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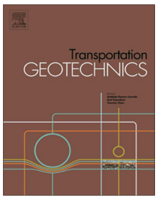

An integrated approach to dynamic analysis of railroad track transitions behavior

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ABSTRACT

Railway transitions like bridge approaches experience differential vertical movements due to variations in track stiffness, track damping characteristics, ballast settlement from fouling and/or degradation, as well as fill and subgrade settlement. Proper understanding of this phenomenon requires the integration of field instrumentation with analytical and numerical modeling. This paper introduces an integrated approach to dynamic analysis of the railway track transitions behavior using field instrumentation, analytical modeling, as well as numerical simulations using the Discrete Element Method (DEM). Several bridge approaches have been instrumented to monitor the track response on a problematic portion of the US North East Corridor (NEC), which is primarily a high-speed railway line with occasional freight traffic, carrying high-speed passenger trains operating up to a maximum speed of 241 km/h. Previous publications by the authors have focused on findings from geotechnical instrumentation of railroad track transitions, as well as the validity of a fully coupled 3-dimensional track dynamic model and image-aided discrete element models. The primary contribution of the current manuscript involves the combination of these three components to propose an integrated approach for studying the behavior of railroad track transitions. Track response data from instrumented bridge approaches were used to determine track substructure layer properties and calibrate a fully coupled 3-dimensional track dynamic model. Loading profiles generated from this model were then used as input for a discrete element based program to predict individual particle accelerations within the ballast layer. The importance of modeling the ballast layer as a particulate medium has been highlighted, and the particle to particle nature of load transfer within the ballast layer has been demonstrated.

Introduction

Railway track transitions present a significant challenge as far as maintenance of track profile is concerned. Due to the sudden change in track stiffness, the "stiff" side of a track transition undergoes lower deformations under loading, compared to the "less stiff" side. This differential movement often results in the formation of a "bump" in the track profile. Bridge approaches qualify as an ideal example of track transitions, with the approach track on either side of the bridge abutment being much less stiff compared to the bridge deck often supported by deep foundations. Differences in track system stiffness and/or damping characteristics, settlement of the ballast layer due to degradation and/or fouling, and settlement of the subgrade and/or fill

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layers are some of the factors commonly reported as mechanisms contributing to the differential movement at track transitions. Proper understanding of different mechanisms contributing to this phenomenon requires the combined application of field instrumentation with analytical and numerical track modeling. Several research studies have focused on investigating the bump development at both highway and railway bridge approaches (Zaman et al., 1991; Stark et al., 1995; Briaud et al., 1997; White et al., 2005; Briaud et al., 2006; Nicks, 2009). A detailed review of these past research efforts, different factors contributing to the bump development at railway track transitions, as well as the effects of possible remedial measures has been presented by Mishra et al. (2012).

Due to the sudden change in track profile, railway track transitions are often exposed to magnified dynamic loads as a train passes over them. Such magnified load levels ultimately result in rapid degradation in track geometry and profile, requiring frequent maintenance and resurfacing. The annual expenditure to maintain track transitions in the US has been reported to exceed USD 200 million (Sasaoka et al., 2005; Hyslip et al., 2009). Nicks (2009) reported that approximately 50% of railroad bridge approaches in North America experienced differential movement problems, characterized by the development of a low approach, usually 6–102 mm in depth. Read and Li (2006) reported that the bump problem is more significant at the “exit” side of a transition, as the train moves from a high-stiffness track to a low-stiffness track. The “bump” formation at railway bridge approaches is usually within 15 m from the abutment (Plotkin and Davis, 2008).

The differential movement at track transitions is particularly problematic for high-speed rail infrastructure as the “bump” is accentuated at high speeds. The issue is even more critical for shared corridors carrying both freight and high-speed passenger trains. Transitions along shared corridors need to be maintained to satisfy the high ride quality requirements associated with high-speed trains. Additionally, these transitions also need to withstand the heavy loads imposed by slow-moving freight trains without undergoing excessive deformations. With the current impetus for development of high speed lines in the US and the challenges associated with shared corridors for operation of passenger trains at increased speeds, preventing and mitigating the problem of differential movement at bridge approaches and other track transitions has become more significant.

This paper introduces an integrated approach to dynamic modeling of railway track transitions through field instrumentation and analytical and numerical modeling. Field instrumentation data collected from Multidepth Deflectometers (MDDs) and strain gauges are used to determine individual track substructure layer deformations and dynamic wheel loads, respectively. Track response data from instrumented bridge approaches are then used to calibrate a fully coupled 3-dimensional dynamic track model. Loading profiles generated from this model are used as input for a numerical simulation program based on the Discrete Element Method (DEM) to predict individual particle accelerations within the ballast layer. Shortcomings associated with other track analysis and numerical modeling approaches based on the principles of finite element, or finite difference methods to characterize the ballast layer as one continuum are highlighted. Accordingly, through the integrated approach, the importance of modeling the ballast layer as a particulate medium is mainly emphasized, and the particle to particle contact for load transfer within the ballast layer is demonstrated. Therefore, the primary objective of this paper is to emphasize the importance of adopting an integrated approach for realistic analyses of ballasted railroad track systems. This has been accomplished with the help of instrumentation and numerical modeling results from different track transition sections. Proposing solutions to mitigate the differential movement problem at track transitions is beyond the scope of this paper.

Field instrumentation of selected track transitions

A research study sponsored by the US Federal Railroad Administration (FRA) is currently being carried out at the University of Illinois with the overall objective of identifying and mitigating different factors contributing to the differential movement at railway transitions. Several problematic track transitions have been instrumented under the scope of the current study to monitor the track response under loading near Chester, Pennsylvania on Amtrak’s North East Corridor (NEC). There are 8–10 closely-spaced undergrade bridges with recurring differential movement problems at the bridge/embankment interfaces. The NEC is primarily a high-speed railway with occasional freight traffic, carrying high-speed passenger trains operating up to a maximum speed of 241 km/h. This segment of the NEC near Chester comprises four tracks, with Tracks 2 and 3 maintained for high-speed Acela Express passenger trains operating at 177 km/h. The predominant direction of traffic along Track 2 is Northbound whereas Track 3 primarily carries Southbound traffic. Data from the instrumented track transitions are being used to calibrate different analytical and numerical models to predict the dynamic track behavior under train loading. A brief description of the instrumentation used in the current study is first presented in the sections below.

Instrumentation details

The instrumentation used in the current study comprised Multidepth Deflectometers (MDDs) for measuring track substructure layer deformations, and strain gauges mounted on the rail for measuring the vertical wheel loads and tie support reactions. The MDD technology was first developed in South Africa in the early 1980s to measure individual layer deformations in highway pavements (Scullion et al., 1989). MDDs typically consist of up to six linear variable differential transformers (LVDTs) installed vertically at preselected depths in a small diameter (45 mm in the current study) hole to measure the deformation of individual track layers with respect to a fixed anchor buried deep in the ground (DeBeer et al., 1989). More details on the operation principle of MDDs can be found elsewhere (Mishra et al., 2012; DeBeer et al., 1989). It is noteworthy