TC-type low-maintenance track was developed in 1997 for the purpose of reducing track maintenance work, and it is currently laid over a distance of more than 230 km in the greater Tokyo area including the Yamanote Line. As 15 years have passed since that first of track was laid, maintenance reduction effects and improvement of track state have been proved. In some specific track conditions such as in sharp curves and on soft roadbed with high groundwater level, however, there were cases where repair work was needed. In order to make the track able to handle such track conditions, we have improved rail fastening clips and wedge-shaped insulators for sharp curves with less than 300 m radius and, for locations with high groundwater level, established construction standards for appropriate drainage equipment by clarifying the track subsidence characteristics and confirming the effect of drainage. Furthermore, we quantified the effect of roadbed hollows that could occur in roadbed on the interface to structures such as abutments, and based on that, we developed a structure of TC-type low-maintenance track that can be applied to diverse track conditions.

**Keywords:** TC-type low-maintenance track, Wedge-shaped insulator, Rail fastening clip, Drainage channel, Mud pumping index, Roadbed hollow

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### 1 Introduction

In order to meet the expected severe environment of future maintenance work such as labor shortages due to low birthrates and tendencies of avoiding dirty, dangerous and difficult work, JR East developed TC-type low-maintenance track with the aim of minimizing maintenance needed. Beginning with introduction to the Yamanote Line in 1997, the track has been laid on lines where relatively lightweight trains run. From 2006, areas where it is laid have been expanded to lines on which freight trains run, including the Tokaido Line, and currently it has been laid over more than 230 km.

Railways outside Japan, those in developed countries in particular, mainly adopt ballastless tracks such as slab tracks and Rheda 2000 tracks when constructing new lines. JR East’s full-scale introduction of low-maintenance track to existing lines is example rarely seen in the world, demonstrating the high value of that technology.

In the 15 years that have passed since its first introduction, it has had an effect of reducing track maintenance cost approx. 70%, and the P value track irregularity index of that track has been improved to approx. 60% of that of ballast tracks. In some specific track conditions such as in sharp curves with less than 300 m radius and on soft roadbed with high groundwater level, however, cases where repair work was needed have occurred. There is also concern that train load or earthquake load could cause roadbed hollows at the interface to track without ballast floor behind abutments.

This article will report the technical challenges of TC-type low-maintenance track in diverse track conditions such as sharp curves, soft roadbed with high groundwater level, and interfaces to structure such as abutments, and it will in introduce countermeasures to those.

### 2 Basic Structure of TC-type Low-maintenance Track

TC-type low-maintenance track is directly fastened track with 400 mm sleeper width and 750 mm rail fastening device intervals, for which ballast is filled and fixed with cement filler (Fig. 1).

#### Composition of the cement for the cement filler layer (hereinafter, the “filler layer”) varies according to whether or not freight trains operate on that track. Direct seat type or tie place type rail fastening devices are chosen according to the train weight and the lateral force applied there (Fig. 2).

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### 3 Improvement of Rail Fastening Devices for Sharp Curve Sections

#### 3.1 Change of Wedge-shaped Insulator

With early TC-type low-maintenance track, direct seat type rail fastening devices were used in sections with less than 300 m curve radius, but polyacetal resin (POM) wedge-shaped insulators became worn in some sharp curve sections (Fig. 3).

It was thought that the insulators became worn due to instantaneous frictional heat by excessive lateral force, so we thus developed a wedge-shaped insulator of nylon 6,6 that has an approx. 100 ºC higher melting point. As a result, we could approximately double antiwear performance, achieving safety improvement and maintenance cost reduction.

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*Technical Center, Research and Development Center of JR East Group*
2 Change of Rail Fastening Clip

For tie plate type rail fastening devices in curves with less than 300 m radius, we used e2009 clips, but a clip broke at a certain location. The field investigation results revealed that large stress had been applied to the clip, so we focused on PR type clips that can control generated stress, performing performance tests for applying PR601A and PR447A clips (Fig. 4). Those clips can be used with the type of current tie plate and insulator.

(1) In-laboratory Basic Tests

We carried out basic tests in a laboratory, such as oblique loading tests and biaxial fatigue tests (Fig. 5) for the three types of clips.

Table 1 shows the specifications and test results for each clip.

PR601A and PR447A clips had lateral displacement of the rail top surface within permissible values for the design load. And checking with the durability limit diagram showed that the stress generated on those clips was within the second destruction limit, confirming that there would be no problems with their use on commercial lines. Those clips also showed no problems such as breakage with loading repeated one million times in the biaxial fatigue test, confirming that they can be used on commercial lines for a long period of time.

(2) Field Tests

Fig. 6 shows the measurement results for lateral force and stress generated on each clip in a curve with 300 m radius.

Stress generated on the e2009 clip was in linearly proportional to the lateral force, reaching approx. 250 MPa at 35 kN lateral force, while stress generated on PR601A and PR447A clips saturated at around 150 - 180 MPa. This was due to the shape of each clip, showing that PR clips have an advantage in installation at locations where high lateral force is generated. Distortion generated on PR clips was also within the yield and fatigue limits of spring steel, causing no problem in terms of durability.1)

Based on those test results, for tie plate type rail fastening devices installed in curves with less than 300 m radius, we have switched e2009 clips to PR447A clips that have an advantage in terms of installation workability too.

3.2 Change of Rail Fastening Clip

In some sections at locations with high groundwater level or with remarkable remaining rainwater, we discovered cases where repair was needed due to roadbed deformation or mud pumping.

The mechanism of roadbed deformation is assumed to be as shown in Fig. 7. Specifically, the pumping effect of the filler layer caused by train load changes water pressure of the water remaining near the roadbed surface, and that facilitates change of roadbed material to a muddy state.5)

Particularly in cases where water remains in an area within 500 mm from the roadbed surface, the effect of train load is remarkable. Such remaining water is thus considered to be one of the causes of roadbed deformation or roadbed mud pumping. For the TC-type low-maintenance track, we have a construction standard that specifies drainage equipment (Fig. 8) be set between the tracks in cases where there is a steady groundwater level in that area. We have verified the effect of those equipment and quantified as follows the characteristics of initial track subsidence when drainage equipment are set up.

Table 1 In-laboratory Test Results for Rail Fastening Clips

<table>
<thead>
<tr>
<th>Units</th>
<th>e2009</th>
<th>PR601A</th>
<th>PR447A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal fastening power kN/piece</td>
<td>12</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>Measured fastening power kN/piece</td>
<td>12.0</td>
<td>10.1</td>
<td>7.1</td>
</tr>
<tr>
<td>Constant of tip spring MN/m</td>
<td>0.49</td>
<td>0.68</td>
<td>0.99</td>
</tr>
<tr>
<td>Lateral displacement of rail top surface mm</td>
<td>2.9</td>
<td>3.3</td>
<td>3.4</td>
</tr>
<tr>
<td>Judgment of durability limit diagram</td>
<td>Within limit</td>
<td>Within limit</td>
<td>Within limit</td>
</tr>
<tr>
<td>Biaxial fatigue test</td>
<td>1 mil. times</td>
<td>1 mil. times</td>
<td>1 mil. times</td>
</tr>
</tbody>
</table>
4.1 Check of the Effect of Drainage Equipment

At slope embankments with high groundwater level, we measured groundwater level, rainfall, and track surface height before and after laying TC-type low-maintenance track.

Fig. 9 shows the measurement results for groundwater level and rainfall before and after installation of drainage equipment. Before installation, the groundwater level remained over the border 500 mm below the track surface (hereinafter, the “border”) for a long time even after rainfall ended at 25 mm of total rainfall. After installation, however, the groundwater level returned to lower than the border in around three hours after rainfall ended even at heavy rainfall of 168 mm. We thus confirmed that the drainage equipment could smoothly drain remaining water at the layer higher than the border after rainfall.

4.2 Amount of Initial Track Subsidence Due to Installation of Drainage Equipment

Fig. 10 shows the distribution of the amount of initial track subsidence in relation to the amount of drawdown of steady groundwater level due to installation of drainage equipment.

The average amount of initial track subsidence after installation was 3.2 mm. There was a tendency for greater subsidence the larger the amount of drawdown of steady groundwater level was. Particularly, when the steady groundwater level is lowered by more than 0.5 m due to installation drainage equipment, the amount of initial track subsidence remarkably increases. In such a case, we believe that we cannot disregard the effect of initial track subsidence on the state of the track.

4.3 Relation between Mud Pumping Index and Initial Track Subsidence

Fig. 11 shows the relation between the mud pumping index, which indicates the probability of roadbed mud pumping occurring, and the amount of initial track subsidence and number of days until recovery from subsidence.

There is a tendency that the higher the mud pumping index is, the greater the amount of initial track subsidence increases and the longer the period until recovery from subsidence becomes. There is also a singularity where the amount of initial track subsidence is particularly large at a mud pumping index of around 16. This singularity is assumed to be because the amount of drawdown of steady groundwater level exceeds 0.5 m at that mud pumping index due to the installation of drainage equipment.

From this relation, we found that the period until recovery from initial track subsidence is around six months even at locations with a mud pumping index of greater than 40.

Based on those results, we have put together construction standards for laying TC-type low-maintenance track and installing drainage equipment as shown in Fig. 12. Applying these standards enables laying of high-quality TC-type low-maintenance track even if groundwater level is high.

Fig. 12 Construction Standards for the Laying TC-Type Low-maintenance Track and Installing Drainage Equipment
Train load or earthquake load causing hollows in the roadbed near the interface to structures such as abutments has been observed, so it is necessary to review safety of train operation in such cases.\(^6\) We thus calculated and quantified the distortion of the filler layer and the vertical displacement of rails according to the size of the roadbed hollow based on the results of structural analysis and loading tests.

### 5.1 Structural Analysis at Roadbed Hollows and Loading Tests

Using the 10 m-long test sample shown in Fig. 13, we carried out structural analysis and loading tests on a full-scale track testing machine to find out distortion of the filler layer and vertical displacement of the rails according to roadbed hollow size. The structural analysis conducted was elastostatic analysis using the Finite Element Method (FEM).

**Fig. 13  Test Sample of 10 m-long Full-size Test Track**

Fig. 14 shows the results of analysis and measurement of maximum distortion generated in the filler layer, and Fig. 15 those of rail vertical displacement. The loading test results exceeded the assumed permissible distortion of the filler layer (92 \(\mu\)) at a hollow length of around 1.5 m, while the results were almost as analyzed with a hollow length up to 1.5 m. On the other hand, if the hollow length was longer than 1.5 m, distortion exceeded the permissible limit of the filler layer and cracking occurred at the bottom of the layer. This is believed to be the reason why distortion of the filler layer and rail displacement remarkably increased in loading tests.

### 5.2 Evaluation of Train Running Safety at Roadbed Hollows

If a roadbed hollow occurred under TC-type low-maintenance track, distortion generated in the filler layer remained less than the permissible limit with a hollow length of up to around 1.5 m, but cracks may occur in the filler layer with longer hollows. Rail vertical displacement remarkably increased remarkably in that case, but it remained around 4 mm even with a 2 m-long hollow and cracking in the filler layer. Such small displacement would not immediately affect train running safety.

### 6 Conclusion

1. For the direct seat type rail fastening device installed to track in sharp curves, we developed a wedge-shaped insulator of nylon 6,6, doubling the antiwear performance of the device.
2. For the tie plate type rail fastening device installed to track in sharp curves, we adopted PR447A clips to reduce the stress generated, preventing breakage of clips.
3. We proved that initial track subsidence of an average of 3.2 mm occurs by installing drainage equipment, but it would be recovered from in around six months. Accordingly, we developed construction standards for laying TC-type low-maintenance track and installing drainage equipment.
4. If a roadbed hollow occurs, cracking may occur in the filler layer with a hollow longer than 1.5 m. But rail vertical displacement would be around 4 mm even with a 2 m-long hollow, not immediately affecting train running safety.

TC-type low-maintenance track has maintenance reduction effects as well as high seismic resistance and buckling strength, contributing to an improvement of safety. We are thus now expanding the range in which that track is applied, including when using continuous welded rail in curve sections of less than 300 m radius.

**Reference:**

3. Takao Kumakura, Yuichiro Hori, Takanobu Kozeki, “Studies on Improvement of TC-type Low-maintenance Track,” Railway Engineering 2011, Japan Railway Engineers’ Association (June 2011)