Development of a Highway Bridge Deck Using Ultra-High Performance Fiber-Reinforced Concrete

Takashi KOSAKA
Assistant Manager, Engineering Department
Hanshin Expressway Company Limited
Osaka, Japan
takashi-kosaka@hanshin-exp.co.jp

Hidesada KANAJI
Manager, Engineering Department
Hanshin Expressway Company Limited
Osaka, Japan
hidesada-kanaji@hanshin-exp.co.jp

Toshimichi ICHINOMIYA
Chief Research Engineer, Kajima Technical
Kajima Corporation
ichinomt@kajima.com

Kimio SAITO
Deputy General Manager, Technology
Kajima Corporation
saito-k@kajima.com

Summary

In urban expressways, lightweight orthotropic steel decks are widely used. However, fatigue cracks occur in the orthotropic steel deck. To address this problem, we developed a light weight highway-bridge deck with high durability using ultra-high performance fiber-reinforced concrete (UHPFRC). A UHPFRC deck has very thin components as compared with the conventional concrete deck, thus we validated the safety of this thin deck structure using finite element analysis. We also verified its fatigue durability using the wheel running fatigue test. We verified the high fatigue durability of the UHPFRC deck and feasibility for its application.

1. The Design Concept of a UHPFRC Deck

In this study, we use ettringite-generating-type UHPFRC (AFt-type UHPFRC) with compressive strength of 180 MPa. Schematics of the UHPFRC deck are shown in Fig. 1 and Fig. 2. Our objective was for the weight of the UHPFRC deck to be comparable to the weight equivalent of an orthotropic steel deck with U-shaped rib. The UHPFRC deck was assumed to be a deck structure supported by four sides, a steel main girder, a steel stringer, and a steel floor beam. The UHPFRC deck is joined to a steel girder by a stud. The behavior of the deck was designed as a composite girder.

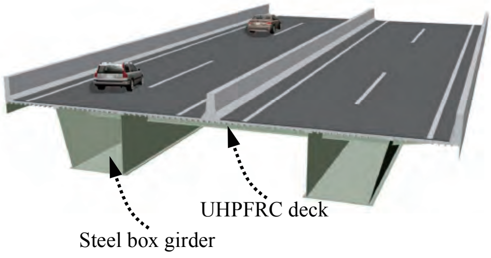

Fig. 1: Bridge deck using UHPFRC

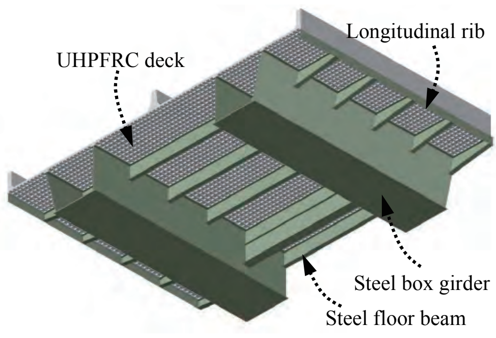

Fig. 2: Composite girder bridge

The UHPFRC deck in this study consisted of a slab on which a wheel loads acts and a rib with a prestressing strand. Based on the minimum concrete cover and the minimum clear distance of reinforcing steel in a prestressing strand, the slab thickness was 40 mm, the component thickness of the deck was set at 83 mm, and the minimum rib width was 70 mm. A structure made with UHPFRC for use in conditions of normal service must have a concrete cover of at least 20 mm and be in excess of the diameter of the reinforcing steel. The UHPFRC deck was designed in a waffle configuration, with ribs in two orientations, as shown in Fig. 3 and Fig. 4.

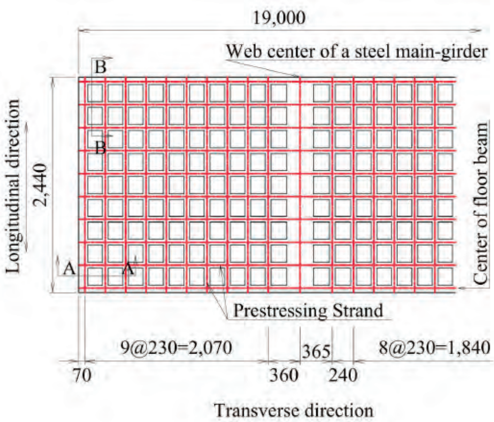

Fig. 3: Top view of a deck (mm)

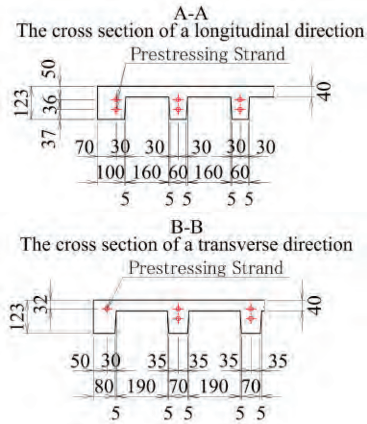

Fig. 4: Sectional drawing of a deck (mm)

2. Verification of the Serviceability in an Analysis

We performed the analysis for the composite girders with a UHPFRC deck. We used three-dimensional finite element analysis to examine the deck behavior by calculating its stress and displacement behaviors. The maximum tensile stress on the top face of the deck was 6.6 MPa, and the ratio of the limiting value for 8.0 MPa of tensile stress was 0.83. The maximum compressive stress under the deck was 80.2 MPa. The ratio of the limiting value for 108 MPa stress was 0.74. Although the gap between the stress of the deck's top and bottom borders was large, results showed that the structure experienced a maximum of about 80% of the stress as a limiting value.

3. Safety Verification by a Wheel Running Fatigue Test

The structure of a UHPFRC deck consists of ribs in two orientations. Therefore, local stress may arise near the point where the ribs cross. By running an actual wheel load in the machine, we verified the variations in local stress to confirm the safety of this thin deck.The test specimen is shown in Fig. 5. The situation of the test is shown in Fig. 6.

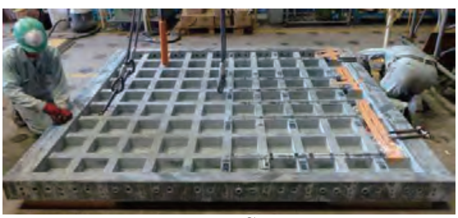

Fig. 5: Test Specimen

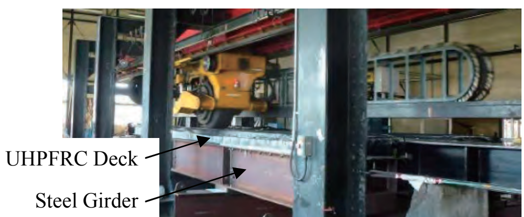

Fig. 6: Wheel Running Fatigue Test

4. Conclusions

(1) We proposed that the dimensions for an AFt-type UHPFRC deck were a slab thickness of 40 mm, a rib height of 83 mm, a rib width of 70 mm, and a rib space of 250 mm. A finite element analysis of this deck showed the static stress to be about 80 percent of the limiting value.
(2) We conducted a wheel running test to evaluate the fatigue durability of the deck, in which a wheel load was applied 200,000 times (100,000 cycles). As the result, there was no damage under the design load.
(3) When a load roughly two times larger than the design load was applied, minor cracks were detected on the side faces of the ribs. However, there was no reduction of stiffness. We confirm that, the fatigue durability of the UHPFRC deck is sufficiently high.