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Corrective countermeasure for track transition zones in railways: Adjustable fastener

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ABSTRACT

Transition zones in railway tracks are the locations with considerable variation in the vertical stiffness of supporting structures. Typically, they are located near engineering structures, such as bridges, culverts, tunnels and level crossings. In such locations, the variation of the vertical stiffness and the differential track settlement result in amplification of the dynamic forces acting on the track. This amplification contributes to the degradation process of ballast and subgrade, ultimately resulting in the increase of maintenance costs.

The paper studies a corrective countermeasure that can mitigate the track degradation in transition zones when differential settlement appears. The countermeasure is the adjustable rail fastener and its working principle is to eliminate the gap under hanging sleepers by adjusting the shims (height of the fastener). The adjustable fasteners are first tested on three transition zones, wherein the adjusted heights of fasteners (accumulated voiding) are recorded after the 2-month and 5-month operation. The test results show the adjustable fasteners are effective to mitigate the track degradation in the transition zones. The effect of the adjustable fasteners on the dynamic behaviour of transition zones is analysed using the FE method. The results show that the adjustable fasteners are effective to reduce the amplification of wheel forces, achieve a better stress distribution in ballast, and decrease the normal stresses in rails in transition zones. Parametric studies are also performed to study the applicability of the adjustable fasteners.

1. Introduction

Transition zones in railway tracks are locations with considerable variation in the vertical stiffness of supporting structures. Typically, they are located near engineering structures, such as bridges and slab tracks. An example of a typical transition zone is shown in Fig. 1.

In those locations, the variation of the vertical stiffness together with the differential settlement of tracks (when the foundation settles unevenly) results in amplification of dynamic forces, which contributes to the degradation of ballast and subgrade, ultimately resulting in deterioration of the vertical track geometry or even the damage of track components. To keep track transition zones in operation, more maintenance is required as compared to free tracks [1,2]. For instance, in the Netherlands, the maintenance activities on the tracks in transition zones are performed up to 4–8 times more often than that on free tracks [3,4]. Transition zones in the other countries of Europe and the US also require additional maintenance [5,6].

Even though many countermeasures have been used in transition zones, severe track deterioration in transition zones is still often observed [7,8]. In [9], three countermeasures including geocell, cement, and hot mix asphalt were applied on three similar transition zones. Compared to a plain transition zone (no countermeasure is applied) as a reference, it has been found that all countermeasures were not sufficient to reduce the settlement in the transition zones. In [10], the countermeasure, which uses an approaching slab linking the ballast track onto a concrete culvert, 'has exacerbated rather than mitigated the (transition) problem'. These findings are in agreement with [11], where the authors indicated that 'the problem of track degradation associated with stiffness variations is far from being solved'.

According to the settlement behaviour of ballast tracks [12–17], the track settlement process can be divided into two stages (as shown in Fig. 2). Stage 1 is the rapid settlement process, caused by the volumetric compaction and abrasion of ballast particles. Stage 2 is the standard settlement process (until the end of the maintenance interval) caused by the frictional sliding of particles. The settlement of ballast, subballast, and subgrade in Stage 1 is: (1) fast, which happens only after few months; (2) large, accounts for approximately 50% of the total settlement in a maintenance interval; (3) somewhat inevitable, which happens even though it was compacted. On the contrary to the large settlement appearing in ballast tracks, the engineering structures barely

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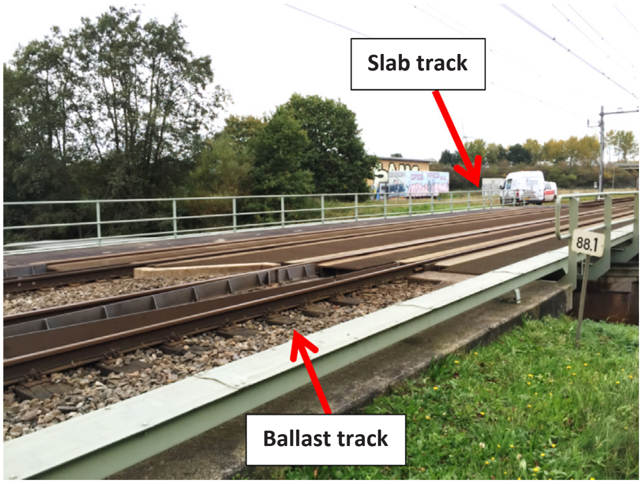

Fig. 1. Track transition zones.

settle, which creates a considerable geometry irregularity (differential settlement). After the differential settlement appears (corresponding to the beginning point of Stage 2, see Point B in Fig. 2), one end of the rails is settled together with the ballast track, while the other end is constrained by the engineering structures, creating gaps under sleepers (also known as hanging sleepers or voiding) on the embankment side.

Due to the existence of the gaps, the dynamic responses in transition zones are significantly increased [19,20]. For instance, a 1 mm gap can increase the sleeper-ballast contact force in adjacent locations by 70% [21]; and the 2 mm gap can lead to 85% increase of wheel forces [19]. It should be noted that the settlement curve in Fig. 2 is only for open ballast tracks. This is because the dynamic responses (e.g. wheel-rail interaction forces and ballast stress) are increased by the differential settlement and alter the settlement curve (mainly in Stage 2). An example of the transition zone with a large differential settlement is shown in Fig. 3 [18].

Therefore, the countermeasures can be categorized according to the settlement behaviour into the preventive countermeasures and corrective countermeasures. The preventive countermeasures are implemented during the construction prior to the track operation, while the corrective ones are used when the track has already settled (the differential settlement is visible). The studies of the transition zones with the perfect geometry, i.e. considering the beginning point of Stage 1 (Point A in Fig. 2), are more suitable for the preventive countermeasures, such as the studies in [8,22–27]; while for the analysis of corrective countermeasures, the numerical models have to take the differential settlement into account. The corrective countermeasures that can timely mitigate the transition zone problems caused by differential settlement (at Point B in Fig. 2) are required further studies.

This study focuses on the corrective countermeasures for transition zones which should meet the following requirements:

Fig. 3. Transition zone with a large differential settlement, from [18].

- The corrective operations should be performed in short track-possession windows manually or by using small machines.
- The corrective countermeasures should be able to mitigate the track degradation in transition zones.

The paper presents the experimental and numerical analysis of a corrective countermeasure – the adjustable fastener. The adjustable fastener intents to fill the partial gap between a sleeper and ballast by shims, whereas it prevents a large operation such as tamping. Even though (unloaded) track alignment is not restored, the hanging sleepers in the vicinity of engineering structures are eliminated, which can slow down the track degradation in transition zones.

The paper is organised as follows. The preventive and corrective countermeasures for transition zones are reviewed in Section 2, including the introduction of the adjustable fastener. The measurement results of three transition zones with the adjustable fasteners are discussed in Section 3. In Section 4, the dynamic behaviour of the transition zone (with differential settlement) with the adjustable fasteners is analysed using FE method. Finally, conclusions are given in Section 5.

2. Countermeasures for transition zones

The countermeasures for transition zones can be divided according to their application period, which is either the design stage (preventive measures) or the operation stage (corrective measures).

When designing a transition zone, the primary goal is to construct a zone with smooth changes of the vertical stiffness from the embankment to the engineering structure. A thorough review of the countermeasures for transition zones can be found in [28]. The countermeasures are applied to embankments or/and engineering structure. The intent of the countermeasures on the embankment is to reinforce the ballast track on different levels using various measures such as:

- Subgrade: the geocell, geotextile, cement, hot mix asphalt [9,29], and transition wedge (special backfill) [30];
- Ballast: the ballast glue [31], under ballast mat [32], pile or steel bar underneath the ballast [8,33], and ballast containment wall [34];
- Sleepers: sleeper modifications such as increasing its length and

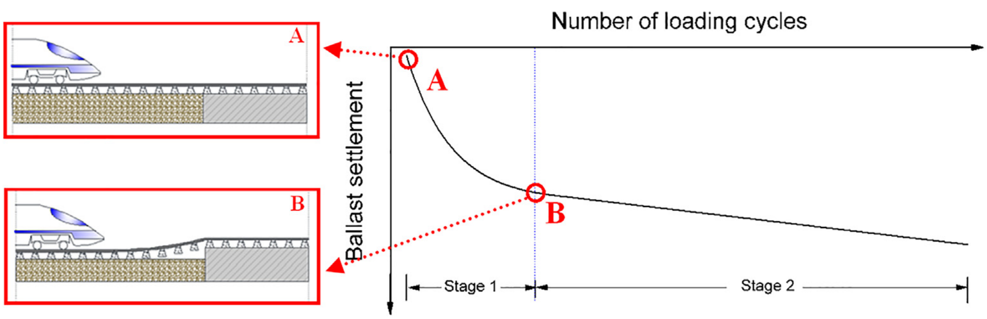

Fig. 2. Schematic permanent settlement curve of ballast as a function of loading cycles (only for open ballast tracks), from [18].