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A study into the mechanical performance of different configurations for the railway track section: A laboratory approach

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ABSTRACT

A traditional railway track is composed of rails, sleepers, fastenings (included rail pads), ballast, and a formation layer. More recently, other configurations have been commonly used in the track section in order to improve its quality and durability. However, the use of different configurations can lead to important changes in fundamental parameters such as the global vertical stiffness of the track, as well as its settlement and rolling resistance. This paper therefore focuses on a laboratory study of the mechanical performance of a number of different track sections, assessing the effect of using various types of elastic elements with varying properties, various types of sub-ballast, and different thicknesses of ballast layer. The results showed that reducing track stiffness by modifying the elastic elements over the ballast layer leads to an increase in the capacity of the track to dissipate energy and to reduce its settlement. However, the reduction in stiffness induced by modifying the configuration under the ballast (by, for example, adding elastic mats) causes an increase in settlement, the latter exerting the strongest influence (even more so than the change in ballast thickness) on track performance. Furthermore, it was seen that changes in track behaviour are lower (particularly in track stiffness) than those observed in the properties of its components.

1. Introduction

A traditional railway track generally consists of rails, sleepers, rail pads, fastenings, ballast and an over ground formation layer. However, with the continuous increase in train speeds and loading capacity, a number of modifications of the track section have been developed with the aim of obtaining a section with a higher bearing capacity whilst increasing the durability of the system. In addition, given the ever-increasing concerns for the environment, new components are being used to not only increase track quality and travel comfort, but also to limit the vibrations and noise that are generated by passing trains.

To this end, modern tracks have utilised an increasing number and thickness of granular layers between ballast and ground in order to obtain a section with a higher bearing capacity and to reduce the stress transmitted to the ground [1]. Of particular importance is the use of a highly compacted granular layer known as sub-ballast, which serves to protect the subgrade. With the same objective, other configurations such as track over asphalt layer (used as sub-ballast) are also becoming widely used in the construction of new railway lines around the world [2–4]. However, it should also be noted that all of these changes in the railway section not only lead to higher vertical strength, but also cause an increase in global vertical stiffness, which would in turn lead to higher dynamic overloads on the track, and therefore, higher deterioration of its components [5].

Thus, recent decades have seen a rise in the tendency to conduct work aimed at reducing the stiffness of the elastic pads used between rail and sleeper. The objective of this work has been to attain an optimal value for the global vertical stiffness that allows for a reduction in track deterioration (and therefore maintenance costs) and energy consumption by trains (service costs) [6,7]. With this same purpose in mind, other elastic elements have been developed, such as under sleeper pads or under ballast (or sub-ballast) mats [8,9], which also provides the track with higher capacity to damp the loads transmitted by trains as well as obtaining an important reduction in track vibration and noise, These changes can therefore help to achieve a more durable and higher quality railway track.

However, it should be noted that all these modifications in track configuration, in addition to the changes applied in vertical stiffness, could lead to important variations in other important parameters such as dissipated energy or track settlement [10], which are associated with service and maintenance costs, respectively.

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Further, such changes can also modify, to varying degrees, the mechanical performance of the railway track, and therefore different sections are required depending on the characteristics of the track. In order to address this issue, this paper examines the different configurations that are used in the railway section in order to determine the effect of the properties of a number of components on the mechanical performance of the track.

In this laboratory study, the behaviour of a track section 1:1 was analysed when different variables in the vertical configuration were included: (i) three different rail pads (very stiff, stiff, and soft pads); (ii) two types of under-sleeper pads (medium and soft); (iii) adding two kinds of under-ballast mat (soft and stiff); (iv) including two types of sub-ballast layer (granular and bituminous); (v) incorporating a stiff elastic mat under each type of sub-ballast; (vi) and modifying the thickness of the ballast layer. The parameters used to evaluate the performance of each configuration were global vertical stiffness and settlement of the section (associated with maintenance costs), as well as dissipated energy (related to service costs).

2. Methodology

2.1. Materials

With the aim of evaluating the effect of using different configurations for the railway track, a box was used in laboratory in order to replicate the various track sections that can be applied in railway infrastructures. The box used in this study, whose appearance is shown in Fig. 1a, was 440 mm in width, 750 mm in length, and 500 mm in height, allowing for the simulation of the railway track section under the rail seat area (with a sleeper spacing near 500 mm), where the highest levels of stress over ballast are expected. The testing box includes a piece of a concrete sleeper (250 mm in width and 357 mm in length) with a tension clamp fastening type VM (composed mainly of a metallic clip type SKL-1, screw spike type VAPE, and an elastic pad) commonly used in Spanish railway tracks, whilst the rail used was a type UIC-54 with a length of 250 mm. These components were reused for all the studied sections since its fatigue life is longer than the duration of the tests developed in this study [11,12].

In addition, all configurations used a ballast layer (whose main properties of the particles are listed in Table 1), and a subgrade layer composed of 2 cm of compacted sand over the metallic floor of the box, presenting an elastic modulus of approximately 70 MPa (Fig. 1b). Fig. 1c also shows the control of the density of the granular layers used in this study (by means of a Pavement Quality Indicator device, PQI) in order to guarantee its appropriate compaction [13].

Table 1
Main properties of ballast and sub-ballast used in the study.

Properties		Ballast	Sub-ballast
Granulometry EN 933-1 [14]	Sieve (mm)	% Passing	% Passing
	63	100	100
	50	85	100
	40	37	100
	31.5	8	100
	16	–	85
	8	–	66
	4	–	50
	2	–	30
	0.5	–	17
	0.2	–	14
	0.063	–	4.2
Content of fine particles (<0.5 mm) EN 933-1 [14] (%)		0.08	–
Fines content (<0.063 mm) EN 933-1 [14] (%)		0.03	–
Fractured faces EN 933-5 [15] (%)		100	100
Density EN 1097-6 [16] (Mg/m^3)		3.24	3.24
Resistance to fragmentation (L.A.) EN 1097-2 [17] (%)		5	14
Determination of particle shape – flakiness index EN 933-3 [18] (%)		6	10
Sand equivalent EN 933-8 [19] (%)		–	61

In addition to the components (rail, fastenings, piece of sleeper, and ballast layer) that were common for all configurations, the effect of including three different rail pads was analysed. A very stiff commercial pad of 6 mm of thickness and made of polyethylene (with more than 1000 kN/mm of secant stiffness) [20], and a 4.5 mm thick stiff pad (around 300 kN/mm) and a 7.5 mm soft pad (close to 100 kN/mm) manufactured both from deconstructed tire tread layers [21]. All rail pads used in this study had horizontal dimensions of 140 mm in width and 180 mm in length, which make them suitable for use under rail type UIC-54. The visual appearance of the rail pads is shown in Fig. 2a.

On the other hand, to measure the effect of adding elastic under-sleeper pads (USP), two different pads were used in this

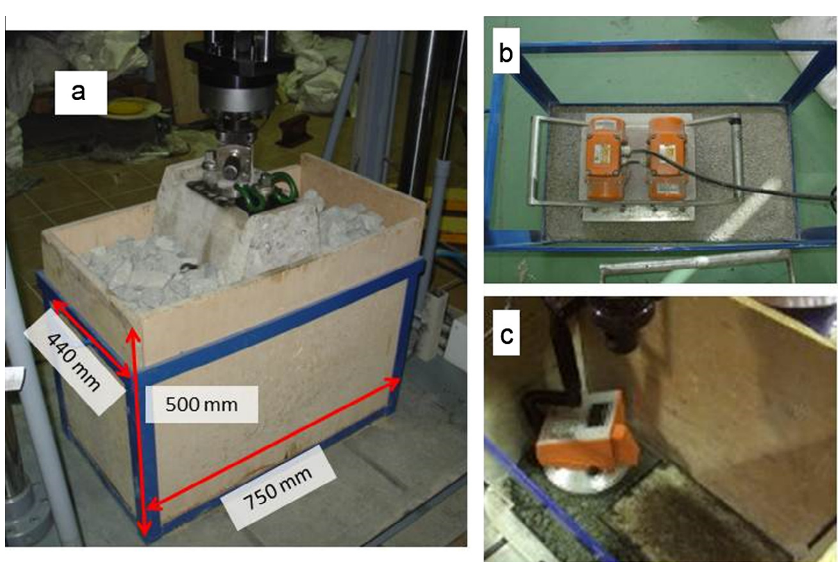

Fig. 1. Visual aspect of (a) the box used for the study, (b) the compaction of a sandy layer to simulate the subgrade, (c) and a control of the compaction of granular layers.