

Design and Construction of Extradosed Bridge with Butterfly Web — Shinmeishin-Mukogawa Bridge —

バタフライウェブエクストラドーズド橋の設計と施工 — 新名神武庫川橋 —



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Synopsis

Shinmeishin-Mukogawa Bridge (**Fig.1**) is the world's first bridge to have an extradosed structure combined with butterfly webs. Butterfly panels are used for the webs of the main girder to improve seismic resistance and make construction easier. Together with the extradosed structure of constant girder height, they also help to make the superstructure considerably lighter. The bridge piers were built using half-precast form components to reduce the labour required in the field, thereby achieving rapid construction. Other new techniques were employed in this project to meet locational restrictions. To construct the pier head, precast segments were used for the cross beam to reduce the need for labour and scaffolding. A new



Fig.1 Shinmeishin-Mukogawa Bridge

separate anchorage system consisting of a single steel plate and concrete columns was developed for the construction of the main towers.

Structural Data

Structure: 5-span continuous extradosed bridge with butterfly webs

Bridge Length: 442.2m

Span: 71.8m + 3@100m + 67.8m

Width: 24.2m

Tower Height: 8.5m

Owner: West Nippon Expressway Co., Ltd.

Designer: Sumitomo Mitsui Construction Co., Ltd.

Contractor: Sumitomo Mitsui Construction Co., Ltd.

Construction Period: Apr. 2011 – Aug. 2016

Location: Hyogo Prefecture, Japan

1. Introduction

Shinmeishin-Mukogawa Bridge is a five-span continuous prestressed reinforced concrete rigid-frame extradosed bridge with butterfly webs (**Figs.2, 3**). The 442m bridge with 100m spans is on the Shin-Meishin Expressway, which is under construction from Takatsuki Junction to Kobe Junction. Detailed design of the bridge was finalised with special consideration given to enhancing its seismic resistance as a whole, as well as to reducing labour on site for rapid and efficient construction. The pier structure was designed to have increased seismic resistance, and the piers were constructed rapidly using half-precast form components. Using butterfly-web

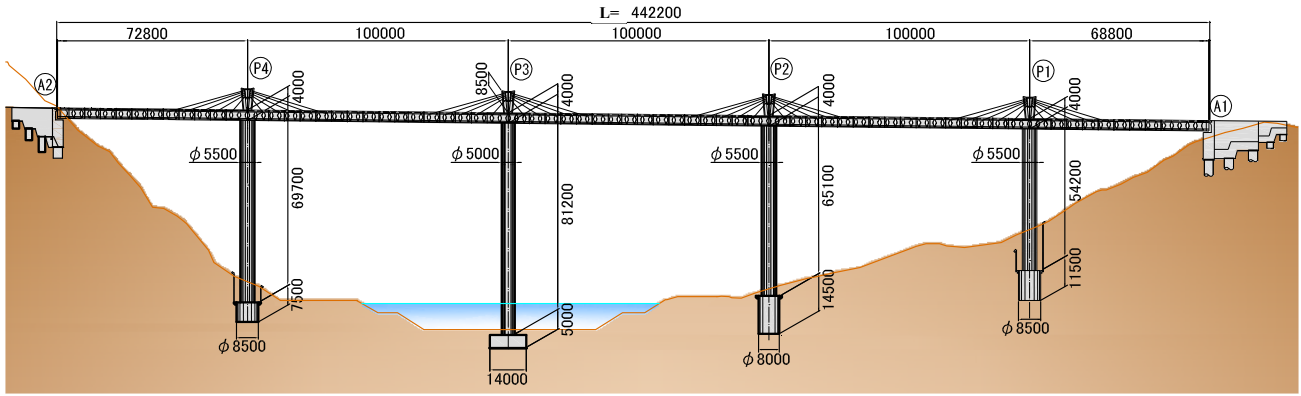


Fig.2 General view

box girders in conjunction with an extradosed structure reduced both the superstructure weight and the amount of on-site work. New techniques were also developed for constructing the pier heads. Precast segments were used for the cross beam in part to reduce the need for labour and scaffolding, and the main towers were designed as a hybrid structure using a single steel plate to meet the dimensional restrictions.

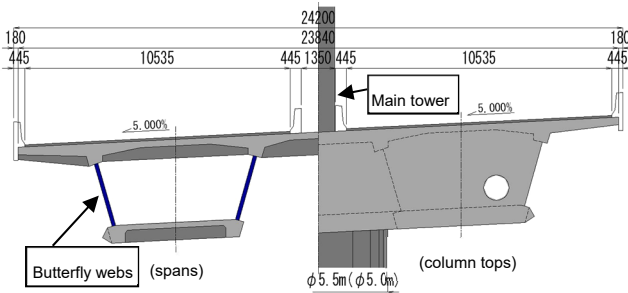


Fig.3 Cross-sectional view of the main girder

2. Design

(1) Extradosed Structure with Butterfly Webs

The superstructure of the bridge has a butterfly-web structure combined with an extradosed structure. The butterfly-web structure consists of butterfly-shaped concrete panels that replace the webs in an ordinary prestressed-concrete (PC) box girder. The panels are precast components prefabricated using high-strength fibre-reinforced concrete with a design strength of 80N/mm^2 (Fig.4). No reinforcing steel was used. This design allowed the web to be as thin as 150mm throughout the bridge, thereby reducing its weight. The girder height had to be constant at 4.0m because of dimensional restrictions when transporting the butterfly webs. To achieve a constant girder height in each 100m span, an extradosed structure was used to stiffen the butterfly-web structure using diagonal tendons at the pier head areas. The use of butterfly webs reduced the total number of construction blocks, thereby shortening the construction period. Using the extradosed structure with a constant girder height in conjunction with the butterfly webs with a reduced weight reduced the superstructure weight by roughly 20% compared to the basic plan, thereby reducing the seismic inertia force successfully.

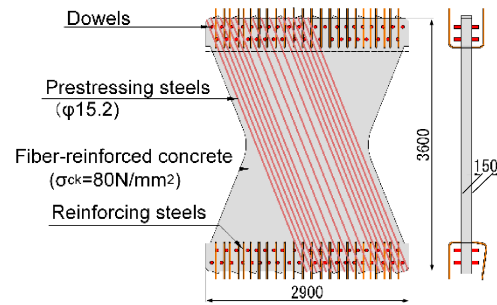


Fig.4 Details of the butterfly web

(2) Seismic Design

Pier P3 located in the middle of the river was designed to have a cylindrical hollow cross section with a diameter of 5.0m in considering the obstruction ratio of the pier width to the channel width. The other piers were originally planned to have square hollow cross sections of 6.5-7.0m. Among the piers, P3 is the tallest at 81.2m was the tallest and P1 is the shortest at 54.2m. A concern was raised about the high rigidity of piers P1, P2, and P4, which could localize the seismic inertia force on the shortest pier, P1. In the detailed design, piers P1, P2, and P4 were therefore changed to hollow cylinders with a diameter of 5.5m to reduce their rigidity and equalize the rigidity levels among all the piers. This changed design, was expected to distribute the seismic inertia force properly and also reduce it considerably because of the lengthened natural periods. Fig.5 shows the ratio of flexural rigidity (EI) to height (h) of the piers, and Fig.6 shows the response at the bottom of the piers. Adequate bearing capacity was ensured by using high-strength reinforcing steel

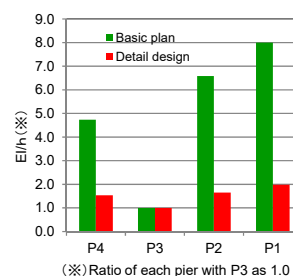


Fig.5 Ratios of flexural rigidity to height of the piers

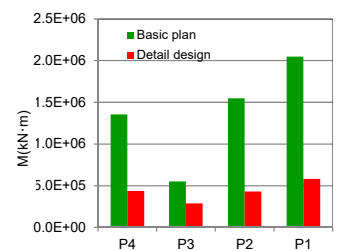


Fig.6 Bending moment at the bottom of the piers

(SD490) for the longitudinal reinforcement and concrete of strength 40 or 50N/mm² for the piers. The total weight of the superstructure and substructure in the detailed design was roughly 35% less than that in the basic plan.

(3) Main Tower Structure

Although it was decided to use separate single-plane anchorages at the centre of the cross section, insufficient space was available for a tower with a conventional hollow separate-anchorage structure made of steel shell or concrete. The tower width was limited to that of the median strip which was only 1.35m. As a solution to this problem, a new separate-anchorage structure was developed using a single steel plate and two concrete columns to meet the dimensional restriction (Fig.7). The steel plate in this anchorage structure is connected to the concrete using dowel reinforcement (Fig.8).



Fig.7 Full view of the main tower

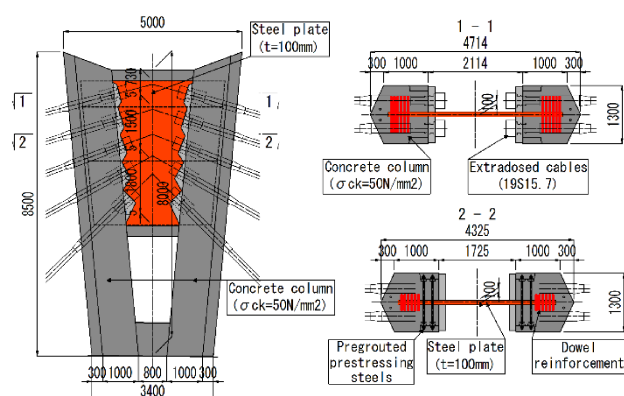


Fig.8 Structural drawings of the main tower

3. Construction

(1) Construction of the Bridge Piers

The tall piers were constructed using the SPER (Sumitomo Mitsui's Precast form for Earthquake Resistance and Rapid construction) method, which is a rapid construction method using prefabricated half-precast components. Hoops and intermediate

ties were embedded in the half-precast components during fabrication to reduce the amount of on-site assembly work. The half-precast components were semi-cylindrically shaped with a height of 2.0m considering transport restrictions and crane capacity (Fig.9). The SPER method enables rapid construction by reducing the amount of on-site work required for reinforcement placing and formwork assembly. The half-precast components were fabricated at a factory and conveyed to the site. They were installed by a crane where longitudinal reinforcement had already been placed (Fig.10). Formwork was assembled for the fill part, and the pier was completed by placing the filler concrete. Using this method almost doubled the speed of construction compared to conventional methods.

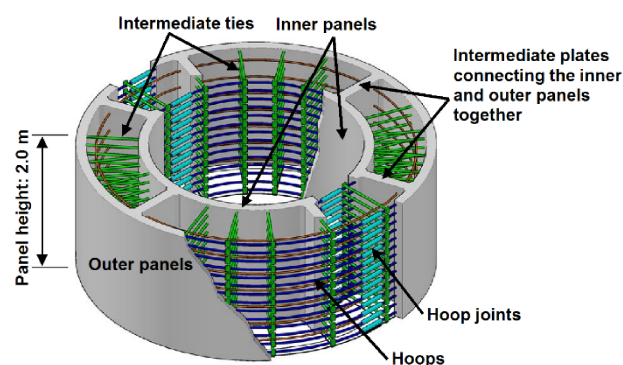


Fig.9 Schematic views of the half precast form



Fig.10 Installing half-precast components

(2) Construction of the Pier Heads

Being relatively wide at 24m, the main girder protrudes from the cylindrical piers of 5.0-5.5m in diameter in the direction perpendicular to the bridge axis. There were concerns that using a conventional scaffolding system would mean more labour for erection and less safety when working at height, the scaffolding would also have had to be very large in scale and have brackets of a maximum length of over 15m installed in a radial shape. For reduced erection labour and improved safety, a new method was developed for constructing the pier heads that minimized the bracket scaffolding. The new pier-head construction method used precast

segments for the cross beam in part and substituted them for formwork scaffolding to carry the loads of other segments to follow during the erection. The bracket scaffolding was simplified by making it carry only the load of the column top. The precast segments to be erected in the direction perpendicular to the bridge axis were designed to have a unit weight of roughly 150 kN and a unit length of 800-900mm considering of the capacity of the lift. Using this method reduced the size of the bracket scaffolding to one third the initial plan, successfully reducing erection labour and improving safety. **Fig.11** shows the pier-head construction steps.

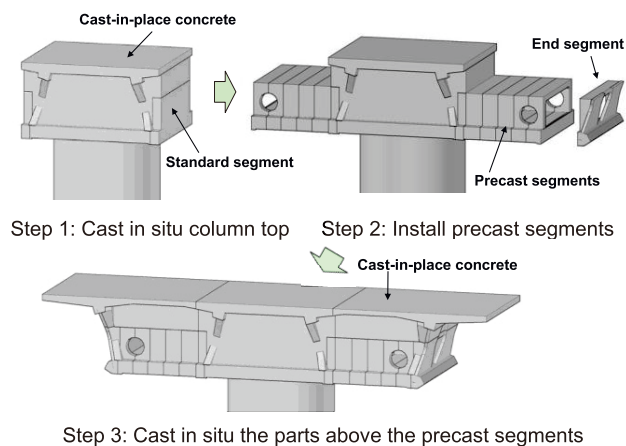


Fig.11 Pier head construction steps

(3) Construction of the Main Girder

Complex work is usually required on the webs of a PC box girder. Using prefabricated butterfly webs reduced such labour considerably. With the main-girder weight reduced by the butterfly-web box-girder structure, it was also possible to make the block length constant at 6.0m. The block length for cantilever erection is determined by the capacity of the launching gantry. In an ordinary PC box girder, it is usually roughly 3.0m around the pier head, where the girder is high or the members are thick, and roughly 4.0m between the piers. The number of blocks for this section was reduced from 14 or 15 in the basic plan to eight in the detailed design. The total number of blocks in the bridge was almost halved from 101 in the basic plan to 54, thereby helping greatly to reduce the number of days in the construction period. **Fig.12** shows a view of the cantilever erection.



Fig.12 Cantilever erection construction steps

4. Conclusion

Shinmeishin-Mukogawa Bridge was constructed using an efficient and rapid method that enables significant labour reduction. Its seismic resistance was improved through reduction of the main girder weight and elaborate design of the pier rigidity. The bridge also has excellent durability and requires reduced maintenance costs. This was achieved by using high-strength fibre-reinforced concrete in the main-girder webs and forming the outside of the piers with prefabricated precast components.

References

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概 要

新名神武庫川橋は、新名神高速道路に建設された橋長442mの5径間連続バタフライウェブエクストラドローズド橋である。主桁ウェブに「バタフライウェブ」を採用し、これにエクストラドローズド構造を組み合わせた世界で初めての構造形式である。本構造の採用により、上下部工重量で約35%の軽量化を可能とし、耐震性向上と環境負荷低減を図ることができた。

本橋では、「プレキャスト技術」を活用した「省力化施工」による生産性向上への積極的な取組みを実施した。橋脚では、ハーフプレキャスト部材を用いた省力化による急速施工（SPER工法）を実現し、高橋脚上の柱頭部では、横桁の一部をプレキャスト化して構築する施工法を採用し省力化施工と支保工軽減を図った。また寸法制限のある主塔には、1枚鋼板と2本のコンクリート柱からなる新しい分離定着方式の主塔構造を開発・採用した。