# Construction of Nagisa Bridge: Hybrid System of Cable-Stayed Prestressed Concrete Bridge and Steel Suspension Bridge

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## Summary

Nagisa Bridge, a single span footbridge, was recently completed in Aomori prefecture, Japan. The structure of this bridge is a hybrid structure of cable-stayed prestressed concrete bridge and steel suspension bridge. It is the first application as this structure type of bridge in the world. Concrete girders near pylons are supported by stay cables. Steel girders are supported by suspension cables in the central part of the span. This is new type system for prestressed concrete bridges with longer span and has many structural features compared with ordinary cable-stayed bridge and suspension bridge. This paper reports a brief overview of construction of Nagisa Bridge with this hybrid system.

**Keywords**: hybrid system, cable-stayed bridge, suspension bridge, prestressed concrete, execution management, field test

## 1. Introduction

Nagisa Bridge, a single span footbridge recently constructed over the Nakamura river mouth in Aomori prefecture, Japan, is the first hybrid system bridge in the world that is a compound structure of cable-stayed prestressed concrete (PC) bridge and steel suspension bridge (Fig.1). PC girders are used for the stay cable sections near pylons. And steel girders are used for the suspended cable section in the central part of the span. There are two bridges which adopted a similar combination of cable-stayed system and cable-suspended system. These are Saint-Ilpize bridge in France [1] and Sidi M'Cid Bridge in Algeria [2]. Both bridges, however, have steel decks only. Nagisa Bridge is the first application of a hybrid system with a combination of PC girder and steel girder.

Regarding the design of Nagisa Bridge, several requirements had to be satisfied. These were to eliminate piers in the river and to design the bridge which would be perceived as a landmark of this area. And also to design a bridge with better aerodynamic stability was required, because this area is often hit with strong wind especially in winter. In consideration of these conditions, this hybrid system which can be made having long span, characteristic appearance and better aerodynamic stability was selected. This paper reports a brief overview of construction of Nagisa Bridge with the new hybrid system, including the field tests conducted prior to the opening of the bridge.

## 2. Hybrid System Bridge Features

The hybrid system bridge has many structural features compared with ordinary cable-stayed bridge and suspension bridge. Fig.2 shows concepts of the hybrid system bridge and ordinary cable supported bridges. In comparison with cable-stayed bridge, this system has better buckling stability and is applicable for longer span, because the axial force occurring in the girder can be reduced by decreasing the number of stay cables. Cable erection can be easier and cable vibration problems can be solved due to shorter stay cables. The height of pylons can be lowered by reducing the number of stay cables. In comparison with suspension bridge, this system has better aerodynamic stability, because the stay cables restrain the deformation of the girder. It is achieved to lessen the tension force occurring in the main cables, because the stay cables support more weight. And anchorage lateral force can be reduced.

*Fig.1 Nagisa Bridge*

## 3. Overview of the bridge

A general view of the bridge is shown in Fig.3. Nagisa Bridge is a single span bridge with span of 110.15m. The main girder is a height of 0.7m and a width of 7.0m (effective width of 4.0m). There are 2 pylons, and those heights are 20.0m and 12.1m respectively. A symbolic appearance was emphasized by making pylon height and cable arrangement asymmetrical. The pylons are composite structures of concrete members and steel shell members.

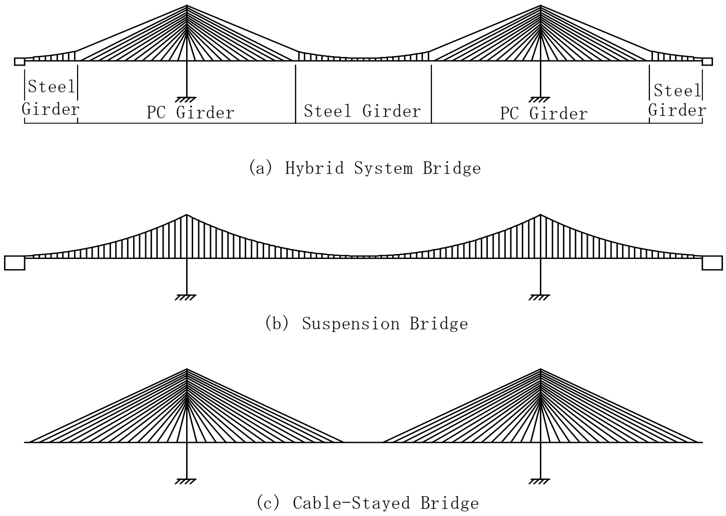



*Fig.2 Concepts of Cable Supported Bride*

This bridge is subjected to harsh conditions such as cold, strong wind, and salt air, since it is located in a cold district and the coastline. Therefore, materials were chosen in consideration of durability and the long service life. the water-cement ratios were less than 36% for the PC girder and were less than 43% for the pylons and the anchorages. The covering concrete thickness of reinforcements was 50 to 70mm, and epoxy coated reinforcements were used. The girder, the pylons and the anchorages were painted against rust. The stay cables were double rustproof cables with a anti-corrosive oil coating and a polyethylene resin covering. For suspension cables, galvanized locked coil ropes with good durability were adopted.

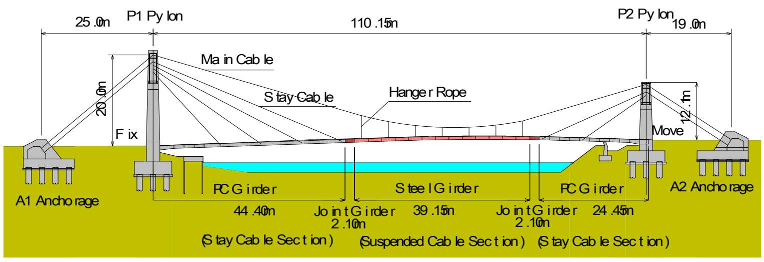



*Fig.3 General view*

## 4. Construction

### 4.1. Overview of Construction

Due to the environment and construction conditions at the bridge site, the bridge was constructed using a precast segmental method with a 450-ton crawler crane. The construction steps are shown in Fig.4. On the first step, the pylons and the anchorages for the suspension cables and the back stay cables were constructed. On the second step, cantilever erection of concrete segments was performed, and the stay cables were installed every four segments. On the third step, the suspension cables were placed and steel girders were erected. On the last step, concrete was placed around the steel shell members anchoring the stay cables on the pylons, and pavement was placed on the girder.

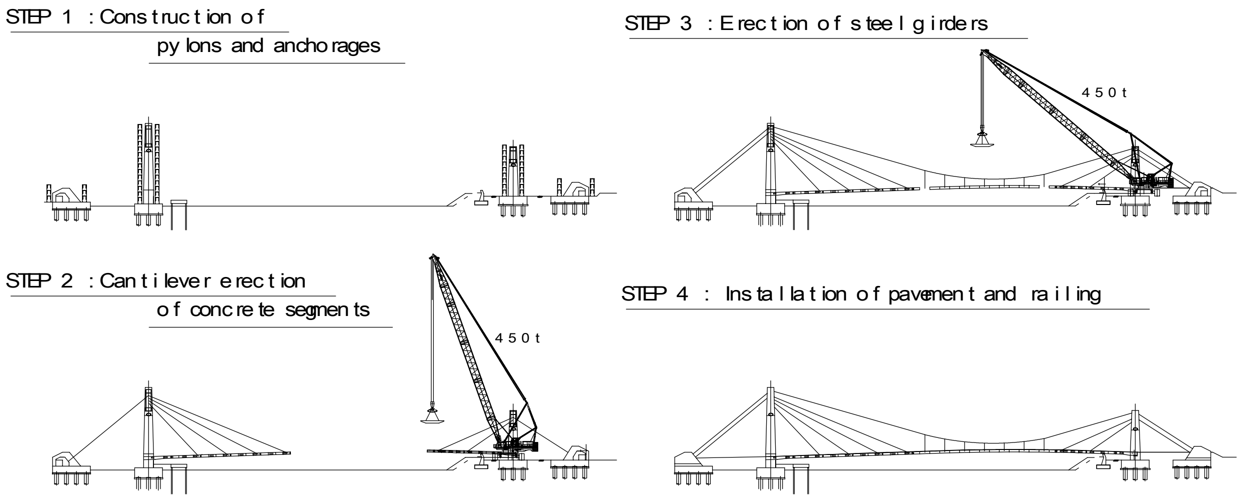



*Fig.4 Construction step*

## 4.2. Fabrication of Main Girders

Fig.5 shows sections of the main PC girder and the main steel girder. The section was designed in consideration of wind stability, durability, and reduction in self-weight. Concrete segment fabrication was done using the long line match-cast method at the factory (Fig.6). The length of each segment was 2.25 m, and its weight was about 220 kN. Steel segments were fabricated at the factory, with a length of 3.0 m and a weight of 70 kN.

It was very important for the jointing segment to transfer the stress between the PC girder and the steel girder smoothly. The jointing segment comprised of a combination of a concrete member and a steel member (Fig.7). The steel member was fabricated first, and filled with self-compacting concrete. The concrete member was fabricated using the match-cast method, and finally prestressing was introduced in order to control crack width caused by the restraint on the concrete at early age.

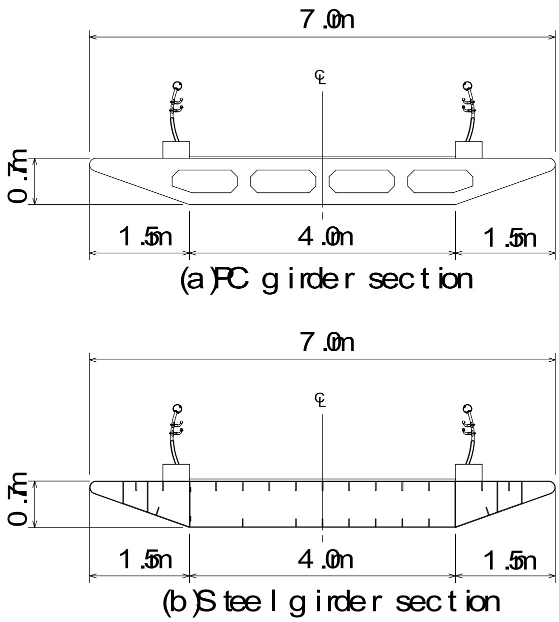



*Fig.5 Main girder section*

*Fig.6 Fabrication of concrete segments*

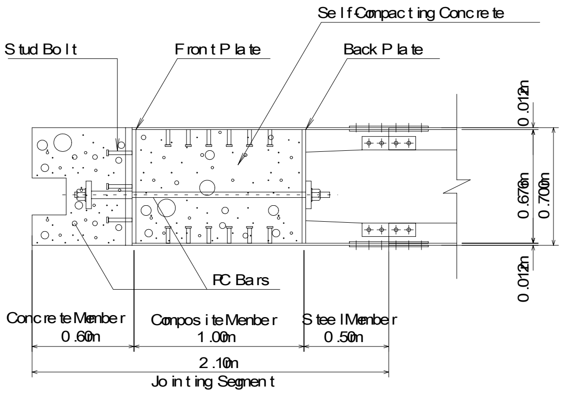



*Fig.7 Jointing segment*

### 4.3. Construction of Pylons and Anchorages

The main bodies of pylons are reinforced concrete structures. In order to make the pylon more compact, steel members were adopted to anchor the stay cables to the pylon (Fig.8). After the concrete section for 2/3 of the pylon was constructed, steel shell members were placed on top of it (Fig.9). After the cantilever erection of the concrete girders and the erection of the steel girders had completed, concrete was placed around the steel shell members to create an integrated unit.

The anchorages have very dense reinforcing bar arrangement. Therefore, self-compacting concrete with a slump flow of 65 cm was used. Concrete volume was 175 $m^3$ for the left anchorage and 162 $m^3$ for the right one.

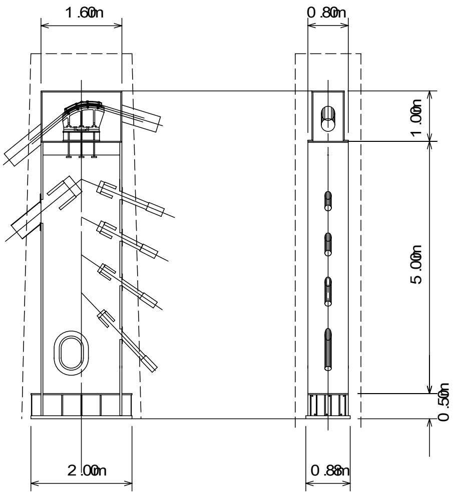



*Fig.8 Steel shell member of P1*

*Fig.9 Steel shell member of P2*

### 4.4. Erection of Concrete Segments

Cantilever erection of concrete segments was performed by using a 450-ton crane without any false work and scaffolding in the river (Fig.10). Cantilever erection was made by tensioning the inner PC bars at each segment. The stay cables, which were fabricated in a factory, were installed every four segments (anchorage span of 9 m).

### 4.5. Erection of Steel Girders

When the erection of the concrete segments and the jointing segments were completed, the suspension cables were placed from A1 anchorage to A2 one through the saddles on top of the pylons using a winch and a crane. The steel girder segments were hung on the hanger lopes using a 450-ton crane (Fig.11). Connection of each steel segments and connection of the jointing segments and steel segments was conducted, after all of the steel segments were suspended.

*Fig.10 Erection of concrete segments*

*Fig.11 Erection of steel girders*

## 5. Execution management

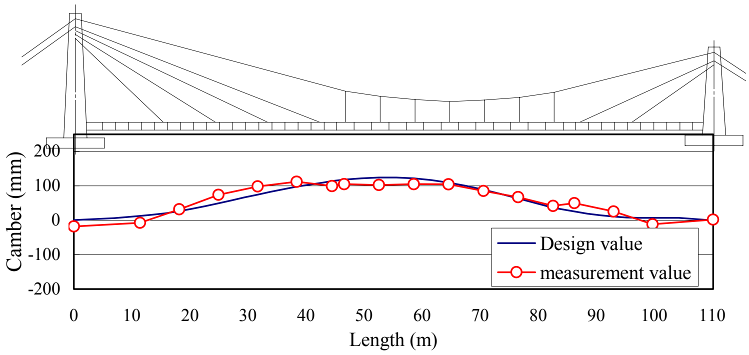



*Fig.12 Results of measurement of displacement*

Due to the fact that the bridge is a highly hyperstatic structure, the structure system changes continuously as erection progresses. And the girder is thin and its stiffness is small, so that fluctuations of deflection of the main girder is large during the construction period. In order to ensure the safety in the construction and obtain the required quality, the monitoring of the behavior of the bridge for the each construction phase was carried out. Measurements of deflection, stress and temperature were taken during the construction. These measurement data were analyzed in real time and compared to the design values. Results of analysis were then reflected in the management of construction.

In the case of cable supported bridges, the deflection of the girder and cable tension control are related closely each other. In addition, the deflection of the main girder is sensitive to temperature fluctuations. In this bridge, the camber control of the main girder was carried out through the cable tension adjustment, considering the influence of temperature fluctuations. The correction values were calculated by considering the predicted defelection and tension per unit temperature of 1 degree centigrade and the difference between the mesurement temperature and the reference temperature of 10 degrees centigrade. Measurements of temperature were taken using thermocouples fixed to the main girders, the pylons, and stay cables. The measurements and the tension adjustments were carried out in the early morning, when the difference in temperature between members was smallest, in order to minimize error.

Fig.12 shows the measurement values of displacement of the main girder when the erection of steel girders was completed. It was successfully done to manage the elevation with adequate accuracy.

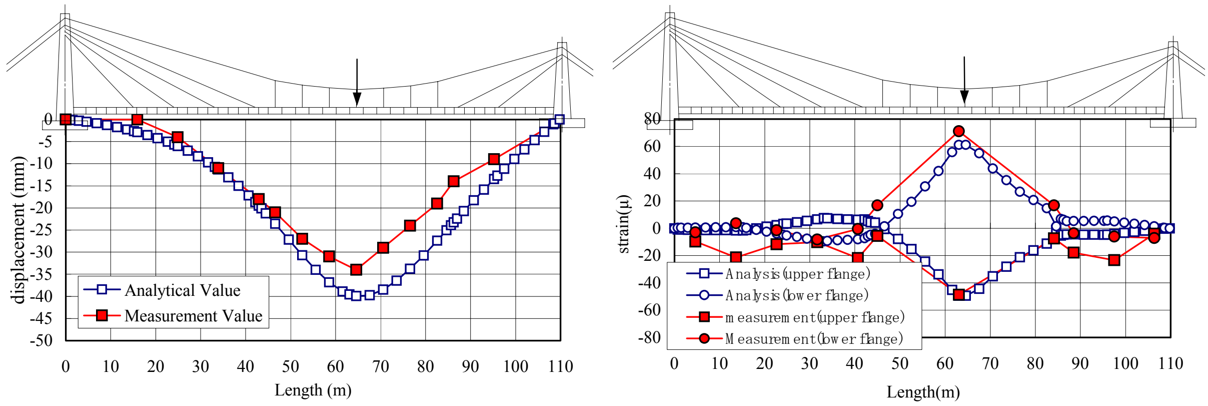
## 6. Field Test

Prior to the opening of Nagisa Bridge, the field loading tests and the field vibration tests were conducted in order to verify the performance of the bridge system and the validity of the analysis method.

In the loading tests, two loaded vehicles were used (Fig.13). The weight of each vehicle was 42 kN. Fig.14 shows the deformation and strain of the main girder measured during loaded in the centre of the span, including the results of the finite deformation analysis with the 2 dimensional model. Although there are small differences between the analytical values and the measurement values, the analysis describes well the tendency of the test results.

In the vibration tests, it was vibrated by dropping the vehicle from square lumber with a height of 9 cm. Accelerometers were set on the girder and the pylon to measure the acceleration. Table 1 shows the results of the test and the analysis. The different modes of vibration are shown in Fig.15. The mode analysis was carried out using the 3 dimensional frame model, considering the initial cable tension. It can be seen that there is good conformance between the measured and the calculated frequencies.

*Fig.13 Field loading test*




*(a) displacement* *(b)strain*

*Fig.14 Loading test result*

*Table1 Natural frequency*

| Mode (Vertical) | Natural Frequency (Hz) | |
|---|---|---|
| | Analysis | Experiment |
| 1st | 0.85 | 0.92 |
| 2nd | 1.25 | 1.34 |
| 3rd | 1.92 | 1.95 |
| 4th | 2.64 | 2.69～2.75 |
| 5th | 3.81 | 3.78～3.85 |

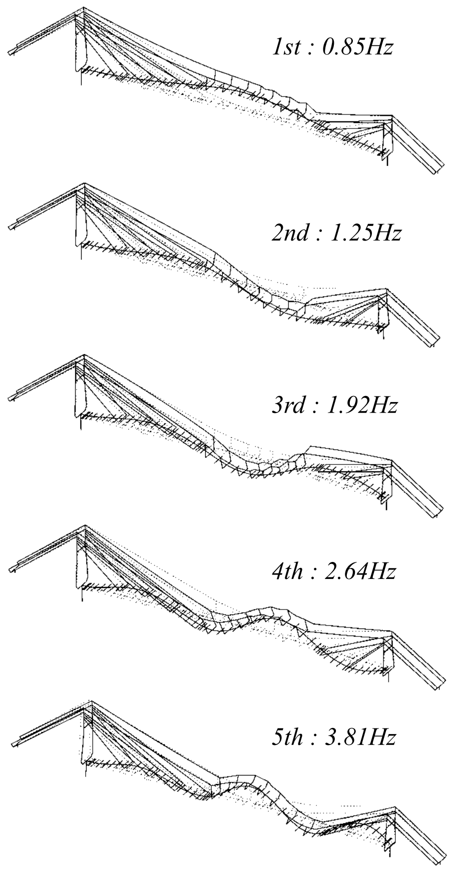



*Fig.15 Results of mode analysis*

## 7. Conclusion

Nagisa Bridge was the first challenge as a compound bridge of cable-stayed prestressed concrete bridge and steel suspension bridge. Therefore there were many problems to deal with during design, material selection, and execution. Nagisa Bridge, however, was completed in December 2002. And the bridge was opened for pedestrians in July 2003.

It is clear that the hybrid system bridge has many features and is competitive in comparison with ordinary cable supported bridges. The successful completion of Nagisa Bridge demonstrated the superior feature of the hybrid system. And the behaviour of such bridges with the hybrid system was verified by conducting field loading tests. It is expected that the adoption of the hybrid system for longer span bridge will increase in the future.

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