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High Performance Bi-Block Sleeper for Improvement the performances of ballasted railway track

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Abstract

This article focuses on the performance of an innovative railway sleeper, recently patented in Italy and called "HP-BB" (High Performance Bi-Block sleeper), under different efficiency conditions of the ballast. The research is carried out through a comparative assessment of traditional mono- and bi-block sleepers, evaluating the lateral resistance of the single sleeper thought as independent of the other constituents of the track.

Keywords: High Performance Bi-Block Sleeper, railway track, lateral sliding resistance

1. Introduction

The conventional ballasted railway superstructure normally involves the use of reinforced concrete mono- or bi-block sleepers. In Italy, for instance, in case of lines running at a speed less than 200 km/h, RFI S.p.A. (*Rete Ferroviaria Italiana*, Italian Railway Network) generally employs a sleeper which is 2.30 m long, with a trapezoidal section and variable dimensions both in height and in width [1], [2]. Whereas a bi-block sleeper consists of two lightly reinforced concrete elements, held together by a steel tie rod whose function is to guarantee the correct track gauge and to keep the adequate spacing among the aggregates in the casting. Compared to mono-block sleepers, bi-block sleepers have greater resistance to lateral actions and lighter weight [2], [3].

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On field experiences, which were carried out in Italy on traditional lines and employed the diagnostic trains “Archimedes” and “Taletes”, allowed to point out that 92.6% of the track alignment faults and 82.6% of superelevation faults occur in line sections with a non-void curvature (circular curves, clothoids and cubic parabolas) [4]. This can be due to the high lateral stresses in the track as trains pass by owing to the centrifugal force, which in the long run cause sleepers to be weakly clamped to the ballast with consequent variations in the original geometry of the track. In order to face these problems, whose solution can be reached only through frequent ordinary and/or extraordinary maintenance activities with high financial costs and deterioration in service levels for users (due to the necessity, for instance, to reduce the speed on faulty lines or to interrupt lines for maintenance work), a new railway sleeper was designed, planned and patented, called “HP-BB” (High Performance Bi-Block sleeper) [5], [6]. It is a reinforced concrete bi-block sleeper equipped with two lateral stoppers with a “clamping action”. The sleeper, whose dimensions are illustrated in Figures 1 and 2, provides the lateral actions with high resistance values under conditions of well-compacted and degraded ballast, as emerged by the analyses performed and better described later.

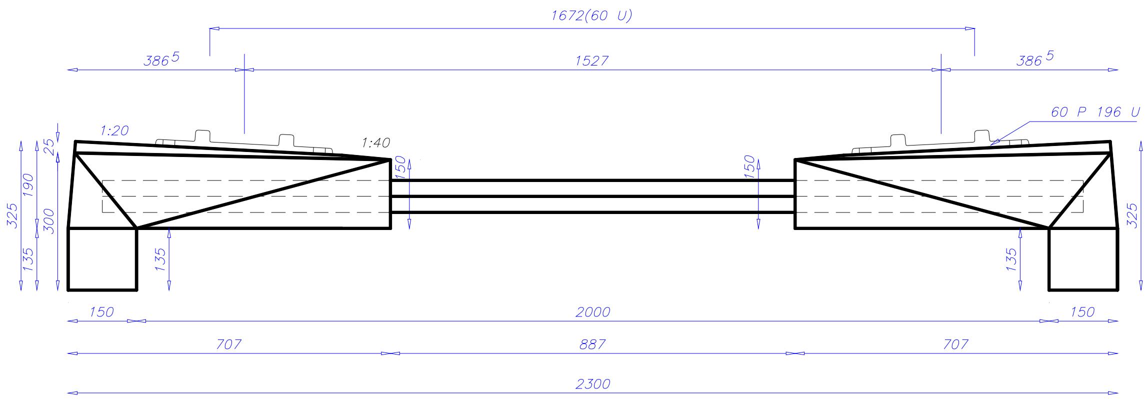

Fig. 1 - High performance bi-block sleeper (prospect)

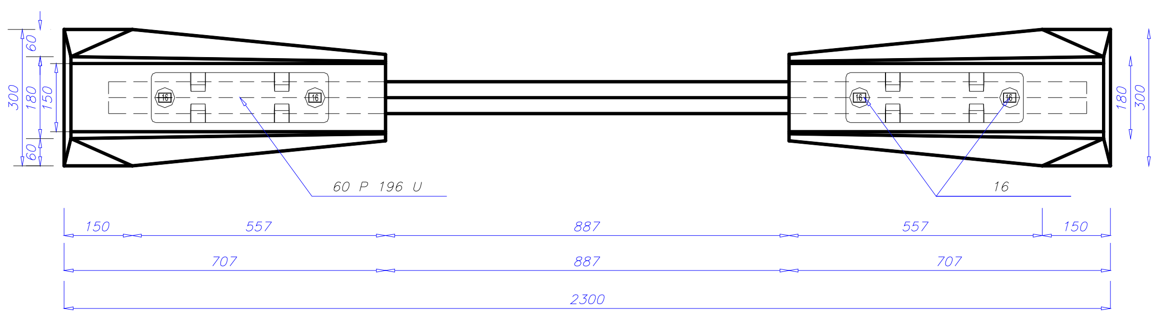

Fig.2. High performance bi-block sleeper (design)

2. Evaluation of lateral sliding resistance

The railway sleepers should be tightly clamped into the ballast body so as to provide the sliding with high resistance values both lengthwise and crosswise. In particular, the specific lateral sliding resistance τ_0 influences the critical load value P_{crit}, the latter being the theoretical minimum axial load value which gives rise to the track "twist". Assuming a track initially deformed by a sinusoid with an amplitude f_o and a wavelength L, a track "frame" characterized by a deflectional stiffness which is evaluated on the horizontal plane equal to EI, is able to stand an axial load P_{crit} given from the following equation [2]:

$$P_{crit} = 2 \cdot \sqrt{\frac{\tau_0 \cdot EI}{\pi \cdot f_0}} \tag{1}$$

Equation 1 shows the proportionality between the critical load P_{crit} and the specific lateral sliding resistance τ_0; therefore, a track marked by high values of τ_0 is able to successfully stand thermal as well as lateral and longitudinal actions generated from railway carriages. The specific lateral resistance values, in case of an unladen track, are equal to $\tau_0 = 11$ kN in mono-block sleepers and $\tau_0 = 14$ kN in bi-block sleepers.
The evaluation of the lateral resistance of a railway sleeper can be carried out through two different criteria: the former, empirical, involves in situ tests with an unladen track; the latter, theoretical, involves the assessment of the resistance of the single element-girder thought as independent of the other elements forming the track frame through specific mathematical models. In order to adopt the latter approach it is required [1], [7]:

- To set the friction angle of the ballast which, under condition of aggregates obtained from crushed stony rock with solid elements in low porosity and with sharp corners, can be assumed as equal to $\varphi' = 45°$;
- To set the specific weight of the ballast which under ordinary conditions can be evaluated as 15 kN/m^3.
  The comparative evaluation of the performances provided by traditional sleepers and by a HP-BB sleeper is here made by taking two limit conditions into consideration:
- *condition A*: ballast in good condition ($\varphi' = 45°$). In this case the friction angle between ballast and sleeper assumes such values which can be estimated through the relation $\varphi'_w = 2/3\ \varphi'$;
- *condition B*: degraded ballast ($\varphi' = 35°$). In this case, precautionarily the value of the friction angle can be set as $\varphi'_w = 1/3\ \varphi'$.

3. Performances of a HP-BB sleeper and comparison with traditional sleepers

In order to establish the behaviour of the new sleeper it is hypothesized that a lithostatic stress distribution is determined in the ballast. Under the conditions of incipient motion the total sliding resistance of the sleeper can be obtained from the sum of the elementary resistances offered by each component of the same sleeper and developing under each part of the structure denoted with letters "b" and/or "B" (see Table1). From the equilibrium conditions [3] are obtained the following expressions which give the lateral sliding resistance of sleepers S whenever there are variations in their geometrical parameters, the mechanical properties of the railway ballast and the weight force (P) transmitted to each sleeper:

- *Mono-block sleeper:*

$$S = \frac{1}{2} \cdot \gamma \cdot H^2 \cdot L \cdot \cot g\theta \cdot \frac{tg\phi' \cdot \cos\theta - sen\theta}{\cos\theta - tg\phi' \cdot sen\theta} + P \cdot tg\phi'_w \tag{2}$$

- *Bi-block sleeper*:

$$S = \frac{1}{2} \cdot \gamma \cdot H^2 \cdot L \cdot \cot g\theta \cdot \frac{tg\phi' \cdot \cos\theta - sen\theta}{\cos\theta - tg\phi' sen\theta} + \frac{2 \cdot P \cdot b}{B + 2 \cdot b} \cdot tg\phi'_w + \frac{P \cdot B}{B + 2 \cdot b} \cdot tg\phi' \tag{3}$$

- *HP-BB sleeper*:

$$S = \frac{1}{2} \cdot \gamma \cdot H^2 \cdot L \cdot \cot g\theta \cdot \frac{tg\phi' \cdot \cos\theta - sen\theta}{\cos\theta - tg\phi' sen\theta} + \frac{2 \cdot P \cdot b}{B + 2 \cdot b} \cdot tg\phi'_w + \frac{P \cdot B}{B + 2 \cdot b} \cdot tg\phi' \tag{4}$$

In which:
- $\theta = 45° - \phi' / 2$
- H, B, b, L are the dimensions of the railway sleepers examined (see Table 1)
- P is the weight force [kN]
- ϕ' ballastfriction angle

The conventional dimensions of the sleepers examined are shown in the following table:

Table 1. Dimensions of the railway sleepers examined

TYPES OF SLEEPER	Geometrical characteristics			
	H [mm]	B [mm]	b [mm]	L [mm]
Mono-block	190	2300	-	300
Bi-block	229	750	750	309
HP-BB	325	2000	150	300

The following graphics show the variation in the sliding resistance S with regard to the sleepers under ballasrt condition A and conditions B). Figure 4 illustrates the law of variation of S when there are changes in the internalfriction angle φ' and the weight (P) transmitted from the railway carriage to each sleeper, inferred from the previous equation (7).

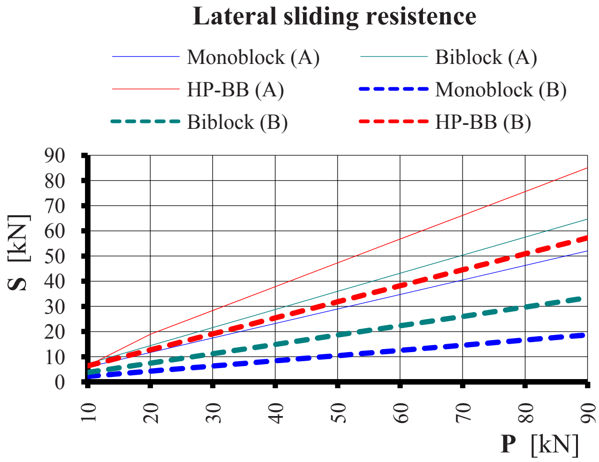

Fig. 3.Comparison of sliding resistances of mono-block, bi-block and HP-BB sleepers

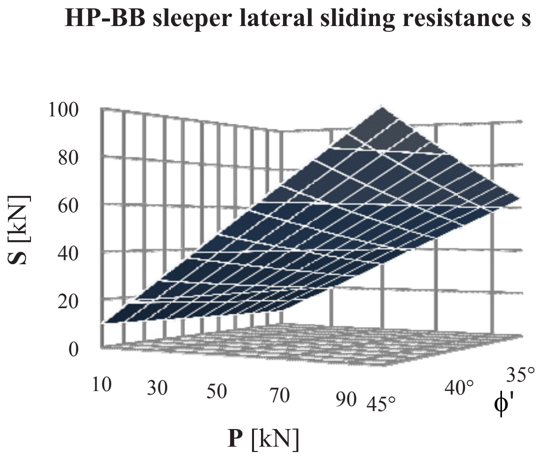

Fig. 4. Lateral sliding resistance of HP-BB sleepers

As shown in Fig. 3, in case of ballast in good condition (condition A), a bi-block sleeper provides an average resistance increase by about 23% compared to a mono-block sleeper. On the other hand, a HP-BB sleeper provides an average resistance increase by 32% and 63% in comparison with bi-block and mono-block sleepers respectively. On the contrary, if the ballast is degraded or old (condition B), the performances of a HP-BB sleeper appear to be even more remarkable although there is a decrease in the sliding resistance in all the sleepers under study as a consequence of a decrease in the friction angles φ’ and $φ'_w$. As a matter of fact, in this condition its resistance is on average greater by 71% than a bi-block sleeper and by 202% (about twice) than a mono-block sleeper.

4. Conclusions

This paper examines the performances of railway sleepers by comparing three different types of structure: mono-block sleeper, bi-block sleeper and a recently devised and patented sleeper called “HP-BB”. The analyses carried out show how the lateral sliding resistance (S), a parameter influencing track stability, is closely linked to the mechanical ballast characteristics, to the sleeper geometry and to the acting vertical load (P). In all the sleepers under study lateral resistance has been observed to decrease whenever the internal friction angle of the ballast was reduced, mainly after aging processes of the railway superstructure.The HP-BB sleeper guarantees the average resistance increase by 32% with regard to a bi-block sleeper and by 63% with regard to a mono-block sleeper in a ballast in good condition (φ’ = 45°). Moreover, in case of degraded ballast (φ’ = 35°), the performances of HP-BB sleepers appear to be even more remarkable: in fact, its resistance is on average greater by about 71% than a bi-block sleeper and by 202% than a mono-block sleeper.

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