An Experimental and Numerical Study on the Effect of Different Types of Sleepers on Track Lateral Resistance

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Abstract

Lateral resistance of railway track is one of the most important parameters in lateral stability. This parameter depends on the conditions of different components of ballasted railway track (such as density of ballast layer, sleeper spacing, type of sleeper, etc.). From this perspective, type of sleeper has an important effect on lateral resistance. However in some conditions, in technical and economical investigations, using a special type of sleeper is not avoidable. In this research, concrete, wooden, and steel sleepers are studied using experimental and numerical analysis by finite element method. According to the experimental results, concrete sleeper B-70 with 2.06 tons has the most lateral resistance among three types of sleepers. Steel and wooden sleepers with the amounts of 1.32 and 1.10 tons are in the next ranking. On the other hand, numerical analysis (modeled according to field conditions) shows that the lateral resistance of concrete, steel, and wooden sleepers is equal to 2.10, 1.36, and 1.15 tons, respectively.

Keywords: Lateral resistance; ballasted railway track; concrete sleeper; wooden sleeper; steel sleepers.

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1. Introduction

Many railway organizations have recently concentrated on developing new trains and increasing their speed. Moreover, for increasing the speed of trains, rail joint should be removed and continuous welded rail (CWR) should be used. Temperature variations can cause significant axial forces in rails, which are the main problems in CWR tracks: tensile fracture at low temperature and buckling at high temperature [Lim, Park and Kang, 2003; Mirfattahi, 2009].

For avoiding buckling, it is necessary to provide the lateral resistance of railway tracks as required. The technical investigations show that different parameters affect the lateral resistance such as type and weight of sleeper, and density and particle shapes of the ballast layer

There are also different ways to increase lateral resistance such as employing winged sleeper, dual block sleepers, sleeper anchoring, frictional sleeper, Xi-track method, and large sleeper [Lichtberger, 2005; ERRI, 1995].

By considering the technical investigation, it seems that available reports and articles about the lateral resistance of railway tracks are limited in number. On the other hand, numerical analysis of lateral resistance is available about the extent of ballast shoulder and friction coefficient between sleeper and ballast in limited sources [Kabo, 2006; Le Pen, Powrie, 2011; ERRI, 1998; Perpinya and Zakeri, 2012; Zakeri et al. 2014]. But, there are some studies that can be mentioned as follows: Kimitoshi Hayano et al. conducted a series of tests on 1/5-scale models to evaluate the lateral resistance of the sleepers of ballasted tracks. In this research, single sleeper pullout tests and track panel pullout tests were investigated on several types of concrete sleepers to investigate the effects of the sleeper shape, sleeper spacing, and number of sleepers on the lateral resistance [Kimitoshi Hayano et al. 2014]. Recently, an innovative approach for increasing lateral resistance was developed by Esmaeili and co-authors in which a nailed B70 sleeper was used and installed in a test track. They found that using a pair of nails with 40 mm in diameter and 1500 mm in length could result in increasing the lateral resistance by more than 200% compared to the tracks with B70 sleepers. This technique can be efficiently used for horizontal anchoring of the curved ballasted railway tracks [Esmaeili et al. 2015]. Another research conducted by Zakeri and colleagues was on the effect of innovative sleepers and frictional sleeper [Zakeri et al. 2014]. It should be mentioned that comprehensive studies have been carried out in SRE (School of Railway Engineering), Iran University of Science and Technology, which provide evaluable findings. Some of these experimental works and field studies can be mentioned as follows: M. Fattollahzadeh, J.A.Zakeri, A.Bakhtiary, R.Talebi, "The numerical modeling of ballasted track".

In this paper, the effect of three types of sleepers on lateral resistance will be studied. Also, numerical analysis and experimental results will be compared. The single tie (sleeper) push test (STPT) is chosen as the laboratory method that is performed using'KS625N' tools.

In 3-D presented model, the ballast layer acts elasto-plastically and the sleeper is considered as an elastic material. Effect of sleeper type on lateral resistance is studied by the interaction between ballast layer and concrete, wooden and steel sleeper. For investigating validation, friction coefficient is assumed 0.1 in the modeling of interaction between ballast layer and sleeper [Kabo, 2006; Bakhtiary, 2011; Zakeri, 2010; Iranian Code of Practice 310, 2004].

2. Materials and Equipment

In this section, geometrical characteristics of all kinds of sleepers are described, at the first step. In addition, ballast aggregation used in laboratory is explained. In the last part, performing the test and preparing track panel will be discussed.

2.1 Sleeper

2.1.1 Concrete Sleeper

In the tests, B-70 sleeper was used. Characteristic of B-70 is shown in Table 1.

2.1.2 Steel Sleeper

Steel sleepers were produced from rolled U-shape section. In addition, to make more contact between steel sleeper and ballast layer, two end faces were curved and got into ballast. So, suitable contact between ballast layer and sleeper resulted in decreasing displacement in longitudinal and transverse directions. In Figure 1, the sample of these sleepers is shown. Characteristic of steel sleeper is presented in Table 1.

2.1.3 Wooden Sleeper

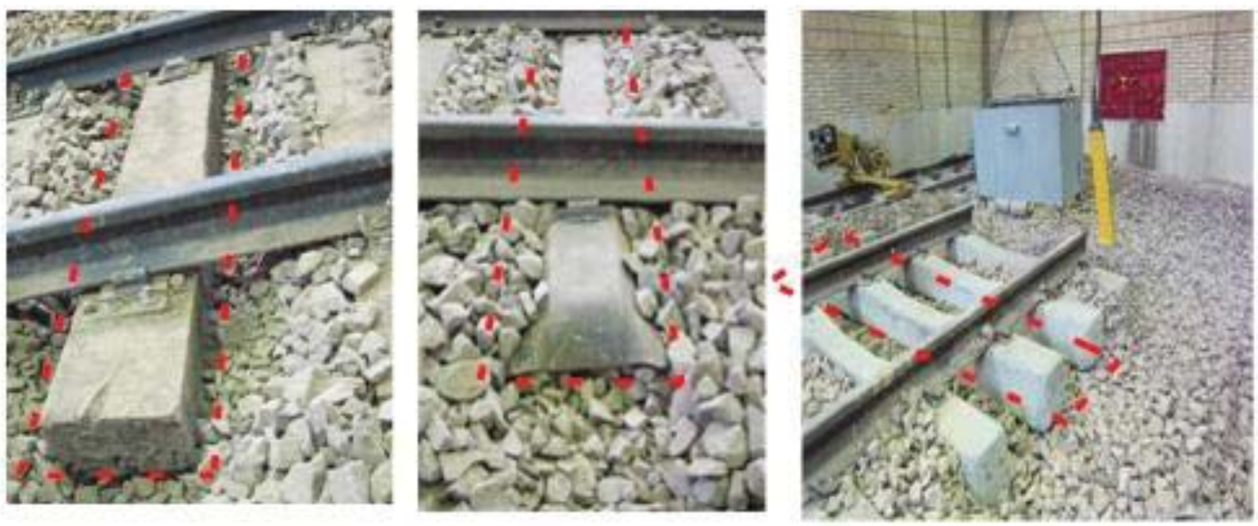
Wooden sleeper used in the tests were according to Leaflet 301 Iranian Code of Practice that was used in a class line of Iran railway. These types of woods resist vertical forces that cause fracture in wood and longitudinal and transverse forces and result in loosing fastening system. Dimensions of wooden sleepers are shown in Table 1. [Zakeri and Mirfattahi, 2012].

2.2 Ballast Aggregation

Ballast materials are obtained from the crushed stone with aggregation, like in Figureure 2. As demonstrated in Figure 2, the desired case corresponded with aggregation No.1 [Iranian Code of Practice N0. 301, and ASTM-C136].

Table 1. Geometric Specifications of the Used Sleepers (Concrete Sleeper B-70, Steel and Wooden Sleeper) In Experimental Tests

	Sleeper Feature				
	Total length of sleeper (mm)	bottom width of Sleeper (mm)	Upper width of sleeper (mm)	sleeper heights (mm)	Total weight of sleeper
Concrete sleeper (B-70)	2600	260	220	220	280
Wooden sleeper	2600	230	230	180.	98
Steel sleeper	2500	260	150	90	80



Wooden sleeper	Steel sleeper	Concrete sleeper

Figure 1.Sleepers used in the laboratory.

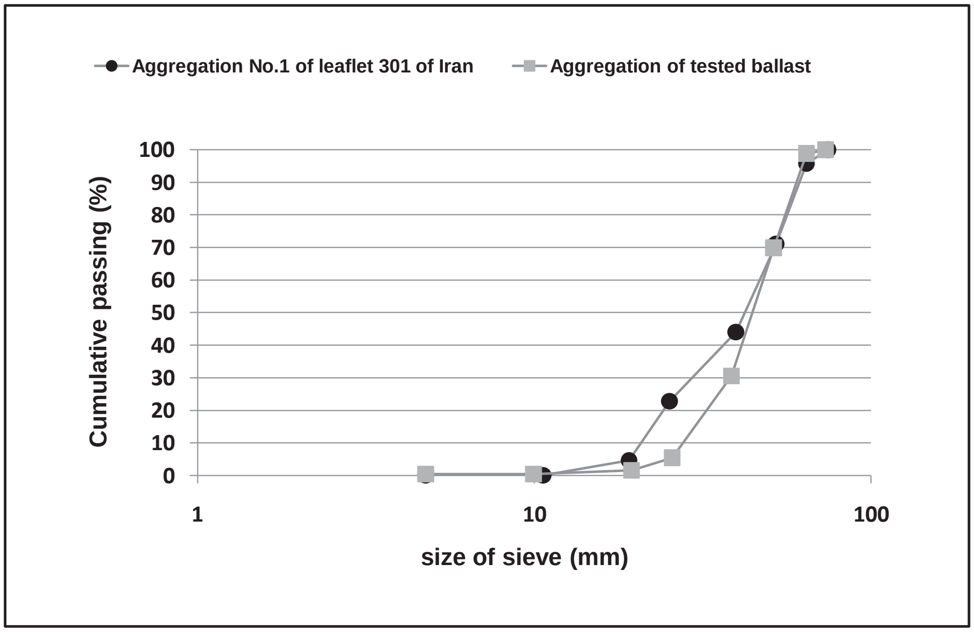


Figure 2. Diagram of the tested ballast aggregation.

2.3 Performing the Test and Preparing Track Panel

According to Figure 3, in order to create conditions similar to the field conditions, the two bearings were used. Bearing A was used to compact ballast layer and bearing B was applied to crib the area. The weight of each one was 29.4 kg. Initially, at the thickness of 30 cm of ballast layer, bearing A was used. Then, track panel was placed on the ballast layer and the base area was filled by lever. Afterwards, the crib zone was filled and bearing B was passed for 20 times. Finally, the end area of the sleeper was filled and bearing B was passed again. Each of the two crib areas of the sleeper was divided into 10 sections and 10 strikes were exerted from the height of 10 cm by lever [Bakhtiary, 2011].

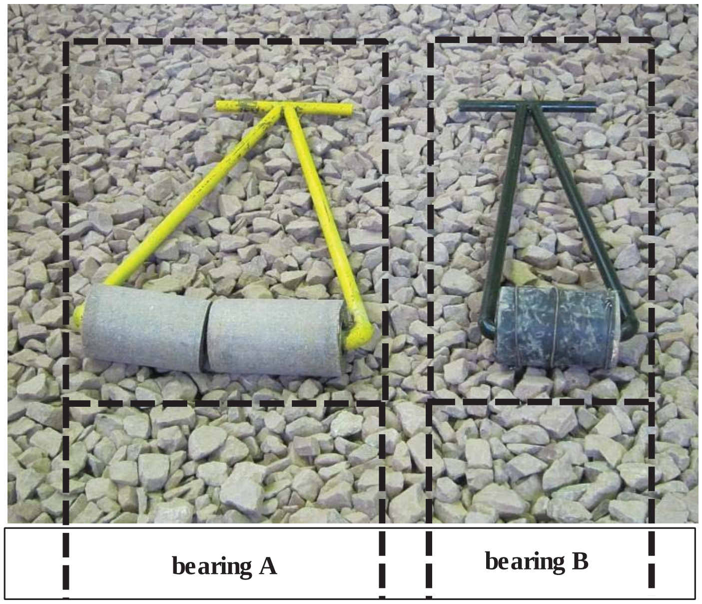


Figure 3. Lever and rollers used for high-density area around the sleeper and ballast layer (10 cm penetration rate of lever is seen).

3. Single Sleeper Push Test (STPT)

In the experimental test, the sleeper was pushed against the rail by a hydraulic device. The sleeper fastening system (pandrol) was released from rail and the force was exerted to the sleeper by the hydraulic jack. The apparatus KS625N was used in this test to measure sleeper's lateral resistance [Bakhtiary, 2011].

4. Developing 3-D Finite Element Model

4-1 Simulation of 3-D Finite Element Model

The purpose of this paper is to study the lateral resistance of concrete, wooden and steel sleepers. It should be mentioned that vertical loading was considered low, because the critical status (minimum lateral resistance) is important to us [Zakeri and Barati, 2013].The geometry of different simulated sleepers is shown in Figure 4. It must be considered that extent of shoulder is 40 cm, slope of shoulder is 1:1.5, and sleeper spacing is 60 cm, as in Figure 5 and the investigated sleeper is single and not connected by rails to other sleepers.

In modeling, the materials of sleeper and ballast are considered elastic and elasto-plastic, respectively. Mechanical properties of the sleepers and ballast are shown in Table 2 [Iranian Code of Practice No. 310, 2004].

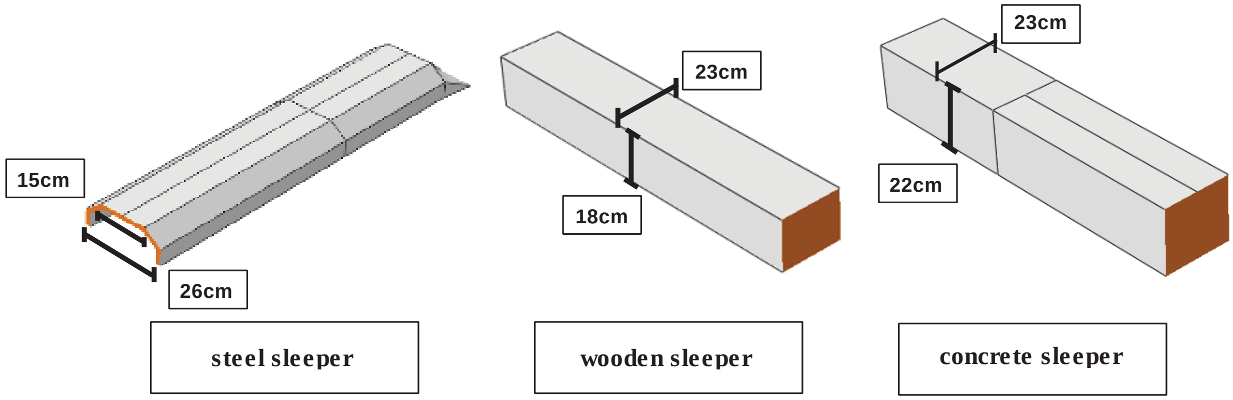


Figure 4.Geometric characteristics of the cross simulated sleeper.

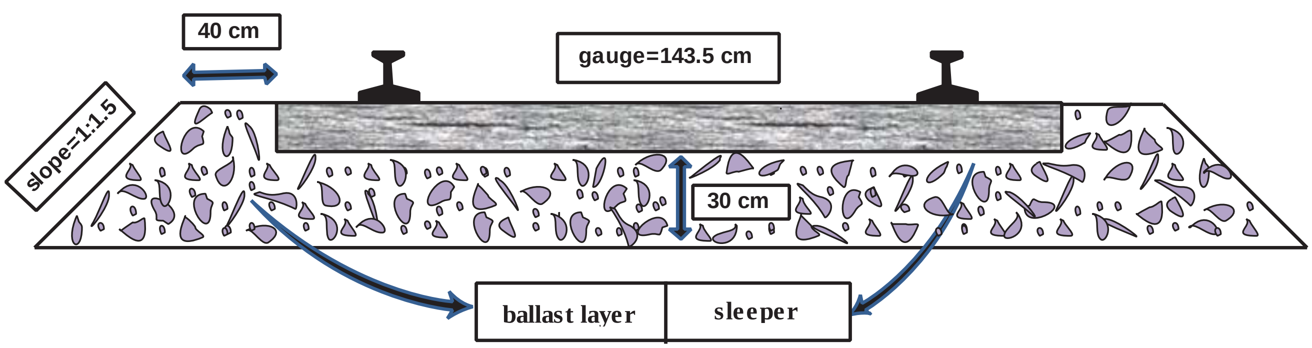


Figure 5.Geometric characteristics of the cross sectional simulated track.

Table 2.Mechanical properties of material.

Property	ballast	Concrete sleeper	Steel sleeper	Wooden sleeper
) kg/m^3(Density	2400	2400	1875	908
Young's modulus) N/m^2(	0.14×10^9	37.5×10^9	200×10^9	6.9×10^9
Poison ratio	0.4	0.15	0.3	0.29

4.2 Boundary Conditions, Loading, Interaction between Sleeper and Ballast Layer, and Mesh Identification

Studying the effect of interaction between sleeper and ballast layer, the friction coefficient of 0.1 is considered. According to Figure 5, the ballast and sleeper are placed on a rigid plate, the bottom layer of which does not have any relative displacement to this rigid plate. It must be mentioned that the rigid plate is modeled completely restrained that it results in increasing lateral stiffness and lateral resistance. Loading as lateral displacement was applied in the center of rail seat and applied statically. The following steps are considered in the numerical analysis:

1- Applying gravitational load (preserved throughout the simulation)
2- Vertical loading (ballast compaction) Fy=-150 kN at each rail pad
3- Unloading Fy=0 kN.
4- Vertical load Fy=-15 KN at each rail pad
5- Prescribed lateral displacement

The FE mesh consists of 3 dimensional 20-node elements: the concrete sleeper was modeled by 672 elements corresponding to 1075 nodes and the model of the ballast by a 40 cm shoulder consisted of 3528 elements corresponding to 15778 nodes [Kabo, 2006 and Kasraei, 2013].

4.3 Validation

Validating of model, a ballast layer with the shoulder extent 40 cm, shoulder slope of 1:1.5, and sleeper spacing of 60 is used and coefficient friction of concrete sleeper with ballast layer is considered 0.1. According to Figure 6, Kabo's [Kabo, 2006] diagram is considered the reference and valid source and simulation diagram was the result of modeling in the current paper. According to Figure 6, it is obvious that the result of the current paper had appropriate accuracy.

5. Discussion

In this section, results of experimental and numerical studies are discussed. It is obvious that geometric conditions of ballast layer are same as before, but friction coefficient between sleepers and ballast layer is different. Friction coefficient between concrete, wooden, and steel sleepers, and ballast layer was considered 0.8, 0.6, and 0.45, respectively. It must be mentioned that numerical modeling is implemented with field conditions [Kabo, 2006].

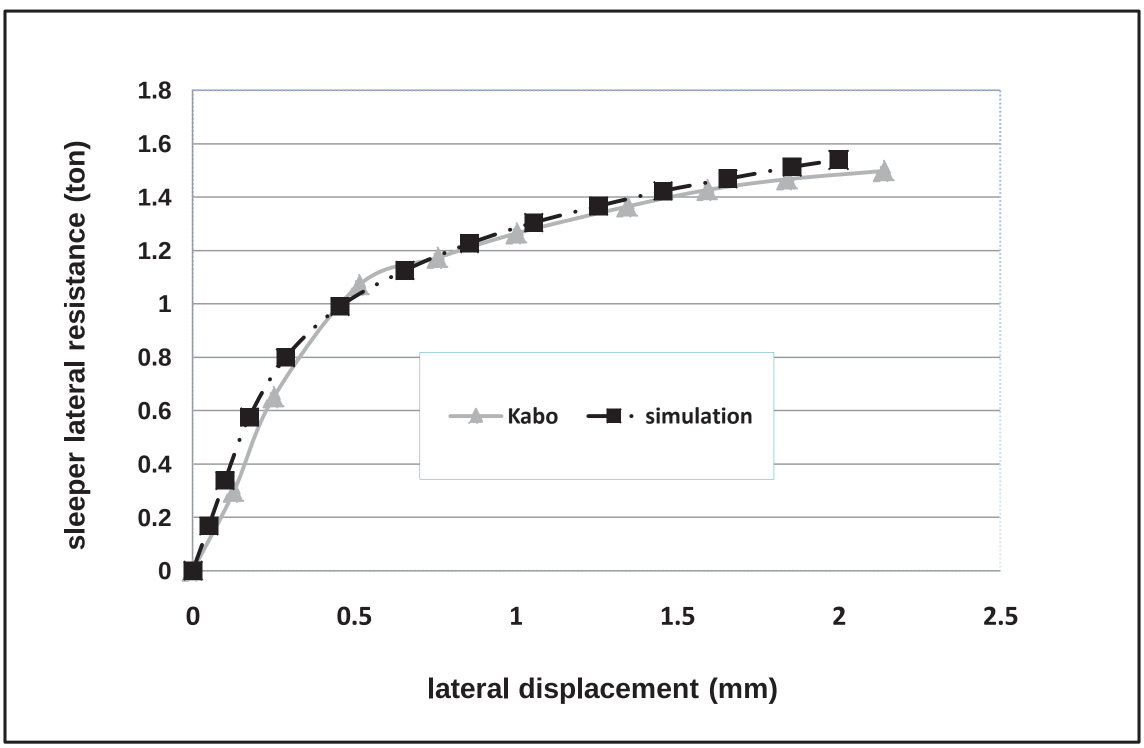


Figure 6.Validation of Modeling.

5.1 Experimental and Numerical Result

According to Figures [7, 8], results of experimental and numerical studies are presented and concrete sleeper had the maximum lateral resistance of 2.06 -2.10 ton; afterwards, steel and wooden sleepers are in the next ranking with values 1.32 -1.36ton and 1.10 -1.15ton,respectively [Bakhtiary, 2011; Kasraei, 2013].With regard to more lateral resistance of concrete sleeper, weight of concrete is a very important parameter. Because of the weight of concrete sleeper and more friction with ballast, it has the most lateral resistance in comparison with steel and wooden sleeper. In this regard, 55% of lateral resistance was provided by bottom section of concrete sleeper. Steel sleeper has less friction with ballast; therefore it has less lateral resistance.

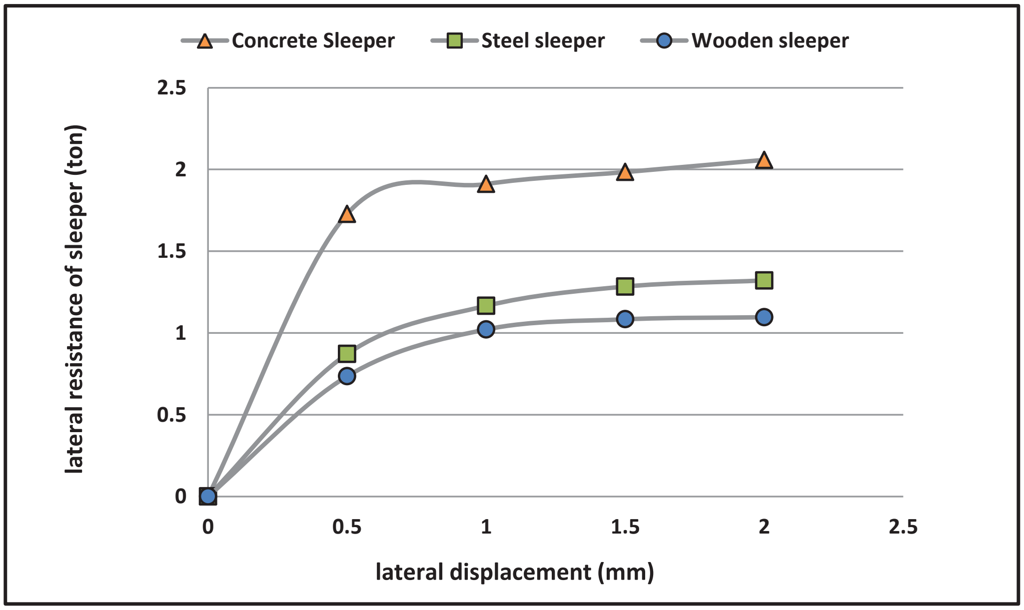


Figure 7. Experimental result for (concrete, steel, and wooden) sleepers

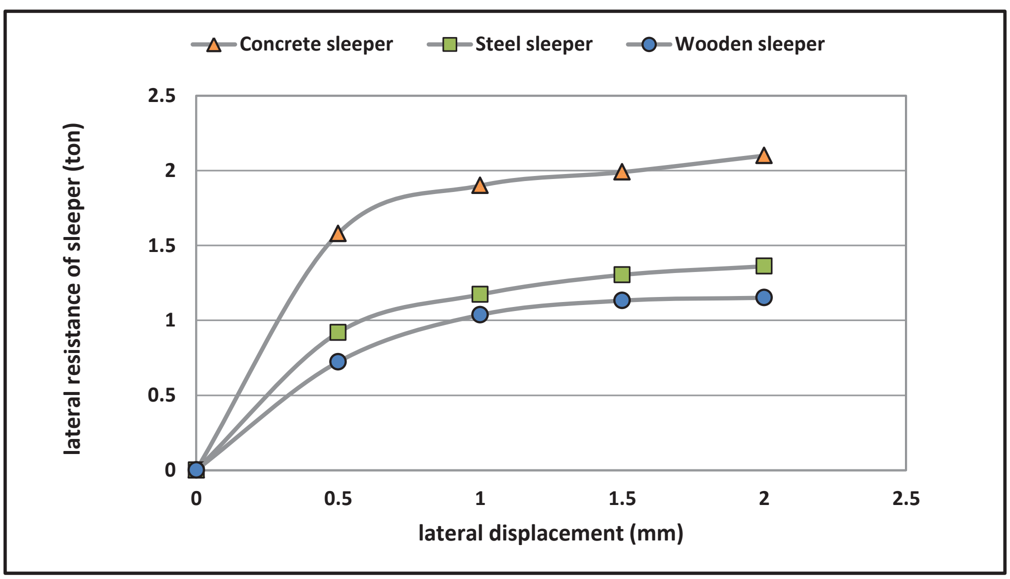


Figure 8.Numerical result for (concrete, steel, and wooden) sleepers

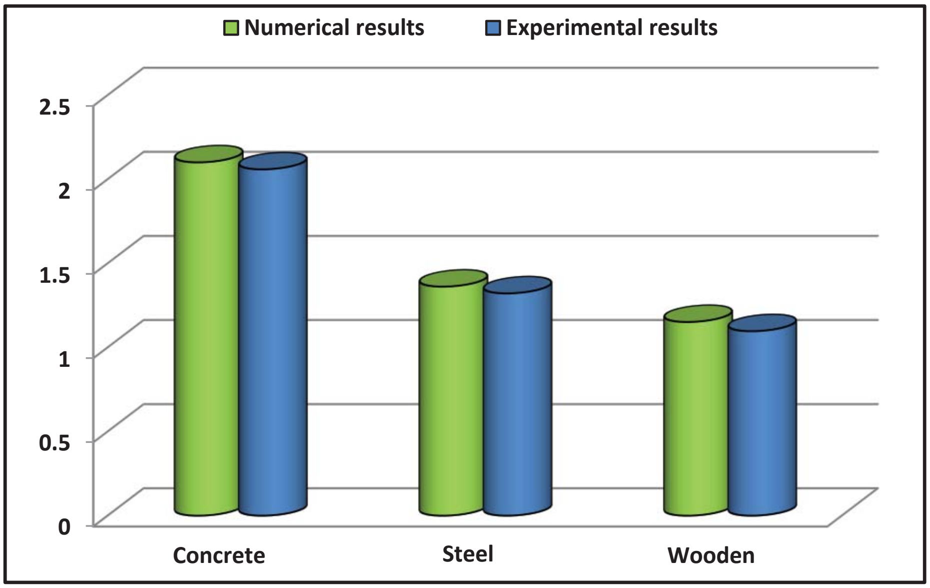


Figure 9. Comparing lateral resistance of sleeper in the laboratory condition and numerical modeling of various sleepers.

5.2 Comparing Finite Element Model and Experimental Result

According to Figure 9, both numerical and experimental results are shown. It must be mentioned that the experimental behavior of ballast in the current study is adapted to the FEM model's aspect density.

6. Conclusions

Lateral stability of ballasted and non-ballasted railway tracks is considered as one of the most important factors in the matter of increasing the velocity of transit fleets for the purpose of infrastructure development. Therefore, it is essential to study lateral resistance in ballasted railway track. An approaches for increasing lateral resistance is the substitution of sleepers with more resistance. It is the aim of this paper to compare the effect of different sleepers on lateral resistance. The experimental and numerical results are shown as follows:

Conclusions demonstrated that the ratios of numerical to experimental results for concrete, steel, and wooden sleepers were 1.02, 1.03, and 1.05, respectively. Also, concrete sleeper had (54-56) percent more resistance than steel sleeper and steel sleeper had (18-20) percent more resistance than wooden sleeper, but this percentage was a function of ballast density and shape of ballast layer that could be different from the other tracks with different characteristics.

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