Construction and Building Materials 157 (2017) 402–415

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Review

Review of the design and maintenance technologies used to decelerate the deterioration of ballasted railway tracks

M. Sol-Sánchez [a,*], G. D'Angelo [b]

[a] Laboratory of Construction Engineering, University of Granada, Av. Severo Ochoa S/N, Granada, Spain
[b] Nottingham Transportation Engineering Centre, The University of Nottingham, University Park, NG7 2RD Nottingham, UK

HIGHLIGHTS

- Review into solutions to reduce degradation of ballasted railway tracks.
- Innovative materials to be applied during track design.
- Maintenance techniques to improve geometry and decelerate ballast degradation.
- Summary of solutions and proposal of further research studies.

ARTICLE INFO

Article history:
Received 6 February 2017
Received in revised form 28 August 2017
Accepted 1 September 2017
Available online 10 October 2017

Keywords:
Railway
Ballasted tracks
Settlement
Degradation
Review

ABSTRACT

Ballasted railway tracks, despite their benefits, present some limitations and drawbacks, mainly associated with geometry degradation due to ballast settlement and particle breakage. Periodic maintenance interventions are thus required as well as renewal processes, which lead to the significant consumption of natural materials and energy whilst causing frequent interruptions to traffic. This is made more problematic when aggregates with appropriate characteristics for ballast are not available in the proximity of the construction/maintenance site, which is becoming increasingly common due to restrictive environmental guidelines. In this context, this paper presents a review of the effectiveness of the major conventional techniques/materials for track design and maintenance as well as innovative solutions that are being developed to reduce track degradation, whilst also analysing their main parameters to optimize track behaviour and durability, depending on its design and the required changes in its mechanical performance. The aim is to then provide a set of recommendations and guidelines for the use of such technologies to improve track response and durability as well as highlighting possible further research associated with both the development of innovative solutions and the improvement of conventional techniques.

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* Corresponding author.
E-mail address: msol@ugr.es (M. Sol-Sánchez).

http://dx.doi.org/10.1016/j.conbuildmat.2017.09.007
0950-0618/

1. Introduction

Ballasted railway tracks represent by far the most used infrastructure in the 1.4 million km of track worldwide [1,2]. In addition to the extensive experience using this solution, there are many benefits derived from the granular composition of the superstructure of ballasted tracks, whose main functions consist of transferring traffic loading from sleepers at reduced and acceptable levels to the subgrade while adequate lateral resistance is provided to avoid displacement of the sleepers in curved sections [1,3–6].

To fulfil these functions, crushed angular stones are required to increase the shear strength of the granular layer, as well as good quality hard stones (generally, a Los Angeles coefficient lower than 14% for high speed lines should be used to reduce breakage and degradation of ballast particle). Nonetheless, the passage of trains causes cyclic movements of the unbound particles, which results in permanent vertical deformations, reducing the geometric quality of track, and therefore, its comfort and safety. This phenomenon, referred to as track settlement, is given by the sum of the plastic deformation of all the layers, of which ballast participates with the highest contribution (up to 50–70% of the total vertical deformation) [5]. Consequently, periodic maintenance interventions are required to restore the original track position. However, traditional maintenance processes are proven to significantly contribute to the degradation of particles [5,7], and thus, to accelerate track geometric deterioration. In this regard, alternative maintenance solutions would be needed [5–9].

Due to these technical and environmental issues, and independent of specific line conditions, ballasted tracks can be considered less convenient in a lifecycle cost analysis due to the high frequency of maintenance and lower durability [4], presenting higher maintenance costs (up to 20–35%) than current slab tracks [3,4,10]. Further, due to the high degree of requirements for this material, when good quality aggregates are not available in close proximity to the construction/rehabilitation site, then social, economic and environmental costs (longer hauling distance, raw material consumption, etc.) can significantly increase.

Thus, due to their widespread and specific advantages in relation to other track forms, in recent decades ballasted tracks are being the subject of much research that has focused on decelerating the loss in geometrical quality associated with ballast settlement and its progressive degradation. Given the wide range of technologies, this paper aims to provide a review of the effectiveness of the main solutions and their main characteristics for optimising track behaviour. This paper is divided into two main sections. The first describes the solutions that are primarily aimed at the design/renewal level, whilst the second section presents the techniques that are ready to be applied to existing tracks during maintenance operations.

2. Design-based solutions

In order to prevent track deterioration and reduce the frequency of maintenance, several design-based solutions have been proposed to enhance traditional ballasted track performance. The majority of the relevant alternatives presented here have in common the fact that they need to be applied during the construction process, or during major maintenance operations.

2.1. Use of elastic elements

Rail pads are the most common elastic elements used in railway track sections to filter and transfer the high-frequency dynamic forces from rail to the sleepers, thereby reducing the stresses on the ballast surface [11]. Their thickness and polymeric composition are the main design factors of these elements [12], while the main characteristic parameter is their static stiffness (measured in kN/mm), which is selected in reference to track section design and its expected global performance [13–16].

Despite the fact that stiff pads were initially used in high speed lines, soft rail pads (with static stiffness around 80–125 kN/mm) are currently used in modern railway tracks, with the objective of increasing ballast protection under the increase in dynamic overloads [17–21]. In this regard, several authors [21–23] have shown that the use of softer rail pads allows for a significant reduction (higher than 50%) in the energy and stress transmitted to the ballast layer when impact loads are applied (due mainly to irregular rail-wheel contact). Further, it was found that the use of rail pads with stiffness lower than 100 kN/mm could lead to a more homogeneous track behaviour throughout sections with different bearing capacities, reducing the stress transmitted to the ballast layer, and therefore, its degradation [24,25].

In addition, a laboratory study [15], which focused on analysing the effect of the properties of the main elements on track behaviour, found that there is a direct and linear relationship (Fig. 1) between the variations in global track stiffness due to modifications in the properties of elastic elements, and the settlement of ballasted tracks and its capacity to dissipate the stress in granular layers. In this regard, lower deformations and higher damping properties can be obtained when track stiffness is reduced by using softer elastic elements in the track superstructure. Nonetheless, it must be considered that the variation in pad stiffness was found to have little effect on global track flexibility.

On the other hand, Under Sleeper Pads (USPs) have been introduced to decrease the settlement that leads to track irregularities while reducing ballast degradation (preventing particle breakage) by decreasing the stresses at the sleeper/ballast interface (higher contact area) [26]. Their thickness generally ranges from 10 to 20 mm, and in view of their static bedding modulus (C_{st}, N/mm^3, defined as the stiffness per unit area), USP can be qualified as stiff (0.25–0.35 N/mm^3), medium (0.15–0.25 N/mm^3), soft (0.10–0.15 N/mm^3) and very soft (less than 0.10 N/mm^3) [19,29].

Despite the fact that, due to their cost, their application is currently limited to specific sections (switches, transitions, tight curves, etc.), according to the UIC (International Union of Railways) recommendations, medium and soft USPs are appropriate to reduce vibrations and stress over the ballast layer. A range of experiences such as in the line between Tokaido and Shinkasen, soft USP (0.2 N/mm^3) has been shown to reduce 22% of the vibrations and stress transmitted to the granular layers [25] while in European experiences [25,27,28], soft USPs (modulus close to 0.2–0.3 N/mm^3) have also been shown to produce a significant reduction in track geometrical deterioration (ratios higher than 30% in