CETRA2024 15-17 May 2024, Cavtat, Croatia
8th International Conferenceon Road and Rail Infrastructure

DYNAMIC BEHAVIOUR OF THE SLEEPER LENGTH TRANSITION IN RAILWAY TURNOUTS

Francesco Marangon, Ferdinand Pospischil
Graz University of Technology, Institute of Railway Infrastructure Design, Austria

Abstract

Railway turnouts are important components of a railroad network. Compared to a normal track, they are more expensive and have many areas with complex dynamics. One of these areas is the transition from long sleepers to short sleepers at the end of a turnout. The dynamics that arise there affect both the vehicles and the infrastructure. As such, understanding and addressing these dynamics is crucial, as they can lead to increased maintenance needs, a reduced availability and, consequently, higher costs. To better understand the occurring dynamics at this jump in stiffness, the actual reaction of the transition must be recorded. As part of the FFG-Comet project Rail4Future, measurements were performed on a turnout in an Austrian main line to this end. These measurements included recording the vertical sleeper displacements at multiple positions in the transition zone as well as the dynamic axle loads outside of the influenced area. The data was used to study the behaviour of this transition zone, especially looking at influencing factors on track panel twist, such as vehicle type, axle load and travelling speed. These new insights into the transition in sleeper length can be used, among others, in the evaluation of vehicle-based measurements, as the measurement itself is influenced by the vehicle.

Keywords: railway turnouts, sleeper length transition, stiffness jump, track panel twist, vehicle-track interaction

1 Introduction

Railway turnouts are an important component of a railway network. Compared to a section of normal track of the same length, they are substantially more expensive. This is not only valid in terms of their initial acquisition cost but also in their maintenance [1, 2]. Therefore, there is a significant amount of research focused on this vital part of railway tracks. This research aims to enhance the design of turnouts, thereby reducing costs and increasing safety [3–7]. The majority of the research typically concentrates on the crossing area or the switch rails of railway turnouts. Both of which are critical components where an increased dynamic is prevalent [6–8]. However, one area which can also have increased dynamics, is most often neglected. It is the transition zone between long and short sleepers at the end of a turnout [4]. There the loading situation as well as the area in contact with the ballast of the sleepers suddenly changes. This sudden transition results in a noticeable change in stiffness, similar to what is observed in other transition zones such as at bridges. A difference to this other transition zones is that this transition within turnouts is also asymmetric. Both the long and short sleepers in that area are not loaded symmetrically due to their geometry. This asymmetrical loading leads to a twist in the track panel since the longer sleepers tend to tilt in one direction and the shorter ones in the other [4].

DOI: https://doi.org/10.5592/CO/CETRA.2024.1582

In general, a jump in track stiffness can lead to higher settlements which could make a tamping action required [9, 10]. Tamping is one of the main maintenance costs in a railway track [11]. This is not the only issue of this transition zone. The twisting of the track panel itself can pose a potential safety hazard and is therefore limited in the standard EN 13848 [12]. The end of a turnout represents a critical area which needs more research to reduce its cost due to the required maintenance and increase its safety.

By improving the understanding of the transition between long and short sleepers in a turnout, one can not only enable future studies looking on how to optimize this area but can also increase safety. To achieve this, it is crucial to analyse how this transition zone behaves under normal track loading. This is the main focus of this study which looks at the behaviour of an existing turnout. The focus lies on the influencing factors on possible track twist, like axle load, speed and travelling direction.

To enable this study of the track panel twist at the end of turnout, a measurement campaign was performed as part of the FFG-Comet project Rail4Future. This project, focusing on the development of a fully networked and digitized railway system, aims to enhance the efficiency and management of railway assets. The measurements included recording the vertical sleeper displacements at multiple positions in the transition zone as well as the dynamic axle loads outside of the influenced area. The gathered data is used to evaluate the aforementioned possible influencing factors.

2 Methods

To perform the measurements, it was important to select a turnout that had not undergone recent maintenance. This enabled an analysis of a turnout which already had developed twist issues and has a well-known history of maintenance and track quality, recorded by the track measurement car. It was necessary since the available time for a measurement campaign was limited and a whole development over time could not be acquired.

The turnout under investigation is situated on a main railway line within the ÖBB-Infrastruktur AG network. This line has mixed traffic and provides an opportunity to study the effect of different vehicle types which correspond to different axle loads on the track panel twist. It is a standard turnout, equipped with 60E1 rails, a 500 m radius and a 1:12 inclination. All sleepers are made of prestressed concrete.

2.1 Measurement setup

In the selected turnout, displacement sensors were installed on both the last long sleeper and second short sleeper to measure their vertical movements. The sensors were fixed with anchors in the ballast. Through this setup, the general deflection and the tilt of both sleepers can be calculated. The arrangement of all displacement sensors is depicted in Figure 1.

Understanding the types of vehicles using the track, especially their axle loads, is crucial. To this end, the vertical force was also measured, at a point well away from the end of the selected turnout. This location was chosen to avoid an influence of the dynamic excitation of several parts of the turnout itself on the measured vertical load. The measurement involved the known method of using shear strain gauges installed in a sleeper bay on the rail web [13]. Having the same shear strain gauge setup around a sleeper nearby, allowed to determine the speed of the trains passing the site. Measured vertical loads were validated through the application of impact loads. These were measured via the deceleration of a known falling weight impacting on different elastic pads placed on the rail.

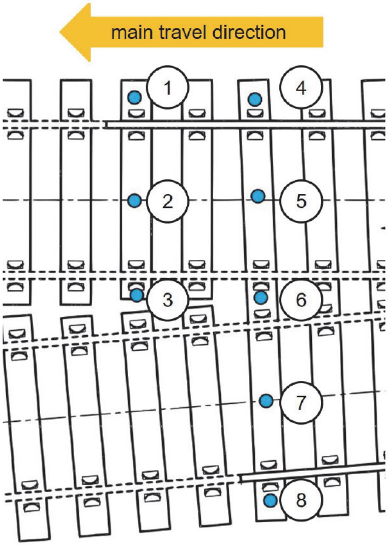

Figure 1 Sensor positions and main travel direction

For the recording of measurement data, commercial universal measuring amplifiers were employed [14]. The sampling rate and pre-filter were configured to be adequately distant from the anticipated signal frequency, ensuring that no significant parts of the signal were overlooked. To do this, the influence length on the shear measurement setup, being the shortest, was chosen and used together with the maximum permissible vehicle speed to calculate the frequency required to acquire the peak. This was than multiplied by a factor of ten and the closest, available prefilter with a frequency higher to this was selected. The sampling rate was chosen to ensure the Nyquist criterion is met.

2.2 Data analysis

To analyse the collected, raw data, a self-developed Python software was utilized. This software is specifically designed to process the data and extract parameters, including vehicle speed and the load of every axle, among others. In the pre-processing stage, the data is filtered and a possible offset removed. The filtering used depends on the sensor type and is different for the strain gauges to the displacement sensors. They frequency was adapted to retain the important information but remove any high frequency noise and vibrations. Second-order Butterworth low-pass filters were applied, with cut-off frequencies of 50 Hz for displacement data and 250 Hz for shear data.

Following this pre-processing, additional steps are required to derive the tilt and displacement from the processed sensor data of multiple sensors. A critical aspect involves correlating the displacement peaks to single axles. With this information the tilting caused by a passage of a specific axle of both sleepers can be determined. This is subsequently used to calculate the twist which equals to the difference of these tilts. Additionally, the vehicle speed is determined by analysing the timings of the passage of each axle over the two shear measurement points.

To better understand the results, it's crucial to comprehend the method used to calculate twist from the recorded deflections. Initially, the tilting of the sleepers is determined using the difference in readings between sensor 3 and sensor 1 or sensor 6 and sensor 4. This difference is then divided by the distance between the sensors and multiplied by the standard track width, yielding the sleeper tilt in millimetres relative to the standard track width.

The twist is subsequently derived by calculating the difference between the tilt of the short sleeper and that of the long sleeper.

To determine an influence of the vehicle and to minimize the influence of flat spots found especially in freight waggons, the data is filtered and split up in three categories. One comprises of just the locomotives, the other of passenger cars and the last of cars from a “S-Bahn” which are lighter than normal passenger cars.

For each train passage, first the twist and vertical load are calculated for every axle. Following this, the average is calculated including only some axles depending on the category. In the case of a freight train passage, the average is derived for the twist and vertical load just using the locomotive axles and it is subsequently added to the locomotives category. To simplify the certain detection of passenger cars of the passed intercity trains, the first and last four axles were excluded to assure the locomotive is not included into the passenger car category. This is necessary since the trains can operate both in a pull an also push configuration. Finally, for the suburban commuter category the mean is calculated over all axles. Since most passages are in the main travel direction, the following results only focus on those. For having a statistically significant amount against this main direction, either the measurements would need to be performed over a longer period of time or a difficult to obtain change of operation would have been required. During the two-week measurement period, each category selected only had less than five passages against the main traveling direction.

3 Results and discussion

Figure 2 presents the average vertical displacement observed in both sleepers for all three categories. The high displacement of the short sleeper would suggest the ballast has already degraded a substantial amount. This is expected since the change in stiffness leads to higher settlements in other transition zones [9, 10]. Contrary the long sleeper which is normally passed before the short one has a vertical displacement within the given limits and expected values, which could both be due to the main travel direction and of course the higher contact area. Finally, the differences between the different categories can be explained due to different axle weights. Whereas the locomotives have the highest axle weights and the suburban commuter train “S-Bahn” the lowest.

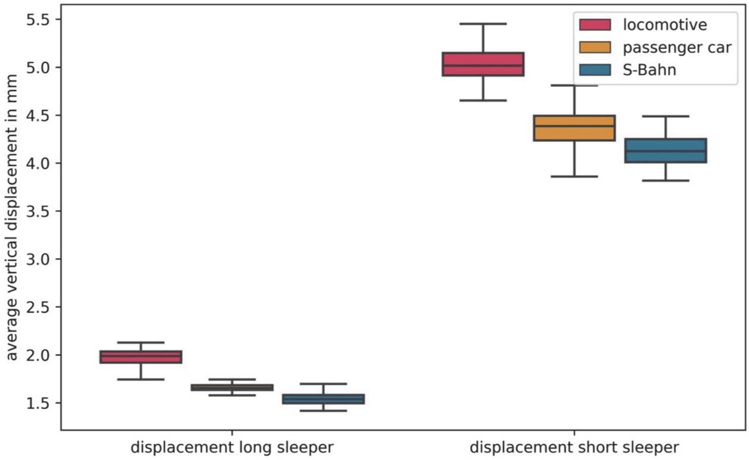

Figure 2 Deflection of long and short sleeper for each data category

In Figure 3 the average twist is depicted over the different average axle loads. The average is calculated for every category according to Section 2.2. Higher axle loads result in an increased average twist. As already mentioned for the deflections, the locomotives have the highest average load and the suburban commuter trains the lowest. It is probable that between the average twist and average weight there is a linear relation. Nevertheless, the coefficient of determination has a value of 0.39 which is quite low. This is mainly due to the scattering of the observed data. The widespread scattering across all categories suggests that it cannot only be attributed to different locomotives or passenger cars, particularly as the suburban trains had same axle and boogie distances.

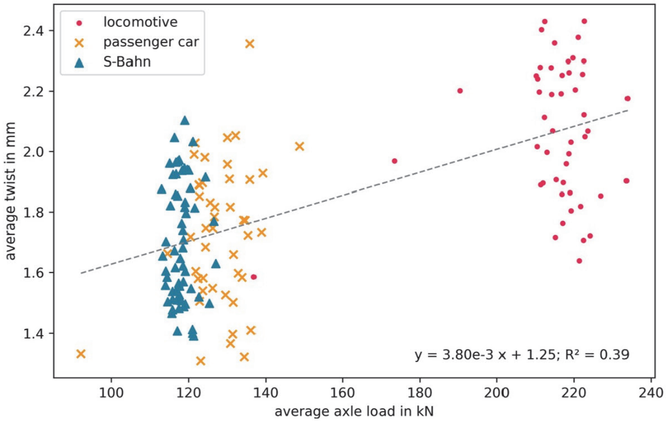

Figure 3 Average track panel twist plotted against average axle load, with the corresponding linear regression line included

Contrary to expectations, higher train speeds do not significantly affect the twist of the track pane. Figure 4 represents the weight-adjusted twist over train speed. The weight influence is removed using the linear function shown in Figure 3. Although some effect of train speed might be anticipated due to the train's rotational inertia and the damping properties of the superstructure, the results show no correlation between speed and twist. It should be noted that since the measurements were only limited on one long and one short sleeper, the maximum twist could potentially occur between other sleepers. In that case it is possible that a small relation between twist and weight is present but not visible in our data.

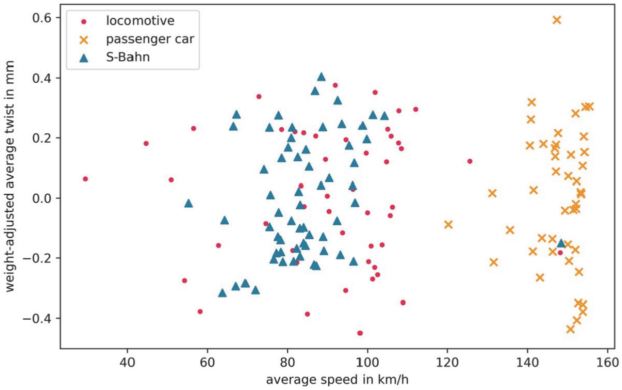

Figure 4 Average twist adjusted for weight across various train speeds

4 Conclusion

By analysing vertical displacements of two sleepers located at the end of a turnout, both the track panel twist and the sleeper displacements were calculated. The twist value was then normalized to the standard track width. All data was categorized into one of three categories: locomotive, passenger car and “S-Bahn”. For the analysis, average axle values were utilized. The turnout analysed in this study had already developed advanced twist issues and significant ballast settlement at the short sleeper, with some settlements exceeding 5 mm. This is in line with expectations, as a jump in stiffness can lead to significantly higher settlements [9, 10]. The results confirm that a suitable turnout was selected as specified in Section 2. Additionally, the findings underline the problem that can arise in the transition zone at the end of a turnout.

In this study, the only influence identified is the effect of the average axle weight on the average track panel twist. A higher axle weight leads to a higher track panel twist. Regarding the relationship with train speed, the results indicate no correlation. This lack of correlation is visible after the weight influence on the track panel twist is removed. The influence of axle weight shows the importance of considering the measurement method, when analysing track panel twist. For instance, when using a measuring car, which in the case of the Austrian railway is lighter than normal locomotives, the twist value is lower. This would need to be considered among others in simulations.

Results of this study cannot be directly compared with the limit value defined in EN 13848. The measurement system is not as defined by the standard [12, 15]. This specification of the measurement system is critical, since the resulting track panel twist can greatly differ. As an example, in this study the maximum average twist is around 2.4 mm. Other preliminary results, not included in this study, focusing on the maximum twist show that some axles lead to significantly higher track panel twists.

Although the results offer valuable insights into the dynamics at the transition between long and short sleepers, this investigation does not look at the development of the twist issues itself. Therefore, it is not possible to assess the impact of this transition on maintenance costs within this study. To achieve such an assessment, long-term measurements or periodic measurements, possibly with the measurement car, would be necessary similar to the study by Loidolt et al. [2]. Nonetheless, the findings contribute to the understanding of the complex dynamics found in the transition zone between long and short sleepers and are a foundation for future research focused at enhancing the performance and safety of railway turnouts.

Acknowledgements

The authors would like to acknowledge the financial support from the COMET K-project Rail-4Future from the Austrian Federal Ministry for Climate Action (BMK),the Austrian Federal Ministry for Digital and Economic Affairs (BMDW), the Province of Styria (Dept. 12) and the Styrian Business Promotion Agency (SFG).

References

[1] Marschnig, S.: Innovative Track Access Charges, Transportation Research Procedia, 14 (2016), pp. 1884–1893, DOI: 10.1016/j.trpro.2016.05.155

[2] Loidolt, M., Marschnig, S.: Life-cycle assessment of aged turnouts: A fusion of economic and technical considerations, Transportation Research Procedia, 72 (2023), pp. 486–492, DOI: 10.1016/j.trpro.2023.11.430

[3] Zarembski, A.M., Palese, J.W., Katz, L.: Reduction of Dynamic Wheel/Rail Impact Forces at Grade Crossings Using Stiffness Transitions, ASME 2001 International Mechanical Engineering Congress and Exposition, 2021, pp. 97–116. DOI: 10.1115/IMECE2001/RTD-25711

[4] Loy, H.: Under sleeper pads in turnouts, Railw. Tech. Rev., 2 (2009), pp. 35–38

[5] Raif, L., Puda, B., Havlík, J., Smolka, M.: Design of high-speed turnouts and crossings, IOP Conference Series: Materials Science and Engineering, 236 (2017), p. 12044, DOI: 10.1088/1757-899X/236/1/012044

[6] Pålsson, B.A.: Design optimisation of switch rails in railway turnouts, Vehicle System Dynamics, 51 (2013) 10, pp. 1619–1639, DOI: 10.1080/00423114.2013.807933

[7] Pálsson, B.A.: Optimisation of railway switches and crossings, Department of Applied Mechanics, Gothenburg, Sweden, 2014.

[8] Loidolt, M., Marschnig, S., Berghold, A.: Track geometry quality assessments for turnouts, Transportation Engineering, 12 (2023), p. 100170, DOI: 10.1016/j.treng.2023.100170

[9] Li, D., Davis, D.: Transition of Railroad Bridge Approaches, Journal of Geotechnical and Geoenvironmental Engineering, 131 (2005) 11, pp. 1392–1398, DOI: 10.1061/(ASCE)1090-0241(2005)131:11(1392)

[10] Dahlberg, T.: Railway Track Stiffness Variations – Consequences and Countermeasures

[11] Ekberg, A., Paulsson, B.: INNOTRACK Concluding technical report, Union of Railways (UIC), Paris, 2010.

[12] European Committee for Standardization, EN 13848-5: Railway applications — Track — Track geometry quality — Part 5: Geometric quality levels — Plain line, switches and crossings, CEN, 2017.

[13] Ahlbeck, D. R., Harrison, H. D., Prause, R. H., Johnson, M. R.: Evaluation of Analytical and Experimental Methodologies for the Characterization of Wheel/Rail Loads, 1976.

[14] Hottinger Brüel & Kjaer GmbH, QuantumX Operating Manual, https://www.hbm.com/fileadmin/mediapool/hbmdoc/technical/A03031.pdf, 15.03.2024.

[15] European Committee for Standardization, EN 13848-4: Railway applications — Track — Track geometry quality — Part 4: Measuring systems — Manual and lightweight, CEN, 2023.