Design and Construction of Extradosed Bridge in Seto Inland Sea
— Bizen ♥ Hinase Bridge —

瀬戸内海に架かるエクストラドーズド橋の設計・施工
— 備前♥日生大橋 —

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Synopsis
Bizen♥Hinase Bridge is located in Hinase-cho, part of Bizen-shi in Okayama prefecture (**Fig.1**). Part of the Bizen–Hinase–Kashirajima road project, it is a 765m bridge providing a road connection from the mainland to Kakui Island. It is a six-span continuous rigid-frame extradosed box-girder bridge made with prestressed reinforced concrete (RC). A 170m extradosed span was used in order to secure a 122.3-m-wide, 18.0-m-high shipping channel between piers P1 and P2. The official name of the bridge, chosen by public competition, is unique for including a heart symbol♥.

Structural Data
Structure: 6-span continuous rigid-frame extradosed box-girder prestressed-concrete (PC) bridge
Bridge Length: 765.0m
Span: 86.8 + 170.0 + 155.0 + 2@135.0 + 80.8m
Width of Deck: 6.5m
Tower Height: 180m
Owner: Bizen City
Technical Adviser: Honshu-Shikoku Bridge Expressway Co., Ltd.
Designer: Yachiyo Engineering Co., Ltd.
Contractor: Joint venture of Sumitomo Mitsui Construction Co., Ltd.,
Shimizu Corporation,
Sasayama Kogyo Co.,Ltd.
Construction Period : Mar. 2010 – Mar. 2015
Location: Hinase-cho, Bizen-city Okayama Prefecture, Japan

Fig.1 Bizen♥Hinase Bridge

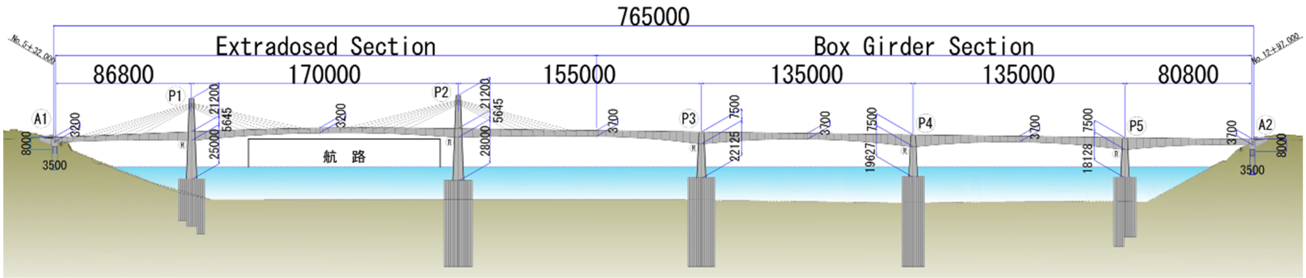

Fig.2 General view

1. Introduction

The main girder of Bizen♥Hinase Bridge was erected using the balanced cantilever method. Extra-large form travelers were used for the extradosed sections to construct blocks that each incorporate cable anchorages, which are located at 7m intervals. The pylons were constructed in RC, with separate anchorages for the cables on each side. To enhance the anti-corrosion performance for this marine location, polyethylene-coated epoxy-strand cables were used within protective pipes, assembling the cables on site before erection. The steel reinforcements in the concrete of the main girder and piers are all epoxy-coated to enhance durability. Moreover, the whole bridge is a rigid-frame structure, eliminating bearings at intermediate piers to enhance maintainability. Displacement adjustment by horizontal loading was adopted to make such a structure feasible.

2. Design

(1) Plan

The site of the abutment seat is a steep cliff formed by wave erosion and although there is a rocky outcrop, there is also a crushed zone. The plan located the abutment away from the crushed zone for long-term stability, producing a bridge length of 765m.

In selecting the bridge type, a six-span continuous box-girder bridge with extradosed sections was chosen by considering cost performance, durability, maintainability, aesthetics, and environmental preservation. For aesthetics in particular, the Hinase Bridge landscape and form review committee deliberated on factors such as harmony with the landscape, resistance to weathering, and the bridge's symbolic value.

(2) Design

A box-girder structure was used for the main girder of the extradosed sections, based on the choices for the number of cable fans and the anchorage methods. In other sections, a box-girder structure with the same web slope was used, resulting in webs of different heights attached to each other. To meet the support requirements, the whole bridge was designed as a rigid frame structure for maintainability. Achieving a wholly rigid frame structure is normally difficult at the scale of this bridge. However, to make the structure feasible, the sectional forces at the pier footings were reduced

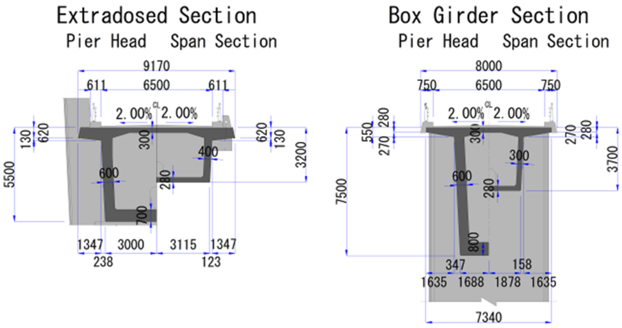

Fig.3 Cross-sectional views

by performing displacement adjustment work with horizontal loading.

For the base, a steel-pipe sheet-pile foundation, which is suitable for bridges with large-scale reaction forces, was adopted based on the geological properties of the bridge erection site.

In keeping with the landscape design, two independent pylons extend upward on either side of the bridge at each extradosed-section pier so that the pier and pylon form a continuous trapezium when viewed from the side. The pylons are not connected across the bridge at the top. The extradosed cable system uses 19S15.2 polyethylene-coated epoxy-strand cables with φ140mm high-density polyethylene protective pipe sheaths. The cables are arranged as two planes of seven tiers, with individual anchorages on the pylons.

To ensure durability, all reinforcements were epoxy-coated and provided with the required cover, except for the top plate of the steel-pipe sheet-pile foundation. **Fig.2** and **Fig.3** show the general and cross-sectional views of the bridge, respectively.

3. Construction

(1) Plan for Temporary Works

Because the bridge spans the sea, a work platform was set up at each pier to function as a base for construction work. Considering the effects on coastal waters and the navigation of fishing boats and regular ships, the work platform had the minimum area necessary to place the concrete pump, mixer, and hoist required when pouring concrete.

Because Kakui Island on the side of abutment A2 is part of the Setonaikai National Park, a survey of hygrophytes (plants that grow in wet conditions) was conducted before construction started.

Moreover, considering the effects of construction water on the surrounding oyster rafts, eelgrass beds, and fish, a steel sheet cofferdam was placed around the steel-pipe sheet-piles at each pier and a silt fence was placed around the work platform periphery to preserve the surrounding waters.

(2) Foundation Works

The structural foundations of the bridge are steel-pipe sheet-pile open caissons (doubling as cofferdams), which were installed by driving in steel-pipe sheet-piles (φ1,200mm, high-strength striped steel joints) at each pier with a vibratory or hydraulic pile hammer.
At piers P1 and P5, the steel-pipe sheet-piles were installed by replacing the bedrock with sand after drilling, and by filling the sand replacement around the steel-pipe sheet-pile periphery with suspension-type superfine particle grout to ensure structural integrity with the bedrock. Double-tube double packer grouting was used to inject the grout, and the required strength ($N > 50$, Standard penetration test (JIS A 1219)) was verified by a standard penetration test to check the strength improvement after injection.
At piers P2 to P4, the steel-pipe sheet-piles were 65m long and driven in by a hydraulic pile hammer from a spud barge with a crane (**Fig.4**).

Fig.4 Construction of steel pipe sheet piles

(3) Pier Works

The bridge piers are RC structures built with the full-scaffolding construction method. Piers P1 and P2 have hollow sections while piers P3 to P5 have solid sections. A thermal stress analysis performed as a measure against mass concrete in the solid section showed that thermal stresses increased after concrete casting. Heat-pipe cooling was therefore performed to reduce the crack width (**Fig.5**).

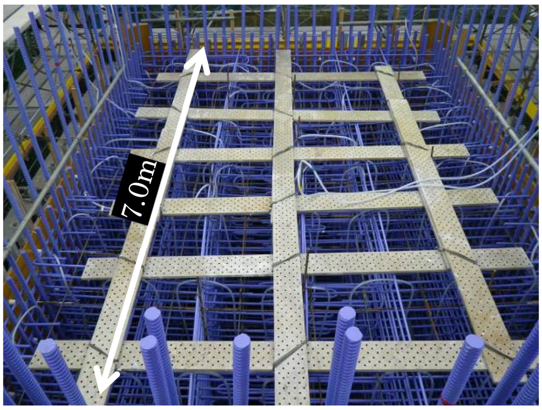

Fig.5 Heat pipe cooling

(4) Pier Table and Pylons

To secure the space required for assembling two extra-large form travelers, bridge pier tables measuring 18m in the longitudinal direction of the bridge were used at P1 and P2.
Similarly, 15m pier tables were used for piers P3 to P5 to accommodate large form travelers.
During construction of the pier-cap falsework, around 10m of the lower part of each pylon was constructed first and brackets were installed to support the falsework from underneath so that cantilevering could proceed in parallel with construction of the upper part of the pylons (**Fig.6**). The cable anchorages on the pylons are RC structures with separate cable anchorages and reinforced by prestressing rods. Therefore, concrete waterproofing protection work (fluorine paint coating) was carried out to ensure durability of the cutout sections after tensioning and embedding the prestressing rods.

Fig.6 Pier table and tower construction

(5) Superstructure and Extradosed Cables

Construction of the superstructure was performed based on the closure sequence shown in **Fig.7**. To enable an entirely rigid-frame structure, horizontal loading was performed during closure construction of P3–P4, P1–P2 and P4–P5, in that order. The box-girder sections of the P3 to P5 cantilevers were constructed in the order P4–P3–P5 using large form travelers to reduce the number of blocks. The extradosed sections of the P1 and P2 cantilevers were constructed in the order P2–P1 using extra-large form travelers. The use of extra-large form travelers enabled blocks to be constructed with lengths of 6.0–7.0m, so that cable anchorages, which were located at 7.0m intervals, could be incorporated into the construction of each block (**Fig.8**).
Cable tensioning for each block was performed after completing each cantilever block and advancing the form traveler. For this reason, space for tensioning was

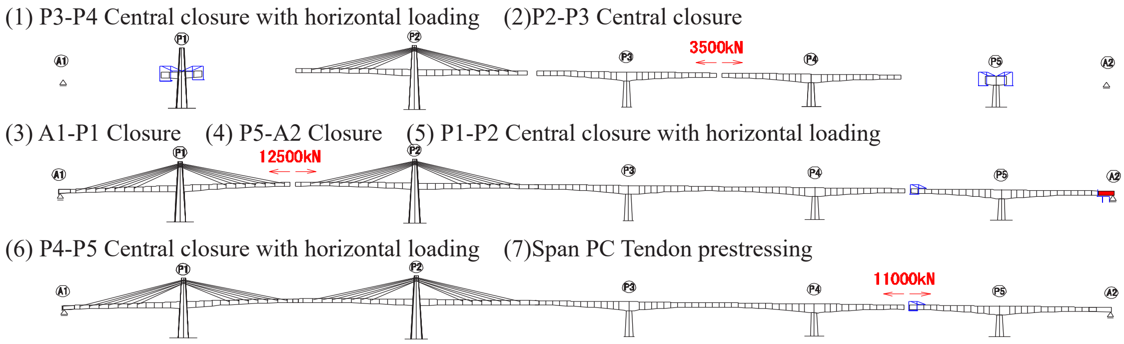

Fig.7 Construction method of girder

provided in the formwork around the cable anchorage protrusion, and cable-tensioning work was included in the main girder construction.

For the extradosed cables of this bridge, to minimize the need for equipment and wharf space required for construction at sea, cables that could be assembled on site were adopted, inserting the strands one at a time into protective pipes before tensioning.

A pushing machine installed on the pylon scaffolding was used to insert the strands. For the tensioning work, a method that tensions one strand at a time using a small lightweight single-strand jack was adopted for workability inside the main girder cantilever formwork and to simplify the jacking device. This tensioning work was carried out in three stages to reduce variations in tension between strands. After tensioning the first strand to remove sag, insertion was performed from the lower layers of the strands in each cable while tensioning was performed from the upper layers so that strands did not cross during insertion and tensioning.

(6) Central Closure

The connected bridge sections (between P1–P2, P3–P4, and P4–P5) were subjected to horizontal loadings of up to 12,500kN before connection to remove residual stress at the piers after the cantilever construction was finished. To secure the necessary displacement, the control method aimed to provide the bridge piers with the curvature assumed in the design. Preliminary measurements showed that foundation stiffnesses were larger than the design values, thereby presumably suppressing any rotational deformation of the bridge piers. Hence, the expected horizontal displacement based on the design will not be generated. An analysis was then performed based on the expected displacement when pier cracks appear and on the cracking stiffness. It is estimated that for a design value of 12,500kN, the displacement can be secured at around 13,000kN, which is almost the same as the expected value.

Fig.8 Large form travelers

4. Afterward

In this construction work, the authors were able to build a highly durable structure with excellent maintainability while preserving the environment during construction.

The bridge opened in April 2014 as part of the network of roads connecting outlying islands to the main island of Honshu. The bridge had been keenly anticipated by local residents and was celebrated with events such as a commemorative marathon held before the opening. It is now used as a community road that offers the convenience of a direct link without having to use water transport.

概　要

備前♥日生大橋は，岡山県備前市日生町に位置し，市道日生頭島線整備事業のうち本土から鹿久居島間を結ぶ橋長765m の離島架橋である。本橋は PC6径間連続エクストラドーズド箱桁橋であり，P1～ P2間では，航路幅122.3m，航路高18.0m を確保するために支間長を170m とするエクストラドーズド形式が採用された。主桁は張出し架設工法を採用し，エクストラドーズド部では7m ごとに配置される斜材定着部を 1 ブロックで一括施工できる超大型移動作業車を使用している。また，主塔は分離定着方式の RC 製とし，斜材については，海洋部における防錆性能を向上させるために保護管内に PE 被覆エポキシストランドを配置し，現場組立て型の架設緊張方法を採用した。主桁および橋脚コンクリートにはすべてエポキシ樹脂塗装鉄筋を使用して，耐久性の向上を図っている。さらに本橋は，中間橋脚の支承を省略することで維持管理性を向上させた全橋脚ラーメン構造とし，その構造を成立させるために水平加力方式変位調整工も実施している。