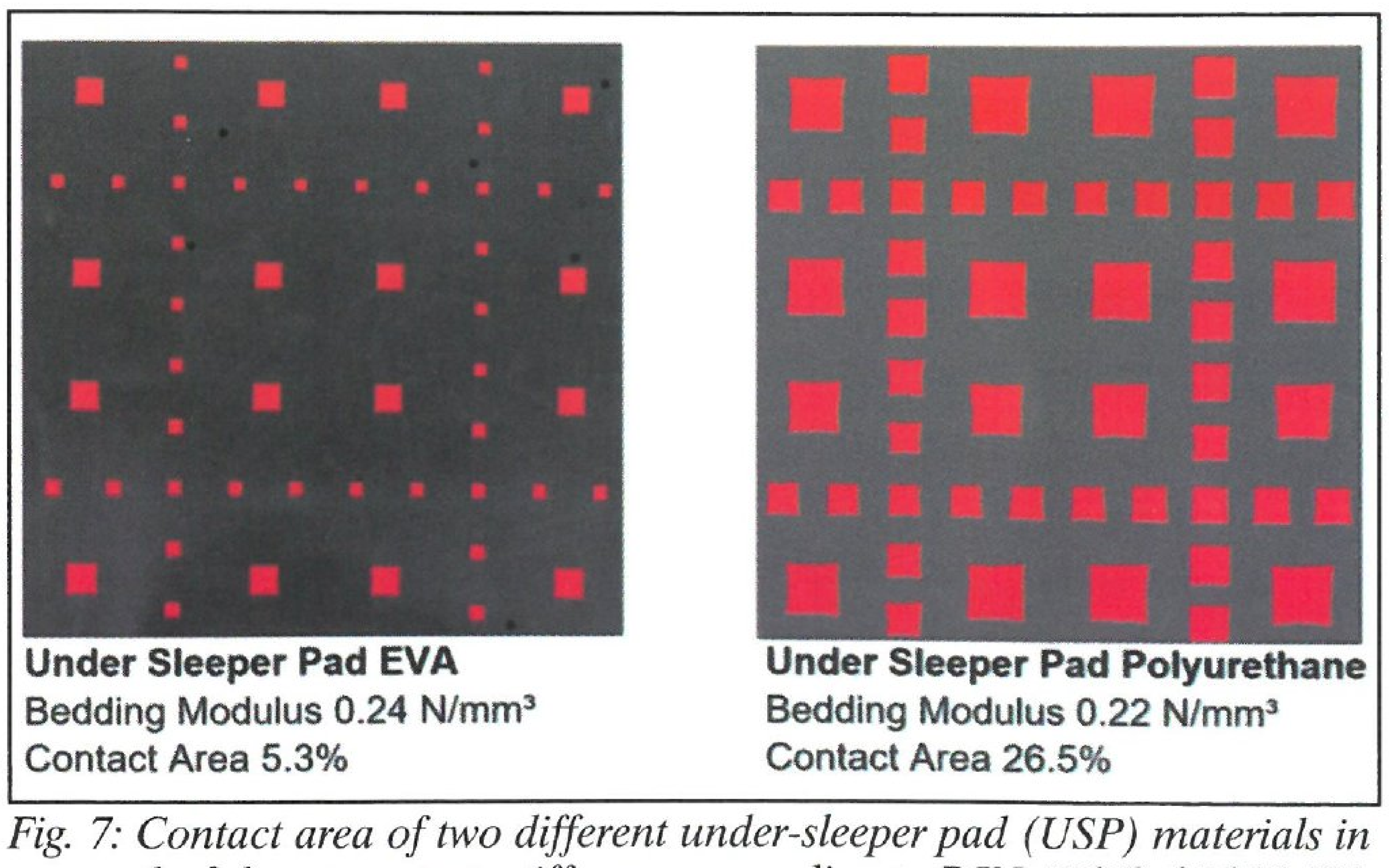

Fig. 7: Contact area of two different under-sleeper pad (USP) materials in the laboratory test: stiffnesses according to DIN 45673-6:2010 [8]

Calculations have yielded that by adopting polyurethane under-sleeper pads, in addition to reduced dynamic forces, a reduction of 80% or more in ballast contact pressure can be achieved – with a significantly better load distribution (Fig. 8).

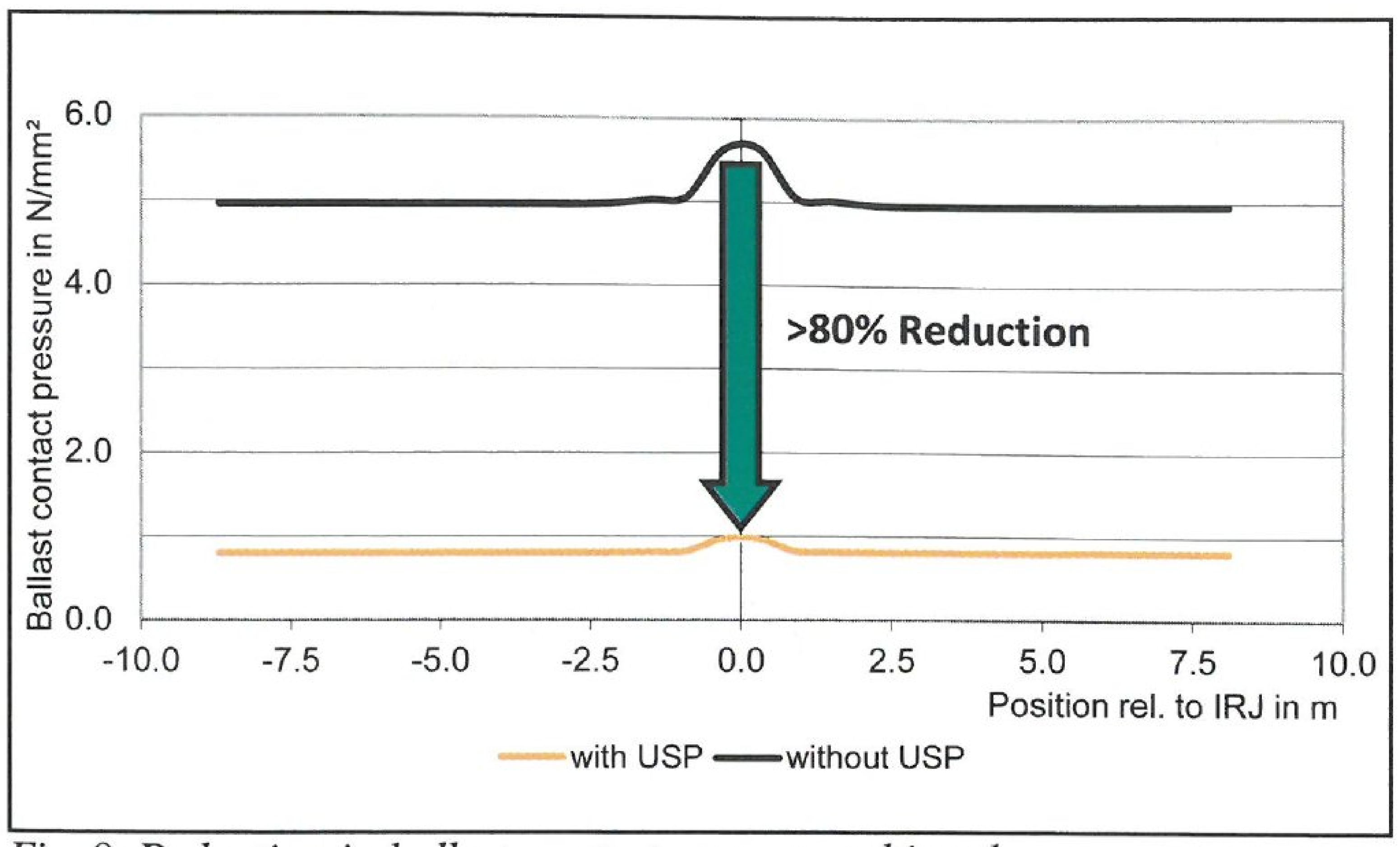

Fig. 8: Reduction in ballast contact pressure achieved by adopting elasto-plastic under-sleeper pads

FIELD MEASUREMENTS CONFIRM EFFECTIVENESS OF UNDER-SLEEPER PADS

Measurements conducted on heavy-haul railway lines in the USA and China have confirmed that the track bedding stiffness and settlement behaviour at both insulated and standard rail joints can be optimised by implementing under-sleeper pads, as alluded to in the following.

Measurements conducted at insulated rail joints on a heavy-haul railway line in the USA

In Spring 2016, an opportunity was provided to equip insulated rail joints with under-sleeper pads on one of the largest heavy-haul railway lines in Nebraska, USA, and to conduct on-site measurements.

In the test section, 33 t axle-load trains operate at a maximum speed of 100 km/h, carrying approx. 500,000 load tons of freight per day. At the time of the measurements, the padded insulated rail joints had been in operation for just over a year. As a reference, an unpadded insulated rail joint in the vicinity was selected, which was exposed to the same axle loading, operating speed, and traffic loading.

Deflection and vibrations were chosen as measurement parameters. Deflection measurements provide information on the behaviour of the insulated rail joint during train passage. This information is necessary to validate the forecasts of models, to make adjustments if necessary and, thus, continuously improve their output quality.

When it comes to the issue of ballast movement and subsequent track settlement, vibration measurements can yield insights. From approx. 30 Hz, the critical frequency range for increased wear of ballast stones starts [11], and the plasto-elastic liquefaction of the ballast increases [12]. If the vibrations in the ballast bed are mitigated within this frequency range, a reduced settlement behaviour can be expected.

Measurement set-up

Deflections were recorded at five different measurement points (see Figs. 9 and 10), with the displacement sensors D1-D4 being used for evaluation, and sensor D5 to check for rail tilt. To measure the vibrations at point A1, a driven pile was positioned in the ballast crib at the insulated rail joint. The accelerometer at point A1 was used to measure the vibrations in the top layer of the subsoil, which are directly proportional to those in the ballast.

Fig. 9: Measurement set-up

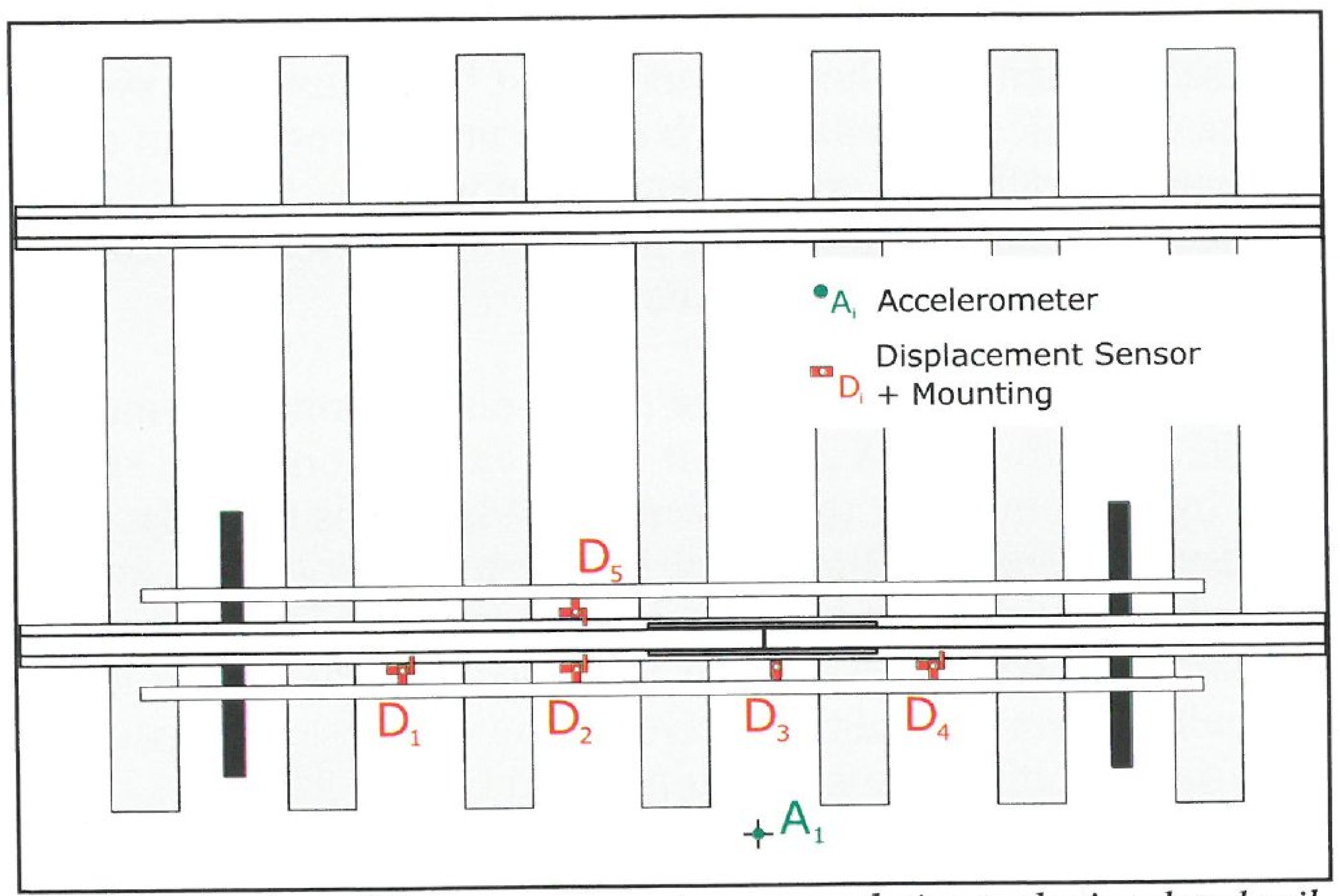

Fig. 10: Location of the measurement sensors relative to the insulated rail joint (D1 to D5 are displacement sensors, A1 is an accelerometer)

Evaluation and interpretation of the results

Due to the different configurations of the individual trains, the deflection values obtained for the locomotive passages which, in contrast to the wagons, have constant axle loads, were used for the evaluation. An example of a measured signal can be found in Fig. 11. Two traction units are shown, both having two bogies with three wheelsets each.

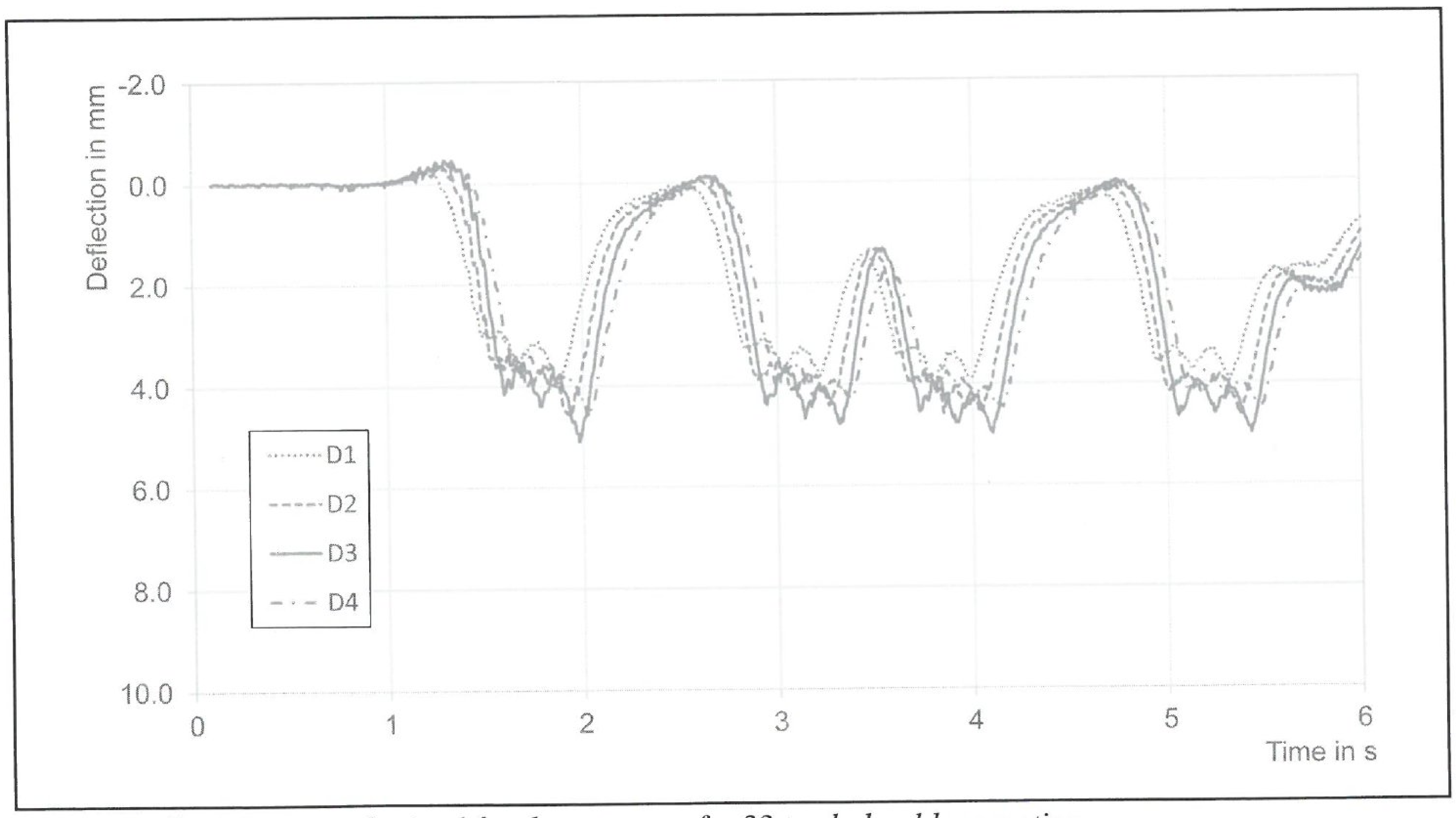

Fig. 11: Deflection curve obtained for the passage of a 33 t axle-load locomotive

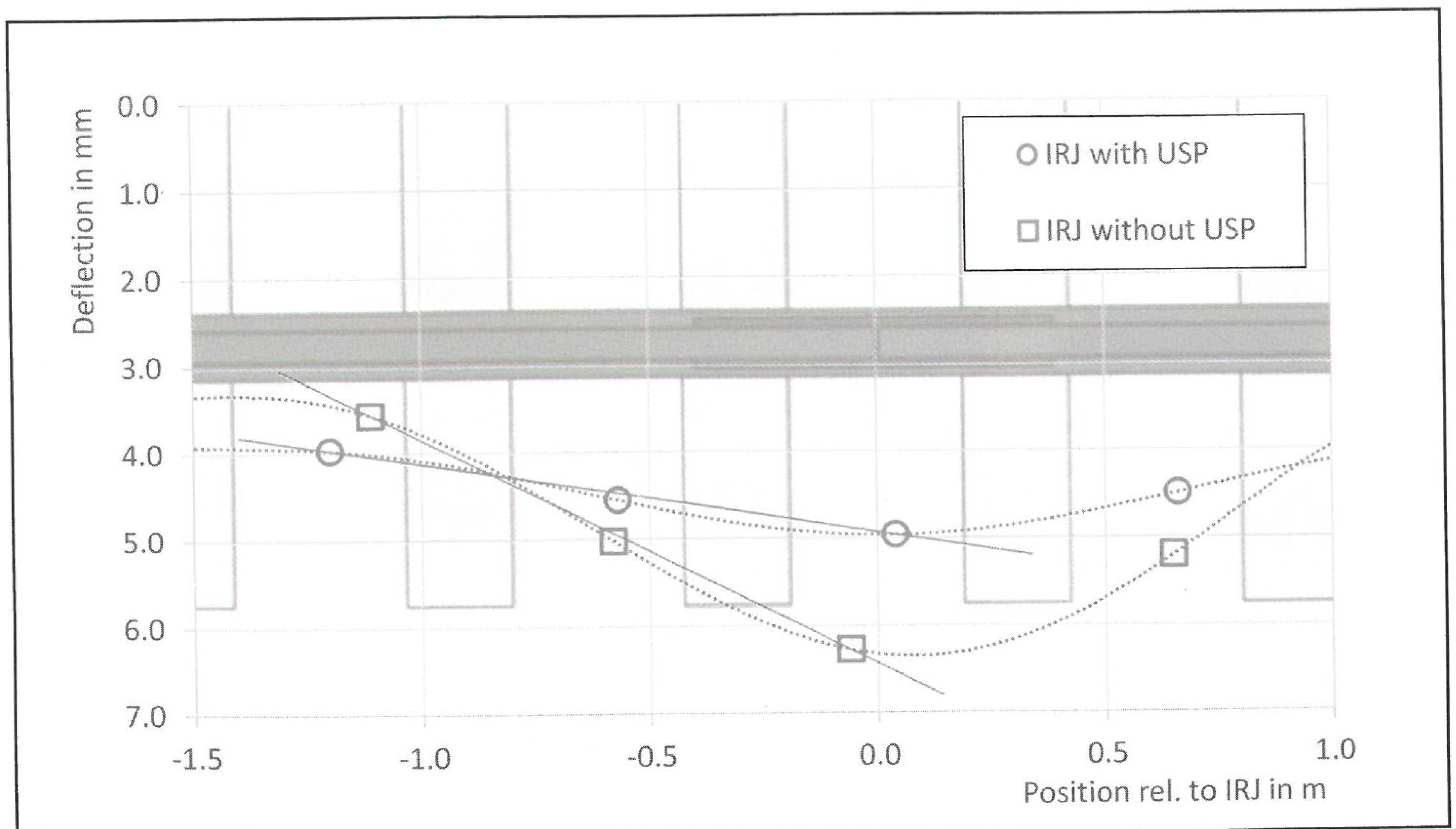

Fig. 12: Average rail deflection at an insulated rail joint with/without under-sleeper pads (USPs)

To get a statistically representative value for the deflection, the deflections of all train passages were averaged, whereby the average deflection for the individual train passages denoted the average of the first three wheelsets. The deflection curve determined can be found in Fig. 12 for both the padded and unpadded insulated rail joints.

As can be observed from Fig. 12, the padded insulated rail joint shows a much more homogeneous deflection than the unpadded one. This phenomenon can be explained by the development of track geometry over time.

Under-sleeper pads are known for their positive impact on ballast movement and track geometry quality, i.e. by their implementation, the deflection remains almost constant over time and the development of track geometry faults reduces.

The reduction of forces transmitted into the ballast bed can be verified by vibration measurements. As noted earlier, ballast wear increases significantly for frequencies above 30 Hz.

As can be observed from Fig. 13, in this frequency range, the unpadded insulated rail joint transfers more kinetic energy in the form of vibrations into the subsoil and, consequently, the ballast is exposed to higher dynamic forces and increased movement. The result is an increase in settlement and ballast wear. The padded insulated rail joint shows a more favourable result.

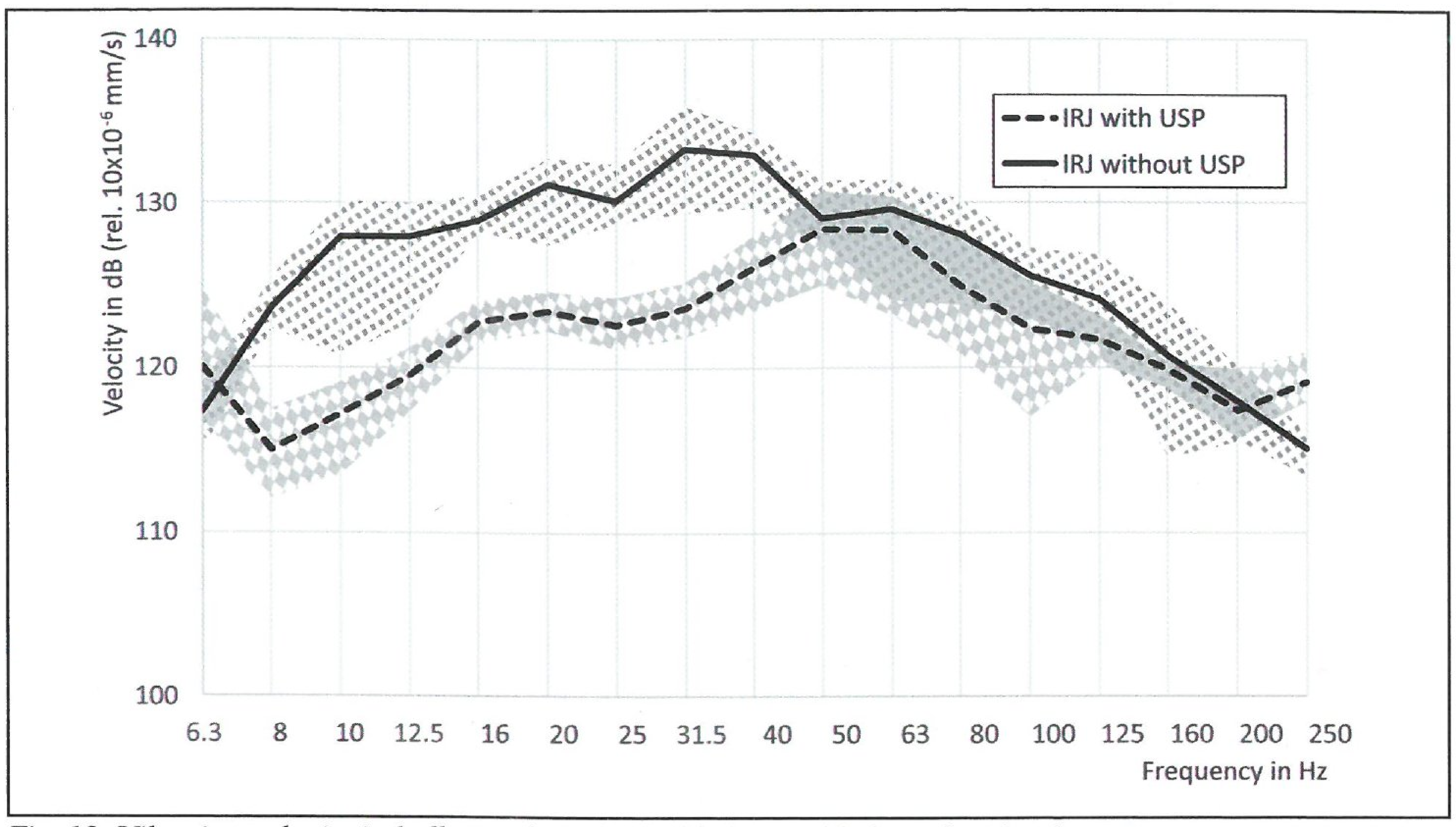

Fig. 13: Vibration velocity in ballast crib at the padded/unpadded insulated rail joint

Measurements conducted at rail joints on a high-capacity heavy-haul railway line in China

In China, Daqin Railway operates the 653 km long Datong-Qinhuangdao heavy-haul railway line – the most heavily loaded freight line in the world, on which 25 t axle-load trains transport nearly 1.5 million load tons of coal daily (Fig. 14) [13].


Fig. 14: Coal train approaching on the line Datong-Qinhuangdao, China – the most heavily loaded freight railway line in the world [13]

In 2015 and 2016, a section of this line, including all rail joints, was equipped with elasto-plastic polyurethane under-sleeper pads which, after more than 1 billion load tons of traffic, showed no signs of damage (Fig. 15).


Fig. 15: Removed padded sleepers after more than 1 billion load tons of traffic – no signs of damage

The track, which carries fully-loaded coal trains, was tamped twice in the unpadded sections within a 519 million load ton period of traffic, whereas no maintenance was required in the padded section. A similar behaviour was observed on the adjacent track, on which empty trains run. Here, the unpadded sections were tamped three times within a 173 million load ton period of traffic, but the padded section did not show any indications that maintenance was required – as also noted in a letter of reference received from the Track Maintenance Department, Taiyuan Railway Bureau, China, dated 10 July 2017.

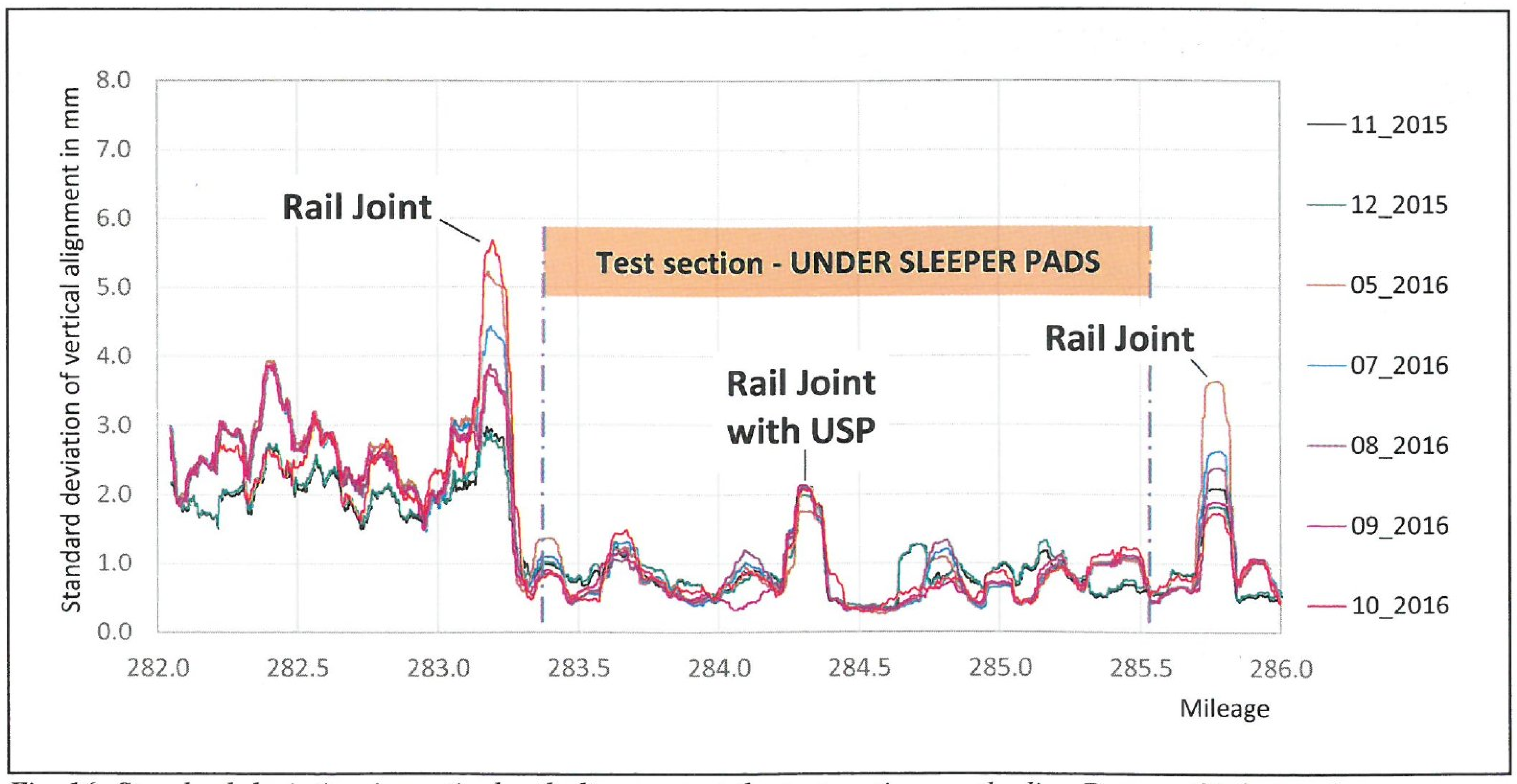

Fig. 16: Standard deviation in vertical rail alignment at the test section on the line Datong-Qinhuangdao

Results of track measurements conducted by track recording cars clearly show the improvement in track geometry achieved in the section with padded rail joints (Fig. 16). The development of the track geometry over time has revealed that the unpadded rail joints show significantly higher rates of deterioration than the padded rail joints. Thus, the rail joints featuring under-sleeper pads preserve the track geometry better.

CONCLUDING REMARKS

At insulated rail joints, a change in track bedding stiffness occurs. This leads to a local increase in dynamic forces, resulting in an accelerated wear of the components of the insulated rail joints, as well as a deterioration in track geometry quality in their immediate vicinity.

By implementing highly elasto-plastic polyurethane under-sleeper pads, which have a large ballast contact area that greatly reduces ballast contact pressure, the track bedding stiffness and settlement behaviour at insulated rail joints (and rail joints in general) can be significantly improved.

FEM modelling allows the most suitable under-sleeper pad design for a specific insulated rail joint situation to be selected. The measurement results obtained on the heavy-haul railway lines in the USA (for padded insulated rail joints) and China (for padded standard rail joints) have shown that under-sleeper pads provide an optimised track bedding stiffness, yielding promising maintenance-related and economic benefits.

It is believed that a further optimisation of track bedding stiffness at insulated rail joints, nearing that of standard track, is possible; this could well be the focus of further research!

REFERENCES

[1] Gallou M., Temple B., Hardwick C., Frost M., El-Hamalawi A.: 'Potential for External Reinforcement of Insulated Rail Joints', Loughborough University's Institutional Repository, December 2016.

[2] Mach M.: 'WS Akademie, 101 Oberbau – Grundlagen', 2016 (www.ws-akademie.at).

[3] Marschnig S.: 'iTAC – innovative Track Access Charges', Monographic Series TU Graz / Railway Research, Volume 1, Verlag der Technischen Universität Graz, Austria, 2016, ISBN: 978-3-85125-493-8.

[4] Jani J.: 'Experimentelle Ermittlung der Kraftübertragungsflächen zwischen Beton/Holzschwellen und Oberbauschotter', Dissertation, TU Graz, Austria, 1993.

[5] Monaco V.: 'Untersuchungen zu Schwellenbesohlungen im Oberbau', Dissertation, TU Graz, Austria, 2003.

[6] Loy H., Augustin A.: 'Pushing the limits of ballasted heavy-haul railway track by means of high-strength under-sleeper pads made of a specially developed PUR', Rail Engineering International, Edition 2015, Number 4, pp. 3-6.

[7] DIN EN 16730:2016: 'Railway Applications – Track – Concrete sleepers and bearers with under-sleeper pads'.

[8] DIN 45673-6:2010: 'Mechanical vibration – Resilient elements used in railway tracks – Part 6: Laboratory test procedures for under-sleeper pads of concrete sleepers'.

[9] Gabl S., Rüger B., Loy H., Pospischil F.: 'Einfluss der Kontaktfläche auf den Querverschiebewiderstand (influence of the contact surface on lateral track resistance)', ETR-Eisenbahntechnische Rundschau (ETR Austria), No. 3/2020, pp. 63-67.

[10] 'Importance of Contact Areas – General Discussion and Measurements', Internal Report of Getzner Werkstoffe GmbH, Bürs, Austria, April 2015.

[11] Freudenstein S., Geisler K., Mölter T., Mißler M., Stolz C.: 'Feste Fahrbahnen in Betonbauweise (Concrete slab tracks)', Betonkalender, Special Edition, Ernst & Sohn, 2015.

[12] Bosch R.: 'Querverschiebewiderstandsmessung mit dem dynamischen Gleisstabilisator (Measuring lateral track resistance using the dynamic track stabiliser)', Eisenbahningenieur No. 6/2007, pp. 15-19.

[13] Huiding D., Pospischil F., Loy H.: 'Heavy-haul in China: Investigating durable elasticity for superstructure', Global Railway Review, No. 5/2018.