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Research Paper

# Investigating the effect of *nailed sleepers* on increasing the lateral resistance of ballasted track

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ABSTRACT

Up to now, various techniques such as using dual-block sleeper, frictional sleeper, safety cap installation, Xitrack utilization and so forth have been proposed in order to improve the lateral resistance of ballasted railway tracks. In all existing methods, no engagement has been considered for track subgrade in this regard. In this paper, benefiting from the steel-driven nails, a new technique called "*nailed sleeper*" is introduced for enhancing the lateral resistance of concrete sleepers. In this regard, a 3D numerical model of ballasted track with single tie (sleeper) was developed using ABAQUS software and it was validated using laboratory single tie (sleeper) push test (STPT) results. Thereafter, by inserting two steel nails in the concrete tie of the model, some sensitivity analyses were conducted on the effective parameters of nails such as length, diameter, location through the sleeper and the elasticity modulus of the subgrade. In the next stage, from a structural point of view, the effect of the nail presence on the flexural and shear behavior of B70 concrete sleeper was controlled based on Australian design code AS 1085.14 requirements. As a result of the numerical and analytical analyses, the most appropriate dimensions and locations of nails were defined. Finally, after constructing a nailed B70 sleeper and installing it in a test track, its lateral resistance was evaluated under cyclic loading, and the obtained results were compared with common B70 sleeper at the same track. Consequently, it was observed that using a pair of nails of 40 mm in diameter and 1500 mm in length can increase the lateral resistance more than 200% compared to the normal condition. This technique can be efficiently used for horizontal anchoring the curved ballasted railway tracks.



## 1. Introduction

Various sources of lateral loads can be introduced for an under operation ballasted track and in this regard the induced forces by the wheel/rail contact, the wind lateral load on rolling stock, track buckling due to rail heating and the centrifugal forces on the curves are worth mentioning. Providing sufficient lateral resistance in under operation ballasted tracks are of main concern in high speed railways and in small radius curves, particularly in continuous welded rail (CWR) lines [1]. Generally, the super structure components of the ballasted tracks including the rails, fastenings, sleepers and ballast layer are the main sources of providing the lateral resistance; in this matter the role of sleeper-ballast interaction in horizontal direction is significant since the ballast layer creates lateral resistance in track through the contact between sleepers and ballast at the bottom, on the sides and in shoulders [2]. In the numerical investigation that was carried out by Kabo [3], the effect of these values was analyzed and a sensitivity analysis was conducted. In another research, based on the experimental results presented by Le Pen and Powrie [4], it was concluded that 26–35% of the lateral resistance is provided by interaction between the sleeper bottom with the ballast and the proportion of side and shoulder ballasts are 37–50% and 15–37% respectively. Moreover, other factors such as the sleeper type, its shape, the sleepers spacing, ballast characteristics, ballast depth, and shoulder ballast width and height can affect the lateral resistance [5]. The lack of lateral resistance in railway tracks can result in lateral displacement of tracks which leads to train or wagon derailment. This phenomenon usually happens in newly constructed or maintained (or tamped) curved tracks and it is followed by serious financial and physical damages. In this respect, for improving the lateral resistance of the tracks, many techniques have been proposed by various researchers and companies. For instance, changing the shape and sleeper geometry for better interaction with ballast layer in horizontal direction can be pointed out and in this regard, the

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'winged sleepers' suggested by Montalban et al. [6] is worth mentioning. As the results of the numerical analysis depicted, creating two wings at the bottom of the sleeper can increase the lateral resistance up to 53%.

In another research, Zakeri et al. [7] proposed the utilization of the 'frictional sleepers', including the jags in the sleeper base. Their lab experiments with this type of sleeper confirmed 68% enhancement in the lateral resistance due to more interaction of ballast particle with sleeper base.

In other studies Ciotlăuş and Kölló [8] and Beck et al. [9] suggested employing 'frame' and 'Y shape sleepers' respectively for enhancing the lateral stability and resistance of ballasted tracks. In contrast to above-mentioned techniques, which have focused on implementing a modification on sleepers, Xitrack technology uses a liquid polyurethane which is poured into the ballast to improve the lateral stiffness of shoulder ballast [10].

Scrutinizing all presented methods for enhancing the lateral resistance, it is obvious that none of them rely on subgrade stiffness and bearing capacity. So, the current study presents an innovative idea called "*nailed sleeper*", which is based on the lateral bearing of driven steel nails in conjunction with the lateral resistance of common concrete sleepers. In this method, the possibility of restricting sleepers horizontally using subgrade without limiting the vertical displacement is investigated. For this purpose, by getting the idea from driven micropiles, two vertical steel nails are inserted through B70 concrete sleeper in subgrade to restrict its lateral displacement.

In order to implement this idea, firstly a 3D finite element model of single tie (sleeper) push test was developed in ABAQUS software and its results were compared with the laboratory STPT results. Afterwards, due to a good agreement between the numerical and experimental results, two steel nails were included in the model and an extensive sensitivity analysis was performed on the important parameters of *nailed sleeper* such as: nail diameter, nail length, nail location through sleeper and subgrade stiffness. Consequently, the best dimensions of the nails were obtained. Knowing the optimum nails geometry, the effect of nail presence on the sleeper's structural behavior was controlled based on Australian design code AS 1085.14 [11]. Finally, utilizing the achieved results in this stage, the nailed B70 sleeper was manufactured and installed in an under-operation railway route and its efficiency in increasing the lateral resistance of ballasted railway track was confirmed through many single tie (sleeper) push tests in comparison to common B70 sleepers.

## 2. Introducing the idea of *nailed sleeper*

The idea of *nailed sleepers* is originated from utilizing steel nails (or steel micropiles) in railroads aiming at connecting super and substructure of ballasted railways together in order to engage the lateral bearing capacity of nail/subgrade system in the lateral resistance of the ballasted tracks. In this system, the interaction between the nails and subgrade in lateral direction in conjunction with concreter sleeper as the capping system acts similar to a group of micropiles which has an adequate potential to enhance the lateral stiffness of the whole track system. Although this idea does not have any background in the field of railway engineering, many researchers in the field of geotechnical engineering have been engaged in it. For instance, the results of a series of experiments conducted by Richards and Rothbauer [12], indicate that the behavior of micropiles under lateral loads depends on the type and the resistance of the first two to five-meter soil layers at the top of the micropiles. In another field experiment and the consequent numerical analysis conducted by Abd Elaziz and El Naggar [13], the behavior of a single hollow micropile under the monotonic and cyclic lateral loading in clay soils was investigated. Through their experiments it was proved that the lateral behavior of micropiles is affected by soil properties in a depth equal to 10 times of micropiles diameters from the top, while the soil layers in lower level does not have any effect in this regard. Yet, in another experiment done by Kershaw and Luna [14], the effect of both vertical and lateral loading on micropiles was studied. Based on their experiments, the presence of vertical static load on micropiles does not have any effect on its lateral resistance.

In this research, according to what is shown in Fig. 1, driving two vertical steel nails (which work as micropiles) in track subgrade through the holes made in concrete sleeper (which acts as pile cap), leads to the interaction of the track superstructure (sleeper and ballast) and track substructure (subgrade) which resulted in an increase in overall lateral resistance in ballasted tracks against the applied lateral forces. Obviously, the nails diameters, lengths and locations along the sleeper have considerable effects on the proposed system performance. On the other side, the lateral stiffness and bearing capacity of the subgrade play important roles in mobilizing the lateral stiffness of the *nailed sleeper* system. Another important issue in real performance of the *nailed sleeper* system is the effect of the nails on structural performance of prestressed concrete sleepers due to insertion of two holes for nail deriving. Considering all the factors mentioned is essential in developing the idea of using *nailed sleeper* system. In response to this essence, utilizing the numerical and analytical approaches as analysis and design tools should be considered. For this reason, the next section is devoted to detailed numerical and analytical calculations to support the *nailed sleeper* idea. Meanwhile, it should be noted that in the proposed system no restrictions have been considered in vertical direction for the nails in the sleepers, so two low friction plastic sheaths were inserted in the concrete sleeper prior to concrete casting during the sleeper production. This issue facilitates the tamping operation on ballasted tracks and it has no negative effects on the vertical stiffness of the tracks as well.

## 3. Numerical analysis of lateral resistance of the *nailed sleeper*

The behavior of *nailed sleepers* under lateral loads is not only affected by nails diameter, length and location along the sleeper, but it considerably depends on geotechnical parameters of ballast layer and subgrade soil. Therefore, in the first place, using ABAQUS 6.13 [15] as finite element software, the interaction of nails and sleeper was investigated considering all issues mentioned before, and a comprehensive sensitivity analysis was done on the effective parameters. In the following section, the 3D numerical model of a single *nailed sleeper* and the analysis done under lateral loading are discussed in detail.

### *3.1. The model geometry, mesh and boundary conditions*

Since the main purpose of this research is to study the behavior of B70 concrete *nailed sleeper* in standard single-track railway, in the process of modeling, the dimensions and the geometry of the B70 sleeper and also the cross-section of single track railway [16] are used according to Fig. 2.

In Fig. 3, the discretized finite element model is shown. It should be mentioned that in the direction perpendicular to the page, the model's thickness was considered equal to 1 m.

In the numerical analysis with ABAQUS, various elements were utilized for track super and substructure meshing. In this regard, for sleeper and ballast and subballast layer, the C3D20 type of hexahedral element with 20 nodes was used while for the subgrade soil modeling, the C3D8 type of hexahedral element with 8 nodes was utilized. On the other hand, the wedge element type C3D15