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Long Term Dynamic Behaviour of the 3MB Slab Track System based on 3D Modelling

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Abstract

The slab tracks are, nowadays, very popular due to the reduced number of maintenance operations required. Indeed, the slab track systems have been an option in the scope of the high-speed lines in Asia but also in Europe to increase the connectivity between the main cities and their influence in the economic growth of the European Union. Thus, in order to assure very good performance of the tracks and also to improve it and reduce the costs associated with the maintenance operations, the short but also the long-term performance must be considered in the design phase. Indeed, despite the importance of the short-term analysis, the integrated evaluation of the long-term is essential since the long-term performance is dependent on the behaviour of the substructure but can influence the global performance of the track. Due to the important role of the performance of the slab tracks in high-speed lines, this work attempts to study and evaluate in detail the behaviour of the “new” 3MB slab track system. This system presents a modular arrangement that allows for an easy correction of the track geometry, as well as a quick repair and renewal in case of an accident. Thus, this study incorporates the analysis and evaluation of the short and long-term dynamic performance of the track using an integrated and hybrid approach that includes 3D modelling and the articulation with a calibrated empirical permanent deformation model to analyse the performance of the subgrade material.

Keywords: slab track, long-term behaviour, 3D modelling, dynamic analysis.

1 Introduction

The popularity of the slab track systems has been increasing exponentially in the last years due to the low number of maintenance operations required. Indeed, the slab track is a system that has been used, mostly in Asia (China, Japan, and South Korea), but also currently in Europe, especially because of the necessity to build high-speed lines and increase the connectivity between the cities and to increase the durability as well as to reduce intensive maintenance that characterised this system. Currently, China is probably the country with the greatest expansion in high-speed lines, which is already about 40000 km long at the end of 2021. Furthermore, China also intends to increase up to 400 km/h the train speed in the next future [1] and there have been tests in UE considering superior speeds.

However, there are different ballastless track systems and the pre-casted slabs are the "new" innovation in the ballastless track systems [2]. Yet, it is important to note that, besides the implementation of this type of structure, particularly in tunnels, the study of its dynamic behaviour, mostly in transition zones, is still little explored, when compared with the existing bibliography for ballasted tracks [3]. Furthermore, the current requirements to increase the speed lead to new challenges in order to improve the rail track performance due to the significant amplification effects of the track-ground vibrations induced by the high-speed trains, especially at critical speeds [4].

Considering the importance of ballastless tracks nowadays, especially, in high-speed lines, one of the positive contributions of this work is related to the study of the performance of the "new" 3MB slab track system. This study incorporates the analysis of the short but also the long-term dynamic behaviour of the 3MB slab track system using an integrated and hybrid approach that includes a 3D modelling and the articulation with a calibrated empirical permanent deformation model to analyse the performance of the subgrade material [5, 6].

2 Methods

The 3MB slab track system is composed of a concrete slab and four blocks on each side to adjust the rail levelling. Each block comprises two rails supports spaced 0.6 m. In the slab interface, an elastomeric layer is placed to mitigate the vibration transmitted to the slab. One of the main advantages of this system is its modular arrangement that allows for an easy correction of the track geometry, as well as a quick repair and renewal in case of an accident. The geometry of the superstructure is depicted in
Figure **1**.

To study the dynamic behaviour of the system, a 3D numerical model was developed in the software ANSYS. This model allows to obtain the short-term performance of the track and it was articulated with the implementation of a calibrated empirical permanent deformation model to characterise the long-term dynamic behaviour. Thus, this method is inclusive and allows to have a global perspective of the performance of this slab track system. The stresses of the

subgrade obtained in the 3D model are the main inputs of the empirical model. The flowchart that characterises the implemented method is described in
Figure **2**.

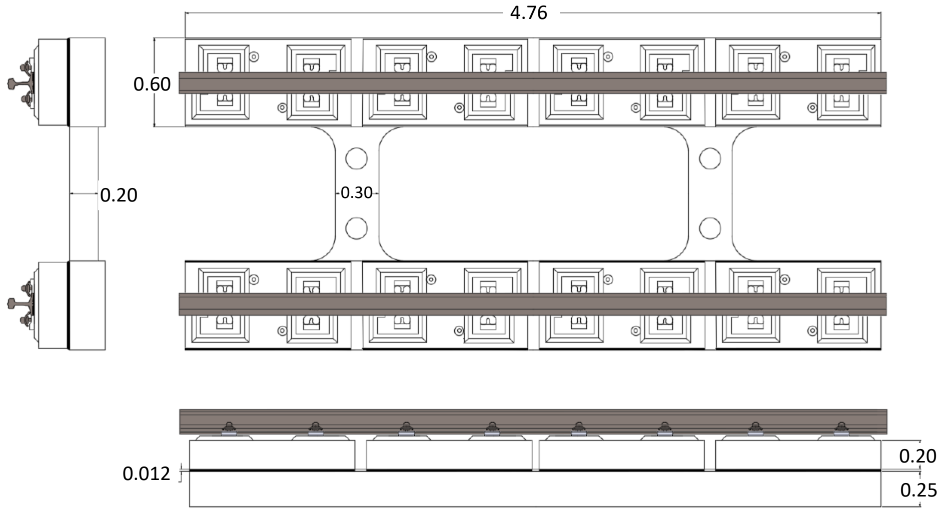


Figure 1: Prototype of the 3MB slab track system ([7])

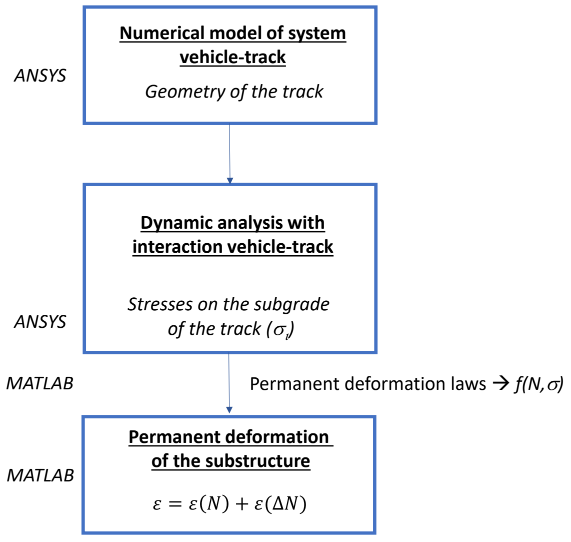


Figure 2: Schematic representation of the simulation process of the permanent deformation of the track (adapted from Ramos [8])

To simulate the degradation process, the effects of the passage of the first bogie of the *Alfa Pendular* at 220 km/h were analysed. The vehicle-track interaction was carried out through the inclusion of contact elements. The empirical permanent deformation model used to simulate the degradation of the subgrade and the respective track was calibrated (the constants of the model were adjusted) considering the comparison between numerical and experimental results based on full-scale cyclic laboratory tests simulated in a ballastless track over more the three million load cycles.

More details about the selection of the model and the calibration process can be found in [5]. The permanent deformation model is described by the following expression:

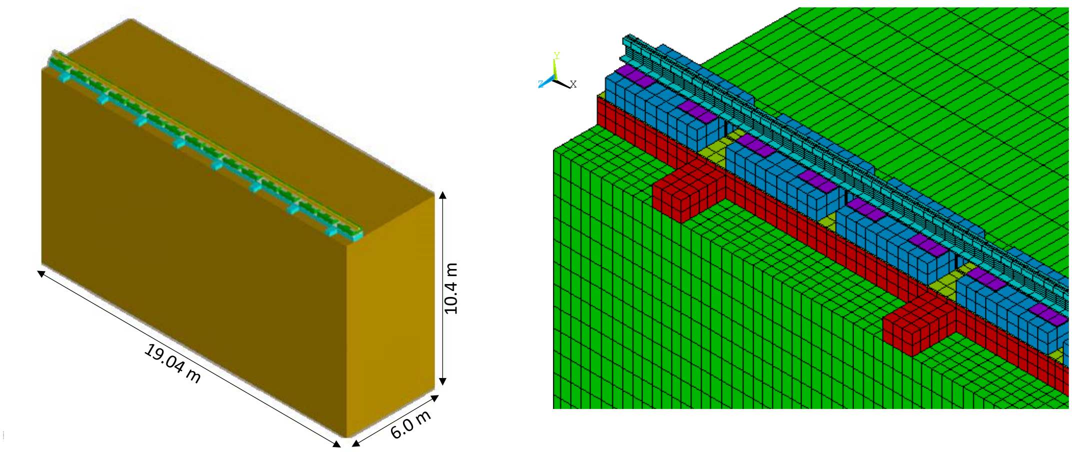
$$\varepsilon_1^p(N) = \varepsilon_1^{p0}[1 - e^{-BN}]\left(\frac{\sqrt{p_{am}{}^2+q_{am}{}^2}}{p_a}\right)^a \cdot \frac{1}{m\left(1+\frac{p_{ini}}{p_{am}}\right)+\frac{s}{p_{am}}-\frac{(q_{ini}+q_{am})}{p_{am}}} \tag{1}$$

where ε_1^{p0}, *B* and *a* are the constants of the model, *N* is the number of load cycles, p_{am} and q_{am} are the amplitude of the mean deviator stresses induced by train loadings, *m* and *s* are defined by the yielding criterion $q=s+mp$; and p_{ini} and q_{ini} are the mean and deviator stresses in the initial state of the material.

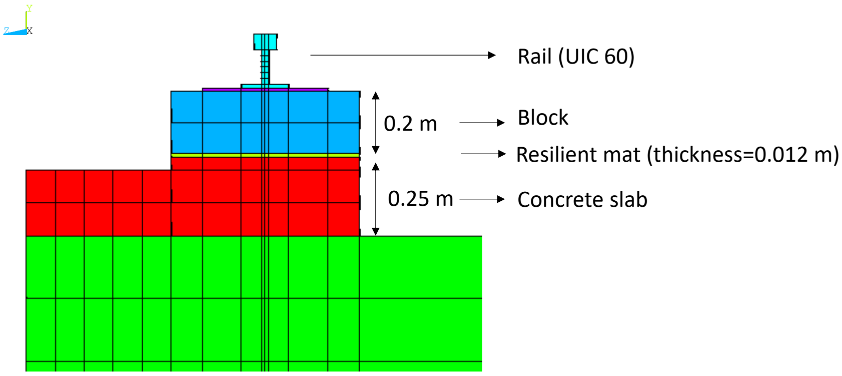
3 Results

The 3D model integrates the super and substructure, which corresponds to the subgrade material. This model allows obtaining the short-term behaviour associated with the displacements, accelerations, and stresses in the several elements of the track induced by the passage of the train. The 3D model is depicted in Figure **3**, as well as the main materials and respective thicknesses.

The embankment is 19.04 m long. Regarding the cross-section, the subgrade has a thickness of 10.4 m and the distance between the centre of the model and the vertical boundary (plane *yx*) is 6 m. The *Lysmer* formulation was adopted to attenuate the waves that impinge the boundaries. To simplify the modelling, the vehicle was only simulated with the bogies, primary suspension, mass and axle of the wheelset and *Hertzian* stiffness. A load of 67.5 kN was used to simulate the wheel load (axle load/2). As depicted in Figure **3**, the model considers the symmetric conditions of the problem. From the modelling, the stresses and displacements were analysed in the rail, concrete slab and subgrade.



a) b)



c)

Figure 3: 3D model: a) complete; b) detail of the model; c) detail of the superstructure

The properties of the superstructure can be found in Matias [7] and the properties of the subgrade and respective calibrated constants of the empirical model can be found in Ramos, Gomes Correia [5]. The obtained short-term results regarding the displacements and stresses in some elements of the track are presented in Figure **4** and Figure **5**.

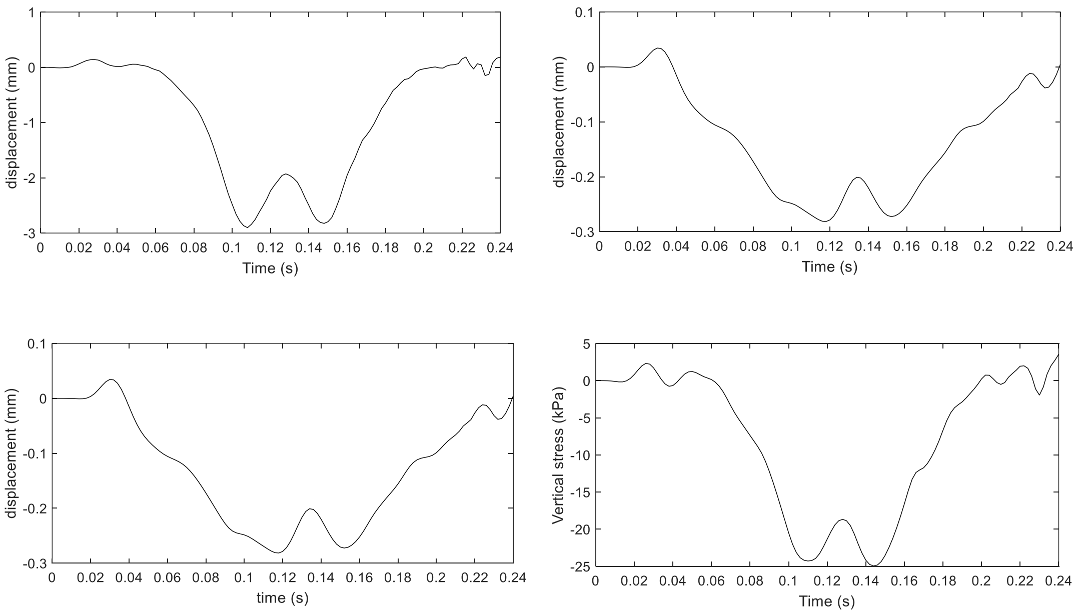


Figure 4: a) rail displacements at x=13.15 m at the top nodes; b) slab displacements at x=13.15 m at the top nodes; c) subgrade displacements at x=13.15 m at top nodes; d) subgrade stresses at x=13.15 m ate top nodes

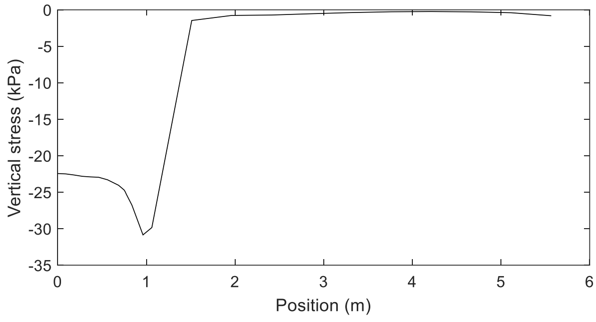


Figure 5: Vertical stress along the cross-section of the subgrade (top nodes) at x=13.15 m

From the 3D model, the stresses in all elements of the subgrade were found and exported to MATLAB to determine the permanent deformation and respective cumulative permanent displacements. The results are presented in

Figure **6** and

Figure 7.

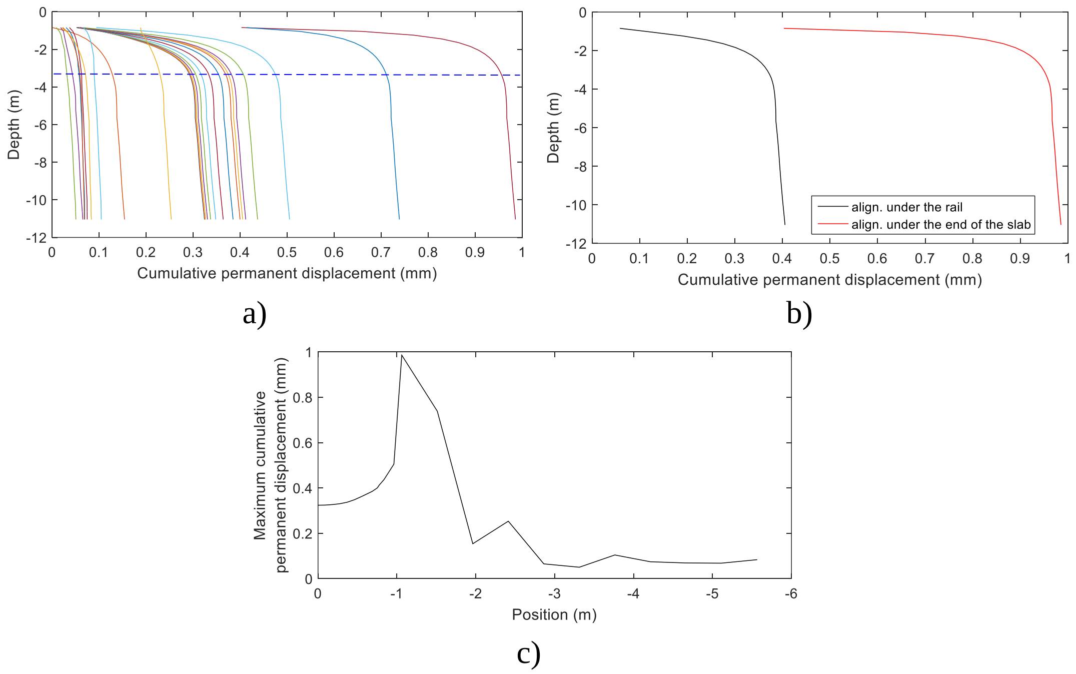


Figure 6 – Cumulative permanent displacement results (section at x=13.15 m): a) all alignments along the cross direction; b) selected alignments along the cross direction; c) maximum cumulative permanent displacement along the cross-section (at x=13.15 m)

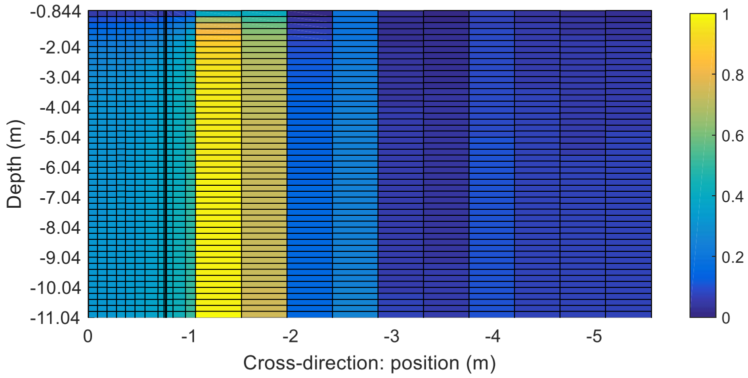


Figure 7: Permanent displacement at x=13.15 m

4 Conclusions and Contributions

The short-term results (
Figure **4**) show a good performance of the 3MB system with acceptable values regarding the rail's displacements. The results are also satisfactory regarding the concrete slab and subgrade displacements and subgrade stresses (maximum value close to 25 kPa, which is within an adequate range). Moreover, the results show that it is possible to distinguish the influence of the passage of the axles (and not only the bogie) in the subgrade. However, there is not a complete unload between the first and second axle of the bogie due to the geometric proximity between both.
Figure **5** shows the variation of the stresses along the cross direction in the subgrade. The results show that the maximum stresses occur in the alignment under the end of the concrete slab, which proves the importance of 3D modelling.

The long-term results (
Figure **6** and
Figure 7) show that the permanent settlement is maximum in the alignment under the end of the concrete slab and corresponds to a value close to 1 mm, which is acceptable. These results are aligned with the stress outcomes. The results depicted in
Figure **6** also show that the cumulative permanent settlements stabilise at a depth close to 3 m, which means that the elements below this value are not contributing to the development of the permanent deformation. This type of information can allow reducing the time of calculus since it is not necessary to obtain the stress results in all elements of the subgrade. In
Figure 7, the distribution of the cumulative permanent settlement along the depth and position in the cross-section is presented. This type of result is important and proves the necessity to have 3D modelling analyses in this kind of problem.

Thus, this work presents and analyses in detail the global performance of the "new 3MB" slab track system developed by ACCIONA using an integrated approach that combines the short-term and long-term analyses using a powerful 3D modelling articulated with a calibrated empirical permanent deformation model. In summary, the results show that this system presents a satisfactory short and long-term performance, with a maximum permanent displacement close to 1 mm.

Acknowledgements

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