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Research Paper

Methodology for the comprehensive analysis of railway transition zones

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ABSTRACT

The paper presents a methodology for comprehensive analysis of railway transition zones (e.g. near bridges), including: an advanced measurement technique which uses a DIC-device to measure the dynamic displacements of rails at multiple locations along the track in transition zones; a Finite Element model of transition zones which considers stiffness variation, differential settlement, hanging sleepers, and vehicle dynamics; an iterative procedure to predict the track settlement in transition zones. An application is presented to demonstrate the effectiveness of the methodology. Experimental analysis, Short-term and Long-term numerical analysis, and Design variation analysis are performed on the transition zone.

1. Introduction

1.1. Background

Transition zones in railway tracks are locations with considerable changes in the vertical stiffness of rail support, which are typically located near engineering structures, such as bridges, culverts, tunnels and level crossings. In such locations, the dynamic responses are always significantly amplified [1], which contributes to the degradation process of ballast and subgrade, ultimately resulting in deterioration of track geometry. The Track geometry in turn causes further amplification of dynamic forces to tracks [2,3]. A typical transition zone in the Netherlands and its vertical geometry are shown in Fig. 1, wherein two large irregularities of track geometry before and after the bridge can be seen. The track vertical geometry was measured by the measuring coach Eurailscout UFM120 [4].

The track deterioration process in transition zones is accelerated with the increase of the operational velocities of passing trains, leading to a tremendous increase of the maintenance efforts on correction of the track geometry in transition zones [1]. Transition zones require more maintenance like tamping and adding ballast as compared to open tracks [5,6]. For instance, in the Netherlands, the maintenance activities on the track in transition zones are performed up to 4–8 times more often than on open tracks [7,8]. In the US $200 million is spent on maintenance of the track in transition zones annually, while in Europe about €97 million is spent on the similar maintenance activities [9,10].

1.2. Literature review of transition zones

Based on field observations and literature studies, the problems that can often be found in transition zones include:

- Damage of the track components: rail surface defects, broken fasteners, cracks in concrete sleepers, breakage of ballast particles, and voids between sleepers and ballast (also known as hanging sleepers) [1,2,6,8,11–19];
- Deterioration of the track geometry, i.e. extra settlement appearing on tracks and forming a "dip" [20]. It can be caused by different reasons which might be the breakage of the track component, the ballast pollution, the ballast penetration into subgrade, and the poor drainage [1,5,21];
- Loss of the passenger's comfort [22].

The reasons causing the transition zone problems are diverse. A thorough review of transition zones can be found in [23]. The major factors can be divided into the following three categories.

- The first factor is the differential (relative) settlement between the ballast track and the engineering structure. The differential settlement can also be considered as geometrical irregularity, which plays a major role in the degradation process of transition zones [22,24–28]. In [25], the transition zone with a geometry defect on rail (modelled by a short subsidence of the rail) was studied and it showed that track geometry defect could significantly increase the wheel force. Similar findings can be found in [29], where the authors showed that a 1 mm sleeper-ballast gap could increase the

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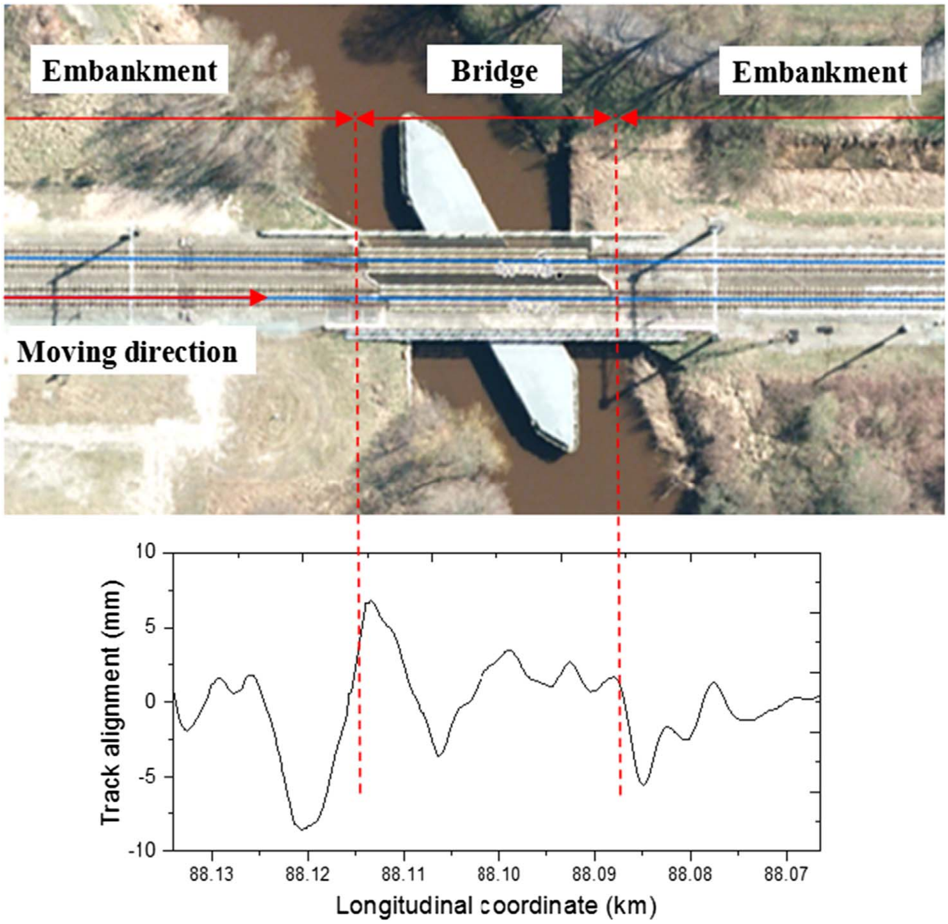

Fig. 1. A typical transition zone and the track vertical geometry measured by the measuring coach.

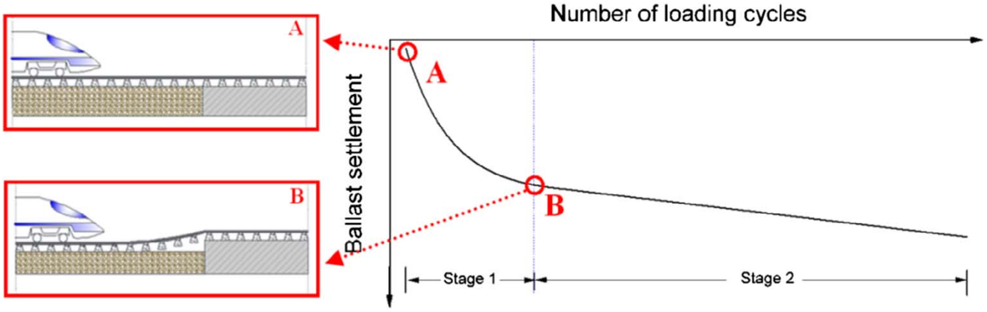

Fig. 2. Schematic permanent settlement curve of ballast as a function of loading cycles (only for open tracks).

sleeper-ballast contact force in adjacent locations by 70%. The extra settlement of ballast tracks as compared to that of engineering structures is mainly due to compaction of ballast and soil layer and the breakage and pulverisation of ballast [17]. After construction or tamping of open tracks, the permanent settlement of ballast can be divided into two stages according to the deformation mechanism of ballast [21,30–32] (see Fig. 2). Stage 1 is the rapid compaction and abrasion process that happens shortly after construction or tamping [21,30]. In this stage, the main deformation mechanism is the volumetric compaction of particles. Stage 2 is the normal settlement process happening until the end of a maintenance interval, wherein the main deformation mechanism is the frictional sliding of particles [30,33–36]. The settlement growth for open tracks is nonlinear in stage 1, while that is almost linear in Stage 2 [30,31].

- The second factor is the abrupt change in the vertical stiffness of tracks [2,15,37–40]. Since the vertical track stiffness determines the rail deflection during the train passages, the stiffness variation leads to the changes in the vertical acceleration of the moving trains and then results in the changes of vertical wheel forces (about 9% increase calculated in [38]), the rail vertical acceleration [15], and the ballast stress [28]. The influence becomes larger with the increase of train velocity [15].
- The geotechnical, construction and maintenance issues, such as the poor quality of used materials, inadequate compaction and consolidation of the fill and embankment, poor drainage conditions [1,16]. In [41], the authors studied the effect of the moisture condition in transition zones. It has found that the dynamic wheel forces are increased in transition zones due to the high moisture in the ballast.