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Field trials for dynamic characteristics of railway track and its components using impact excitation technique

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Abstract

Assessment of condition of railway track is crucial for track design, repair, and effective maintenance operations. In-field dynamic testing in combination with track modelling represents an efficient strategy for identification of the current condition of railway track structure and its components. Field investigations for the dynamic characteristics of a railway track and its components were carried out and are presented in this paper. A non-destructive technique using impact excitation, so-called '*modal testing*', was utilized in these trials. Integrated approach combining field measurements, experimental modal analysis, and finite element modelling to evaluate the dynamic parameters of the in situ railway track components are appended. A ballasted railway track site in Central Queensland managed by Queensland Rail (QR) was selected to perform the field tests. Six sleeper-fastening-rail assemblies were selected for dynamic testing. The frequency response functions (FRFs) were recorded by using Bruel & Kjaer PULSE vibration analyser in a frequency domain between 0 and 1600 Hz. The data obtained were best fitted using the least-square technique to determine the dynamic stiffness and damping constants of the tested track components. In addition, the experimentally determined resonance frequencies along with the dynamic properties of the track components can provide an important input for determining the maximum speed and axle load for the future track upgrades. This paper also points out on how to judge the dynamic responses (e.g. FRFs) together with the visual inspection of existing conditions from the field experience. Examples of testing results representing the deficient integrity are additionally highlighted. Based on the results, the impact excitation technique is an efficient method susceptible to the structural integrity of railway track structures.

Keywords: Railway track; Rail pad; Concrete sleeper; Dynamic characteristics; Field trials; Modal testing; Impact excitation; Condition assessment; Track simulation

1. Introduction

Demand for mass transportation, freight and coal transport across a continent has become a major contribution driving research and development in railway industry to build railway tracks meeting such variety of services. Everyday there exist increasingly the needs of railway utilization (e.g. heavier axle loads, faster speeds, more frequent, etc.), whilst the existing track infrastructure is questioned for its current capacity, functionality and remaining service life. As well known, the railway structures are inevitably degrading and deteriorating due to the everyday services. Information on the structural integrity and deterioration of railway tracks is very limited. The relationships between deterioration and maintenance/renewal associated with railway infrastructure would be of great interest to track engineers and managers concerned with minimizing maintenance/renewal costs. Having a better understanding of maintenance and renewal and the deterioration rates could lead to improved strategic planning and implementation [1]. In reality, the structural conditions of railway tracks are typically not known either before or after maintenance procedures since in practice the maintenance and renewal operations are usually based on empirical criteria.

At present, accelerating degradation of railway tracks creates many problems to railway engineers. In order to

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both maximize safety and minimize costs of track maintenance and renewal, assessment and monitoring of the structural health of railway track and its components must be done. There are a number of testing methodologies available to undertake the identification and monitoring of the conditions of the track structures and their individual components [2]; for instance, the ground penetrating radar for estimating track modulus [3], the time frequency transform technique for diagnosing fastening system [4] or the new trend of using ultrasonic waves for detecting flaws and imperfections in rails [5]. However, one of the most practical approaches is to use an instrumented impact hammer to impart excitations into the in situ/in-field tracks and to measure the dynamic responses for condition assessment [6,7]. This method has been successfully extended to the track structures in an urban environment [8,9]. In those studies, the track was simplified as a two-degrees-of-freedom (2DOF) discretely supported continuous rail system representing two effective masses of rail and sleeper, as well as two dynamic stiffness and two dashpots of rail pad and ballast formation, respectively. Modal testing has been found to be a very useful tool in assessing the properties of railway tracks. In this study, modal testing was adopted for the field investigations while the analytical and FEM models were used to evaluate the structural conditions of the railway tracks.

In Queensland, Australia, there are various problems identified on the coal lines due to the heavy axle loads and tilt topography. The structural integrity of the track components on some of the lines needed to be investigated. As part of the Rail-CRC project, the University of Wollongong (UoW) together with Queensland Rail (QR) and Queensland University of Technology (QUT) joined forces in order to investigate the conditions of a heavy haul railway track in Mackay, Central Queensland [10–13], as illustrated in Fig. 1. Modal results were obtained from field measurements and used to assess the current structural conditions of the railway track. Based on the discrete support model, equations of motion of a 2DOF dynamic model of railway track have been formulated using Fast Fourier Transform (FFT) approximation technique, in order to extract the modal properties of track components from the field dynamic testing results obtained using an instrumented hammer impact technique. However, the dynamic responses obtained imply the local track behaviours only. Thus, random positions to be tested must be of a wide range that could represent the integrity of whole area.

Fig. 1. Typical ballasted track on a coal line in Central Queensland (after [7]).

This paper presents an integrated approach that combines field testing, experimental modal analysis, and finite element modelling to evaluate the dynamic parameters of in situ railway track components. Six sleeper-fastening-rail assemblies were selected for dynamic testing. The frequency response functions (FRFs) were recorded by using Bruel & Kjaer PULSE vibration analyser in a frequency domain between 0 and 1600 Hz. The data obtained were processed using least-square curve-fitting technique to determine the dynamic stiffness and damping constants of the tested track components. These results can supply a track maintenance engineer with very important information on the current structural conditions of the railway track. In addition, system identification to evaluate the track system dynamics has been developed and performed. The experimentally determined resonance frequencies together with the dynamic properties of each track component can provide a significant input for determining the maximum speed and axle load for the future track upgrades. However, in this study only ballasted railway tracks are considered.

2. Track simulation

One of the first analytical models of railway track dynamics was developed by Timoshenko in 1926 [14]. In that model, the rail was considered as an infinite uniform Euler beam, laid on a continuous damped elastic Winkler foundation. Later, Grassie and Cox [15] found from the experiments that there are only two dominant resonances in the frequency range of interest for railway track. The first resonance, an in-phase mode at about 100 Hz, corresponds to the sleeper and rail moving together on the ballast. The second resonance, the out-of-phase mode at the frequency somewhere between 300–500 Hz depending on the rail pad parameters, corresponds to the opposite vibration of sleepers on ballast and rails on the rail pad. Cai [16] found that modelling the rail and sleeper as Timoshenko beam provides the best analytical results.

For design and maintenance purposes, complicated models of railway tracks seem to be impractical when considering the field testing [2]. It has been demonstrated that simple analytical and finite element models calibrated using experimental data are capable of providing reliable predictions of railway track vibration response. In this study, the ballasted tracks are considered as shown in