Application of International Standards in the Design of Monoblock Concrete Sleepers for Argentinian Railways

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Abstract: It is presented a State of the Art of international standards in the field of monoblock concrete sleepers design and calculation. Taking into account the fact that the Argentinian broad track gauge (1,676 mm) is different to international track gauge (1,435 mm) that is worldwide used, a comparative analysis is developed in order to evaluate the performance of internationals standards in the design of the sleepers used in Argentinian railways. Recommendations for future research are provided.

Key words: concrete sleeper, international standards, bending moments.

1. Introduction

Since its invention in the early 1800s, railways have played an important role in the transportation of passengers and goods, providing one of the safest and most sustainable ways of transportation nowadays. Generally, a typical railway structure could be divided into two main components: the railway superstructure—formed basically by rails, rail pads, the fastening system and sleepers, and the railway substructure [1]. In this context, this literature review aims to present different international standards that are applied for the design of one of the main elements of railway superstructure, the sleepers, and to specially analyze the aptitude of their specifications for the calculation of the sleepers used with the Argentinian broad track gauge.

2. Design of Mono-Block Concrete Sleepers

Sleepers represent one of the most important elements of a railway superstructure since they play an essential role in the distribution of vertical, transversal and longitudinal loads. Historically, wood has been the most common material used to produce railway sleepers, since they have always shown a good relationship between the achieved performance and the associated useful life. However, due to restricted resources, environmental issues and requirements regarding geometrical tolerances—especially for high-speed and heavy freight lines, other materials started to be used as a replacement of timber [2]. As a consequence, twin-block and mono-block concrete sleepers were developed and successfully employed, nowadays the use of mono-block pre-stressed concrete sleepers being more popular than any other type [1].

Regarding general aspects, a typical mono-block concrete sleeper is made of: concrete, wires or bars, steel plates—if the pre-stressing technology requires them, and plastic dowels or embedded anchors—depending on which type of fastening system is used. Since resistance to wheel loads represents the most important structural requirement, sleepers are principally designed to resist these vertical loads and the resulting bending moments [3]. Several aspects are involved in the calculation of these moments, being the distribution of contact pressures between the sleeper and the ballast one of the most important issues [4]. As Kumaran et al. in Ref. [4] said, it is not easy to exactly predict the resulted real distribution of contact pressures in the field, which undoubtedly makes the estimation of bending
moments a very complex task. Some international standards adopt simplified formulas, obtained from empirical research works, for the design of concrete sleepers and fastening systems. However, it is proved that if sleepers are designed by the application of empirical formulas and without an appropriate mechanistic analysis of the possible stresses produced in the real field, inefficiencies in the design could undoubtedly exist, which could potentially increase maintenance costs [5]. In this way, as Edwards and Dersch [6] said the need for resilient component designs and mechanistic design practices is recognized not only by operators (end users), but also by manufacturers of concrete sleepers and fastening systems.

Unfortunately, many ways of failure and defects have been observed in this type of sleepers, being the presence of cracking from center binding and dynamics loads some of the most common ones [6]. Taking into account that these failures may be produced due to the incorrect designs assumptions, it seems that an improvement of the design process of fastening systems and concrete sleepers and a better understanding of the failures modes are needed to maximize the lifespan of concrete sleepers [6].

3. International Standards: Design Processes

Several international standards and manuals set the basis for the design of mono-block concrete sleepers. Some of the most recognized institutions that keep continuously updated their specifications and standards are:

- **UNE-EN 13230-1/2010**, Railway Applications-Track-Concrete Sleepers and Bearers-Part 1: Requirements [7]. In this standard it is recommended the design process developed by UIC [8] in the Report 713—Design of Monoblock Concrete Sleepers.
- **ABNT NBR 11709-2015**, Concrete Sleepers—Design, Materials and Components [10].
- **2014 AREMA Manual for Railway Engineering, Chapter 30, Part 1** [12].
- **2017 AREMA Manual for Railway Engineering, Chapter 30, Part 1** [13].

From the first quick analysis, it can be concluded that all design processes seem to agree on the fact that the maximum negative bending moments at the center of the sleeper and positive in the rail seat—those ones that produce tensile stresses in the upper and bottom surfaces of the sleeper respectively—would be produced at different instances of the sleepers lifespan and will strongly depend on the quality and frequencies of tamping works. Following this line of thought, many of the analyzed standards specify different support conditions schemes for the calculations of positive and negative bending moments, considering the ballast reaction of a newly-tamped track of a partially and full consolidated track. As an example, Fig. 1 shows the support condition scheme recommended by UIC [8] for the design of rail seat positive bending moments and center negative bending moments.

Analyzing the performance of international standards for the design of sleepers used in Argentinian broad track gauge (1,676 mm) tracks, it could be observed that no all the design processes have a direct application for this purpose. As it is said by UIC [8]—cited by the 13230-1:2010 [7]—the main application of the methodology included in the Report 713 is the design of international track gauge (1,435 mm) sleepers, and it is not clear if it is possible to apply the same process for the design of sleepers used with other track gauges. Likewise, similar characteristics present the design process included in the 2014 AREMA Manual for Railway Engineering, Chapter 30, Part 1 [12], analyzed by Edwards and Dersch [6]. From their study, the authors could observe that the origin and assumptions for the determination of bending moments are unclear,
since most of the used factors are presented without an explanation of how they were derived and what they are based on. In this way, taking into account that tables and figures included in this Manual appear to be empirically derived from practical experience and not from a mechanistic approach [6], it could be concluded that the presented factors and tables would not have a direct application for the design of sleepers used with track gauges different to the international one (1,435 mm), considering the fact that this is the track gauge widely used in the United States of America.

On the other hand, it was observed that the prEN 13230-6:2014 [9], the ABNT NBR 11709-2015 [10], the AS 1085.14-2012 [11] and the 2017 AREMA Manual for Railway Engineering [13] present design methodologies for narrow, international and broad track gauge sleepers that, despite they present different geometries to the ones used in Argentinian tracks, they could be easily adapted by the definition of some special assumptions.

4. Determination of Bending Moments Using Different International Standards

A comparative analysis of the values obtained for bending moments in broad gauge (1,676 mm) sleepers using the design processes included in the following international standards and manuals were developed:

- prUNE-EN 13230-6/2014, Railway Applications—Track-Concrete Sleepers and Bearers-Part 6. Design [9].
Analyzing the formulas presented in the different documents, it could be observed that, despite all design processes seem to be based in similar hypothesis, they are not homogenous regarding the structural performance required, since different values of bending moments were obtained from the application of their formulas. Moreover, the following issues were observed when the mentioned formulas were applied for the determination of bending moments in broad gauge (1,676 mm) sleepers:

- In the design process included in prUNE-EN 13230-6/2014, the center negative bending moment “Mc,neg,100” is obtained from a chart which was developed for a broad gauge different to the one used in the Argentinian railway tracks. Likewise, the methodology specifies that this moment, as well as the factor “kic” that considers the difference between the calculated bending moments and the characteristic ones measured in the track, can be applied only for sleepers with 2.60 m of length, while the sleepers installed in Argentinian railway tracks can be longer than this value.

- Similarly, the factor “αc” used by the methodology included in the 2017 AREMA Manual for Railway Engineering for the determination of the center negative bending moment is obtained from a table where the maximum possible length of sleeper is 2.59 m. In this way, this manual presents a similar issue to the one observed for the prUNE-EN 13230-6/2014.

Despite the mentioned issues and considering the limitations that the methodologies have, some assumptions were assumed in order to adapt the design processes for the determination of bending moments in broad gauge (1,676 mm) sleepers of 2.70 m length. From the application of the formulas the following values were obtained:

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Rail seat positive bending moment (t.m)</th>
<th>Center negative bending moment (t.m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pr UNE-EN 13230-6</td>
<td>1.39</td>
<td>1.75</td>
</tr>
<tr>
<td>AREMA 2017</td>
<td>1.66</td>
<td>1.35</td>
</tr>
<tr>
<td>AS 1085.14-2012</td>
<td>1.71</td>
<td>1.66</td>
</tr>
</tbody>
</table>

From the obtained values, it can be concluded that the results are not homogenous regarding structural requirements. Moreover, it can be observed that the rail seat positive bending moment obtained using the prUNE-EN 13230-6/2014 is lower than the value obtained for the center negative bending moment, while for the other two methodologies the oppose situation is observed. This noticeable difference could be associated not only with the different hypothesis assumed by each design process, but also to the assumptions made for the adaptation of the methodologies to determination of bending moments in broad track gauge sleepers.

Finally, it is important to consider that all standards and manuals include methodologies for the determination of bending moments, but not all of them require the calculation of shear forced or the verification of other type of stresses that could affect the performance of sleepers along their lifespan.

5. Relationship between Support Conditions and Bending Moments

As it was before mentioned, Fig. 1 presents the typical support conditions schemes used by most of the standards for the determination of bending moments. However, as Edwards and Dersch [6] said, with this type of simplified methodologies the real characteristics and consolidation condition of ballast are disparaged, while it is proved that the stiffness and consolidation of the support highly affect the forces that receive all the superstructures [6]. In this way, it could be concluded that an estimation of the different bending moments associated to different schemes of support conditions should be developed to obtain more accurate results. Moreover, although this type of studies undoubtedly requires a deeper and more complex study, it is important to consider that their results would help to understand if the construction methodologies and maintenance works developed in Argentina effectively produce similar support conditions and load states to the ones considered by international standards.
Regarding to the vertical stiffness of the railway track, Fig. 2 shows different values of “Ballast Coefficients” empirically obtained by different authors from track measurements and used by Teixeira [14] in his research work. As it can be observed, the obtained values of ballast coefficients strongly depend on the quality and stiffness of the subbase, which lead to the conclusion that the construction techniques and maintenance works would have a high impact on track deflections and on the associate stresses produced on the superstructure.

As a consequence of that, AENOR [9] has included in his standard the analysis of a beam on an elastic foundation (Fig. 3) as an alternative design process of bending moments. Following this line of thought, Standards Australia [8] also includes in his specifications the BOEF method (“Beam on Elastic Foundation Method”) as an alternative to the empirical method. What is more, this organization also recommends the use of finite element analysis as a more sophisticated design method.

<table>
<thead>
<tr>
<th>PARAMETRO (Unidades)</th>
<th>AUTOR (AÑO)</th>
<th>CARACTERÍSTICAS DE LA VÍA</th>
<th>VALOR MEDIO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Eisenmann (1969)</td>
<td>Suelo muy malo</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suelo malo</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suelo bueno</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>López Ptn (1976)</td>
<td>E plataforma = 13 MPa</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E plataforma = 30 MPa</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E plataforma = 70 MPa</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>Eisenmann y Ramb (1997)</td>
<td>Suelo mala capacidad portante</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suelo buena capacidad portante</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>Esved (2001)</td>
<td>Fundación mala calidad</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fundación buena calidad</td>
<td>0.2</td>
</tr>
</tbody>
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Fig. 2 Vertical stiffness of tracks measured in conventional railway tracks [12].

Fig. 3 Support condition scheme suggested by AENOR [9] for the determination of center negative bending moment.
6. Conclusions

From the results, it could be concluded that not all the international standards and manuals have a direct application in the design of Argentinian broad track gauge (1,676 mm) mono-block concrete sleepers. Moreover, it could be observed that the results obtained using the design processes proposed by AENOR [9], Standards Australia [11] and AREMA [13] were not homogeneous regarding structural requirements. This noticeable difference could be associated with the different hypothesis assumed by each design process, but also to the assumptions made for the adaptation of the methodologies to determination of bending moments in broad track gauge sleepers. This justifies and reinforces the work performed by argentinian engineers in the development of the recently approved IRAM 1609-1 standard [15] which sets a new methodology for the determination of bending moments in broad track gauge concrete sleepers.

Regarding to the relationship between the resulted bending moments and the stiffness of the track, it could be observed that with all the simplified support condition schemes adopted by international standards, the characteristics and real condition of the ballast are not considered for the determination of bending moments. In this way, it is unknown if this scheme actually represents the constructions and maintenance technics used in Argentina. As alternative to the empirical method, AENOR [7] and Standards Australia [8] include a method based on the Beam on Elastic Foundation Theory. However, the use of this complex method would undoubtedly reduce the practicality of the design process.

Finally, further works could involve the determination of bending moments in broad gauge (1,676 mm) sleepers associated to different values of railway track stiffness, by the utilization of the Beam on Elastic Foundation theories and finite element methods, in order to compare them with the results obtained from the application of design processes recommended by international and national standards and manuals.

Moreover, other type of stresses that may affect the performance of sleepers along their lifespan could be obtained from this analysis—as it can be for example unwanted shear or tensile stresses—in order to evaluate if their overlap with the mentioned bending stresses requires modifying the structural verifications that are currently required for this type elements.

References

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