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Auxiliary rails as a mitigation measure for degradation in transition zones

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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.

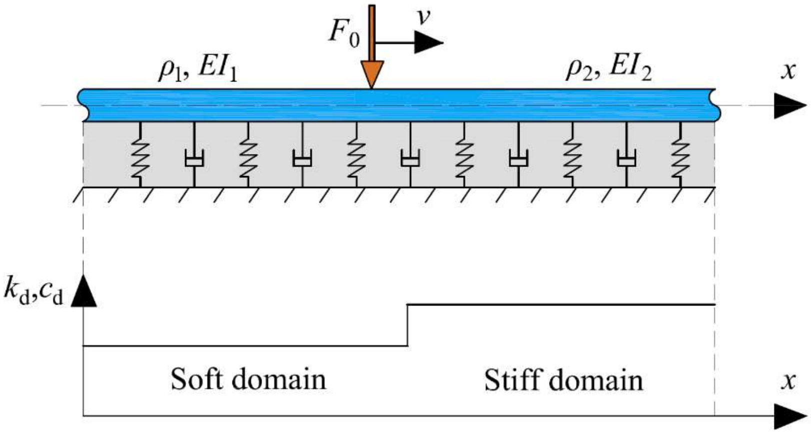

Figure 1: Model schematics.

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:

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

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

$$q_1 = \left(\frac{k_{\mathrm{d,r}}}{k_{\mathrm{d,l}}}\right)^{\frac{3}{4}}, \tag{2}$$

where $k_{\mathrm{d,l}}$ and $k_{\mathrm{d,r}}$ 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,

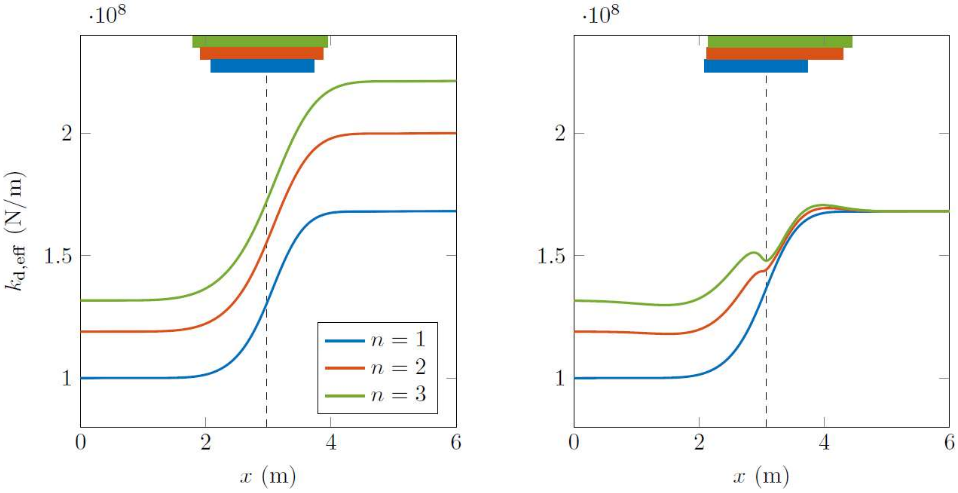

Figure 2: Quasi-static track stiffness for different number of rails; additional rails over both domains (left panel) and over the soft domain only (right panel); the location of the abrupt change in foundation stiffness is marked by the vertical dashed line; the length of the transition in track stiffness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

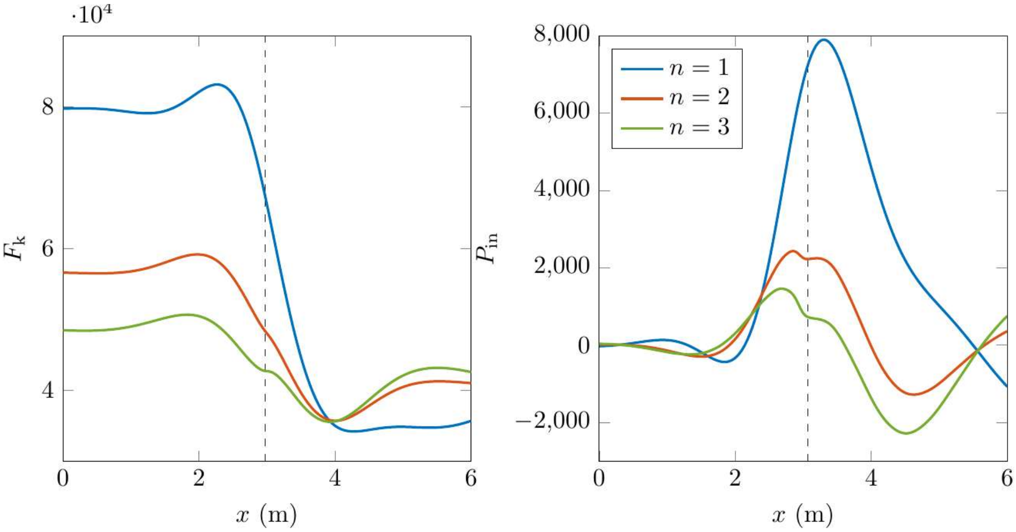

Figure 3: The force transmitted to the supporting structure (left panel) and the power input by the moving load (right panel) for different number of rails; the additional rails are imposed over the soft domain only (case B); the location of the abrupt change in foundation stiffness is marked by the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

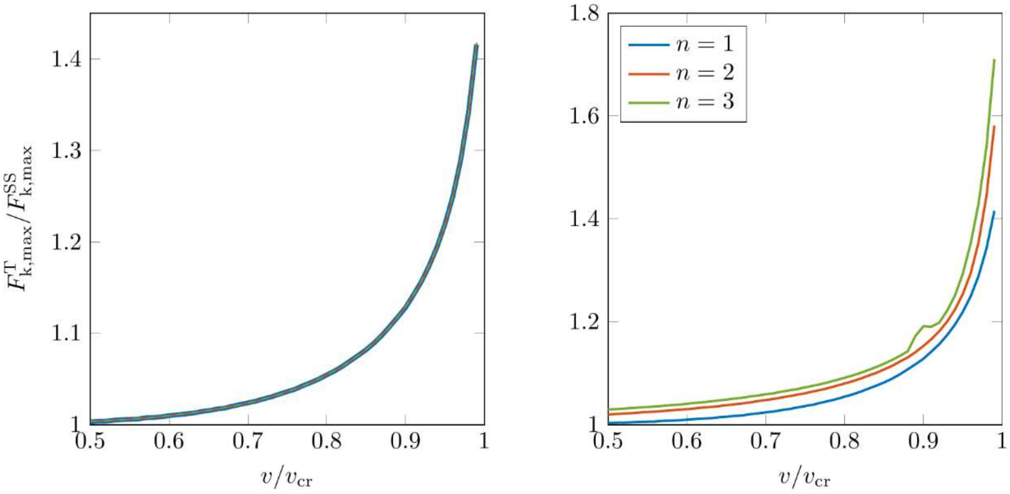

Figure 5: The amplification of the transmitted force in the transition zone for different load velocities; additional rails over both domains (left panel) and over the soft domain only (right panel).

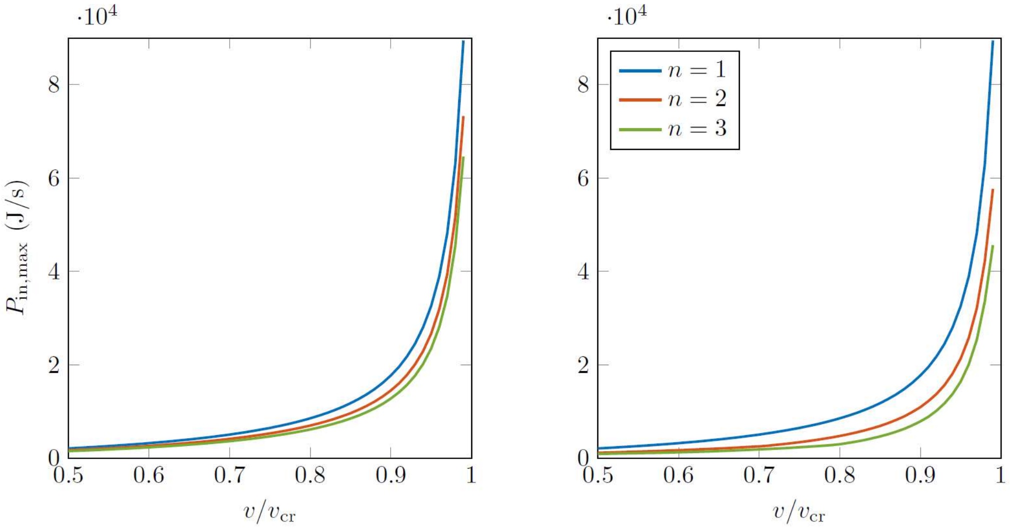

Figure 4: The maximum power input by the load for different load velocities; additional rails over both domains (left panel) and over the soft domain only (right panel).

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.

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