DESIGN AND CONSTRUCTION OF THE KATSURASHIMA VIADUCT –PRESTRESSED CONCRETE CORRUGATED STEEL WEB BOX GIRDER BRIDGE WITH RIBS AND STRUTS –

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ABSTRACT

Since the viaduct was constructed in a mountainous region with very irregular terrain, incremental launching method, which does not require the installation of supports or the like was selected. While this method is superior for construction under such conditions, the considerable weight results in high construction costs. Moreover, the section forces during launching are reversed compared with those after completion, therefore, the total weight of the prestressing steel is increased. Accordingly, in order to make the incremental launching method more streamlined and economical, a corrugated steel web structure was introduced to reduce the weight. In addition, so-called separated-section method that involves the use of ribs and struts was developed, and it was decided to conduct the incremental launching process with a section for which the wing slab was constructed later (hereafter "core section"). As results, the efficient and economical construction was achieved, using a construction method and the first structure in the world: a corrugated steel web PC box girder viaduct with ribs and struts, constructed by means of incremental launching using the core section. This paper will cover the design and construction of the Katsurashima Viaduct, focusing principally on the new technologies adopted during the construction process.

１. INTRODUCTION

The New Tomei Expressway is currently under construction as a national highway construction project. Its objective is to improve the durability of the Tomei Expressway, Japan’s most important road transport network. The Katsurashima Viaduct, a 216-meter-long 4-span continuous prestressed concrete box girder bridge, is located in the approximate center of this expressway. Photos 1 and 2 show a full view of the Katsurashima Viaduct. The bridge was constructed in a mountainous region with very irregular terrain. Accordingly, planning was conducted based on the assumption that the incremental launching method, which does not require the installation of supports or the like, would be used. While this method is superior for construction under such conditions, the considerable weight results in high construction costs. Moreover, as the section force at the time of completion is the reverse of that at the time of construction, the total weight of the prestressing steel is increased. Accordingly, in order to make the incremental launching method more streamlined and economical, a corrugated steel web was introduced to reduce the weight of the bridge. In addition, a new method called separated-section method that involves the use of ribs and struts was developed, and it was decided to conduct the incremental launching process with a section for which the wing slab was constructed later (hereafter "core section"). The result was the achievement of an efficient and economical bridge, using a construction method and structure without parallel anywhere in the world: a corrugated steel web PC box girder bridge with ribs and struts, constructed by means of incremental launching using the core section. This paper will cover the design and construction of the Katsurashima Viaduct, focusing principally on the new technologies adopted during the construction process.

Photo. 1. Full view of the Katsurashima Viaduct

Photo. 2. Full view of the Katsurashima Viaduct

2. THE KATSURASHIMA VIADUCT ON THE NEW TOMEI EXPRESSWAY

The following is an overview of the Katsurashima Viaduct. Refer to Fig. 1 for a general view of the bridge, Fig. 2 for a cross section of the main girders, and Tab. 1 for the quantities of the main materials.

Project name: New Tomei Expressway Katsurashima Viaduct PC Superstructure Eastbound Construction Project
Commissioned by: Yokohama Branch, Central Nippon Expressway Co.,Ltd.
Location: Katsurashima, Okabe-cho, Shida-gun, Shizuoka Prefecture (Japan)
Project term: March 2003 - May 2005
Structural mode: 4-span continuous prestressed concrete box girder bridge with corrugated steel web
Design load: B live load
Bridge length: 216.000 m
Span length: 52.650 m + 2 x 54.000 m + 52.700 m
Effective width: 16.500 m

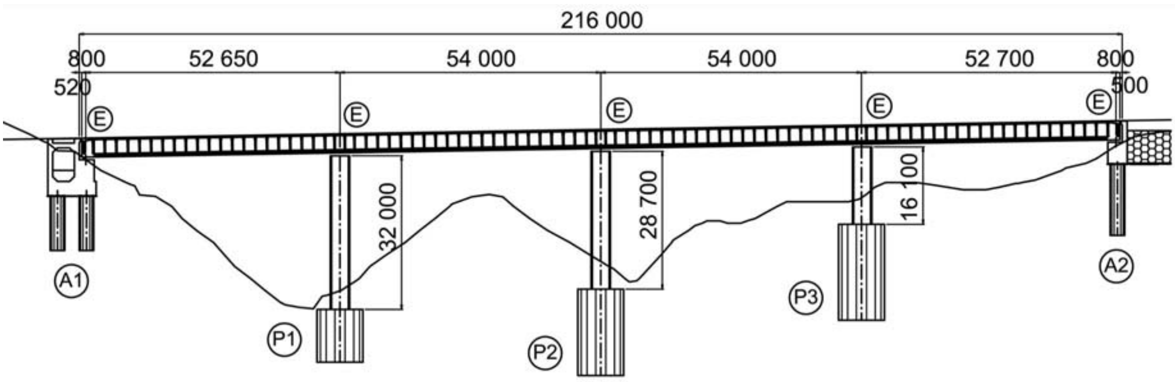


Fig. 1. General view (side view)

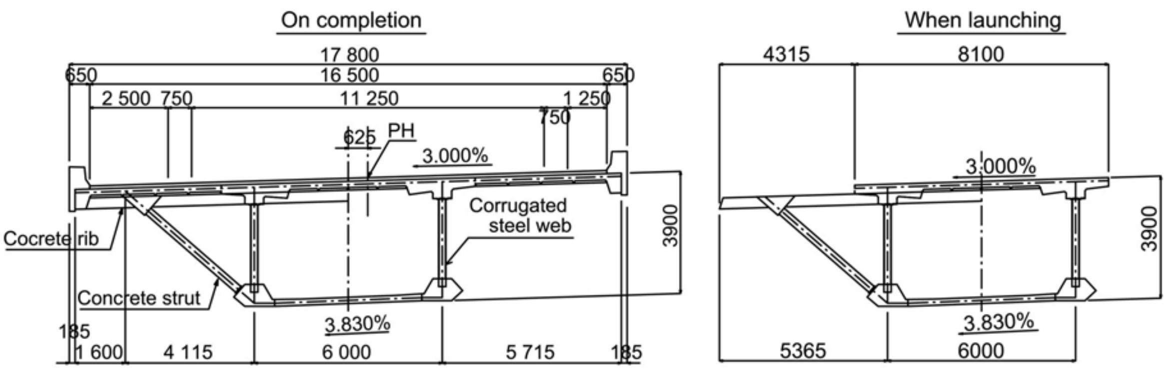


Fig. 2. Cross section

3. DESIGN

The following is an overview of the design, focusing on the new technologies used in the construction for the Katsurashima Viaduct.

(1) Technical Features

Four major new technical features were adopted in the construction of the Katsurashima Viaduct.

		Unit	Quantities	Specification
Concrete	Cast in situ	m^3	1,925	σck=40N/mm^2、60N/mm^2
	Ribs and Struts	m^3	220	σck=50N/mm^2
	Precast panels	m^3	176	σck=50N/mm^2
Formwork		m^2	9,671	
Reinforcing steel		t	659	SD345
Prestressing tendon	Longitudinal	kg	64,231	SWPR7B 19S15.2, 27S15.2
	Transverse	kg	18,228	SWPR19 1S21.8
Corrugated steel		t	190	SM490Y

Tab. 1. Quantities of the main materials

(a) Use of Corrugated Steel Web Box Girder Structure with Ribs and Struts

The structure is one in which the upper slab of a conventional corrugated steel web box girder bridge is supported with ribs and struts (Fig. 3). The use of this structure enables the wing slab to be lengthened and makes it possible for the box girder to have a narrower bottom slab. This both reduces the weight of the superstructure and enables the bridge pier width to be decreased.

(b) Use of Incremental Launching by Means of Separated-Section Method

Fabrication of main girders was done using the separated-section method, and incremental launching using the core section was conducted (Fig. 4).

(c) Upper Slab Comprising PCPca-Panels and Cast-in-Place Concrete

To form the upper slab, PCPca-panels were placed between ribs and cast-in-place concrete was placed using these slabs as formwork (Fig. 5).

(d) Diversion of Cable Use During Launching Erection to Become Tendons in Completed Bridge

The prestressing cables used during the launching erection process were deverted for use in the completed bridge.

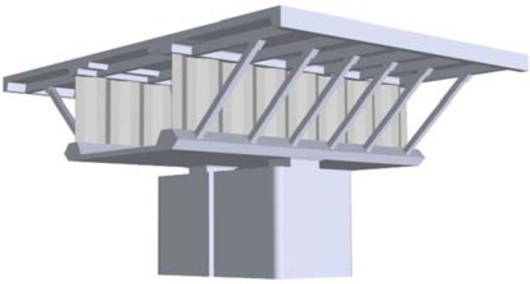


Fig. 3. Corrugated steel web box girder structure with ribs and struts

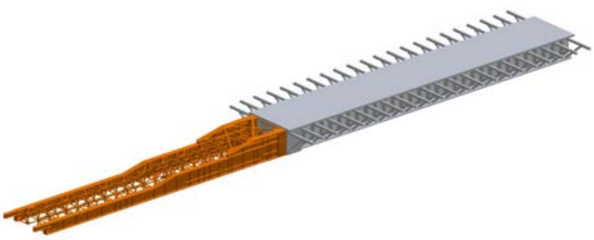


Fig. 4. Incremental launching using the core section

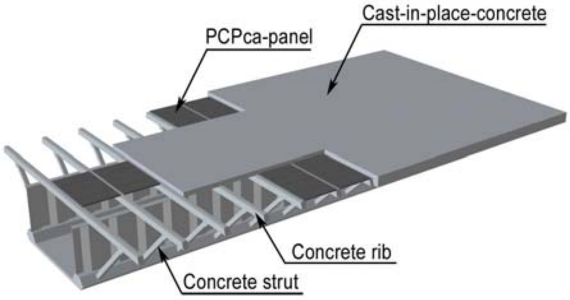


Fig. 5. Construction method of upper slab

(2) Incremental Launching Using Separated-Section Method

The use of ribs and struts on this bridge enabled the wing slab to be lengthened, and the use of corrugated steel for the web enabled the dead load to be reduced. As a result, the proportion of total bridge weight accounted for by the weight of the wing slab was comparatively great (approximately 35%). Accordingly, the weight during the incremental launching process can be expected to be greatly reduced by conducting incremental launching with a core section containing no wing slab. For this reason, it was decided to construct this bridge through incremental launching, using a new method unparalleled anywhere in the world: separated-section method. As will be covered later, the use of this method enabled the weight of the main girders during construction to be reduced by approximately half in comparison with the conventional method, in which the full cross-sections of prestressed concrete box girders are incrementally launched. In addition, construction equipment costs and the quantity of prestressing steel were both greatly reduced. Particularly important is the fact that the maximum reaction force during the incremental launching process was kept to 13,000 kN or below, and incremental launching was possible by distributing the effort between two standard vertical jacks (6,500 kN).
The main issue connected with the decision to perform the construction using separated-section method was what method to use for construction of the subsequent construction sections. For this bridge, a structure that combined ribs and struts was adopted, and these were fabricated in the fabrication yard together with the core section. This reduced manpower requirements for the construction of the wing slab following the completion of the incremental launching process. PCPca-paneles were placed between the ribs using a miniature crane placed on the bridge surface, and these were used as formwork for the placement of the concrete. This made form travellers unnecessary for the later stages of construction.

(3) Diversion of Lauching Erection Cables for Cables for Use in Completed Bridge

For the construction of this bridge, the full external tendon method was adopted. With the conventional method of incremental launching construction using the full external tendon method, some of the cables placed in the zigzag pattern shown in Fig. 6 (left) are not needed when the bridge is completed. These cables are removed and other cables are added where an insufficiency exists. When the incremental launching method was used for construction, this had the problem of increasing the total number of prestressing cables used. Accordingly, the pattern in which the temporary cables used for erection were placed was changed to the straight up and down pattern shown in Fig. 6 (right). This enabled the tension of the prestressing cables placed on the top side to be released following the completion of the incremental launching process. Their placement was then changed for retensioning and diversion to use as tendons on completion.
In diverting the temporary erection cables, the following is a description of the problems relating to ensuring the soundness of the cables and the resolution of these problems.

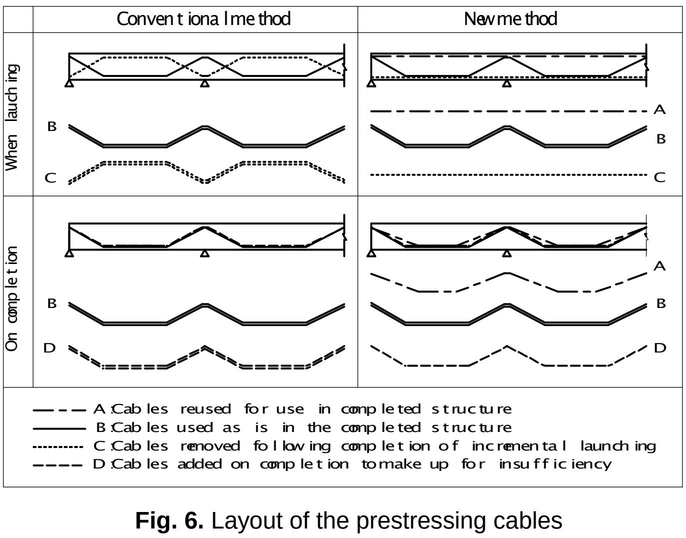


Fig. 6. Layout of the prestressing cables

(a) Saddle-shaped deviators prevent damage to cables

When reuse the erection cables removed as part of the conventional method to use as tendons in the completed bridge, the reuse of these cables after release of tension and removal can be considered. In such cases, it was difficult to avoid damaging the cables during this series of operations, or to discover damage in the event that it had been caused. Accordingly, the saddle-shaped deviator shown in Fig. 7 was adopted. After the tension of the erection cables placed straightly on the top side was released, they were reoriented to the newdeviator as is.
With the deviator for the girder at the support, the cable angle changed from a straight orientation to a downward orientation. This was resolved through the use of a vertically elongated trumpet shape for the outlet of the deviation duct.

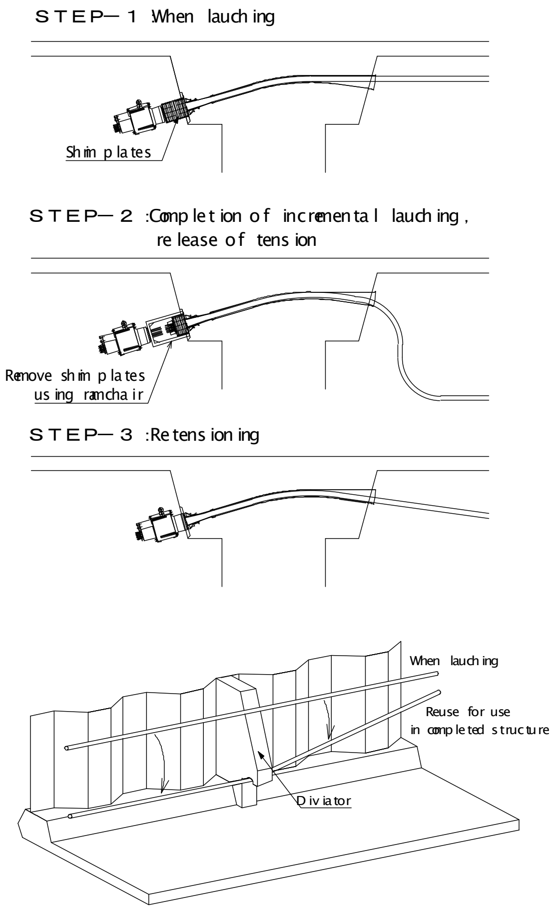


Fig. 7. Diverting of the temporary erection cales

(b) Using shims to take account of differences in distance between anchorages

In order to change the cables from a linear arrangement to a deflection arrangement, the distance between anchorages will be longer at completion than during the construction process. Accordingly, if the cables are simply retensioned and anchored as is, the locations anchored using wedges during the erection process will be located within the anchorage intervals at completion. In order to avoid this, during the erection process shim plates were provided and tensioned, as shown in Fig. 7, and at completion the cables were anchored on the inside of the locations at which they were anchored using wedges during the erection process.

(c) Preventing cable rusting

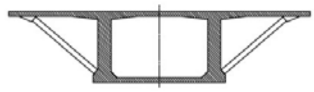
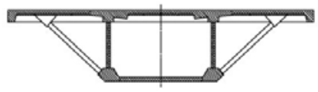
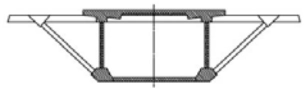
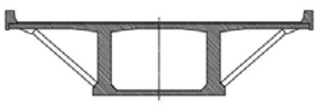
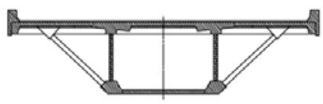
In order to prevent rusting of the erection cables during the construction process, prestressing strands with epoxy resin coating were used.

(4) Comparison of Quantities with Conventional Method

In order to validate the economic benefits provided by the new technologies adopted for this bridge, a comparison of quantities used was conducted for this method and the conventional construction method. Design was implemented for four design condition cases and the reduction effectiveness of each new technology was considered.

(a)Comparison of Main Girder Weight When Incremental Launching and Dead Load on Completion

Tab. 2 shows a comparison of the weight of main girders for each span (54 m). Changing from a concrete web to a corrugated steel web during the incremental launching process reduced the weight by approximately 30%, and conducting the incremental launching with only the core section reduced the weight further by approximately 20%. As the table shows, for the completed bridge as well, the weight was reduced 25% with respect to the dead load including bridge surface load.

	Conventional method (Incremental launching method of PC box girder)	Incremental launching method of Corrugated steel web box girder	
	Full section	Full section	Core section
Main girder weight when lauching			
	20,000 kN (1.00)	14,500 kN (0.72)	10,500 kN (0.52)
Dead load on completion			
	24,000 kN (1.00)	18,000 kN (0.75)	

Tab. 2. Comparison of main girder weight and dead load for each span (54 m)

(b) Comparison of Longitudinal Tendon Weight

Fig. 8 shows a comparison of longitudinal tendon weight. The weight of the longitudinal tendons during the incrementtal launching process tended to be about the same as the main girder weight shown in Tab. 2. Changing from a concrete web to a corrugated steel web during the incremental launching process reduced the weight by approximately 30%, and conducting the incrementtal launching at the core section reduced the weight further by approximately 20%. In addition, the total number of tendons used was reduced by 15% by diverting cables (Case 1 and Case 2). The number was reduced further by 15% through the change from a concrete web to a corrugated steel web (Case 2 and Case 3), while the shift from incremental launching at all sections to incremental launching at the core section resulted in a further 15% reduction (Case 3 and Case 4). The combination of these reductions enabled the total numberof cables to be reduced by approximately 50% with the new method (use of corrugated steel web, incremental launching at the core section only, diversion of erection cables to use in complete bridge) as compared to the conventional method.

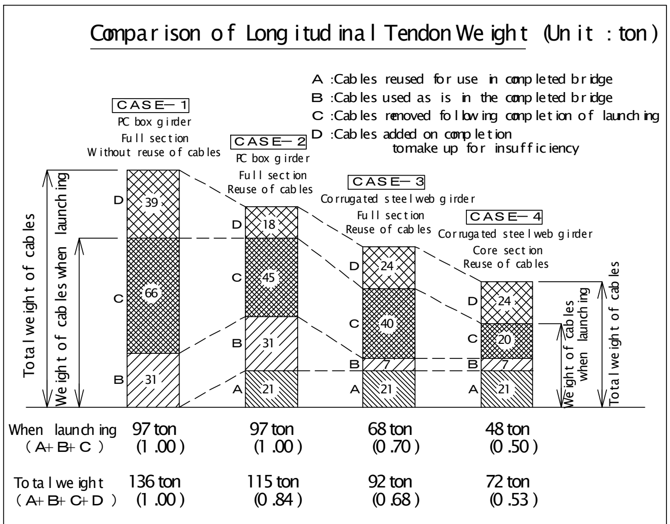


Fig. 8. Comparison of longitudinal tendon weight

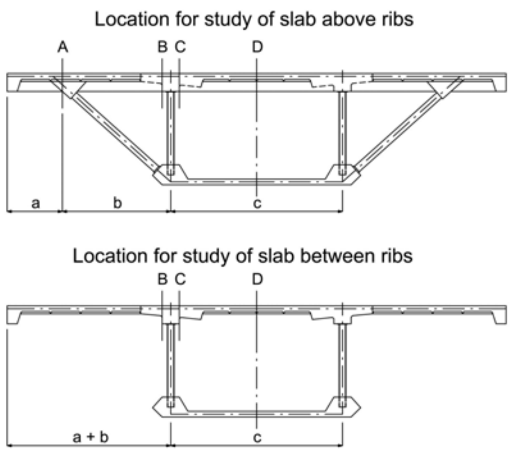


Fig. 9. Location for study of slab with ribs and strruts

(5) Design of Slab with Ribs and Struts

The design of the bridge transverse direction required not only slab design but also the design of ribs and struts. The structural characteristics of a slab with struts will differ greatly depending on the ratio of the wing length (a + b) shown in Fig. 9 and the slab span length (c), as well as the positions at which the struts are provided (a). Accordingly, the optimazed layout was determined after consideration of the stress produced at the location of the study section shown in Fig. 9.
The struts were precast concrete members fabricated at the factory. Concrete struts are heavier as compared to steel struts, but they are also approximately 50% cheaper, so it was decided to use concrete struts.
Fig. 10 and Fig. 11 show the strut upper and lower joints, respectively. The upper joints are the joints with precast ribs. To integrate the struts with the ribs, a rigid joint structure was used in which loop joints were provided and the gaps filled in with non-shrink mortar. For the lower joints, a round protrusion/depression key structure was used. In addition, a single stainless steel reinforcement was provided to function as an anchor bar, both as a failsafe measure and for positioning purposes.
The struts are members in which axial compression is predominant. Axial compression is greatest when both live load and wind load are applied; in such situations, compressive force of approximately 500 kN is applied. A check was conducted to ensure that the compression stress (also taking into account the bending moment generated at the ends of the struts) was within the allowable value. In addition, tensile force is produced in the struts when wind load only is applied from one side. However, it was confirmed that the section force combining this force and dead load would not become tensile force.

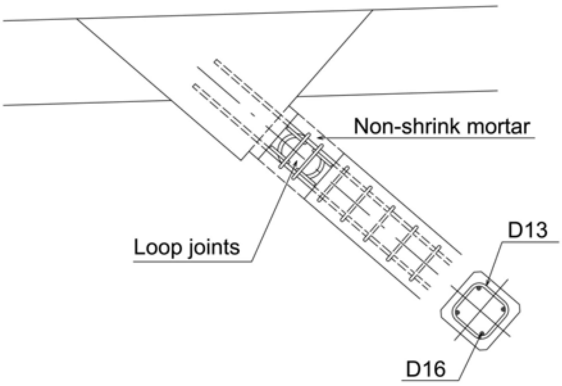


Fig. 10. Upper joint of the strut

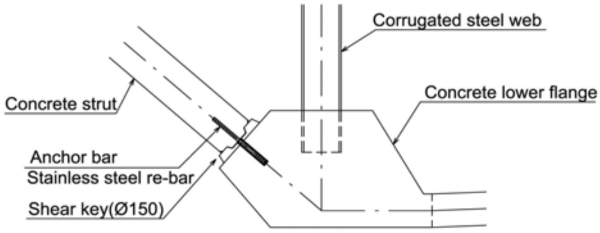
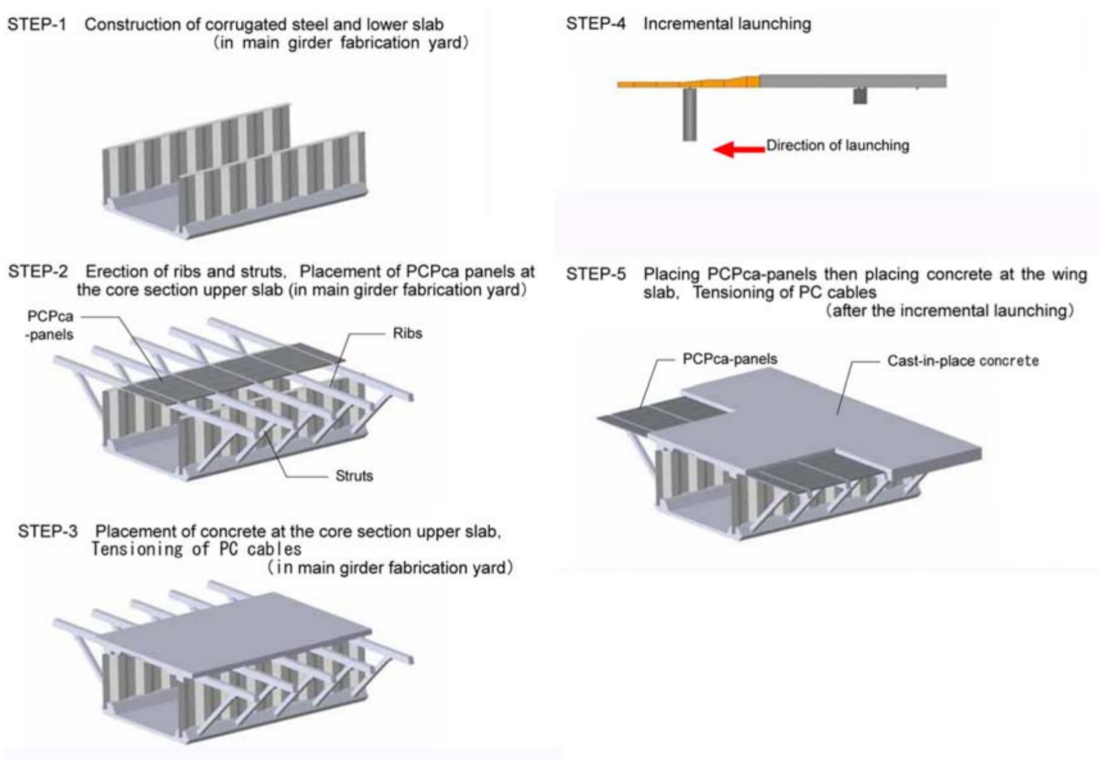


Fig. 11. Lower joint of the strut

４. CONSTRUCTION

(1) Steps in Overall Construction Process

Fig. 12 shows the overall construction procedure. The full external tendon method was adopted. A system was used in which the main girders for each span were fabricated and the formwork equipment was simplified. As shown in Fig. 12, the corrugated steel web, ribs and struts were used effectively, and only formwork equipment for the lower slab construction was needed. For the upper slab, PCPca-panels were placed between the ribs, and these were used as formwork for the placement of the concrete. The adoption of this construction method simplified equipment requirements, reduced manpower requirements and shortened the construction period.



(2) Construction of Main Girders

(a) Use of Precast Members for the Corrugated Steel and Concrete Lower Flange

As the concrete lower flange is subjected to considerable localized compression stress during the incremental launching process, 60 Mpa high strength concrete was used. In addition, with the aim of (1) achieving dependable construction of joints with high strength concrete (2) shortening the process(3) improving the erection precision of the corrugated steel, it was decided to use precast members for the corrugated steel and concrete lower flange, and these were fabricated in a different yard from the main girder fabrication yard (Photo 3).
The precast sections of the corrugated steel and lower flange were transported by trailer from the precast member fabrication yard to the main girder fabrication yard and then erected using a 100-ton crane. The fabrication and erection in advance of these precast members enabled the support platforms for the corrugated steel to be eliminated and allowed the construction of the lower slab and the placement of ribs and struts to be done concurrently, reducing the time required for the process.
(b) Construction of Core Section Slab

The core section slab was constructed at the main girder fabrication yard prior to the incremental launching process. The fabrication of the slab was done by placing PCPca-panels on top of the ribs and then using these as formwork to assemble steel reinforcements and prestressing steel on top and then placing concrete.

(c) Construction of External Tendons when Incremental Launching

After the fabrication of the main girders for the core section was complete, the external tendons were tensioned in the incremental launching process. Photo 4 shows the anchorages for the cables (provided with shim plates) that were to be diverted for use in the completed bridge.

Photo. 3. Precast members for the corrugated steel and concrete lower flange

Photo. 4. The anchorages for the cables provided with shim plates

(3) Incremental Launching

In the incremental launching process, the main girders for each span were divided into four blocks and fabricated, and incremental launching was conducted for one full span (54 m) at a time. Distributed control of reaction force was achieved through the use of an Active Reaction Control (ARC) system for incremental launching. This method involved placing vertical jacks on top of sliding jacks to enable the main girder to move horizontally without moving up or down. With conventional methods, it is difficult to control reaction force during horizontal movement, but this new method made it possible to control reaction force easily and dependably. Photo 5 shows an overall view of the incremental launching process.

(4) Construction of Wing Slab

After the incremental launching process was complete, the wing slab was constructed. The wing slab was constructed using the same method as for the construction of the core section slab. Photo 6 shows the placement of PCPca-panels for the wing slab. It was possible to conduct the placement operation using a miniature crane provided at the core section, making large erection equipment unnecessary.

Photo. 5. Overall view of the incremental launching process

Photo. 6. The placement of PCPca-panels for the wing slab

(5) Diversion of External Cables

The procedure for diver of the external cables consisted of five steps: (1) release tension (2) remove shims (3) replace wedges (4) reconfigure cable placement (5) retension. Before the tension was released, the cables were temporarily suspended from the inserts placed at the ribs, using lever blocks and slings. During the reconfiguration of cable placement, these were loosened to allow the cables to descend and then be placed at the saddle shaped deviators. Photo 7 shows the deviators for the reused cables. Photo 8 shows the result after cable retensioning.

Photo. 7. The deviators for the reused cables

Photo. 8. The result after cable retensioning

５. AFTERWORD

This study has examined the design and construction of the Katsurashima Viaduct, which has a structural form that is a world first: a corrugated steel web PC box girder bridge with ribs and struts. The bridge used an effective combination of ribs, struts, PCPca-paneles and corrugated steel web along with cast-in-place concrete and represents a new composite structure bridge in which these elements were used effectively from construction through completion. This structure is an extremely effective method in an area of prestressed concrete bridges (those with span length 40 - 60 m) that had previously not been one of specialties. This method is expected to further expand the applicable range of prestressed concrete bridges.
Following completion of the final incremental launching process in November 2004, the erection cables were diverted for use in the completed bridge and the wing slab was constructed. The Katsurashima Viaduct was completed in May 2005.
It is the author's hope that this paper may prove useful in future planning, design and construction of prestressed concrete bridges.

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2. Aoki, Wada, Sakurazawa, Morohashi. Design and Construction of a Corrugated Steel Web PC Box Girder Bridge with Ribs and Struts: The Katsurashima Viaduct on the New Tomei Expressway. *Journal of Prestressed Concrete,* Vol. 47 No. 3 (in Japan)