In light of the derailment of Shinkansen cars in service in the 2004 Mid Niigata Prefecture Earthquake, JR East has been conducting R&D on and measures for prevention of Shinkansen derailment in earthquakes. That included development of the following preventive measures against derailment in earthquakes for tracks. (as of April 2017)

(1) Aseismic glued insulated joint rails (installation completed)
(2) Rail rollover prevention devices for slab tracks (under construction)
(3) Rail rollover prevention devices for ballasted tracks (development completed)
(4) Rail rollover prevention devices for solid bed track with resilient sleepers (development completed)
(5) Removal of expansion joints (under construction, considering expanding the range of those subject to removal)

Development is completed for rail rollover prevention devices for slab tracks, and installation of those is underway. Development is completed for rail rollover prevention devices for ballasted track as well, and a decision has been made to introduce those starting in fiscal 2017. This paper will thus report on development of rail rollover prevention devices for ballasted tracks.

1. Introduction

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2. Measures to Prevent Shinkansen Deviation from Rails and Derailment in Earthquakes

One reason major damage to derailed cars was avoided in the Mid Niigata Prefecture Earthquake was that underfloor equipment and wheels sandwiched the rails, and the cars continued moving forward guided by the rails. On the other hand, rail fasteners were destroyed by the derailed cars, and the tail car lost the “guides” keeping it on the track, allowing it to escape to the adjacent track side (Fig. 1). This demonstrated that cars could be guided until they safely stop if rails function as running guides, so a measure for actively using rails to prevent cars from escape the track was thought up.
A policy was thus adopted at JR East to introduce “L-shaped guides” for cars and “rail rollover prevention devices” for track and prevent the spread of damage at derailment by the two measures functioning together.

L-shaped guides are inverted L-shaped devices attached to the gear boxes of bogies (Fig. 2), designed to guide cars by the rails in case of derailment. They are attached to all commercial trains operating in JR East’s Shinkansen sections. In order for those L-shaped guides to function effectively, rails need to be secured on the track and rollover and large lateral movement of rails need to be prevented. We therefore decided to install on the track rail rollover prevention devices, which prevent large lateral movement and rollover.

3. Performance Required in Rail Rollover Prevention Devices

The following performance requirements must be satisfied by rail rollover prevention devices.

(1) Rail rollover prevention performance
Rails receive loads from derailed wheels or from derailed cars via the L-shaped guides. The rails must not roll over from this load and lateral movement must be kept under a certain amount so derailed cars do not deviate from the track (wheels do not fall from sleepers, etc.) (Fig. 3). With ballasted track, lateral movement must be kept to within 225 mm. Load in horizontal directions applied to rails by Shinkansen cars in an earthquake is prescribed to be 200 kN as a result of studies based on relatively hard support stiffness assuming slab track.1)

(2) Impact durability performance
The wheels of derailed cars will run over the rail rollover prevention devices. The rail rollover prevention devices must not break due to that, and rollover prevention performance must be maintained. We confirm durability of rail rollover prevention devices at time of impact by impact tests using actual bogies traveling at low speeds (60 km/h or slower), and we evaluate durability at impact by impact analysis for high speeds (up to 360 km/h). By comparing impact analysis results with those of actual bogie impact tests, we have confirmed that sufficient precision is achieved.

(3) Electrical insulation performance
Rail rollover prevention devices are metal devices installed to existing track, so there is a risk of them affecting track circuits. They therefore must have insulation resistance prescribed in design standards for railway structures2). The target value for leakage conductance in Shinkansen track circuits is 0.35s/km or less.

Electrical insulation required per 1 km

\[ R = \frac{1}{0.35} = 2.86 \Omega/km \] (Shinkansen)

As sleepers are parallel circuits in track circuits, from

\[ \frac{1}{R} = \frac{1}{r} + \frac{1}{r} + \frac{1}{r} + \ldots + \frac{1}{r} = \frac{n}{r} \]

we know that insulation resistance per sleeper is

\[ r = n \times R = 1720 \times 2.86 = 4.9k\Omega \] (n: number of sleepers)

4. Development of Rail Rollover Prevention Device for Ballasted Track

Fig. 4 shows a rail rollover prevention device for ballasted track. With ballasted track, rail rollover prevention devices cannot be installed between rail fasteners as is possible with those for slab track where introduction is already underway (Fig. 5). So, by protecting all rail fasteners from the derailed wheels, load from horizontal impact is borne by rail fasteners’ resistance to tilting, and performance to prevent rail overturn and large lateral movement is secured by the entire ballasted track (rails + rail fasteners + PC sleepers + ballast).
Rail rollover prevention devices have a structure where fastening bolts of the rail fasteners are used to attach to existing PC sleepers in order to make installation work easier. They are also light enough to enable manual installation (approx. 6 kg each for both inside and outside rail). Shape meets the following requirements taking into consideration maintenance management after installation.

1) Improved visibility of spring clips
2) Ability to adjust clip supporting wedges
3) Water, dirt, etc. does not accumulate on fastening bolt part

Also, the device was made to be a shape that allows judgment of fastening bolt looseness by Shinkansen track material monitoring that is being studied for future introduction.

(1) Rail rollover prevention performance

Rail rollover prevention performance is confirmed by weight tests as shown in Fig. 6. In tests, we impacted rails with weights with the height from which weights were dropped set to that where impact forces would be the design load (200 kN for slab track). Weights were impacted against the side of the rail head, and the results of that are shown in Fig. 7. From the results, impact load on receiving side with all ballasted track rail fasteners fastened was 115 kN and rail head lateral displacement was approx. 26 mm. Displacement is within tolerance of 225 mm, so rail rollover prevention performance requirements were confirmed to be satisfied.

(2) Confirmation of impact durability performance

Impact resistance performance was confirmed by impact analysis using non-linear dynamic analysis. Fig. 8 shows the analysis model. In analysis, we modeled Shinkansen ballasted track and Shinkansen cars and confirmed state of individual materials and behavior of wheels when derailed wheels impact rail rollover prevention devices.

In confirming impact durability performance, we studied durability with “continuous arrangement” where rail rollover prevention devices are attached to all sleepers as well as “discrete arrangement” where the devices are attached to every other sleeper and “intermittent arrangement” where they are attached intermittently to a certain number as shown in Fig. 9.

Fig. 10 shows an example of analysis results. We confirmed that with continuous arrangement where rail rollover prevention devices are attached to all sleepers, impact durability performance is achieved against wheels impacting at a speed of 360 km/h. On the other hand, more vertical movement of wheels is required to climb over the rail rollover prevention devices with discrete arrangement and intermittent arrangement, and the possibility of the devices being destroyed was high.

From those results, we decided to use continuous arrangement of rail rollover prevention devices.

(3) Confirmation of electrical insulation performance

We confirmed that electrical insulation resistance met requirement of resistance to be 4.9 kΩ for Shinkansen ballasted track in all conditions—dry, rain, and fouled—prescribed in design standards for railway structures. We then test installed on 1.3 km (one unit length of track circuit) of commercial track and confirmed effects on track circuits (Fig. 11).

In continuously investigating signal reception level fluctuation in sections where the devices are installed, we confirmed that rail rollover prevention devices do not affect track circuits by comparing before and after installation and comparing to adjacent lines. However, peeling and the like of some insulating material were confirmed six months after installing. We therefore gave the foot part and insulating material of rail rollover prevention devices a shape where peeling does not easily occur and changed to a structure where, on the chance that adhesion area does peel, insulating material does not fall or scatter (Fig. 12).
5. Rail Rollover Prevention Device Installation Plan

Table 1 shows the plan for future installation of rail rollover prevention devices. Measures for slab track implemented up to now will be expanded to ballasted track from fiscal 2017 with completion expected by fiscal 2029. In that, priority sections (Tohoku Shinkansen approx. 50 km, Joetsu Shinkansen approx. 150 km) are set based on the latest findings on active seismic faults with installation planned to be done by fiscal 2020.

<table>
<thead>
<tr>
<th>Line</th>
<th>Section</th>
<th>Track length [km]</th>
<th>Plan length [km]</th>
<th>Slab (installation complete)</th>
<th>Ballast</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tohoku Shinkansen</td>
<td>Tokyo - Shin-Aomori</td>
<td>1,352</td>
<td>967 (473)</td>
<td>80</td>
<td>1,047</td>
<td></td>
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<tr>
<td>Joetsu Shinkansen</td>
<td>Omiya - Shinbashi</td>
<td>539</td>
<td>484 (103)</td>
<td>23</td>
<td>507</td>
<td></td>
</tr>
<tr>
<td>Hokuriku Shinkansen</td>
<td>Takasaki - Joetsumyoko</td>
<td>352</td>
<td>103 (103)</td>
<td>—</td>
<td>103</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>2,243</td>
<td>1,554 (679)</td>
<td>103</td>
<td>1,657</td>
<td></td>
</tr>
</tbody>
</table>

6. Conclusion

We have confirmed that performance requirements for rail rollover prevention devices for ballasted track are met through various performance confirmation tests and test installation on commercial lines, and we have been gradually installing them since fiscal 2017. Into the future, we will continue pursuing R&D for Shinkansen earthquake derailment countermeasures with an aim of further improving Shinkansen safety and reliability.

Acknowledgements

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Reference: