

Hybrid prestressed concrete bridges with steel truss webs-Sarutagawa bridge and Tomoegawa bridge

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ABSTRACT: The Sarutagawa Bridge and the Tomoegawa Bridge are hybrid pre-stressed concrete bridges with steel truss webs constructed on the Shin-Tomei Expressway in Japan. They are the world’s largest composite truss bridges, with the rigid frame structure applied for the first time in the world. In addition, they are situated in a mountainous region and create the appearance in harmony with surroundings. This paper reports design and construction of the Sarutagawa Bridge and the Tomoegawa Bridge.

1 INTRODUCTION

The Sarutagawa Bridge and the Tomoegawa Bridge (Figure 1) are hybrid prestressed concrete bridges with steel truss webs constructed on the Shin-Tomei Expressway in Japan. They located in Shizuoka Prefecture a part of the Shin-Tomei Expressway which was opened in 2012 and are situated in a mountainous region. The Sarutagawa Bridge and Tomoegawa Bridge, including earthwork road sections, have a total length of 1.2km and width of 16.5m. They are the world’s largest composite truss bridges, with the rigid frame structure applied for the first time in the world.

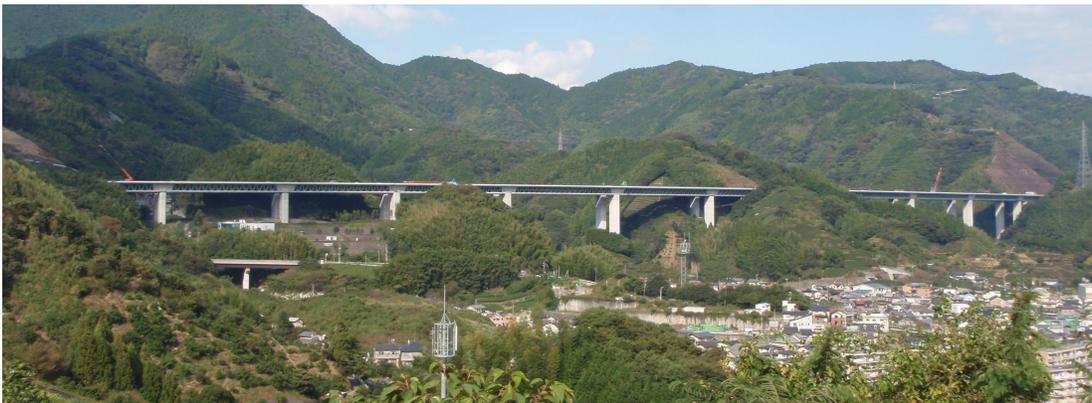


Figure 1. Overview

2 OUTLINE OF THE PROJECT

These bridges individually consist of separate westbound and eastbound line. Construction of the westbound line preceded that of the eastbound line; the westbound line (Table1, Figure 2) constructed from 2003 to 2006, the eastbound line (Table1, Figure 3) constructed from 2006 to 2009.

Table 1. Outline of the project

	Westbound line	Eastbound line
Structure	PC continuous rigid frame composite truss bridge	
Span length	Sarutagawa 625m (63.5+2*90+100+2*110+58.5) Tomoegawa 479m (57+3*119+62)	Sarutagawa 610m (48.5+2*90+100+2*110+58.5) Tomoegawa 479m (57+3*119+62)
Effective width	16.5m	16.5m

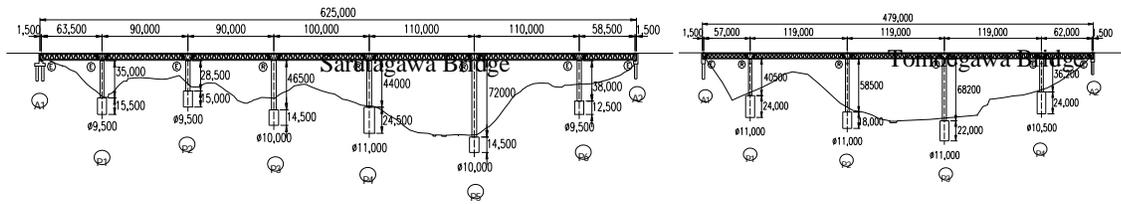


Figure 2. Westbound line

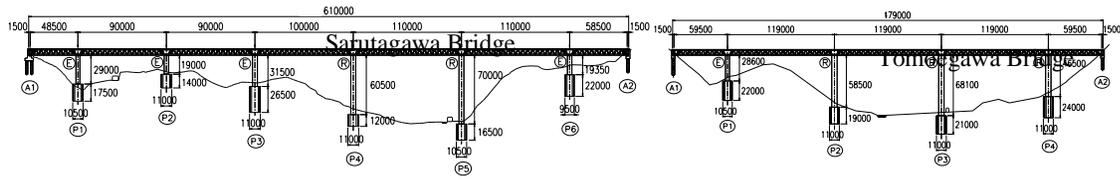


Figure 3. Eastbound line

During the work on the westbound line, new joint systems were developed and the composite truss structure was tested for its validity and safety through various analysis and experiments. Based on the knowledge obtained from the proceeding project, the number of truss panels was reduced from 4 to 3 and further rationalization efforts were made on the eastbound line (Figure 4).

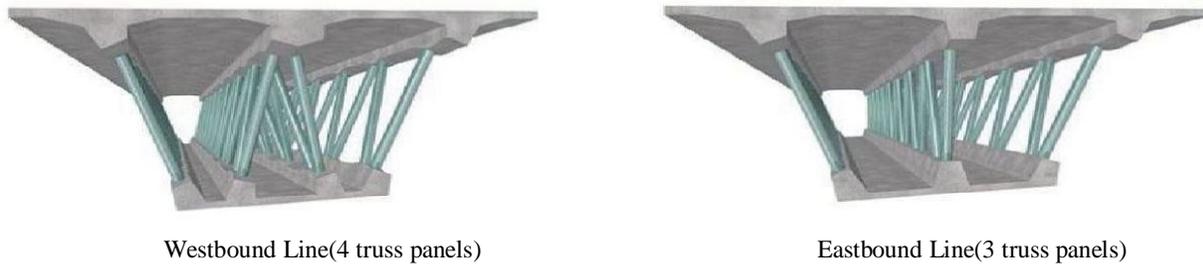


Figure 4. Cross Section

3 STRUCTURE

The PC composite truss bridge is a hybrid structure in which webs of a conventional PC box girder bridge are replaced by steel truss diagonals. The application of steel truss webs reduces the dead weight of main girder, rationalizes construction. It provides good visual transparency and also creates the appearance in harmony with surroundings, adding an attractive aesthetic feature to the structure.

The main girder is composed of upper and lower concrete slabs and steel truss webs (Figure 5). The truss type is Warren truss type and a truss span is 5.0m. The upper and lower slabs are prestressed concrete slabs and stiffened by longitudinal concrete ribs.

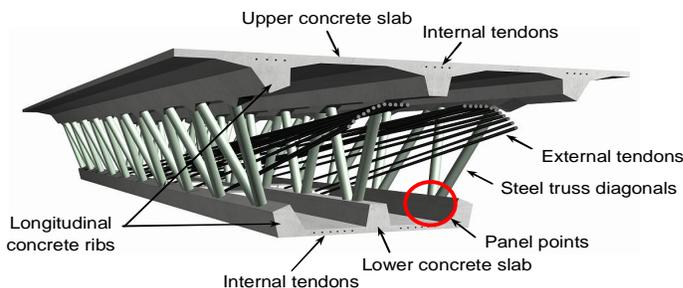


Figure 5. The main girder cross section

3.1 Joint System

The panel points where the steel truss is connected to the concrete slabs are the most important regions in this structure. Double steel-pipe joint system and double friction gusset joint system were developed in the design of westbound line and used in these bridges in an effort to rationalize both the structural design and construction work. Structural properties and safety performance of these new joint systems were verified through partial model experiment and composite truss beam model experiments during the development. In case of westbound line, double steel-pipe joint system were used at the panel points when the axis forces were under 3000kN and double friction gusset joint system were used at the panel points when the axis forces were above 3000kN. In the other hand, in case of eastbound line, double friction gusset joint system were used at all the panel points.

3.1.1 Double steel-pipe joint system

As shown in Figure 6, the double steel-pipe joint system is composed of the processed steel pipes with outer ribs which are extensions of the steel truss diagonals, perforated steel pipes with inner and outer ribs which are placed outside of the steel pipes, and a plate connecting these perforated steel pipes together. Axial force of a truss diagonal is transmitted from its outer ribs at the joint through the concrete to the outer steel pipe with ribs. The axial force is then transmitted to the other truss diagonal as shear force through the steel reinforced concrete structure consisting of the surrounding reinforced concrete and the connecting plate.

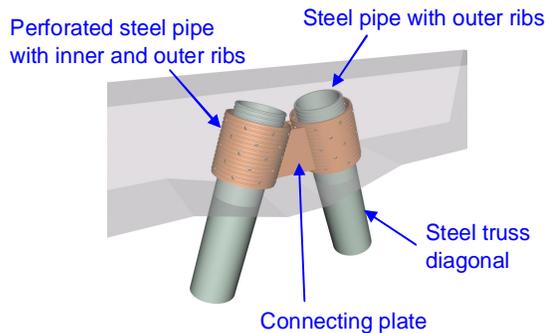


Figure 6. Double steel-pipe joint system

3.1.2 Double friction gusset joint system

As shown in Figure 7, a gusset is joined to the steel truss diagonals by full penetration welding. Two splice plates sandwich the gusset. High strength bolts fasten them all together, so that the steel members primarily transmit shear force through this friction grip connection. The high strength bolt connection by double friction allowed the joint system to be designed compact.

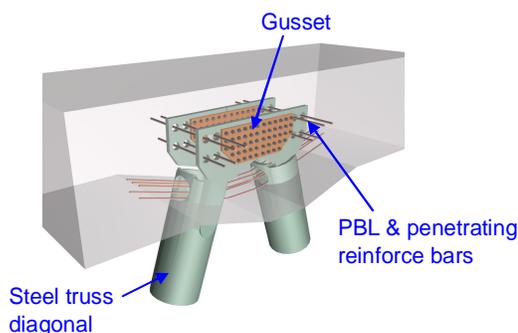


Figure 7. Double friction gusset joint system

3.2 Design of the Superstructure

3.2.1 Design of the longitudinal direction

For the longitudinal structure analysis, a stepped analysis was carried out using plane frame models based on the construction steps so that section force generated in the truss components (the upper and lower slabs and truss diagonals) was evaluated precisely. The external tendons were also modeled in the analysis in order to evaluate their effect quantitatively.

3.2.2 Arrangement of the tendons

There are cantilever tendons and continuity tendons for both the Sarutagawa Bridge and the Tomoegawa Bridge. The cantilever tendons have internal and external tendons. Internal tendons (12S15.2) are arranged in the upper slab and are anchored at the end of each segment near longitudinal ribs. External tendons (19S15.2) are placed from the pier top segment to the lower slabs of cantilever segments. These cantilever external tendons are installed to reduce the axial force in the truss diagonals (Figure 8).

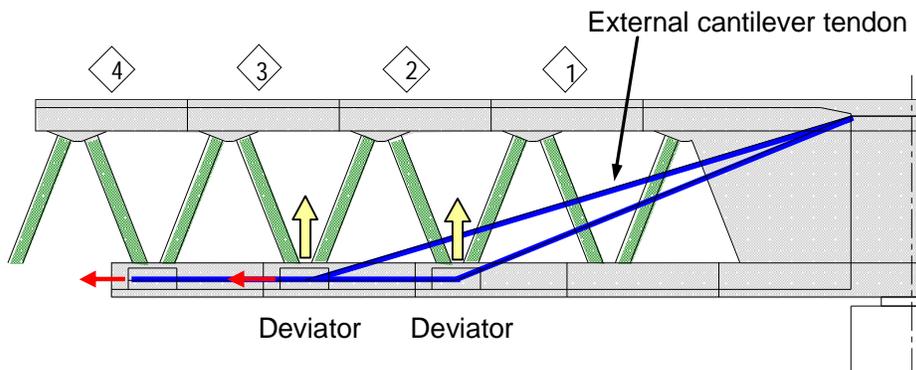


Figure 8. External cantilever tendons

There are internal and external tendons for continuity tendons. They are prestressed after stitching each cantilever. Internal tendons are arranged in the lower slabs. External tendons are deviated in the lower slabs and anchored at the pier top segment. Internal tendons are protected against corrosion by cement grout. External tendons, which are fabricated in a factory, are multiple galvanized strands with high-density polyethylene covering. The arrangement of external tendons is shown in Figure 9



Westbound Line (4 truss panels)



Eastbound Line (3 truss panels)

Figure 9. External tendon arrangement

3.2.3 Design of the steel truss diagonals

The truss diagonals are comprised of SM490YB steel pipes. A single range of pipes with an external diameter of 457.2mm is used. Their thickness ranges from 9mm to 30mm. The steel truss diagonals are designed as elements which receive axial force and bending moment since they are rigidly connected at the panel points. Compression diagonals under high axial force are filled with the same concrete as concrete slabs to reduce the plate thickness.

3.3 Construction of the Superstructure

The cantilever segments have an equal length to the intervals of the Warren truss (5.0m), taking advantage of the truss structure for rational construction. The panel points are positioned in alternate patterns between the upper and lower slabs every 2.5 m (one-half the segment length), and construction joints of the upper slabs are placed 2.5 m ahead of those of the lower slabs, so that loads applied to the form travelers during construction are reduced (Figure 10).

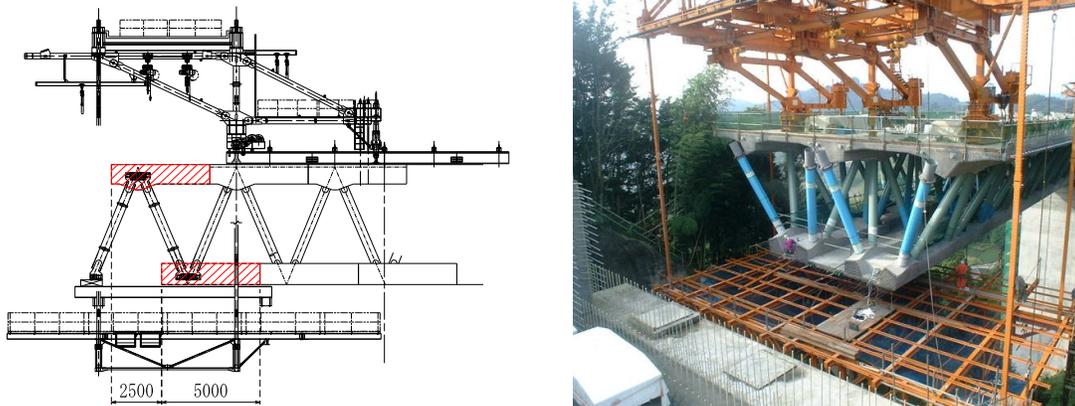


Figure 10. Form travelers

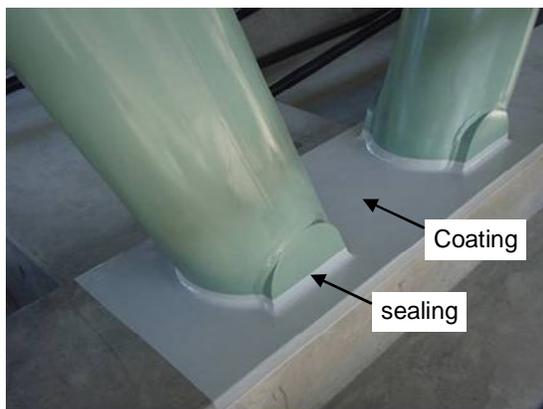


Figure 11. Waterproof of connection

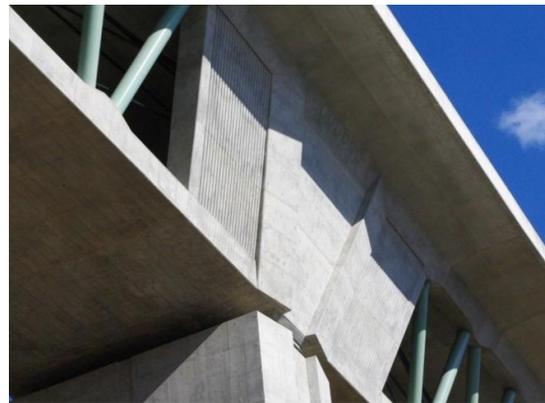


Figure 12. Textured wall

3.4 Waterproof of Connection

The panel points of the steel truss diagonals are directly embedded in the concrete slabs, so these are able to be structural weak points. There is a concern that the corrosion of connections is caused by rainwater or condensation. Therefore, the area around the boundary between the steel pipe and concrete is covered with epoxy resin coating and is sealed with silicone sealant (Figure 11).

4 APPEARANCE

The length (longitudinal distance) of the pier top segments is about 17.5 m, which is longer than a common length of 12.0 m in conventional PC box girder bridges. This is because the studded steel truss diagonals connected by the joint systems are embedded in the concrete webs as smooth transmission of force from the steel members to the concrete. The large concrete surfaces of the webs are textured in aesthetic consideration (Figure 12).

The color of the steel truss diagonals adapts low intensity green, because of considering harmony with around mountains and not feeling the perception of heaviness and pressure. As a result, these bridges provide good visual transparency (Figure 13)

5 MAINTENANCE

After opening the Shin-Tomei expressway which was opened in 2012, these bridges are inspected on the basis of inspection manual. The inspection manual is only for them and was made for in order to tell design concept and structural features of them to the inspector. It is expected to be useful for efficient and effective inspection.



Figure 13. Appearance of bridge

6 CONCLUSIONS

The Sarutagawa Bridge and the Tomoegawa Bridge were completed in Dec. 2009, after over ten years from the start of foundation and substructure construction in July 1999. During the work on the westbound line, new joint systems were developed and the composite truss structure was tested for its validity and safety through various analysis and experiments. Structural properties and safety performance of these new joint systems were verified through partial model experiment and composite truss beam model experiments. Based on the knowledge obtained from the preceding project, the number of truss panels was reduced from 4 to 3 and further rationalization efforts were made on the eastbound line. We hope findings obtained from this project would be of help in future development of PC composite truss bridges.

REFERENCES

- T. Yamaguchi and K. Aoki, An experimental study on performance of joints for composite truss bridge, IABSE 2005, Portugal (2005)