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LIGHT-RAIL SYSTEMS AROUND THE WORLD

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EUROPEAN STANDARDS FOR RAILWAY TRACK

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FIBRE OPTIC RAIL-FOOT CABLES

In a test phase in Germany a new fibre optic cable has demonstrate its quality

Under Sleeper Pads in Turnouts

Modern railway tracks distribute the loads from rail vehicles via the rails, rail seats and sleepers as evenly as possible. There are limitations when it comes to turnouts. Points show an irregularity in regard of the vertical elasticity. Mostly they are too stiff. But their elasticity can be adjusted by under sleeper pads.

1 Challenge

Modern railway tracks need to be able to bear the loads from rail vehicles via the rails, rail seats and sleepers as evenly as possible and distribute such to the track superstructure and to the subgrade. By distributing these loads sufficiently, stresses can be kept as low as possible, helping to minimize maintenance expenses and thus increase the operating life of the track system.

Although one can draw on tried and trusted calculation methods, as per Zimmermann [1] for beams on elastic foundation in respect of the load distribution effect, there are limitations when it comes to turnouts. Due to their geometry (Fig. 1), turnouts show an irregularity which can result in various degrees of rail deflection within different areas, even if other boundary conditions remain unchanged.

Fig. 1: Turnout with rigid crossing frog and check rails

Harald Loy

System Development

Address: Getzner Werkstoffe GmbH
Herrenau 5, A-6706 Buers

harald.loy@getzner.com

Variations in stiffness along the tongue and frog area, as well as the constantly changing load-bearing surface area of the sleepers in the ballast superstructure result in discontinuity of the track system.

The differences in the load-distributing over the turnout length is a 3-dimensional problem which can be grasped and analyzed using Finite Elements Methods (FEM). By installing additional elastic elements with defined stiffness it is possible to increase the load-distributing effect of the rails. At the same time the load-bearing characteristics of the track frame can be optimized. One cost-effective way of approaching this target is to use under sleeper pads (USP) with varying degrees of stiffness.

In the following a short presentation of the fundamental impact of the bedding modulus, the possible increase in superstructure elasticity via USP and a 3-dimensional FEM turnout model for optimizing the USP arrangement is provided.

2 Bedding Modulus

The static and dynamic loads on the track superstructure stemming from rail traffic mainly depend on the behaviour of the track bed, as well as the geometry and stiffness characteristics of the track frame. For traditional ballasted track, the elasticity derives primarily from the flexibility of the ballast bed and the subgrade. It is generally expressed via the bedding modulus C and represents the relationship between the surface pressure and the related rail deflection.

$$C = \frac{p}{y} \quad [\mathrm{N/mm^3}] \quad \text{with}$$

p = pressure between sleeper and ballast [N/mm^2]
y = rail deflection [mm]

In simplified terms, the bedding modulus indicates how much pressure [N/mm^2] results in a deflection of 1 mm. As surface pressure is already included, the bedding modulus is used to describe stiffness in cases where the elasticity primarily results from a surface mounting, for example with traditional ballasted track, or for characterizing flat elastic elements such as ballast mats and USP.

The bedding modulus of different kinds of ballasted track ranges from roughly 0.05 N/mm^3 (very soft) to more than 0.40 N/mm^3 (very hard) on average, depending on the installation conditions [2]. For new rail lines, the higher stiffness mainly results from the construction of compacted substructure and anti-frost layers. Moreover, the use of the Dynamic Track Stabilizer (DGS) in ballasted track also results in consolidation. While measures of this kind increase the load-bearing ability of the track bed, at the same time the rail's function as a load-distributing element is reduced, with negative ramifications for dynamic effects in wheel/rail contact, and this can lead to increased stresses on the ballast.

Higher degrees of bedding stiffness due to consolidated ballast and subgrade with greater load-bearing capacity can be adjusted by installing elastic elements with lower levels of bedding modulus.

Regarding the beam on elastic foundation according to Zimmermann, a reduction of the bedding modulus from C to C* decreases the ballast pressure by the factor $\sqrt[4]{C^*/C}$.

If the effect of a reduced ballast pressure is quantified with regard to consideration of track stability using the 2nd power law, a reduction in the ballast pressure of 15% results for example in a lengthening of the intervals for track maintenance by a factor of 1.4. With regard to consideration of track stability using the 4th power law, the same reduction in the ballast pressure results in lengthening the interval by a factor of 1.9, i.e. the duration until the next track maintenance is almost doubled!

The applicability of this assessment of track stability is backed up adequately by the derived results of the AASHO Road Tests [3] and the experience gathered by Deutsche Bahn following introduction of heavy superstructures using UIC 60 rails [4]. In this regard, reference is made to a direct 'hard mounting' of the sleepers on the ballast.

Fig. 2: Concrete sleepers with Sylomer® under sleeper pads (USP)

In regard to the flexibility of the ballasted track, the resulting bedding modulus of the standard gauge track should be set in a way that sufficient rail deflection is ensured, which should not be less than 1.0–1.2 mm [6], taking into consideration the load-distributing effect in the track and the turnouts. The limiting factor is generally the maximum permissible amount of rail foot tension.

3 Increasing Superstructure Elasticity with Under Sleeper Pads (UPS)

USP are a cost-effective way for subsequently increasing the elasticity of the superstructure and reducing wear and tear on the ballast (Fig. 2). USP are elastic elements located between the sleeper and the ballast and are today available in a continuous range from approximately 0.02 N/mm³ to harder than 0.30 N/mm³ for standard products, Determination of bedding modulus is given by BN 918 145 – 01 on a prescribed load plate with ballast profile [5].

The investment cost is far lower than those for the installation of ballast mats. Ballast mats are mainly used where direct mounting to a hard subgrade, e.g. on a bridge, should to be avoided.

USP does not necessitate the installation of elastic railpads. The track frame consisting of the rails and concrete sleepers, which is rigidly connected into a load-bearing structure via the rail fasteners, can thus remained unchanged in its traditional role. This is also valid for upgrading of tracks, as the costs involved for such work are also comparatively low.

With ballasted track, elastic USP not only allow for a longer rail bending line, which reduces loads on the ballast, they also help to prevent contact abrasion as the top layer of ballast can become embedded in the pads. Hard contact points between the bottom of the sleeper and the ballast are alleviated and the track mounting is more homogeneous. The pads also help to prevent sudden settling of sleepers due to cavitations [7].

Due to stabilization of the top ballast layer, migration of ballast rocks due to dynamic forces is shifted to lower layers, which can have a benign effect on the long-term quality of the superstructure.

Even under the assumption of declining effectiveness over the effective lifetime of the rail, USP still cannot result in any detrimental impact on the track superstructure. In this regard, they can be seen as fail-safe elements. The track superstructure will always exhibit more favourable characteristics than structure without any USP.

There are numerous ways to ensure adequate adhesion of the pads to the sleepers. One possibility is to glue the pad to the cured concrete, but the general trend in the future shows that the pads are integrated directly into the sleepers as a part of the manufacturing process. A tight connection can be achieved using a plastic mesh, half of which is integrated into the sleeper pad and the other half of which can be vibrated into the wet concrete of the sleeper.

Tests in Germany have shown that the use of sleeper pads allows for significantly improved track behaviour and dynamic vibration behaviour compared to traditional ballasted track [8]. In Austria, turnouts with USP were already installed in 2002 and measurements have shown a reduction of vibrations in the 40 Hz–50 Hz frequency range. Moreover, substantially less subsidence was found in turnouts with rigid crossing frogs, even compared to constructions with moveable crossing frogs [9]. The positive experiences with USP in turnouts have led to the development of a standardized design for the Austrian Federal Railways.

4 Geometrical Discontinuities at Turnouts

Compared to straight track, for which calculations are easy to conduct due to the relatively homogenous geometry with constant rail profiles and sleeper mounting surfaces, calculating elastic elements in turnouts is far more complex. The main reasons for higher effort include the varying profiles of the rails, the additional construction elements and the generally strong variations in the sleeper conditions. These parameters result in varying degrees of vertical load deflection.

Looking at a standard right-hand turnout, there is an initial jump in stiffness at the transition point from the stock rail sleepers, which are not supposed to be tamped in the middle, to the heavier turnout sleepers which are often located in front of the switch panel (Fig. 3).

In the switch panel itself, switching machines which are integrated into hollow steel sleepers can result in additional discontinuities. The switch rails themselves have an increasing moment of inertia from the toes to the centre of the turnout. During passage of the vehicle, while the stock rail is loaded with one wheel load, the softer switch rail results in a lower distribution of load when subject to the load from the opposite wheel load. In the area of the closure rail, the continuously growing sleeper areas are also noticeable. The massive frog together with the wing rails results in the greatest stiffness. Due to the check rails and the long sleepers, the distribution of the loads is greatest in this area. Immediately after the last long sleeper there are often eccentrically placed short sleepers with shortened sleeper heads on the interior side. This results in a strong load on one side, with corresponding torsion of the track, depending on the track design.

The geometrically determined discontinuity

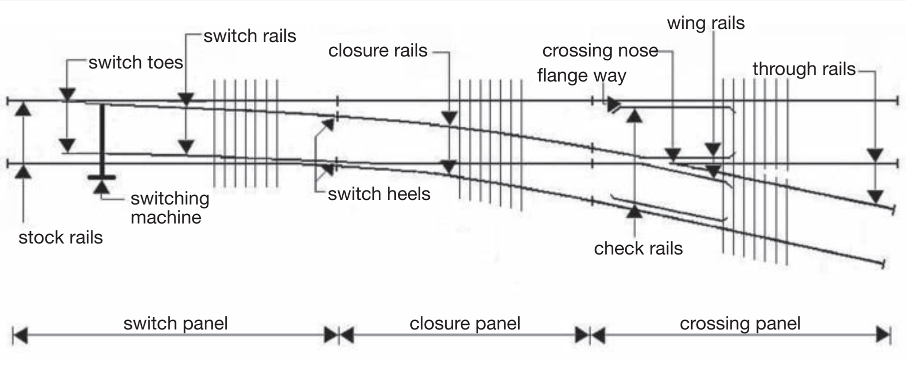


Fig. 3: Components of a standard right-hand turnout

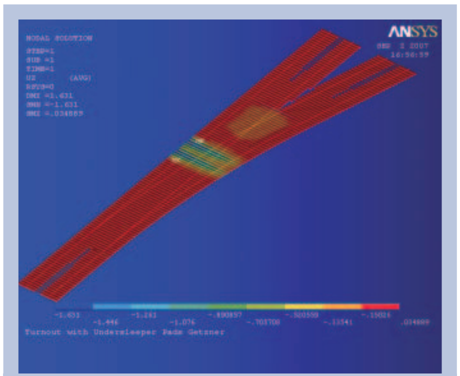


Fig. 4: FEM turnout model for the optimization of under sleepers pads

in the turnout area causes strong localized variations in the loads on the superstructure. With a lower bedding modulus, the bending lines can be lengthened which reduces the amount of pressures on the ballast. At the same time, by optimizing the distribution of the bedding modulus with various USP it is possible to smooth out the differences in stiffness stemming from the geometry. Thus, careful design and installation of various types of sleeper pads can achieve a double positive effect in the turnout area: Loads on the superstructure can be reduced and the turnout can be 'smoothed out'.

5 FEM Turnout Model

It is necessary to understand the entire system in order to be able to transpose the positive experiences gained with padded sleepers to applications involving turnouts. And furthermore to balance out the geometrically determined differences in vertical load distribution. The Finite Elements Method (FEM) can help us to grasp this system (Fig. 4).

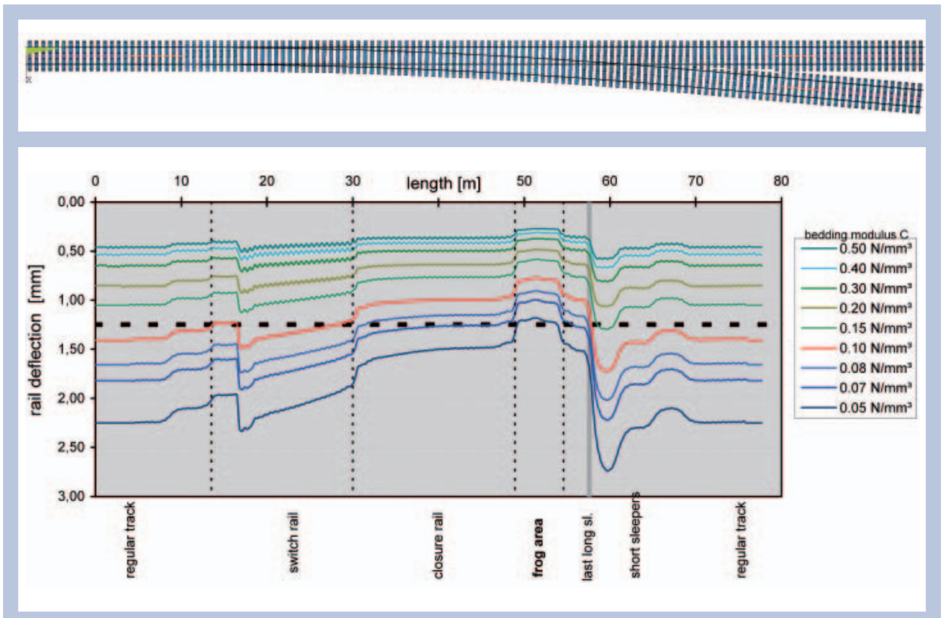


Fig. 5: Deflection pattern of the rail through the entire turnout by reduced bedding modulus step by step

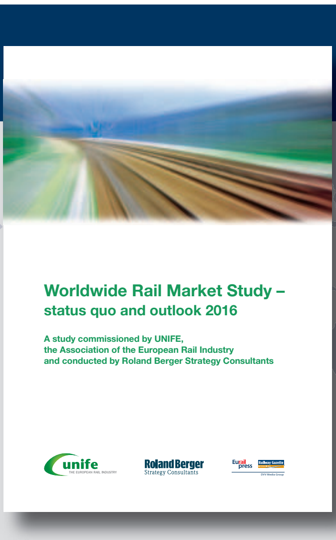
Using FEM and high-performance computers, it is possible to generate a complete turnout with padded sleepers and to perform analyses in respect of its load-bearing functions. In contrast to the manual calculation method according to Zimmermann, there is no need for idealization by transformation of the entire structure (transverse sleepers in longitudinal sleeper superstructure, resultant stiffness for several elastic levels). But in order to cut calculation times, the individual components are reduced by base elements to their relevant functionality and the necessary degrees of freedom. Another advantage of the model is that variable parameters can be assigned for all geometries and stiffness in the rail elements (tongue, crossing frog, check rails, etc.). The same is valid for sleeper parameters and the non-linear behaviour of the rail fasteners (rail plate/baseplate function under pressure loads - fastening clips function under tension loads). Moreover, the behaviour of the bedding (sleeper pads and ballast) can be modelled using any desired non-linear deflection curves.

As the individual elastic levels are not 'superposed' by the formation of resultant spring stiffness, it is possible to simulate a division of the flexibility in levels above and below the sleepers. As a result, it is also possible to individually observe deformation variables.

Parameterization of the model allows for any standard turnout to be generated with the defined characteristics and for calculations to be carried out with a moving load collective, corresponding to the load impact of the bogies. As a result, one obtains all of the vertical deformation in the entire structure (subsidence and rises); the strains result from the kinematic conditions and the parameters of the construction components. A holistic model of this nature can be helpful for grasping the system comprising the elastically mounted turnout in the ballasted track and making targeted adjustment for the further development of such.

6 Analysis of Load-Bearing Behaviour

In order to understand the bedding impact on the vertical rail deflection, the stiffness of the ballast and the subgrade throughout the entire turnout area is uniformly and stepwise reduced within the framework of a simulated calculation. The maximum rail deflection can therefore be calculated for each load position, based on the load col-



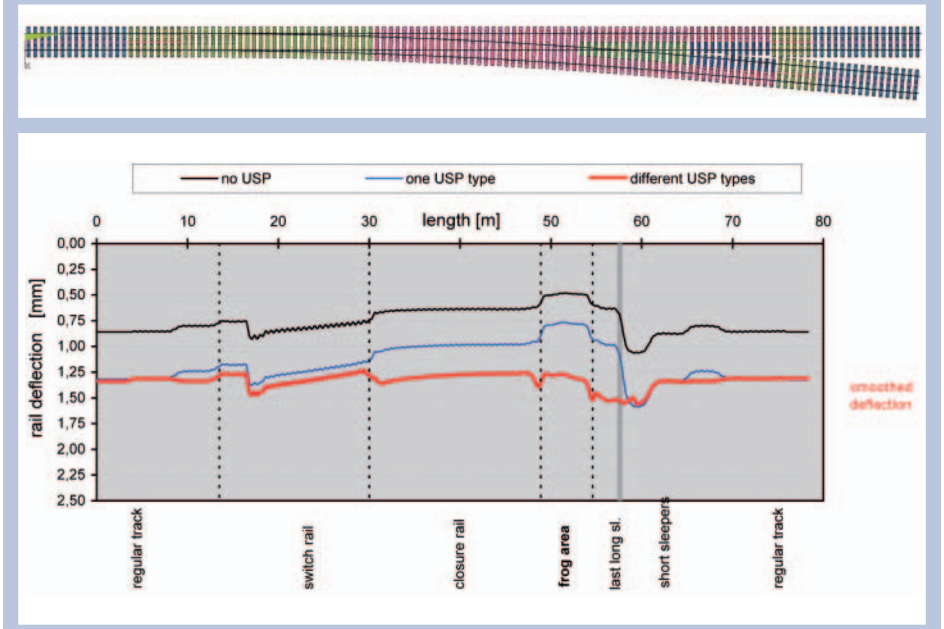


Fig. 6: Comparison of rail deflection patterns with optimized track using different USP along the turnout

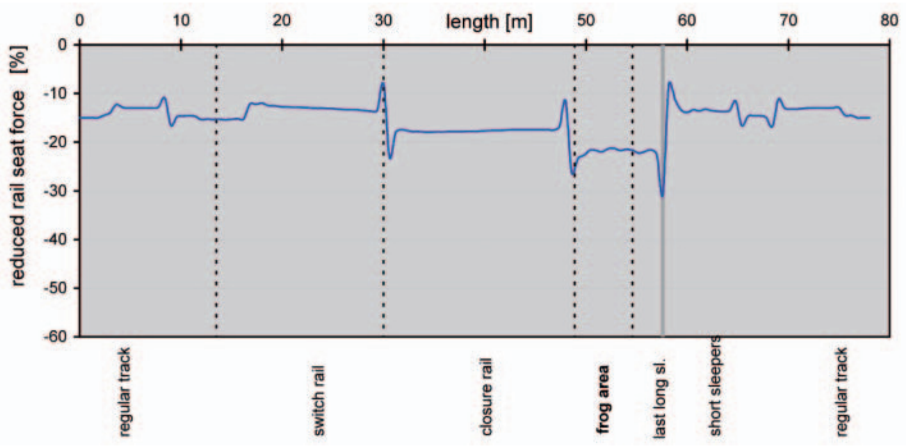


Fig. 7: Reduction of rail seat forces along the turnout with optimized solution

lective for a typical bogie (axle load 220 kN, 3 m spacing). The deflection patterns presented in Fig. 5 represent the envelope for the maximum vertical deformations of the relevant rail.

One can see that a lowering of the bedding modulus results in an increase in rail deflection as desired. But at the same time the various differences in the stiffness can also be seen along the path of the turnout. The differences in the deformation curves are magnified. The lower the bedding modulus is, the more pronounced the differences are. In this regard, the amount of deflection is lowest in the crossing frog due to the higher level of rail stiffness and the large surface area of the sleepers, whereas immediately after the last long sleeper.

By optimizing the arrangement of USP with varying degrees of stiffness, these differences can be smoothed out. Fig. 6 shows a comparison with an improved arrangement of stiffness using various types of USP.

The first curve shows as an example the deflection curve without any additional USP. The rail deflection of 0.8 mm in the regular track results exclusively from the defined bedding modulus of the ballast and the subgrade of 0.2 N/mm^3. If the vertical deformation is increased by the uniform installation of additional under sleeper pads, the resulting bedding modulus of roughly 0.10 N/mm^3 leads to an increase in deflection to 1.3 mm before and after the turnout. The differences in vertical rail deflection can be smoothed out by the installation of various USP, in the event of identical initial levels. This allows for a more homogenous pattern of deflection to be achieved (using different USP types). The turnout is smoothed in its function as a load-bearing element.

Fig. 7 shows the reduction of rail seat forces compared to a turnout without USP. Even with the relatively stiff pads used in this case (> 0.2 N/mm^3) the forces transmitted into the superstructure can be reduced on the order of 10 % to 30 %, depending on the part of the turnout.

7 Summary

The use of under sleeper pads (USP) can increase the elasticity of track superstructure with relatively low investment costs. At the same time the ballast, which is a latent source of track instability, is stabilized, as individual ballast rocks can become embedded in the surface layer of the USP. Loads on the superstructure are reduced by a more homogenous mounting of the sleepers and track stability is improved.

Moreover, in turnouts, the geometrically determined differences in stiffness can be smoothed out. To achieve this target, USP with various degrees of stiffness can be used, positioned in a way that the entire construction features improved load-bearing conditions. This allows the track to be smoother. Track irregularities resulting from turnouts can thus be mitigated and vibrations can be reduced.

Using a turnout model based on the Finite Elements Method, it is possible to analyze the load-bearing behaviour of the construction. As data can be varied for different parameters, it is possible to analyze a very wide range of geometric boundary conditions and stiffness conditions. The challenge involved is to take into consideration the non-linear bedding properties.

Using the FEM turnout model, an optimized arrangement of Sylomer® USP can be calculated for any situation.

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