

# COMPOSITE TRUSS BRIDGES USING SUSPENSION STRUCTURE

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## **Abstract**

A unique construction method developed over more than 10 years produces a rational structure, erecting a single span composite truss bridge using a suspension method. For this structure, the steel truss and concrete deck are constructed on the spanning cables. During construction, the horizontal forces of these cables are anchored into the ground, but after completion of the bridge, the forces are transferred to concrete upper and lower chords as prestressing forces. A single span composite truss bridge of this type can be constructed without temporary supports or false work. Using this method to bridge a deep valley produces benefits in terms of both construction cost and sustainability. A single span bridge requires less excavation than other bridge types, and utilizing a composite truss with this construction method can minimize the environmental impact of construction.

## **Introduction**

75% of the land area in Japan is mountainous, and so road construction naturally involves a large number of bridges and tunnels. When building bridges over deep valleys in particular, small- and medium-sized bridges and those up to 100 m in length may involve increased costs depending on the need for erection equipment, pier construction, work roads and so on, and in many cases large-scale excavation, which may have a significant impact on the immediate environment. Today, sustainable technologies are desired, so there is a need for efficient methods with low environmental impact in Japan, where bridges must often be constructed in mountainous regions.

In a little over ten years, the method introduced in this paper has progressed from laboratory testing to use in small pedestrian bridges, and from there to use in highway bridges. It has proven to be a superior method for constructing bridges in mountainous regions. This method is a unique one in which the bridge is constructed on top of cables that have been extended. The horizontal force of the cables anchored through ground anchors in the erection process is transferred to the bridge after completion and acts as prestressing force. This makes it easy to construct simple girder bridges up to approximately 100 meters in length above valleys without falsework. Moreover, as excavation and the like can be kept to a minimum, the method does not unduly impact the environment.

This paper will discuss the development of the method for constructing composite

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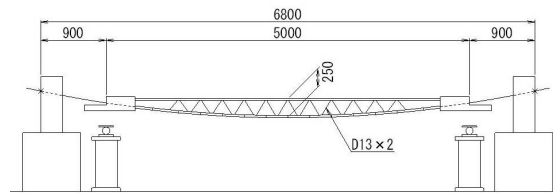
truss bridges using this suspension structure.

### **Development in the Laboratory**

As the stress ribbon bridge does not require falsework and erection girders for erection, it is a superior method for constructing single span bridges across steep valleys. However, in order for the structure to be established, the horizontal force produced in the suspended slab must be anchored to the ground. In the case of the deck type stress ribbon bridge in particular, the horizontal force is even greater, as the weight of the struts and slab is applied to the suspended slab. This limits its potential applications.

To resolve this problem, Yokohama National University and Sumitomo Mitsui Construction Co., Ltd. developed a method [1] in which a deck and truss diagonal members are constructed on top of a stress ribbon that has been erected as a support, forming a composite truss structure with the stress ribbon as the lower chord member and the deck as the upper chord member. Subsequently, the tension of the suspension cables is transferred to the both chords to form a simple girder bridge. In other words, the force transmitted to the abutment ground anchors is anchored to the bridge to form a self-anchored structure that acts like a prestressed structure. At first the weight of the bridge is almost completely supported by suspension cables, so it is as if a prestressing arrangement in which the dead weight shear force and bending moment cancel each other out almost perfectly is automatically created. Accordingly, the stress produced at the truss nodes can be restricted to that produced by the weight of the wearing surfaces and the live load. Another advantage of this structure is that the use of a composite structure reduces the weight of the bridge itself, and the ground anchors are not permanent ground anchors but those used for erection only. This makes it possible to reduce the safety factor, enabling the ground anchor requirement to be reduced.

In this way, the use of a suspension structure for erection eliminates the need for enormous erection equipment and enables construction time to be reduced through the use of precast members. Accordingly, it is a method that combines both economy and structural efficiency.



In order to verify the behavior of a structure built using this new erection method, tests were conducted using a reduced scale model like the one shown in Fig. 1. In order to make these tests simulate the actual bridge to the greatest extent possible, suspension cables were extended and the model was constructed, after which the suspension cables were released to form a simple girder bridge. The

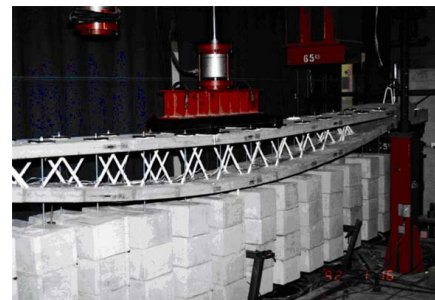


Fig. 1 1/5 Scale Model

prestressing level to which the suspension cables were released was the same as the level for a bridge with a span length of 50 m. After release, the cables were grouted prior to loading. This is the same process used on an actual bridge.

Fig. 2 shows the relationship between the applied load and the deflection in the center of the span. The results of calculation were analyzed based on the assumption that there would be bonding to the lower chord member cables, so the load-bearing capacity was approximately 10% greater than the test results. In actuality, it is thought that cracking occurred in the lower chord member, cutting the bonds and reducing the load carrying capacity.

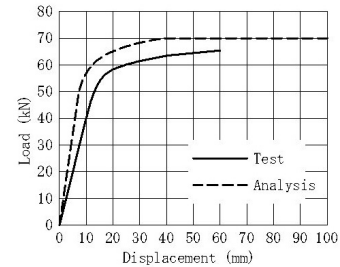


Fig. 2 Load VS Deflection

The tests conducted using the reduced scale model revealed the following:

- (1) Composite truss bridges erected using a suspension structure can be designed and are sufficiently practical.
- (2) Prestressing can be introduced to the bridge by releasing the suspension cables. This is the exact prestressing amount that will cancel out the dead load.
- (3) Composite truss bridges constructed using a suspension structure are highly rigid structures with sufficient load-bearing capacity.

### **The Challenge of Application to Highway Bridge**

The Seibun Bridge [2] (Fig. 3 and 4) is a highway bridge that crosses a tributary of the Yoshino River in Yamashiro-cho, at the western edge of Tokushima Prefecture on the island of Shikoku. The bridge is a single-span prestressed concrete composite truss bridge with concrete upper and lower chord members and steel diagonal members. It was constructed using a suspension structure for erection (Fig. 5 and 6). For the location at which the bridge was constructed, other configurations such as an arch configuration were also considered. However, the single-span composite truss bridge configuration was selected for the following reasons. (1) The location at which the bridge was constructed is a steep valley approximately 50 meters in height from the river, so a structure that could be erected by crossing a distance of approximately 100 meters in a single span, without the



Fig. 3 Seibun Bridge (Side View)



Fig. 4 Seibun Bridge (Inside View)

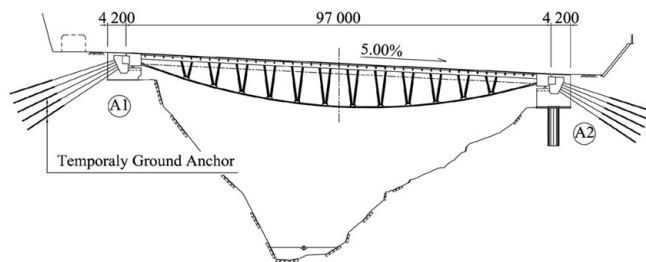


Fig. 5 General View

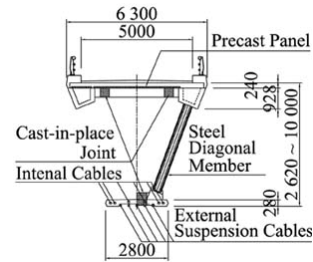


Fig. 6 Cross Section

need for supports, was required. (2) A national highway cut into the hillside runs just behind the A1 pier on the left bank, so there is almost no space for erection around the pier. (3) Because colluvial soil deposits measuring 4-6 meters are distributed at the surface near the A2 bridge pier, it was necessary to avoid a structure in which large horizontal reaction force was applied to the foundation. Therefore, this unique configuration was selected because it was also more economical than the others.

The Seibun Bridge is a single-span composite truss bridge, erected with an externally-anchored suspension structure, but having a self-anchored structural system on completion. When the bridge was completed, the girder deck acted as the upper chord member, while the stress ribbon acted as the lower chord member. The use of concrete tension ties for the lower chord member enabled the deflection in the center to be reduced from 154 mm to 25 mm and the stress variations caused by live load from the cables to be reduced from 140 N/mm<sup>2</sup> to 20 N/mm<sup>2</sup>. The rationality of these concrete tension ties is also noted by Marti [3]. The features of the construction were as follows. (1) The suspension cables strung between the abutments are used to support the weight of the bridge itself, so falsework is not needed during the erection process. This also minimizes the tree cutting and ground excavation work that is required, making a major contribution to environmental preservation. (2) The suspension cable tension is gradually increased during the erection process, with the maximum value reached when the closing the concrete for the upper and lower chord members. This transfers the suspension cable anchorage position from the rear of the abutments to the ends of the bridge superstructure. In other words, the superstructure is changed from externally-anchored to self-anchored, eliminating the horizontal force applied as external force to the abutments. This eliminates the need for ground anchors after completion and reduces the impact on the ground. (3) Self-anchoring using the tensioning of suspension cables acts as prestressing force on the upper and lower chord members. This makes the structure extremely rational, as the tensioning acts effectively as the necessary prestressing force with regard to local bending of the upper chord member and with regard to the lower chord member ties.

The construction procedure is shown in Fig. 7. The vertical displacement produced during the erection of the bridge is produced only by the geometric rigidity of the cables, so considerable sag is produced along with the load that is applied. If this converges in the steps in the middle of the construction process, great stress will be concentrated at those

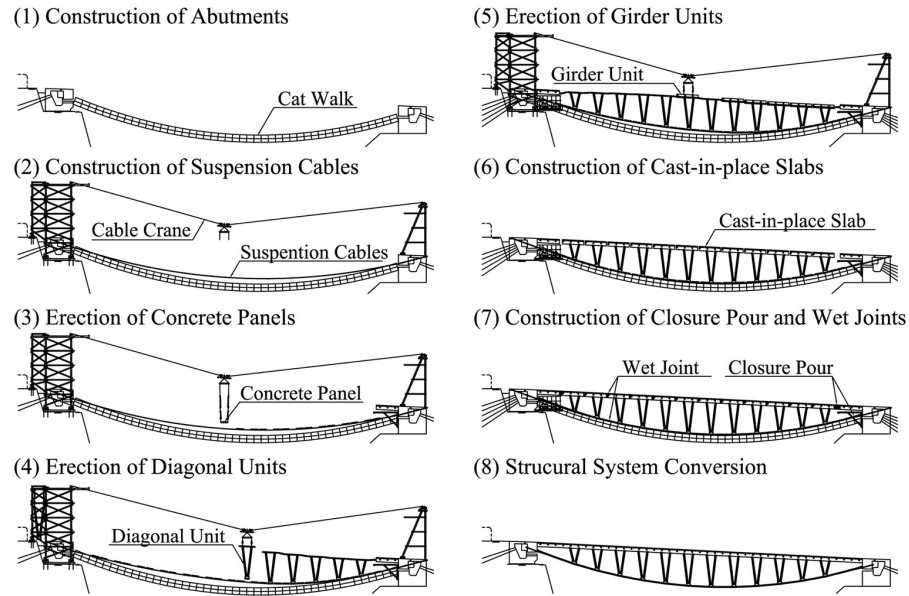


Fig. 7 Construction Procedure

locations. Accordingly, precast members were used for most of the members (Fig. 8 to 10) and a closure pour was provided at the end to prevent stress from being produced. In addition, as the bridge section is an inverted trapezoid, without each of the precast members being connected the structure is extremely unstable, particularly in the out-of-plane direction (Fig. 11). For this reason, the construction sequence and procedure were extremely important. The total sag deformation during construction was 1.696 meters. However, the error to the design value was -18 mm.

The structural system conversion procedure is shown in Fig. 12. First, after the temporarily fastenings for the segments on both ends had been removed, the suspension cable tension was changed from the rear of the abutments anchored during the erection process to the end segments of the superstructure. In order to ensure balance, the changing of the suspension cable tension was done in 12 stages, including the removal of the ground



Fig. 8 Erection of Precast Panel



Fig. 9 Erection of Diagonal Unit





Fig. 10 Erection of Girder Unit

anchor load. As a result of this structural conversion from a self-anchored system to an externally-anchored system, approximately 10,000 kN of the tension from the suspension cables was introduced to the upper chord member and 2,000 kN was introduced to the lower chord member. When the structural conversion was complete, the internal tendons were inserted inside the lower chord member and tensioned, completing the bridge construction. The Seiyun Bridge was completed in December 2004.



Fig. 11 Side Wire Stabilizers

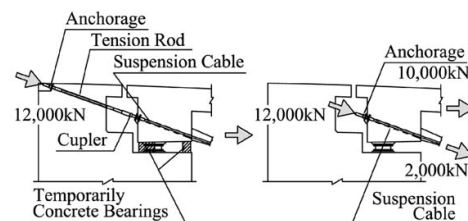


Fig. 12 Structural Conversion

Due to the increased concern in recent years for preserving the environment, the use of bridge construction methods that preserve the pre-construction environment to the greatest extent possible is desirable. The use of the suspension structure described in this paper for bridge erection, and the construction of composite truss bridges that use concrete tension ties for the lower chord member, constitute a technology that can answer these needs, and a solution that can offer economic advantages as well.

### Evolution into the Double Suspension Structure

The erection method discussed up to now that involves the use of a suspension structure is one in which the bridge is constructed on suspension cables that have been extended first. For this reason, the Seiyun Bridge, whose upper chord member is heavier than that of the Ganmon Bridge, is most unstable at the point just before the structure is complete. In order to resolve this problem, side wire stabilizers were used. The bridge that resolved this problem completely was the Seishun Bridge (Fig. 13).

Fig. 14 shows the basic concept of the double suspension structure. A double row of suspension cables is extended. The primary cables are used to support the deck load, and the secondary cables are used to adjust the sag of the primary cables. In other words, the bridge is constructed not from the bottom up, as in the conventional method, but from the

top down. This greatly increases stability during erection. In this method, too, both primary and secondary cables are converted to a self-anchoring system.

Fig. 15 shows a general view of the Seishun Bridge. The restrictions on construction were that no anchors should remain in the ground when the bridge was completed, and the maximum gradient of the bridge deck must be no more than 5%. For this reason, a stress ribbon bridge was not suitable, and so a form like that of the Seiu Bridge was used. However, unlike the Seiu Bridge, this bridge was a pedestrian bridge, and so there was no need to increase overall rigidity as a truss structure. For this reason, struts were provided and the suspended slab section was made more lightweight through the use of only cable rigidity rather than that of concrete members.



Fig. 13 Seishun Bridge

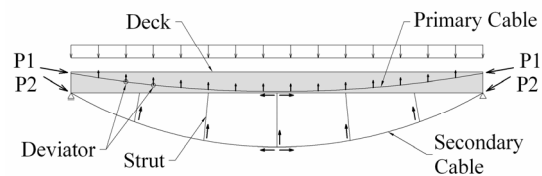


Fig. 14 Concept of Double Suspension Structure

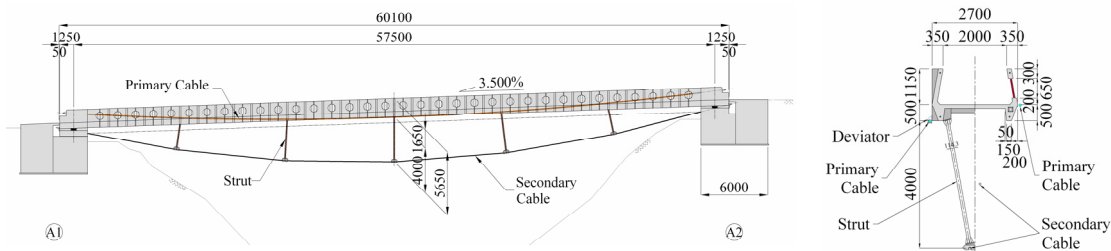


Fig. 15 General View

As shown in Fig. 16, in the construction process, first the primary and secondary cables were extended and precast segments were sent along the primary cables (Fig.17).

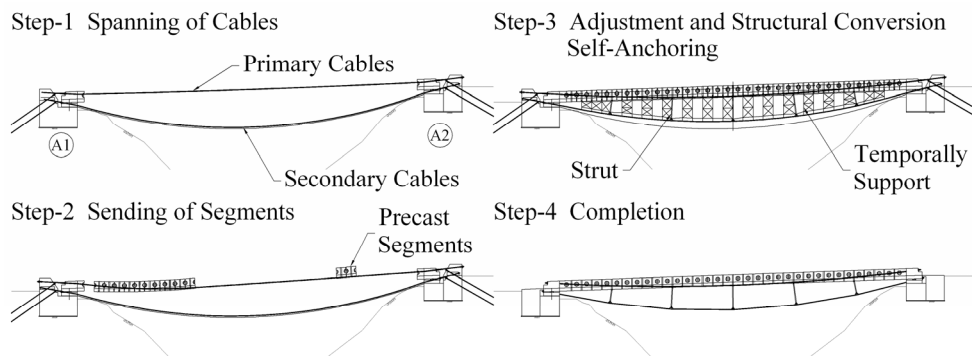


Fig. 16 Construction Procedure

When the erection of the segments was complete, the struts and temporary struts were put in place, and the secondary cables were tensioned to adjust the primary cable sag (Fig.18). Next, the wet joints between the segments were constructed, and both primary and secondary cables were transferred to the deck to convert the structure to a self-anchoring one. Finally, the temporary struts were removed to complete the bridge. The construction process took approximately one month from erection of the precast segments to bridge completion, and the bridge was completed in June 2006. The use of a double suspension structure greatly improved stability during the erection process.



Fig. 17 Erection of Precast Segments



Fig. 18 Adjustment of Secondary Cables

## **Conclusions**

As noted above, the method of erecting composite truss bridges using a suspension structure has been developed over a period of more than 10 years, and it is a method that is applicable to small- and medium-sized bridges and highway bridges of up to 100 m in length. Moreover, as the resulting structure is a simple girder bridge, the environmental impact at the erection location is minimal, making it a sustainable construction method. In addition, this is a superior method for use in deep valleys in which large erection equipment cannot be used and so on.

Composite truss bridges have transparency and the slender upper and lower chord members have structural elegance (Fig. 19). Moreover, the bridge weight is first almost entirely supported by the suspension cables, but in the end this is converted into prestressing force applied to the bridge. Accordingly, the method is a rational one that uses no unnecessary materials from construction through completion, with the exception of the external anchors used during the erection process. Moreover, the instability during erection that was a concern initially was resolved



Fig. 19 Seibun Bridge



through the use of a double suspension structure.

Currently in bridge construction, life cycle costs that comprise both initial costs and maintenance costs are evaluated. In the near future, however, bridge construction may be evaluated quantitatively in terms of environmental impact, and the sustainable costs that represent that cost on an ongoing basis may be added to life cycle costs. In the event that this happens, we are confident that the method shown in this paper will be a major contribution to bridge construction.

## **References**

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