Scientia Iranica A (2014) 21(1), 101–107

SCIENTIA IRANICA

Sharif University of Technology
Scientia Iranica
Transactions A: Civil Engineering
www.scientiairanica.com

Research Note

Comparing lateral resistance to different types of sleeper in ballasted railway tracks

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Received 20 December 2012; received in revised form 16 April 2013; accepted 8 June 2013

KEYWORDS
Lateral resistance of railway;
Ordinary concrete sleeper;
Steel sleeper;
Wooden sleeper.

Abstract. Identifying the contribution of each part of a railway to total lateral resistance is considered an important issue in choosing the type of sleeper for providing the lateral stability of a ballasted railway track. On the other hand, identifying the percentage effect of each part can also help to present new methods for increasing its lateral resistance. The methodology of this study was based on experimental work in the laboratory. In this paper, the contribution of each part of the sleeper, comprised of a base, crib and shoulder, towards total lateral resistance, was determined using STPT tests. In all measurements, the greatest value of lateral resistance was related to the area under the sleeper (base zone) and its corresponding values in concrete, steel and wood sleepers were 62%, 56% and 51%, respectively. The contributions of the shoulder and crib area to lateral resistance were 28% and 9% for the concrete sleeper, 27% and 22% for the wooden sleeper and 18% and 26% for the steel sleeper, respectively.

1. Introduction

One of the most important hazards for Continuous Welded Rail (so called CWR) tracks is lateral buckling, which may be created by various factors such as increased axial and lateral forces. Lack of the lateral resistance of a track and consequently the increase in lateral displacement can cause train derailment and superstructure damage [1]. Therefore, it is necessary to identify the factors which influence the reduction in lateral displacement of the track and provide lateral stability. Few studies have been performed on the effects of different parts of a ballasted railway track on total lateral resistance. Data of lateral sleeper resistance tests are rarely presented in such a way to facilitate identification of the separate contributions of the base, crib and shoulder. Most test results are unpublished reports held in private companies. There are also uncertainties relating to the presence, or otherwise, of a vertical load during the push or pull test, which could have a dramatic effect on measured resistance. On the other hand, parameters, such as the compaction rate of a ballast layer, ballast layer particles, cleanliness or contamination of the ballast layer, influence total lateral resistance [2-6]. As an example, the results of a UK railroad research done by Shenton and Powell [2], which tried to determine the lateral resistance of sleepers under different railroad conditions, can be found in the design manual AREMA [6], and the results of experiments by Le pen [7], Dipilato et al. [8], Selig et al. [9] and Kabo [10] can be referred to. These results are expressed in a separate section below. The research method of this paper is based on an experimental investigation. For this purpose, in the School of Railway Engineering at Iran University of Science and Technology, a number of experiments were performed. In these experiments, the single sleeper push test (so called STPT) was used. In all experiments, a special process was

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applied to the same testing conditions, as explained later.

Also, in this paper, the percentage effects for different parts of a sleeper (sleeper base, crib and sleeper end with ballast shoulder (sleeper shoulder)) on the lateral resistance of a track were investigated in three types of sleeper: ordinary concrete, steel and wood.

2. Literature review

The total resistance of sleepers consists of three parts:

a) Underside friction resistance (base zone): this is the resistance at the base of the sleeper which depends on friction between the ballast and the underside of the sleeper and, therefore, on the friction value and vertical load (normal force).

b) Crib resistance of sleeper: this is the resistance at the crib area of the sleeper, derived from active ballast pressure, in accordance with the classic soil pressure theory. This pressure depends on the height of the embankment, the density of the granular material and the coefficient of friction between the granular material (ballast).

c) The shoulder resistance (ballast shoulder): this is equivalent to the passive earth pressure of soil mechanics [11,12].

In order to obtain the contribution of different parts of the sleeper, a few studies have been undertaken as field and laboratory research. All these studies have been limited to only one range for each part. However, the mechanical and geometrical properties of a track and its components can affect the results [13,14]. Some of these studies are listed in the following Tables 1-3. According to Table 1, Dipilato et al. [8] obtained the relative effect of components in lateral resistance for two cases of loaded and unloaded tracks. It was observed that the largest portion of lateral resistance was related to the base zone, and, subsequently, crib and shoulder zones. On the other hand, lifting up in front of the wheels presented quite different results. The effect of base zone on total resistance and the other two components reduced and increased, respectively [8].

Table 2 presents a comparison of lab results (Le pen (2010)) with ERRI results (1995). In this table, ERRI used the data from an ORE to show total lateral

Table 1. Relative effect of sleeper components in lateral resistance of sleeper.

Lateral resistance force	Percent of the total resistance	
	Loaded railway	Unloaded railway
Ballast bed/base	90-100	50-60
Ballast bed/crib	0-5	10-20
End-resistant of sleeper	0-5	30-40

Table 2. Comparison of lab results of Dr. Lepen with ERRI result (1995).

Shoulder size extent by height (mm)	Shoulder (2-20 mm mean)		Crib contribution (2-20 mm mean)		Unloaded track base contribution (mean peak H/v ratio up to 20 mm displacement × weight of sleeper and rails: 0.55 × 3755)		Total (N)	Total resistance estimated from ERRI data for median estimate for loose tamped/relay (N)	Difference in total resistance relative to ERRI data (%)
	(N)	(%)	(N)	(%)	(N)	(%)			
200	899	15	2935	50	2065	35	5900	5485	8
300	2150	30	2935	41	2065	29	7151	5900	21
400	1973	28	2935	42	2065	30	6974	6315	10
600	2317	32	2935	40	2065	28	7318	7145	2
400 × 125	2976	37	2935	37	2065	26	7977	7353	8

Explanation: The last row of the first column is related to additional ballast above the ballast shoulder amount of 125 mm in height.

Table 3. Result of experiments of lateral resistance of railway in the UK.

Resistance components	**Lateral resistance of each sleeper (KN)**				**Type of sleeper**
	Characteristics of ballast & Ballast aggregate size				
	76 mm		**38 mm**		
	Dense	**Loose**	**Dense**	**Loose**	
Base	1.28	1.03	1.01	1.01	Wooden
	2.64	1.83	2.68	2.14	Concrete
Crib	3.9	0.9	1.7	1.01	Wooden
	4.56	1.29	1.87	1.11	Concrete
Shoulder (229 mm)	0.3	0.28	0 8	0.44	Wooden
	1.3	0.13	0.51	0.46	Concrete
Total	4.44	2.21	3.51	2.46	Wooden
	8.5	3.25	5.06	3.71	Concrete

resistance against the shoulder. Table 2 shows that experimentally determined resistances are generally up to 10 percent more than the estimated ERRI resistance for a loose tamped/relayed track, except for the 300 mm shoulder size (which is considered anomalous) [7,5].

Also, Shenton and Powell (1973) conducted a detailed investigation into British railways, which was done to determine the amount of lateral resistance under different conditions. In this study, according to type and ballast conditions, the size of the ballast shoulder at both ends of the sleeper and the ballast material, a comparison was made between different values of lateral resistance.

The important results of this study are presented in Table 3 [2].

Different parts of a sleeper are shown in Figure 1. These parts are in contact with the ballast layer and play an important role in the total lateral resistance of a ballasted railway track. Figure 1 presents the test panel in the SRE (the superstructure laboratory of the school of railway engineering) at Iran University of Science and Technology.

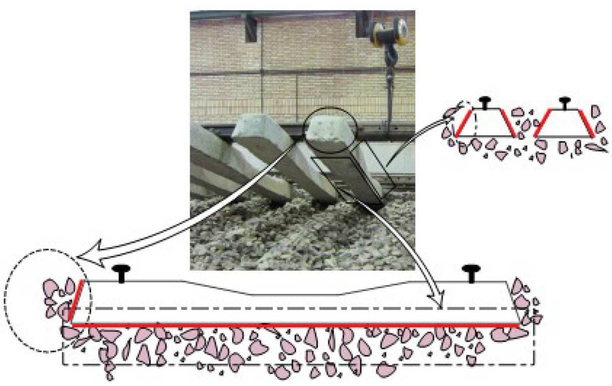

Figure 1. Different parts of sleeper (sleeper base, sleeper crib, sleeper end with shoulder ballast (sleeper shoulder)) that affect total lateral resistance of ballasted railway track.

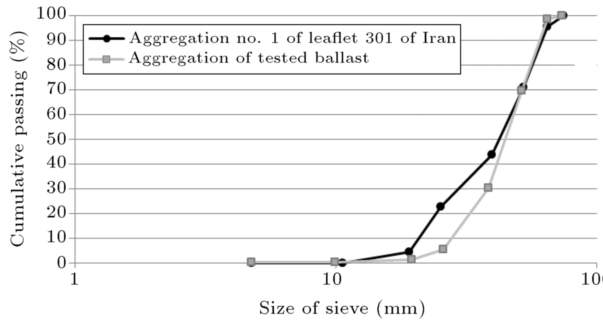

Figure 2. Sizing of ballast aggregate.

3. Materials and equipment used in the test

3.1. Type and size of used ballast materials

The applied ballast materials included broken rock with the sizing in Figure 2.

As can be seen, aggregation was based on leaflet 301 of Iran, No. 1, and the ASTM standard (ASTM-C136) [15,16].

3.2. STPT test

STPT is a standard test to predict the lateral resistance of sleepers. In this test, interaction between the ballast and sleeper, ballast weight and the friction between them causes resistance formation against sleeper lateral displacement. Of course, the lateral resistance of the sleeper must not be mistaken for the lateral resistance of the track.

In this test, the sleeper fastenings are opened and force is exerted on the sleeper by a hydraulic jack. Apparatus KS625N is used in this test to measure sleeper lateral resistance. This apparatus consists of a processor, a spring gauge to measure displacement, a hydraulic jack (oil), an electrical pump, a chamber of the hydraulic pump and the hose of pressure transmission from the pump to the hydraulic cylinder.

The hydraulic cylinder removes the sleeper out of the track while being situated on the sleeper (by opening the pandroll fastenings based on the sleeper shoulder), as it exerts vertical force on the sleeper body using a steel tip. On the other side, a sensor is placed on the sleeper (like the connection of the hydraulic cylinder) and its tip is tangent to the side of the second rail. It is compressed before loading and the sleeper displacement is measured versus the track with sleeper movement and gauge return. Setting of different parts of the apparatus on the track is shown in Figure 3 [17].

4. Performing the test and preparing the track panel

To simulate laboratory conditions with real conditions for the tests, the process of bearing was used to form the initial compaction in the ballast layer. Two bearings of A & B were used, as shown in Figure 4. Type A and type B were used to bear the ballast layer before track panel insertion and to bear the crib area, each weighing 24.4 kg, respectively. Initially, in 30 cm of ballast thickness, bearing A was used to compact the ballast layer. For this purpose, this bearing was passed 20 times; then, the track panel was placed on the ballast layer and the area under the ballast was filled by a crowbar, as shown in Figure 5. After the area base was filled, the lateral resistance of the track was measured. Then, the crib area was filled, bearing B was passed 20 times and the lateral resistance of the track was measured. Finally, the shoulder sleeper was filled. To do so, according to Figure 5, each of the two crib areas of the sleeper was divided into 10 sections, and 10 strikes were exerted onto the 10 cm high point by the crowbar.

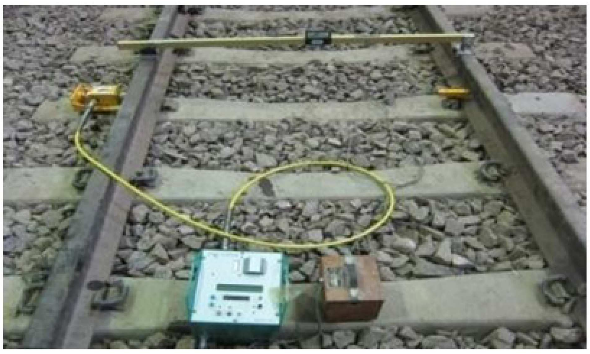

Figure 3. The setting of different parts of apparatus on the track.

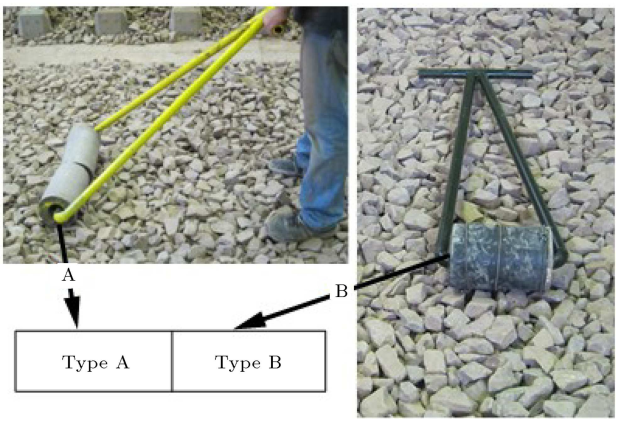

Figure 4. Rollers used in roller stamping process.

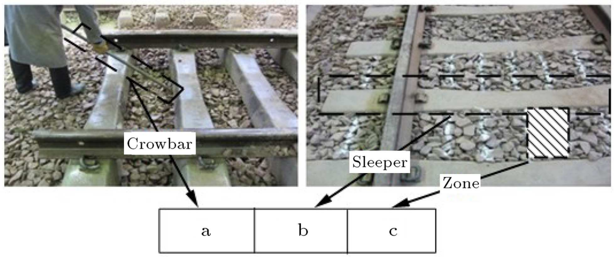

Figure 5. Steel sleeper tests. a: Use of crowbar to compact the base and crib zone of sleeper; b: Sleeper tested; and c: surrounding areas of sleeper.

5. Results and discussion

To compare the results from the sleepers, the width and slope of the shoulder were considered 40 cm and 45°, respectively. In steel and wooden sleepers, specific fastenings were used so that KS625N was inserted. A sample of these fastenings is shown in Figure 6.

The experimental result was validated through a comparison with previous experiments performed by the first author [13,14].

Retaining the same geometric properties and analogous conditions, the same results were obtained.

Experimental results of the lateral resistance of sleepers are listed in Table 4.

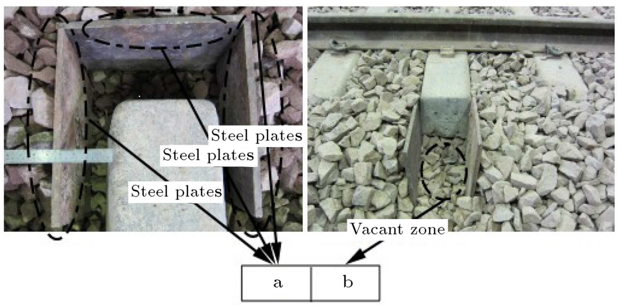

Figure 6. Concrete sleeper tests. a: Using steel plates to separate different sections of concrete sleeper; and b: shoulder zone of concrete sleeper.

Table 4. Results of experiments of lateral resistance of sleepers.

	Lateral resistance of base zone (kg)	Lateral resistance of crib zone (kg)	Lateral resistance of shoulder zone (kg)	Total lateral resistance (kg)
Concret sleeper	509	77	232	818
Steel sleeper	383	177	127	687
Wooden sleeper	324	142	174	640

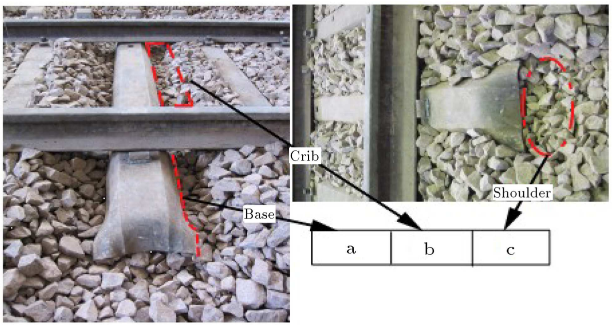

Figure 7. Ballast section: a: base zone; b: crib zone; and c: shoulder zone.

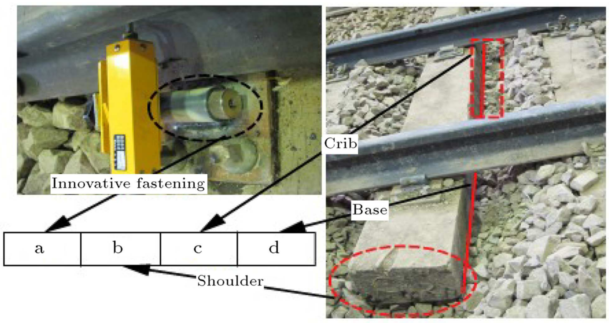

Figure 8. Wooden sleeper tests: a: innovative fastening devices used to install strain gage; b, c, and d: surrounding the wooden sleepers during testing.

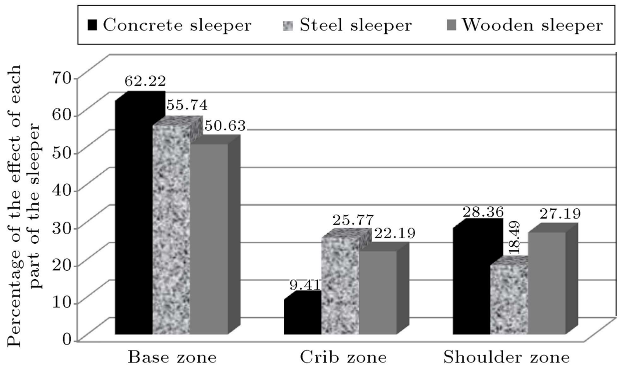

Figure 9. Percentage of lateral resistance of each part in total resistance.

5.1. Ordinary concrete sleepers

Each section is separately examined. For this purpose, steel sheets were used, as demonstrated in Figure 7. As seen from graphs of Figures 6 and 8, maximum lateral resistance was related to the base area at 509 kg, which allocated 62. 22% of the total lateral resistance of the sleeper to itself. Shoulder and side areas were placed at the next ranks with 232 and 77 kg of 28.36% and 9.41%, respectively.

5.2. Steel sleeper

Similar to concrete sleepers, the lateral resistance of the sleeper was assessed in three cases. In the first case, after a 30 cm layer of ballast was compacted with bearing A, a track panel with a steel sleeper was placed, and the area under the sleeper was filled up with the crowbar, as shown in Figure 9. Due to the curvature of the area under the sleeper, finding the compaction of the part beneath was more difficult. The next stages were filling the crib area, the bearing and filling the shoulder area (similar to the compaction operation of the ballast layer in the concrete sleeper, according to Figure 5). According to Figure 8, it can be seen that maximum lateral resistance was related to the base area with 383 kg, which was equal to 55.74%. The contribution of the shoulder and crib area of the sleeper related to total lateral resistance was calculated to be about 127 kg and 177 kg, which were equivalent to 18.49 and 25.77 percent, respectively.

5.3. Wooden sleeper

Similar to the operations undertaken in the order of the test, a wooden sleeper was also used. To do so, steel sheets were used to compress the ballast before the test. According to Figure 7, it is seen that the maximum lateral resistance of the ballast track with the wooden sleeper was related to the base zone at 324 kg, covering 50.63% of total lateral resistance. The end part and side part of the sleeper covered 27.19 and 22.19% of total lateral resistance at 174 kg and 142 kg, respectively. Similar to the concrete sleeper, maximum lateral resistance was related to the base area, and the shoulder and side sleeper were the next rankings.

6. Conclusion

Lateral stability in ballast and non-ballast tracks is believed to be one of the most basic factors in the issue of increasing fleet velocity to improve infrastructures.

The first step in increasing lateral resistance can be the different parts of sleepers and the contribution of each part to total lateral resistance.

In this paper, the factors influencing the lateral resistance of sleepers and the percentage of effects were investigated. The performed tests focused on three types of sleeper (ordinary concrete, wooden and steel). Using graphs and the results of the tests, it was evident that:

1. In all the sleepers, the maximum effect in the lateral resistance of the track was related to the base area, equalling 62%, 56% and 51% in concrete, steel and wooden sleepers, respectively.
2. In wooden and concrete sleepers, the end part of the sleeper (shoulder sleeper) was of second priority, with 27 and 28%, respectively, while the side part of the sleeper had a greater effect versus the shoulder sleeper, equalling 26%. The reason can be attributed to the sleeper shape and the friction formation in two internal and external u-cross sections of the steel sleeper.
3. The minimum value of the lateral resistance of concrete and wooden sleepers was related to their side part, equalling 9% and 22%, respectively.
4. The contribution of the steel sleeper from its end part was about 18%. The presence of a slope and the lack of enough surfaces in the end of the steel sleeper helped to reduce its efficacy.
5. From the quantitative values, it can be concluded that increasing base resistance is more reasonable for increasing lateral resistance. This can be realized in changing the base area from smooth to rugged (friction sleeper) in concert sleepers, using sleeper anchoring in wooden sleepers and hardeners in steel sleepers.

Acknowledgements

The authors are grateful to the Iranian Railway Research Center for financial support throughout this study. Also, they wish to thank technical engineers, P. Saheb Al Zamani and A. Kasraei for their help and suggestions.

References

1. Lim, N.H., Park, N.H. and Kang, Y.J. "Stability of continuous welded rail track", *J. of Comp & Stru.*, **81**, pp. 2219-2236 (2003).
2. Shenton, M.J. and Powell, M.C. "The Resistance offered by the ballast to lateral movement of sleepers", Report Number 82034-7002., Summary of BR Tests, ORE D117, British Rail (1973).
3. Sato, Y.and Hamazaki, S. "Experimental study on lateral resistance of track skeleton in ballast", Report of RTRI (Railway Technical Research Institute), **24**(1) Railway Technical Research Inst., Kansas City, USA (1983).
4. European Railway Research Institute (ERRI) "Theory of CWR track stability", Final Report ERRI.D 202 / rp3, Utrecht, the Netherlands (1995).
5. European Railway Research Institute (ERRI) "Measurement of lateral resistance characteristics for ballast track", Final Report ERRI.D 202/DT 361 ERRI, Utrecht, the Netherlands (1998).
6. American Railway Engineering and Maintenance-of-Way Association (AREMA), "ties", Manual for Railway Engineering, Chapter 30, Washington D.C., **2**, pp. 2-1 2-24 (2012).
7. Le Pen, L.M. and Powrie, W. "Contribution of base, crib, and shoulder ballast to the lateral sliding resistance of railway track: A geotechnical perspective", *Journal of Rail and Rapid Transit Journal*, **225**, pp. 113-128 (2010).
8. Dipilato, M.A., Levergood, A.V., Steinberg, E.I. and Simon, R.M. "Railroad track substructure design and performance evaluation practices", Final Report No. FRA/ORD-83/04.2, U.S. DOT Transportation Systems Center, Goldbergzoino and Associates Inc, Cambridge, Massaachusetts (1983).
9. Selig, E.T. and Waters, J.M. "Track geotechnology and substructure management", In *Railway Engineering and Its Application*, Thomas Telford Press, pp. 8.5-8.18, UK (1994).
10. Kabo, E. "A numerical study of the lateral ballast resistance in railway tracks", *Rail and Rapid Transit Journal*, **220**, pp. 425-433 (2006).
11. Lichtberger, B. "Track compendium, formation, permanent way, maintenance and economics", In *Railway Engineering*, Eurail Press, Hamburg, Germany (2005).
12. Esveld, C. "Modern railway track", 2nd Ed. In *Railway Engineering*, TU-Delft Press, pp. 428-430, Delft, the Netherlands (2001).
13. Zakeri, J.A., Mirfattahi, B., Fakhari, M. "Lateral resistance of railway track with frictional sleepers", *Proceedings of the Institution of Civil Engineers - Transport Journal*, **165**(2), pp. 151-155 (2012).
14. Zakeri, J.A. "Frictional concrete sleeper and its influence on the lateral resistance of track", Report 160/5776, Iran University of Science and Technology, Tehran, Iran (2010).
15. ASTM Standards C136-96a. "Test method for sieve analysis of fine and coarse aggregates" (1996).
16. Leaflet 301 of Iran, No. 1 "General and technical specifications of railway superstructure", No.1, pp. 80-83 (2010).

17. Xavier, P. and Zakeri, J.A. "Reliability and safety in railway", In *Lateral Resistance of Railway Track*, Chapter 13, In Tech. publisher, pp. 357-374 (2012).

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