Development of Solid-Bed Track with Removable Resilient Ties

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In planning a new railway line, important factors when deciding the track structure are 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, authors concluded that it had satisfactory performance as a low-maintenance and low-noise track.

Keywords : solid-bed track, noise, maintenance, fastening, vibration

1. Introduction

In general, railway ballasted tracks need periodical track maintenance work, because track ballasts are gradually destroyed by repeated train loads. Therefore, huge expenditures have been needed to maintain tracks in good condition. 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 1970s¹⁾. It is confirmed that they have excellent performance to maintain good track geometries and reduce the track maintenance costs. However, it was pointed out that (1) noise levels on slab tracks were higher than those of ballasted tracks under train running and (2) construction costs of the STR-B were more expensive than those of slab tracks and (3) renewal of track components was difficult after being put into operation. So, the authors developed an improved solid-bed track to solve these problems. This paper describes the track structure, test results at a Test Site and a revenue line. The contents of this paper were originally presented at the World Congress on Railway Research in Köln in 2001²⁾.

2. Outline of the prototype solid bed track with resilient tie

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 on 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, the main counter-

measures against noise available on 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 the 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 the 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 (Fig. 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 25 m from the viaduct as that of a ballasted track with ballast-matt, and was 7 dB (A) lower at a position 30 cm below the 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 Tracks (VG-Slab) as shown in Fig. 2.
- (2) It was difficult to renew track components such as resilient tie pads and ties, when they were fatigued or damaged.

Fig. 1 Solid-bed track with resilient ties (STR-B)

Fig. 2 Vibration reducing slab track (VG-Slab)

3. Proposal of new solid bed track with removable resilient ties ³⁾

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 Fig. 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 the uplift-force.

Fig. 3 Solid-bed track with removable resilient ties (STR-D)

Fig. 4 Rail fasteners

Fig. 5 Special tie

3.2 Outline of structure

3.2.1 Rail fastener ⁴⁾

The design condition of a rail fastener for this track is shown in Table 1. An outline of rail fasteners without tie plate is shown in Fig. 4.

Table 1 Design conditions of a rail fastener

Items	Values
Rail	60 kg/m
Tie	Special Tie
Spring constant of track pad	60 MN/m
Spring constant of tie pad	30 MN/m
Tie space	625 mm
Resistance to rail-creepage	5 kN/m/rail
Adjustment magnitude of fastener	
Vertical (Up)	+ 20 mm
Horizontal (Right and Left)	± 7 mm

3.2.2 Tie

The tie for ballasted tracks named Special type is applied to the STR-D (Fig. 5). It is cheaper and smaller

than that for the STR-B. It is 300 mm wide, 2000 mm long and 220 mm thick. One tie weighs approximately 240 kg.

3.2.3 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 180 mm wide, 250 mm long and 20 mm thick. The spring constants of tie pad and side pad are about 30 MN/m. That of end pad is about 300 MN/m. The tie pads set in the hard cases directly support the tie (Fig. 6).

3.2.4 Hard case

The hard case made of polypropylene was designed to fit the special tie. The typical hard case is 356 mm wide, 590 mm long and 138 mm high. Ribs are set outside the hard case to adhere to the concrete bed as shown

Fig. 6 Composition parts

Fig. 7 Hard case

in Fig. 7. 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.

3.2.5 Solid concrete bed and laying

The STR-B was constructed according to the following procedure.

- (1) Box-type concrete bed called "crib" is set on the viaduct.
- (2) Ties coated with resilient materials are transported and unloaded in the crib.
- (3) They are arranged at equal spaces in the longitudinal direction.
- (4) The position of rails is adjusted in reference to the datum points set on the top of side wall of the crib, after ties are fastened to the rails.
- (5) A track panel is supported temporarily by supporting bars.
- (6) Ties are fixed by filling fresh concrete in the space under and around them.
- (7) After the concrete is hardened, the space around the ties is covered with ballast.

In the construction of the STR-D, the crib is not installed to reduce costs or improve construction workability. It is constructed according to the following procedure.

- (1) Reinforced bars are set on the concrete bed.
- (2) Ties are transported and unloaded on the roadbed.
- (3) The track panel is constructed.
- (4) The track panel is temporarily supported by the bars.
- (5) Forms are installed inside and outside the track panel.
- (6) Fresh concrete is once injected under and around ties.
- (7) The forms are removed from inside and outside the track panel.
- (8) 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.

Table 2 Design conditions of the concrete bed

Items	Values
Wheel load	85 kN
Lateral load	$85 \times 0.8 = 68 \text{ kN}$
Longitudinal load due to temperature change	10 kN/m/track
Brake load	$85 \times 0.15 = 12.8 \text{ kN}$
Traction load	$85 \times 0.25 = 21.3 \text{ kN}$

4. Tests to confirm the fundamental performance³⁾

First, a 10 m-long STR-D was laid on a viaduct of the Hino Civil Engineering Test Site of RTRI as shown in Fig. 8. This track was offered for fundamental tests such as a static loading test, dynamic loading test and longitudinal loading test.

4.1 Static loading test

The STR-D was loaded with a static wheel load of 80 kN and a lateral load of 60 kN by the Dynamic loading car (DYLOC) as shown in Fig. 9. At the same time, the stress and displacement at every part of the track were measured. These test results are shown in Fig. 10. It shows that the maximum rail displacement was 1.5 mm when a wheel load of 80 kN was loaded right above the part of rail fas-

tening, and 1.7 mm 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 47 MN/m (spring con-

Fig. 8 STR-D laid on a viaduct in Hino Civil Engineering Test Site of RTRI

Fig. 9 Dynamic loading car (DYLOC)

Fig. 10 Measured rail displacement (Wheel load = 80 kN)

stant of support = 14 MN/m). This was about one-third the value of the Standard Slab Track (S-Slab) (130 MN/m).

4.2 Running test of track motor car

The relationship between track motor car velocity and wheel load is shown in Fig. 11. The relationship between track motor car velocity and rail displacement is shown in Fig. 12. As seen from these figures, the track spring constant was 38 MN/m (spring constant of support = 11 MN/m). This was about half the value of the S-Slab.

As a result of a running test of the track motor car, the vibration acceleration level of STR-D was about 15 dB lower than that of the S-Slab on the underside of viaduct slab as shown in Fig. 13.

As a result of the frequency analysis, the vibration acceleration level of STR-D is lower than that of S-Slab in the frequency domains exceeding 80 Hz as shown in Fig. 14. Generally, the structure-borne noise during the passage of trains is dominant in the frequency domains between 500 and 2000 Hz. Therefore, the STR-D is expected to have the effect to reduce structure-borne noise as compared with the S-Slab.

Fig. 11 The relationship between track motor car velocity and wheel load

Fig. 12 The relationship between track motor car velocity and rail displacement

Fig. 13 The relationship between track motor car velocity and vibration acceleration level on the underside of viaduct slab

Fig. 14 1/3-octave-band spectra, vibration measured on the underside of viaduct slab during the passage of motor car

4.3 Longitudinal and lateral resistance tests

As a result of longitudinal and lateral resistance tests shown in Fig. 15, the STR-D was confirmed to have enough resistance characteristics as a track.

Fig. 15 Longitudinal and lateral resistance tests

4.4 Durability test

As a result of the durability test by dynamic repeated load, 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.

5. Tests at revenue lines ³⁾

5.1 Test in the Osaka Loop Line

To confirm the noise reducing effect in comparison with the VG-Slab, a 88 m-long STR-D was laid on a viaduct along the Osaka Loop Line in 1997 as shown in Fig 16.

Fig. 16 STR-D laid on viaduct along Osaka Loop Line

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 Fig. 17. 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.

Fig. 17 The difference of sound pressure levels between the rail-side and below the viaduct

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 Fig. 18.

Fig. 18 The difference of noise levels between the rail-side and below the viaduct

Fig. 19 The STR-D laid on viaduct along another revenue line

Fig. 20 The difference of noise levels between the rail-side and below the viaduct

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.

5.2 Test in the other revenue line

Furthermore, to confirm the noise reducing effect in comparison with the ballasted track, a 75 m-long STR-D was laid on a viaduct along another revenue line as shown in Fig. 19. Figure 20 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 levels 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. Conclusion

The STR-D was proposed as a low-noise and low-maintenance 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 another revenue line, and tests to confirm the noise reducing effect was executed. The test results revealed that the noise of STR-D was about 5 dB (A) lower than that of VG-Slab.

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