



Review

The use of elastic elements in railway tracks: A state of the art review

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HIGHLIGHTS

- An analysis of elastic elements to improve railway track behavior and durability.
- A review of studies about rail pads, under-sleeper pads and under-ballast mats.
- The effect of diverse parameters on elastic elements behavior is described.
- Recommendations about stiffness of elastic elements have been drawn.

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ABSTRACT

Railway is envisaged as the transportation mode of the future, but in spite of its advantages, its development is not exempt from technical difficulties that lead to track deterioration. To overcome these drawbacks, research in this field needs to be developed. Geometry degradation, as well as noise and vibration, have been identified as problems that need to be reduced, which could be possible by modifying track vertical stiffness and obtaining a more homogeneous value along the track. One measure to minimize these problems involves the installation of elastic elements (e.g. rail pads, under-sleeper pads, and under-ballast mats) in the railway track. In fact, this has now become the most effective means to vary track vertical stiffness as well as to abate noise emission and vibrations caused by the passage of trains. This paper discusses the problems associated with track stiffness, geometry degradation, and vibrations, and at the same time, studies the characteristics of elastic elements as well as the research carried out to test and evaluate their effectiveness. After reviewing and analyzing a wide range of research initiatives, this paper proposes a set of recommendations and guidelines for the use of elastic elements in railway infrastructure as well as highlighting a series of possible further investigations.

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1. Introduction

Since their invention, railway trains have become one of the most popular transportation modes in the world. Their freight capacity, high efficiency and functionality, combined with their minimal environmental impact, have made trains one of the most frequently chosen options for transporting people and merchandise from one place to another. Moreover, high-speed train travel has transformed the railway into one of the most attractive transportation modes with features that significantly enhance rapid communication between cities. Such properties make high-speed trains preferable to other modes, especially on busy routes with a heavy transportation demand [1].

Although railway transport has advantages, the increase in rail freight being transported and train velocity make it not exempt from technical difficulties, and the study and research for finding new solutions is essential. The increase in speed and the load transported has incurred higher forces on the track as well as the increase of the noise and vibrations caused by the trains [1,2]. In addition, the higher speed leads to an increase in the dynamic overload that may accelerate the track deterioration, a problem which is particularly marked on tracks with inappropriate values of vertical stiffness [3,4], making it necessary to obtain an optimal global stiffness of the infrastructure.

Consequently, if railway systems are to continue to grow in socioeconomic importance, finding solutions for the negative effects of those technical difficulties is imperative since this will undoubtedly facilitate the future development and evolution of railway transportation method. In this regard, the most frequent measure taken to reduce stresses on railway tracks and to abate noise emissions and vibrations is the incorporation of elastic elements into railway tracks [5]. The purpose of this is to improve track performance and overcome problems stemming from high-speed train traffic. Broadly speaking, elastic elements used in ballasted tracks fall into three categories: (i) rail pads (installed between rails and sleepers); (ii) under-sleeper pads (embedded beneath sleepers); and (iii) under-ballast mats (installed on the granular layer in the case of ballast tracks, and underneath the slab in the case of slab tracks).

This paper provides a review of the technical properties of elastic components within the context of recent research and experience initiatives. The first section briefly describes the main problems on railway tracks which could be mitigated or reduced by using elastic elements. The following section studies the main types of elastic component, such as rail pads, under-sleeper pads, and under-ballast mats, and analyzes their most salient features. It also explains the way in which the installation of these components modifies the properties and parameters of railway infrastructure.

2. Main problems of railway tracks

There are different types of damage in the railway system (deterioration of the geometrical quality of the track, defects on the track surface, settlement of the granular layers, fatigue of materials, etc.), which need to be identified and analyzed in order to develop specific solutions to reduce track deterioration and maintenance costs, while achieving higher durability of the

infrastructure [6]. In addition, the emission of air-born noise and the propagation of waves through the ground constitute serious social and environmental problems that should be studied and reduced. In this regard, the importance of track stiffness in terms of both its long-term performance and the reduction of other modes of track deterioration should be taken into account.

2.1. Track deterioration

According to Nielsen et al. [7] and Teixeira [8], there are various types of deterioration of the track quality in reference to the damage source, causing different modes of failure. The deterioration modes could be associated with the track component degradation: the service life of rails, sleepers and fastener systems plays an essential role in the railway infrastructure since their failure could cause train derailment as well as important maintenance costs. Nonetheless, these components, due to the materials which they are made of, have a high fatigue strength and durability. Thus, when they reach the end of their service life, the best solution is to replace them [9].

Granular layers also present a further progressive deformation with the passage of trains, causing an accumulative deterioration of the track geometry, which is a fundamental parameter, especially on high-speed lines. This failure mode is due to the settlement of granular layers as a consequence of the loss of contact between particles or the breakage of them caused by the repeated dynamic loads. The granular layer settlement is equal to the sum of the deformation of the diverse layers used in order to distribute the loads transmitted to the sub-layers. Selig and Waters [10] showed that the ballast is the layer with highest contribution to the track settlement (up to 50–70% of the total vertical deformation). Fig. 1 shows an example of ballast settlement in a railway track.

Various authors [11,12], using measurements from French and Japanese railway tracks, have shown that the ballast settlement accords with an exponential law, with the greater deformations occurring at the beginning of the track service (due to low material compaction), followed by a progressive vertical deterioration. On the other hand, some authors [10] have found that there is a lineal relationship between the mean settlement and the differential vertical deformation of the track, which indicates that an increase in ballast deterioration can lead to important degradation of the track geometry (longitudinal and transversal levelling, alignment and buckles).

In order to reduce these problems, there are various possible solutions, such as the use of ballast particles with high performance; an increase in the number of maintenance tasks; or finally the replacement of the granular material. However, these solutions can lead to important increases in social, economic and environmental costs due to the necessity of using more specific material (longer hauling distance, high consumption of raw materials, etc.) as well as a higher quantity of ballast during maintenance and rehabilitation tasks, whose frequency is also increased. Given these problems, a more efficient solution is the reduction of load transmitted to the ballast layer in order to obtain lower settlement, and therefore, higher durability of the railway tracks. For this purpose, elastic elements are used since their resilient behavior allows for a reduction of the stress on the ballast layer at the same time that the contact area between components is increased.

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