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The Resilience of Vision-Based Technology for Railway Track bed Monitoring

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Abstract

Innovative non-contact sensing and monitoring systems based on Vision-Based (VB) technology are becoming a viable method to remotely capture railway track vibrations and quality. This paper describes the use of VB system for the measurement of track vertical displacements and the estimation of track stiffness. The dynamic response of the track under a moving vehicle load was investigated through experimental and numerical modelling using a series of large-scale trails and finite element (FE) simulations. The accuracy of the VB system was examined with a conventional sensor used to measure the rail deflection. The viability of VB system in detecting voids between rail and sleeper due to faults in fastening were discussed. Results obtained from the VB monitoring was then used to calibrate FE models used to estimate the subsoil stiffness. The paper concludes with a discussion of how this methodology can be utilised in the railway industry for assessing the track performance with less complicated and more cost-effective hardware compared to conventional monitoring systems.

Keywords: Vision-Based technology, finite element, railway track, stiffness, monitoring.

1 Introduction

A durable track bed stiffness is an important factor influencing the resilience of a railway as this directly influences the magnitude of rail oscillations from train traffic [1]. The ability to accurately measure both rail level movements and trackbed stiffness is strongly desirable especially if correlations between the two can be used for design predictions of resilience.

Numerical analysis such as finite element analysis (FEA), is well-suited to model trackbed behaviour and can simulate rail level movements in response to loading [2]. However, the accuracy of the numerical analysis is highly dependant upon relevant input parameters e.g. stiffness of the trackbed elements and a means to validate modelling assumptions and subsequent predictions is important.

Conventional assessment of track bed stiffness or rail displacement uses instruments such as Falling Weight Deflectometer, Geophone, accelerometer or, Linear Variable Differential Transformer [3]. However, these traditional methods require contact with the track and non-contact technologies are highly demanded to meet safety requirements with less traffic disruption.

Recent research has applied non-contact Vision-Based (VB) monitoring systems to the structural health monitoring and assessment of civil engineering infrastructures [4-6]. The VB technique uses an image acquisition device (cameras or frame grabber boards) and a method of video-processing, e.g. a computer with image processing software to filter the signal with appropriate algorithms in order to output displacement measurements over time. Use of a VB system to measure railway track displacements was first explored by Bowness et al. [7] and further researched by Priest et al. [8] as a means of gathering dynamic railway deflection data caused by the passage of a train. Since then, VB system has been successfully used to evaluate railway trackbed conditions [8-10].

This paper focuses on the use of VB system for the measurement of track vertical displacements under vehicle loading and the estimation of track stiffness. A dynamic void meter was used to evaluate the accuracy of the VB system. The viability of VB system in detecting voids between rail and sleeper due to faults in fastening are discussed. Results obtained from the VB monitoring was then used to calibrate FEA models used to estimate the subsoil stiffness.

2 Methods

Trackbed monitoring tests were conducted in a full-size outdoor railway test track at Van Elle's premises in Nottingham. The test track comprised a 100m by 5m area of jointed rail supported by concrete sleepers on 350 mm deep ballast. The ballast is underlain by a 1.7m thick layer of an ashy Made Ground material overlying Sandstone. A two-axle rail vehicle (30 tons COLMAR Railroad loader) with 4.37m axle spacing attached to a trailer with 4m axle spacing was used as the moving load. The speed of the vehicle was limited to 12km/hr-19 km/hr in the trials.

A target-based VB system comprising a modified GoPro camera, equipped with a zoom lens, was used for measuring the vertical deflection of the track. The computer vision algorithms used the collected images (video frames) including the predefined Region of Interest (ROI) captured by the digital camera for video-processing. A series of artificial planar targets were used to measure the displacement of the railway track components. The vertical displacement of the rail web and the sleeper were measured by tracking the targets attached to them (ROI 1and ROI 2). To ensure that the same location was monitored by the sensor and the VB system, a target was attached to the void meter box (ROI 3), representative of the sensor movement. The maximum vertical displacement range of ROI 3 was then compared with the measurement obtained by void meter.

Measurements were taken using a GoPro camera mounted on tripod, in stable location looking at the targets attached to the rail and the sleeper at distances of 2-3.5 m from the measured line. The sampling frequency (frames per second) used during recording were up to 120 Hz. A typical image with targets is illustrated in Figure 1. Measurements were performed for several vehicle passages in same location assessed.

Figure 1. A typical video image with Region of Interests (ROIs).

A two-dimensional (2D) plane strain FE approach was used to estimate the subsoil stiffness under the effect of dynamic loading (Figure 2). The rail and sleepers were modelled as elastic media, while the ballast layer and substructures were simulated as elastoplastic media using the Mohr–Coulomb constitutive model. Stiffness of the track components were derived from literature. Stiffness of the subsoil was estimated from ground investigation data with parametric study used to consider a range of reasonable values. The loading regime and frequency were adopted in the FE models based on the vehicle speed, mass and the axle configuration used.

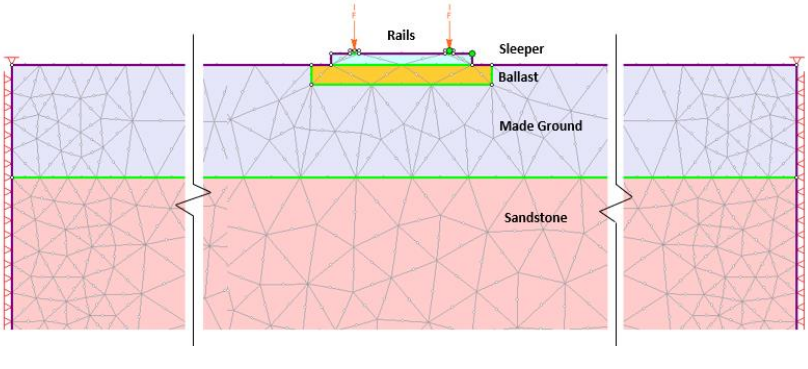

Figure 2. Schematic display of the 2D FE-model.

3 Results

The vertical displacements of both rail and sleeper of a standard ballasted track were measured by VB system. A target (ROI 3) was taken as representative of void meter box displacement. The comparison was made between the void meter and VB measurements of ROI 3 for all tests with 1-5% differences.

Figure 3 shows a typical time-displacement plot of the rail, sleeper and the displacement range of the sensor obtained from VB system for passing the vehicle with no trailer. From this plot, the maximum displacement was obtained correspondingly for the rail, sleeper, and sensor box.

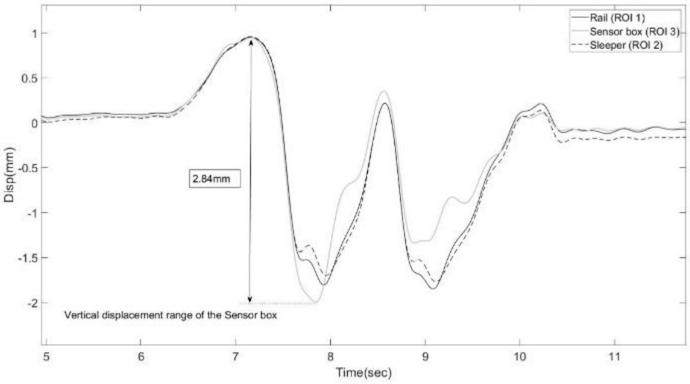

Figure 3. Vertical displacement versus Time for vehicle with no trailer, obtained by VB system.

The maximum displacement range in the sensor location measured by VB system (2.84mm) shows close agreement with the measurement by the sensor (void meter) 2.74mm.

The void meter is only able to measure the movement of the rail surface and so cannot detect any voiding between sleepers and rail. Whereas the VB system measured the displacement from all track components, allowing voiding to be determined by subtracting rail displacement from sleeper displacement. In these trials, voiding due to exaggerated relative movement between rail and sleeper was instigated by removing the clips from a sleeper. Displacement versus time for trials with and without the sleeper clip are presented in Figures 4 and 5, respectively.

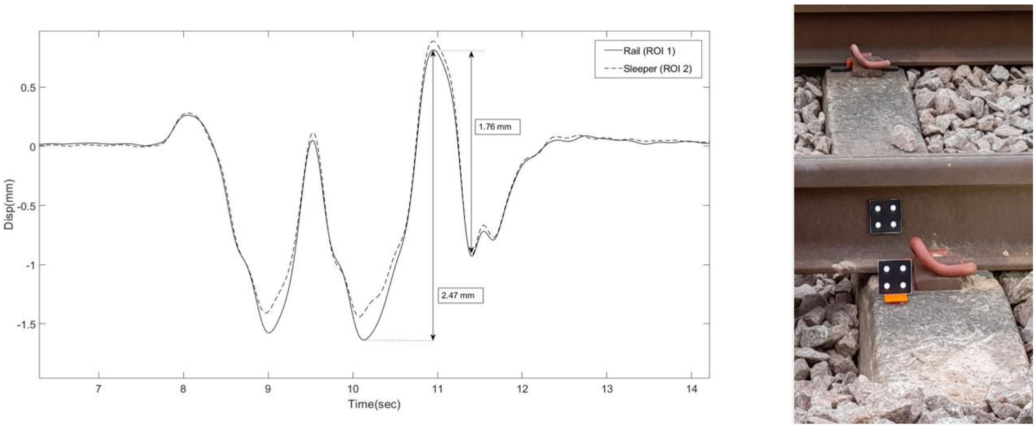

Figure 4. Vertical displacement versus Time for a trial with clip on the sleeper, obtained by VB system

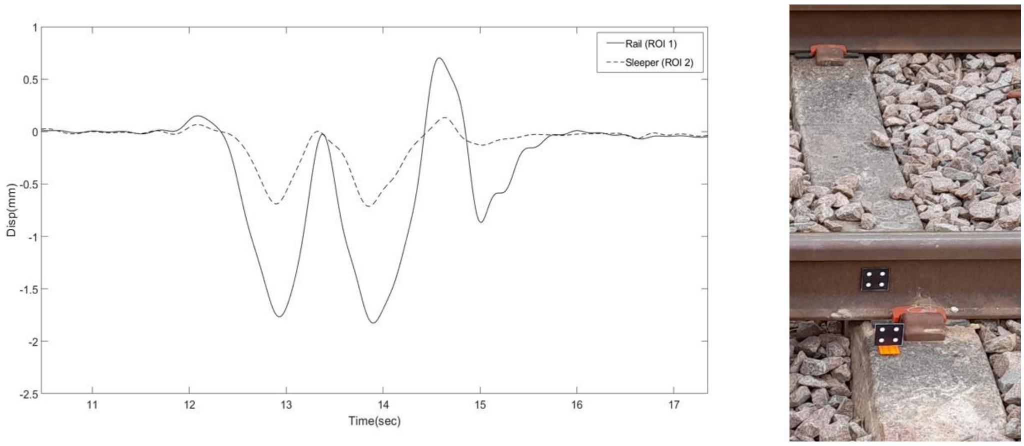

Figure 5. Vertical displacement versus Time for a trial without clip on the sleeper, obtained by VB system.

An important feature to notice from these figures is the difference between the displacement of the sleeper (void) and the displacement of the rail where the railway system is clipped and unclipped. Figure 4 shows a large void which is about 1 mm due to unclipped system, while the clipped system experienced smaller void (is about 0.2-0.35 mm) between the sleeper and the rail which (see Figure 4).

Results form VB system obtained for the trails with a vehicle (no trailer) and considering clipped rail condition were used to calibrate the FE models and consequently estimate the subsoil stiffness through a parametric study.

2D FE model is not able to simulate the transient response of the trackbed under a moving load, however the dynamic response of the track under cyclic loading is achievable. Therefore, only the maximum downward movement of the track under cyclic load was extracted from the graph produced by FE results, to compare them with the peaks from VB system. The peaks were compared with the peaks of two axles obtained from VB system in Figure 6 to estimate the Made Ground stiffness as 25-35MPa.

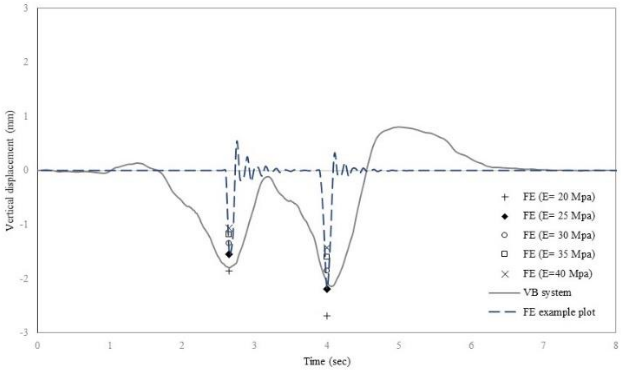

Figure 6. Comparison between a VB plot and FE displacement values at varying subsoil modulus of elasticity.

The findings of this project indicate the feasibility of using VB technology for the accurate displacement and dynamic analysis of the railway trackbed components.

4 Conclusions and Contributions

The feasibility of using Vison-Based system in measuring of railway track displacement was explored through a series of large-scale trials. The reliability and accuracy of the VB system was approved by a digital void meter. The results showed that the VB system can be directly employed with high accuracy for the evaluation of track performance and hence track stiffness. The VB system can measure the displacement of track components (i.e., rails and sleeper), and detect voiding occurred between the components, while the void meter only provides the total displacement of the track. The VB results highlights the role of the rail-sleeper fastening system in reducing voids. In addition, the results from VB system were used in a 2D FE models to estimate the subsoil stiffness. This establishes the basis of a predictive tool which could estimate how rail level movements may change if sub soil stiffness deteriorates over time due to environmental effects or increases due to remedial works.

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