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CONTENTS

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Development of fast-setting UHPFRC for bridge deck overlay

Application examples on site

1. Introduction

There are approximately 730,000 road bridges in Japan. About half of them will be 50 years old by 2030. Many of these bridges are suffering from deterioration by fatigue of the slabs due to the heavier repeated wheel running loads and number of passing vehicles, chloride attack caused by the application of deicing agents and damage caused by the freeze-thaw effect. Deteriorated slabs have been repaired by the bridge deck overlay method, which involves removing and replacing the top surface. However, the conventional material used for the repair, which is Steel Fiber Reinforced Concrete (SFRC), has poor workability and integrity, and degradation has recurred.

Therefore, as a material for the bridge deck overlay method, we developed a fast-setting Ultra-High-Performance Fiber-Reinforced Cement-based Composite (UHPFRC). UHPFRC is a suitable material for repairing and reinforcing slabs because it has high crack resistance and density, and excellent durability.

As the compressive strength of the fast-setting UHPFRC is quickly developed, the traffic can be opened in three hours after pouring the UHPFRC. In addition, its fluidity can be adjusted to suit the construction area over the slops up to 10%.

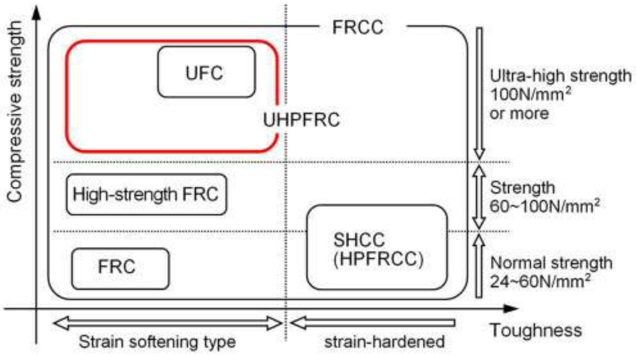
With developing the fast-setting UHPFRC, the dedicated batcher plant, transporter and concrete paving machine have been also deployed. By means of the above-mentioned developments the construction can be carried out in only one lane at night. This results in reducing the impact on road users.

2. Outline

In Japan, large-scale renewal projects are carried out by replacing the slabs and using the bridge deck overlay method as the slabs of road bridges deteriorate with age. However, there were issues such as degradation due to inadequate integration of the SFRC with the existing slab and the need to verify the substructure foundation due to the increased load on the superstructure.

Recently, UHPFRC, which has high strength and densification, has been considered as a replacement material for SFRC to ensure integrity with the existing slab by using it for the bridge deck overlay method. However, there are only a few examples of application of fast-setting UHPFRC.

This paper describes the development of fast-setting UHPFRC based on ambient temperature curing Ultra-high-strength Fiber reinforced Concrete (UFC), and its application to in-service bridges in order to improve the load carrying capacity and fatigue durability of existing bridge decks. According to the classification in Japan, the compressive strength of UFC is 180 N/mm^2 or higher, and that of UHPFRC is 100 N/mm^2 or higher (Figure-1).



UHPFRC Ultra-high strength cementitious composite material reinforced with steel fiber and organic fiber

Figure-1 Classification of UHPFRC in Japan1)

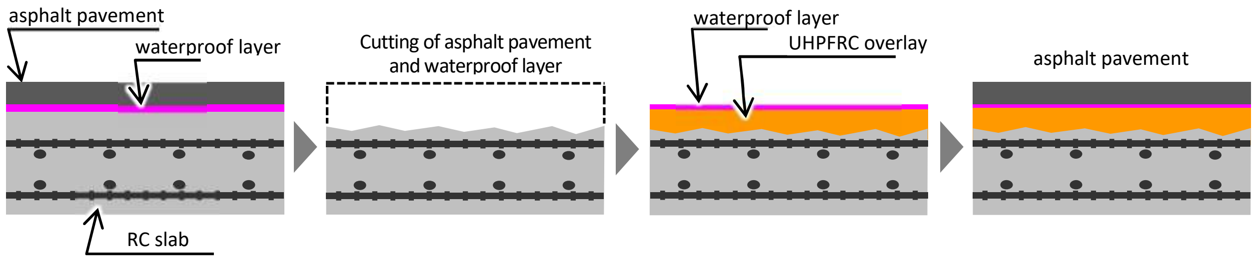


Figure-2 Outline of the bridge deck overlay method

3. Outline of fast setting UHPFRC

(1) Background of material development for the bridge deck overlay method

The deterioration factors of slabs include fatigue of the slabs due to heavier repeated wheel running loads and number of passing vehicles, as well as lifting, delamination, and graveling of the bridge slabs due to chloride attack caused by the application of deicing agents and damage caused by the freeze-thaw effect (Photo 1).

Photo-1 Deterioration of the upper surface of the slab

For bridges where deterioration is limited to the top surface of the deck, the bridge deck overlay method is often used to increase the flexural and shear capacity of the deck. Where slab deterioration is significant, the existing slabs are removed and replaced with precast slabs. This results in significant delays in the start of construction, especially on heavily traffic sections near urban areas, due to the time required to minimize social impacts.

Although SFRC has been widely used as a material for the bridge deck overlay method, there have been reports of lifting and delamination due to inadequate integration with the existing deck slab. Therefore, we have developed a fast-setting UHPFRC that can be used for the bridge deck overlay method to improve durability and integration with the exiting slab.

(2) Outline of the bridge deck overlay method using UHPFRC

UHPFRC is an ultra-high-strength material and has high crack resistance, and even if cracks occur, the crack width does not increase. In addition, since UHPFRC is a dense material with low permeability, the penetration of chloride ions and water is limited to the surface layer. Therefore, there are options for omitting the waterproofing layer, changing to a lower grade waterproofing layer than normally used, or combining with waterproofing asphalt, which can reduce construction time. Omission or simplification of bridge waterproofing work could reduce work process within the conventional regulation time and reduce the regulation time due to construction.

The bridge deck overlay method involves cutting and grinding the existing slab surface by approximately 10 mm and adding 50 mm or more of SFRC on top of the existing slab surface. UHPFR has the same construction method, but because it is an ultra-high strength material and there is no need for coarse aggregate, the reinforcement layer can be thinner than SFRC, and UHPFR also has superior long-term durability (Fig-2).

(3) Fast-setting UHPFRC Formulation and Specifications

The basic mix of the fast-setting UHPFRC is shown in Table 1, and the materials used are listed in Table 2. The constituent materials are modified from the "Guidelines for the Design and Construction of UFC (UFC Guidelines) 2)" published by the Japan Society of Civil Engineers. Rapid hardener, which is a powder, is used as a fast-setting material for the purpose of reducing the regulation time due to construction. Table 3 shows the UHPFRC target performance and measured values.

(a) Accelerated neutralization depth

The flow rate of UHPFRC was set in a range of 150 to 280 mm to suit the slopes of the construction area over. The flow rate is set so that the higher the slope, the lower the flow rate, and has been confirmed to be used up to 5% on bridges and up to 10% in laboratory tests. The flow rate of the mortar was adjusted by setting the amount of high performance water reducer and retarder to be added for each ambient temperature between 5 and 40 degrees Celsius.

(b) Compressive strength

The compressive strength of SFRC used for the bridge deck overlay method has a management standard value of 24 N/mm^2 or more at a given age (usually 3 hours) according to the Structural Construction Management Guidelines3) (Management Guidelines) used by Japanese expressway companies, and this material also met this performance. In addition, the target value of 120 N/mm^2 or more was met for compressive strength at 28 days.

Table-1 Formulation of UHPFRC

W/P	Unit weight(kg/m^3)					Addition(kg/m^3)	
(%)	W	P	S	SP*	HA**	SF	CR
16	210	1327	837	8～30	140	157	4～10

* mixing ingredients into water, ** Included in P

Table-2 Materials used in UHPFRC

Type	Symbol	Remarks
Mixing water	W	Tap water
Premix material	P	Premix binder for high strength
Fine aggregate	S	Silica sand
Admixture	SP	High performance water reducer
Reinforcing steel fiber	SF	φ0.16×13mm
Rapid hardener	HA	Powder
Retardants	CR	Powder

Table-3 Target performance of UHPFRC

		UHPFRC (Material age)	
		Target value	Measured value
Flow (mm)	JIS R 5201(Static)	150 to 280	185
Air volume (%)	JIS A 1128	4.0 or less	3.0
Compressive strength(N/mm^2)	JIS A 1108	24.0 (3hours)	34.8 (3hours)
		120 (28days)	150 (28days)
Static modulus of elasticity(kN/mm^2)	JIS A 1149	-	44.3
Adhesive strength (N/mm^2)	JIS A 1171	1.0 (3hours)	1.5 (3hours)
		1.5 (28days)	2.7 (28days)
Crack Initiation Strength(N/mm^2)	JIS A 1113	6.0	9.25
Length change	Test Method 439	Less than 250μ	211μ expansion
Neutralization(mm)	Test Method 439	-	0
Apparent diffusion coefficient of chloride ion(cm^2/year)	JCSE-G572 and JCSE-G574	-	0.032

(c) Adhesive strength

UHPFRC showed high adhesive strength of 2.7 N/mm^2 at 28 days of age. In the bridge deck overlay method, the integrity of the existing and overlay sections is important in order to restore and improve the load-bearing capacity of the slab. The adhesive strength between the concrete and the repair material was found to be sufficient compared to the 1.5 N/mm^2 or more adhesive strength specified in the Management Guidelines.

(d) Crack initiation strength

The average crack initiation strength at 28 days was 9.25 N/mm^2, which was lower than the UFC Guidelines average of 11.7 N/mm2. The compressive strength of this material was approximately 130-150 N/mm^2, which was lower than the UFC Guidelines average of 194 N/mm^2. Therefore, the crack initiation strength is also considered to be low.

(e) Percentage change in length and mass

Figure 3 shows the measured rates of change in length and mass. The rate of length change was 211 μ expansion strain at 28 days. According to the Management Guidelines, the dimensional stability of the bridge deck overlay method was defined as a shrinkage rate of 255 μ or less, which satisfied UHPFRC.

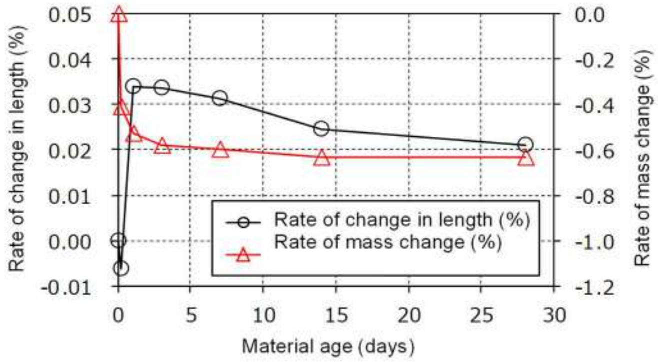


Figure -3 Percentage change in length and mass

(f) Accelerated neutralization depth

The depth of neutralization after 52 weeks of acceleration test in a 5% concentration environment was 0 mm for all sample dimensions, and no neutralization was observed.

(g) Apparent diffusion coefficient of chloride ion

The apparent diffusion coefficient of chloride ions after 52 weeks of immersion in a 10% NaCl solution was 0.032cm^2/year, a larger value compared to the apparent diffusion coefficient of UFC (0.0019cm^2/year), but smaller than that of ordinary concrete (0.14 to 0.9 cm^2/year).

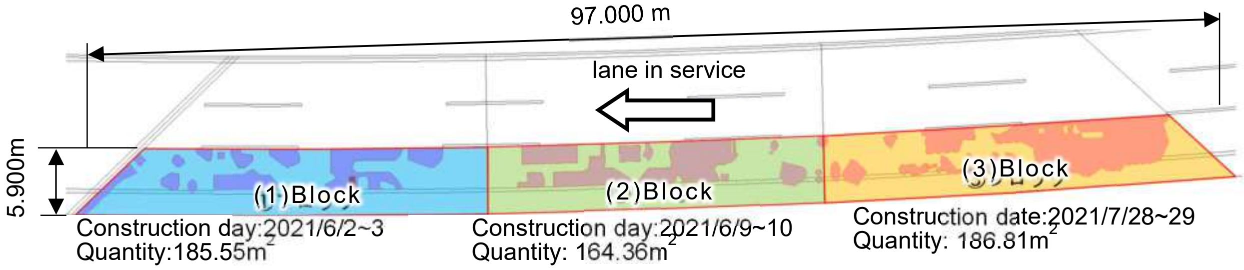


Figure-4 The bridge deck overlay area

3. Record of implementation

The reinforced concrete slab (RC slab) was constructed in the 1960s, and the top surface of the slab was overlaid by SFRC in 2000. In 2019, a hammer sounding investigation was conducted on the upper surface of the subject RC slab. The results showed that the entire surface of the existing slab had deteriorated. This included lifting at the interface between the overlay and the existing slab. It was therefore decided to trial the fast-setting UHPFRC to repair the deteriorated areas (536.7 m^2) of the first lane overlay, including the shoulders. (Figure-4).

(1) Construction machinery and joints

Figure 5 shows a schematic of the machine layout. After cutting and cleaning the pavement and removing the damaged areas, the machine was placed. The mixer, generator and other equipment were installed in the on-board plant, and the materials used were measured in 0.5 m^3 flexible container packs and placed in an area where they could be lifted by the crane of a truck-mounted unit (Photo-2).

In previous construction tests on the equipment used, the mixing time for UHPFRC was about 20 minutes, but because it is fast-setting UHPFRC, the mixer had to be washed after each batch, resulting in a production cycle of about 40 minutes for each batch. UHPFRC can be installed in less than 40 minutes, and even if it were mixed continuously, it would be at the construction joints of each batch.

Therefore, it was decided to install a partition formwork for each batch and to install a construction joint for each block. The construction joints were treated by applying a fast-setting two-component epoxy resin adhesive.

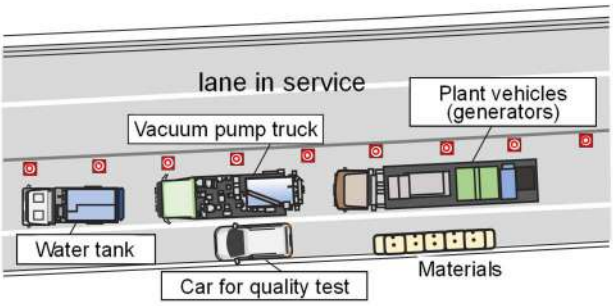


Figure-5 Machine layout

Photo-2 On-board plant

(2) Construction method

The construction was as follows: First cut and grind the pavement, then remove and backfill the deteriorated areas, and finally overlay the slab with UHPFRC.

After the pavement was removed, a hammer sounding investigation was performed on the upper surface of the RC slab. Deteriorated areas, such as uplift and delamination, were removed by human power chipping and these sections were repaired with UHPFRC prior to the bridge deck overlay. The overlay area has a 5% cross slope and is subject to traffic vibration from adjacent lanes, which can cause deformation of the materials in the overlay area. The interface between the existing slab and the UHPFRC was applied a fast-setting two-component epoxy resin adhesive on all surfaces.

A wheelbarrow was used to transport materials due to one-lane work zone. Electric vibratory trowels and a large engine screed (Photo-3) were used for compaction.

Photo-3 Large engine screed

Based on the results of previous construction tests, the overlay was performed from the higher slope to the lower slope, taking into account the deformation characteristics during the overlay. Especially, the outer perimeter of the block was carefully compacted with electric vibratory trowels.

A curing agent that does not interfere with adhesion to the asphalt pavement was used as a finishing agent in the leveling process, and curing sheet was used to prevent drying of the surface between immediately after the overlay and the asphalt paving. The surface was observed prior to the paving and was in good condition with no cracking observed (Photo-4).

Photo-4 Completion of work

(3) Fluidity

The flow of UHPFRC after mixing was stable at approximately 220 mm (Figure-6), regardless of ambient temperature, by adjusting the amount of high-performance water reducer and retarder. UHPFRC could be compacted and finished with electric vibratory trowels for up to 30 minutes after mixing.

Using this construction method, the construction time from completion of mixing to overlaying and finishing was approximately 10 minutes for each batch. Although there was a tendency for the flow to drop slightly earlier during periods of direct sunlight, the installation was completed smoothly with no impact on the job.

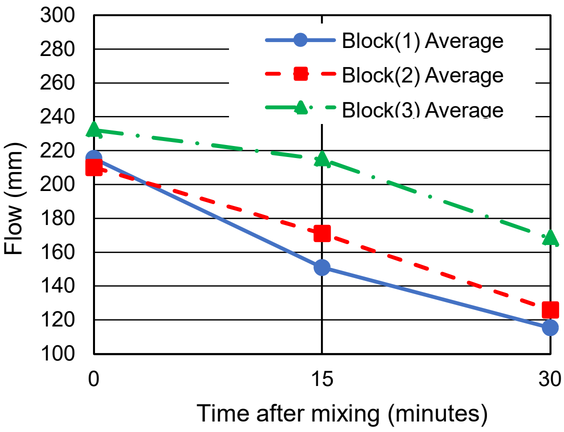


Figure-6 Elapsed change Mortar flow

(4) Compressive and Adhesive Strength Test Results

Samples were taken in the field and tested for compressive strength. Figure 7 shows the results of the compressive strength tests. The compressive strength was greater than 24 N/mm² after 3 hours, 100 N/mm² after 7 days, and 140 N/mm² after 28 days, meeting the target strength (120 N/mm²). In addition, the adhesive strength with concrete was confirmed to be 1.0 N/mm² or more at 3 hours as a result of on-site adhesive strength tests conducted in accordance with the Management Guideline.

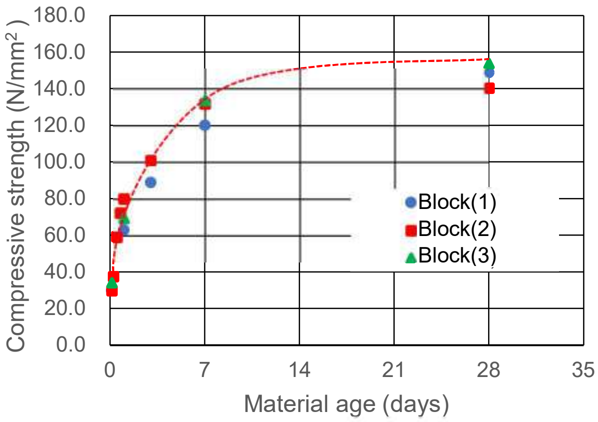


Figure-7 Compressive strength test results

(5) Results of Overlay Height Check

A 3D laser scanner was used to measure fabrication quality after construction was complete. The bridge deck overlay was controlled to within ±10 mm of the design height. The average thickness was 35.6 mm compared to the design thickness of 30 mm.

4. Conclusion

It was confirmed that the fast-setting UHPFRC satisfied the Management Guidelines standard values for adhesive strength and dimensional stability of cross-sectional repairs used for the bridge deck overlay, and that the depth of neutralization and the apparent diffusion coefficient of chloride ions were less and more durable than those of ordinary concrete or SFRC.

The field application of the fast-setting UHPFRC confirms that construction can be completed within one-lane restrictions on an in-service expressway, and that fluidity suitable for construction can be managed by adjusting the mix to match the ambient temperature. Based on the above, we believe that the fast-setting UHPFRC can be effectively used as a replacement for the SFRC used in the bridge deck overlay method.

Design and construction guidelines for UHPFRC are still under development, and there is currently no clear design method for UHPFRC in Japan. Further tests are being conducted to evaluate the fatigue resistance of the fast-setting UHPFRC, which takes advantage of its high tensile strength, and its integrity with the existing slab.

In this construction project, the existing mixer and other equipment were used to produce UHPFRC, which required a long mixing time, resulting in a much longer construction time compared to SFRC. Therefore, it is essential to develop a mixer and other equipment with high production capacity, and it is also important to develop transportation and laying machines that match the production capacity. In addition to developing materials, we will continue to develop equipment such as mixers.

5. Reference

1. Japan Society of Civil Engineers Concrete Committee. Subcommittee on Structural Application of Fiber Reinforced Concrete (Phase 2) Committee Report Structural Design of Fiber Reinforced Concrete and its Issues, I-7, Fig. 1.1.1
2. Japan Society of Civil Engineers. Design and Construction Guidelines for Ultra High Strength Fiber Reinforced Concrete (Draft), 2004
3. East/Central/West Nippon Expressway Company Limited: Guidelines for Construction Management of Structures, 2020.

6. Conctact Information

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Bridge Deck Slab Replacement by CAP SLAB

Precast Prestressed Concrete Slab Exclusively Developed for PC I-Girder

1. Introduction

In recent years, renewal project has been und-erway in Japan to address aging expressways. In renewal project of expressway, vehicle traffic must be restricted in order to replace deck slabs that directly support vehicle loads.

Therefore, there is a need to develop a construction method that can shorten the time required for the bridge deck replacement. Due to its structural features, replacing the deck slab of a prestressed concrete (PC) composite I-girder bridge requires a lot of work on site impacting the traveling public significantly.

2. Outline

The "CAP SLAB" is a precast (PCa) deck panel that has a unique shape at the bottom to cover the top flange of prestressed I girder (Fig-1).With this shape, the deck panel and girders can be integrated simply by installing rebar dowels on the girder top flange and grouting the gap between the deck panel and the girders. This minimizes on-site work and greatly improves construction speed. In addition, the thickness of the deck slab can be maintained and the road profile does not need to be raised.

Furthermore, since the CAP SLAB is fabricated in a precast factory, it is easy to adopt prestressed concrete structures that can enhance the fatigue durability of deck slabs due to vehicle traffic by stabilizing the quality of the deck slabs.

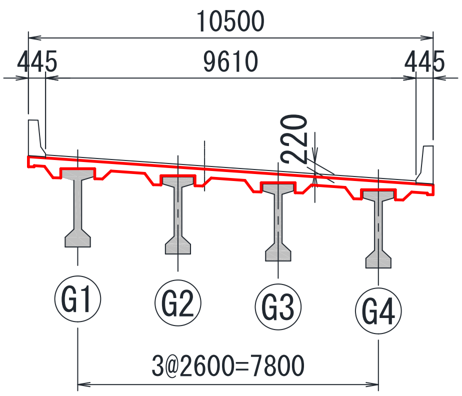
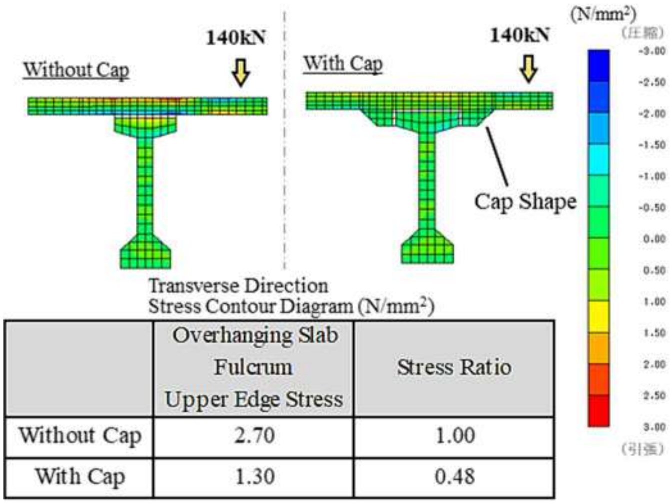


Figure-1 CAP SLAB

3. Detailed Description

(1) Structural Design of CAP SLAB

The CAP SLAB has a "cap" shape that covers the upper flange on existing PC girders, such that the cap portion functions as a strut against negative bending moment caused by the slab behavior. This reduces stresses generated in the slab (Fig-2).



	Overhanging Slab Fulcrum Upper Edge Stress	Stress Ratio
Without Cap	2.70	1.00
With Cap	1.30	0.48

Figure-2 Cap shape effect (stress reduction)

This effect limits the increase in slab thickness and raises the total composite girder height, minimizing the impact on existing PC girders and abutment approaches (Fig-3).

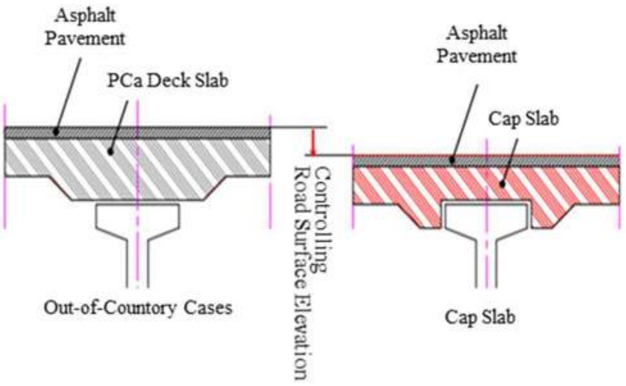


Figure-3 Cap shape effect (deck level reduction)

For the PCa panel fabrication, the shape, sizes and positions of the upper flange were premeasured using a 3D scanner on-site and grouped into several types, which enables better fit of PCa panels into the existing girders to maintain quality(Fig-4).

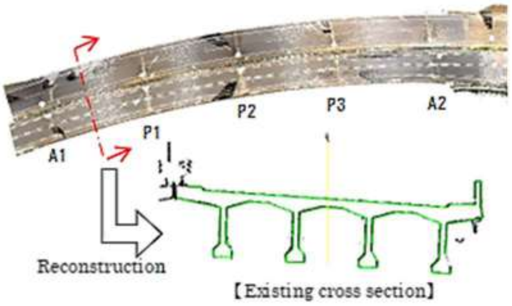


Figure-4 3D scanner

To make a composite section, the PC girder and slabs were connected by using post-installed anchors in upper flange and non-shrink mortar filling. The reliability of the designed structure was confirmed through full-scale tests. (Figs-5 and 6).

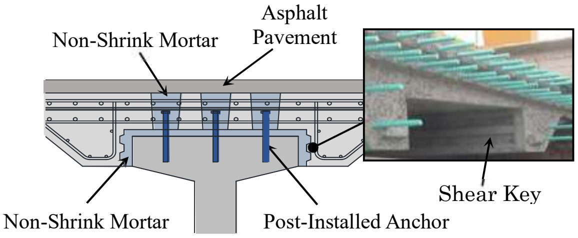


Figure-5 Details of joints between the CAP SLAB and PC girders

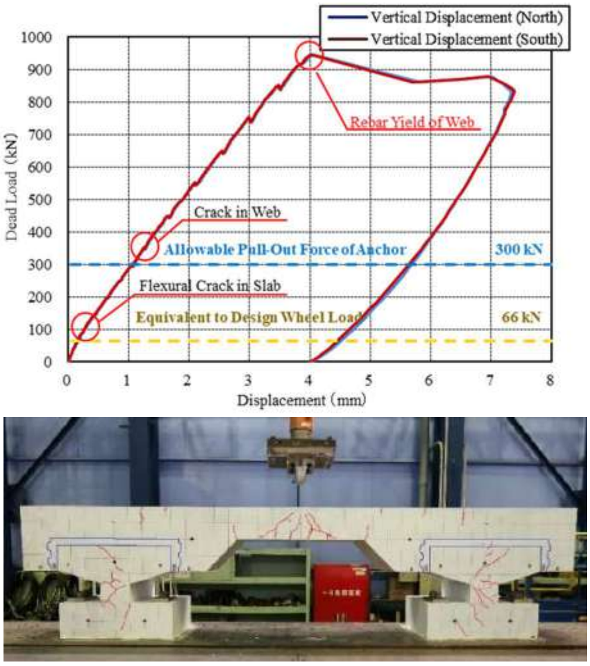


Figure-6 Full-scale structural performance verification experiment (load transfer verification)

(2) Construction

①Removal of Existing Deck Slabs

The conventional method requires concrete removal with water jets to reuse rebars in existing PC girders for composite section connections, which is time concerning work in construction. By using the cap slab method with post-installed anchors and non-shrink mortar, the rebars can be cut by wire saw and slabs can be removed in short term. Existing slabs were cut and removed along the upper flange of existing PC girders using concrete cutters (vertically) and wire saws (horizontally). Steel bars from the PC girders were also cut (Figs-6 and 7).

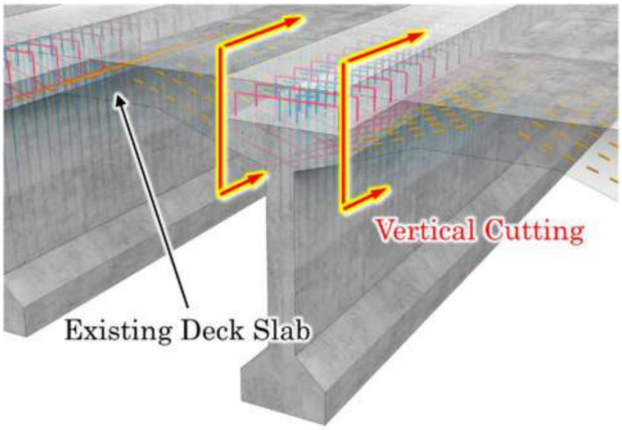


Figure-6 Cutting and removing existing deck slabs between girders

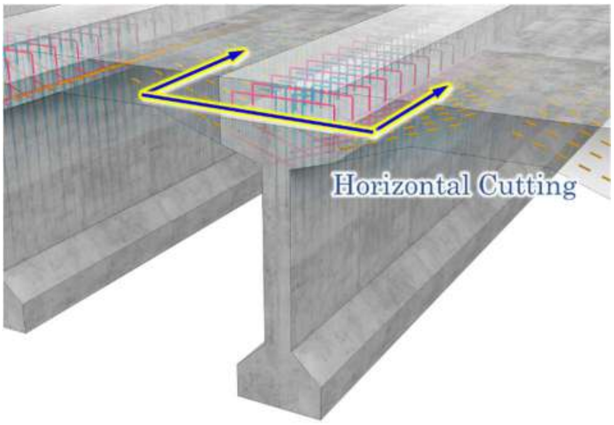


Figure-7 Cutting and removing existing deck slabs on girders

②Erection of PCa Panels

The PCa panels were erected (Photo-1), and a cementitious anchoring system was used to set shear connector rebars on the top of the upper flanges of existing PC girders. Boundary surfaces between PCa panels and upper flanges of the main girder were filled with ultra-fast-curing non-shrink mortar. Holes in the PCa panels for rebars for shear connectors were also filled with non-shrink mortar.(Figs-8 and 9).

Photo-1 Erection of PCa panels

Figure-8 Cutting and removing existing deck slabs on girders

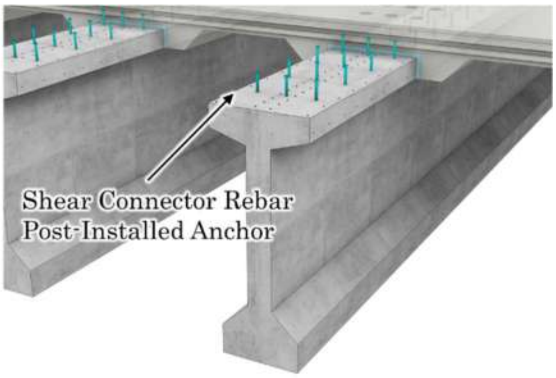


Figure-9 Cutting and removing existing deck slabs on girders

4. Anticipated Results

(1) Accelerated Construction

The CAP SLAB method completes the bridge deck replacement three times faster than the conventional replacement methods. The existing bridge removal is simplified by allowing concrete sawing around the girders. Precast new bridge elements eliminate the needs for cast-in-place operations on site.

(2) Economic benefits are improved

The PCa panels used on previous projects increase the total thickness of bridge decks, requiring the roadway profiles to be raised at each end of projects. The CAP SLAB method does not change the roadway profile completely eliminating the works.

(3) Quality and durability are improved

The quality of the precast components is enhanced because they are manufactured in a controlled factory providing ideal curing conditions for the concrete structure. Prestressing the precast elements adds durability to the replacement structure.

6. Record of implementation

The CAP SLAB method is applied to the Kamitagawa Bridge projects for the Chuo Expressway in Japan. The Kamitagawa Bridge is a four-span simply supported bridge consisting of prestressed I-girders and link slabs connecting the bridge deck without joints (Photo-2).

Photo-2 Kamitagawa Bridge

7.Conclusion

Development of new precast deck panels eliminated a significant amount of on-site work. Applying the CAP SLAB to highway renewal projects reduces impacts to the travelling public during construction and contributes to extending service life of our infrastructures.

8.Conctact Information

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Infrastructure Development Institute-Japan (IDI) is a general incorporated association operating under the guidance of Ministry of Land, Infrastructure, Transport and Tourism of Japanese Government.

IDI provides consulting services to facilitate international assistance to developing countries, to promote international exchange of information and human resources, and to support globalization of project implementation systems targeting both developed and developing countries in the field of infrastructure.

IDI has been publishing a free quarterly journal called “IDI Quarterly” since1996 to introduce information related to public works and construction technologies developed in Japan, to foreign countries. We have distributed the journal to administration officials in more than 90 countries around the world via e-mail.

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