Field investigation on the lateral resistance of railway tracks with frictional sleepers

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Abstract. Tie type is one of the most effective parameters for changing the lateral resistance of ballasted track. In this study, the lateral resistance of an existing curve-to-lateral movement is investigated in the field in two conditions: with simple mono-block concrete ties (B70) and with friction concrete ties (B70F). After that, lateral resistance is measured through the panel displacement method. The results show that the lateral resistance of the railway track increases by approximately 67% with the use of friction concrete ties (B70F) instead of standard mono-block concrete ties (B70).

Keywords: Field testing and monitoring; railway systems; railway track design; strength and testing of materials

1. Introduction

The benefits of continuous welded rails (CWR) and engineers’ tendency to prefer such types of track have made improvements in railways’ lateral stability more of a priority than ever. In jointed rail track, much damage occurs around rail joints of conventional railway tracks. This may include railhead deformation, flaws in rail sides, defects in sleepers and fasteners (Gonzalez-Nicieza, C., 2008), damage to the ballast bed, lateral shift of the railway track etc. To reduce the enormous cost of maintenance and also to optimise the benefits of CWR, lateral resistant of track must be increased (Kabo, 2014).

The resistance between a single tie and the ballast bed comprises three main elements: friction resistance on the both sides of the tie, passive resistance at the shoulders and friction resistance at the bottom of tie. The friction resistance components at the bottom of the tie are created via sliding of the ballast grain on the relatively smooth surface of the concrete tie. In laboratory testing, the coefficient of friction was measured at around 0.5, with the internal friction of ballast grain between 0.9 to 1.4 (Barati, 2010).
Several studies have been carried out on how to measure the lateral resistance of the different ties and railway track. Amongst these are Lichtberger (2007). Maintenance effects have been achieved with the following: tamping machine, dynamic track stabilizer and ballast regulator. (Plasser and Theurer, 2007) Investigations have been carried out in order to design and construct a frictional sleeper, determine the effectiveness of employing this type of sleeper and increase the lateral resistance in an actual railway track (Zakeri, 2010). It is worth mentioning that the design and construction of wing concrete sleepers had already taken place in Austria (Lichtberger, 2005). However, this practice is not widespread in railway applications due to various executive problems.

In this paper, we first present the results of tests conducted on an actual railway track with the simple and frictional concrete sleeper (Zakeri et al, 2018, Nordal, 2003) in the railway track curve with the radius of 250 meters. Secondly, the impact of employing the frictional concrete sleeper is described.

2. Measuring Methods of Lateral Resistance

One of the most significant operations for the safety and stability of railway tracks is determination of the track’s lateral resistance. According to literature reviews, this lateral resistance is influenced by factors such as tie type, weight and dimensions of the ties, intervals, ballast gradation, quality of ballast stone, ballast depth, the shoulder height, ballast layer compaction, rail type and fastening system.

In most cases the resistance to lateral movement can be measured by two standard tests. These are the single tie push test (STPT) and track panel loading test. In these tests, the displacement of tie is measured in proportion to the applied force by applying the force to the sleeper. According to the Iranian national railway code no. 301, the applied force on 2 mm displacement is the lateral resistance of track.

To implement STPT testing, the single tie is pushed against the rail using a hydraulic jack, applying the horizontal force to the outer fastener. An LVDT is installed on the tie and the amount of tie movement is measured. Then, the processor records the lateral movement of a tie.

In the multi tie push test method (MTPT), a track panel of 4–6 meters length is placed on the ballast layer and then, after application of the horizontal force to the track panel, the lateral displacement is measured. Thus, in MTPT test, the resistance of railway track frame is measured. Test results presented by Lichtberger (2005), with different speeds and frequencies, are shown in Figure 1. It can be seen that the track’s lateral resistance will decrease after track tamping, due to losses of shear interlocking between ballast particles. Also, the track lateral resistance will increase by use of the dynamic track stabilizer (DGS).
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Figure 1. The lateral resistance of railway track measured in different conditions (Zakeri 2018)

3. **Friction Concrete Tie**

The bottom of a concrete tie has been designed so that the involvement of ballast stone grains with the tie, and then the friction coefficient on the bottom of the tie, will increase. Consequently, the lateral resistance of the track will increase. As shown in Figure 2a, all parts of the friction concrete tie resemble a single concrete tie (B70) except its base surface which is spatial trapezoid-shaped, with a large base, small base and heights of 10 cm, 6 cm and 2.5 cm, respectively. The entire maintenance operation is completed easily where this type of sleeper is used. The reason is the transfer of the shear zone from the surface of contact (in the B70 sleeper) to the lower surface between the ballast particles (in the B70-F sleeper as shown in Figure 2b).

![Figure 2](image-url)  
**Figure 2.** a) The bottom of frictional concrete sleeper; b) shear zone under the frictional sleeper
4. Field Tests Determining the Lateral Resistance of Track

Field tests were conducted on an existing tight curve of railway track (Mirfattahi, 2009). First, the track’s lateral resistance was measured on a track with concrete ties B70. Then, the conventional concrete ties B70 were replaced by the friction concrete ties (B70F) at the test site in the northern district of Iranian Railways. The lateral resistance of the new track was measured again. In all test processes, the same and equal conditions were observed.

In particular, matching two points with the experimental conditions is essential, those points being:

1. Weather conditions (dry and wet conditions)
2. Physical conditions at/of the railway track

In order to match the physical conditions, the railway track panel was first tamped and then stabilized with the DGS in both tests; this is shown in Figures 3a and 3b. The conditions of track characteristics were considered: the ballast’s shoulder width, the ballast’s layer slopes at both sides, the ballast depth in the crib zone and sleeper spacing.

To carry out this field investigation, the multi tie push test method was employed, using a hydraulic jack. The LVDT equipment was used to measure the lateral displacement that must be installed in place along with the applied horizontal force. This is shown in Figure 4a.

![Figure 3](image1.png)

**Figure 3.** a) Tamping the desired curve before the first test using the lining, levelling and tamping machines; b) uses of stabilizer (DGS) in the desired curve before the first test

The jack tip must be vertical to the rail (as the applied force). At this point, the situation is quite ready for testing. At the moment, \( t=0 \), the horizontal force is applied to the inner rail. By employing the hydraulic jack, the force was recorded by time. Also by employing LVDT, the displacement was recorded by time. Thus, the displacement was calculated based on time.

In the second stage of this field study, the single concrete tie was replaced by the friction concrete tie and relevant tests (as in the first stage) carried out. Then, the data obtained from these tests was compared.

The impact of the vertical load was not regarded in this field test. In order to perform the second stage of tests, Figures 4b to 6b) show the removal of the conventional railway track (with simple concrete sleepers) and installation of a new railway track (with frictional concrete sleepers) in the desired curve.
In order to investigate the effect of the frictional concrete sleeper on the rate of variation of the track’s lateral resistance in the desired curve, the results of the two-stage field test will be explained, interpreted and compared.

**Figure 4.** a) Installation of the hydraulic jack; b) removal of the conventional railway track with 120-ton railway crane

**Figure 5.** a) Installation of railway track prepared with B70-F sleeper by employing 120-ton railway crane; b) aligning the rails for welding
Figure 6. a) The ballast scattering; b) tamping and stabilizing operations after installation of the railway track prepared with B70-F sleeper (before the second stage of test)

5. Test Results

5.1 Results of the First Stage
The result of the panel displacement method is shown in Figure 7, which shows that the displacement is taken up to 6 mm and the level of the applied force is about 7 tons. The amount of this displacement versus 2 mm displacement (for determining the lateral resistance of railway track (Zakeri et al, 2012)) indicates that, in the sharp railway track curves with the simple concrete sleeper, it is difficult to provide the stability with the applied lateral force (including centrifugal force and wind load) and the track can be displaced in the lateral direction. Actually, the force necessary for 2 mm displacement of railway track is about 3.9 tons (see Figure 7) which is provided by creating this value in the curves. That is why most railways limit the welding of joints in sharp railway track curves.
5.2 Results of the Second Stage
The result of panel displacement method is shown in Figure 8. This figure shows that displacement is limited to a maximum of 3 mm and that increasing of the force is not feasible. The maximum lateral force that is necessary to cause 3mm lateral displacement is around 8.3 tons. These values represent the effect of the variation of sleeper type on increasing the track’s lateral displacement.
5.3 Assessing the Test Results

In this section, as shown in Figure 9, the curve fittings were used in both stages to compare the applied lateral force to the track.

According to Figure 9, the changing process of simple and frictional concrete sleeper curves shows that the lateral stiffness of the track, which uses the frictional concrete sleeper, is greater than that of the other track. For comparing the applied forces, the maximum values of forces in both stages and on equal displacements are compared and the ratio of \( \frac{F_F}{F_N} \) is presented in the last column of Table 1. This ratio is shown as a curve in Figure 10.

From Figure 10 it could be concluded that the ratio of \( \frac{F_F}{F_N} \) in certain value, changes between 1.5 and 1.77 and their average will be around 1.67. This simple comparison shows an increase of around 67% in the lateral resistance of a railway track using the frictional concrete sleeper.

Figure 8. The panel displacement methods on the track, using the frictional concrete sleepers

Figure 9. Comparison of simple and frictional concrete sleeper resistance curve fittings
Figure 10. Ratio of \((F_F/F_N)\) versus lateral displacement

Table 1. Simple and frictional concrete sleeper; maximum lateral force

| Lateral displacement (mm) | Maximum lateral force, using B70F sleeper \((F_F)\) (Ton) | Maximum lateral force, using B70 sleeper \((F_N)\)(Ton) | Ratio \(F_F / F_N\) |
|---------------------------|--------------------------------------------------------|-------------------------------------------------------|-----------------|
| 0.25                      | 1.4272                                                 | 0.9377                                                | 1.5220          |
| 0.50                      | 2.4443                                                 | 1.4408                                                | 1.6965          |
| 0.75                      | 3.3752                                                 | 1.9212                                                | 1.7568          |
| 1.00                      | 4.2200                                                 | 2.3790                                                | 1.7739          |
| 1.25                      | 4.9787                                                 | 2.8142                                                | 1.7691          |
| 1.50                      | 5.6513                                                 | 3.2268                                                | 1.7514          |
| 1.75                      | 6.2377                                                 | 3.6167                                                | 1.7247          |
| 2.00                      | 6.7380                                                 | 3.9840                                                | 1.6913          |
| 2.25                      | 7.1522                                                 | 4.3287                                                | 1.6523          |
| 2.50                      | 7.4803                                                 | 4.6508                                                | 1.6084          |
| 2.75                      | 7.7222                                                 | 4.9502                                                | 1.5600          |
| 3.00                      | 7.8780                                                 | 5.2270                                                | 1.5072          |
| 3.25                      | -                                                      | 5.4812                                                | -               |
| 3.50                      | -                                                      | 5.7128                                                | -               |
| 3.75                      | -                                                      | 5.9217                                                | -               |
| 4.00                      | -                                                      | 6.1080                                                | -               |
| 4.25                      | -                                                      | 6.2717                                                | -               |
| 4.50                      | -                                                      | 6.4128                                                | -               |
| 4.75                      | -                                                      | 6.5312                                                | -               |
| 5.00                      | -                                                      | 6.6270                                                | -               |
6. Conclusion
In many conventional railway tracks, there are multiple tight curves of radius less than 400 meters. This makes the welding of all joints impossible, due to the lack of sufficient lateral resistance. Field investigations show that a great deal of damage occurs around rail joints: defects in fasteners, railhead plastic flaws, deformation of railhead sides, failure in sleepers, ballast layer damages, lateral shift of railway track, etc. From our study of this matter, we conclude:

1. In this paper, the use of the friction tie instead of conventional tie has been recommended. The impact of using friction ties on an existing curve with a radius of 250 meters has been investigated and the results of the track lateral resistance with conventional and friction concrete ties presented.

2. In terms of methodology, in this paper firstly field tests were conducted on an existing tight curve (radius of 250 m). The track’s lateral resistance was measured on a track with conventional ties (B70). Then, these ties were replaced by the friction concrete ties and the lateral resistance was measured again.

3. In general, test results show that the amount of the force that is necessary to move the track panel at the specified value with the friction concrete ties is about 1.67 times the force that is necessary with the conventional ties.

4. In conclusion, the lateral resistance of a railway track with friction concrete ties will increase by 67%. The field test results are in accordance with experimental STPT results, which verified the effectiveness of the track panel displacement method and STPT method.

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