UFC APPLICATION AND THE FEATURE OF PC BRIDGE IN JAPAN

Manabu HOSOTANI
Manager, Design Dept. Civil Engineering Div., Taisei Corporation, Tokyo, Japan

Hiroyuki MUSHA
Manager, Technology Center, Taisei Corporation, Tokyo, Japan

Kazuyoshi KASAKURA
Manager, Design Dept. Civil Engineering Div., Taisei Corporation, Tokyo, Japan

Hidehiko INAHARA
Manager, Design Dept. Civil Engineering Div., Taisei Corporation, Tokyo, Japan

Norio WATANABE
Manager, Design Dept. Civil Engineering Div., Taisei Corporation, Tokyo, Japan

Jun SAKAMOTO
Manager, Technology Center, Taisei Corporation, Tokyo, Japan

Hikari OHKUMA
Manager, Tokyo Branch, Taisei Corporation, Tokyo, Japan

Akio OHTAKE
Manager, Tokyo Branch, Taisei Corporation, Tokyo, Japan

ABSTRACT:
The Ultra-high strength Fiber reinforced Concrete (hereafter, UFC) that has compression strength 200N/mm^2 was developed, and UFC application to many kinds of structure has been increasing in recent years in Japan. UFC application in the PC bridge field is advanced because of taking advantage of thin members and weight reduction achieved by its ultra-high strength and high durability. Various, new technologies had been developed by using the UFC characteristic, and the range of those arrives from the design technique to structural types and the construction method. In this report, the cases about the PC bridges where various unique technologies are applied are introduced, and those features are described.

Keywords: UFC, ultra-high strength, fiber reinforced, bridge, precast segment, wet joint, PBL

1. INTRODUCTION

UFC has recently been developed and is being applied to civil engineering structures. This new UFC has a compressive strength of 200N/mm^2. It also has high ductility, provided by the reinforcing effects of steel fibers, and extremely high durability, ensured by the closely packed microstructure of the matrix. The first application of UFC has been to bridges. Structural members made of this ultra high strength and highly durable material are lighter and thinner than members made of conventional concrete, permitting for the first time the construction of 8-15cm thick structural members and simply supported girders with spans exceeding 50m. Nine UFC footbridges and three UFC road bridges (including those containing only some UFC) have now been completed in Japan. In addition, the new expansion project for the Tokyo International Airport calls for using UFC for a large road bridge and slabs.
As guidelines for the application of UFC to structures, "Guidelines for the Design and Construction of Ultra High Strength Fiber Reinforced Concrete (Draft)"[1] (hereinafter referred to as "Guidelines for UFC") were published by the Japan Society of Civil Engineers in 2004. Because UFC has unique materials and properties, UFC structures can take advantage of new design methods, structural types, and construction methods that cannot be applied to conventional concrete structures. This report describes the characteristic features of PC bridges that use UFC (hereinafter referred to as UFC bridges).

2. FEATURES OF UFC (DUCTAL)

The bridges described in this report use a type of UFC called Ductal, which is an inorganic composite material made from the reactive powders of cement, pozzolan, and other materials. Ductal has the following features.

(1) Ultra high strength

Ductal has a characteristic compressive strength of 180N/mm^2, which allows structural members to be designed taking into account the tensile strength of the concrete. Because standard curing (heat curing at 90°C) develops Ductal's specified strength and stabilizes its physical properties, shrinkage and creep are minimal. Table 1 compares the physical properties of Ductal and ordinary high strength concrete.

Table 1 Characteristics of UFC compared to conventional high strength concrete

ITEM	UNITS	UFC(*)	CONVENTIONAL HIGH STRENGTH CONCRETE
Compressive strength	N/mm^2	180	40
Tensile strength	〃	8.8	2.7
First cracking strength	〃	8.0	1.3
Young's modulus	kN/mm^2	50	31
Mass per unit volume	kN/m^3	25.5	24.5
Shrinkage strain		50×10^{-6}	230×10^{-6}
Creep coefficient		0.4	2.6
Water permeability coefficient	cm/s	4×10^{-17}	10^{-10}
Chloride ion diffusion coefficient	cm^2/year	0.002	0.700

(*) after standard heat curing (90℃ heat treatment for 48 hours)

(2) High durability

Ductal has a densely packed microstructure with a water-to-binder ratio of W/B=0.14 that lowers the water content per unit volume of the UFC to the hydration limit and minimizes the voids in the product. Table 1 shows that Ductal is highly resistant to mass transfer. That is, the coefficient of water permeability and the diffusion coefficient of chloride ion in Ductal are about $1/10^6$ and 1/300 those of ordinary high strength concrete. Accordingly, the chloride ion concentrations at the locations of steel (rebar with a 20mm thick concrete cover) changes extremely slowly over time. (Figure 1)

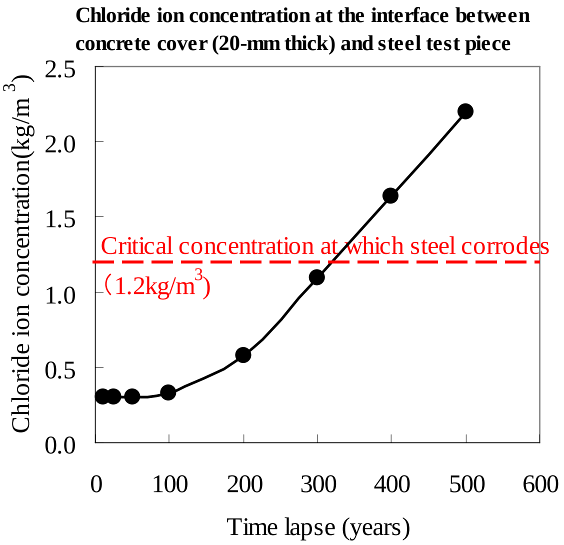

Figure 1 Changes over time in chloride ion concentration

(3) High ductility

Ductal contains high strength steel fibers (2% by volume, with a tensile strength of not less than 2.0 x 10^3N/mm^2, 0.2mm in diameter and 15mm long). The cross-linked steel fibers help control cracking, which makes Ductal highly ductile. As a general rule, Ductal structures do not require rebar.

3. FEATURES OF UFC BRIDGES

Despite the excellent properties mentioned above, UFC has the following limitations when applied to PC bridges.

i) Use of UFC in precast members

Because UFC is a high-grade material, its quality must be strictly controlled. A final compressive strength of 200N/mm^2 can be obtained only when steam curing at 90°C is conducted. Because UFC requires steam curing, they must precast in plants equipped with steam curing equipment. Therefore, structure designs must assume the use of precast UFC members.

ii) Cost-efficient application of UFC

In order to obtain ultra high strength such as 200N/mm^2, it's essential to keep coarse aggregate ultra high strength. It is, however, very difficult nowadays. The bonding strength at the boundary surfaces between the matrix and coarse aggregate is another concern. Beams subject to particularly strong flexural or shear forces are likely to have the vulnerable boundary surfaces. Therefore, UFC does not use coarse aggregate but contains large amounts of reactive powders to create a matrix with a closely packed microstructure, which ensures ultra high strength and durability. Ductility is provided by the large amount of steel fibers—157kg/m^3—that is mixed into the UFC. Because of this mix proportion, UFC has a high unit price. Therefore, minimum use of Ductal quantity is very important for cost competitiveness. To minimize the amount of UFC needed for a structure, the structural members must be made thinner, and the structural and construction plans must be ingeniously designed.

With these limitations and material properties in mind, UFC has the following basic structure and configuration when applied to PC bridges.

(1) Thinner members

Since UFC doesn't require rebar, cover concrete for rebar is unnecessary, and members can be made thinner. Figure 2 shows the relationship between the thickness of the members and the span of various UFC bridges. The thickness of the members (top and bottom slabs and web) is almost within 5-13cm for a span of up to 50m, indicating that the members can be very thin regardless of the bridge span. Many UFC bridges also adopt an outer cable system, which allows a further reduction in member thickness.

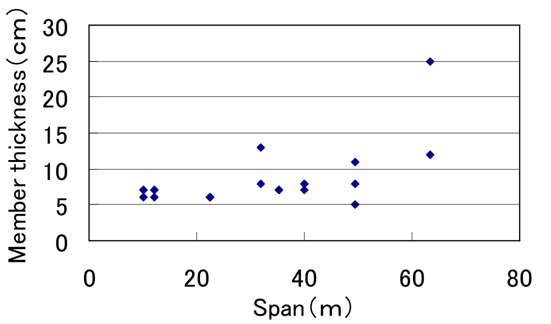

Figure 2 Relation between member thickness and span

(2) Lighter members

Thinner members result in a significantly lower dead weight. Figure 3 shows the relationship between the quantity of UFC per square meter of slab area and the span of various UFC bridges. The quantity of UFC per unit area is about 20cm, or about a quarter of that of ordinary PC bridges, which proves a substantial reduction in the dead weight.

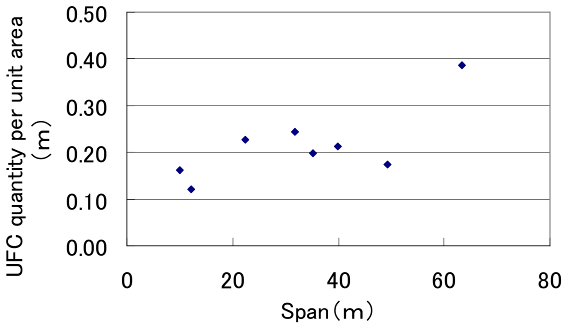

Figure 3 Relation between UFC quantity per unit area and span

(3) Lower girder height and longer bridge span

Because the members are thin, the compressive stresses introduced into the UFC bridges by prestressing are a few orders higher than those of conventional concrete bridges. Because of reducing the weight of the members, less force is required to support the dead weight. These properties make it possible to lower the height of the girders and lengthen the bridge span. (Figure 4)

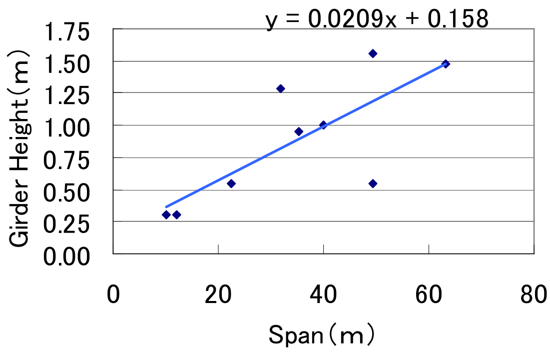

Figure 4 Relation between girder height and span

4. APPLICATIONS OF UFC TO FOOTBRIDGES

4.1 Sakata Mirai Bridge[2][3][4][5], completed in 2002. (Photo 1)

This footbridge is a single-span PC box girder and has a 49.4 m span. It is the first PC bridge in Japan to utilize UFC. The bridge has the following features:

(i) Very thin members (Photo 2). Top slab: 5cm thick; webs: 8cm thick.

(ii) The body of the bridge is 53tons, or about one-fifth the weight of a conventional concrete bridge.

(iii) Low girder height (55cm at girder ends) and a long span (50m). The standard ratio of girder height to span is about 1/17 for simply supported box girder bridges having a span of about 50 m, but this bridge has a ratio of 1/90 at the girder ends and a ratio of 1/32 at the center of the girder (1.56m in height).

(iv) A distinctive design, with large circular openings in the webs.

Photo 1 Sakata Mirai Bridge

Photo 2 Erection of center block

4.2 Akakura Onsen Yukemuri Bridge [5][6], completed in 2004. (Photo 3)

This is a 36.4m long, single-span PC box girder bridge with an effective width of 3.0m..

(i) The top and bottom slabs and webs are 7cm thick.

(ii) The girder is 95cm in height, and the ratio of girder height to span is about 1/40.

(iii) It is divided into upper (top slab) and lower (U-shaped girder) portions.

Photo 3 Akakura Onsen Yukemuri Bridge

Table 2 Structural dimensions - 1

	Sakata Mirai Bridge	Akakura Onsen Yukemuri Bridge	Toyota City Gymnasium Footbridge
Type of Structure	Single span PC box girder	Single span PC box girder	Single span PC box girder (2 cell)
Prestressing steel	25S15.2B×2: outer cable system	19S15.2B×5: outer cable system	19S15.2B×4 outer cable system
Length	50.2m (Span: 49.35m)	36.4m (Span:35.3m)	28.007m(Span: 22.500m)
Width	Total width: 2.4m, effective width: 1.6m	Total width: 3.5m, effective width: 3.0m	Total width: 4.7m, effective width: 4.0m
Girder Height	0.55m(at end)、1.56m(at center)	0.95m	0.55m
Member Thickness	Top slab:5cm, bottom slab:11cm Web:8cm	Top slab:7cm with rib, bottom slab:7cm Web:7cm	Top slab:6cm, bottom slab:6cm Web:6cm
Type of Bearing	Rubber	Rubber	Rubber
Owner	MAETA CONCRETE INDUSTRY LTD	Mogamityo, Yamagata Prefecture	Toyota City, Aichi Prefecture
Construction Period	2002.03-2002.09	2003.09-2003.12	2005.12-2007.02

4.3 Toyota City Gymnasium Footbridge [7], completed in 2007. (Photo 4)

This footbridge is 28.0m long and has 0.55m girder height. It features a single-span, PC two-cell box girder approach with an effective width of 4.0m. All members are 6cm thick. This is the first UFC bridge to adopt the dry joint (adhesive joint) construction method.

Photo 4 Toyota City Gymnasium Footbridge

Photo 5 Cross section of girder

4.4 Hikita Footbridge, completed in 2007. (Photo 6)

This 64.5m long through bridge was constructed in Tottori Prefecture in 2007. Its 63.3m span is the longest of UFC bridge, and it may be the world's longest concrete through-girder bridge.

(i) Web thickness: 12cm; bottom slab thickness: 25cm.

(ii) Distinctive design, with many circular openings in the webs.

Photo 6 Hikita Footbridge

4.5 Mikaneike Bridge completed [8], in 2007. (Photo 7)

This 81.2m long, two-span (2 x 39.9m), continuous PC box girder bridge has an effective width of 3.0m. It is the first continuous girder type PC bridge to use UFC and is a model for future long bridges.

(i) Top slab: 7cm thick; web: 8-20cm thick; bottom slab: 8cm thick.

(ii) Girder height: 1.0m; ratio of girder height to span: 1/40.

(iii) The cross-section of the box girder shows (Figure 6) that it is divided into upper (top slab) and lower (U-shaped girder) portions.

Photo 7 Mikaneike Bridge

Table 3 Structural dimensions - 2

	Hikita Footbridge	Mikaneike Bridge	Sherbrooke Bridge	Peace Footbridge
Type of Structure	Single span PC through bridge	2 span PC box girder	Single span PC truss web bridge	Single span π-shape PC arch
Prestressing steel	19S15.2B×8: inner cable system	19S15.2B×4: outer cable system	4S12.4 and 7S12.4: 12cable	12S15.2B×6 inner cable system
Length	50.2m (Span: 49.35m)	81.2m (Span:39.9+39.9m)	Span: 60m	Arch span: 120m, Arch rise: 15m
Width	Total width: 2.4m, effective width: 1.6m	Total width: 3.6m, effective width: 3.0m	Total width: 3.3m, effective width: 2.9m	Total width: 4.3m, effective width: 3.0m
Girder Height	0.55m(端部)、1.56m(中央部)	1.0m	3.0m	1.3m
Member Thickness	Top slab:5cm, bottom slab:11cm Web:8cm	Top slab:7cm with rib, bottom slab:8cm Web:8 to 20cm	Top slab:3cm with rib, bottom slab:38cm Web: φ15cm	Top slab:3cm with rib, Web:16cm
Type of Bearing	Rubber	Rubber	unknown	-----
Owner	MAETA CONCRETE INDUSTRY LTD	Ohnojyo City, Fukuoka Prefecture	Sherbrooke Univ., CANADA	Soul City, KOREA
Construction Period	2002.03-2002.09	2005.12-2007.02	1997 completion	2002 completion

4.6 Overseas applications

(1) Sherbrooke Bridge, in 1997. (Photo 8)

Located on the campus of Sherbrooke University in Canada, this was the first bridge to use UFC. It has a span of 60m and a trussed web structure.

Photo 8 Sherbrooke Bridge

(2) Peace Footbridge: in 2002. (Photo 9)

This arch bridge in Seoul, Korea, has a span of 120m. It has a unique design that people walk from a steel connecting bridge across an arch rib constructed of UFC.

Photo 9 Peace Footbridge

5. APPLICATIONS OF THE UFC TO ROAD BRIDGES

UFC has also been applied to road bridges, as described below. (Table 4)

5.1 Higashi Kyushu Expressway Horikoshi C Ramp Bridge[9] (Figure 5 and Photo 10 and 11)

This 16.6m long ramp bridge has a span of 16m. It is located at the Kita Kyushu JCT of the Higashi Kyushu

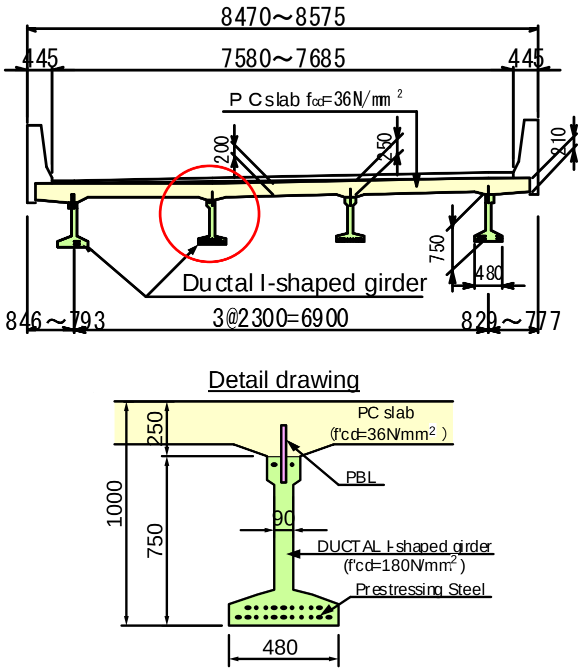

Figure 5 Horikoshi C Ramp Bridge Cross Section

Photo 10 UFC Pretension I-shaped girder

Expressway and the Kyushu Expressway. The bridge was originally designed as a simply supported pretension PC hollow slab bridge, but the design was later changed to that of a composite girder bridge with a UFC main girder and a cast-in-situ PC slab. This was the first time in Japan (and the second time in the world) that UFC had been applied to the main girder of a road bridge. The PC composite girder bridge uses UFC for the pretension I-shaped girder (Photo 10), ordinary concrete (design compressive strength: 36N/mm^2) for the slab, and has an arrangement of 22 PC steel strands (1S15.2B). The girder and slab were joined with Perfobond Strip shear connector (which German name is Perfobond Leisten, hereinafter referred to as PBL). Because no rebar is used, the web is 9cm thick and the weight of the main body including the slab is more than 30% lighter than in the original design. The use of UFC had the following advantages.

(i) The number of girders was decreased from 11 to 4. It made the erection period shorter not to affect the traffic of the intersecting roads. The process from erection to temporary attachment could be completed in about one hour.

(ii) The weight of a single girder was reduced from 12tons to 5tons. A smaller crane could be used for erecting the girder.

Photo 11　Horikoshi C Ramp Bridge

5.2 Hokkaido Jukan Expressway Torisakigawa Bridge [10] (Photo 12)

This 554m long, 11-span, continuous PC box girder bridge has a maximum span of 56m and uses corrugated steel webs constructed by the incremental launching method. To reduce costs, the following construction method was adopted. Instead of using a temporary steel launching nose, as is needed for conventional PC bridges, the front section of the main girder was constructed of corrugated steel webs and the steel upper chord and the lower chord were constructed of UFC to save weight. After launching was completed, these components became permanent members. The launching nose was 44.8m long and divided into five blocks. The UFC lower chord joint was a cast-in-situ wet joint. To ensure full prestressing under axial stresses, five 7S15.2 prestressing tendons were arranged as inner cables in the UFC lower chord. By adopting UFC instead of conventional concrete for the lower chord, the cross section of the launching nose was smaller, and the launching nose was lighter.

Table 4　Structural dimensions – 3

	Horikoshi C Ramp Bridge	Torisakigawa Bridge
Type of Structure	Single span presstressed I-shaped girder	11-span PC box girder uesd corrugated steel webs
PC鋼材	1S15.2B×22: pretension cable	UFC lower beam: 7S15.2B×5 per UFC beam
Length	16.6m (Span: 16.0m)	UFC part: Span:44.8m
Width	Total width: 8.47-8.58m	Total width: 11.3m
Girter Hight	1.0m (UFC girder: 0.75m)	3.191-4.065m
Member Thickness	Web:9cm, bottom frange:48cm	UFC lower beam : 60cm × 42.5cm
Type of Bearing	Rubber	Rubber
Owner	West Nippon Expressway Company Limited	East Nippon Expressway Company Limited
Construction Period	2005.03-2005.07	2004.07-2006.12

Photo 12　UFC lower beam with corrugated steel web

6. TECHNICAL FEATURES OF UFC BRIDGES

The uniqueness of the materials and structures of UFC bridges have allowed unprecedented technologies to be developed and applied to the bridges. The technical features of the UFC bridges are described below.

6.1　Division into blocks

Because UFC precast members are thinner, the members are drastically lighter than conventional concrete members. Although large members can be manufactured, the dimensions are determined by factors relating to the manufacture, transportation, and structural design of the members, as explained below using the Mikaneike Bridge [8] as an example.

For 3.5m wide bridges such as the Mikaneike Bridge, it is common to divide the bridge in the longitudinal direction into about 2m long segments within the limitations of truck transportation and weight limits. For the Mikaneike Bridge, however, as can be seen from the cross section, the girder was divided into upper (top slab) and lower (U-shaped girder) portions. (Figure 6) This allowed the 2.10m wide U-shape girder to be loaded easily on a truck bed and the girder to be divided in the longitudinal direction into large blocks 8-10m in length. (Photo 14)

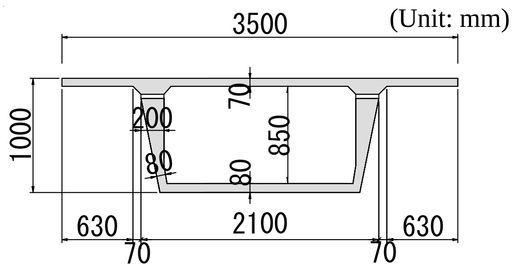

Figure 6　Cross section of Mikaneike Bridge

Photo 13　Precast block of Mikakeike Bridge (width:2.1m, length: 10.5m, weight: 9.2t)

This method of dividing the girder into large blocks is used not only for the Mikaneike Bridge but also for other UFC bridges.
Considering the division of the girder, the thickness of members and the quantity of prestressing steel must be minimized in the structural design. In the design of UFC members, in contrast to ordinary concrete members, the UFC can be expected to have a tensile stress of up to $8.0N/mm^2$. For the Mikaneike Bridge, the joint between the blocks needed to be compressed across the entire cross section, which became a factor in determining the quantity of prestressing steel that was needed. In designing the UFC girder, it was divided into the longest possible blocks in order to reduce to a minimum the number of joints. Moreover, the joints were located as far as possible from the point where the maximum moment was induced. The length of the blocks was ultimately determined by the mixing capacity of the UFC manufacturing plant and the usability of the formwork.
The 3.5m wide top slab was divided into 36 blocks, each 2.1m in length in the longitudinal direction. This size allowed for easy loading onto truck beds, and 4 to 5 blocks could be laid out on one UFC block. (Photo 15)

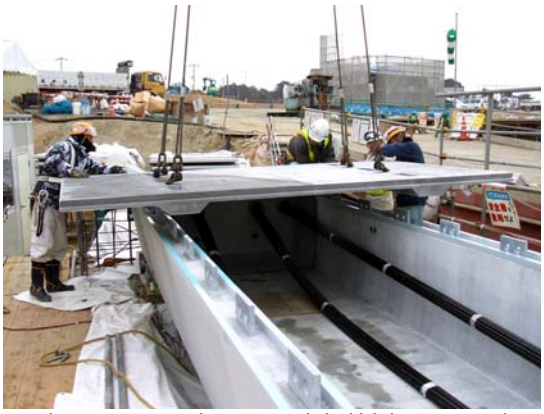
Photo 14 Setting UFC slab (thickness 7cm)

6.2 Joints of girder blocks

Two types of joints can be used between the UFC precast girder blocks: dry joints and wet joints. A dry joint uses an epoxy resin-based adhesive to directly join precast girders. A wet joint uses UFC to fill a space between two UFC girders. Table 5 compares the two types of joint.

(1) Dry joint (adopted for Toyota City Gymnasium Footbridge[7])

Girders are often joined with an adhesive when the girders are erected by the precast segment method. For UFC containing large amounts of cement and other reactive powders, more self-shrinkage is induced during curing than is the case with conventional concrete. This shrinkage can deform the joint surfaces. To ensure accurate joint surfaces for the Toyota City Gymnasium Footbridge, a match-cast system was adopted in which the joint surfaces of the prefabricated blocks were used as a cross-form for placing concrete for new blocks. In addition, the UFC girders could be joined using a dry joint by improving the structure of the forms to maintain the accuracy of the joint surfaces and the subsequent construction of shear keys.

Table 5 Comparison of dry and wet joints between girder blocks

	Dry joint	Wet joint
Advantages	• Economical for long spans	• highly accurate joint surfaces are not required
	• Few work types are needed and short joining process	• Girder blocks are easily aligned
	• The joint is unnoticeable	• Economical for small bridges
Problems	• highly accurate joint surfaces are required	• Curing facilities are necessary
	• Girder blocks cannot be easily aligned	• Many work types are needed and a curing period is required
	• Requires equipment for pulling the blocks	• Colors at the joint may differ

(2) Wet joint (adopted for the Mikaneike Bridge and others bridges)

In a construction method unique to UFC bridges, a hollow (dent) is created in each joint surface of the precast girders. This hollow is then filled with cast UFC to join the girders. This method was developed for the construction of the Sakata Mirai Bridge and the shear transmission performance was verified experimentally. The results of this experiment are described in “Shear Transmission Capacity of Joints” in the reference material for the Guidelines for the UFC.”[1]
Generally speaking, because the shear capacity of a girder structure inevitably is lower at the joint than in the general section, the joint often determines the structural specifications. For a UFC wet joint with a concave structure on the girder side, however, past experiments have verified that shear transmission performance at the joint is no worse than in the general section. The reasons for this are described below.

(i) Because UFC bridges have thin members, the compressive stresses introduced by prestressing are high. For the Mikaneike Bridge, the average compressive stress calculated by dividing the effective prestressing force by the cross-sectional area of the girder is about $25N/mm^2$, which is a few times larger than that of general PC bridges. The Sakata Mirai Bridge and other UFC bridges show the same tendency. In most cases, shear force resistance provided by only the frictional force can carry all shear force without any shear keys. The Mikaneike Bridge has a shear capacity of 6,000kN and a shear force in an ultimate state of 1,200kN, indicating a high level of safety even when a shear key is not considered.

(ii) As shown in Figure 7, a diagonal compression member is formed in the shear key at the joint when a shear force acts on a structure. Because the concave shear key is also UFC, the joint has very high compressive strength and does not fail in shear.

(iii) As the shear force increases, cracks begin to develop from the corners of the shear key. Because both the main body and the shear key are reinforced with steel fibers, they are strong enough not to widen cracks suddenly.

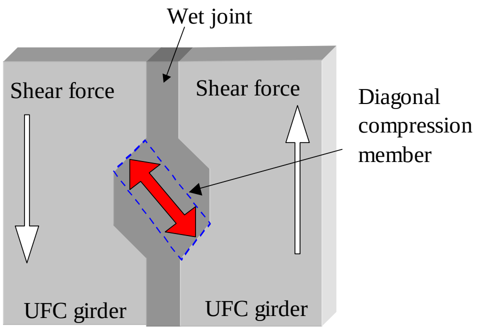

Figure 7 Mechanism of shear transmission at wet joint

For these reasons, the wet joint has excellent shear transmission performance. The shear capacity of the wet joint is comparable to that of the general section. This has been verified not only by shear experiments under loads acting on footbridges [2][6] but also by experiments using heavy vehicle loads on road bridges.

6.3 Joint between slab and girder

For the Akakura Onsen Yukemuri Bridge [6] and the Mikaneike Bridge [8], the box girder was divided into a top slab and a U-shaped girder for manufacture and transportation. These two pieces needed to be connected at the erection site. Cast-in-situ UFC and PBL were used to connect the top slab and the U-shaped girder. Figure 8 is an outline drawing of the joint between the top slab and the U-shaped girder. This connecting method is originally used to connect a steel girder with a concrete slab, and has been applied to a UFC slab. However, this method was unable to balance the compressive strength of the UFC with the anchor bolts or stud shear connectors, and the steel yielded. For this reason, PBL with a 22mm thick steel plate was used for both bridges to connect the UFC slab to the girder.

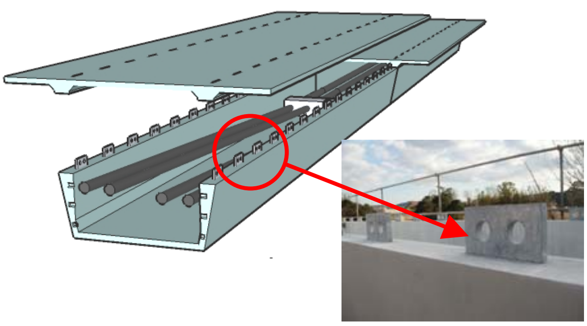

Figure 8 PBL joint between slab and U-shaped girder

7. CONCLUSIONS

Because of the uniqueness of UFC, including unprecedented strength and durability, new design techniques were needed for applying UFC to structures. New construction technologies, specifications, and structural member compositions have been developed. Taking the lead from UFC structures, UFC bridges are employing cutting-edge technologies. At a time when the superstructures of general PC bridges are constructed with concrete having a compressive strength of 40-50N/mm^2, the ability to construct long-span bridges with a material having a compressive strength of 180N/mm^2 without using rebar has brought a new perspective to the world of concrete. It is hoped that this technology will strongly accelerate the further development of concrete in the next generation.

REFERENCES

[1] JSCE (Japan Society of Civil Engineers), “Guidelines for the Design and Construction of Ultra High Strength Fiber Reinforced Concrete (Draft),” 2004

[2] Musha, H.; Ohtake, A.; Seki, F.; Ohkuma, H.; Kodama, A.; Kobayashi, T, “Design and Construction of SAKATA-MIRAI Bridge Using of Reactive Powder Composite,” Bridge and Foundation Engineering, vol.36, No.11, 2002.11., pp.1-10

[3] Musha, H.; Ohtake, A.; Kodama, A.; Kobayashi, T, “Case and Feature of PC Pedestrian Bridge Where UFC was used,” Journal of Prestressed Concrete Japan, JPCEA, Vol.45, No.2, Mar, 2003, pp.40-48

[4] Tanaka, Y.; Musha, H.; Ohtake, A.; Shimoyama, Y.; Kaneko, O, “Design and Construction of Sakata－Mirai Footbridge Using Reactive Powder Concrete,” Proceedings of the 1st fib Congress 2002, Vol.1, Session 1, 2002.10, pp.103-104

[5] Musha, H.; Tanaka, Y.; Ohtake, A., “Segment structure that used ultra-high strength fiber reinforced concrete in Japan,” fib symposium on Segmental Construction in Concrete & fib Expo'04, Theme 6, New Delhi, India , 2004.11

[6] Tanaka, Y.; Musha, H.; Ohshima, K.; Abe, Y., “Development of a Long Span Prestressed Concrete Bridge using Ultra High Strength Fiber Reinforced Concrete,” Concrete Journal, JCI, Vol.42, No.8, Aug., 2004, pp. 30-36

[7] Ohshima, K.; Nakashima, M.; Tanaka, K.; Inahara, H., “Execution of Toyota Pedestrian Bridge,” Concrete Journal, JCI, Vol.46, No.6, Jun., 2008, pp. 25-30

[8] Musha, H.; Ishida, Y.; Yamanoi, T.; Yamashita, T, “Mikaneike Bridge –The First Continuous Girder Bridge Using Ultra-High Strength Fiber Reinforced Concrete,” Journal of Prestressed Concrete Japan, JPCEA, Vol.49, No.5, pp.18-26

[9] Kuroiwa, T.; Iwasaki, I.; Ohkuma, H., “The First Road Bridge constructed with Ultra-High Strength Fiber Reinforced Concrete,” Concrete Journal, JCI, Vol.43, No.10, Oct., 2005, pp. 39-44

[10] Higashida, N.; Yoshida, A.; Yasuzato, T.; Shiratani, K.; Inahara, H.; Ohshima, K., “Plan and Design of Torisaki River Bridge of Hokkaido Jukan Line –Incremental Launching Erection using Corrugated Steel Web Girder-,” Bridge and Foundation Engineering, vol.39, No.11, 2005, pp.13-20