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Technical Paper

Deformation characteristics of fresh and fouled ballasts subjected to tamping maintenance

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Abstract

A number of train passes over time induces large settlement on ballasted railway tracks. Tamping maintenance application, which is practised worldwide, can lead to additional subsequent track settlement from the disturbances caused by the tamping tools. In this study, a series of model tests on a scaled-down ballasted railway track was conducted to examine the settlement characteristics of ballast subjected to tamping maintenance application. The particle movements during cyclic loading were tracked using a particle image velocimetry (PIV) approach to study the local deformations induced by the tamping tools. The results revealed that the intrusion of fouling material and subsequent maintenance application altered the settlement characteristics significantly. The PIV results revealed that the top ballast is loosened by the tamping tools. It was also found that the strength properties of ballast deteriorate with the fouling of the material. Notably, the strain hardening behaviour of ballast is weakened when the material undergoes 30% fouling or more according to the fouling index, FI_p (i.e., an indication of degree of ballast fouling). The results of this study suggest that track maintenance should involve the tamping of fouled ballast before FI_p reaches 30%.

Keywords: Ballasted railway track; Fouled ballast; Fouling index; Model test; Particle image velocimetry; Settlement characteristic; Shear strain; Tamping application; Triaxial compression test

1. Introduction

Most of the railway tracks throughout the world are ballasted railway tracks, which are preferred over concrete railway tracks. Many aspects, including simplicity in construction and maintenance works, have led to the wide use of the ballasted railway tracks. Track settlement occurs gradually over time with long-term service due to the large number of train passes. Excessive settlement can cause poor passenger comfort, speed restriction and potential derailments. As reported in Selig and Waters (1994), ballast contributes to most of the substructure settlement (see Fig. 1) although the main function of the ballast layer is to restrain the track geometry. It has also been reported that a major portion of the track maintenance budget is spent on the substructure (Ionescu et al., 1998; Raymond et al., 1978).

In ballasted railway tracks, ballast fouling occurs when the finer materials (i.e., the materials smaller than fresh ballast) mix with fresh ballasts due to heavy repeated train loads. It is expected that fresh or clean ballast is used in the construction of a railway track with the fouling components not exceeding 2% (Indraratna and Salim, 2005). Generally, finer materials

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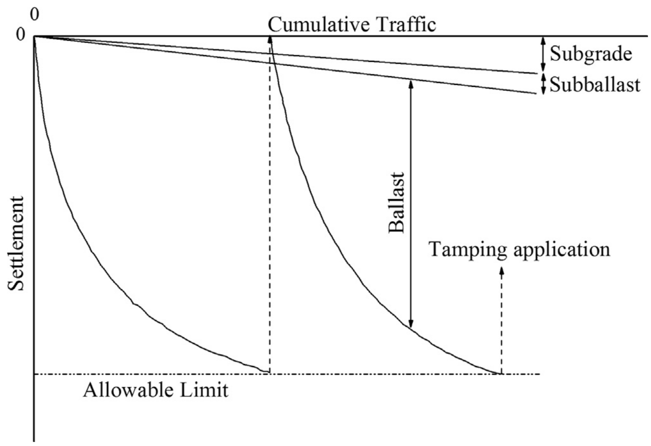

Fig. 1. Substructure contributions to settlement (modified after Selig and Waters, 1994).

come from underlying layers as well as being produced by particle crushing (Hossain et al., 2007; Indraratna et al., 2011a; Selig and Waters, 1994). However, it should be noted that the source of fouling materials may be differ according to the nature of railway tracks and the source of original ballast (Selig and Waters, 1994; Feldman and Nissen, 2002). As reported by Indraratna et al. (2002a) and Indraratna and Salim (2005), a wide variety of material is used as ballast around the world: economic and environmental issues are among the considerations when sourcing ballast. Finer material intrusions alter the original particle size distribution (PSD) of ballast, from uniform gradation to less uniform gradation, depending on the amount of fouling materials mixed with fresh ballast. The altered gradation of fouled ballasts results in settlement characteristics different than those of fresh ballast (Indraratna et al., 2006). Huang and Tutumluer (2011) and Indraratna et al. (2011a) discussed the effects of ballast fouling on geo-grid reinforced ballasts and found that the strength properties of fouled ballasts are affected by the degree of ballast fouling. Cambio and Ge (2007) have also reported that the strength properties of fouled ballasts are significantly affected by the intrusion of fouling materials into fresh ballast.

Once the railway track settlement reaches the allowable limit, maintenance is necessary to return the railway track to its original position since differential settlement can result in many problems, including derailment. Tamping application is practised worldwide as the main maintenance application (Indraratna and Salim 2005). One of the problems arising from the use of tamping application is that the tamping tools can loosen the top ballast and also induce particle crushing depending on penetration depth of the tamping tools into the ballast layer.

As discussed briefly in this paper, ballast deteriorates due to many reasons, including breakage of angular corners and sharp edges (i.e., resulting into finer materials), an infiltration of fines from the surface and finer materials pumping from the underlying layers under train loading (Indraratna et al., 2011a; Selig and Waters, 1994). As a result of these actions, ballast becomes fouled, less angular and its shear strength is reduced (Indraratna et al., 2005). Angular particles have better load spreading properties due to better interlock than rounded particles (Holtz and Gibbs, 1956; Indraratna et al., 1998; Leps, 1970). Due to the increasing importance of the ballasted railway tracks, a number of studies on the deformation characteristics of fouled ballasts have been conducted in the recent past (Indraratna et al., 2001; Lackenby et al., 2007; Raymond and Bathurst, 1994). However, the effects of ballast fouling or tamping application itself on settlement characteristics have scarcely been studied, resulting in a lack of knowledge on the settlement characteristics of fouled ballasts subjected to maintenance applications.

Generally, the degree of ballast fouling is described by a fouling index (Ionescu, 2004; Selig and Waters, 1994). Later, Feldman and Nissen (2002) proposed a volume-based fouling index due to variations in specific gravities of fresh ballast and fouling materials. Recently, Indraratna et al. (2010) and Indraratna et al. (2011c) modified the volume-based fouling index proposed by Feldman and Nissen (2002) due to its practical limitations and introduced slightly different fouling indexes. The fouling indexes proposed by Feldman and Nissen (2002) and Indraratna et al. (2010) are important when the fouling material has a low specific gravity compared to fresh ballast. The volume-based fouling indexes are also very useful when studying the drainage characteristics of ballasted railway tracks since they take the voids in the ballast particles into account more appropriately than mass-based fouling indexes. The volume-based approach proposed by Indraratna et al. (2010) has later been used in laboratory and numerical approaches as well (Indraratna et al., 2013, 2014). Since the specific gravities of the materials used in this study were approximately the same (e.g., 2.75 of fresh ballast compared to 2.65 of fouling material) and because of its simplicity of use, the fouling index reported by Ionescu (2004) is still used to classify the fouled ballasts. The original equation proposed by Ionescu (2004) was modified to fit into the scale-down materials used in this research as given in Eq. (1). In the equation proposed by Ionescu (2004), they were given as $P_{0.075}$ and $P_{13.2}$, which were simply modified to $P_{0.015}$ and $P_{2.64}$ respectively taking account of the scaled-down ballast (i.e., 1/5th scale) used in this study. According to Ionescu (2004), ballast with $FI_{\rm p} < 2$ is considered clean (or fresh) ballast, when $10 \leq FI_{\rm p} < 20$ the ballast is considered moderately fouled, when $20 \leq FI_{\rm P} < 40$ it is consodered fouled ballast, and when $FI_{\rm p} > 45$ the ballast is considered highly fouled.

$$FI_{\rm p} = P_{0.015} + P_{2.64} \quad (1)$$

where $FI_{\rm p}$ is fouling index, $P_{0.015}$ and $P_{2.64}$ are percentages passing at 0.015 and 2.64 mm respectively.

In this research, settlement characteristics of fouled ballasts with different fouling indexes were studied by conducting model tests on a scaled-down railway track. The field tamping application was simulated on the model trackbed using a simple tool and its effects on subsequent settlement were examined using a particle image velocimetry (PIV) approach. The PIV method was used to track the particle movements and