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Scaled model tests for evaluating effects of sleeper spacing on the lateral resistance of railway ballasted tracks

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ABSTRACT

A series of 1/5 scaled model tests were conducted in the laboratory to investigate the lateral resistance of ballasted track bed having various amounts of sleeper spacing. Singe-sleeper pullout tests and track-panel pullout tests were conducted on timber sleepers, PC No.3 sleepers and winged sleepers. The test results suggest that it is necessary to consider the changes in the rail load supported by sleepers and in the interference between adjacent sleepers to evaluate the change in the lateral resistance caused by the alternation of the sleeper spacing.

Keywords: railway ballasted track; lateral resistance; sleeper spacing

1 INTRODUCTION

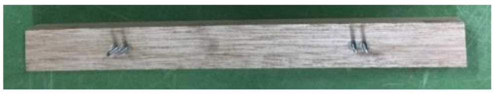
A railway sleeper is a small and shallow foundation that has the primary function of supporting the rails and traffic loads. Another important function of sleepers in ballasted tracks is the provision of sufficient lateral resistance to prevent lateral movement of the rails. A significant increase in the temperature of steel rails may produce thermal elongation. The thermal elongation of steel rails induces excessive axial forces, which creates a tendency of the steel rails to bend and exert a lateral force on the sleepers (e.g. Kerr, A. D., 2004). If the lateral force overcomes the lateral resistance of the sleepers, rail buckling may occur.

Recently in Japan, attempts have been made to increase sleepers' spacing when timber sleepers are replaced by concrete sleepers in railway ballasted tracks (Kanemaru et. al., 2016) However, it has not been investigated in detail so far how lateral resistance of ballasted track bed alters with the change of sleeper spacing. Therefore, in this study, a series of 1/5 scaled model tests were conducted in the laboratory to evaluate the lateral resistance of ballasted track bed having various amounts of sleeper spacing.

2 MODEL TEST METHOD AND TEST CASES

Model tests were carried out using 1/5 size models on a real scale. The sleepers used were timber sleepers, PC No.3 sleepers and winged sleepers, as shown in Fig.1. The winged sleepers had 10 mm wing-like projections at bilateral sides. Although PC No.3 and winged sleepers in real tracks are designed to be pre-stressed concrete, the sleepers prepared for the model tests were made from mortar and not be pre-stressed.

To prepare 1/5-scale ballasted tracks, ballasts which particle sizes were 1/5 of actual ones were used in the model tests. The ballasts were crushed stones of Andesite which had been retrieved in Yamanashi prefecture in Japan. Figure 2 shows the particle size distribution curve. The range of particle size distribution specified in the Japanese railway technical standard is also shown in the figure.



a) Timber sleeper

b) PC No.3 sleeper

c) Winged sleeper

Fig. 1. Sleepers used in the model tests

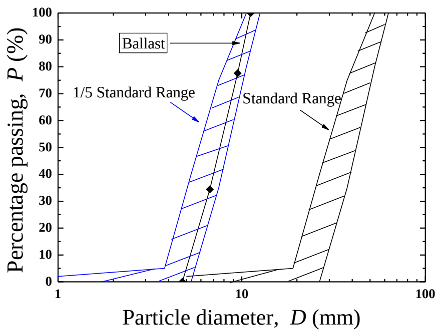


Fig. 2. Particle size distribution curve of ballast used for the model tests

The model test apparatus shown in Figure 3 was used to load the sleepers laterally. The model test apparatus consisted of a sand box and a lateral loading jack with a load cell. The sand box was mainly made from aluminum. Sandpapers were attached to the bottom plate to ensure frictional resistance between the ballasts and the bottom plate.

In preparing the ballasted tracks, the track beds were first constructed using the ballast to achieve a dry density of 1.60g/cm^3 in the sand box. A single sleeper or track panel (consisting of five sleepers and a rigid frame) was then set in the ballasts. The lateral loading jack was used to pull out a single sleeper or track panel using a tie rod and a constant displacement rate. The lateral resistance of ballasted track beds for the single sleeper or the track panel was measured by the load cell, which was connected to the tie rod.

2.1 Single-sleeper pullout test

Figure 4 is a schematic of the ballasted tracks that were prepared for the single-sleeper pullout test conducted on a PC No.3 sleeper. The track bed was rectangular and measured 829.2 mm by 632 mm at the bottom, and 560 mm by 632 mm at the top. The total thickness of the track bed was 74.8 mm.

During the construction of the track bed, a single sleeper was embedded in the ballast. Then, a prescribed weight was put on the top surface of the sleeper, to simulate the 50kg/m rail load supported by a single sleeper when the sleeper spacing is 140 mm in model scale. After construction of the ballasted track, two displacement transducers were installed close to both ends of the single sleeper, as shown in Figure 4, to measure the lateral displacements during lateral loading. Lateral loadings were conducted at a constant displacement rate of 0.4 mm/min. The lateral loads were continuously recorded using a data logger until the lateral displacements exceeded 10 mm. Single-sleeper pullout tests were conducted on a timber sleeper, a PC No.3 sleeper and a winged sleeper.

2.2 Track-panel pullout test

Figure 5 is a schematic of the ballasted tracks prepared for the track-panel pullout tests conducted on PC No.3 sleepers having sleeper spacing 140 mm. The track bed preparation procedure was the same as that for the single-sleeper pullout tests. However, five sleepers were embedded in the ballasts.

The sleepers were spaced at a predetermined amount. The amount of sleeper spacing was 140, 210, 240 or 300 mm depending on the test cases. A rigid frame was set on the embedded sleepers to connect them. The weight of the rigid frame was adjusted to simulate the 50kg/m rail load supported by five sleepers when the sleeper spacing is 140, 210, 240 or 300 mm.

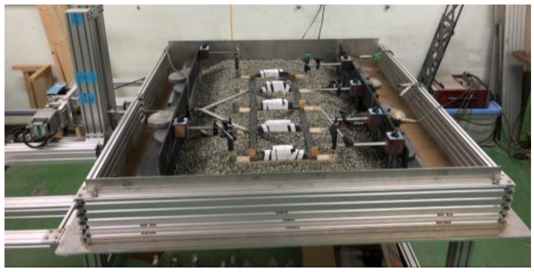


Fig. 3. Model test apparatus used for single-sleeper pullout tests and track-panel pullout tests

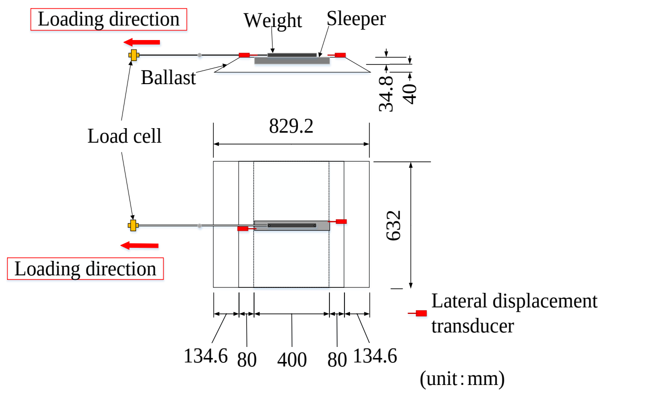


Fig. 4. Schematic views of ballasted tracks that were prepared for single-sleeper pullout tests conducted on a PC No.3 sleeper

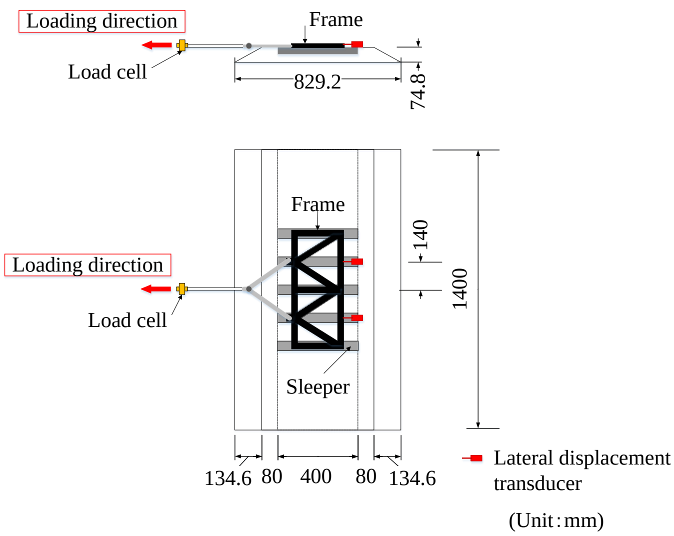


Fig. 5. Schematic views of ballasted tracks that were prepared for single-sleeper pullout tests conducted on a PC No.3 sleeper

After construction of the ballasted track, two displacement transducers were set at prescribed positions to measure the lateral displacements of the sleepers. Lateral loadings were conducted at a constant displacement rate of 0.4 mm/min in a same way as in the single-sleeper pullout tests. Track-panel pullout tests were conducted on timber sleepers, PC No.3 sleepers and winged sleepers. However, in case of the timber sleepers, the track-panel pullout test was conducted only for the condition of 140mm sleeper spacing.

3 MODEL TEST RESULTS

3.1 Single-sleeper pullout test results

Figure 6 shows the lateral load - lateral displacement relationships obtained from the single-sleeper tests conducted on a timber sleeper, a PC No.3 sleeper and a winged sleeper. The lateral displacements shown are the means of displacements measured by two lateral displacement transducers. As can be seen from the figure, the lateral loads of all the sleepers gradually increased with increasing lateral displacement.

It is also found that the lateral loads of the PC No.3 sleeper and the winged sleeper are higher than that of the timber sleeper at the same lateral displacements. From the test results shown in the figure, lateral resistance *LR* (N/one sleeper) was evaluated for each test. Here, the lateral resistance *LR* (N/one sleeper) is defined as the mean of lateral loads per one sleeper recorded at the lateral displacements between 5 and 10 mm, at which the lateral loads become relatively steady. It is found that *LR* (N/one sleeper) of the PC No. 3 sleeper and of the winged sleeper was 1.41 and 1.61 times as that of the timber sleeper, respectively. The single-sleeper test results suggest that when the timber sleepers are replaced by the concrete sleepers in ballasted tracks, the maximum sleeper spacing at which the lateral resistance before the replacement can be secured, is 197 mm for the PC No. 3 sleeper and 225 mm for the winged sleepers.

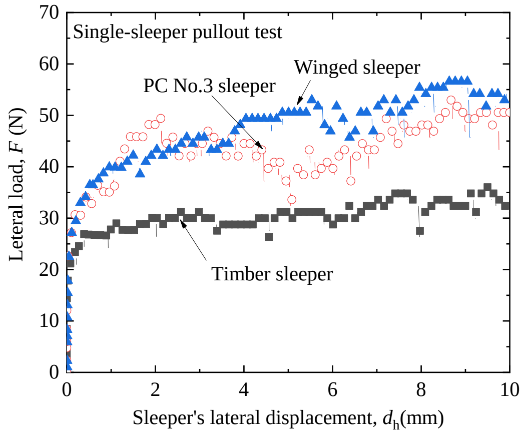
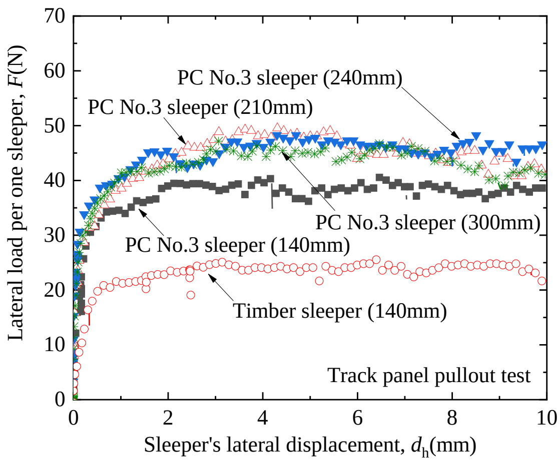


Fig. 6. Lateral load - lateral displacement relationships obtained from the single-sleeper pullout tests

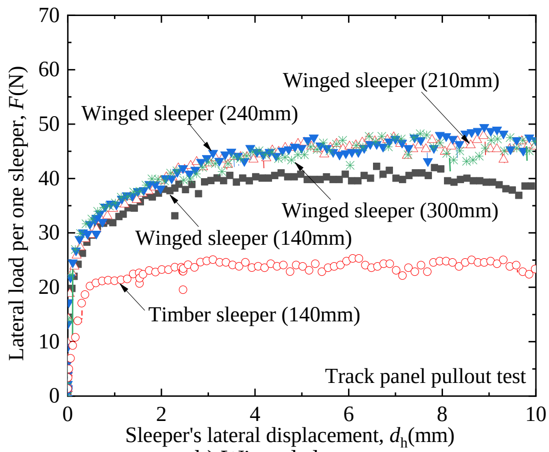
3.2 Track-panel pullout test results

Figure 7 shows the lateral load - lateral displacement relationships obtained from the track-panel pullout tests conducted on the timber sleepers, PC No.3 sleepers and winged sleepers. Lateral loads shown in the figure are those per one sleeper. The lateral displacements shown are the means of displacements measured by two lateral displacement transducers. As can be seen from the figure, the lateral loads of the PC No.3 sleeper and of the winged sleeper are higher than that of the timber sleeper at the same lateral displacements.

It is also found that even though the sleeper type is same, the lateral load mobilized are different among the test cases having different sleeper spacing. This is supposed to be caused (1) by the change in bottom frictional resistance of the sleepers owing to the change in the rail load supported by the sleepers, and (2) by the change in the interference between adjacent sleepers owing to the alternation of the sleeper spacing.



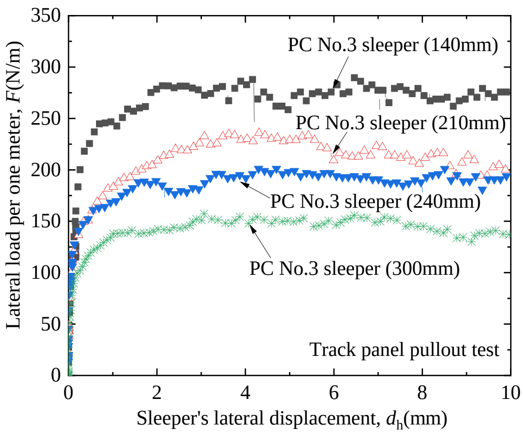
a) PC No.3 sleeper



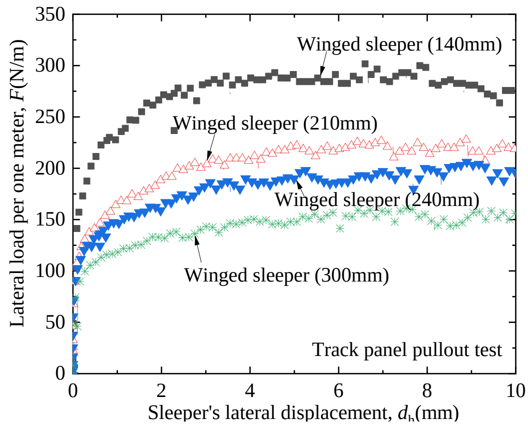
b) Winged sleeper

Fig. 7. Lateral load per one sleeper - lateral displacement relationships obtained from the track-panel pullout tests

The lateral loads per one sleeper shown in Fig.7 can be converted to the lateral loads per one meter by taking the sleeper spacing into the consideration. Figure 8 shows the lateral load per meter - lateral displacement relationships obtained from the track-panel pullout tests conducted on PC No.3 sleepers and winged sleepers. It is observed that for both the PC No. 3 sleepers and the winged sleepers, the lateral loads per meter decrease as the sleeper spacing increases.



a) PC No.3 sleeper



b) Winged sleeper

Fig. 8. Lateral load per one meter - lateral displacement relationships obtained from the track-panel pullout tests

4 CHANGE IN LATERAL RESISTANCE OF TRACK BED WITH THE ALTERNATION OF SLEEPER SPACING

Based on the results shown in Fig. 8, lateral resistance *LR* (N/m) for PC No.3 sleepers and winged sleepers was evaluated for each sleeper spacing. Here, the lateral resistance LR (N/m) is defined as the mean of lateral loads per one meter recorded at the lateral displacements between 5 and 10 mm. Fig. 9 shows the relationship between *LR* (N/m) and the sleep spacing. In the figure, lateral resistance *LR* (N/m) for the timber sleepers obtained from the track-panel pullout tests conducted for the 140 mm sleep spacing is also shown.

Based on the results shown in the figure, the track-panel pullout test results suggest that when timber sleepers are replaced by the concrete sleepers in ballasted tracks, the maximum sleeper spacing at which the lateral resistance before the replacement can be secured is 268 mm for the PC No. 3 sleeper and 273 mm for the winged sleepers, respectively. This means that the sleeper spacing for PC No. 3 sleeper and for the winged sleeper becomes 1.91 and 1.95 times as that of the timber sleeper, respectively. These are higher than those obtained from the single-sleeper test results. The fact indicates that it is important to consider the change in the rail load supported by sleepers and the change in the interference between adjacent sleepers to evaluate the change in the lateral resistance of ballasted track bed associated with the alternation of the sleeper spacing.

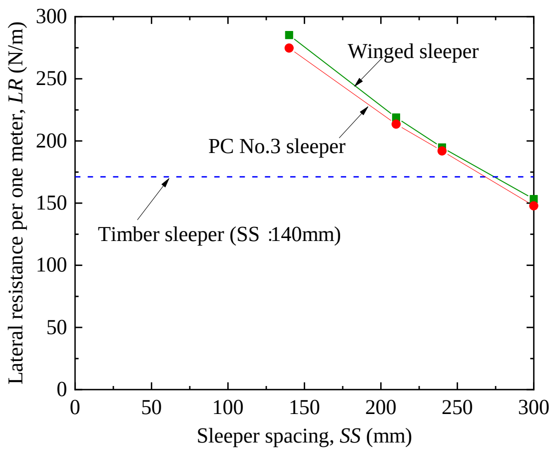


Fig. 9. Relationship between *LR* (N/m) and the sleep spacing

5 CONCLUSIONS

In this study, a series of 1/5 scaled model tests were conducted in the laboratory to evaluate the lateral resistance of ballasted track beds with various amounts of sleeper spacing. Singe-sleeper pullout tests and track-panel pullout tests were conducted on timber sleepers, PC No.3 sleepers and winged sleepers. The test results suggest that it is necessary to consider the changes in the rail load supported by sleepers and in the interference between adjacent sleepers to evaluate the change in lateral resistance of ballasted track beds associated with the change of the sleeper spacing.

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