

Ballastless Tracks on Asphalt Pavements - Design and Experiences in Germany –

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ABSTRACT: During the last three decades different types of ballastless tracks have been developed, tested and built in high speed lines of the German DB-AG.:

- single rail supports directly fixed on a pavement (CRCP only).
- prefabricated, prestressed slabs or frames connected to a treated base
- sleeper panels rested on a pavement (AC or CRCP) or connected in a monolithic way (CRCP only)

The axle loads of railway vehicles are much higher compared to heavy trucks. But due to the good load distribution reached by rail and resilient rail supports and due to a sufficient contact area between sleeper and treated base the contact pressure on pavement surface can be decreased. Therefore asphalt pavements offered suitable solutions for ballastless track developments. The concrete sleeper panel must be fixed by suitable components to the asphalt pavement to handle the horizontal forces caused by traffic and by temperature changes. The weight of sleepers should be considered in respect of rail uplift forces. In addition to the bearing capacity for asphalt pavements the occurrence of deformations caused by the time and temperature dependent visco-elastic behaviour of asphalt must be taken into consideration. Due to the accuracy of the vertical track-alignment according to the design speed up to 300 km/h and more and due to the sufficient surface drainage the deformations must be limited, but enable better adaptation at the interface between sleeper and pavement. Experiences born at test sections and revenue lines are given.

Key words: Ballastless Track, Sleeper panel, Asphalt pavement

1. INTRODUCTION

The fixation of sleeper panels for high speed tracks on asphalt courses is first of all a combination of conventional railway-track and road construction technologies. The experiences and quality level reclaimed from both techniques can be utilised.

But it must be taken into account that the requirements of ballastless tracks construction to the paving technology are in respect to some design parameters much higher and sharper, respectively. E.g. the maximum cant (for German tracks $u_{\max} = 170$ mm equivalent to a cross-fall of about 11,8 % in comparison with a maximum cross-fall of 7 % for roads) and the higher design speed (now up to a level between 300 km/h and 350 km/h) have

to be converted into continuously high quality at the construction site. Additional elements are needed to handle the horizontal load transfer especially in transversal direction.

2. GENERAL PAVEMENT DESIGN

2.1 Road pavements

State-of-the-art of pavement design and construction in Germany is fixed in regulations covering the experiences in situ and theoretical investigations and calculations. Sharing this knowledge the road-engineer is enabled to choose a suitable design for the planned pavement using the design catalogue RStO 01 (FGSV 2001).

Content of the RStO 01 (FGSV 2001) are load dependent classifications of asphalt, concrete and block pavements and accordant solutions given by possible layer combinations of the chosen superstructure. For motorway constructions the competition between asphalt and concrete pavements was helpful to force steady development on both technologies (block-roads are not allowed for fast and heavy traffic). Concrete pavements in Germany are usually built as Jointed Plain Concrete Pavements (JPCP).

As input-data for the RStO 01 (FGSV) the expected loading number during the road-lifetime is needed. The actual or expected loading numbers have to be summarised to a loading value B, which is the number of loading by respective Equivalent 10t Single Axle Loads (ESAL). Lifetime of roads is usually set to be 30 years. Due to local differences of climatic conditions an additional thickness or reduction of thickness of the base layers (usually unbound material) must be taken into account. Figure 1 shows an example for heavy loaded pavements ($B > 32 \cdot 10^6$ ESAL) which requires a total thickness of 30cm of asphalt layers.

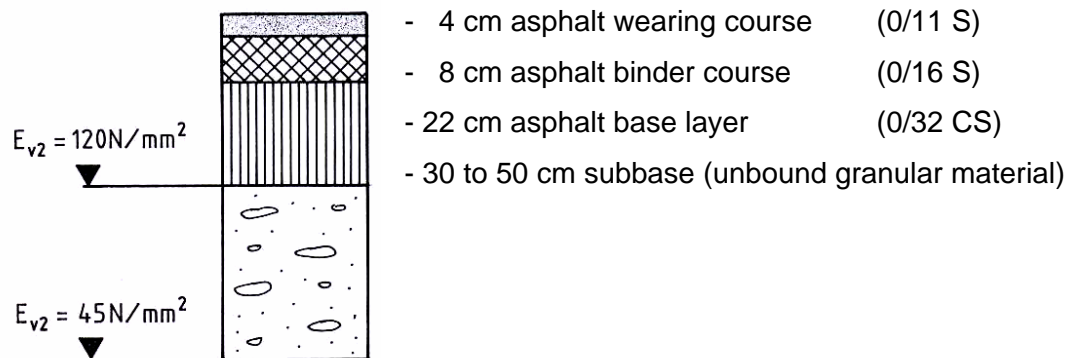


Figure 1: Thickness design according to RStO 01 Road classification SV- Line 1

SV is equivalent to $B > 32 \cdot 10^6$ ESAL (FGSV 2001).

2.2 Railway tracks

For conventional ballasted tracks on earthwork the sleeper panel is supported and horizontally (longitudinal and transversal) fixed by the ballast. Decisive property of this kind of support is to be a non rigid one. Without additional resilient elements a load distribution by the rail can

be reached, which is usually sufficient for secondary tracks. Due to small plastic deformations and movements within the ballast matrix by load transfer changes of track-geometry occur and track maintenance by tamping is needed. Furthermore the ballast is a suitable element to work as a connecting link between prefabricated track-parts (sleeper panel) and the parts built in place (base layers and earthworks).

Exchanging the ballast layer by concrete or asphalt layers with high stiffness to guarantee constant and continuous track alignment and mechanical properties additional resilient elements are needed, which are usually positioned under rail-foot. Furthermore the ballast-property of track fixation in combination with the ability to compensate unavoidable tolerances must be replaced by suitable track design and stringent quality control for ballastless tracks. In general for all ballastless track systems the interface between cross-section elements prefabricated in plant and elements laid in place is the most sensitive aspect concerning the long time behaviour. State-of-the-art of ballastless track design and track construction in Germany is fixed by the Deutsche Bahn - AG in the specification "Anforderungskatalog zum Bau der Festen Fahrbahn" (DB-AG 2002). Required life-time is usually at least 60 years.

During the last three decades different kind of track systems have been developed, tested and are now in service for German high speed links. According to the main principles of design all these ballastless track systems can be divided into three main-groups:

- I. Discrete rail supports directly fixed on a continuously reinforced concrete pavement (CRCP).
- II. Prefabricated, prestressed slabs or frames connected to a treated base using sealant mortars
- III. Sleeper panels supported by an asphalt pavement (AC).
or connected to a continuously reinforced concrete structure (CRCP).

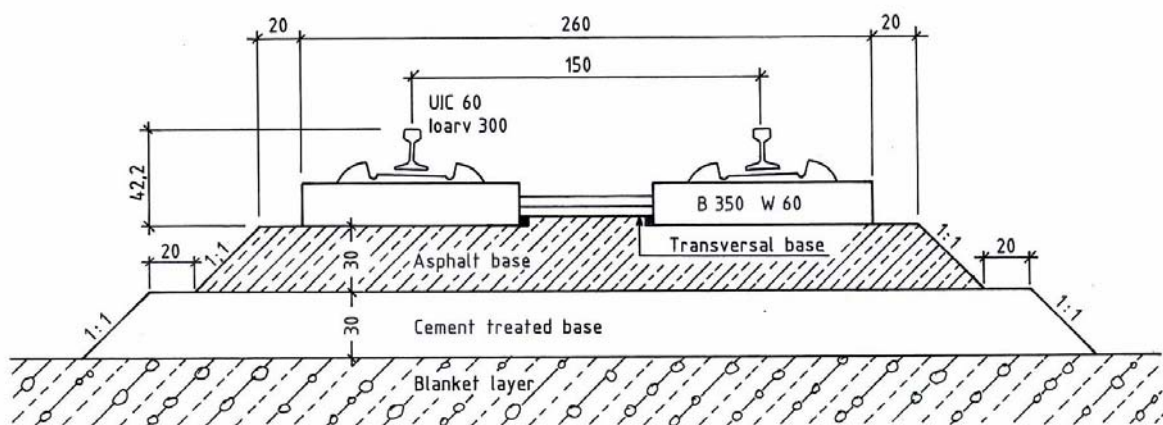


Figure 2: Sleeper panels supported by an asphalt pavement (ATD-System, Nantenbach 1993)

Asphalt base:	4 cm asphalt wearing course	0/11
	6 cm asphalt base layer	0/16
	20 cm asphalt base layer	0/22 (two layers paved)

Fixation of discrete rail seats directly on asphalt pavement has been investigated in the past, but did not meet the durability requirements because of the visco-elastic behaviour of asphalt mixtures. So asphalt pavements can be used together with sleeper panels or prefabricated slabs and frames only.

Like the most ballastless track solutions asphalt pavements are usually rested on a cement treated base (or a bituminous base) in a thickness of 30 cm (CTB) on top of the granular blanket layer. Alternatively asphalt layers in a total thickness of 40cm paved on frost blanket layer have been built (e.g. line Hohenthurm – Halle in 1995).

3. BEARING CAPACITY

Road pavements and ballastless track structures have to handle different kind of acting forces within vertical and horizontal (longitudinal and transversal) direction which are caused by traffic and/or environmental impacts.

3.1 Vertical loading

Road design (public roads) is based on the equivalent 10-to single axle-load (ESAL) or a $Q = 50$ kN wheel force, respectively. Dependent on the wheel design and air pressure this load is distributed towards the pavement contact area causing a contact pressure of about $p = 0,7$ N/mm² up to $p = 0,9$ N/mm² (see Figure 3).

For track design different maximum axle loads up to the design axle load configuration given by the load scheme UIC 71 are used, which gives a maximum axle load of 250 kN. Maximum axle loads of actual high speed trains are about 170 kN (ICE 3) and further reduction is expected.

Due to the good load distribution by the rail (which caused a reduction of the decisive rail seat loads) and by sleepers with large contact areas (minimum sleeper length 2,40 m) towards the pavement with a width of 3,0m to 3,2 m a sufficient distribution of the wheel load (which is about 100 kN) according to the transversal direction can be achieved (Leykauf and Freudenstein 1998). To guarantee that no negative bending moments are activated within the sleeper centre this area of the sleeper has to be free of vertical contact. In this case the slab-thickness can be designed using Zimmermann's theory modelling an infinite beam which is supported in a continuously and resilient way. Neglecting the elasticity of the pavement itself the rail seat loads (S_{stat}) caused by the train or loading scheme (UIC 71) can be calculated. Additionally these static rail seat loads (S_{stat}) have to be increased (S_{dyn}) to consider centrifugal forces and dynamic effects (Eisenmann and Leykauf 2000). Usually the contact pressure between sleeper and pavement will be lower than 0,3 N/mm² (see Figure 3).

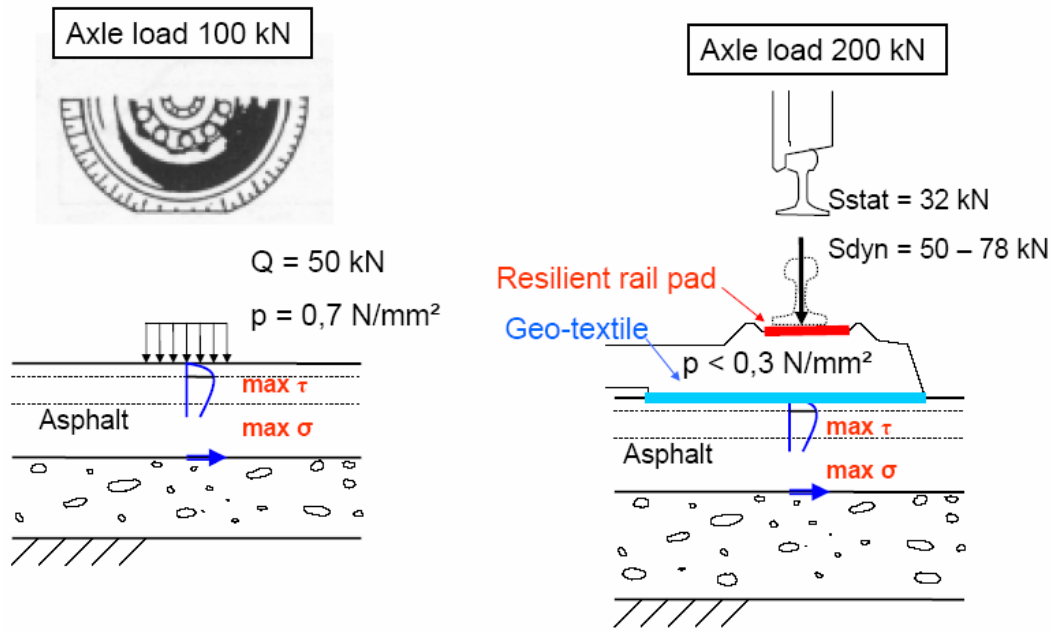


Figure 3: Loading of asphalt pavements; Comparison between road and railway.

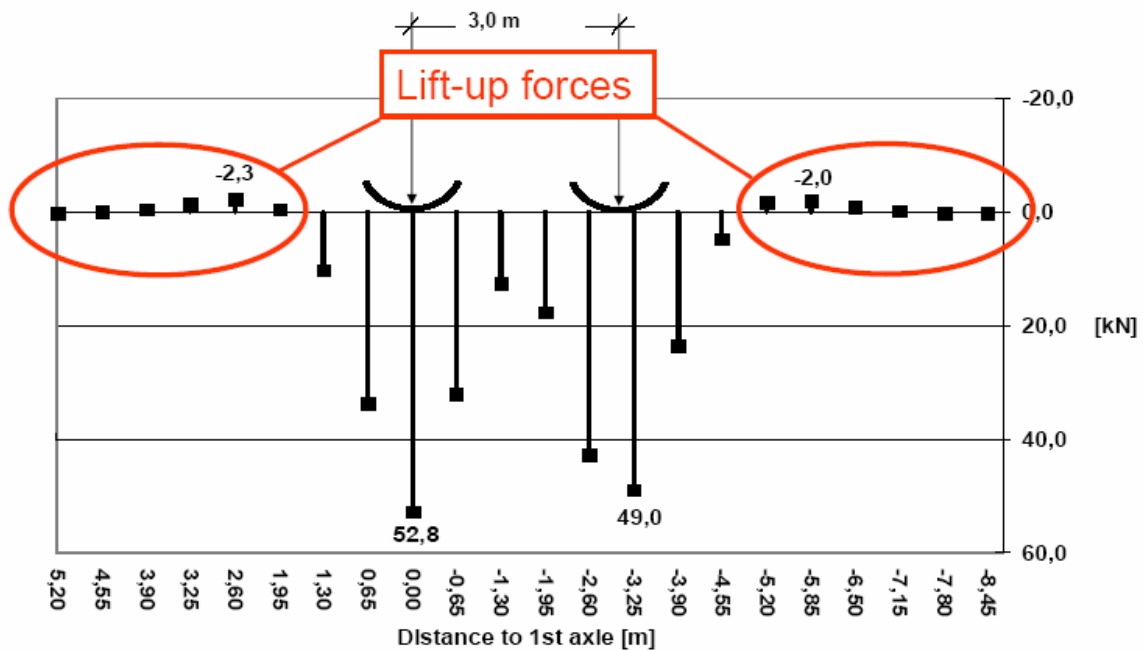


Figure 4: Dynamic rail seat loading [kN] in case of an ICE 1 boogie (static axle load 196 kN).

By the bending behaviour of the rail additional, small negative rail seat loads are activated. Being not totally neutralised by the sleeper weight and due to the absence of a rigid vertical fixation of the sleeper towards the asphalt layer these forces will cause a low pumping effect between sleeper and pavement. To avoid damages within the contact area by dynamic loading and to reduce the effects of pumping in case of presence of water or moisture at the interface, respectively an interlayer which allows small elastic/plastic deformations should be used (see figure 3).

3.2 Horizontal loading

Centripetal forces are activated guiding vehicles along curves and have to be transferred to the sub-system as well as longitudinal forces by braking or accelerating.

Additional for railway tracks horizontal forces caused by temperature-changes of the continuously welded rails due to climate conditions or usage of eddy current brakes must be controlled on the safe side to avoid track buckling. Different kind of solutions for ballastless tracks on asphalt pavements have been developed to control the horizontal forces and to guarantee sufficient track stability which is a very important safety relevant parameter. Devices like stone-dovels (GETRAC System), angled iron plates at the bottom of the sleeper (SATO System) and transversal bases in track axis (ATD-System) have been used (see figure 2).

4. SERVICEABILITY

In addition to the bearing capacity of asphalt pavements the occurrence of deformations caused by the time and temperature dependent visco-elastic behaviour of asphalt must be taken into consideration. The principal shear stresses caused by heavy loading during high temperature conditions ($> 20^{\circ}\text{C}$) within the asphalt pavement can be used as an indicator for the rutting and the following "aqua-planing" effect on roads or for plastic deformation at the interface between sleeper and surface of ballastless tracks (see figure 5). After pre-compaction effects material movements under constant volume conditions are decisive and the increase of plastic deformation versus the load cycles can be described using a kind of square root formula.

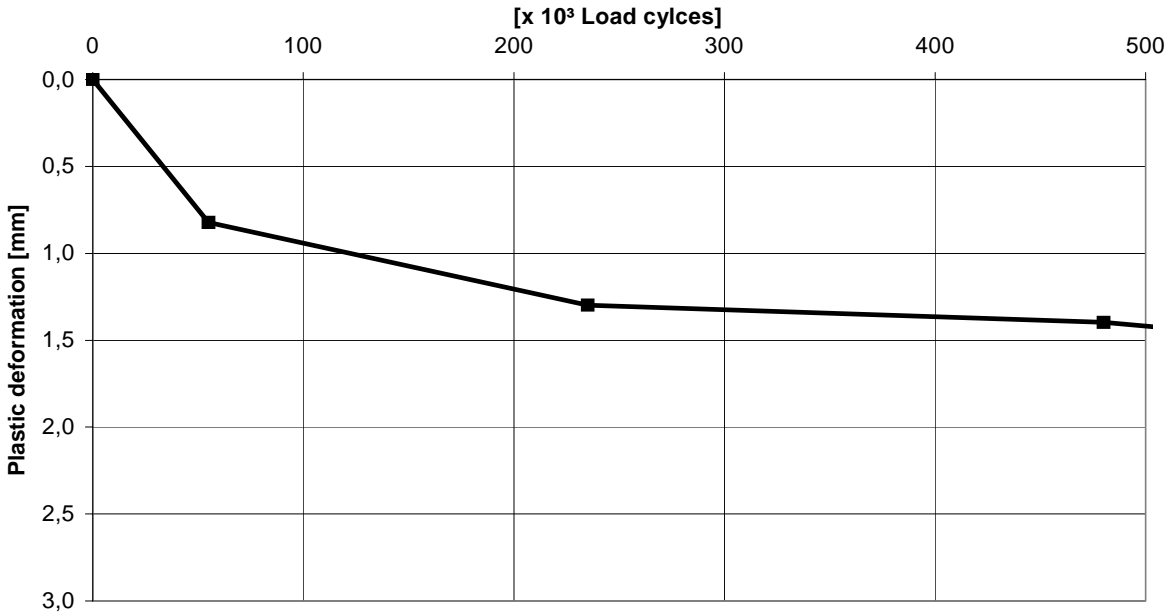


Figure. 5: Plastic deformation of an asphalt pavement surface beneath a concrete sleeper block due to a cyclic rail seat loading of 55 kN; Asphalt surface temperature 32°C.

Due to the accuracy of the vertical track-alignment for high speed tracks and due to the necessity of sufficient surface drainage these deformations must be limited. But on the other hand they will enable better adaptation at the interface between sleeper and pavement during service life. Plastic deformations will be increased in case of original higher contact pressures, such as are activated at rail supports, which are higher than the required height. So tolerances within the height of rail seats caused by tolerances of sleeper height and evenness of the asphalt surface will be harmonised.

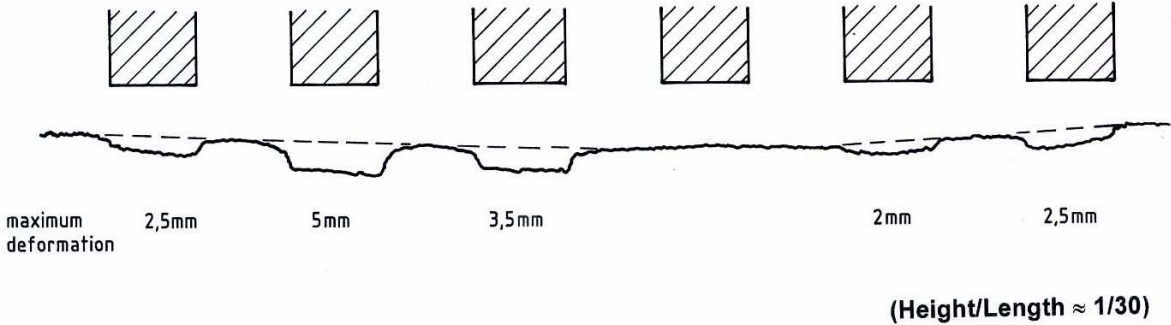


Figure 6: Surface profile measurement - Longitudinal direction of asphalt base. ATD-Nantenbach 1997 after 4 years in service (Leykauf and Mattner 1998)

The resistance against plastic deformations can be increased e.g. by the usage of crushed sand for asphalt mixtures. On the other hand the maximum values of temperature at the surface of the asphalt pavement can be decreased and harmonised if the surface is covered with an absorption layer which is sometimes required for the reduction of noise emission, too.



Figure 7: SATO-test section in Waghäusel during construction (left picture) and after installation of prefabricated absorbing elements (wood concrete) or old ballast (bottom of right picture) to reduce noise emission

Advantages of plastic deformations caused by the viscous properties of asphalt are the possibility to harmonise non-uniform rail seat loadings in combination with the geo-textile at the interface and the increase of resistance against horizontal movements (longitudinal and transversal) during services life.

On the other hand disadvantages can be mentioned because small changes in track geometry are contradictions in case a very stringent ballastless track philosophy (see chapter 1) is applied. It must be taken in to account that moisture will be present at the interface between sleeper and pavement for a longer time. Possible effects caused by moisture concerning frost heave displacements or erosion-effects had been investigated by laboratory test series. But not any significant negative effects had been identified (Lechner and Leykauf 2001).



Figure 7: Test set-up to investigate erosion effects due to dynamic loading and frost-heave behaviour (unloaded condition).

Due to the absence of kneading work by running wheels ageing (hardening) takes more effect on asphalt increasing the probability of thermal cracking for ballastless track pavements. Measures to counteract are: higher bitumen content, usage of polymer modified bitumen and a lower air void content (Eisenmann and Leykauf 2000).

5 CONCLUSIONS

For German high speed links about 650 km of slab track are in use. About 80 km have been designed as sleeper panel systems rested on asphalt pavements. Based on a sufficient structural design in thickness and cross-section and based on proven pavement-technologies asphalt bases are able to meet the requirements concerning the bearing capacity for ballastless tracks. The fixation of the sleeper panel is an important detail, which must be able to prevent track buckling. Accuracy and quality especially concerning the contact area between sleeper and pavement are needed to reach an even contact pressure and low plastic deformation. Therefore an elastic/plastic interlayer between asphalt base and sleeper is required.

Because of stiff support conditions given within tunnel sections the usage of an asphalt pavement in a thickness of about 15cm gives a minimum of total track construction height. This advantage has been used for track modernisation measures within existing tunnels.

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