

**Delft University of Technology** 

# Auxiliary rails as a mitigation measure for degradation in transition zones

Fărăgău, A.B.; Jain, A.; de Oliveira Barbosa, J.M.; Metrikine, A.V.; van Dalen, K.N.

DOI 10.4203/ccc.1.19.4

Publication date 2023

**Document Version** Final published version

#### Published in

Proceedings of The Fifth International Conference on Railway Technology: Research, Development and Maintenance

#### Citation (APA)

Fărăgău, A. B., Jain, A., de Oliveira Barbosa, J. M., Metrikine, A. V., & van Dalen, K. N. (2023). Auxiliary rails as a mitigation measure for degradation in transition zones. In J. Pombo (Ed.), Proceedings of The *Fifth International Conference on Railway Technology: Research, Development and Maintenance* (Vol. CCC 1). (Civil-Comp Conferences; Vol. 1). Civil-Comp Press. https://doi.org/10.4203/ccc.1.19.4

#### Important note

To cite this publication, please use the final published version (if applicable). Please check the document version above.

Copyright

Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

Takedown policy Please contact us and provide details if you believe this document breaches copyrights. We will remove access to the work immediately and investigate your claim.



Proceedings of the Fifth International Conference on Railway Technology: Research, Development and Maintenance Edited by J. Pombo Civil-Comp Conferences, Volume 1, Paper 19.4 Civil-Comp Press, Edinburgh, United Kingdom, 2022, doi: 10.4203/ccc.1.19.4 ©Civil-Comp Ltd, Edinburgh, UK, 2022

# Auxiliary rails as a mitigation measure for degradation in transition zones

A.B. Fărăgău<sup>1</sup>, A. Jain<sup>1</sup>, J.M. de Oliveira Barbosa<sup>1</sup>, A.V. Metrikine<sup>1</sup>, K.N. van Dalen<sup>1</sup>

# <sup>1</sup>Faculty of Civil Engineering and Geosciences, Delft University of Technology, the Netherlands

### Abstract

This paper studies the effectiveness of adding auxiliary rails as a mitigation measure for degradation in transition zones of railway tracks. More specifically, it investigates the settlement mechanisms counteracted by the additional rails. Results show that when the system's response is in the quasi-static regime, adding auxiliary rails over the soft part of the transition zone is beneficial while adding them over the whole transition zone is not. Furthermore, the auxiliary rails have a beneficial impact also when the system's response is in the dynamic regime; the beneficial effect is caused by the improved load distribution to the supporting structure and not from counteracting the dynamic response amplification that occurs at transition zones. While this mitigation measure has been previously investigated, the contribution of this study lies in a more in-depth analysis of the mechanism through which auxiliary rails can mitigate the degradation at transition zones.

Keywords: Transition zone, Auxiliary rails, Settlement mechanisms

## 1 Introduction

Transition zones in railway tracks are areas with significant variation of track properties (e.g., stiffness, mass, etc.) encountered near man-made structures such as bridges, tunnels, or culverts. These zones require more frequent maintenance than the regular parts of the railway track, leading to high costs and reduced availability of the track. A substantial part of the maintenance performed in transition zones is concerned

with restoring the vertical position of the track, which changes over time due to soil and ballast settlement.

The mechanisms leading to geometry degradation of the track can be split in two categories: i) mechanisms leading to the initiation of the geometry degradation (e.g., in stress/strain amplification caused by the difference in properties between the open-track and man-made structure [1-4]) and mechanisms that accelerate the degradation once it has initiated (e.g., hanging sleeper [5], unlevel rail). This study focuses on the former category.

One mitigation measure that is widely used in practice is to insert auxiliary rails in between the standard rails to increase the bending stiffness of the track in the transition zone [6,7]. The advantage of this measure is its applicability to already built tracks without the need of a substantial reconstruction. Although this solution seems widely used (e.g., in Germany [6]), there is not much research about it. More specifically, although some measurements [7] and simulations [6,7] show this solution to be successful, the degradation mechanism(s) it is trying to counteract is not clearly stated.

This study investigates the settlement mechanisms counteracted by additional rails by using a simplified 1-D system consisting of an infinite Euler-Bernoulli beam on Kelvin foundation acted upon by a moving constant load (Figure 1). The Kelvin foundation has an abrupt jump in stiffness and damping dividing the system into two domains: the soft domain (to the left of the abrupt jump) and the stiff domain (to the right of the jump). Furthermore, this study focuses on the zone in the immediate vicinity of the abrupt jump and does not consider the region where the open track transitions to the zone with auxiliary rails.

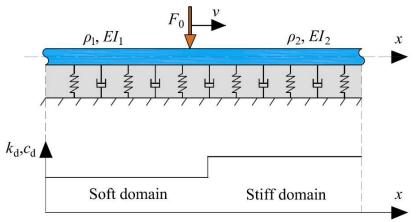


Figure 1: Model schematics.

## 2 Quasi-static regime

To determine the influence of additional rails on the smoothness of the transition, we first need to define the transition smoothness. In the quasi-static scenario (load velocity is small compared to the critical velocity in the track), the smoothness s can be described geometrically by accounting that it should be i) inversely proportional to the ratio q of the static track stiffness (including the beam) between the stiff and soft

domains, and ii) proportional to the length lt over which this transition takes place, as follows:

$$s \sim \frac{l_{\rm t}}{q-1}.\tag{1}$$

The denominator is chosen as q-1 to represent that when the stiffnesses of the two domains are equal, the smoothness becomes infinite.

The auxiliary rails can be added in both domains (case A) as seen in [6], or over the soft domain only (case B) as seen in [7]. In case A, the track stiffness ratio  $q_1$  reads

$$q_{1} = \left(\frac{k_{\rm d,r}}{k_{\rm d,l}}\right)^{\frac{3}{4}},$$
(2)

where  $k_{d,1}$  and  $k_{d,r}$  are the foundation stiffnesses (without the beam) of the soft and stiff domains, respectively. It is clear that the additional rails do not influence the track stiffness ratio in case A because the bending stiffness, being the same in both domains, cancels out in  $q_1$ . In case B, the track stiffness ratio  $q_2$  reads

$$q_2 = q_1 n^{-\frac{1}{3}},\tag{3}$$

where *n* is the number of rails. In case B, the additional rails lead to a decrease in the static track stiffness, but it can be seen from Eq. (3) that the above a certain *n* (e.g., n=3), adding more rails does not significantly influence  $q_2$ .

Figure 2 presents the quasi-static track stiffness for cases A and B. As predicted, it can be observed that the additional rails do not lead to a beneficial change in stiffness ratio for scenario A, while they do in scenario B. Apart from the track stiffness ratio,

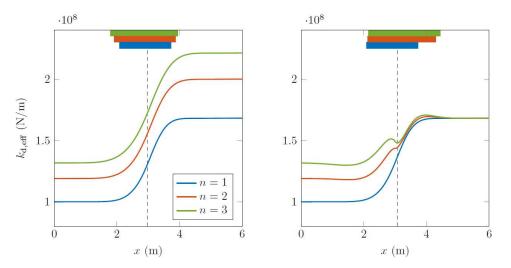


Figure 2: Quasi-static track stiffness for different number of rails; additional rails over both domains (left panel) and over the soft domain only (right panel); the location of the abrupt change in foundation stiffness is marked by the vertical dashed line; the length of the transition in track stiffness is depicted through the horizontal bars at the top.

also the transition length influences the smoothness. As seen in Figure 2,  $l_t$  increases with adding extra rails, but the increase is negligible in both scenarios. To conclude the quasi-static analysis, adding rails over both domains does not lead to a significant change in the transition smoothness, while adding rails over the soft domain only leads to a smoother transition mainly through reducing the track stiffness ratio  $q_2$ .

#### **3** Dynamic regime

In the dynamic regime, when the load velocity is closer to the critical one, the response under the load does not show a quasi-monotonic change when passing over the transition zone; therefore, the function defined in Eq. (1) is not any more a good indication for the transition smoothness. Better quantities to investigate in order to assess the influence of the additional rails are the amplification of displacements and forces as well as the power input by the load as it crosses the transition zone [8].

Figure 3 presents the force  $F_k$  transmitted to the supporting structure and the power input  $P_{in}$  by the moving load for a load velocity of 75% of the critical one (in the system without auxiliary rails). It can be seen that the additional rails have a beneficial effect on the magnitude of force transmitted to the supporting structure in the soft domain (where most degradation occurs). However, the amplification of the force caused by the transition in stiffness (which is associated with degradation [2]), does not seem to change significantly with the addition of rails (approx. 5% increase compared to the force in the open track). As for the power input, the effect of the additional rails is very strong too, the power input decreasing significantly.

Figure 4 presents the maximum transmitted force  $F^{T}_{k,max}$  in the transition zone normalized by the maximum transmitted force  $F^{SS}_{k,max}$  in the steady state for different load velocities; this quantity shows the response amplification caused by the transition

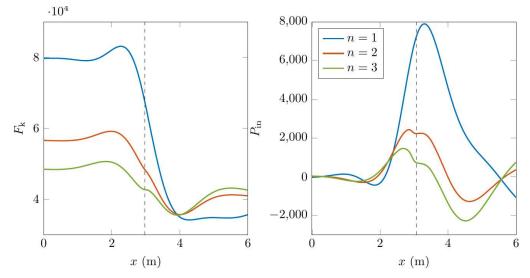


Figure 3: The force transmitted to the supporting structure (left panel) and the power input by the moving load (right panel) for different number of rails; the additional rails are imposed over the soft domain only (case B); the location of the abrupt change in foundation stiffness is marked by the vertical dashed line.

zone. It can be observed that the additional rails do not affect at all the response amplification in scenario A, while for scenario B, the amplification even increases with increasing the number of rails. The increased amplification in scenario B is likely to be caused by the transition in bending stiffness (present only in scenario B) additional to the transition in foundation stiffness (present in both scenarios). These results show that for the degradation mechanism associated with the response amplification, the additional rails are not effective when applied over both domains and even have a negative impact when applied over the soft domain only.

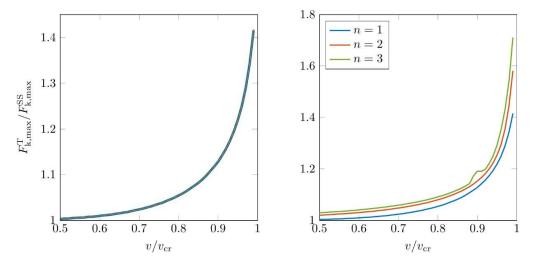


Figure 5: The amplification of the transmitted force in the transition zone for different load velocities; additional rails over both domains (left panel) and over the soft domain only (right panel).

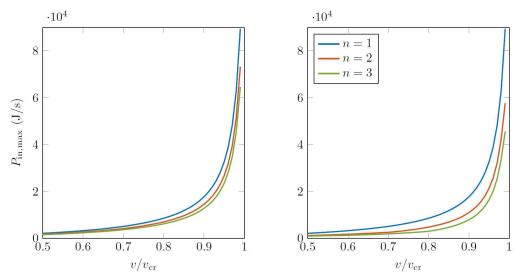


Figure 4: The maximum power input by the load for different load velocities; additional rails over both domains (left panel) and over the soft domain only (right panel).

Figure 5 presents the maximum power input by the load as it crosses the transition zone. This quantity is representative for the smoothness of the transition in the dynamic situation. It can be seen that the additional rails are effective at decreasing the maximum power input, especially for scenario B.

#### **4** Conclusions and Contributions

This study investigated the effect of the additional rails as a mitigation solution against degradation at transition zones in railway tracks. More specifically, we studied the effect on the amplification of displacements and forces at transition zones, mechanism associated to the initiation of degradation.

For the quasi-static regime (load velocity is small compared to the critical one), results show that implementing the additional rails over both soft and stiff domains (case A) does not lead to a smoother transition in track stiffness. However, if the additional rails are implemented over the soft domain only (case B), the transition in track stiffness does become smoother, mainly due to the increase of track stiffness in the soft domain; the length of the transition in track stiffness does not get significantly affected in neither of the two cases. These results show that, when it comes to the quasi-static track stiffness, beneficial effects can be obtained if the additional rails are implemented over the soft domain only.

Auxiliary rails have a beneficial effect in the dynamic regime too. Results show that the magnitude of the force transmitted to the supporting structure in the soft domain (where most degradation is observed) decreases with additional rails. However, the amplification of the transmitted force caused by the transition in foundation stiffness does not get affected at all with the addition of rails in scenario A, while it even increases in scenario B, for the whole sub-critical velocity regime. This result shows that this mitigation measure is not effective in counteracting the amplification of displacements and forces at transition zones; nonetheless, it is effective in distributing the load over a larger portion of the track, decreasing the magnitude of the transmitted force. Even though the dynamic amplification can increase, the magnitude of the maximum transmitted force is lowered when additional rails are implemented, suggesting that this mitigation measure can be effective.

To conclude, this study shows that the additional rails as a mitigation measure for degradation at transition zones of railway tracks can be effective. Its potential comes from the improved load distribution to the supporting structure and not from counteracting the dynamic response amplification that occurs at transition zones. While this mitigation measure has been previously investigated, the contribution of this study lies in a more in-depth analysis of the mechanism through which it can mitigate the degradation at transition zones.

#### Acknowledgements

This research is supported by the Dutch Technology Foundation TTW [Project 15968], part of the Netherlands Organisation for Scientific Research (NWO), and which is partly funded by the Ministry of Economic Affairs.

# References

- [1] M.J.M.M. Steenbergen, "Physics of railroad degradation: The role of a varying dynamic stiffness and transition radiation processes", Computers and Structures 124, 102–111, 2013.
- [2] A.B. Fărăgău, A.V. Metrikine, and K.N. van Dalen, "Transition radiation in a piecewise-linear and infinite one-dimensional structure-a Laplace transform method", Nonlinear Dynamics 98(4), 2435–2461, 2019.
- [3] J.M. de Oliveira Barbosa, A.B. Fărăgău, and K.N. van Dalen, "A lattice model for transition zones in ballasted railway tracks", Journal of Sound and Vibration 494, 2021.
- [4] K.N. van Dalen, A. Tsouvalas, A.V. Metrikine, J.S. Hoving, "Transition radiation excited by a surface load that moves over the interface of two elastic layers", International Journal of Solids and Structures, 73–74, 99–112, 2015.
- [5] M. Sysyn, O. Nabochenko, V. Kovalchuk, "Experimental investigation of the dynamic behavior of railway track with sleeper voids", Railway Engineering Science 28(3), 290–304, 2020.
- [6] M. Shahraki, C. Warnakulasooriya, K.J. Witt, "Numerical study of transition zone between ballasted and ballastless railway track", Transportation Geotechnics, 3, 58-67, 2015.
- [7] H. Heydari-Noghabi, J.N. Varandas, M. Esmaeili, J. Zakeri, "Investigating the Influence of Auxiliary Rails on Dynamic Behavior of Railway Transition Zone by a 3D Train-Track Interaction Model", Latin American Journal of Solids and Structures, 14, 2000-2018, 2017.
- [8] A.B. Fărăgău, T. Mazilu, A.V. Metrikine, T. Lu, K.N. van Dalen, "Transition radiation in an infinite one-dimensional structure interacting with a moving oscillator—the Green's function method", Journal of Sound and Vibration 492, 2021.