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Modelling the improved behaviour of a switch installed on ballast-asphalt track

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Abstract

Switches and crossings are a critical part of railway infrastructure and have a complex superstructure, creating variable support and bending stiffness along the track length. These variable structural and loading effects lead to faster rates of track geometry deterioration compared with plain line. Multibody vehicle-track interaction and finite element models combined with empirical predictions have been used to assess the likely benefits and improvements of using an asphalt layer combined with reduced ballast depth under S&C, in terms of long-term ballast differential settlement as well as in terms of reducing stress levels within the ballast and the subgrade layers. The assessment is primarily comparative against a baseline scenario site without asphalt layer. The introduction of asphalt track configurations reduced the variation in trackbed stiffness and increased stiffness throughout the switch panel. Using stresses calculated from finite element modelling, the ballast settlement was calculated using a semi-empirical equation to account for higher load cycles. The introduction of the asphalt layer reduced both maximum and differential settlements, originating from the ballast layer, in the switch panel with respect to the baseline scenario. Furthermore, the maximum stresses transmitted to the subgrade are generally reduced for both asphalt thicknesses with respect to the baseline.

Keywords: asphalt track, switches & crossings, vehicle-track interaction, finite element method

1 Introduction

Switches and crossings (S&Cs) are a critical part of railway infrastructure and have a complex superstructure. This complexity creates variable support and bending stiffness along the track length and with repeated cycles of train loading, gives rise to deteriorating and more variable track support and associated transient dynamic loads. These variable structural and loading effects lead to faster rates of track geometry deterioration compared with plain line. Several countermeasures to reduce deterioration rates have been proposed in recent years, for example, the use of an asphalt layer to improve the homogeneity of the trackbed support along the whole S&C. In a typical asphalt trackbed construction, a layer of asphalt of 100 to 200 mm is placed beneath the ballast layer, which is commonly slightly reduced in thickness compared with typical ballasted track construction. The asphalt layer should help reduce peak stresses onto the layers below and reduce the potential for differential settlement of the trackbed, thereby mitigating against the development of abrupt support stiffness changes and faster geometry deterioration. Laboratory tests show important reductions in ballast settlement and foundation pressure, especially for soft subgrade soils [1]. Rose [2] summarises international experience, highlighting differing practices. Wehbi [3] shows a reduced depth of construction using a thicker asphalt layer relative to other applications. However, no experimental work has been published specifically on ballast-asphalt track configuration installed under S & C.

As part of the In2Track2 project (grant agreement no 826255), the University of Huddersfield (UoH) and University of Southampton supported Network Rail in monitoring a NR60 S&C as a baseline case (no asphalt) and modelling the expected improvement from asphalt track constructions [4]. Site monitoring was carried out by installing accelerometers temporarily on the bearers. Measured data was interpreted to provide a characteristic deflection at each bearer.

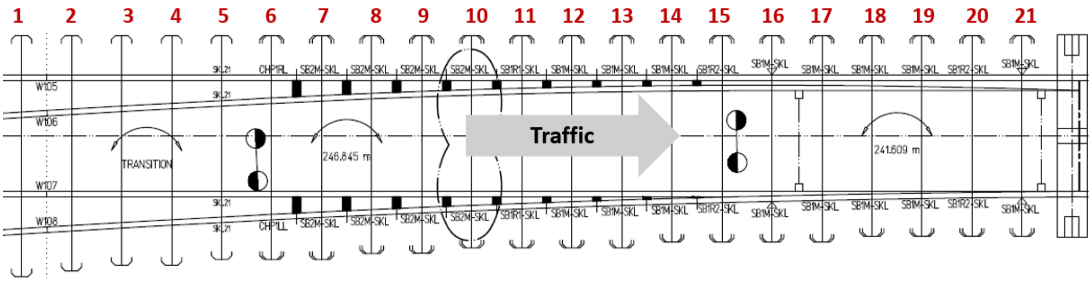


Figure 1: Switch panel

The current paper focuses on modelling the improvement in performance and resulting reduced degradation, expected from installation of an asphalt layer under the switch panel in Figure 1. To achieve this objective, vehicle-track interaction (VTI) and finite element (FE) models, calibrated against site measurements for the baseline scenario, are developed. The models are used to:

a. evaluate the equivalent stiffness when an asphalt layer is added;
b. evaluate the change in dynamic vertical bearer displacements and forces;
c. estimate the change in stress levels in the ballast and subgrade.

2 Methods

Figure 2 provides an overview of the methodology employed. A description of the methodology is as follows: **(a)** A VTI model [5] is calibrated using the measured bearer deflection ranges from baseline case. **(b)** A FE model is built including the bearers, the ballast layers and subgrades and calibrated to match the overall track stiffness from the VTI modelling. **(c)** Two configurations of asphalt track (Figure 3) are introduced in the FE model and the updated trackbed stiffness calculated. **(d)** These stiffness profiles are fed back into the VTI model to compare the vertical displacements, contact forces and forces. **(e)** The VTI bearer load traces are applied to non-linear FE models and **(f)** the stresses after 30 cycles used to **(g)** assess long-term settlement, aided by a semi-empirical settlement equation [6].

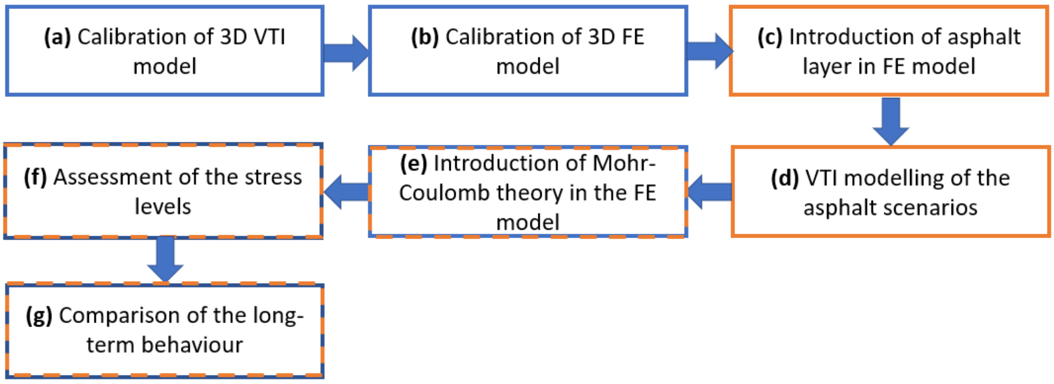


Figure 2: Overview of methodology. Blue boxes for baseline scenarios and orange for asphalt scenarios

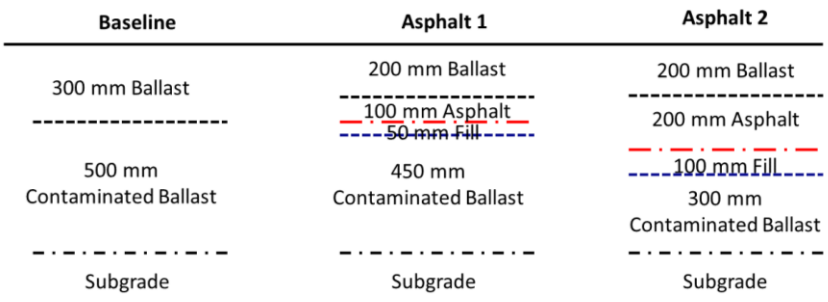


Figure 3: Asphalt scenarios

The switch panel has been simplified by fixing bearer type and spacing. The cross-sectional profile in **Figure 4** and material properties in Table 1 have been assumed for substructure. The asphalt material properties used are those from Wehbi [3].

Two types of static FE models were built in ANSYS [9].

A. **Linear elastic static FE model** used to estimate the increased resilient modulus for the asphalt scenarios. The trackbed stiffness variation, evident in the field measurements, could have several origins. The modulus of contaminated ballast has been selected as a convenient way to introduce the observed variation into FE models. The modulus of the contaminated ballast layer under each individual sleeper was assigned via a simple calibration procedure.

B. **Non-linear static FE model** used to estimate stresses introduced by the vehicle loads. The ballast layer is modelled as Mohr-Coulomb material, reducing unrealistic tensile stress.

Table 1: Material properties.

Material	**E (MPa)**	ν	**ρ (kg/m³)**	**Friction angle (deg)**	**Dilation (deg)**	**c' (kPa)**
Sleeper	57,000[a]	0.2	2688	n/a	n/a	n/a
Ballast	130	0.2	1600	45	0.1	1
Contaminated Ballast	2.5-130[c]	0.25	1800	n/a	n/a	n/a
Asphalt	5,000	0.35	2400	n/a	n/a	n/a
Granular Fill	120	0.3	2000	n/a	n/a	n/a
Subgrade	120-225[d]	0.49	1800	n/a	n/a	n/a
a Kostovasilis [10] c Varies along switch panel d Increases with depth						

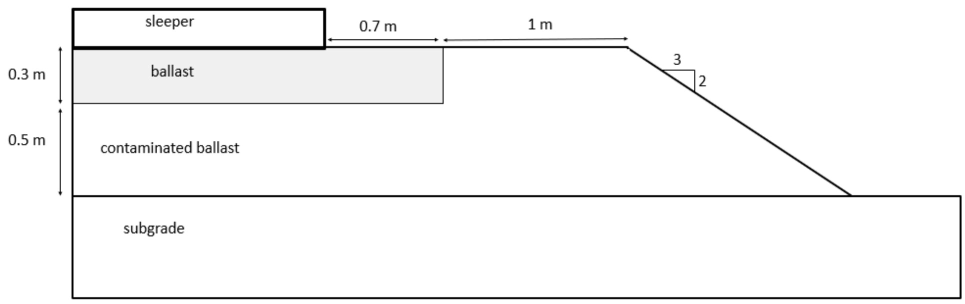


Figure 4: Track cross-section (baseline scenario).

3 Results

Using the VTI model, the equivalent trackbed stiffness distributions have been derived from the measured bearer displacements. A reasonable match between stiffness profiles obtained from the VTI and the FE models is observed in Figure 5. However, the FE model tends to smooth the stiffness profile through the switch, underestimating peak values and overestimating troughs. The two asphalt configurations (Figure 3) were introduced into the FE model to estimate the change in trackbed stiffness (Figure 5). In both asphalt scenarios, the stiffness profiles are smoothed compared to the baseline. The smoother stiffness profile is likely to reduce irregularity growth rates. However, the extent of this smoothing will be sensitive to the true origin of the stiffness variation in the baseline. Furthermore, both asphalt variations increased the trackbed stiffness through the switch panel.

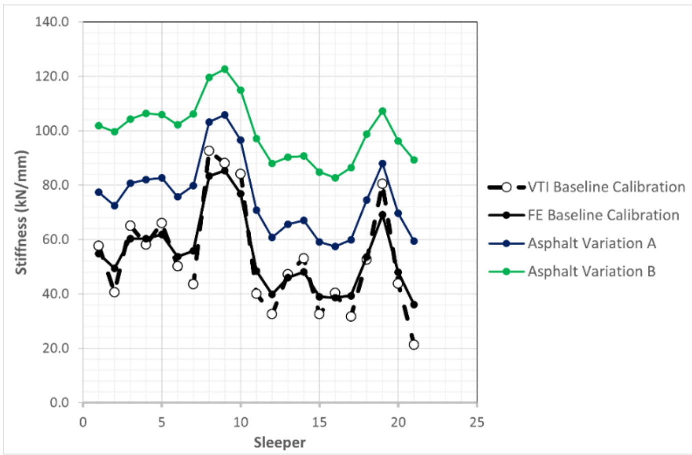


Figure 5: Trackbed stiffness for asphalt configurations.

Type B FE models for all three scenarios were built to predict stresses (see example in Figure 6) and used to estimate ballast settlement. Figure 7(a) shows the predicted ballast settlement along the switch panel for the baseline scenario and the two asphalt scenarios at 100,000 cycles. Adding a layer of asphalt helps to reduce the maximum settlement value and to homogenise stiffness along the whole panel. On the other hand, the higher stiffness in the Asphalt 2 scenario leads to higher settlement variations along the switch panel, in line with the predicted contact forces (Figure 7(b)). It is worth underlining that this conclusion only takes into account one aspect of the system, which is the ballast settlement.

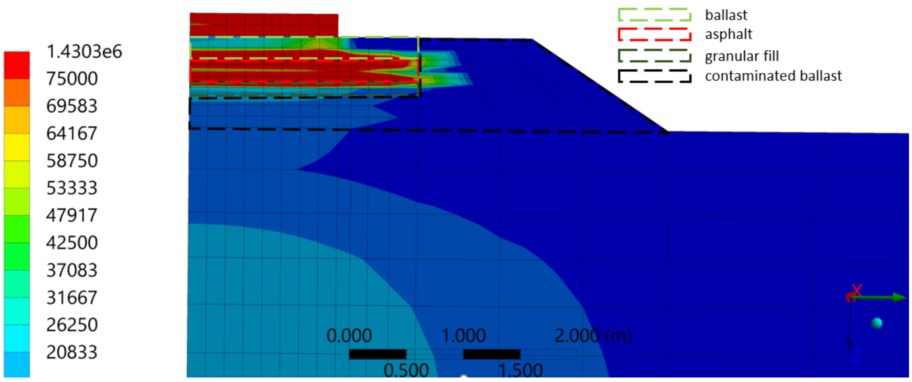
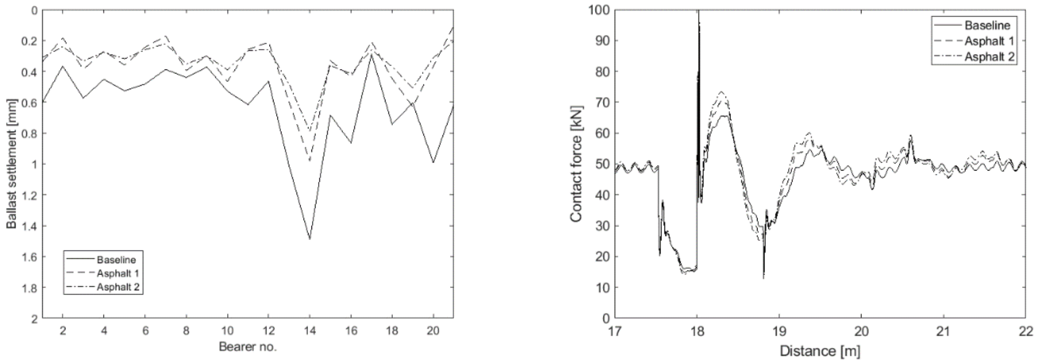


Figure 6 Deviatoric stress along track long-section, maximum load on sleeper 17 for Asphalt B scenario.



(a) (b)

Figure 7: (a) Predicted ballast settlement along the switch panel at 100,000 cycles and (b) wheel-rail contact forces with different asphalt scenarios.

Figure 8 shows the deviatoric stresses in the subgrade at 0.65 m depth along the switch panel for the three scenarios analysed. The presence of asphalt layers decreases the maximum stresses passed to the subgrade, reducing differential and absolute settlements and possibly preventing failure. At bearers no. 8-10 and bearer no. 19 (see Figure 1 for bearer numbers), subgrade stresses below asphalt scenarios exceeds that of the baseline case. Increased contact force, see Figure 7(b), around the bearer locations explains this deviation from the general trend.

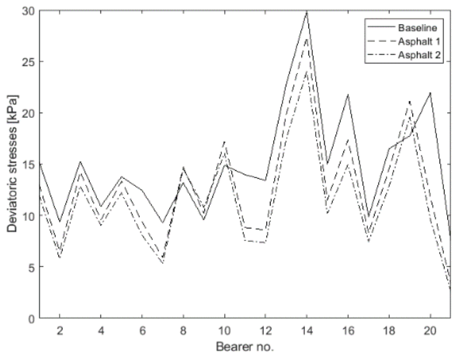


Figure 8: Deviatoric stresses in the subgrade at 0.65 m depth

4 Conclusions and Contributions

Numerical models and empirical predictions have been used to assess the likely benefits and improvements of using a combined asphalt layer with reduced ballast depth under S&C, in terms of long-term ballast differential settlement as well as in terms of reducing stress levels within the ballast and the subgrade layers. The assessment is primarily comparative against a baseline scenario site without asphalt layer, monitored by the UoS. The introduction of asphalt track configurations reduced the variation in trackbed stiffness and increased stiffness throughout the switch panel. A FE model using a Mohr-Coulomb material for the ballast was established for the switch panel and 30 load cycles from the VTI modelling were used to predict stress levels. The ballast settlement was calculated using a semi-empirical equation to account for higher load cycles. The introduction of the asphalt layer reduced both maximum and differential settlements in the switch panel with respect to the baseline scenario. However, at some location settlements slightly increased for the thicker 200 mm asphalt layer with respect to 100 mm asphalt layer due to increased contact loads. Furthermore, the maximum stresses transmitted to the subgrade are generally reduced for both asphalt thicknesses with respect to the baseline. In the long-term, these reduced stresses are likely to further reduce absolute and differential settlements. Therefore, differential settlements originating in both the ballast and subgrade will be reduced by the introduction of an asphalt layer under existing switches. Reduced differential settlements may translate into reduced deterioration and damage including within the superstructure. However, system design including asphalt thickness should be optimised to minimise the adverse effects of local increases in contact force produced by higher trackbed stiffnesses and necessary wheel-rail load amplification in S&C.

Future work
Some areas for further development are highlighted:

- Monitoring at a broader range of S&C installations and continuously over a lifecycle. These installations should include ballasted S&C and an S&C installed with an asphalt sublayer.
- Detailed optimisation of asphalt thickness, granular layers and resilient track components including additional design criteria, ensuring the long-term integrity.
- Parametric study to investigate potential benefits of asphalt layers under S & C with different subgrade properties and track layout.

Detailed modelling of the crossing panel with and without asphalt layer to assess potential benefits. The crossing panel presents some peculiarities including longer bearers and baseplate system that should be accurately modelled to achieve realistic ballast settlement predictions

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