A Study of the Effect of Track Irregularity Prevention Methods for the Transition Zone between Different Track Structures

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It is common knowledge that at the transition zones between ballastless and ballast track, track irregularity becomes locally discontinuous; therefore, hanging sleepers are likely to occur. As a countermeasure for local track irregularity, the authors have developed a track structure which uses automatic irregularity-correcting sleepers called AICS. In this paper, the authors performed cyclic loading tests with full-scale track models, simulating transition zones. The authors thereby clarified that the AICS has superior performance in the prevention of hanging sleepers and that elastic sleepers have some degree of efficacy.

Keywords: transition zone, ballast track, track irregularity, hanging sleeper, AICS

1. Introduction

When unloaded sleepers on ballast track are unsupported and are suspended from the rail they are said to be “hanging sleepers.” The impact created when a train passes over a hanging sleeper accelerates track damage due to ballast being crushed or mud pumping. Hanging sleepers are more common in transition zones such as around ballast/ballastless track boundaries, crossings and rail joints. Although the mechanism which generates hanging sleepers has not been completely clarified, it is supposed that hanging sleepers on ballast/ballastless track boundaries occur due to the following factors:

- 1) Compared with ballastless track, ballast track deformation is relatively large; therefore discontinuous local settlement is likely to occur (Fig. 1a).
- 2) Where local settlement increases, sleepers are suspended from the rail when there is no load and there is one supporting point - the extremity of the ballastless track - which produces hanging sleep-

ers (Fig. 1b).

- 3) Furthermore, over-raising the rail during track repairs is difficult to achieve at the ballast/ballastless track boundary. Therefore, even when employing a tie-tamper to perform this task, the ballast density remains low, and hanging sleepers can therefore reoccur easily.

As such, it is essentially impossible to reduce the plastic deformation of the ballast to zero, and therefore it is extremely difficult to prevent hanging sleepers in the ballast/ballastless track transition zone. For example, hardening the boundary area in question with cement will indeed stiffen that zone, but will produce the effect of simply shifting the transition point along; this solution therefore does not tackle the essence of the problem. However, even if subsidence of the ballast near the boundary part itself cannot be prevented, inserting material to adjust the sleepers individually according to the level of ballast subsidence would make it possible to maintain the rail level and would thus prevent hanging sleepers. Consequently, the authors of this paper developed the Automatic Irregularity-Correcting Sleeper (hereinafter called “AICS”) to reproduce the abovementioned action automatically [1,2]. To date the authors have verified that track structures with AICS have superior resistance to hanging sleepers by moving-load tests on small-scale track models and by cyclic loading tests on full-scale models.

On the other hand, some examples have been found where track irregularity seemed to be reduced by installing a certain number of elastic-sleepers, equipped with under-sleeper pads, in transition zones on commercial lines. Although this measure is aimed at reducing the dynamic load acting on the ballast, no quantitative verifications of its effect have been performed. As a result the authors performed comparative verifications with both methods (AICS and elastic sleepers) to check their influence on reducing track settlement by cyclic loading tests on full scale track models of the transition zone.

Fig. 1 Concept of the hanging sleeper in the transition zone

2. General outline of AICS

The AICS employed in this paper has independent left and right correction, and is a newly constructed quasi finished-product prototype (Fig. 2, Fig. 3). This is a composite FRP sleeper housing Automatic Subsidence Compensating devices (hereinafter called “ASC device”) under each rail. Since the each device corrects the ballast subsidence independently, it is possible to correct different levels of deformation between the two rails.

The AICS exerts a lateral resistance of approximately 10kN per sleeper through the ASC protective covering which acts as a lateral resistance board retaining lateral ballast resistance [3].

The ASC device combines two nested boxes, namely an inner case and an outer case, as shown in Fig. 4; the upper surface of the inner case is connected to the rail through the sleeper; the bottom of the outer case maintains contact with the ballast through the base plate. The inner case is full of spherical pellets approximately 2 mm in diameter. When the outer case sinks with ballast subsidence creating a gap between the inner and outer case, the pellets fall through the outlet into the gap under the inner case;

Fig. 2 Basic structure of AICS

Fig. 3 AICS

Fig. 4 Principle of the Automatic Subsidence Compensating Device

Fig. 5 Concept of the hanging sleeper prevention with AICS

consequently, the gap is filled with the pellets increasing the virtual height of the ASC device. Consequently, even if local subsidence of ballast progresses no hanging sleeper is generated, demonstrating that rail irregularity can be prevented, as shown in Fig. 5.

For the round pellets, ceramic or various metal balls were studied as possible candidates. Other aspects being examined to determine the optimum design are shape of the outlet, the area, and particle diameter of the pellets.

3. Outline of the model tests

As an example of the full size track model, Fig.6 shows the AICS case set up. This track model simulates the boundary between ballast and ballastless track (Fig. 7). It comprises 11 sleepers including one directly-fastened PC-sleeper (type PC-3) on a concrete block at the end of the track model. The subgrade was made with gravel sand and EPS; the subgrade stiffness was made with an equivalent K_{30} -value of 50MN/m^3 .

The three test cases are shown in Table 1; a standard case where all ten sleepers on the ballast are PC-sleepers; a low stiffness case where all ten sleepers on the ballast are elastic-sleepers; and the AICS case where out of the ten sleepers on the ballast seven of them near the directly-fastened sleeper have the AICS. The number of AICS to be installed was defined on the basis of the results from the moving-load test on the small track model [2]. The elastic sleeper used in this test was based on the PC-3; a sleeper pad with a static spring rate $=9\text{ MN/m}$ was bonded to the bottom (Fig. 8).

Loading conditions are shown in Table 2. Fixed-point cyclic loading was performed on two points which are shown in Fig. 6; loading frequency is 5Hz (however, 1 Hz for the first 1000 times). The sine wave axle loads of

Fig. 6 Outline of the track model (AICS Case)

Fig. 7 Track model (AICS Case)

Table 1 Test cases

Standard	Directly fastened sleeper $\times$ 1 PC-3 sleeper $\times$ 10
Low stiffness	Directly fastened sleeper $\times$ 1 PC-3 Elastic sleeper $\times$ 10
AICS	Directly fastened sleeper $\times$ 1 AICS $\times$ 7 PC-3 sleeper $\times$ 3

Fig. 8 Elastic sleeper

Table 2 Loading conditions

Load	Sine wave axle load 0-100kN $\times$ 2	
Loading frequency	5Hz (1Hz for the first 1000 times)	
Number of loading cycles	Standard case	20,000
	Low stiffness case	400,000
	AICS case	1 million

Fig. 9 Model test set up

0-100kN are loaded until maximum of 1 million times. The situation of the model test is shown in Fig. 9.

4. Test results

4.1 Track model deformation

Figure 10 shows deformed shapes of the rail (under load, left and right rail average). In the standard case, track settlement rapidly increased shortly after loading started. After 20,000 loadings, settlement reached a maximum 11 mm. Even though there was no sign of the trend coming to an end, loading was stopped when the vibrations and impact associated with hanging sleepers became too heavy. In the low stiffness case, settlement rose steeply after loading just around the loading point producing 8 mm subsidence after 20,000 loading cycles, and the hanging sleeper phenomenon was observed. However, since impact against the ballast was eased by the elastic material on the bottom of the sleeper, after initial settlement further settlement only progressed slowly. In the AICS case, although there was initial settlement of about 3 mm immediately after loading began, subsequent settlement remained marginal up to 1 million cycles, and no hanging sleepers were observed.

Figure 11 shows final deformed shapes of the rail in each case (under load, left and right rails independently). There was slight variation in subsidence between the left and right rails in the standard case, whereas there was almost none in the low stiffness and the AICS cases.

The rail deformation shapes in the above cases however were produced under fixed-point cyclic loading conditions; this means therefore that they are not necessarily the same as the shapes which would appear under moving-load conditions such as those accompanying actual train running [2, 4].

Figure 12 shows displacement-amplitude distributions of the rail (right and left rail average). The displacement-amplitude of about 7 mm in the standard case arose due to

Fig. 10 Deformed shapes of the rail under loading

Fig. 11 Final deformed shapes of the rail under loading

Fig. 12 Rail displacement-amplitude distribution (average of left and right rails)

the marked hanging sleeper conditions. In the low stiffness case, the displacement-amplitude was just over about 3 mm, which is slightly above what is considered to be a good condition; however, it is presumed that the size of the gap completely separating the sleeper from the ballast was constrained at a low value by virtue of the sleeper pad itself following the deformation. In the AICS case, assurance was obtained that track stiffness remained normal because the displacement amplitude was less than around 2 mm.

4.2 Track settlement process

Figure 13 shows the settlement processes for the right-and-left rails between sleepers No.4 and No.5 where settlement was most prominent; Fig. 14 shows the displacement-amplitude processes for the same points. Initial settlement immediately after loading started in the low stiffness case was greater than in the standard case because sleeper pad under the elastic sleeper seemed to undergo plastic deformation in addition to ballast deformation.

Moreover, the displacement-amplitude in the low stiffness case reached 4.5 mm after about 1000 cycles, stabilizing thereafter at 3.2 mm; this is probably due to the visco-elastic deformation characteristics of the sleeper pad. In other words, given that the loading frequency was 1 Hz up to 1000 cycles, the sleeper pad damping effect seemed to be relatively small; however, the frequency was subsequently raised to 5 Hz making the damping effect appear to be relatively large, which makes it possible to presume that equivalent stiffness was also high.

Fig. 13 Left and right rail settlement between sleepers No.4 and No.5

Fig. 14 Left and right rail displacement amplitudes between sleepers No.4 and No.5

In the standard case, settlement continued to increase rapidly even after initial settlement whereas in the AICS case, the settlement rate was very slow after initial settlement and the displacement-amplitude was also stable.

4.3 Subsidence compensating effect of AICS

Figure 15 shows the compensation distribution for each ASC device built into the AICS measured after 850,000 loading cycles, which is equal to the relative displacement between the inner case and the outer case or ballast subsidence. This figure suggests that compensation under each rail is not necessarily uniform even for a same sleeper. The cause is thought to be variation in both rigidity and strength of the ballast. However, as shown in Fig. 11, rail deformation in the AICS case shows there is very little difference between the left and right rails, suggesting that the subsidence difference which should occur due to variation in ballast strength/rigidity under the sleeper was corrected by the two ASC devices built into the AICS.

Fig. 15 Compensation distribution due to Automatic Subsidence Compensation Device

5. Conclusion

The results of the cyclic loading tests on the transition zones between different track structures using actual size track models are as follows:

- 1) It was clarified that, in the transition zone between different track structures on a weak subgrade, hanging sleepers are likely to appear, resulting in rapid ballast track settlement due to impacts caused by the hanging

sleeper.

- 2) It was proved that installing elastic sleepers in the transition zone offered the possibility of a sharp reduction in track settlement. However, this approach was not fundamentally able to prevent the appearance hanging sleepers.
- 3) Confirmation was obtained that installing seven or more AICSs in the transition zone, prevented generation of hanging sleepers and reduced track settlement.
- 4) It was confirmed that the prototype AICS, with independent left and right compensation, can correct track subsidence differences.

6. Future work

In order to lower the cost of the hanging sleeper prevention function, the authors are now developing the AICS-SS which facilitates the addition of automatic subsidence compensation to existing track without removing the existing sleepers. The AICS-SS (Fig. 16) is a short sleeper equipped with ASC devices and is attachable to each rail independently, between existing sleepers. Since the AICS-SS is very simple to attach and remove to the rail, it is not necessary to actually change the sleeper thereby offering the opportunity to significantly reduce construction costs.

AICS was developed not only for application in railway transition zones but also around rail joints (Fig. 17). Tests for its application to rail joints will be performed in the near future.

Fig. 16 AICS-SS

Fig. 17 Example applying the AICS-SS to a Rail Joint

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