Application of Flat UHPFRC Slabs to a Composite Girder Bridge with Inbound and Outbound Combined Traffic — Deck Slab Replacement on the Moriguchi Route of the Hanshin Expressway —

上下線一体合成鈑桁橋への平板型 UFC 床版の適用 — 阪神高速12号守口線床版取替工事 —

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Synopsis

To contribute to improving quality of life and stimulating the economy in the Kansai region of Japan, the Hanshin Expressway Co., Ltd. has been conducting slab replacement work on the Moriguchi Route (Route 12) as part of the Expressway Renewal Project since 2020. This is the first slab replacement work for a mainline bridge on the Hanshin Expressway. Flat ultra-high-performance fiber-reinforced concrete (UHPFRC) slabs[1] were adopted as the new slabs to be installed after removal of the existing reinforced concrete (RC) slabs.

This is the first time that flat UHPFRC slabs have been used in slab replacement work for a composite bridge carrying dual-lane traffic in each direction. Furthermore, because the period of road closure was limited to only 17 days, much thought in the early stages of the project went into planning a detailed and efficient work sequence for installing the flat UHPFRC slabs. This paper introduces the design and accelerated construction process of the flat UHPFRC slabs for the Moriguchi Route (**Fig. 1**).

Fig. 1 After installation of flat UHPFRC slabs

Structural Data

Structure: Simple composite girder bridge
Bridge Length: 35.0 m
Span: 34.5 m
Width: 17.60–18.64 m
Owner: Hanshin Expressway Co., Ltd.
Designer: Kajima Corporation
Contractor: Kajima Corporation
Construction Period: Feb. 2020 – Apr. 2021
Location: Osaka Prefecture, Japan

1. Outline of Flat UHPFRC Slabs

The existing 170-mm-thick RC slabs of the Moriguchi Route were designed with the previous design code overlooking the shear capacity, especially their fatigue shear capacity. Replacing those existing RC slabs with conventional precast prestressed concrete (PCaPC) slabs designed as per the current design code would have meant a slab thickness exceeding 170 mm, which might have increased onerous on-site work such as the strengthening of steel girders and substructures and the adjustment of road surface elevation. Flat UHPFRC slabs are precast concrete (PCa) slabs designed with the current design code and developed primarily for slab replacement. Taking full advantage of the mechanical properties of UHPFRC, such as roughly five times the compressive strength and more than twice the crack initiation strength of ordinary concrete, the newly developed flat UHPFRC slabs are very light as a result of being thinner than the existing RC slabs; also, removing the haunches from the undersides of the slabs to rationalize their manufacturing helped to reduce their self-weight. Having thinner slabs eliminates any need to adjust the height of the road surface when replacing the existing RC slabs, which would have been inevitable with conventional PCaPC slabs. The lighter weight also reduces the amounts of additional reinforcement required for steel girders and substructures. The fatigue resistance of thin flat UHPFRC slabs was revealed by wheel tracking tests and was found to be greater than that of conventional PCaPC slabs [2]. Also, the high density of UHPFRC prevents chemical compounds such as chloride ions penetrating the slabs, thereby maintaining their structural durability. Flat UHPFRC slabs are prestressed in both longitudinal and transverse directions (**Fig. 2**). In the longitudinal direction, prestressing force is applied using post-tensioning after the flat UHPFRC panels are installed on the steel girders with their longer sides perpendicular to the bridge centerline, and soon after transverse joints are constructed. In the transverse direction, prestressing force is applied using pre-tensioning with suitable equipment available at the PCa factory.

The conventional PCaPC slabs for which post-tensioning is used to apply prestressing force in the longitudinal direction are often designed to have cast-in-place sections at both ends to give space for the tensioning work. For improved quality and durability of the cast-in-place sections and reduced onsite construction time, both slab ends were constructed with the PCa end panels of the flat UHPFRC slabs, and the PCa center panel with anchorage blisters to stress and anchor those longitudinal tendons coming from the left and right end panels was designed and arranged at the middle of the span. Anchoring those numerous tendons coming from both end panels in the very limited area available in the center panel was feasible only by fully utilizing the mechanical properties of UHPFRC.

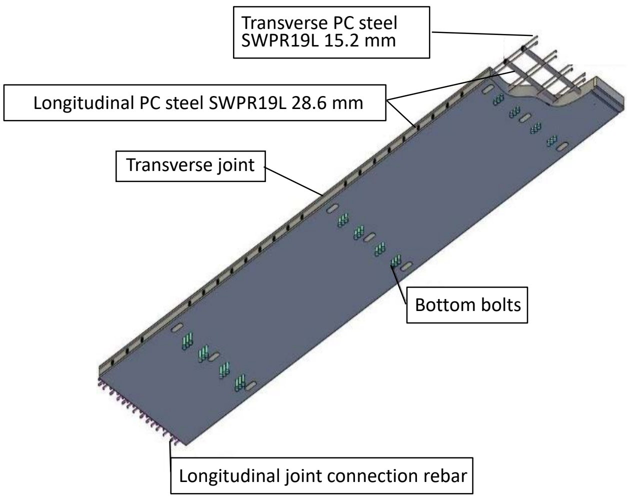

Fig. 2 Conceptual diagram of flat UHPFRC slab

2. Design of Flat UHPFRC Slabs

These flat UHPFRC slabs were designed by combining the standard panels with end panels and center panels with anchorage blisters and then pre-casting the entire slab replacement section. This four-lane bridge is 17.60–18.64 m wide, with longitudinal joints in the median barrier to connect the slabs, which have been split into inbound and outbound lanes. To accommodate the change in width, slab manufacturing was rationalized through fixed incremental adjustment of the slab width (**Figs. 3 & 4**).

Compared with non-composite girder bridges, fully composite girder bridges have more through-holes in their slabs for stud dowels, so a new anti-gap structure was adopted to curtail any increase in the number of through-holes.

In addition to the transverse joints, UHPFRC has been adopted as the in situ infill concrete in the longitudinal joints and the joints between the steel girders and slabs. Utilizing the material properties of UHPFRC, the principal objectives were to ensure equivalent durability for the transverse joints and the UHPFRC PCa slabs, to reduce the width of the longitudinal joints, and to further strengthen the composite joints to prevent displacement of the composite section. The specifications for the slab thickness and the design of the longitudinal joints and anchorages are described below.

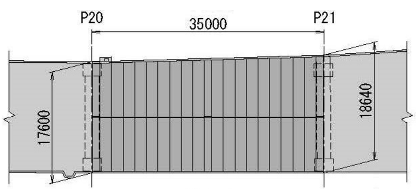

Fig. 3 Plan view

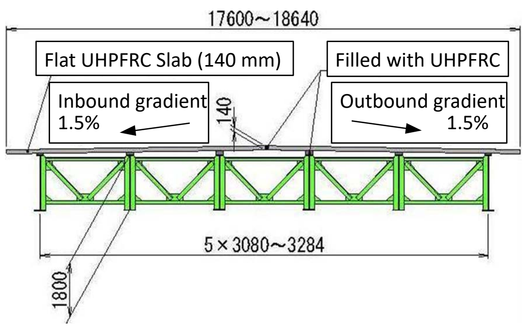

Fig. 4 Cross-sectional diagram

Table 1 Comparison of slab thickness and bending rigidity

	Existing RC Slabs	Flat UHPFRC Slabs
Compression strength (N/mm^2)	24	180
Slab thickness (mm)	170	140
Moment of inertia per unit length (mm^4/mm)	4.09×10^5	2.29×10^5
Elastic coefficient (N/mm^2)	2.50×10^4	4.60×10^4
Bending rigidity per unit length (N·mm^2/mm)	1.02×10^{10}	1.05×10^{10}

Table 2 Comparison of slab weights

	Slab thickness (mm)	Total slab weight (kN)	Change in weight (%)
Existing RC Slab	170	2964	-
Flat UHPFRC Slab	140	2329	-21.4
PCaPC slab	220	3664	23.7

(1) Specifications for Slab Thickness

The design live load for the existing RC slabs is TL-20 (previous Japanese road traffic loads model), with a thickness of 170 mm. By contrast, the thickness of the flat UHPFRC slabs was set to 140 mm considering the B live load (current Japanese road traffic loads model). Having been unable to conduct sufficient research to fully understand the impacts of lowering the bending rigidity of slabs on steel girders by replacing the existing RC slabs with flat UHPFRC slabs, a thickness that affords the same bending rigidity as that of the existing RC slabs was adopted (**Table 1**). When focusing solely on the structural feasibility of the flat UHPFRC slabs, the slab thickness can be reduced to about 125 mm, with further reductions likely based on new research results. In many cases, the slab thickness of a general PCaPC slab is set to 220 mm rather than the design minimum thickness of 190 mm, mainly because of the complex rebar arrangement at the transverse joints.

Next, the weights of the three types of slabs described above are compared (**Table 2**). When an existing RC slab is replaced with a general PCaPC slab, the weight increases by 23.7%, whereas when it is replaced by a flat UHPFRC slab, the weight is reduced by 21.4%. As a result, although temporary reinforcement of the steel girders is required for the construction load when these slabs are installed, they do not need to be permanently reinforced to accommodate an increased live load.

(2) Design Outline of Longitudinal Joints

The slabs for this composite bridge—which carries two lanes of traffic in each direction—have a cross slope of 1.5% from the median barrier to the berm in each direction, resulting in a peak at the median barrier for the slabs (**Fig. 4**). It is difficult to fabricate flat UHPFRC slabs—which are pretensioned and prestressed in the transverse direction—with a bulge shape. Also, there are considerable transportation

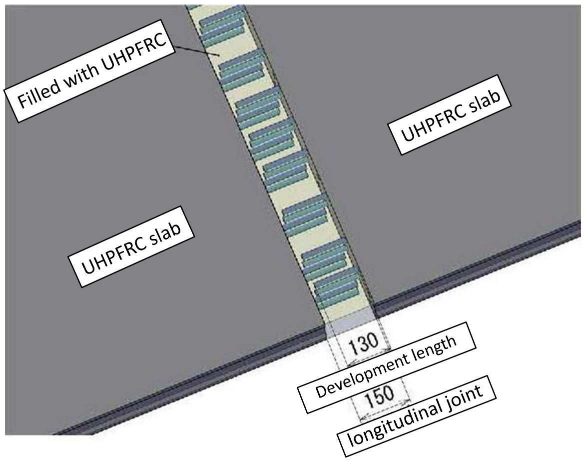

Fig. 5 Conceptual diagram of longitudinal joint structure

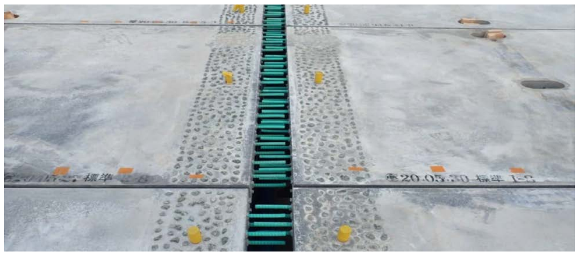

Fig. 6 Longitudinal joint before filling with UHPFRC

restrictions when manufacturing 17.60–18.64-m-wide slabs for a composite girder bridge carrying two lanes of traffic in each direction. Therefore, the flat UHPFRC slabs are split for each direction, and joints to connect the opposing-direction slabs are arranged in the median barrier.

Because the longitudinal joints are positioned within the median barrier and are not directly impacted by wheel load, the tension generated in the joints is not controlled by being prestressed, so fatigue resistance is ensured by installing steel reinforcement joints. Epoxy resin-coated steel bars protrude from the slab edge and are anchored in the median barrier space to connect the slabs for the inbound and outbound lanes. The composition of the UHPFRC in the joints is almost the same as that of the UHPFRC in the slabs, and its high adhesion strength and the short rebar anchorage length of 130 mm (for D16 rebars) enable the joints of the standard panels of this bridge to be very narrow with a width of only 150 mm (**Figs. 5 & 6**).

The protruding steel rebars at the longitudinal joints are designed to resist the tension in the transverse direction that occurs when combining the live load with self-weight and imposed loads, and the tensile stress in the rebars is kept below 120 N/mm^2. After properly designing the longitudinal joints, their fatigue resistance was confirmed by conducting fixed-point fatigue tests.

3. Construction of Flat UHPFRC Slabs

To prevent the supply of flat UHPFRC slabs from being affected by roadwork-induced congestion, they were all brought in and temporarily stored on-site in advance. Also, two dedicated arm-type erection machines (fabricators) were used to accelerate slab installation.

The UHPFRC used as in situ infill concrete for the transverse and longitudinal joints, composite section, and slab joint sections was manufactured continuously night and day using a soundproofed 500-litre vehicle-mounted mixer to increase the filling speed.

As a result, slab replacement work was completed on day 11, installation of concrete barriers and the median barrier was completed on day 13, and installation of the noise barrier was completed on day 15.

(1) Installation of Flat UHPFRC Slabs

For this construction work, flat UHPFRC slabs were installed using two fabricators that were used for the Tamade entrance [3].

Because the full road width could be occupied for construction purposes, each UHPFRC slab transported by a 10-ton truck was held by the fabricator, turned by 90°, and installed in its predetermined position by running along the pre-installed panels (**Fig. 7**). After the fabricator gripped the precast panel, it had to pass under a gantry road sign before entering the floor slab replacement section, but installation could proceed regardless of the gantry because the fabricator was only 2.7 m high. As a result, 42 PCa UHPFRC slabs could be installed in 21 h; the average installation time was 30 min per slab, with the quickest done in just 18 min.

(2) Manufacturing of In situ Infill UHPFRC

A large-capacity vehicle-mounted mixer was used to ensure the manufacturing cycle of in situ infill UHPFRC. Of the two capacities of vehicle-mounted mixer available, namely 1.0 m^3 and 0.5 m^3, the smaller one was selected based on its supply speed. To shorten the cycle time of manufacturing the in situ infill UHPFRC, the mixing materials—except the admixture used to enhance the workability—were pre-weighed and packed in advance to be put into the mixer with a crane.

Fig. 7 Slab installation using fabricators

Conclusion

Flat UHPFRC slabs were used for the first time as replacement slabs for a mainline bridge as part of the Expressway Renewal Project of the Hanshin Expressway. Through this construction work, the applicability of flat UHPFRC slabs to composite girder bridges carrying two lanes of traffic in each direction has been clarified. Also, as a result of the authors' expedited construction process to complete slab replacement within a limited period of traffic closure, the work was completed on day 15. The principal measures adopted for this construction are listed below.

(1) Changes in the road surface height related to the slab replacement were avoided by adjusting the height of the composite section resulting from a 30-mm reduction in thickness of the flat UHPFRC slabs compared with the existing RC slabs.

(2) The weight of the flat UHPFRC slabs was reduced by 21% compared with the existing RC slabs, and even when the B live load (current Japanese road traffic loads model) was considered, permanent reinforcement of the steel girders was no longer required.

(3) UHPFRC was used as the in situ infill concrete, allowing thinner longitudinal joints to be used. The flat UHPFRC slabs were manufactured by fabricating the inbound and outbound lanes separately and then connecting them after installation.

(4) Two dedicated arm-type fabricators were used to install the slabs, thereby expediting the pace of slab installation.

(5) A 500-litre vehicle-mounted mixer was used to manufacture the in situ infill UHPFRC for a steady and continuous supply throughout the day and night.

In addition to the UHPFRC slabs at the Tamade and Shinanobashi entrances, the slabs on this bridge will be continuously monitored, and the results will be used to further improve UHPFRC slabs.

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概　要

阪神高速道路（株）では，2020年のリニューアル工事に合わせて，12号守口線で床版取替えを実施した。本工事は，阪神高速道路で初めての本線橋での床版取替えである。既設の鉄筋コンクリート床版撤去後に設置する更新床版には，平板型の超高強度繊維補強コンクリート製床版（平板型 UFC 床版）を適用した。上下線一体多主合成鈑桁橋への適用は本工事が初めてである。本稿では，上下線一体多主合成鈑桁橋の更新床版として適用した平板型 UFC 床版の設計と急速化を図った施工について紹介する。