Design and construction of open deck bridge

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ABSTRACT: A railway bridge intersecting a river was to be reconstructed, as part of a river improvement project. It was necessary to reconstruct the bridge at a length of 119.2 meters, as the old bridge was a steel deck bridge of 52.78 meters, and obstructed flood flow. The most effective way to keep construction cost at a minimum is to limit the roadbed height at access. Therefore, in selecting the style of the new fin-back type bridge, through-bridge form was applied to keep the rail level as low as possible, and in consideration of aesthetics, at three-span continuation PRC through-bridge was chosen. In addition, the bridge is an open deck type which has openings in the deck as the bridge is located in one of the heaviest areas of snowfall in Japan, so it was necessary to take measures to cope with snowfall.

1 INTRODUCTION

The river improvement project by Yamagata prefecture was undertaken along the Yoshino River which flows through Nanyo-shi, Yamagata. As part of this project, the First Yoshino River Bridge was to be reconstructed intersecting the river between Takahata Station and Akayu Station on the Ou Main Line.

The old bridge was a steel deck bridge with a length of 52.78 meters, and since it obstructed the flow of the river in times of flood, it was necessary to reconstruct the bridge at a length of 119.2 meters. The old bridge is shown in Photograph 1. Then bridge form was selected in consideration of the following points: First, there are railroad crossings on both side of this bridge, and a large amount of construction cost would be required to relocate or to raise these crossings. Therefore it was necessary to select a type that could keep the roadbed height of the approach part at a minimum to economize on construction cost. Furthermore, it was necessary to consider aesthetics and the view from the train window. Finally, because the bridge is located in one of the heaviest areas of snowfall in Japan, it was necessary to take measures to cope with snowfall to save on labor for maintenance work such as snow removal.

In order to meet the above conditions, a fin-back type three-span continuation PRC through-bridge with open deck was chosen. In this report, we introduce the design and the construction of the First Yoshino River Bridge with this form.

2 THE BRIDGE SUMMARY

The summary of the First Yoshino River Bridge is shown below:

- Bridge name: First Yoshino River
- Location: Nanyo-shi, Yamagata
- Bridge form: three-span continuation PRC through bridge with open deck
- Length of bridge: 119.2 meters
- Span length: 34.1 m + 49.7 m + 34.1 m
- Alignment: straight line
- Vertical gradient: none

The general figure of the bridge is shown in Figure 1 and the cross section of the girder is shown in Figure 2.
Through-bridge type was selected so that rail level need not be raised significantly possible, in order to save in construction cost. Furthermore, in consideration of aesthetics and view from the train window, the fin-back type was selected for continuity and heighten the beam only at the piers (see Figure 1). Finally, as a measure to cope with snowfall, open deck type was chosen in order to make snow removal work unnecessary.

In addition, the structure of the bridge’s track is that which has PC ties with elastic material attached to the undersurface, borne by concrete for height adjustment. A summary of the track structure is shown in Figure 3. This track has low-maintenance features such as slab track, and its structure is effective in reducing noise and vibration.
3 DESIGN SUMMARY

3.1 Structure summary

The open deck type was adopted as a measure to cope with snowfall. The structure of the girder is shown in Figure 4. First of all, a stringer bears the load of the track directly. Next, horizontal beams which were installed at right angles with the stringers bear the load of the stringers which in turn are bearing the track. Furthermore, it has the lattice structure in which the main beam bears the load of the horizontal beam. The underside of the girder is shown in Photograph 2.

The shape of the girder is fin-back style in consideration of aesthetics and the view from train window. As seen in Figure 2, by slanting the web and placing the upper flange inside of the web, it was made possible by the shape of the girder section to place the main-direction prestressed steel of the anchorage blocks inside the main beam, without adverse effect on the structure gauge.

Furthermore, the horizontal beam interval was 3.75 m, 5 times the railroad tie interval, so that railroad tie may be laid on a horizontal beam to prevent reduction of the open area ratio on the deck due to railroad ties. The section of the stringer was made with T-type section, for the purpose of keeping the width for laying track and reduction of the upper tensile stress.

Finally, in consideration of safety, such as maintenance work, grating was installed in the opening of the deck. In order to prevent accumulation of snowfall, the lattice opening pitch was set at 60 mm by 200 mm.

3.2 Structural analysis

3.2.1 Design condition

The design criteria of this bridge is shown in Table 1.

### Table 1. Design criteria.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Bridge name</td>
<td>First Yoshino River</td>
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<tr>
<td>Bridge form</td>
<td>3 span continuation PRC through bridge which has open deck</td>
</tr>
<tr>
<td>Length of bridge</td>
<td>119.2 meters</td>
</tr>
<tr>
<td>Span length</td>
<td>34.1 m + 49.7 m + 34.1 m</td>
</tr>
<tr>
<td>Alignment</td>
<td>Straight</td>
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<td>Skew</td>
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<td>Characteristic values of loads</td>
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<td>Train load</td>
<td>EA-17 (locomotion load)</td>
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<td>Maximum speed</td>
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<td>Impact factor</td>
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<tr>
<td>Side span</td>
<td>0.29 (ultimate limit state)</td>
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<tr>
<td>beam &amp; Center span</td>
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<tr>
<td>stringer</td>
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<tr>
<td>Horizontal beam</td>
<td></td>
</tr>
<tr>
<td>Train number</td>
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</tr>
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<td>35/day (each line both directions)</td>
</tr>
<tr>
<td>Freight trains</td>
<td>75/day (each line both directions)</td>
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<td>Environmental condition</td>
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</table>

3.2.2 Analysis model

In the analysis of a through-bridge, the plane lattice model is generally used. However, in the case of a structure in which a main beam and a stringer are combined as in this bridge with the horizontal beam, it cannot evaluate axial force by bending deformation of the main beam that occurs to a stringer. Therefore, analysis was conducted using a solid lattice model with a main beam, a stringer, and a horizontal beam as wire rods. The summary of the solid lattice model is shown in Figure 5.

3.2.3 Design of members

The main beam and stringer were designed as PRC structure in order to prevent creep deformation, and permanent load was designed so as to prevent tensile
stress from occurring on the upper edge. As the result of calculation, the volume of deformation at the time of the end of creep was controlled by about 10 mm. Furthermore, since this girder is the structure where the horizontal beam is hung by the main beam, the hanging load from a horizontal beam acts on the main beam. Then, in addition to the shear reinforcing steel of the main beam, reinforcing bars for hanging have been arranged on the main beam.

The horizontal beam which is supporting a stringer was designed as PC structure. This bridge’s structure is a main beam and stringer joined by a horizontal beam, with rigid juncture. Thus, the member force from the horizontal direction caused by the difference of the axial direction deformation of the main beam and stringer acts on the horizontal beam, in addition of the member force of the vertical direction. So, the flexural moment of two directions was taken into consideration in the design of the horizontal beam.

4 CONSTRUCTION SUMMARY

4.1 Change of track

At first, a temporary bridge and temporary embankment were put up downstream of the old bridge, before beginning the construction of the new bridge. Next, the commercial line was detoured after the track was installed on the temporary bridge and embankment. After that, the new bridge was constructed after the old bridge was dismantled. Finally, the commercial line was returned to the main line after the new bridge was completed. By the 4 steps stated above, the track was changed and the First Yoshino River Bridge reconstructed. We show the change of tracks in Figure 6.

4.2 Placing of concrete in sections

The volume of concrete for the girder of this bridge is about 634 m³. At this construction, the concrete was placed in four sections for the following reasons: First, the shape of the girder is complicated. Reinforced bars and prestressed steel were installed with high density. Furthermore, yard space was limited due to the site being above a river, and thus there were limitations in space available for concrete pumps and agitator trucks. Finally, the concrete plant did not have high capability for producing concrete.

The joint was set at a section where the shear force was as slight as possible. Consideration was made to the location of anchorages of prestressed steel and the position of the horizontal beam. The location of dividing sections and member force are shown in Figure 7.

4.3 Test placing of concrete

There was some concern regarding concrete compaction at this girder, because this girder is a U-shape through-girder with slanted web as shown in Figure 2, and the slope of the haunch of the lower flange has a gentle grade and is wide as well. Furthermore, in the joint area of the main beam and the horizontal beam, the prestressed steel anchorage, reinforcing bars and anchorages, etc. are crowded. So it was tested using a full-size test piece as shown in Photograph 3, for the purpose of confirming the method of placing concrete and the condition of concrete compaction.

In this test, as shown in Figure 8, the opening to insert an internal vibrator was prepared in the
formwork of the haunch at pitches of 100 by 100, cylin-
drical vibrator was used for the slanting web, and it
was considered as an appropriate construction method
which could ensure sufficient compaction of concrete.

As a result of the test, since the condition of comp-
action of concrete was satisfactory, concrete was
placed by this method in the final construction.

4.4 Prestressing order
As the main beam, the stringer, and the horizontal beam
which differ in member rigidity are joined rigidly in
the shape of a lattice, there is a possibility that crack-
ing may occur in a member or juncture of this bridge
due to imbalance, such as drying shrinkage, thermal
stress, and prestressing. Especially, sufficient strength
may not yet have developed in the concrete at the time
of initial prestressing. Thus, a prestressing order was
determined so that prestressing forces are introduced
into the members equally and gradually. The steps of
the prestressing order are shown in Figure 9.
STEP 1. Prestressing of the horizontal beam tendons on the pier and abutment
In order to prevent cracking by the dead load at the time of main beam prestressing, tendons of the horizontal beam on the support are tensioned.

STEP 2. Primary prestressing of the stringer tendons
In order to prevent cracking by the upper curvature at the time of horizontal beam prestressing, one tendon of the each stringer is tensioned.

STEP 3. Primary prestressing of the horizontal beam tendons
In order to prevent cracking by the curvature at the time of main beam prestressing, the tendon of the half of all the horizontal beams is tensioned.

STEP 4. Prestressing of the main beam tendons
Tendons of all the main beam are tensioned.

STEP 5. Secondary prestressing of the stringer tendons
All the remaining stringer tendons are tensioned.

STEP 6. Secondary prestressing of the horizontal beam tendons
All the remaining horizontal beam tendons are tensioned.

Figure 9. Steps of the prestressing order.

Photograph 4. Panorama of the bridge.

As a result, potentially harmful cracking in this girder was controllable.

5 CONCLUSIONS

We have indicated the particular characteristics of construction and appropriate measures for design of a bridge which has an open deck. In addition, since the rail level of this bridge is restricted, height adjustment concrete under PC tie shown in Figure 3 was as designed thin as 70 mm. Therefore, construction management was carried out strictly. The design and construction as shown in this paper was conducted, and the construction ended with no problems.
the construction of track change over is also finished, and is now in use as shown in Photograph 4.

Here, the cover snow situation of a deck when it snowed in January last year is shown in Photograph 5. As can be seen in the photograph, the open deck type has greatly reduced problems with snow.

The PRC bridge with open deck has few construction records even in Japan, and this case is the second in our company. In a district with much snowfall, it seems that open deck structure is effective. We would be pleased if this paper could become a reference for design and construction of the same type of bridge.