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Use of Sylomer® under-sleeper pads to reduce ballast wear on a Scandinavian heavy-haul railway line

The heavy-haul railway line between Luleå and Narvik can conveniently be considered in two parts: the Swedish section (Malmbanan) and the Norwegian section (Ofotbanen). This line has been carrying continuously increasing loads, and so the infrastructure manager decided in 2014 to insert under-sleeper pads as a means of improving the quality of the track geometry. This decision was influenced by the positive experience that the Austrian Federal Railways (ÖBB) had had with the use of pads under concrete sleepers and also by projects such as Innotrack and RIVAS. This article contains a brief description of the Iron Ore Line in Scandinavia and the challenges due to heavy train loads. It also explains how under-sleeper pads work and describes the approaches tried out for switches and crossings.

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1. OVERVIEW AND FACTS

Malmbanan is a railway line providing a route for heavy freight trains in the north of Scandinavia, linking the sea ports of Luleå (Sweden) and Narvik (Norway). It is the world's most northerly electrified railway line, has a total length of 473 km and is used primarily for the transport of iron ore and pellets from the mines in Kiruna und Malmberget to the ports [1].

The Swedish section in the south-eastern part of the region is state-owned, and the infrastructure is managed by Trafikverket (the Swedish transport authority). The line's mixed traffic includes passenger and general-freight trains as well as the heavy freight trains organised by LKAB (Luossavaara – Kiirunavaara Aktiebolag), the Swedish operator of the iron mines. These last-mentioned trains can have up to 68 wagons with an axle load of 30 t and they run over Malmbanan at 60 km/h in a laden state and at 70 km/h if empty. It takes two IORE locomotives to haul the laden trains with a total mass of 8500 t and a length of approximately 750 m.

Back in the 1960s, the railway line was designed for an axle load of 25 t, and then in the 1990s upgrading work began for higher loads. Since 2000, an axle load of 30 t has been possible over the entire length of the through tracks between Narvik and Kiruna. The output of iron ore has been increasing, leading in recent years to a continuous growth in the tonnage transported. A further increase in traffic loads is expected between now and 2018. Figures 3 and 4 compare the number of iron-ore trains and the annual tonnage transported in 2013 with the expected loads in 2018 [1].

FIG. 1: Iron Ore Line between Luleå and Narvik [1]

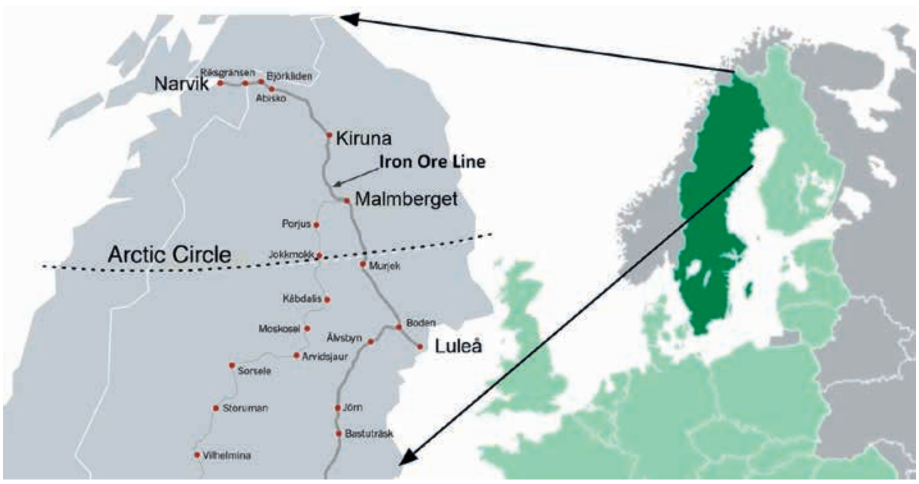

FIG. 2: IORE locomotive [1]

As part of the renewal work on the section of the line between Gällivare and Koskullskulle the operator has replaced wooden sleepers with concrete ones with pads. Since 2014, some 20 000 concrete sleepers with pads have been laid over a length of approximately 10 km. The concrete sleepers have been supplied by Strängbeton and equipped with pads of the type SLB2210G.

2. CHALLENGES DUE TO HEAVY TRAINS

There are limits to what ballasted track will withstand, and these arise particularly with heavy trains. High axle loads and high freight tonnages cause a disproportionate load on the track. It is essential to use top-quality track components to guarantee the availability of the lines by minimising the outlay necessary for maintaining them. Having switched to high-grade rail steels and prestressed-concrete sleepers, the next-weakest link in the permanent way is the ballast. It is common railway knowledge that placing pads under the sleepers contributes significantly to reducing ballast wear. This is primarily explained by increasing the contact area between the underside of the sleeper and the top layer of ballast. Synthetic pads have to be used for this purpose, since they make it possible for ballast stones to become embedded suffering as little damage as possible. An ideal distribution of the load in the track, on the other hand, is achieved by increasing the elastic deflection curve, and for that purpose highly elastic sleeper pads are optimal, since they do not lose their permanent flexibility even if subjected to loads for decades. Permanently flexible sleeper pads, which, thanks to a high degree of plasticity, also embed the ballast better, place tough demands on today's material sciences. The very considerable loads caused by movements of heavy freight trains are to be understood as a particularly tough challenge in this respect. Finding ideal combinations of elastic and plastic properties is not a contradiction, as is shown by current development approaches for maximum loads.

Stresses on track components due to heavy traffic

The International Heavy Haul Association (IHHA) defines "heavy haul" as an operation that meets at least two of these three criteria [2]:

> total train mass equal to or greater than 5000 tonnes
> annual traffic load equal to or greater than 20 million tonnes
> axle load of 25 tonnes and more

Iron-ore trains	Number of trains per day 2013	Number of trains per day 2018	Annual tonnage carried [million tonnes] 2013	Annual tonnage carried [million tonnes] 2018
Northern section (Kiruna – Narvik)	8	12	32	48
Southern section (Malmberget – Luleå)	3-4	4	14	18

FIG. 3: Expected increase in the tonnage carried on the line up until 2018 [1]

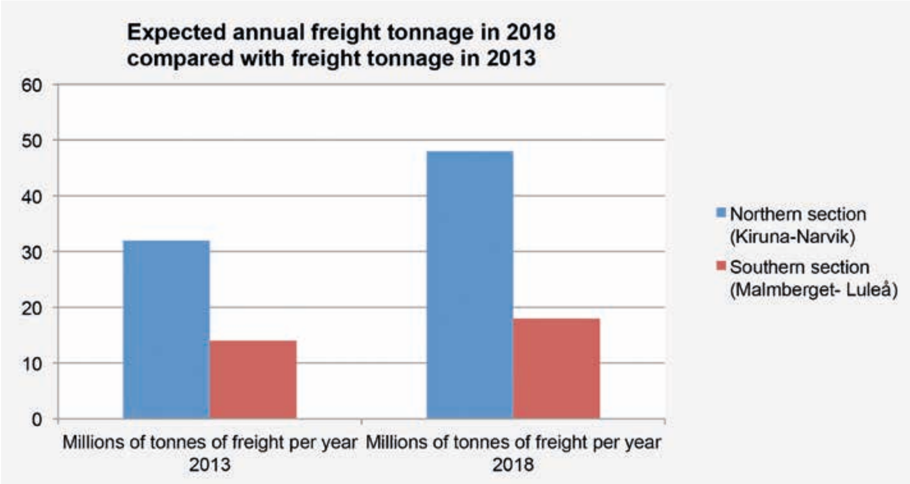

FIG. 4: Expected increase in the tonnage carried on the line up until 2018 [1]

FIG. 5: The line between Gällivare and Koskullskulle equipped with wooden sleepers before renewal

FIG. 6: Concrete sleepers with SLB2210G under-sleeper pads

Whereas passenger traffic with high frequencies is to be found especially in the world's most densely populated conurbations, typical lines carrying heavy, long-distance freight are to be found in other countries too, such as the USA, Canada, China, »

FIG. 7: Heavy freight train on Malmbanan

Australia and South Africa. Those countries have already accumulated extensive experience in the design of sustainable railway lines. A likely trend for the future seems to be that the findings from these lines will also influence other fast-growing infrastructures, such as the dedicated freight corridors that some countries are planning or for the networks of private mining companies, some of which are very extensive. The targeted increase in the axle loads and the increasing tonnages on heavy-haul lines place tough demands on the railway infrastructure and its components. Leaving aside the breakage of tensioning clamps, it is the degradation of ballast, starting at the contact surface between sleepers and ballast, that is one of the primary factors shortening the life of railway installations. Figure 8 shows by way of example the problematical transitional zone between an open track and a bridge structure. Such discontinuities in a track, which ought generally to be constructed so as to be as regular as possible, lead to a particularly intensive load effect with the fracturing and pulverisation of the ballast stones. The formation of white patches is often a clear indicator that this is happening. The consequence of ballast degradation is a continuous deterioration in the quality of the track geometry. It is possible to counteract such negative effects with top-grade under-sleeper pads, often in combination with suitable rail pads.

3. UNDER-SLEEPER PADS MADE OF SYLOMER®

Under-sleeper pads constitute a yielding springy layer underneath the sleepers and increase the contact areas with the ballast from 2-8 % (without pads) to more than 30% (with pads), depending on the boundary conditions. It has already been demonstrated on many occasions that a higher contact area leads to a better assimilation of the load into the ballast and a reduction in the load acting on the subgrade. Under-sleeper pads prevent the breakage of ballast stones on account of overloading, and the extent of track settlement is reduced. There is also a positive impact on the formation of cavities. In order to quantify the general long-term effect of sleepers with pads, extensive investigations have been carried out in the track, to measure the rate of track deterioration, going back as far as 2001 [3]. The sections studied provide impressive evidence of the positive influences on the track superstructure for various boundary conditions. All the track sections with under-sleeper pads show a significantly reduced rate of deterioration. Even in sections with only a thin layer of ballast, it proved possible at least to double the tamping interval. The higher the load on the track, the more efficient the effect of the pads. Under-sleeper pads bring about an appreciable reduction in the maintenance outlay and the life-cycle costs of a railway line [4]. The quintessence is that the sections of line thus equipped have a higher availability. Today, under-sleeper pads are fairly consistently used in the following instances:

- as a standard component for concrete sleepers for more conservative treatment of the ballast
- reduction in settlement for all designs of ballasted superstructure
- reduction in the formation of short-pitch and other corrugations in rails in tights curves
- adjustment of the stiffness of the track in sections with a reduced ballast height
- equipping of transitional sections between differing systems of track superstructure
- reduction in vibrations
- avoidance of ballast cavities, and

FIG. 8: Examples of typical problems encountered on heavy-haul railway lines throughout the world: destruction of ballast under concrete sleepers (left), fractured tensioning clamps (middle) and cracked sleepers (right) are mostly the result of excessively high dynamic loads

FIG. 9: Laying sleepers with pads

> optimisation of geometrically inevitable ballast differences in switches and crossings.

Not all materials are equally suitable for meeting up to these tasks. One material that has been shown to stand out as extremely robust and long-lived is Sylomer®, which is made from special polyurethane (PUR). In the manufacture of PUR a broad range of properties can be set by adjusting the mixing ratio of the reactive input materials to match the requirements profile. The principal components by volume are polyol and isocyanate, and the ratio between them has an essential influence on the mechanical properties and the comparatively high ultimate tensile strength of the finished products. In developing PUR under-sleeper pads with the aim of reducing ballast wear, the decisive considerations are to achieve an optimum mixing ratio and to choose the correct manufacturing process in order to finish up with elastic and plastic properties in balance with one another. It is the outcome of developments that have taken several years that we today have more advanced under-sleeper pads available to us, which in particular compensate for the maximum loads resulting from heavy freight trains and also offer an impressive technical performance, as emerges from the following account.

4. CONTACT AREA AND BALLAST COMPRESSION

It is thanks to the plasticity of the under-sleeper pads that the top layer of ballast is able to embed itself in the pad material.

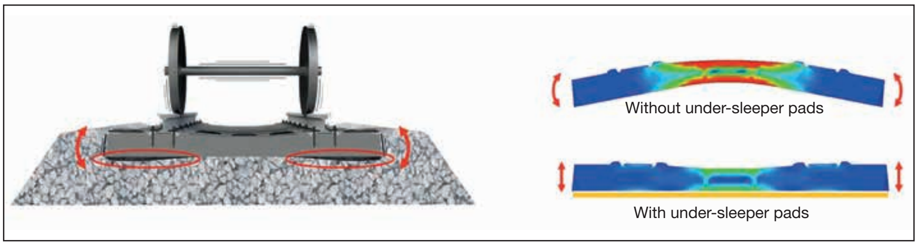

FIG. 10: Formation of cavities under concrete sleepers without pads. With sleeper pads, cavities are avoided and load-transmission

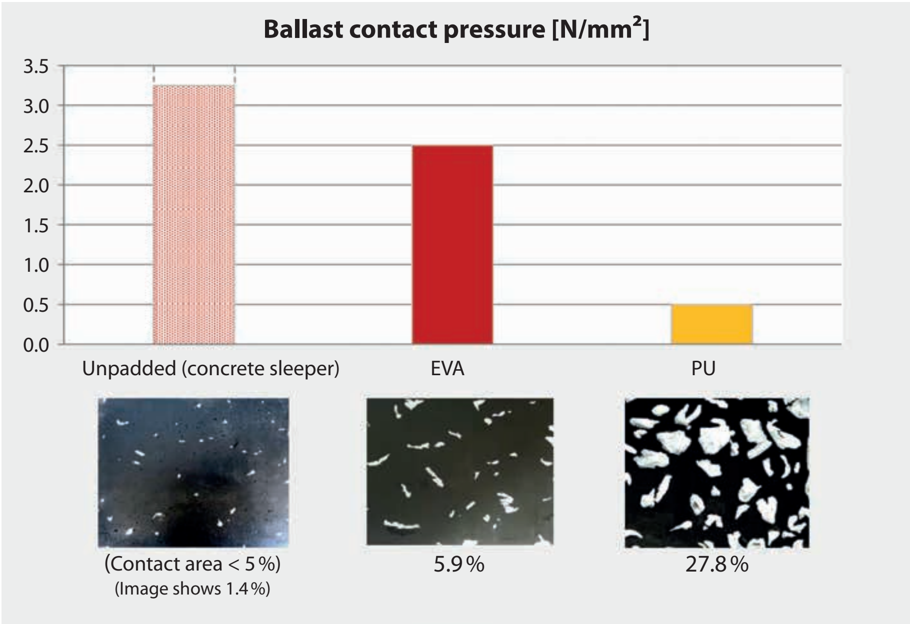

FIG. 11: Mean ballast contact pressures under the concrete block representing the sleeper. Comparison between a concrete sleeper without pads, with EVA pads and with PUR pads. The principal influence reducing the ballast contact pressure is the greater contact area

This is a very important, safety-relevant effect, which plays a significant role above all in resisting the lateral displacement of the track. As research has shown, this resistance is significantly higher when pads are present than in the absence of this embedding possibility [5]. As far as safety is concerned, it has been clearly shown that sleepers with elastic pads have a positive influence on track stability [6].

The principal consequence of the pad flexibility is that the forces are transmitted more uniformly to the ballast bed. Getzner has developed a methodology of its own for quantifying the contact area quickly and very accurately. A digital analysis of various studies has determined that the effective area of contact with the ballast lies in the range of 25 – 33 %.

Without the plastic properties of the pad material, the contact areas would generally be much less.

Figure 11 compares the contact areas without pads, with EVA pads and with PUR pads (same stiffness). As would be expected, this comparative view shows that the contact area of sleepers without pads is the lowest (1.4 % in the test after the cyclical loading test and generally < 5 %), the EVA pad material has a somewhat higher score (5.9 % in the test), but the PUR material has the largest contact area (27.8 %, for the same nominal bedding modulus of the materials). The most important parameter influencing contact pressures is the effective ballast contact area. The greater the contact area, the more uniform the load transmission, and the resulting contact pressure on the ballast in the track is then correspondingly lower.

concrete sleeper without pads, with EVA pads and with PUR pads. The principal influence reducing the ballast contact pressure is the greater contact area.

5. CONTACT IN REAL TRACKS

The contact area was established on sleepers removed from a test section of railway track near Furet in Sweden. Two different products had been in use in the transitional zone between an open track and a bridge, namely elastic sleeper pads of the type SLS1308G »

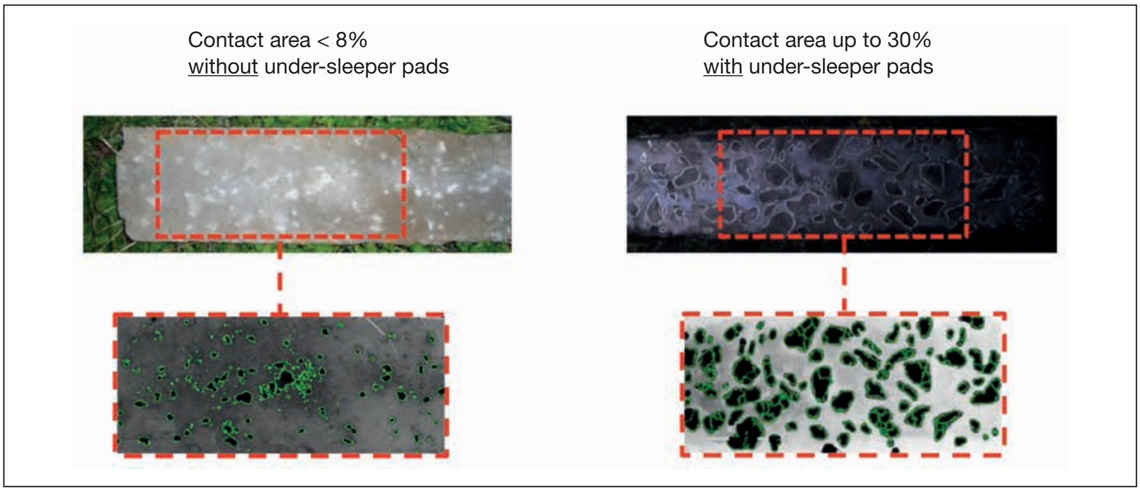

FIG. 12: Furet/Sweden: Comparison of the contact area of sleepers with and without pads

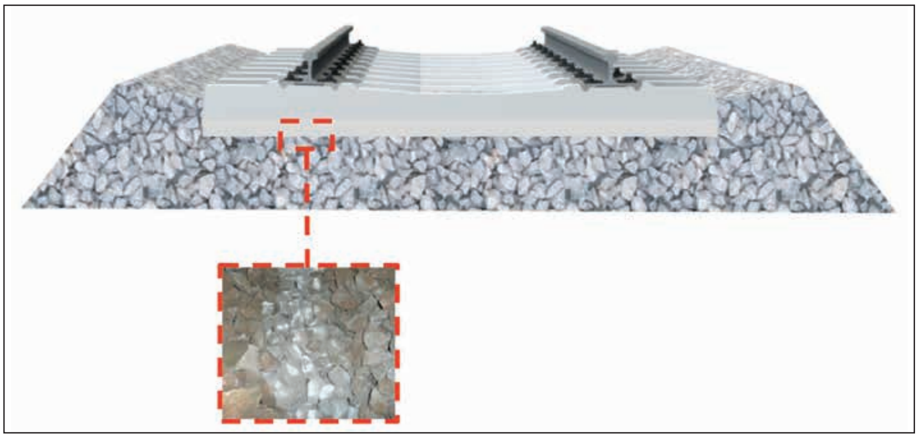

FIG. 13: Furet/Sweden: Abrasion and destruction of ballast under sleepers without pads

and synthetic ones of the type SLB2210G. In September 2014, after remaining in service for nine years in a track with an annual load of around 12 – 15 million tonnes, individual concrete sleepers with pads were removed. The impressions made by the ballast in the sleeper pads were recorded using digital analysis and the percentage of the contact area relative to the total was computed. The measurements made on the sleepers with pads in a railway track confirm the results obtained from other measurements. The contact area of sleepers with pads is around four times higher than that of sleepers without pads. Figure 12 shows that the maximum contact area of sleepers without pads is only 8 %, whereas those with pads achieve a contact area of up to 30 %.

It was established that as a consequence of the higher contact area the ballast was less worn under the sleepers with pads. The ballast under the sleepers without pads showed clearly visible abrasion, indicating ballast destruction (Fig. 13).

6. IMPROVEMENT IN QUALITY OF TRACK GEOMETRY

The positive effect of installing under-sleeper pads made of Sylomer® has been validated on various sections of test track in different countries [7]. For comparative purposes, individual sections were equipped with further-developed PUR under-sleeper pads. Test sections were also set up without under-sleeper pads in order to establish the differences in the tracks' long-term behaviour. Precision levelling was used to record the tracks' settlement behaviour. Figure 14 shows examples of mean settlement curves. In this example, the trends were already clearly recognisable after 377 days. The mean track settlement had reached a value of 7.5 mm in the zone with pads. In the track without sleeper pads, by contrast, the track settlement had already reached a mean value of 12.5 mm. That meant that the settlement of the classical ballasted track was more than 65 % greater than in the zone with under-sleeper pads, which certainly reflects the experience from other locations where such pads had been used – despite the relatively short observation period.

The test sections of track in which sleeper pads were installed displayed a much more homogenous quality of track geometry, which can even be recognised with the naked eye in certain circumstances, as illustrated in Fig. 15.

Generally speaking, stabilising the ballast with under-sleeper pads results in higher resistances to lateral displacement of the track [8]. As a rule, the greater the contact surface, the higher the achievable resistance to lateral displacement. It will be noted that, as a result of the improved quality of the track geometry, the formation of cavities can be almost entirely prevented in track with under-sleeper pads [9].

For heavy-haul railway lines, further developments working towards "semi-plastic pads" may deliver an even greater benefit.

7. SLEEPER PADS IN SWITCHES AND CROSSINGS IN THE SWEDISH RAILWAY NETWORK

International experience, such as that of the Austrian Federal Railways (ÖBB), and positive results from the Innotrack project [10] led Trafikverket to decide to install under-sleeper pads. In 2014, a framework contract was concluded for the delivery over a two-year period of around 100 000 Getzner under-sleeper pads for switches and crossings. Since 2014, approximately 40 000 such sleepers have been laid in the Swedish railway network.

Given the complex geometries of switches and crossings, the outlay in labour and financial terms for maintaining track there is very much higher than for plain track. It is especially the differences in the stiffness of the track bed in the direction of travel, which is inevitably due to the design of the switch-

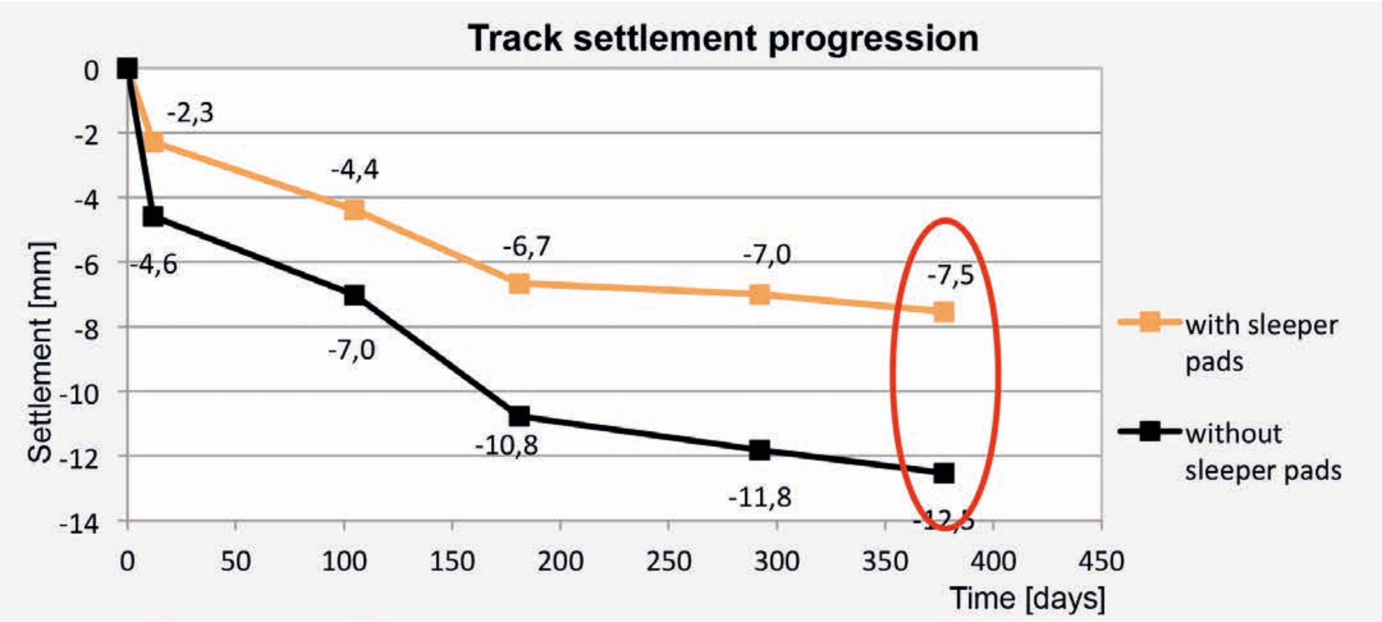

FIG. 14: Mean settlement over time with and without sleeper pads after a test period of 377 days

es and crossings that lead to differences in the settlement of the rails. This results in additional stresses in the track superstructure when a train passes over it. Clear-cut improvements in the stability of the track geometry and vibration abatement can be obtained here through the use of elastic under-sleeper pads. The ballast is subjected to less stress, and the tamping intervals can be increased. The life-cycle costs of switches and crossings can be very considerably reduced.

If the system of elastically supported switches and crossings is to be installed in a targeted fashion in a ballasted track, it is vital to understand the demands made of the elasticity and also what happens when a train passes. This requirement led Getzner Werkstoffe to develop a non-linear mathematical model based on the finite element method (FEM). This model offers the possibility of placing the elastic under-sleeper pads of the Sylomer® or Sylodyn® type in the various zones within switches and crossings so that the jumps in stiffness can be smoothed out and thus significantly reduced.

8. CONCLUSIONS AND OUTLOOK

Since 2014, under-sleeper pads have been installed on the heavy-haul railway line between Luleå in Sweden and Narvik in Norway. Trafikverket expects the use of these pads to extend service life and improve the availability of the line, thanks to a reduced outlay on maintenance. Studies on the Furet test section have already confirmed that there is a marked reduction in ballast destruction if concrete sleepers are fitted with pads, given the increase in the contact sur- »

FIG. 15:
The differing quality of comparable sections of track is obvious, with under-sleeper pads (left) and without them (right)

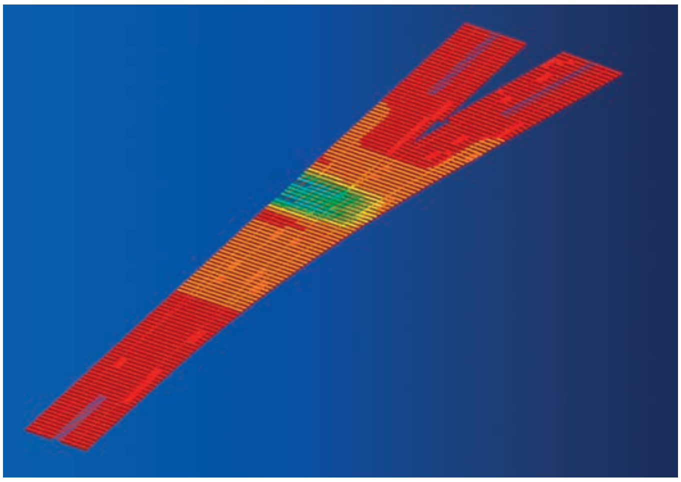

FIG. 16:
FEM model for optimisation the use of pads on switches and crossings

face. Furthermore, longitudinal-level measurements show that there is an improvement in the quality of the track geometry [11].

On the basis of these findings from test tracks and their confirmation in international experience, Trafikverket decided in favour of concrete sleepers with pads made of Sylomer®. Experimental reports from the Austrian Federal Railways (ÖBB), the Innotrack project and RIVAS form the basis for the decision to use them as a standard, with the aim of reducing ballast wear both on open track and in switches and crossings.

It is particularly on heavy-haul railway lines such as Malmbanan that the track ballast constitutes the limiting factor. In connection with swapping wooden sleepers for concrete ones, the demand arose for additional elasticity to be provided under the sleepers. Under-sleeper pads made of Sylomer® do indeed cause less wear and tear to the ballast.

Innovative developments in materials show the possibility of combining elastic and plastic properties in the track in an ideal way. The results are both a better distribution of the loads in the track and a reduction in the contact pressures between the sleeper and the top layer of ballast. This, in turn, leads to a reduction in settlement in combination with an improved quality of track geometry. The benefits for the infrastructure manager lie in the reduced maintenance outlay and the higher availability of the railway lines. The design of the classical ballasted superstructure benefits from lasting improvements through such innovative developments. F

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