Design and Construction of the Ribbed U-Shaped Core Segmental Bridge with Butterfly Webs
— Okegawa Viaduct —

バタフライウェブを用いたリブ付きＵ形コアセグメントの設計・施工
— 桶川高架橋 —


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Synopsis
The Okegawa Viaduct (**Fig.1**) is located in an urban area of Okegawa City, Saitama Prefecture, and is part of a ring expressway (Metropolitan Inter-City Expressway) with a radius of 50km from the center of Tokyo. The total length of the viaduct is approximately 3km, with a total of 71 spans and a standard span length of 45m. The Okegawa Viaduct was constructed by a precast segmental span-by-span method. The segments are uniquely shaped, being U-shaped precast segments[1] that include two butterfly web panels[2] and a horizontal rib. The deck, constructed after longitudinal prestressing of the U-shaped girder, is made of cast-in place (CIP) concrete placed on precast panels supported by the ribs. The butterfly web structure enables light weight and high durability. This bridge meets the requirements of a lighter main girder and low maintenance structure, and is therefore a sustainable structure.

Fig.1 Okegawa Viaduct

Structural Data
Structure: Multi-span continuous prestressed concrete (PC) butterfly web box-girder bridge
Bridge Length:
Inbound Line: 585.0m, 217.0m, 470.0m, 258.0m
Outbound Line: 585.0m, 217.0m, 519.5m, 237.5m
Span:
Inbound Line:
43.65m + 11@45.0m + 43.8m,
48.3m + 53.0m + 36.5m + 36.0m + 40.8m,
43.8m + 5@45.0m + 4@40.0m + 38.75m,
38.75m + 40.0m + 41.0m + 44.0m + 49.0m + 42.55m
Outbound Line:
43.65m + 11@45.0m + 43.8m,
48.3m + 53.0m + 36.5m + 36.0m + 40.8m,
43.8m + 5@45.0m + 4@40.0m + 38.75m,
34.75m + 36.5m + 2@40.0m + 45.0m + 48.4m
Width:
Inbound Line: 11.4m, 11.4m, 11.4m-21.21m, 11.4m
Outbound Line: 11.4m, 11.4m, 11.4m, 11.4m-19.87m
Owner: East Nippon Expressway Co., Ltd.
Designer: Sumitomo-Mitsui, P.S. Mitsubishi JV
Contractor: Sumitomo-Mitsui, P.S. Mitsubishi JV
Construction Period: Jun. 2013 – Mar. 2015
Location: Saitama Prefecture, Japan

1. Introduction
Fig.2 shows the general drawing plan and elevation of the Okegawa Viaduct. To shorten the construction

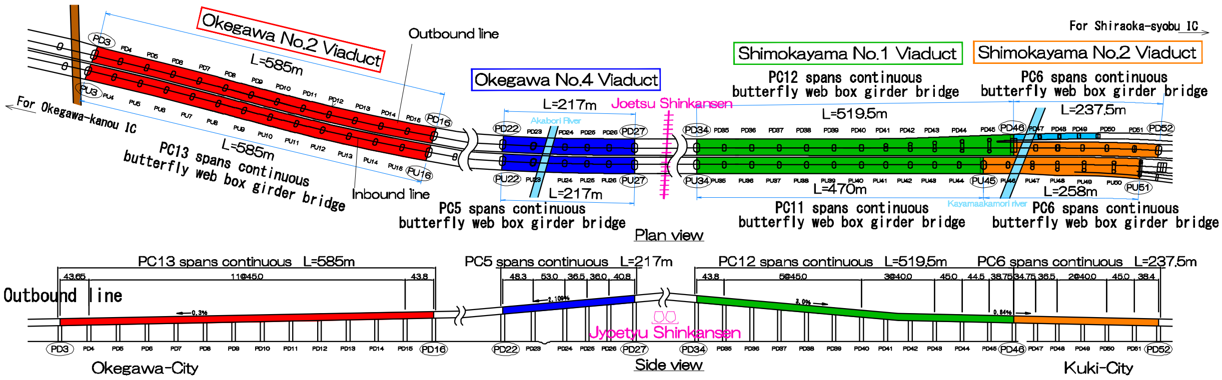


Fig.2 General view

schedule for this bridge, all the main girders were precast, including those at the pier caps. Because no assembly yard could be secured in the vicinity of the construction site, the factory-fabricated precast segmental construction method was adopted. Because the bridge segments were transported by trailers on public roads, their weight was restricted to 30t at most, while the segment length was restricted to 3m. **Fig.3** shows the cross- section view, while **Fig.4** shows a segment of the Okegawa Viaduct. In selecting process for the segment cross-section, a major consideration was to make the segment as long as possible while keeping it light to keep it within the limiting weight range for trailer transport. A "ribbed U-shaped core segment with butterfly webs" was used as the bridge segment cross- section. For the pier cap segments, to keep the segment weight down to 30 t, each pair of pier cap segments was designed as a half-precast structure provided with precast bulkheads.

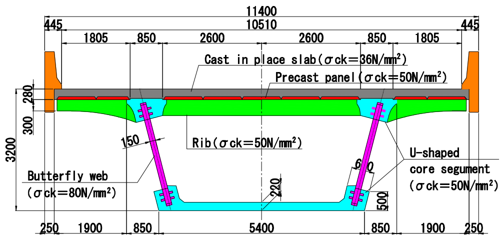


Fig.3 Cross section of the girder

Fig.4 U-shaped core segment with butterfly webs

2. Selection of Section Shape

(1) Comparative Study of Cross-Sections

Making the factory-fabricated segments as light as possible and reducing their number led to faster erection. In selecting the cross-section, three alternatives were compared, for their structural properties, constructability, and economic performance (**Table-1**). Each alternative is described as follows.

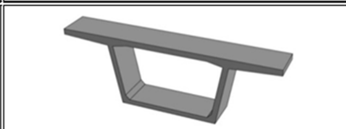
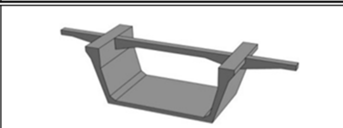
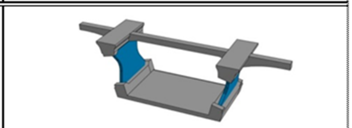
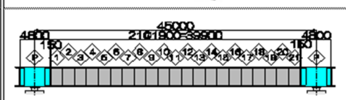
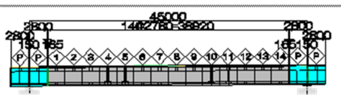
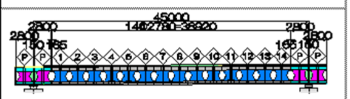
Type-1: Full section segment. This type has a full section typical of field-fabricated precast segmental construction, but fabricated at the factory.

Type-2: U-shaped core segment (concrete web). This type has an open cross section in a U shape. The upper deck slab is precast similar to Type-1 but is cast later.

Type-3: U-shaped core segment (butterfly web). This type is lightened further by using butterfly webs in place of the solid webs used in Type-2.

With the segment weight set to 30t, the number of segments can be reduced by roughly 40% by using a U-shaped core segment. In addition, the main girder weight per span can be reduced by 3% compared to Type-1 by using butterfly webs. By using a U-shaped core segment with butterfly webs, the total segment weight for one span was halved, allowing a lighter erection girder as well.

Table-1 Applicable section shapes

	Type-1:Full section segment	Type-2:U-shaped core segument (concrete web)	Type-3:U-shaped core segument (butterfly web)
Cross Section			
Segment layout			
Num. of segment	21 /span (1.00)	14 /span (0.66)	14 /span (0.66)
Weight of segment	6664 kN/span (1.00)	4049 kN/span (0.61)	3594 kN/span (0.54)
Area of joint face	132 m^2/span (1.00)	46 m^2/span (0.34)	34 m^2/span (0.25)
Weight of Girder	8530 kN/span (1.00)	8915 kN/span (1.05)	8300 kN/span (0.97)

(2) Constructions Steps for the U-shaped Core Segment

The construction steps are illustrated in **Fig.5**. Segment fabrication, transport, and erection were performed on the ribbed U-shaped core section (STEP1). After segment erection was completed, 80mm thick precast concrete panels acting as formworks were laid out between the ribs (STEP2). Finally, CIP concrete was poured to complete the main girder (STEP3).

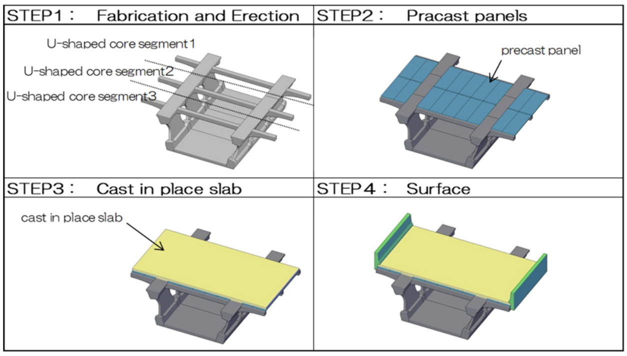


Fig.5 Construction steps

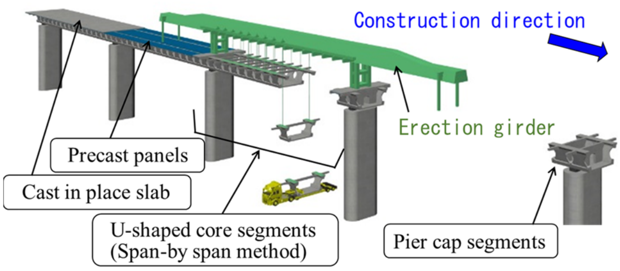


Fig.6 Erection procedure

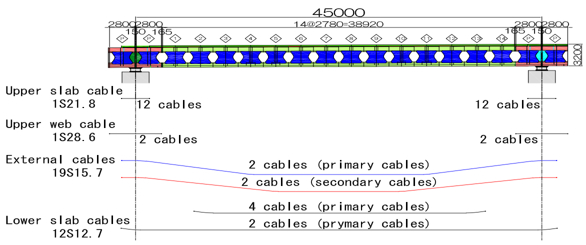


Fig.7 PC cable layout

3. Design

(1) Longitudinal-direction Design

This bridge was erected continuously from one side in sequence. **Fig.6** shows the erection procedure. The primary cables were designed to support the segment self-weight and the precast panel and upper slab dead loads. The secondary cables were steel tendons that were tensioned after the upper slabs were poured to introduce prestress to the upper deck slab for loads after completion. A schematic diagram of the PC cable layout for the standard 45m span is shown in **Fig.7**. The main girder stress limit of this bridge with CIP slabs is the limit for crack development at the upper edge of the slab at the design load. This value was used to fully prestress at the joint on the lower edge of the segment. The U-shaped segment uses concrete with design strength (σ_{ck}) 50MPa.

(2) Transverse-direction Design

Because a thin panel offers little stiffness in the transverse direction, the tensile stresses arising in the butterfly web panel when live loads act on the bridge can be controlled by providing ribs, with the aim of stiffening the upper deck slab. In addition, because the torsional rigidity is small because of the open cross section of the U-shaped core segment, the torsional deformation during segment lifting and deck slab pouring could be controlled by the ribs, which was confirmed with a finite-element analysis. The ribs which were laid out with precast concrete panels doubling as formwork for the 200mm thick CIP deck slab concrete, were loaded with the poured concrete and a the live load after curing when it started acting as a PC composite deck slab structure. Accordingly, one strand of 1S21.8 steel wire was used to transversely prestress the rib to control the crack width at the design load.

(3) Butterfly Web Panel

The butterfly web panel in this bridge uses high-strength fiber reinforced concrete (design strength (σ_{ck}) 80 MPa) without steel reinforcing bars. The number of pre-tensioned tendons was determined with no allowance for tension at dead loading, but ensuring that cracks would not develop at the design load. The butterfly web panel was set to 150mm thick to enable the installation of the required number of pre-tensioned tendons, as well as to resist the compressive forces acting on the panel at ultimate load.

4. Fabrication at the Factory

The U-shaped core segments were fabricated in two precast concrete factories in Tochigi and Ibaraki, approximately 100km from the bridge construction site, on casting yards within their premises. A total of 1,035 segments were fabricated, comprising of 900 span segments fabricated by the short line match casting method and 135 pier cap segments, in which there are two segments per pier cap. With regard to the work schedule, the span segments were cast on a cycle of one segment per day for each casting cell. Although the pier cap segment (**Fig.8**) was divided into two parts for fabrication, match casting was not used because the splice between the paired segment parts was integrated using an adjusting joint. To shorten the casting cycle for the pier cap segment, and to prevent incomplete concrete filling due to overcrowded bar arrangements at the external cable anchorage or around the passage ducts, the diaphragms were firstly fabricated as precast components with the concrete poured in while lain flat horizontally. The web panels were fabricated at the Oyama factory in Tochigi.

Fig.8 Pier cap segments

Fig.9 Erection of segments

5. Construction at the Site

(1) Pier Cap Construction

The pier cap segments were erected with a 250t crane. The lower slab of the segments was provided with blockouts to embed the bearing support anchor bars. After the two pier cap segments were erected, concrete was poured into the blockouts, together with the layer section and adjusting joint, to integrate with the bearing supports. The butterfly web panels on the pier cap are configured as a structure not embedded in the diaphragm, enabling visual inspection of the panel surfaces for maintenance purposes.

(2) Span-by-span Erection

A hanger-type erection girder with total length 110m and total weight roughly 550t was used to erect the span segments. Four erection girders were used, with two commencing from the top of the piers at the western end of Okegawa No.2 Viaduct and two from the top of the piers at the eastern end of Shimokayama No.2 Viaduct. After all the segments for one span were supported by temporary suspending devices on the erection girder (**Fig.9**), adhesive was applied on the splicing surfaces, four splicing steel bars (φ26mm) were installed and post-tensioned simultaneously with a jack to splice the segments. After splicing the segments, design strength (σ_{ck}) 50MPa concrete (containing expansive additive and short fibers) was poured into the adjusting joint provided between the pier cap segment and span segment with a clearance of roughly 150mm. After filling the adjusting joint with concrete, the primary cables (six internal and two external) required before pouring the upper deck slab were tensioned.

(3) PC Composite Deck Slab Construction

After the erection girder was moved, the precast concrete panels, which were to be the embedded concrete formworks of the upper deck slab, were laid out on top of the ribs using a 25t crane. Next, the reinforcement was assembled, the transverse prestressing tendons (1S19.3mm) were inserted, and the concrete for the upper deck slab was poured. The deck slab uses concrete with design strength (σ_{ck}) 36MPa (containing expansive additives), which was poured by concrete pump trucks.

6. Conclusion

This paper discusses the use of a structure comprising U-shaped core segments incorporating butterfly webs in the design and construction of the Okegawa Viaduct. This structure enables a shorter construction schedule because of a lighter main girder, and fewer segments. Because the segment with butterfly webs is a high quality product fabricated at a factory, it is highly durable and is more maintainable because there is no need to contend with reinforcement corrosion caused by salt air and concrete carbonation. Hence, it is a structure that leads to both lower construction and lower maintenance costs.

References

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[2] Ashizuka K., Miyamoto K., Kata K., Kasuga A., *Construction of a Butterfly Web Bridge*, Proceedings of fib Symposium, Stockholm, pp. 545-548, 2012.

概　要

桶川高架橋は圏央道の「桶川加納 IC」と「白岡菖蒲 IC」間に位置する PC 多径間連続桁橋であり，総延長約3.0km となる 8 橋の工事である。本橋では，工程短縮の観点から柱頭部も含め，全ての主桁をプレキャスト化した。架設現場近郊に製作ヤードを確保できないことから，工場製作のプレキャストセグメント工法を採用した。本橋は，バタフライウェブを用いたリブ付きU形コアセグメントによるスパンバイスパン架設工法を採用し，セグメントの製作・運搬・架設の総数の低減，および，柱頭部のハーフプレキャスト化を実現し，工程短縮を図っている。また，セグメントを品質確保が図れる工場製作とし，さらに，鉄筋を使用していないバタフライウェブを使用することによって高耐久化を図っていることから，本構造は維持管理コストの削減につながる構造である。