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Effect of ballast sides retaining walls on the lateral resistance of railway tracks

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Abstract

In this study, the application of the retaining wall was proposed as a solution in order to reduce the lateral displacement of the ballast layer, particularly in sharp curves and bridges. In this regard, a series of single tie push tests were performed on panels with the shoulder ballast width of 300 mm, 400 mm, 500 mm with and without the presence of L-shape and T-shape retaining walls. Overall, it was proven that the application of the L-shape wall led to a 15.8% increase in the lateral resistance, and T-shape walls have a higher impact on the stability of the track. On the other hand, the shoulder width of 400 mm was proposed as optimum width for ballasted tracks with the presence of retaining walls.

Keywords

Retaining wall, STPT, Lateral resistance, Overturning, Shoulder ballast width.

1. Introduction

The lateral movement of the ballast railway tracks, particularly in continuously welded rails (CWR) due to the train movement or temperature changes, is one of the factors influencing the track buckling in the sharp curves [1], [2]. As reported by Kish, A [3], the deflection of a curve with 291 m radius is 40 % greater than that of the straight line. In contrast to the statement of the AREMA standard [4] about desregard of railroad surcharge influence on ballast retaining wall, passing the train through railway bridges with a sharp curve causes serious problems due to the lack of space to adequately provide lateral stability for track movement. On the other hand, the ballast layer movement would decline on account of the friction between sleepers and ballast particles [3]. The combination of aforementioned factors causes ballast aggregates spreading laterally due to inadequate confining pressure [5], misalignment and train derailments in consequence.

To meet above-mentioned challenges, modifications to the ballast layer geometry such as increment of shoulder width and decline in the shoulder slope is one of the methods which increases the dead load of the structure, leading to the additional deflection by passing trains particularly in long bridges [6](Fig. 1(a)). Existing research recognizes the critical role played by ballast layer components (crib, shoulder, and base) on the lateral resistance of railway tracks [7-13]. In order to evaluate the influence of ballast shoulder width on the lateral resistance of the track, experimental tests have been performed by the ERRI Committee [14]. Accordingly, "the effect of the shoulder width on lateral resistance was negligible" that can be attributed to the lack of the enclosure of the ballast shoulder for movement. To inhibit the lateral movement of ballasted tracks, other alternatives were recommended by researchers such as a mixture of ballast-bituminous [15, 16], and using scrap tires in retaining walls [17, 18]. A major problem with the bitumen stabilized ballast is that the higher stiffness of the ballast layer leads to intensifying vibrations on bridges. Alternatively, using scrap tires would be required more space for long-term performance of tires retaining walls on a bridge. The use of geogrid in the ballast layer is another solution to improve the shear strength of ballasted tracks [19, 20]. The application of various types of retaining walls has been proposed to stabilize earth structures [21]. Reclaimed railway sleepers, Gabion, stone block, are examples of different types of retaining wall used in railway tracks (Fig. 1(b-d)).

(a) (b)

(c) (d)

Fig. 1 (a) Using a gradual slope in shoulder ballast zone [22], (b) Reclaimed railway sleepers retaining wall [23] , (c) Gabion gravity structure [24], (d) Stone block walls [25]

Up to now, far too little attention has been paid to the performance of retaining walls on ballasted railway bridges, particularly in sharp curves as illustrated in Fig. 2. Although the application of concrete retaining wall is more costly than ballast layer reinforcement methods, less weight and space occupancy with high strength are particular advantages of concrete retaining walls utilization in confining ballast particles on railway bridges. In general, retaining walls are categorized as gravity and non-gravity walls. Considering the low ballast height and bridge structure, the use of concrete retaining walls, illustrated in Fig. 3, could be practical alternatives to deal with the lateral displacement of railway tracks on bridges. The selection of a suitable retaining wall is affected by several factors such as cost, safety, available clearance to the boundary fence, foundation conditions, maintenance, and appearance [26]. Among all these retaining walls, due to the sufficient stability and less weight of cantilever walls in comparison with other types, cantilever walls with and without the toe, have been considered to conduct experimental tests in the present research.

Fig. 2 Side view of ballasted track on a bridge with (a) partial damage (b) complete collapse of retaining walls.

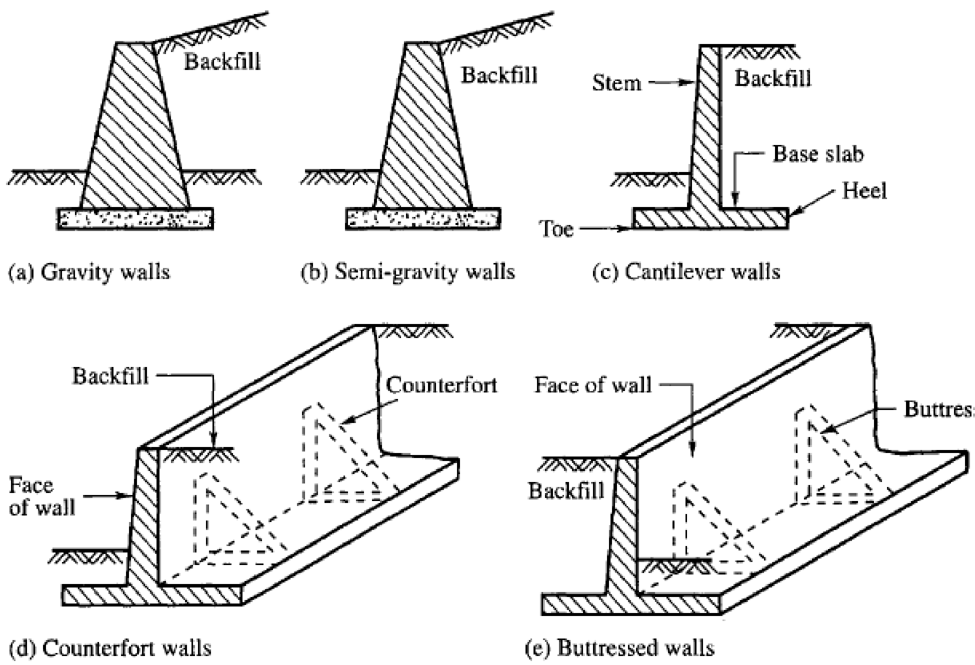

Fig. 3 Most common types of concrete retaining walls [27].

The focus of this research is the application of the retaining wall with the density of 2400 kg/m^3 in ballasted tracks to evaluate the stability of the aforementioned retaining walls against the lateral displacement of sleepers. According to the definition of the stability stated by Das, B. M [28], possible overturning, sliding and bearing capacity of retaining walls should be taken into consideration. In this regard, a series of single tie push tests (STPT) were implemented on different condition of the ballast layer to examine the lateral resistance of different shape of retaining walls.

2. Ballast panel specifications

1.1. Ballast and concrete properties

Ballast gradation plays the main role in the stability and safety of the track [29]. Thus far, previous studies suggested that the average and maximum particle size in high-speed railway tracks should be in the range of 36-41 mm and 53 mm, respectively [30]. Fig. 4(a) shows the particle size distribution selected according to China National Standard TBT 2140. To construct retaining walls, C40 concrete with the density and compressive strength of 2550 kg/m^3, and 40 MPa was used, respectively.

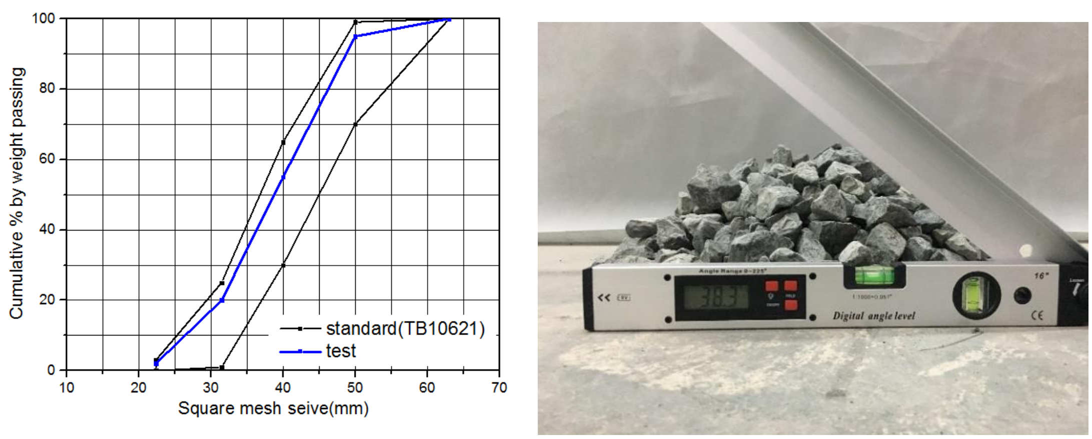

Fig. 4 (a) Ballast particle size distribution, (b) Repose angle of ballast.

1.2. Test plan and methodology

In this study, firstly, single tie push tests were conducted on a ballast panel with three shoulder widths of 300, 400 and 500 mm in order to compare with the results of ballast lateral resistance in case of with and without retaining wall. It is noteworthy that many researchers proposed the width of 500 mm as an appropriate size for the shoulder width [7], [31]. The geometrical conditions of the ballast panels are depicted in Fig. 5.

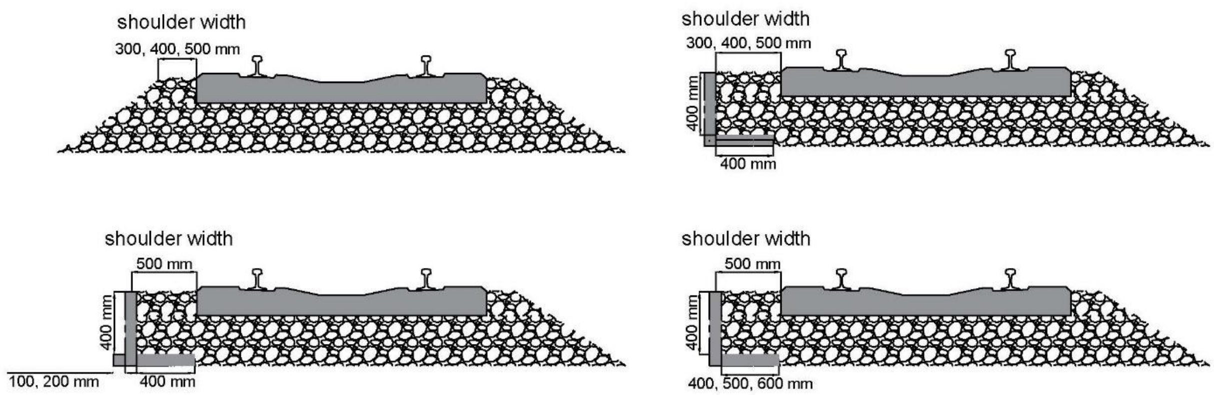

Fig. 5 Ballast sections used in STPTs.

In order to evaluate the effect of the dimensions of the heel and toe, all retaining walls have the same thickness, width, and height of 60 mm, 490 mm, and 400 mm, respectively. Although the use of steel bars for ballast retaining walls was recommended by RailCorp [32], L400 unreinforced walls are widely used in China railway system. Consequently, the variation of the length of walls from 400 to 600 mm was considered in this study. On the other hand, the stability of the aforementioned walls against sliding and overturning was assessed according to AREMA standard [33] (Fig. 6). As shown in Fig. 4(b), since the repose angle of ballast is about 38.3˚, coefficient of active earth pressure (k_a) is calculated as follows:

$$k_a = \frac{1-\sin\emptyset}{1+\sin\emptyset} = \frac{1-0.62}{1+0.62} = 0.234 \qquad (1)$$

To calculate the resistance force against sliding, the friction coefficient of concrete to concrete surface equals 0.53 according to the results presented by Zhao, W [34]. As depicted in Table 1, the applied retaining walls are stable against sliding and overturning due to the high safety factor (SF > 1.5).

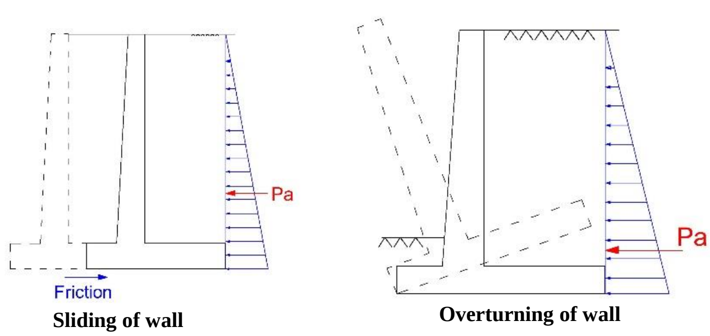

Fig. 6 Stability requirements of retaining walls [35].

Table 1 Stability of walls against sliding and overturning.

Wall	W_w	W_b	P_a	F_s	SF	Mr	Mo	SF
L400	59.976	133.28	31.92	102.42	3.20	33.55	4.25	7.88
L500	67.473	166.6	31.92	124.05	3.88	51.92	4.25	12.19
L600	74.97	199.92	31.92	145.69	4.56	74.37	4.25	17.47

$\mathbf{W_w}$: Weight of wall, $\mathbf{W_b}$: Weight of ballast, $\mathbf{P_a}$: Active pressure, $\mathbf{F_h}$: Resistance force against sliding,

$\mathbf{M_r}$: Restoring moment, $\mathbf{M_o}$: Overturning moment, **SF**: Safety factor

After placing retaining walls, ballast was compacted in three layers by a vibrating compactor with the weight and frequency of 80 kg and 67 Hz to achieve a ballast layer with the length, width, height, and density of 10 m, 3.6 m, 0.35 m, and 1700 kg/m^3, respectively. In the next step, mono-block sleepers were placed on the ballast bed. It should be noted that in case of using retaining walls, one side of the ballast layer was limited by the retaining wall, the space between sleeper ends and walls was corresponding to the shoulder width. The lateral force was applied by a hydraulic jack with the maximum capacity of 10 tons and the loading increment rate of 0.5 mm/min and recorded by the data logger INV3018A at each 0.5 mm of sleeper lateral displacement which was considered as the lateral resistance of the retaining wall. In all STPTs, the sleeper maximum lateral displacement was limited to 10 mm. For each test condition, STPT was repeated 3 times to ensure the accuracy of results. In order to measure sleeper movement and consequential ballast lateral displacement, LVDTs with an accuracy of 0.001 mm and measuring the course of 30 mm attached to the top and down of the sidewall as well as the sleeper end (Fig. 7). It is noteworthy that displacement of the wall along the length is approximately equal as reported by Ahn, IS [36], consequently only one LVDT was installed in each level.

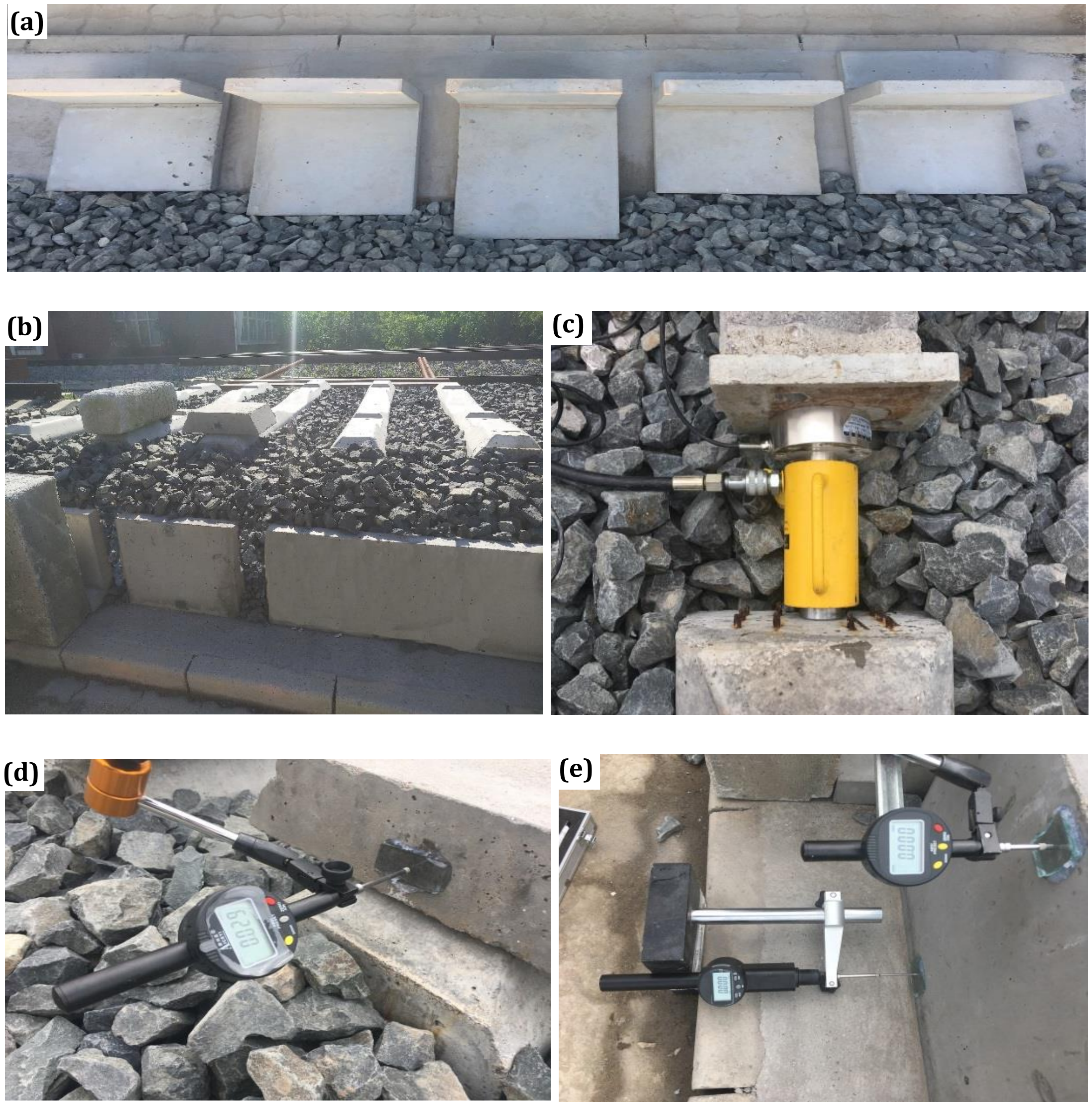

Fig. 7 (a) Different shape of retaining walls, (b) Test panel, (c) Loading jack, (d, e) LVDTs installation.

3. Experimental results and discussion

In this section, the impact of the presence of the retaining wall, shoulder ballast width, and different shapes of walls (L shape and T shape) is evaluated by single tie push tests. The deformation behavior was further investigated to figure out the interaction between the wall and shoulder ballast subjected to lateral force. Since mechanical properties of walls are the same, only the shape of retaining walls affects the ballast lateral resistance. The results are described as follows.

3.1 Ballast lateral resistance with and without retaining wall

As shown in Fig. 7, for panels with SW= 300 and 500 mm, the resistance of the sleeper is approximately equal up to the displacement of 2 mm. Overall, there is little difference between the resistance of ballast track with and without walls that it can be attributed to the applied static loading instead of dynamic loading in the real state. It can be assumed that the retaining wall resists against lateral load after 2 mm displacement of the sleeper, so that lateral resistance of panels with SW 300 and 500 increased by 8% and 3% in case of using retaining walls. By contrast, growth in lateral resistance of W-SW400 was considerable, so that the ultimate resistance increased by 15.8 % in comparison with NW-SW400. Therefore, the application of retaining wall for ballast track with the shoulder width of 400 mm is efficient among the above-mentioned panels.

3.2 Influence of shoulder ballast width on lateral resistance

Fig. 8 shows the resistance of the retaining walls for panels with shoulder ballast width of 300, 400, 500 mm. The increment of shoulder width led to the rise of lateral resistance so that the resistance of the panel with a shoulder width of 500 mm was about 22 % and 4 % higher than that of panels with the shoulder width of 300 mm, and 400 mm, respectively. Therefore, due to the insignificant difference between resistance of panels with SW400 and SW500, 400 mm is optimum shoulder width in ballast tracks. In addition, a high proportion of the growth in resistance occurred up to the displacement of 2 mm. On the other hand, in case of using the retaining wall, maximum resistance occurred earlier, particularly for panel with SW = 500 mm.

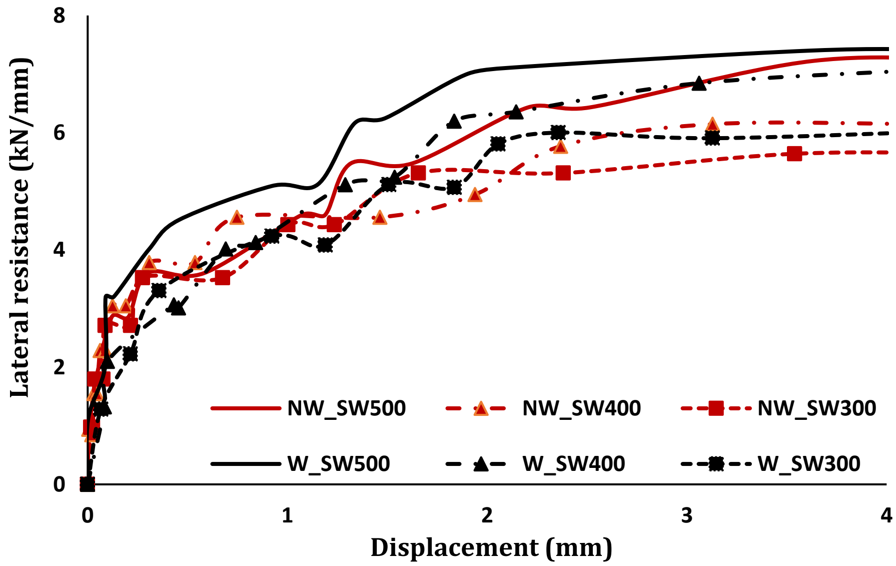

Fig. 8 Lateral resistance of L400 with different shoulder width.

NW: No retaining wall, **W**: With the presence of retaining wall

3.3 Influence of walls shape on the deformation of retaining walls

In order to determine the overturning of the walls, firstly the lateral displacement of the top and bottom of walls was recorded. Eventually, the ratio of relative displacement to the wall height was considered as the degree of the wall rotation. As shown in Fig. 9, due to the static load applied on the sleeper, the higher length of retaining wall, the lower overturning in L-shape walls, so that the rotation decreased from 0.145˚ to 0.015˚ for panel with L600-SW500 instead of L400-SW500. Also, approximately equal rotation occurred with the replacement of L600 with T-shape walls. On the other hand, changes in the lateral displacement of various retaining walls were the same as overturning. It indicates that overturning has a direct relation with the horizontal force applied by the sleeper. Therefore, the use of T200 fulfils the appropriate resistance against ballast movement so that the rotation was 8 times lower than the rotation of L400 for panels with the same shoulder ballast width.

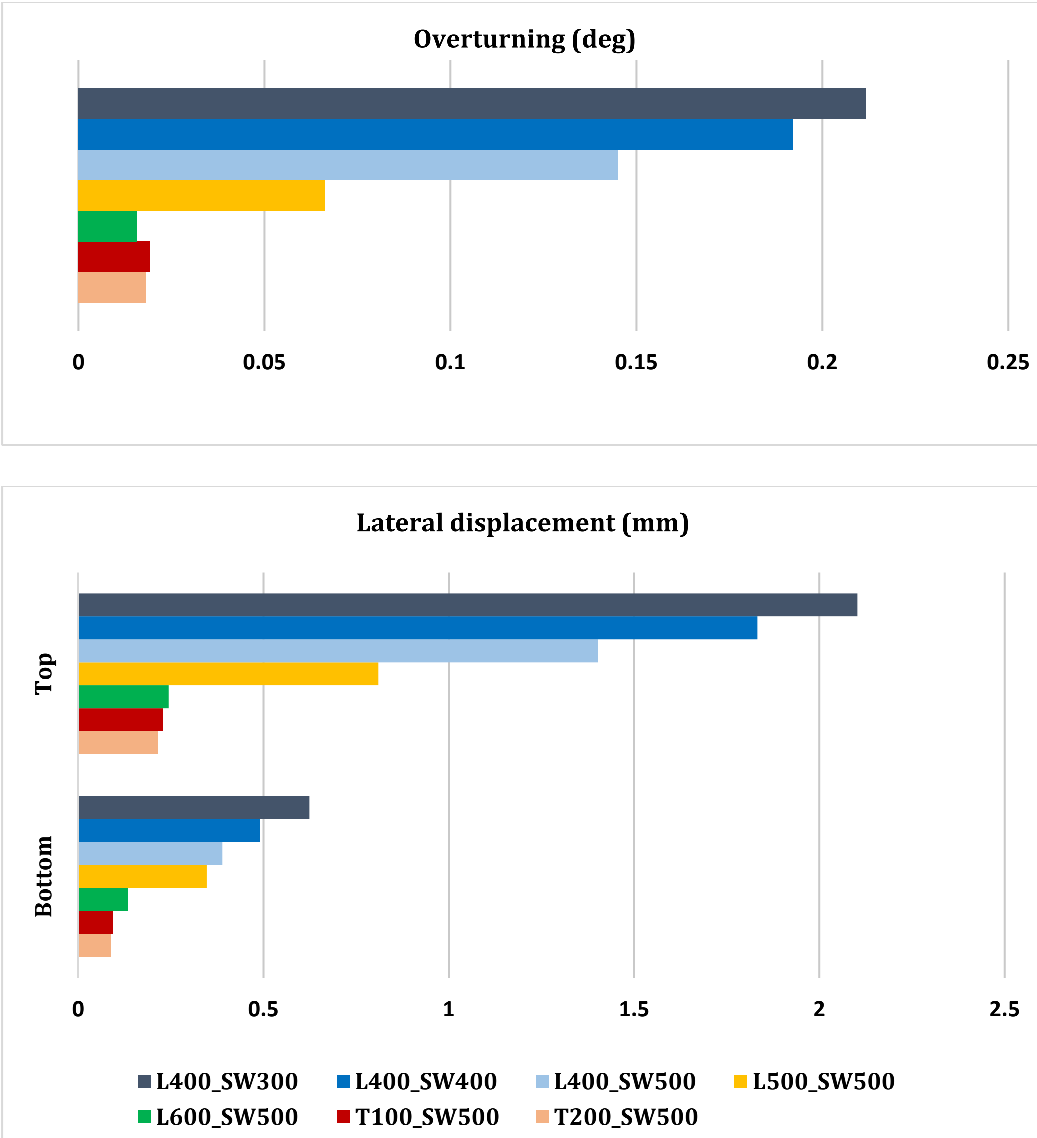

Fig. 9 Overturning and sliding of retaining walls.

4. Conclusion

The single tie push tests conducted in the present study could help to realize that the lateral displacement of a ballasted track with the presence of the retaining wall. In this study, shoulder ballast width, and shape of the retaining wall were considered as effective parameters on ballast lateral resistance. Due to the rotation of the wall, the displacement of the top of the wall can differ substantially from the displacement of the bottom of the wall. In this regard, the application of the T-shape wall reduced overturning significantly and provided higher stability against lateral movement. It was found that the application of retaining walls play a very important role in the permanent displacements of the ballast layer, so that lateral resistance reached the maximum value in an earlier period. Therefore, the replacement of the shoulder ballast with retaining walls could be a practical solution for sharp curves or railway bridges owing to the reduction in the width of the ballast bed. For further studies, the deformation of the ballast layer with and without the presence of the retaining wall under cyclic dynamic loading is recommended.

Acknowledgments

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