The First UFC Railway Bridge in the World
— Kayogawa UFC Railway Bridge —

世界初の UFC 鉄道橋
— 萱生川橋 —

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Synopsis
The Kayogawa Bridge is the first railway bridge in the world to be constructed of UFC (Ultra-high strength fiber-reinforced concrete). Due to river improvements, the old Kayogawa Bridge needed to be replaced with a pre-stressed concrete U-girder. The girder originally was designed to have a 390 mm-thick slab. By using UFC, however, a slab just 250 mm thick could be constructed, thereby avoiding the need to raise the railroad track and reducing the cost of the project. This paper describes the design and construction of this bridge.

Structural Data
Bridge Length: 15.86 m
Span: 14.5 m
Width: 4.0 m
Girder Height: 1.50 m
Owner: Sangi Railway Corporation
Designer: All Nippon Engineering Consultants Corporation
Contractor: Taisei Corporation
Location: Mie Prefecture, Japan

1. Introduction
The Kayogawa Bridge (Fig. 1) in Japan is the first railway bridge in the world to be constructed using UFC.

Due to river improvements, the old railway bridge, a steel deck bridge 9.6 m in length with a girder height of 695 mm, needed to be replaced with a low-maintenance concrete bridge. As a result of river improvements and changes in the flood control plan, this new bridge had to be 1.65 times longer than the original bridge and the elevation of the bottom surface of the girder and to be higher to accommodate a higher estimated high-water level (HWL). To satisfy these conditions without changing the height of the railroad track (Fig. 2), the concrete lower slab had to be 250 mm thick. A slab constructed of conventional concrete, however, would have to be 390 mm thick, which would require changing the height of both the railroad track and an adjacent station, thereby increasing the cost of construction.

By using UFC, a slab just 250 mm thick could be constructed, avoiding the need to change the height of the railroad track and reducing the total cost of the project. The designs of a UFC bridge and a conventional concrete bridge are compared in Table 1.

2. Design
The design of this bridge is based on the Design Standards for Railway Structures, with occasional references to Commentary[1], and UFC Guidelines[2]. As no precedent existed for using UFC in railway bridges, the thinner slabs were difficult to evaluate. Therefore, the characteristics of UFC member were subjected to
numerous FEM analyses and other examinations. The thin UFC member also results in a bridge with less flexural rigidity than a conventional prestressed concrete bridge. The vibration and deflection characteristics of this UFC bridge were analyzed and compared with those of a conventional bridge.

(1) Thickness of member

Table 1 compares the Kayogawa Bridge with a conventional concrete bridge. The top flange width of 350 mm was determined by the minimum size of the tendon anchorage for the longitudinal prestressing strands in the main girder. The lower slab thickness of 250 mm was determined by the arrangement of the longitudinal and lateral sheaths for the prestressing strands. Three-dimensional FEM analysis confirmed that the principal stress was within the limits for UFC tensile stress (-8N/mm²). (Fig.3, Fig.4)

(2) Resistance to lateral buckling

The top flange of the girder is 350 mm wide, which is less than the minimum width of 435 mm prescribed by the railroad standard. Therefore, the girder’s resistance to lateral buckling was evaluated using Euler buckling analysis with three-dimensional FEM analysis. (Fig.5) In this analysis, the web reached the lateral buckling limit when the acting load was approximately 155 times...
greater than the ordinary fluctuating load, confirming that the bridge can resist lateral buckling.

(3) Vibration properties
Since the members of this UFC bridge are thin, the natural period tends to be longer than that of a conventional concrete bridge. Therefore, the bridge’s vibration properties were evaluated to determine the bridge’s resonance when a train passed over it. The characteristic frequency was calculated using a simple calculation method, \( f = \frac{\pi}{2 \times L_b} \cdot \sqrt{\frac{(EI/g)}{D}} \), and three-dimensional FEM analysis. Using the simple calculation method, the characteristic frequency of the UFC bridge was 11.1 Hz, while that of a conventional concrete bridge was 11.0 Hz. Using eigenvalue analysis and FEM analysis (Fig.6), the primary mode frequency was 10.2 Hz for both the concrete bridge and the UFC bridge.

(4) Deflection
The design deflection limit \( [\delta] \) value was set to \( [\delta < \text{span}/500] \) assuming the stability of a running train during normal service. The deflection was calculated using two-dimensional frame analysis and three-dimensional FEM analysis with consideration of the skew angle. Two-dimensional frame analysis returned a deflection value of 4.8 mm, while FEM analysis returned a deflection value of 5.0 mm. (Fig.7). In both cases, the values were well below the deflection limit value of 29.0 mm.

(5) Reinforcement rebar
Conventional design requires rebar reinforcements in the tendon anchorage and the unseating prevention stopper. Because UFC structures generally do not require reinforcement rebar, the need for rebar in this bridge was examined. Three-dimensional FEM analysis of the splitting tensile stress at the back of the tendon anchorage (Fig.8) showed that the principal stress was 7.6 N/mm², which is below the limit level of 8.0 N/mm² for UFC tensile stress.

3. Construction
The bridge was constructed in a factory using the pre-cast segment method. The segments were then transported to the construction site. A 65-ton crane placed the segments in a segment assembly yard (Fig.9). Cast-in-place UFC was then poured into the spaces between the segments. Four of 12-wire x 12.7 mm diameter steel strand (SWPR7B 12S12.7) for prestressing were placed in the web. Seven of 19-wire x 21.8 mm diameter steel strand (SWPR19 1S21.8) were placed in the lower slab. After confirming the strength of the filled spaces, the steel strands were prestressed, unifying the segments into a single girder. The old bridge was replaced with the new bridge in the early morning hours to avoid disrupting normal rail services. The process took only three hours. (Fig.10)
4. Conclusion
Kayogawa bridge was the first railway bridge to be constructed using UFC. Additional testing and measurements confirmed that the bridge was safe and properly designed. Because no precedent existed for a railway bridge constructed using UFC, the girder height of a conventional concrete bridge (first draft design) was adopted in order to avoid an extreme decrease in flexural rigidity. This resulted in a safety factor of 0.5-0.7 < 1.0. Moreover, no problems were revealed by FEM analysis. Therefore, this bridge could be considered overdesigned in some aspects. Furthermore, since the bridge has a short span, the thickness of the member was determined by the placement of certain elements, such as the tendon anchorages, rather than by the stress. Therefore, long-span bridges that utilize the characteristics of UFC are possible.

References