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
Construction Period: Apr. 2010 – Jul. 2010
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

Fig. 1 Kayogawa UFC railway bridge

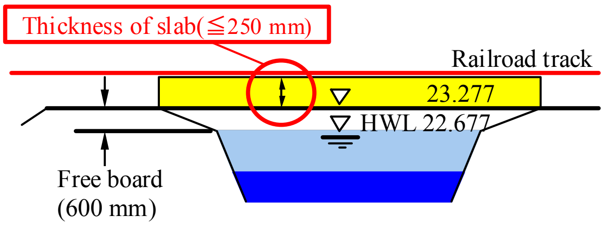
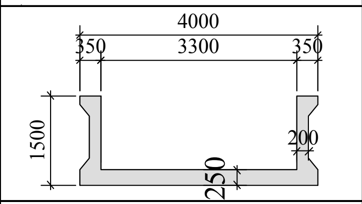
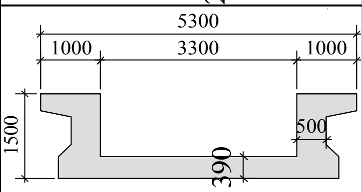


Fig. 2 Design conditions for slab

Table 1 Comparison of slabs for UFC and conventional concrete bridges

	Cross section (mm)	Area of cross section	Design load	Flexural rigidity
UFC through bridge		A=1.6 m^2 (0.5)	Girder: 700 kN (0.54) Track: 500 kN Ballast: 500 kN Train: 1100 kN Total: 2300 kN (0.79)	EI=1.6×10^7 kN・m^2(0.76)
Conventional concrete through bridge		A=3.2 m^2 (1.0)	Girder: 1300 kN (1.00) Track: 500 kN Ballast: 500 kN Train: 1100 kN Total: 2900 kN (1.00)	EI=2.1×10^7 kN・m^2(1.00)

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/mm^2). (**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

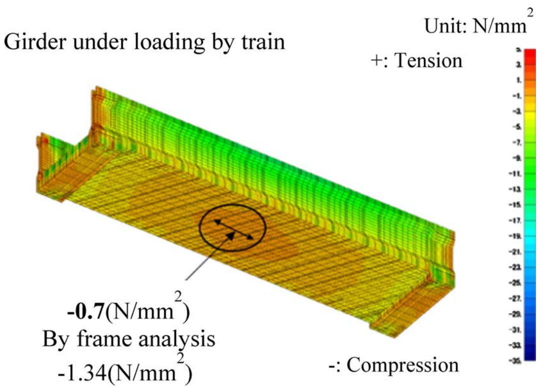


Fig. 3 Longitudinal stress

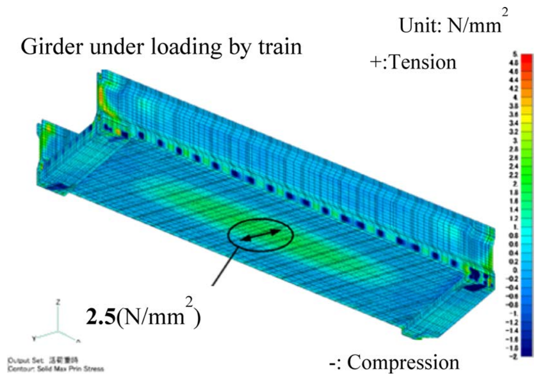


Fig. 4 Principal stress

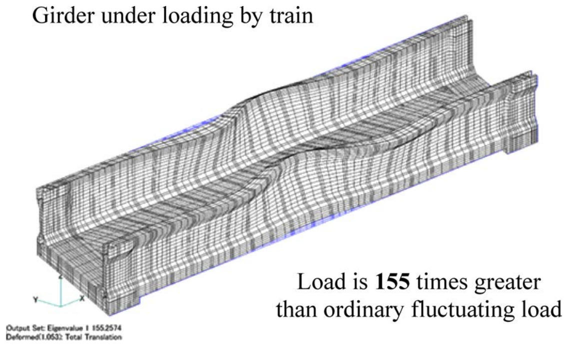


Fig. 5 Buckling mode analysis

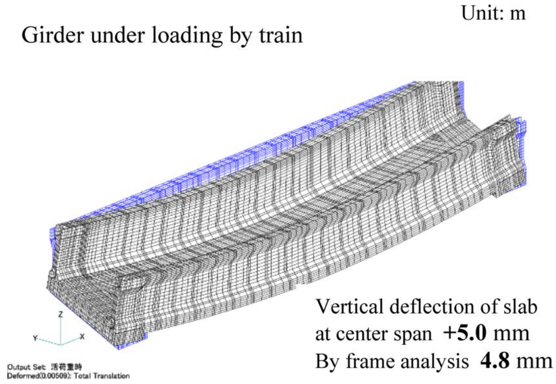


Fig. 7 Deflection

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, $f = \pi/(2 \times Lb2) \cdot \sqrt{((EI \cdot g)/D)}$, 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.

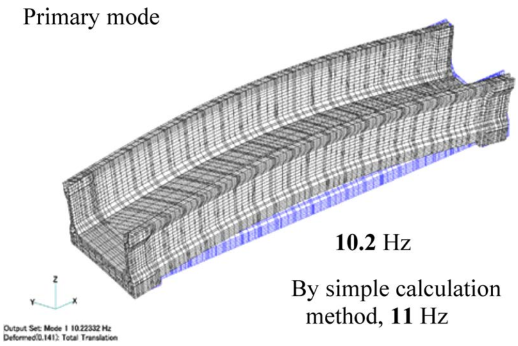


Fig. 6 Primary mode of characteristic frequency

(4) Deflection

The design deflection limit [δ] value was set to [$\delta <$ 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/mm^2, which is below the limit level of 8.0 N/mm^2 for UFC tensile stress.

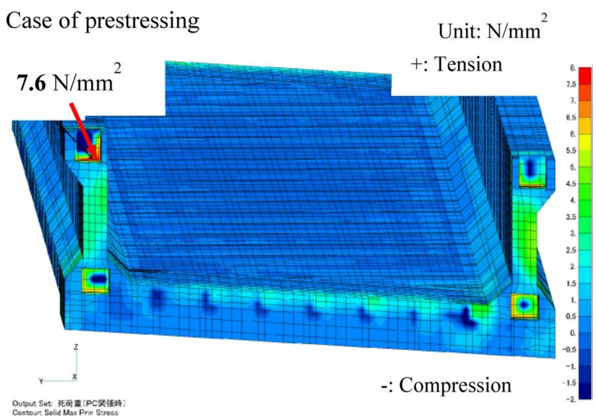


Fig. 8 Principal stress of back side of tendon anchorage

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**)

Fig. 9 Transporting the segments

Fig. 10 Before lateral transfer

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

[1] Railway Technical Research Institute (RTRI), *Design Standards for Railway Structures and Commentary* (Concrete Structures), 2008 (in Japanese)

[2] JSCE (Japan Society of Civil Engineers), "*Guidelines for the Design and Construction of Ultra High Strength Fiber Reinforced Concrete (Draft)*," 2004 (in Japanese)

概　要

本橋は，河川改修に伴う鋼桁橋の改築工事として計画されたが，その際に橋の長スパン化と河川計画高水位の上昇が計画に盛り込まれているため，橋の桁高が増加してしまい，営業線の軌道高を嵩上げしなければならないと言う問題を抱えていた。これに対し，橋梁を下路桁構造とし，鉄道橋梁では世界で初となるUFCを採用することで，床版厚を390mm（従来コンクリートの場合）から250mmへと薄くすることにより，営業線の軌道高を上げることなく橋の長スパン化が可能となると共に，それによる工事費の削減をも実現した。

本稿では，従来の鉄道PC下路桁との設計比較，UFC鉄道橋の設計概要とFEM解析を用いた設計検証概要，および本橋の施工概要について報告する。