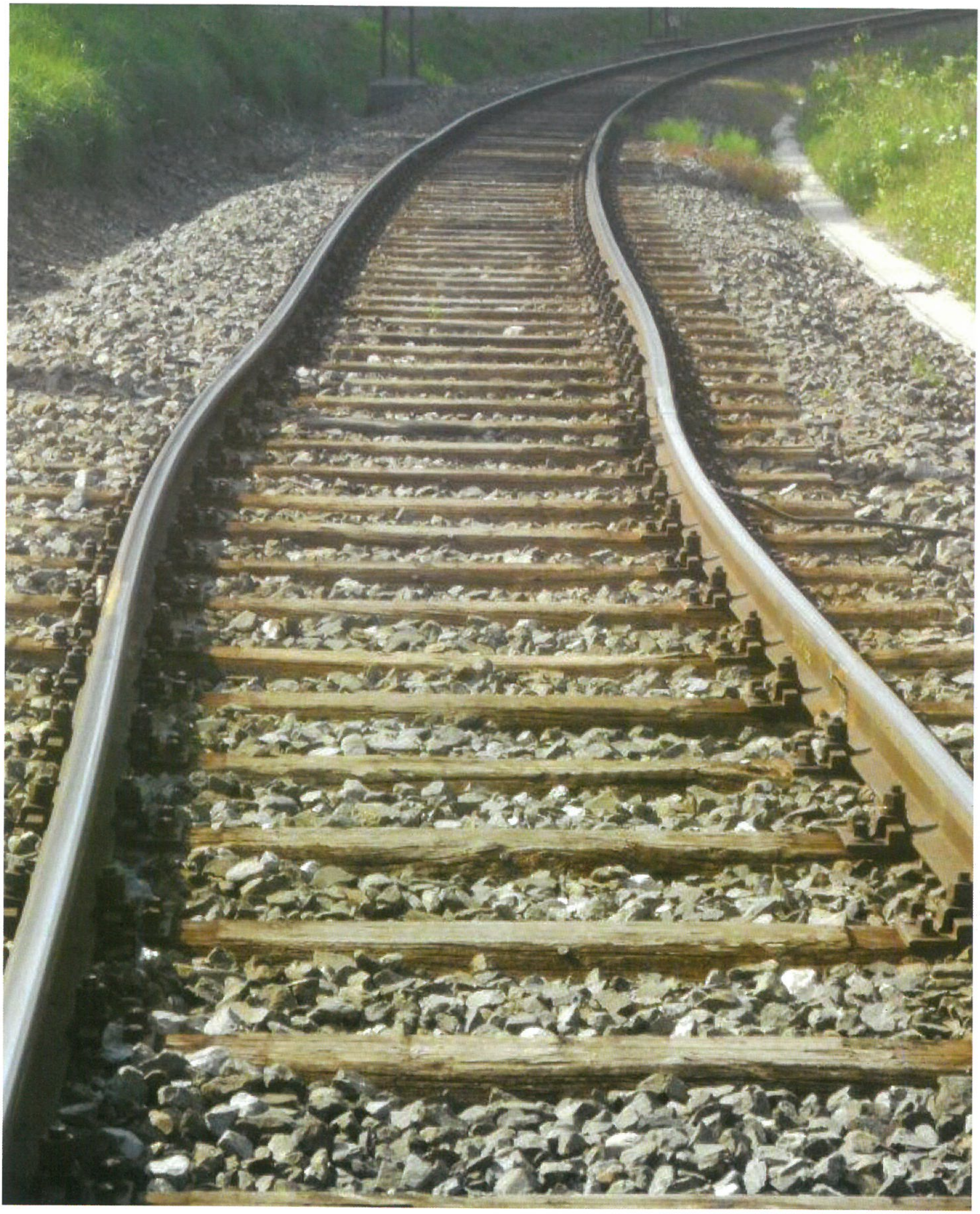
RAIL ENGINEERING INTERNATIONAL

EDITION 2021
NUMBER 2



Influence of the sleeper/ballast contact area on lateral track resistance — effectiveness of under-sleeper pads examined by laboratory experiments

The demands placed on railway track are increasing due to faster train operating speeds and heavier axle loads. Therefore, and also because high train frequencies greatly reduce the time windows available for track maintenance, modern permanent way research aims to come up with track components that contribute to an increase in track availability. In this respect, this article looks at laboratory experiments that were conducted to examine the effect of different under-sleeper pads with varying material properties on lateral track resistance and, thus, the enhancement of track availability.

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LATERAL TRACK RESISTANCE – A MATTER OF HIGH IMPORTANCE

Continuously welded rail (CWR) track, by its nature, limits temperature-induced rail deformations, but is prone to increased internal rail stress, which dissipates via the rail and the sleepers onto the ballast bed. This leads to ballast quality deterioration, as well as ballast stone movement, subsequently jeopardising track geometry durability, as well as track component quality and safety and, thus, track stability. Track geometry durability is particularly dependent on lateral track resistance (LTR), i.e. the resistance of the track to lateral displacement.

Numerous field measurements conducted in the past have demonstrated that a ballasted CWR track with unpadded concrete sleepers provides an adequate level of LTR on straight sections of track, but that for CWR track in tight curves additional measures are needed [1].

However, with temperatures rising due to global warming, straight CWR track is also becoming more prone to geometry deformations. In Europe, for instance, there has been an increase in the number of days on which rail temperatures of over 60°C have been recorded [1]. Particularly in 2019, this has led to an increase in the occurrence of track geometry deformations, even on straight sections of track.

Increasing LTR by using under-sleeper pads

Existing field measurements have demonstrated that by using concrete sleepers with under-sleeper pads (padded sleepers), a higher LTR is achieved than by using unpadded sleepers.

The aforementioned findings have already resulted in an amendment of the ÖBB regulation RW 07.06.05, which now specifies minimum radii for padded and unpadded sleepers [2].

Furthermore, research findings have revealed that increasing the sleeper/ballast contact area by adopting under-sleeper pads (USPs) with elasto-plastic material properties acts as a major driver for achieving a high level of LTR [3], [4], [5].

There are currently many types of USP available on the market that vary in terms of function, material used and respective properties. USPs provide a defined elasticity in the track and, provided that appropriate material properties have been selected, an increase in the sleeper/ballast contact area. This leads to a reduction in ballast quality deterioration and ballast movement, which has a positive impact on LTR and, thus, track stability [3].

The effectiveness of different types of USP can, to some extent, be determined by means of in-track measurements. However, the results of in-track measurements naturally show a rather high scatter because of the different prevailing local conditions (see Fig. 1) [6], making an explicit interpretation often difficult, as alluded to in the following (see also Fig. 1).

It should be noted that LTR is, amongst others, dependent on sleeper geometry and degree of ballast compaction. In addition to local factors, the effect of additional measures, such as the use of USPs or safety caps, is also evident.

As for ballast compaction, whenever new track is laid or following maintenance tamping, there is a process of ballast stone movement – the ballast bed is not yet in a consolidated state.

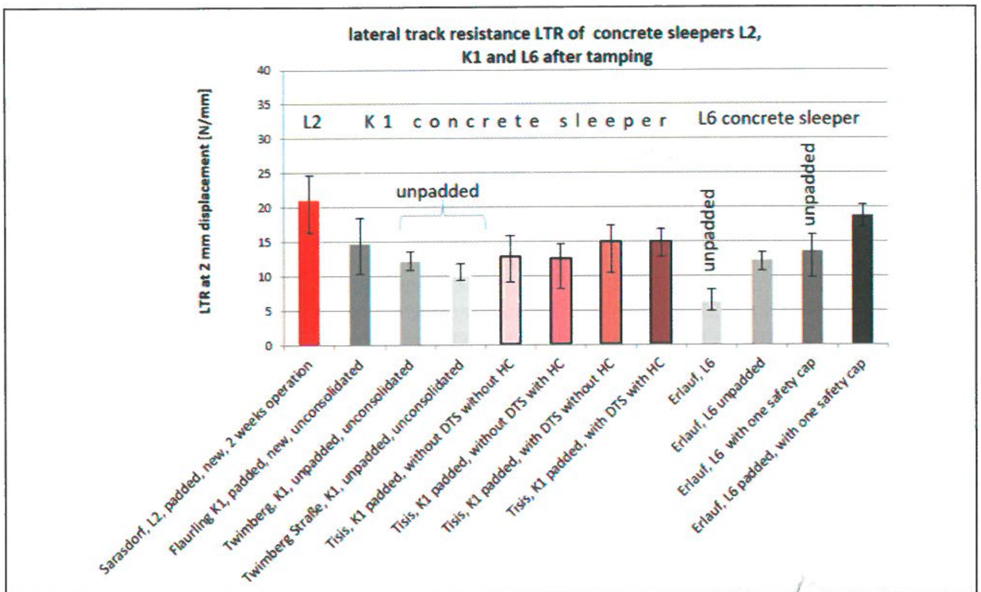

Fig. 1: Average LTR values obtained for concrete sleepers L2, K1 and L6 following tamping (HC is sleeper-end ballast consolidation), in-situ measurements [6]

By using a dynamic track stabiliser (DTS), which puts the ballast and track panel into a horizontal vibration and, at the same time, applies a static vertical load to the ballast, a homogeneous re-arrangement of the ballast stones and an even consolidation of the ballast bed is achieved. In this manner, DTS use pre-empts initial track settlement, which results in an immediate enhancement of LTR. A similar effect, though not to the same extent, is achieved by sleeper-end ballast consolidation. As traffic loading increases (and, thus, a further compaction of the ballast bed occurs), a consolidation or bonding between the sleeper surface and the ballast occurs.

To be able to investigate the effect of different types of USP on LTR in a more comparable manner than by in-situ measurements, a laboratory test method was developed that allows experiments to be conducted with controlled test parameters, as well as reproducible information to be obtained, as alluded to in the following.

LABORATORY EXPERIMENTS: THE IMPACT OF UNDER-SLEEPER PADS ON LTR

The following five types of USP were selected for the laboratory experiments: the SLB 3007 (polyurethane (PUR) with elasto-plastic material properties), the SLB 1510 (PUR with elasto-plastic material properties), the SLN 1010 (PUR with highly elastic material properties), the SL NG (PUR with plastic material properties), all of which are from Getzner Werkstoffe GmbH, and, from Paul Müller Technische Produkte GmbH, the M02 (ethylene vinyl acetate (EVA) with elasto-plastic material properties).

Preparations for the laboratory experiments

A total of 12 square concrete blocks (300 mm x 300 mm x 100 mm) were prepared as test pieces to determine the effect that the sleeper/ballast contact area has on LTR (square concrete blocks were used instead of full-size sleepers, as these can be easily handled and moved without the support of machinery). Sleeper pads of varying rigidity and up to 10 mm thick were applied to the top and bottom of eight of these concrete blocks (one type of USP per side), giving these eight test pieces a total height of 120 mm. The remaining four test pieces had a different type of USP fitted to just one side. Also a larger test piece measuring 600 mm x 300 mm x 100 mm was prepared, to which two different types of USP were fitted (one type per side), with the aim to demonstrate the effect that doubling the size of the sleeper/ballast contact area has on LTR.

In order to ensure that the experimental conditions were as comparable and as realistic as possible, a metal-framed ballast box measuring 1.15 m x 1.15 m was set up (see Fig. 2). Inside this ballast box, the sides of which were lined with a rigid under-ballast mat, ballast stones of grain size 1 were manually inserted in two layers, each 15 cm deep, and then consolidated using a vibrating plate.

As noted earlier, LTR entails the resistance of the track to lateral displacement. As the sleepers sort of "float" on the ballast bed, contributory factors that also influence LTR include the ballast at the sleeper ends and in the sleeper cribs, as well as the friction between the ballast and the USP. The fact that the use of USPs only has an impact on the frictional resistance of the pad itself meant that nothing else had to be considered when setting up the experiment. The test pieces were therefore laid on a uniformly pre-consolidated ballast bed (Fig. 2).

Further, due to the embedding of the ballast stones in the padding material, an increase in resistance occurs that may cause an uplifting of the test pieces or a repositioning of the ballast stones. To counter this problem and carry out the experiments in accordance with DIN 45673-6 [7], the test pieces were weighted down during the LTR determination tests.

DIN 45673-6 permits the use of test pieces that measure 300 mm x 300 mm x 200 mm as a substitute for full-size sleepers. As the selected concrete blocks are only half as high than is specified in DIN 45673-6, a steel plate weighing 18.4 kg was used as compensation. This gave a total test mass of 40 kg.

LTR MEASUREMENTS – PRIOR TO AND FOLLOWING LOADING

To obtain comparable values, the LTR was determined twice for the same test piece, i.e. firstly prior to and, secondly, following loading. For the LTR measurements, four displacement sensors and a load cell with a hydraulic cylinder were fitted to the outside of the ballast box (see Fig. 3). The four displacement sensors allowed not only the recording of displacement, but also that of torsion or tilting.

Fig. 2: Ballast box and arrangement of the test pieces for the laboratory experiments [3] (Photo: Sandro Gabl)

Fig. 3: Test set-up for the laboratory experiments, LTR measurement [3] (Photo: Sandro Gabl)

LTR measurements prior to loading – ballast in an unconsolidated state: results

In Fig. 4, the LTR measurement results obtained prior to loading, expressed as absolute values (averaged from the respective test pieces) for a displacement of 2 mm, are shown. In addition, the error indicators show the scatter of the test series. The scatter between the results is low owing to the lack of any consolidation or bonding between the USP and the ballast. From Fig. 4, it can be observed that the unpadded concrete test pieces only generated 116 N (i.e. 62% of the padded one that had the lowest LTR effect), and that among the padded ones themselves, depending on the choice of USP, the scatter ranged from 189 N to 273 N (i.e. around 45%).

As for any changes to the USP padding material, the following observations were made. As the M02 has a smooth, compact surface structure, this one remained almost entirely without any ballast indentations. Also in the case of the SLN 1010, there were no visible changes in the padding material, although its rough fabric surface created a stronger bond with the ballast, which explains its higher LTR as compared to that of the M02. As for the remaining USPs (SL NG, SLB 3007 and SLB 1510), slight ballast indentations could be detected; which explains their higher LTR values.

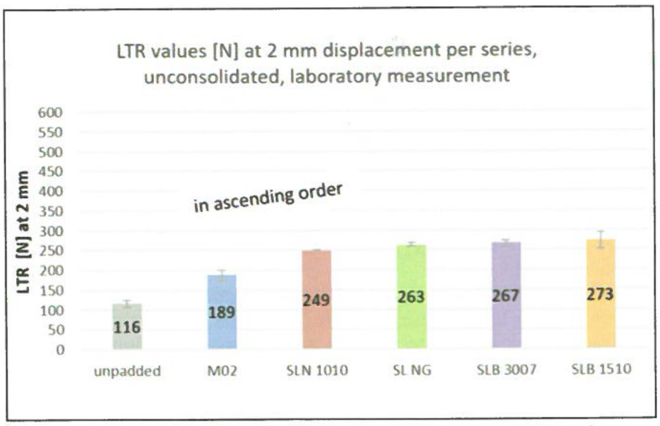

Fig. 4: Mean LTR values [N] at 2 mm displacement per series, with error indicators, unconsolidated ballast, laboratory measurements [3]

LTR measurements following loading – ballast in a consolidated state: results

For the second stage of the experiment, new concrete blocks were prepared as test pieces and the ballast sprayed with white lime to allow the percentage of ballast contact area to be determined from the ballast indentations in the padding material following loading, using imaging software. The test pieces were then loaded at load level 2 in accordance with the long-term fatigue test parameters specified in DIN 45673-6, following which the LTR was measured and the contact surface areas were assessed.

In Fig. 5, the LTR measurement results obtained following loading, expressed as absolute values (averaged from the respective test pieces) for a displacement of 2 mm are shown in ascending order from left to right.

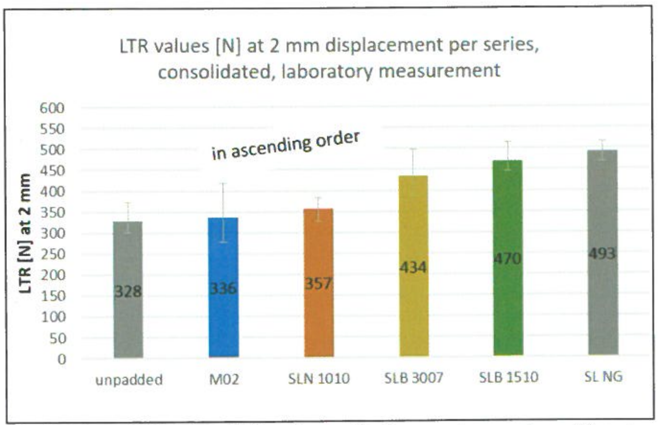

Fig. 5: Mean LTR values [N] at 2 mm displacement per series, with error indicators, consolidated ballast, laboratory measurements [3]

As can be observed from Fig. 5, the measured LTR value of the unpadded test piece (328 N) does not differ significantly from that of the test piece fitted with the M02 type of USP (336 N). This may be explained by the fact that the M02 is primarily used to protect the ballast and is not designed to increase LTR [8]. Its use, however, does not result in any lowering of LTR.

Further, due to its highly elastic material properties, the mean LTR value of 357 N obtained for the SLN 1010 is just 21 N (i.e. 6%) higher than that obtained for the M02. The reason for this is that the SLN 1010 is primarily used for vibration protection and, therefore, is made from material with properties that differ from those used in products designed specifically for ballast protection. The mean LTR values obtained for the elasto-plastic SLB 3007, SLB 1510 and SL NG are markedly higher.

The SL NG, which prior to loading achieved a mean LTR value of 263 N, following loading, achieved the highest value (493 N) of all the USPs examined.

Further, the scatter between the results obtained following loading is higher than those obtained prior to loading.

Finally, in addition to the experiments noted, various test piece sizes and half sleepers were also used for validation purposes, which yielded LTR values that were very comparable to those that were obtained using the concrete blocks.

Analysis of the ballast contact areas following loading

The analysis of the size of the ballast contact areas revealed large differences between the individual types of USP, varying from around 3% to more than 30%. This suggests that the ballast contact area depends, on the one hand, on the bedding modulus of the USP and, on the other hand, on the surface condition and deformation behaviour of the adopted USP material.

In Fig. 6, the relationship between ballast contact area and the LTR results of the examined USPs is shown. Though it should be noted that such a relationship can only be discerned to a limited extent.

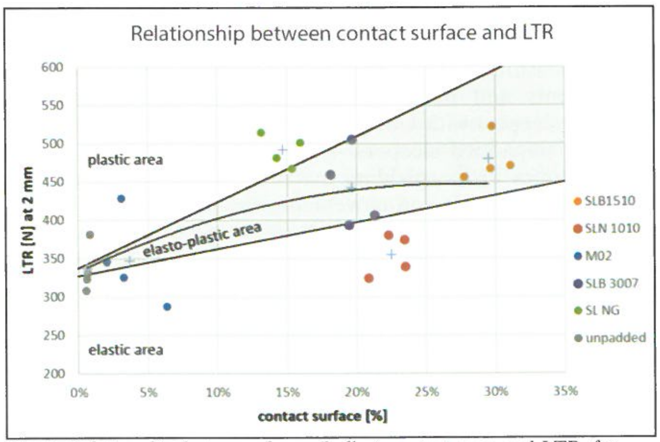

Fig. 6: Relationship between sleeper/ballast contact area and LTR, for different USP material properties, laboratory measurements [3]

As can be observed from Fig. 6, the unpadded test piece, which had the smallest contact area, also generated the lowest LTR. This effect was also observed in the case of the M02, the SLB 3007 and the SLB 1510. In the case of the SLN 1010 and SL NG, a different behaviour was noted.

The evaluation of the laboratory experiments established that there is no compelling, direct evidence of any connection between ballast contact area and LTR. On the contrary, LTR is also a function of the deformation behaviour of the respective USP. Those with a pronounced elasto-plastic behaviour return the highest LTR value, which decreases as the elastic behaviour increases.

The USP deformation behaviour is therefore the key factor for determining LTR, although the influence of the ballast contact area is also evident. The largest ballast contact area occurs when using soft USPs with a low bedding modulus. In this respect, it should be noted that the condition of the surface of the side of the USP facing the ballast must also be taken into consideration. Usually, in order to provide the necessary creep resistance, a protective and load distributing layer is usually applied to soft USPs, which reduces the ballast contact area.

CORRELATION BETWEEN RESULTS FROM LABORATORY EXPERIMENTS AND FIELD TESTS

Comparing the results from laboratory experiments with those from field tests is only possible to a limited extent. In contrast to sleepers in the track, the test pieces used were not fully ballasted, which meant that it was only possible to investigate the pad friction component of LTR. Although pad friction significantly influences LTR, existing studies show that it is only 50% effective against lateral displacement of the track [4]. LTR also depends on the resistance provided by the ballast in the sleeper cribs and at the sleeper ends, i.e. factors that are influenced by the geometry of prevailing sleepers.

The in-track measurements, the results of which are shown in Fig. 1, were conducted for different types of sleeper. The SL NG type of USP, for instance, has only been used in trials on secondary railway lines of ÖBB featuring L6 sleepers (rectangular shape with no tapering in the middle). The mainline railway lines of ÖBB usually feature K1 or L2 sleepers (that are tapered in the middle) with USPs of type SLB 3007. Therefore, a comparison of pad friction for different sleeper profiles is of minor interest. Further, LTR also depends on prevailing local conditions, such as ballast bed height, degree of ballast compaction, as well as other ballast properties (e.g. stone size, angularity, etc.).

The trend of the effect of USP use can be very clearly determined at the laboratory. However, owing to the small amount of data available and the fact that the laboratory experiments described were a first attempt to perform such trials at a laboratory at all, the results showed a relatively high scatter. This clearly shows the need to conduct further investigations before more substantive conclusions can be drawn.

FINAL REMARKS

As the measurement results obtained from both the laboratory experiments and the field tests have shown, by adopting concrete sleepers with USPs, a higher LTR is achieved than by adopting unpadded sleepers – due to the embedding of the ballast stones in the padding material, which reduces ballast quality deterioration and movement. The measurement results from the field tests have naturally shown a rather high scatter because of the different prevailing local conditions, making it difficult to interpret the results. Therefore, in order to allow a reproducible, simpler comparison of different types of USP as regards their effect on LTR to be made, the laboratory test method with controlled test parameters described in this article was developed.

As expected, the results from the initial trials have also shown a relatively high scatter, which is why further laboratory trials are recommended. Nevertheless, the laboratory experiments have clearly shown that the extent to which LTR is affected by the different types of USP (highly elastic/elasto-plastic/plastic) depends on their respective material properties.

REFERENCES

[1] Pospischil F.: 'Längsverschweißtes Gleis im engen Bogen (CWR track in tight curves)', Dissertation, University of Innsbruck, Austria, 2015.

[2] 'Regelwerk 07.06.05 – Oberbau / Oberbauschweißtechnik, Schienenbearbeitung und Zerstörungsfreie Prüfungen (Regulation 07.06.05 – Track / Track welding techniques, rail treatment and non-destructive testing)', ÖBB-Infrastruktur AG, Vienna, Austria, 2017.

[3] Gabl S.: 'Einfluss der Kontaktfläche auf den Querverschiebewiderstand (Influence of ballast contact area on lateral track resistance)', Diploma Thesis, University of Applied Sciences, St. Pölten, Austria, 2019.

[4] Iliev D.: 'Die horizontale Gleislagestabilität des Schotteroberbaus mit konventionellen und elastisch besohlten Schwellen (The horizontal track geometry stability of ballasted track with conventional and elastic under-sleeper pads)', Dissertation, Technical University of Munich, Germany, 2011.

[5] 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.

[6] Prager G., Steiner E.: 'Messung des Querverschiebewiderstandes – L2 Betonschwellen Neulage (mit Besohlung) (Measuring the lateral track resistance – L2 Laying of new concrete sleepers (with padding)), University of Innsbruck, Austria, 2016.

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

[8] Information retrieved from 'https://www.paul-mueller.com/de/produkte/schwellensohlen.html' on 31 January 2020 at 18:20.