Rapid Replacement Technology for Ultra High Strength Fiber Reinforced Concrete Hollow Girder Railroad Bridge
— Improvement Work for the Keio Inokashira Line and Shimokitazawa Station —

UFC ホロー桁鉄道橋の急速架替え技術
— 京王井の頭線　下北沢駅改良工事 —

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Synopsis
Ultra high strength fiber reinforced concrete (hereinafter referred to as “UFC”) is a high-performance material with a design strength of 180 N/mm^2, about four times that of ordinary concrete. It has excellent properties including high durability, high toughness, and high fluidity. It uses steel fibers instead of rebar, meaning that members can be made thinner and lighter. Thus, in recent years UFC has been increasingly used in precast concrete structures, particularly in bridges. This article describes the use of UFC in a railroad bridge replacement for the second time ever in Japan. Because the bridge was on a main railway line in the Tokyo metropolitan area, construction works were limited to nighttime hours. The bridge was constructed with lightweight UFC hollow girders and was designed to allow a staged construction schedule to minimize the impact on operations of the commercial railway line.

Structural Data
Structure: Prestressed concrete simple hollow girder bridge
Bridge Length: 20.4 – 9.5 m
Span: 19.4 – 8.4 m
Width: 7.3 – 5.9 m
Girder Height: 0.8 m
Owner: Keio Corporation
Designer: Fukken Engineering Co., Ltd
Contractor: Taisei · Maeda · Nishimatsu · Zenitaka · Mitsui Sumitomo Joint Venture
Construction Period: Jun. 2016 – Oct. 2017
Location: Tokyo Prefecture, Japan

1. Introduction
As part of a construction project to create continuous grade separation and conversion to four tracks (the latter of which completed in March 2018) on the Odakyu Odawara Line between the Yoyogi Uehara and Umegaoka train stations[1], it was necessary to remove existing bridge piers on the Inokashira Line for replacement with a new railroad bridge near Shimokitazawa Station, where the rail line intersects with the Keio Inokashira Line. This article reports mainly on the superstructure replacement project in

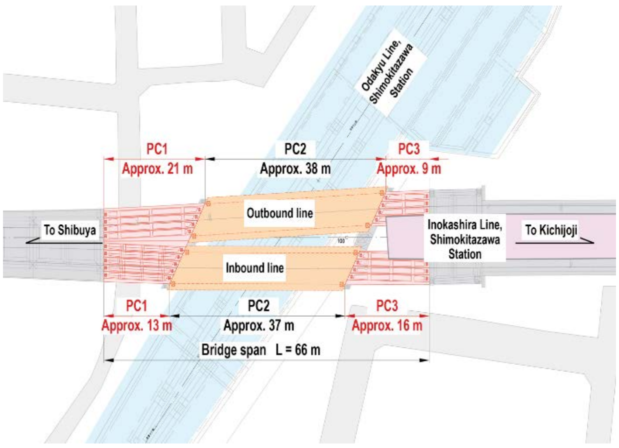

Fig. 1 Position diagram

which UFC was used. After replacement, the bridge section was designed to be a 3-span simply supported prestressed concrete (hereinafter referred to as "PC") hollow girder bridge (spans PC1–PC3) with inbound and outbound lines (to and from Tokyo, respectively; **Fig. 1**). The initial plan for PC1 and PC3 was to use precast concrete girders made of ordinary concrete, resulting in very heavy girder weights. The cranes used for the erection would be large and heavy. If those cranes were placed directly above underground Odakyu Line structures still under construction at the same time, there would be serious concerns about requirements for extensive reinforcement and other impacts on those structures. The decision was therefore made to use UFC to effectively reduce the weight of the PC1 and PC3 girders. To prevent interference with line operations, the bridge had to be replaced without delay during the period from passage of the last train on one day to arrival of the first train on the next day. Multiple UFC precast girders were therefore erected in two stages, and in the final form, the UFC girders were structurally integrated by placing ultra-fast in-fill concrete at joints and applying prestressing force in transverse direction [2].

2. Overview of the Structure

Fig. 2 shows a general structural drawing of the bridge. Note that this figure shows the PC1 outbound line, which has the longest span length.

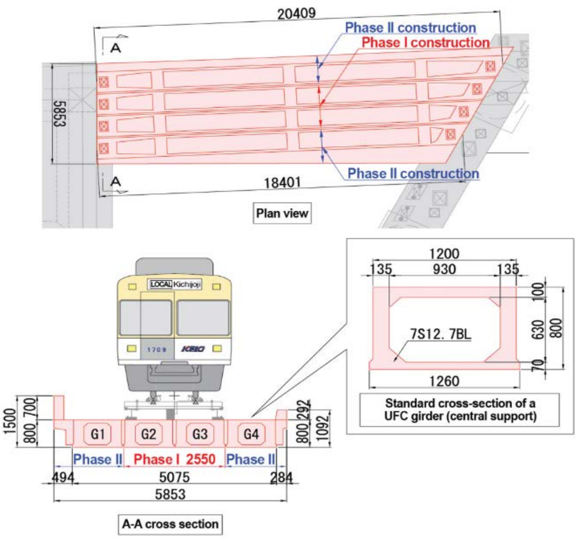

Fig. 2 Structural overview (PC1, outbound line)

Staged construction was performed to reduce the girder weight during erection, as mentioned above. In Phase I construction, two main UFC girders satisfying the conditions for train operation were pre-integrated and the temporary tracks being used as construction girders were replaced with UFC girders. In Phase II construction, two more UFC girders were erected as single girder beside the two main girders erected in Phase I, and after the placement of in-fill concrete at the longitudinal joints between the Phase I girders, the entire Phase I and Phase II structures were integrated using transverse PC steel.

The fabrication of UFC members requires 48 h of steam curing at 90 °C during the manufacturing process. The segments were therefore fabricated at a secondary products plant and joined in place using the precast segment construction method. The UFC girder was divided into three segments in the bridge axis direction, and joining surfaces were fabricated using the match-cast method.

3. Summary of the Construction

(1) Construction Flow

As described earlier, there were a total of four bridges, PC1 and PC3 for each of the inbound and outbound lines. Each of these four bridges is an independent structure, and the construction flow shown in **Fig. 3** was used for each. Of those construction tasks, tasks 6 and 8 required particularly careful planning and implementation because of their potential to interfere with train operations.

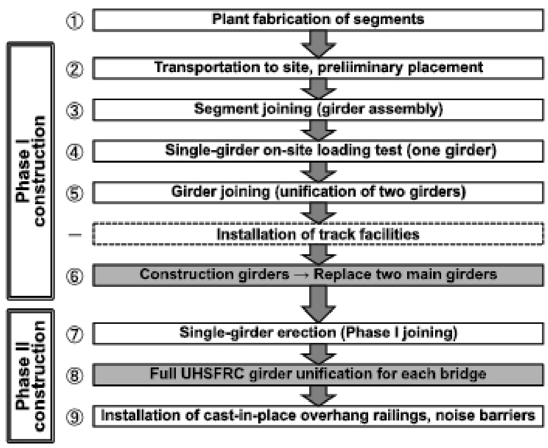

Fig. 3 Construction flow

(2) Segment Fabrication

Segments had a maximum length of 10 m and weight of 11.3 t. Segments were manufactured by mixing a premixed cement-based powder with silica sand, water, a special-purpose water reducer, and steel fibers. Because surfaces of UFC materials tend to dry out, one segment was continuously cast while the full casting quantity was kneaded in a hopper. After demolding from the formwork, standard heat curing was performed for 48 h at 90 °C, followed by finishing and stocking in the plant (**Fig. 4**).

4. Phase I Construction

(1) Segment Joining

Segments fabricated at the plant were delivered to the site, where segments that were axially divided into three parts were joined and assembled into a single UFC girder. As **Fig. 5** shows, assembly work was performed on a special field assembly trestle consisting of tracks and bogies. Pulling operations were performed by placing PC steel rods (ø23 mm) and center-hole

Fig. 4 Fabrication of UFC segments

jacks for pulling at four upper and lower locations on both sides of the UFC girders. After the three segments were pulled together on the ground assembly girders, the main prestressing steel cables were tensioned and grouted to complete the joining of each girder.

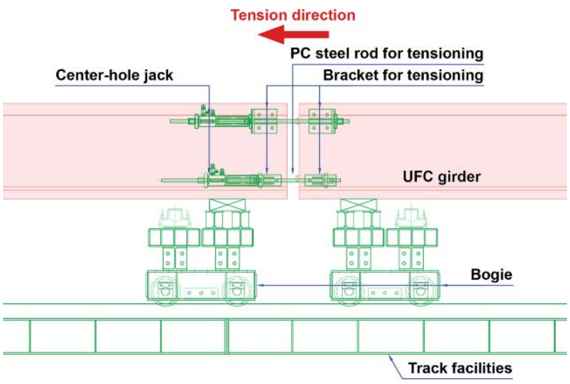

Fig. 5 Joining equipment

(2) Joining Girders (Integrating the Two Main Girders)

Two axially joined UFC girders were placed on the temporary horizontal girders, the transverse prestressing sheaths between UFC girders were joined, and the in-fill concrete was poured. After the spacing concrete had strengthened, the transverse PC steel were tensioned to integrate the two girders (**Fig. 6**). The spacing concrete used here was early-strength concrete with slump of 15 cm. After pre-integrating the two main girders, sleepers, rails, and other track equipment were installed on the top surface of the girders and transported to the construction area.

(3) Replacement of the Two Main Girders

Careful and thoughtful planning was prioritized for replacement works of the temporary tracks used as construction girders with the main UFC girders. To avoid interfering with train operations, it was necessary to start these tasks after the last train of the workday and to complete them before the first train of the next day.

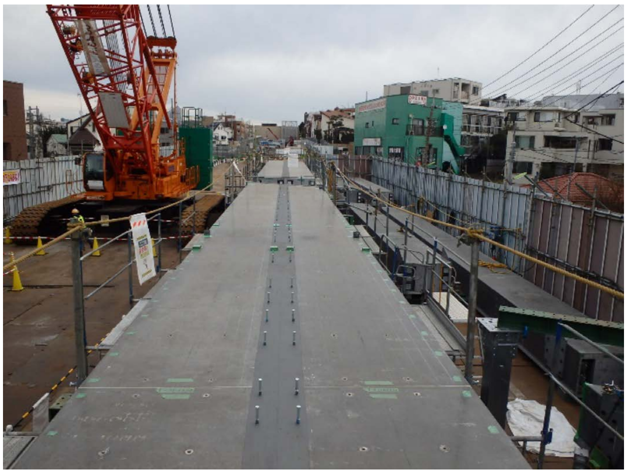

Fig. 6 Unification of the two main girders

Fig. 7 During erection

Therefore, the tasks to be performed that night and their contents had to be carefully considered to ensure that they could be quickly and accurately performed. The erection of pre-integrated girders during the night is shown in **Fig. 7**. All replacement works were completed within the period of power shutoff and track closure. The presence of deflection or deformation during train travel was checked after erection. The results showed there to be 40–50% of the design deflection amount, which was considered reasonable.

5. Phase II Construction

(1) Single-girder Erection

After Phase I construction, the girders were erected by crane one at a time, with single girder placed beside the two main girders. Since those single girders were erected with no track equipment, a height difference occurred due to differences in deflection caused by the girder erected in the Phase I construction (4 mm maximum at the span center), but since the amount was small, it was decided to scrape it to the width of the spacing material.

(2) Girder Integration

The structurally integrated girders comprising the two main girders erected during Phase I construction and the single girders erected in Phase II construction are shown in **Fig. 8**.

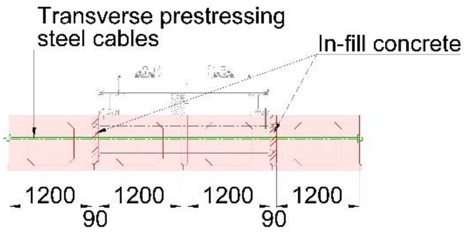

Fig. 8 Integrated girder structure

Once single girders were erected beside the two main girders, the in-fill concrete would be poured between those girders and the transverse prestressing steel cables would be stressed. Here, the in-fill concrete must have a certain level of strength when the prestressing steel cable is under tension. A fast-hardening concrete was necessary to finish these tasks before the start of power supply the next day. For these tasks, therefore, an ultra-fast-hardening concrete mixed by a special jet concrete mixer truck (**Fig. 9**) was adopted.

Fig. 9 Jet concrete mixer truck

A test mix was performed before the construction, and the formulation was determined to ensure that the mix would have the required working time for placement (30 min), and that it would develop the compressive strength required for tensioning in 90 min.

As described above, all tasks were completed within the track closure time, and the work was completed without interruption until the start of train service on the following day.

6. Conclusion

This bridge construction project involving girder replacement on a commercial line was successfully completed after careful planning and rehearsals to avoid any burden on railroad users (**Fig. 10**).

Fig. 10 Completed construction

The application of UFC in a railroad bridge maximized the material's utility, namely, the ease of devising ways to reduce weight by thinning the members and optimizing their shapes. In addition to this, various precasting and integration methods, such as girder-axial joining of segments and girder-to-girder joining using ordinary and ultra-fast-hardening concrete, depending on the construction progress.

Weight reduction of refurbished structures is often an issue in recent projects aimed at mitigating the aging of social infrastructure; therefore, methods like the ones described here can be expected to be increasingly used. The authors hope that this project, which took the lead, will serve as a reference for future renewal projects. This project will hopefully be looked to as a cutting-edge reference for future refurbishment projects.

References

[1] Shinoda, T., Tsunashima, T., Iwamoto, A., Yamaguchi, T., Kitamura, T., Zhao, Y.: *Design and construction of a UFC railroad bridge*, Bridge and foundation engineering, Vol. 52, No. 4, Kensetutosyo, Tokyo, pp. 15–20, Apr. 2018 (in Japanese).

[2] Shinoda, T., Iwamoto, A., Yamaguchi, T., Kitamura, K.: *Railway Bridge Combined by Multiple UFC Girders using Quick-hardening Concrete ―Rapid Construction for Replacement of Keio Inokashira Line Shimo-kitazawa Station Bridge―*. Concrete Journal, Vol. 57, No. 3, JCI, Tokyo, pp. 207–212, Mar. 2019 (in Japanese).

概　要

UFC（超高強度繊維補強コンクリート）は，設計基準強度が180N/mm2を有し，高耐久・高じん性・高流動などの優れた特性をもつ高性能な材料である。また，鉄筋の代わりに鋼繊維を用いているため，部材の薄肉化・軽量化を図ることが可能となり，近年では橋梁を中心としたPC構造物への適用が進んでいる。

本工事は，国内で2例目となる鉄道橋においてUFCを採用して架替え工事を行った。首都圏の主要路線であるため，営業線の運行への影響を最小限とするため，軽量なUFCホロー桁で構成される床版橋とし，かつ，段階施工が可能な構造とすることで架替えを行った。