Development of Solid-Bed Track with Removable Resilient Ties

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Summary
Important factors when deciding the track structure in planning a new railway line include environmental preservation, construction cost, maintenance cost, durability, and construction workability. A low-noise solid-bed track with removable ties was proposed as one of the candidates for new lines. To confirm its performance, this track was laid and tested at the Test Site of Railway Technical Research Institute (RTRI) and revenue lines. Through these tests, the authors concluded that it had satisfactory performance as a low-noise and low-maintenance track.

Keywords
Solid-bed track, noise, maintenance, fastening, vibration

1 Introduction

In general, railway ballasted tracks need periodical maintenance work, because track ballast is gradually destroyed by repeated train loads. Therefore, a large amount of expenditure has been needed to maintain tracks in good conditions. To reduce the track maintenance costs, the former Japanese National Railways (JNR) developed slab tracks in the 1960s and a solid-bed track with resilient ties (STR-B) in the 1970s (Sato, 1981). It is confirmed that they have excellent performance to maintain good track geometries and reduce track maintenance costs. However, it was pointed out that (1) noise levels of slab tracks were higher than those of ballasted tracks under train running, and (2) construction costs of the STR-B were higher than those of slab tracks and (3) renewal of track components was difficult after put into operation. So, the authors developed an improved solid-bed track to solve these problems. This paper describes the track structure and test results obtained at a Test Site and a commercial line.

2 Outline of Prototype Solid Bed Track with Resilient Ties

It has become increasingly important to cope with environmental problems such as noise since the introduction of new higher speed trains. Generally speaking, noise levels on slab tracks are about 5 dB(A) higher than those of ballast tracks. The track to be used in urban railways should have excellent performance not only in reducing
maintenance costs, but also in decreasing emission of noise and vibration from the viewpoint of environmental preservation. In general, main countermeasures against noise available for the track structure are as follows.

1. Smoothing of rail top surface roughness (to reduce rolling noise).
2. Adoption of elastic rail fastener (to reduce structure-borne noise).
3. Increasing of middle mass such as slabs or ties, and adoption elastic supports for it (to reduce structure-borne noise).
4. Adoption of absorbing materials on the track (to reduce rolling noise).

It is difficult to sufficiently reduce the track spring constant of slab track by underlaying a rubber mat, because the track slab has a rigidity as an intermediate mass. To solve this problem, a solid-bed track with resilient ties filled with resin (STR-A) was proposed in 1975. After testing at the Test Site of RTRI, the STR-A was installed at the Osaka Loop Line and Tohoku Shinkansen Line.

Then, a solid-bed track with resilient ties filled with concrete (STR-B) instead of resin was proposed to reduce construction costs (Figure 1). In 1979, the STR-B was tested at the Test Site of RTRI and the Tohoku Shinkansen Line. The test on the Tohoku Shinkansen line proved that the noise level of this track was nearly the same at a position 25m distant from a viaduct in comparison with a ballasted track with ballast-mat, and was 7 dB (A) lower at a position 30 cm below a floor slab of the viaduct. However, there were still a few points to be improved such as the following.

1. The construction cost of the STR-B was 1.3–1.4 times higher than that of Vibration Reducing Slab Track of Type G (VG-Slab) as shown in Figure 2.
2. It was difficult to renew track components such as resilient tie pads and ties, when they were fatigued or damaged.
3 Proposal of New Solid-bed Track with removable resilient ties

3.1 Characteristics of structure

To solve these problems, the authors proposed a new solid-bed track with removable resilient ties (STR-D) as shown in Figure 3. The features of this track are as follows in comparison with those of the STR-B.

1. To reduce costs, inexpensive ties and tie pads are used instead of large ties and resilient coat made of urethane elastomer.
2. It is easy to renew track components without breaking the concrete bed, because hard cases made of polypropylene are set under ties.
3. It is easy to adjust the rail level vertically not only by fastenings but also by adjustable pads under ties.
4. Side pads between the tie and hard case resist uplift-force.

![Figure 3. STR-D](image)

3.2 Outline of structure

1. Rail fastener

The design condition of a rail fastener for this track is shown in Table 1 (Fukui, 1997). An outline of rail fasteners without tie plate is shown in Figure 4.

<table>
<thead>
<tr>
<th>Items</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail</td>
<td>60 kg/m</td>
</tr>
<tr>
<td>Tie</td>
<td>Special Tie</td>
</tr>
<tr>
<td>Spring const. of track pad</td>
<td>60 MN/m</td>
</tr>
<tr>
<td>Spring const. of tie pad</td>
<td>30 MN/m</td>
</tr>
<tr>
<td>Tie space</td>
<td>625 mm</td>
</tr>
<tr>
<td>Resistance to rail-crcrepage</td>
<td>5 kN/m/rail</td>
</tr>
<tr>
<td>Adjustment magnitude of fastener</td>
<td></td>
</tr>
<tr>
<td>Vertical (Up)</td>
<td>+20 mm</td>
</tr>
<tr>
<td>Horizontal (Right and Left)</td>
<td>±7 mm</td>
</tr>
</tbody>
</table>

![Figure 4. Rail Fastener](image)
Figure 4. Outline of rail fasteners

(2) Tie
The tie for ballasted tracks named Special type is applied to the STR-D (Figure 5). It is cheaper and smaller than that for the STR-B.

Figure 5. Special Tie

(3) Tie pad, end pad and side pad
Tie pads, end pads and side pads are made of natural rubber (NR) and styrene-butadiene rubber (SBR). The typical tie pad is 180mm wide, 250mm long and 20mm thick. The spring constants of tie pad and side pads are about 30MN/m. That of end pad is about 300MN/m. The tie pads set in the hard cases directly support the tie (Figure 6).

(4) Hard case
The hard case made of polypropylene was designed to fit the Special tie. The typical hard case is 356mm wide, 590mm long and 138mm height. Ribs are set outside the hard case to adhere to the concrete bed as shown in Figure 6. The tie pads and side pads are not glued to hard cases so that they can be removed easily when they are damaged or fatigued.

(5) Solid concrete bed and laying
The STR-D is constructed according to the following procedure.
  _ Reinforced bars are set on the concrete bed.
  _ Ties are transported and unloaded on the roadbed.
  _ The track panel is constructed.
  _ The track panel is temporarily supported by the bars.
  _ Forms are installed inside and outside the track panel.
  _ Fresh concrete is injected under and around ties once.
The forms are removed from inside and outside the track panel.

The track is completed.

In a detail design of this track, the wheel load, lateral load and longitudinal loads are considered. The design condition of the concrete bed is shown in Table 2.

![Diagram of composition parts](image)

**Figure 6. Composition parts**

**Table 2. Design condition of the concrete bed**

<table>
<thead>
<tr>
<th>Items</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheel load</td>
<td>85 kN</td>
</tr>
<tr>
<td>Lateral load</td>
<td>85 - 0.8 = 68 kN</td>
</tr>
<tr>
<td>Longitudinal load due to temperature change</td>
<td>10 kN/m/track</td>
</tr>
<tr>
<td>Break load</td>
<td>85 - 0.15 = 12.8 kN</td>
</tr>
<tr>
<td>Traction load</td>
<td>85 - 0.25 = 21.3 kN</td>
</tr>
</tbody>
</table>
4 Tests to confirm the fundamental performance

First, a 10 m-long STR-D was laid on a viaduct of the Hino Civil Engineering Test Site of RTRI. This track was offered for fundamental tests such as a static loading test, dynamic loading tests and a longitudinal loading test.

4.1 Static loading test

The STR-D was loaded with a static wheel load of 80kN and a lateral load of 60kN by the Dynamic loading car (DYLOC). At the same time, the stress and displacement at every part of the track were measured. These tests results are shown in Figure 7. Figure 7 shows that the maximum displacement of rail was 1.5mm when a wheel load of 80kN was loaded right above the part of rail fastening, and 1.7mm when the load was applied at the middle of rail fastenings. As seen from this result, the track spring constant calculated from the wheel load and the vertical rail displacement was 47MN/m (14MN/m per fastening). This was about one-third the value of the Standard Slab Track (S-Slab) (130MN/m).

Figure 7. The displacement of rail when the STR-D was loaded with a static wheel load of 80kN

4.2 Running test of track motor car

The relationship between track motor car velocity and wheel load is shown in Figure 8. The relationship between track motor car velocity and rail displacement is shown in Figure 9. As seen from these Figures, the track spring constant was 38MN/m (11MN/m per fastening). This was about half the value of the S-Slab.

4.3 Lateral and vertical resistance tests

As the results of lateral and vertical resistance tests, the STR-D was confirmed to have enough resistance characteristics.

4.4 Durability test

As a result of durability test, the STR-D was confirmed to have enough durability characteristics.
Through the above tests, it can be concluded that there would be no problems for laying this track on revenue lines.

![Figure 8. The relationship between track motor car velocity and wheel load](image1)

![Figure 9. The relationship between track motor car velocity and rail displacement](image2)

5. Tests to confirm the effect of noise reduction on revenue lines

5.1 Test in the Osaka Loop Line

To confirm the noise reducing effect in comparison with the VG-Slab, a 88m-long STR-D was laid on a viaduct along the Osaka Loop Line in 1997 as shown in Figure 10. The difference (reduction) of sound pressure levels for both tracks between the rail-side and a point below the viaduct based on the result of frequency analysis is shown in Figure 11 (Horiike, 1998). As seen from this Figure, the reduction of noise of the STR-D is 2-5 dB (A) larger than that of VG-Slab in most frequency domains. The relationship between the difference of noise levels (between the rail-side and a point below the viaduct) and the train velocity for both tracks is shown in Figure 12. As seen
from this Figure, the difference of noise level of the STR-D is 25-27 dB (A) at the velocity of 55-90 km/h, and that of the VG-Slab is 21-22 dB(A). The authors conclude that the noise reducing effect of STR-D is about 5 dB (A) larger than that of the VG-Slab.

Figure 10. STR-D laid on viaduct along the Osaka Loop line

Figure 11. The difference of sound pressure levels between the rail-side and below viaduct
5.2 Test in the other revenue line

Furthermore, to confirm the noise reducing effect in comparison with the ballasted track, a 75m-long STR-D was laid on a viaduct along another revenue line. Figure 13 shows the relationship between the difference of noise levels (between the rail-side and a point below the viaduct) and the train velocity for both tracks. As seen from this Figure, the difference of noise level of the STR-D is 18-22 dB (A) at the velocity of 45-85 km/h, and that of the ballasted track is 11-16 dB (A).
6. Conclusions

The STR-D was proposed as a track for new lines. Test results to confirm the fundamental performance of this track revealed that it had satisfactory performance as a track for revenue lines. On the basis of this result, the STR-D was laid along the Osaka Loop Line and other line, and tests to confirm the noise reducing effect was executed. The test results revealed that the noise of STR-D was about 5dB (A) lower than that of VG-Slab.

BIBLIOGRAPHY

