1. Introduction

Solid-bed track equipped with resilient sleepers (STR) is one type of ballastless tracks where under sleeper pads are installed beneath sleepers which are directly supported by the concrete trackbed. The concrete trackbed supports the wheel load, and the lateral load transmitted from the sleeper. STR is not only effective for saving on maintenance work, but also useful for reducing structure borne noise and ground vibration [1].

STR has already been widely introduced in the urban areas, mainly on viaducts. However, as the concrete trackbed is made of reinforced concrete, construction take a long time because of the need to manage the complex arrangement of reinforcing bars and the preparatory formwork. Also, construction costs are relatively high. Consequently, there have been calls to increase the speed of construction and reduce the construction cost of STR.

For that purpose, by introducing the shear-key on each side of the sleepers to resist lateral load, we developed a new solid-bed track equipped with resilient sleepers (STR) using the shear-key, as shown in Fig. 1. The STR Type-S design also makes installment of the concrete formwork easier, and short fiber reinforced concrete removes reinforcement bars in the concrete trackbed. This paper reports on the results of full-scale track model tests conducted for the development of STR Type-S and on the actual construction in the field.

2. Full-scale track model tests

In order to confirm the loading capacity of STR Type-S as a track, a full-scale track model equipped with a single sleeper was set up to perform lateral loading tests. Fig. 2 shows the details of the full-scale track model equipped with a single sleeper. Lateral loading tests confirmed the loading capacity of each sleeper in the sleeper longitudinal direction and in the rail longitudinal direction [2]. This paper reports on the lateral loading test results in the sleeper longitudinal direction.

The thickness of the concrete trackbed under the sleeper was set to 80 mm the thinnest possible depth of placed concrete. Also, the shape of the joint section of the concrete trackbed was assumed in the full-scale track model.
Shear-keys were installed at 45° angles on each side of the sleeper. We designed and manufactured the prestressed concrete sleepers that satisfies Japan industrial standard (JIS) [3]. Under sleeper pads with the same spring constant (30 MN/m) as those used on existing STR (Type-D), were installed beneath the sleepers.

Two kinds of short fiber reinforced concrete were used for the trackbed, using Polypropylene fiber (PP fiber) or Polyvinyl alcohol fiber (PVA fiber). The amount of fiber mixed into the concrete was adjusted and set to minimize fluctuation in the fresh properties modified due to addition of fiber, and also so that the improvement in flexural toughness in the end was the same regardless of the fiber type (PP fiber: 0.5 vol.%, PVA fiber: 0.375 vol.%). In addition, assuming the penetration of drying-shrinkage cracks in the concrete trackbed, steel plates coated with a releasing agent were placed in the position shown in Fig. 2. This meant that the concrete trackbed under the lower edge of the side of the sleeper was completely cut off.

In the lateral loading tests, a lateral load was exerted onto the concrete trackbed by pressing the end of sleeper using a hydraulic jack. Loading and unloading cycles were repeated until the concrete trackbed yielded.

Figure 3 shows the results of the lateral loading tests in the sleeper longitudinal direction. The maximum load was about 105 kN for both types of fiber. In both cases, after the maximum load was reached, oblique cracks developed. There was no damage to the shear-key on the side of the sleeper. The concrete trackbed satisfied performance requirement against the design load stipulated for verifying performance (about 50 kN) in the curves with small radii [4]. The loading test in the rail longitudinal direction was also performed in the same way, and it was confirmed that its performance also met requirement against the design load in the rail longitudinal direction [2].

3. Performance confirmation tests on the test line

Based on the results described in the previous chapter, experiments were performed with a view to bringing STR
Type-S into service. A section of STR Type-S was conducted, equipped with seven sleepers on a viaduct section of the test line, and then lateral loading tests, track motor car running tests and impact hammer vibration tests were carried out [5].

Figure 4 shows the details of the constructed STR Type-S. For the construction, first, we installed the reinforcing bars for connection with viaduct. Second, the sleepers were fastened to the rails, and the rail height was maintained to meet finished track geometry by using a jig to adjust it. The sleeper spacing was set at 700 mm, and existing palate type fasteners for STR Type-D were used as rail fastening devices (spring constant of track pad: 60 MN/m).

After preparing the track panel, the concrete trackbed form was put in place and the concrete was placed. In order to conduct lateral loading tests under the most unfavorable conditions, before concrete placing, a vinyl sheet was laid on the upper surface of the viaduct slab (below the lower surface of the concrete trackbed) to remove adhesion between the concrete trackbed and the viaduct. This means that the concrete trackbed and the viaduct were connected only by the reinforcing bars.

Prior to concrete placing, PP fiber was added at 0.5 vol.% to the base concrete (nominal compressive strength 27 MPa, slump 18cm, air amount 4.5 ± 1.5 %) which was loaded into the agitator truck. Results of investigations presented in the previous chapter showed that there was no difference in loading capacity whichever of the two fibers used. Therefore, short fiber reinforced concrete mixed with PP fiber was used in this test.

The prepared short fiber reinforced concrete was pumped over the horizontal equivalent distance of 60 m by concrete pumping (Fig. 5). Workability of the concrete was good, and no pump piping blockages were found. After removing the formwork, no construction defects such as insufficient filling in the concrete trackbed (Fig. 6) were found. For the two types of short fiber reinforced concrete

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**Fig. 4** Details of STR Type-S on test line (unit: mm)

**Fig. 5** Concrete pumping of short fiber reinforced concrete for concrete trackbed

**Fig. 6** Constructed STR Type-S on test line
using PP fiber or PVA fiber, concrete pumping tests over horizontal equivalent distance of 150 m were also performed respectively assuming actual implementation, and it was confirmed that they can be pumped satisfactorily.

Lateral loading tests in the sleeper longitudinal direction, motor car running tests and impact hammer vibration tests were performed after 28 days of concrete placing. Fig. 7 shows the results of the lateral loading tests. Lateral loads were applied three times to a sleeper without rail fastenings, targeting the design load of about 50 kN. The tests were executed under severe conditions with no adhesion between the concrete trackbed and the viaduct; however, it was confirmed that STR Type-S had sufficient strength against the design load of about 50 kN. Similar lateral loading tests were carried out on the rail with rail fastenings, and it was also confirmed that STR Type-S had sufficient strength.

In the track motor car running tests, the track support stiffness was obtained by calculation based on the measurement of the wheel weight of track motor car (30 kN) and the maximum rail vertical displacement in the respective sections of the STR Type-S and the slab track. The track support stiffness obtained for the STR Type-S was 36 MN/m, which is about 50% less than for slab track (68 MN/m). Since the spring constant of the rail pad and that of the under sleeper pad of STR Type-S were set respectively to the same values as those on existing STR Type-D, the track support stiffness obtained was substantially in agreement with the 38 MN/m measured on STR Type-D in the past [1].

Finally, the impact hammer vibration test was performed. The impact loads were applied to one side of the rail in the center of the viaduct. Vibration acceleration was measured using an accelerometer installed at the bottom of the floor slab of the viaduct under the impact loading point. Results confirmed that the vibration acceleration was smaller in the ranges of 10 Hz or less (contributing to ground vibration) and 300 Hz or more (contributing to structure borne noise) than on slab track. This therefore confirmed that STR Type-S has the same vibration reducing performance as the existing STR Type-D.

4. Field construction

STR Type-S was practically adopted in the construction, and its workability and cost in the actual construction environment were confirmed.

Figure 8 shows the STR Type-S construction site. It was confirmed that the required arrangement of the formwork for the concrete trackbed can be easily achieved by pressing the form to the sleepers, and the concrete placing of the concrete trackbed can be smoothly executed. As a result of surface observation after removing the form, concrete filling failures were not recognized.

Figure 9 shows the integrated construction cost. The integrated construction cost was calculated assuming the construction of a 940 m extension on the viaduct.

The calculated construction cost of the STR Type-S concrete trackbed was 60% lower than for the STR Type-D, due to the easier placement of the formwork and lower amount of placed concrete. It was also confirmed that the overall track construction cost could be reduced by 20%. In addition, the more efficient method used for construct-

![Fig. 8 STR Type-S construction site](image)

(a) After formwork

![Fig. 7 Relationship between lateral load and lateral displacement on test line](image)

(b) Constructed STR Type-S

![Fig. 9 shows the integrated construction cost. The](image)
We developed a new STR Type-S using shear-keys to achieve the efficient construction work. The results on full-scale track model tests confirmed that the STR Type-S meets required railway track performance criteria. Furthermore, actual construction of a section of STR Type-S confirmed that construction cost of the concrete trackbed was able to be cut by 60% compared to the existing STR Type-D, reducing overall track construction cost by 20%. Furthermore, the narrower concrete trackbed of STR Type-S made track laying 1.7 times faster, reducing the construction time.

References

[1] Ando, K., Mukai, A., Horiike, T., Sunaga, Y., Takao, K., and KITO, A., “Development of Solid-Bed Track with Resilient Ties,” Quarterly Report of RTRI, Vol. 43, No.3, pp. 107-112, September 2002.

[2] Tanigawa, H., Takahashi, T., Momoya, Y., Tsubaki, T., Komatsu, S. and Asano, A., “Lateral loading tests on solid bed track with resilient sleepers that can resist the lateral load by the shear key on the side of the sleeper,” The 71st JSCE Annual Meeting Proceedings, Japan Society of Civil Engineers, VI-095, pp. 189-190, 2016 (in Japanese).

[3] Japan standards association, “Prestressed concrete sleepers - Post-tensioning type,” Japan Industrial Standards, JIS 1202, 1997 (in Japanese).

[4] Railway Technical Research Institute, Design Standards for Railway Structures and Commentary – Track Structures, Maruzen Publishing Co., Ltd., Tokyo, JAPAN, 2012 (in Japanese).

[5] Tanigawa, H., Takahashi, T., Momoya, Y. and Kikkawa, S., “Performance confirmation tests of STR Type-S,” The 72nd JSCE Annual Meeting Proceedings, Japan Society of Civil Engineers, VI-129, pp. 257-258, 2017 (in Japanese).

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