Design and Construction of the first composite truss bridge in Japan
Kinokawa Viaduct, Wakayama, Japan

Masato YAMAMURA
Professional Engineer
Kajima Corporation
Tokyo, Japan

Hiroaki OKAMOTO
Professional Engineer
Kajima Corporation
Tokyo, Japan

Hiroo MINAMI
Professional Engineer
Kajima Corporation
Tokyo, Japan

Summary

This project is to build a viaduct in Wakayama, Japan. Owner adopted a design build bidding system for the first time in its history of a bridge project in order to tender a construction work including both the superstructure and the substructure together. As a result of bidding, it was decided that the first composite truss bridge in Japan is constructed. Through the project, it was confirmed that the construction and the economical efficiency of the composite truss bridge are equivalent to or better than the conventional pretressed concrete box girder bridge.

Keywords: composite truss bridge; design build; steel truss diagonal; panel point section; steel box-type joint structure; balanced cantilever erection

1. Introduction

This project is to build a viaduct over the Kinokawa River in Wakayama. Ministry of Land, Infrastructure and Transport (MLIT) adopted a design build bidding system for the first time in its history of a bridge project in order to tender a construction work including both the superstructure and the substructure together. In the tendering method used at this time, only the basic performance requirements such as the bridge length, road classification, effective width, and live loads are specified. A proposal of a variety of bridge design, mainly for its form and the number of span, was admitted by MLIT. As a result of bidding, the contract was awarded to Kajima Corporation that proposed the composite truss bridge for the project.

2. Outline of the Kinokawa viaduct

2.1. Outline of the Project

Project name: Kinokawa viaduct
Owner: Ministry of Land, Infrastructure and Transport
Contractor (Design/Build): Kajima Corporation
Location: Shingu City, Wakayama Prefecture, Japan
Total bridge length: 268m
Span length: 51.85m+85.0m+85.0m+43.85m
Deck width: 11.15m

Photograph-1. Kinokawa viaduct

2.2. Composite truss bridge

In a composite truss bridge, the box girder bridge's concrete webs are replaced with steel truss diagonals and the upper and lower deck slabs are made of prestressed concrete(Figure-2). This structure has the following characteristics compared with a conventional prestressed concrete box girder bridge:

a) By reducing the main girder dead weight, the load to not only the superstructure but also to the substructure can be reduced.

b) Since it doesn't require assembling the web section form works, reinforcement bars, and prestressing cables, and concrete installation, it saves labor and reduces construction time.

c) Because it uses the truss structure as the web section, it increases transparency and enables a bridge to be merged into the surrounding aesthetic environment.

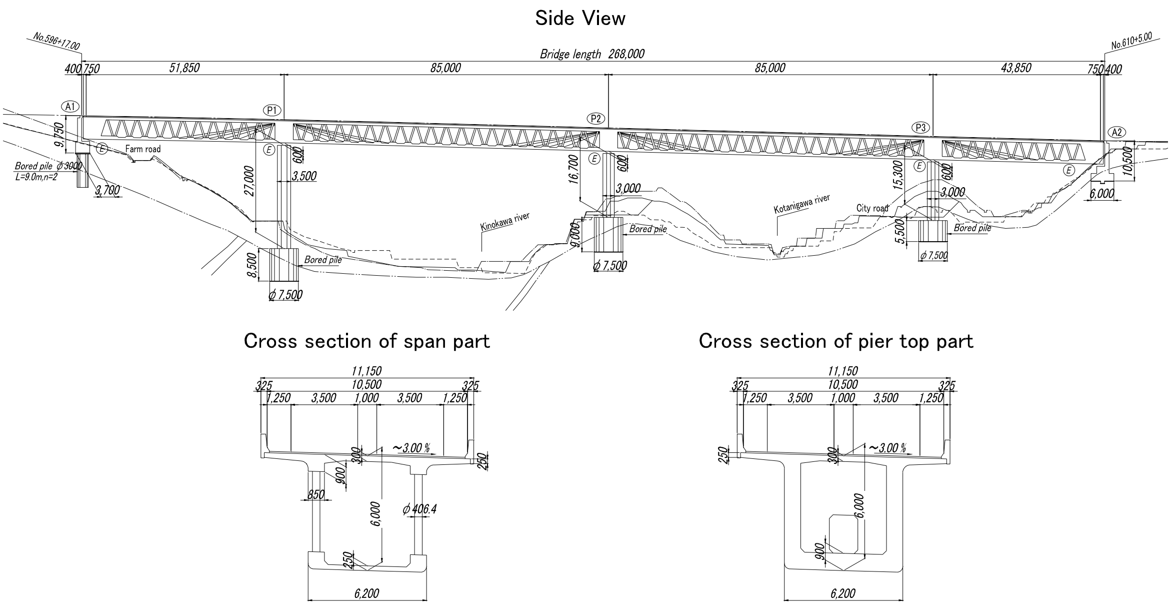


Figure-1. General view

2.3. Panel point section

In the structure of a composite truss bridge, one of the most important elements is the panel point section. A steel box-type panel joint structure developed by Kajima Corporation has been adopted(Figure-3). A steel box-type panel joint structure has the following advantages:

a) Manufacturing is easier.

b) Material procurement is easier.

c) Since there is no connection between tensile diagonals and compressive diagonals before casting concrete, the setting adjustment of these portions can be done more easily.

Prior to its adoption, a fatigue test of a full-scale model was conducted to check safety against repeated load. Static load tests were also performed to ensure safety(Photograph-2).

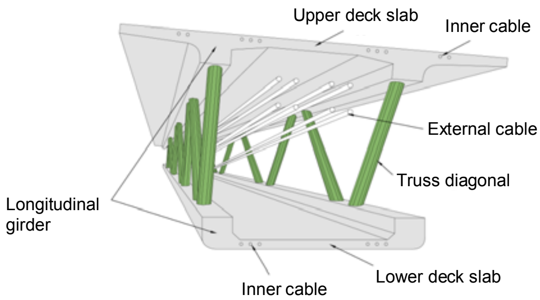


Figure-2. Composite truss bridge

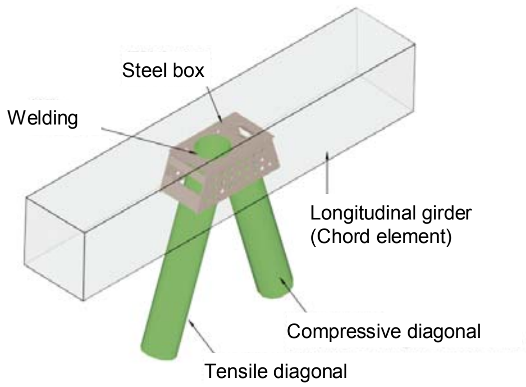


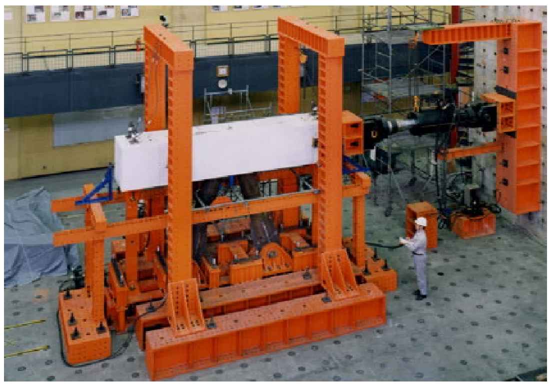
Figure-3. Steel box-type joint

3. Design

3.1. Characteristics

3.1.1. Bridge scheme

After comparing the rigid frame structure and the continuous girder structure (for their advantages and disadvantages), the latter (continuous girder structure) was chosen. The main reason for its selection was that the continuous girder structure with quake-absorbing bearings could simplify the superstructure, reduce the size of the bridge pier/foundation, and improve the construction efficiency and durability of the structure system as a whole without increasing the total cost.



Photograph-2. Fatigue test of full scale

3.1.2. Girder cross section

The girder cross section was made to be equal to 6m in girder height over the entire bridge. Because a composite truss bridge replaces the concrete webs with steel tubes, it hardly increases the dead weight even for the higher girder. Therefore, the girder height has increased as far as the construction limit height of the intersecting road, to increase the cross-sectional rigidity and cross-sectional durability and to reduce the quantity of the prestressing cables.

3.1.3. Steel truss diagonal

Round-shape steel tubes (STK490, diameter:406.4mm, thickness: 9.5~22 mm) were used as the steel truss diagonal, because there is no weldability problem in the joint structure and more economical than a rectangular steel tube. The inside of the steel tubes, where compressive axial force acts on, were filled with the same concrete used for the deck slab. By this work, the tubes become steel/concrete composite structure resulting in the reduction of the steel tube plate thickness.

3.2. Longitudinal design

As the longitudinal design model, the plane framework truss model shown in Figure-4 was chosen because: 1) cross-sectional forces of the truss components (upper and lower deck slabs and diagonal) can be directly computed and 2) an effect of an additional cross-sectional force due to displacement between the deck slab axis center and the diagonal axis center can be taken into account.

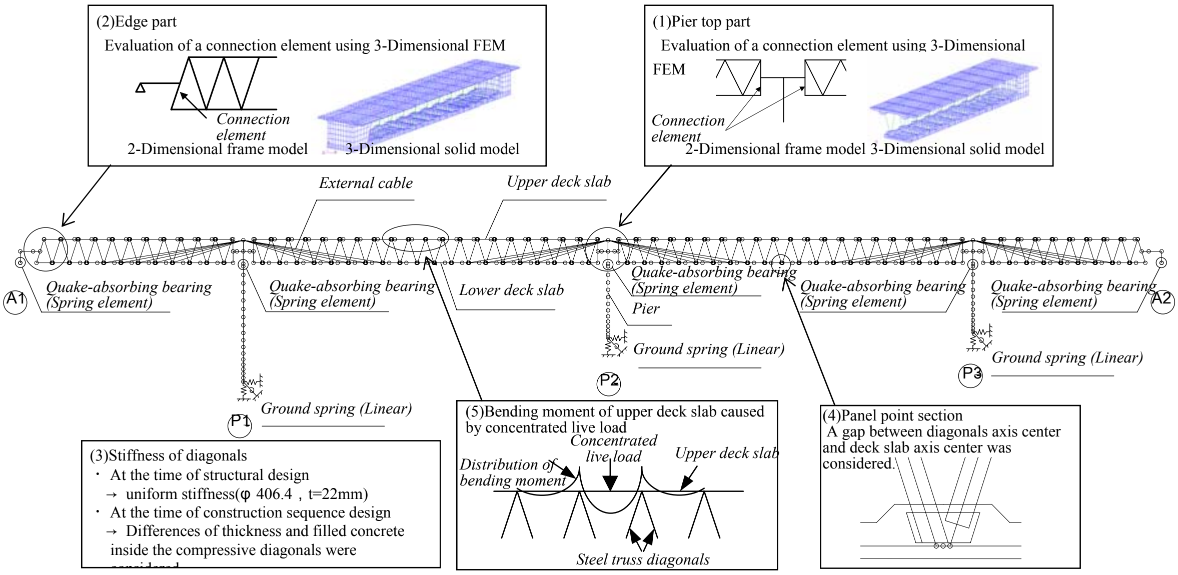


Figure-4. Analysis model of longitudinal design

3.3. Deck slab design

While the deck slab of a conventional prestressed concrete box girder is continuously supported by webs in the longitudinal direction, the deck slab in a composite truss bridge has a structure which is continually supported by the steel truss diagonals. Therefore, it is expected that the behavior and cross-sectional force will be evaluated to be different from the actual ones in the plane framework model, which is usually used to design conventional box girders of the deck slab. Deck slab design was conducted using three-dimensional finite element method analysis using shell elements (Figure-5).

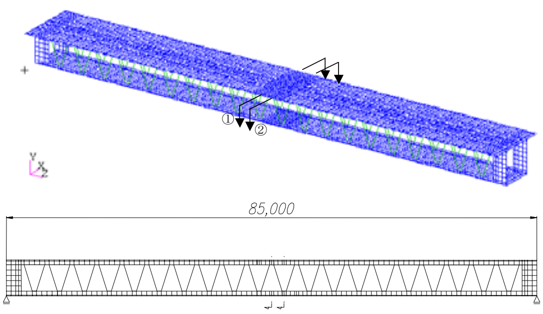


Figure-5. Analysis model of deck slab

3.4. Diagonal design

The diagonal was designed by taking into account the diagonal cross-sectional force, the deviated loading of live load, and the cross sectional force in a transverse direction to the bridge axis in all stages from construction time to the end of creep phenomenon after completion.

In designing the tensile diagonal, inspection was conducted for: 1) the element cross sections as elements which loaded axial force and bending moment and 2) shear forces of elements which loaded both compressive stress and shear stress at the same time, following the procedure in "Specifications for Highway Bridges, Part II, Steel Bridge"(Japan Road Association).

The compressive diagonals filled with concrete were designed as concrete and steel composite tube. Resistivity of the compressive diagonal is computed using a method introduced in "Concrete-filled Steel Tube Structure Designing and Processing Guide" (Japan Architecture Society).

3.5. Design of panel point section

Because the panel point section of a composite truss bridge is one of the most important structural portions that compose the composite truss structure and also because the behavior of the panel point section greatly influences the behavior of other elements, a special attention was paid in a design stage to the following three points:

a) The joint structure should not be collapsed before other elements.

b) Stress of reinforcing steel materials, such as steel plate and reinforcement bar that compose the joint structure, should remain below the yield point even when the ultimate load is applied.

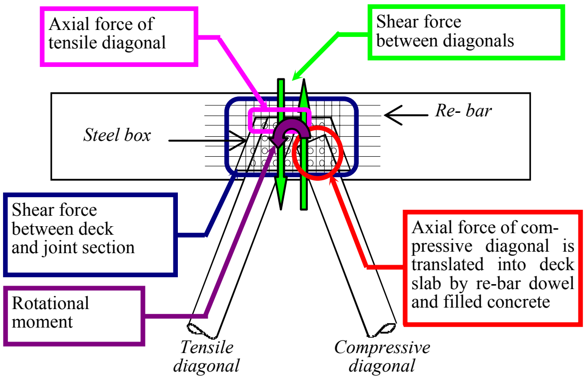


Figure-6. Panel point structure

c) No crack should occur of the concrete surrounding the joint structure at the design load.

4. Construction

4.1. Construction procedure

The construction procedure is shown in Figure-7. A construction service road was constructed first from A2 abutment to P3 bridge pier. The construction of the bridge was started simultaneously with the construction of the service road (including the temporary piers) at locations where the surface for construction work had been made available. The bridge pier foundations and bodies were constructed consecutively for P3, P2 and P1 piers in this order. The main girders were constructed also in the same order. A1 and A2 abutments on both sides of the bridge were constructed while the main girders were placed. The cantilevered main girders were connected to each other on columnar supports and suspended supports.

4.2. Superstructure

4.2.1. Column-top structures

The column-top structures were constructed on the bracket support on the bridge pier in three lifts: (i) lower deck slab, (ii) cross beams at the column top and (iii) upper slab deck. 12 diagonals were installed at the top of the column. The steel box under the tensile diagonal was installed on the concrete spacer resting on the formwork, and on the support. The steel box on the tensile diagonal was placed on the steel installed using the support of upper deck slab formwork.


Photograph-3. Diagonals at the column-top

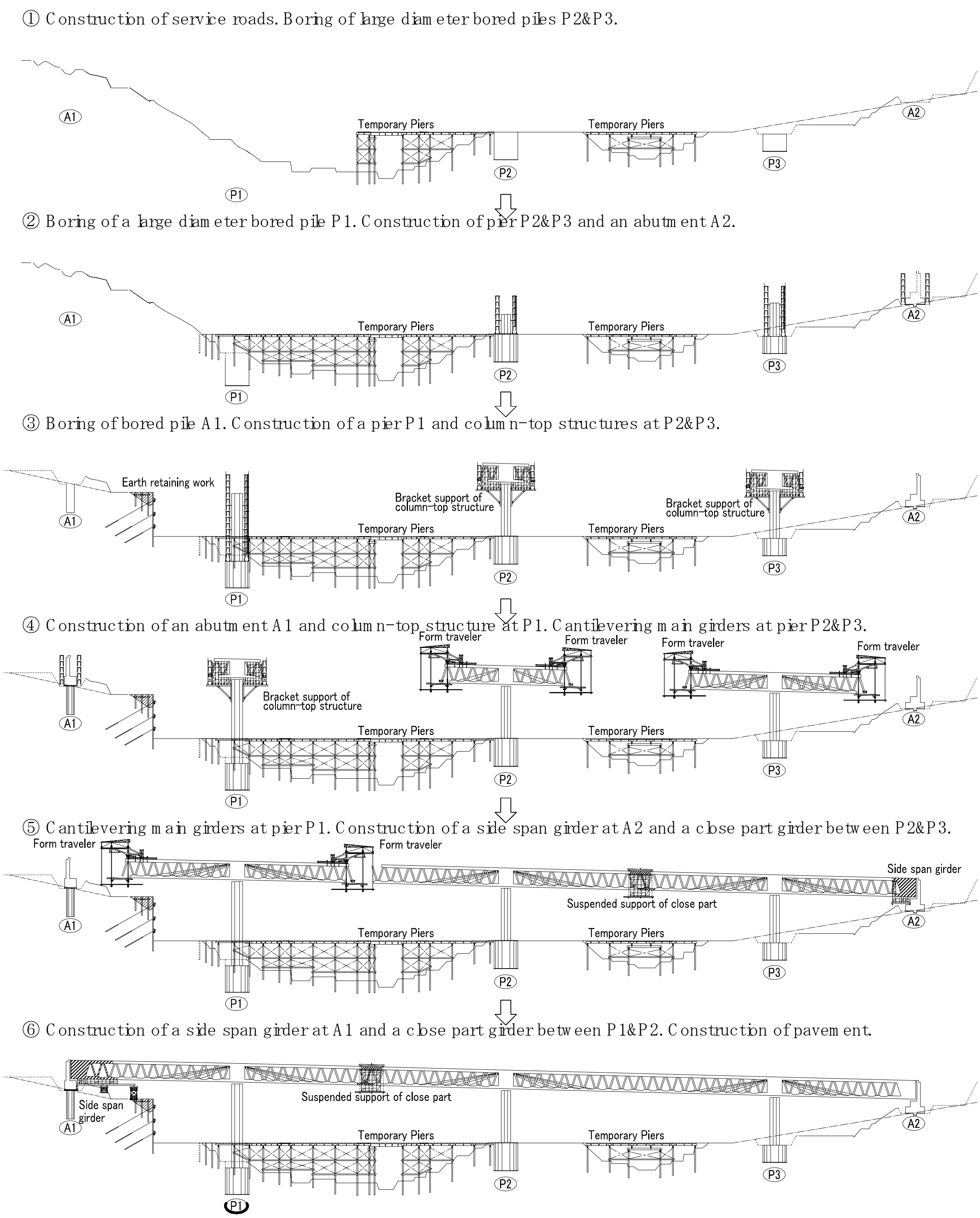


Figure-7. Construction procedure

After they were placed, the diagonals were fixed using stationary jigs such as transverse members and braces. The condition of diagonals erection at column tops is shown in Photograph-3.

4.2.2. Cantilevering

The procedure for cantilevering main girders is illustrated in Figure-8. The cantilevering procedure for the steel-concrete composite truss bridge was basically similar to that for prestressed concrete box girder bridges. The installation of truss diagonals given in Figure-8 (ii) was a challenge in constructing the composite truss bridge. A four-meter block was constructed on either side in seven to eight actual working days.

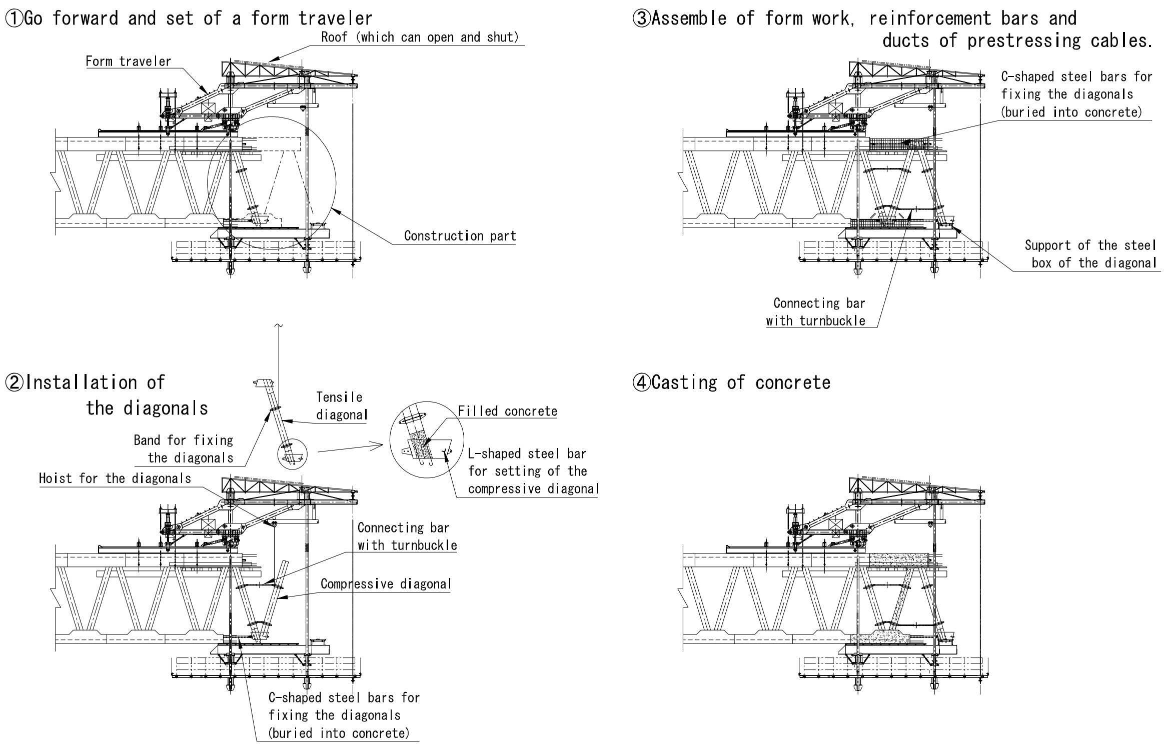
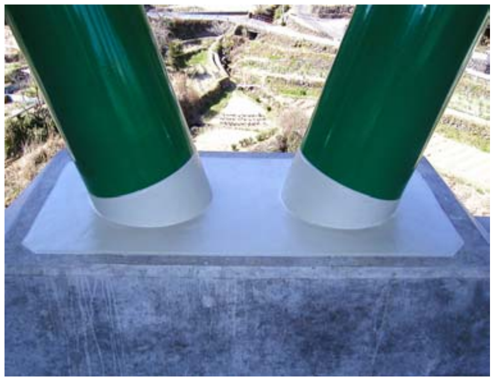


Figure-8. Procedure for cantilevering main girders

4.2.3. Waterproofing urethane coating at connections between steel pipes and concrete

Steel pipes of 406.4 mm diameter were used as the steel truss diagonals. Steel pipes applied with waterproof covering were embedded direct into the concrete. The area near the place where the steel pipes were embedded is generally vulnerable to corrosion induced by rainwater or condensation liquid water. Rainwater or condensation liquid water is also likely to enter the minute gaps between the steel pipe and concrete that are created due to loading, solar radiation or concrete shrinkage. The area around the boundary between the steel pipe and concrete was therefore covered with coating to prevent corrosion and ensure waterproofing (Photograph-4).



Photograph-4. Waterproofing coating

5. Cost-effectiveness

The direct construction cost of this bridge was compared with a prestressed concrete box girder bridge that was proposed in the basic design phase, which was submitted by MLIT (Figure-9). A 5% saving of total direct construction cost was achieved as the first composite truss bridge in Japan.

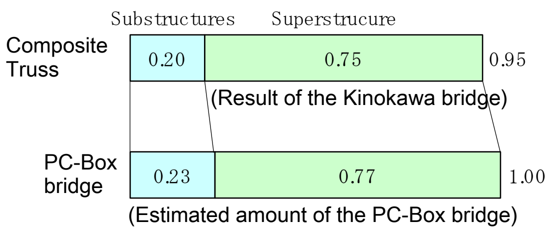


Figure-9. Comparison of the direct construction

6. Conclusion

Through the project introduced in this article, it was confirmed that the construction and the economical efficiency of the composite truss bridge are equivalent to or better than the conventional pretressed concrete box girder bridge. As we expect to build many composite truss bridges in the future, we hope this article helps the public and engineers become more familiar with composite truss bridges.