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Comparison of performance of concrete and steel sleepers using experimental and discrete element methods

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ABSTRACT

Experimental and numerical discrete element analyses have been performed to investigate trackbed behaviour for concrete mono-block and steel sleepers. For the laboratory and numerical approaches considered, ballast settlement as well as ballast-subgrade interface pressure is measured. Consideration is also given to the steel sleeper installation process by the comparison of a statically driven steel sleeper to a "wished-in-place" configuration.

Introduction

Railways are integral to the transportation system of many countries around the world. Consequently, it is necessary from the safety and economic perspectives that they maintain their design geometry over their lifespan, with minimal interruption to day to day operations for maintenance. However, with the passage of traffic over a prolonged period, sections of a railway track inevitably deteriorate, leading to speed restrictions and poor levels of passenger comfort.

The behaviour of a railway track (bed) under cyclic loading has been the focus of considerable research in recent times (Indraratna et al., 2009, 2001, 2005; Saussine et al., 2006; Lu and McDowell, 2010; Lobo-Guerrero and Vallejo, 2006). Understanding railway track behaviour is of importance to gain insight into the complex mechanisms that lead to track deterioration especially as a railway track comprises of several interdependent components. It remains important to policy makers, rail practitioners and researchers to identify new techniques, innovations or processes that will prolong intervals between scheduled track maintenance so as to provide a sustained degree of passenger comfort and maintain the economic activity that rail transport yields.

Track settlement is an undesired effect of the repeated or cyclical loading of a railway track that can originate from several sources including subgrade settlement, ballast densification which may or may not be a consequence of ballast crushing, lateral spreading of the ballast, and deterioration of the sleepers amongst others. According to Selig and Waters (Selig and Waters, 1994), the contribution of ballast to substructure settlement is more pronounced than that other sub-structural elements (see Fig. 1).

Small scale and large scale laboratory experiments as well as field trials (Yoo and Selig, 1979; Indraratna et al., 2010) have been conducted to provide qualitative and quantitative insight into the behaviour of railway tracks subjected to cyclic loading in different environmental conditions. Such endeavours have been made possible by

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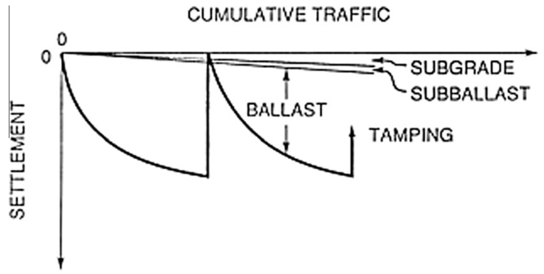

Fig. 1. Substructure contributions to settlement (Selig and Waters, 1994).

the use of facilities such as the box test apparatus (Norman, 1983; Lim, 2004), large cylinder triaxial apparatus (Aursudkij et al., 2009; Indraratna et al., 1998) and railway testing rigs (Le Pen and Powrie, 2011; Brown and et al., 2007). Additionally, different numerical approaches have been pursued to predict track behaviour (Karrech et al., 2007; Oscarsson and Dahlberg, 1998). This paper is based on box tests experiments on representative sleepers sections, large scale experiments with full length sleepers and numerical analysis conducted at the University of Nottingham.

An economic case is occasionally made for the use of steel sleepers over concrete sleepers on the basis that it permits the deferral of track renewal by a number of years on secondary or slower railway lines (Steel sleepers, 2001). The behaviour of a concrete mono-block sleeper is compared to a steel sleeper with the aim of providing evidenced-based guidance to support or discourage current industry practice. With regards to the steel sleeper, two installation methods were investigated. Steel sleepers require the interaction between the ballast that fills their hollow undersides and the ballast bed they sit on for stability and support. The common practice amongst railway maintainers is to drive the sleepers into a scarified bed of substandard (or highly degraded) ballast using a relatively static passing load such as a ballast train or tamper but there is no research evidence to support this method (Steel Sleepers Invade Concrete Territory, 2000; Tata Steel, 2013). This paper investigates the suitability of this practice by comparing the behaviour of a driven sleeper to a sleeper installed with minimal mechanical agitation, referred to as the 'Wished into Place' (WIP) method.

Of the experimental approaches used, the box test on a section of sleeper offers the simplest means to investigate the behaviour of a cyclically loaded railway track in a controlled laboratory setting. It permits the measurement of important track variables such as transient or permanent sleeper displacement using displacement transducers situated at positions of relevance during cyclic load application. Selig and Waters (1994) used the box test to measure horizontal stresses generated as a result of cyclically loading ballast. Lim (2004) used the box test to investigate the influence of tamping on ballast degradation where it was proven to be reliable with regards to its consistent reproduction of track stiffness and settlements as well as aggregate particle size distributions after tamping.

Two numerical approaches utilising the numerical Discrete Element Method (DEM) have been used to validate the experimental results on box tests and to examine the behaviour of the ballast at particle scale which can be difficult to achieve experimentally. The first numerical approach is a realistic particle shape method developed by Ferellec and McDowell (2010a,b, 2008), whiles the second considers ballast particles to be of an idealised simple shape. Both approaches have their own merits that are highlighted in later sections. The experimental and numerical approaches of the box test were used as preliminary investigations of the performance of concrete and steel sleepers to precede the full scale and more resource intensive tests that followed. Large scale railway test facilities offer the prospect of testing a short section of railway track at full scale but in a laboratory environment. In the UK several of such facilities exist albeit differing in size and range of measuring capability. The Nottingham Railway Test Facility (RTF) was used to investigate the use of geogrid reinforcement in railway tracks (Kwan, 2006) and to investigate the impact of tamping maintenance on ballast behaviour (Aursudkij, 2007). The investigations were shown to be successful in demonstrating the competence and capability of this test facility.

In line with the logic of this study, the first part of this paper describes experimental box tests used to compare the performance of sections of concrete and steel sleepers in terms of settlement. The second and third parts respectively defines realistic and simplified DEM models, their application to the box tests described in the first part, for confirmation of the results in terms of settlement which are explained by analysis of the ballast/sleeper interaction at the particle scale. The final part describes the performance of the two types of sleeper using full length sleepers in realistic testing conditions through settlement and ground pressure analysis.

Sleeper section tests in laboratory

Test description

Sleeper section tests were performed using the box test apparatus (Fig. 2) which is essentially a box 700 mm long, 300 mm wide and 450 mm deep designed to represent a confined three-dimensional cross-section of a full-size railway track. Apart from one reinforced Perspex face used for observation and a wood base, the remainder of the entire box is constructed from case-hardened steel.

The wood base of the box test apparatus is lined with a 6 mm thick rubber mat to provide a subgrade reaction representative of typical railway track subgrade condition. Prior to use, a 3 mm mat was tested in compression for a range of stresses over a 100 cm^2 platen area.

For a maximum stress of 190 kPa at the base of the box and a deflection of 0.48 mm as per the aforementioned compression test, if the platen is assumed to be a rigid foundation on an infinite elastic half-space, an equivalent elastic subgrade modulus can be obtained by solving for E_s in equation 1 (Brown, 1969a, Brown, 1969b):

$$\rho = \frac{qdI(1-\upsilon^2)}{E_s} \quad (1)$$