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Novel performance-based technique for predicting maintenance strategy of bitumen stabilised ballast

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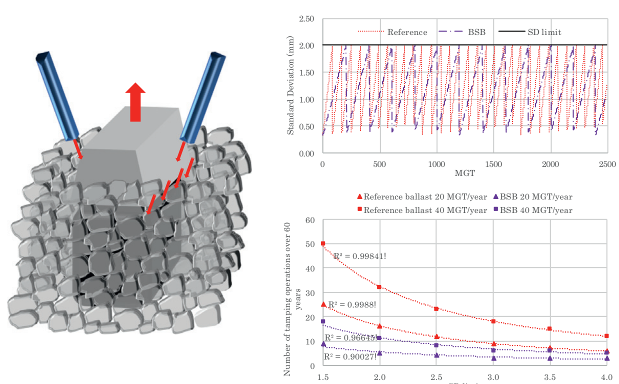
HIGHLIGHTS

- Ballasted track-bed affected by settlement and contamination due to traffic and maintenance.
- Bitumen stabilised ballast (BSB) as solution to reduce track-bed maintenance burdens.
- Novel integrated track-bed degradation model to predict maintenance strategies.
- Increased intervals between minor and major maintenance operations due to the used of BSB.
- Sensitivity analysis to traffic and quality level set for the infrastructure.

GRAPHICAL ABSTRACT



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ABSTRACT

Despite being the most used worldwide, railway ballasted tracks presents high maintenance cost related to ballast settlement and particle degradation. With the aim of reducing life cycle costs, bitumen stabilised ballast (BSB) has been recently proposed as a relatively cheap alternative maintenance solution to be applied to existing tracks. This study aims at assessing the potential advantages of this technology, defining a novel maintenance strategy of traditional ballasted track-beds. A protocol for the application of the BSB technology and its associated maintenance strategy is defined. To estimate minor and major maintenance operations of BSB scenario in comparison to traditional ballasted track-bed, an integrated model, based on laboratory tests, combining the evolution of track irregularities and ballast contamination with traffic, was used. Results together with a sensitivity analysis related to main parameters adopted revealed that the application of BSB is expected to provide a significant increase of intervals between both minor and major maintenance activities.

1. Introduction

1.1. Background

The railway plays a fundamental role in most transportation systems. It provides a fast means of transportation via a durable and economical system. Ballasted track, which consists of track

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superstructure supported on a layer of granular material (ballast), represents the most used type of structure compared to other alternatives such as concrete slab [1,2]. This type of track presents relatively low construction costs, high maintainability at a relatively low cost (for a single operation), and the possibility of using indigenous material while providing relatively high damping capacity, noise absorption and high flexibility, self-adjusting properties (in the case of non-homogeneous subgrade) and high hydraulic conductivity [1,3–6].

However, the unbound nature of ballast, which allows it to fulfil its main functions, is also related to reduction of geometric quality of the track, and therefore, its safety and ride comfort [7–12]. The passage of trains causes cyclic movements of the particles that result in permanent vertical and lateral deformations. Thus, for this track form vertical settlement of granular layers and ballast particle degradation represent the major problems affecting frequency of maintenance and track durability. In particular, differential settlement, which is generally due to abrupt changes in vertical stiffness, leads to increased dynamic loading, which can further increase permanent deformation, leading to a self-perpetuating mechanism [13].

Ballast layer settlement, which forms the highest contribution to total track settlement [3], occurs in two major phases [11]. The first one is faster and occurs when ballast is in a loose state (after tamping or renewal) and is a consequence of initial major consolidation (re-compaction). The second is due to various mechanisms that occur under cyclic loading: densification, distortion and degradation. Densification is characterised by a progressive consolidation; distortion is the mechanism whereby individual particles slide and roll; and degradation represents the change in particle size due to attrition and breakage [14].

Aside from contributing to permanent deformation, the degradation mechanism can also prevent the ballast layer from fulfilling its main functions. Indeed, mineral contamination from particle breakage and wear due to traffic loading and maintenance represents the highest source (with more than 70%) of ballast layer fouling [3,15]. This phenomenon jeopardises the rapid draining and elastic characteristics of the ballast layer as well as its ability to be effectively maintained by tamping [3,16].

1.2. Track degradation and degradation models

Track geometry degradation is affected by several factors: traffic loads and speed, construction materials and methods, and maintenance history, among others [17]. The track geometry is described by several parameters [18]: vertical alignment (or longitudinal level), horizontal alignment, gauge, cant and twist (Fig. 1).

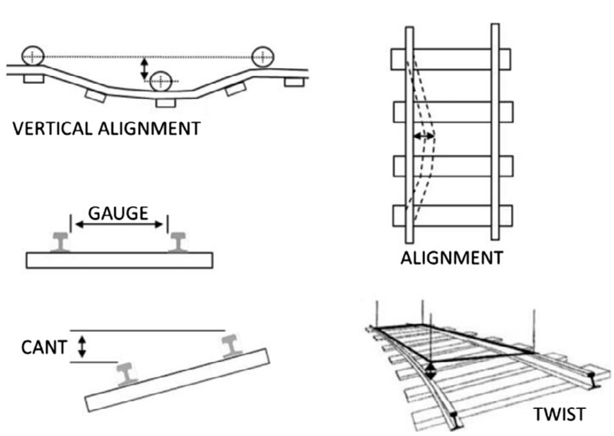

Fig. 1. Track quality parameters [19].

Standards prescribe minimum and maximum allowable values for these parameters based on the type of railway line. BS EN 13848 [18] states the existence of three indicators of track quality: extreme values for isolated defects, standard deviation (SD) over a typical length (200 m), and mean value. Depending on the type of line and the speed, there are three main limits for these indicators above which different actions need to be undertaken [18]: the Immediate Action Limit (IAL), which, if exceeded, requires measures to reduce the risk of derailment to an acceptable level; the Intervention Limit (IL), which, if exceeded, requires corrective maintenance in order that the immediate action limit is not reached before the next inspection; and the Alert Limit (AL), which, if exceeded, requires that the track geometry condition is analysed and considered or regularly planned maintenance operations.

In order to plan and/or predict maintenance interventions, rail authorities and practitioners often use the standard deviation as a convenient means of quantifying the geometric quality of a track section [20]. In this regard, Table 1 shows the Alert Limits for the longitudinal level SD according to European Standards [18].

When quality indexes exceed these limits, maintenance is needed to restore the quality of the track.

Predicting future degradation of infrastructure components is an essential element in maintenance planning. In this regard, the loss of track quality is due to a combination of many factors, the major one being the repetitive passage of trains [19]. Experience shows that track quality degradation is a function of load amplitude and number of repetitions (Million Gross Tons, MGT) [21]. By periodic inspection of the track this relationship can be determined for each specific section. However, according to Veit [22], variations are observed in the deterioration rate at the same loading level; indeed, the heterogeneity and anisotropy of all granular layers can cause differing local settlements.

Esveld [23] reports deterioration rates in terms of SD of track irregularities (vertical alignment) varying from 0.007 to 0.02 mm/MGT. Similar results (0.005–0.025 mm/MGT) were reported by Khouy [24] for a Swedish line with mixed passenger and freight traffic. Slightly lower values, varying between 0.00217 and 0.0119 mm/MGT, were presented by Hawari and Murray [25] for three heavy haul lines in Australia.

Over the past 30 years, several efforts have been employed to develop analytical models to predict degradation of railway tracks. An extensive literature review [17,19] revealed that field data of track geometry degradation (SD of track irregularities) are best fitted by linear empirical laws as in Eq. (1):

$$SD(MGT) = A + C \cdot MGT \tag{1}$$

where $SD(MGT)$ is the standard deviation corresponding to the traffic in MGT; A is the initial value of standard deviation; and C is the coefficient which relates the standard deviation to the cumulative traffic after the initial degradation phase (A).

Nevertheless, most of the models consider track settlement (or track vertical strain) as the main controlling factor in track

Table 1
Longitudinal level AL standard deviation according to BS EN 13848 (adapted from BS EN 13848-5:2008+A1:2010 2010).

Speed (in km/h)	Standard deviation (SD) (in mm) AL	
	Minimum	Maximum
$V \leq 80$	2.3	3
$80 < V \leq 120$	1.8	2.7
$120 < V \leq 160$	1.4	2.4
$160 < V \leq 230$	1.2	1.9
$230 < V \leq 300$	1	1.5