Concrete Arch Bridge Constructed by Composite Arch
— The Warumi-Ohashi Bridge —

合成アーチ巻き立て工法によるコンクリートアーチ橋
— ワルミ大橋 —

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Synopsis
The Warumi-Ohashi Bridge crosses over the Warumi Straits, which is located in the Okinawa coastal semi-national park (**Fig.1**). The form of the bridge was selected in consideration of the ship-route limit and the landscape. The bridge is a concrete arch bridge constructed by Concrete Lapping method with Composite Arch (CLCA).
In order to secure durability, the measures against salt attack were taken.
The measurement of the stress in the concrete arch rib was carried out to secure the safety of construction.

Fig.1 The Warumi-Ohashi Bridge

Structural Data
Structure: Reinforced concrete fixed arch bridge with 11-span continuous prestressed concrete hollow slab
Bridge Length: 315.0 m
Span: 26.3 m + 25.0 m + 3@20.0 m + 60.0 m + 5@24.0 m + 22.3 m
Width: 11.0m
Arch Span: 210.0 m
Owner: Okinawa Prefecture
Designer: CTI Engineering Co., Ltd.
Contractor (Superstructure): Joint Venture of The Zenitaka Corp., Takenaka Engineering & Construction Co., Ltd., and Kokuba-Gumi Co., Ltd.
Construction Period: Sep. 2005 – Dec. 2010
Location: Okinawa Prefecture, Japan

1. Introduction
The Warumi-Ohashi Bridge has a 11-span continuous prestressed concrete hollow slab as the upper deck. The 210 m long arch span of the bridge is the fifth longest span among concrete arch bridges in Japan.

2. Design
(1) Aesthetic Design
"The Warumi-Ohashi bridge type selection committee" (chairperson: Masamitsu TSUKAZAN, professor at the University of the Ryukyus) was established in 2000. The evaluation was performed on five items: economical efficiency, structural characteristics, construction method, landscape, and maintenability. Finally, concrete arch bridge with upper deck was selected (**Fig. 2**).

(2) Structural Design
Construction methods greatly influence the structural design of concrete arch bridges. Since typhoons frequently visit Okinawa, Concrete Lapping method with Composite Arch (hereinafter referred to as

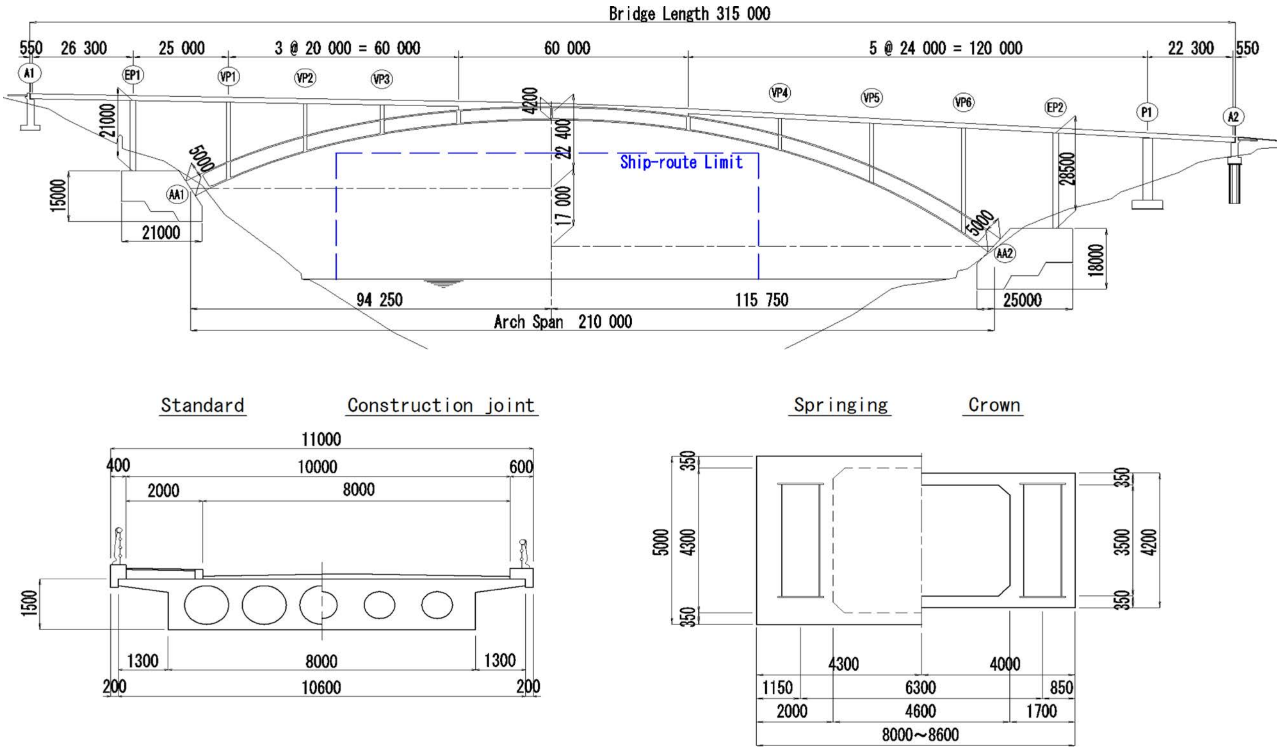

Fig.2 Elevation and cross sections of the Warumi-Ohashi Bridge

"CLCA") was adopted for arch rib construction taking into account the safety during construction.
Because the cross section of the arch rib changes along with the construction stages by this method, the stresses of the members must be examined in each stage. The cross section of the member is determined considering the stress in each step (**Fig. 3**).

(3) Measures against salt attack

The measures against salt attack with following materials were taken.

- Epoxy resin coated rebar
- Epoxy resin coated tendon
- Polyethylene sheath for tendon

The allowable crack width was determined as 0.10 mm for durability; in order to satisfy this requirement, measures such as reinforcing with rebar were taken.

3. Construction

(1) Erection of the composite arch

The steel arch segments, the length of which was about 8.0 m, were fabricated at the factory in Futtsu city, Chiba Pref., and shipped to Okinawa. Then they were carried by trailers into the site. Twin box shaped arch ribs with braces were erected by cable crane that had pylons on the slabs at the both sides of arch abutment piers (**Fig. 4**). The steel boxes were filled with concrete (**Fig. 6**), then the arch ribs became composite arches. The construction procedures are shown in **Fig. 5**.

(2) Lapping of the composite arch

These composite arches were lapped with concrete

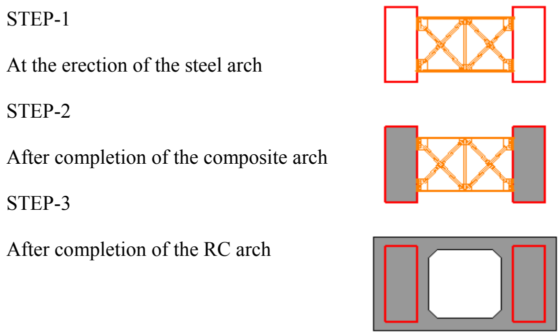

Fig.3 Cross section of arch member in each step

Fig.4 Erection of steel box arch rib with cables

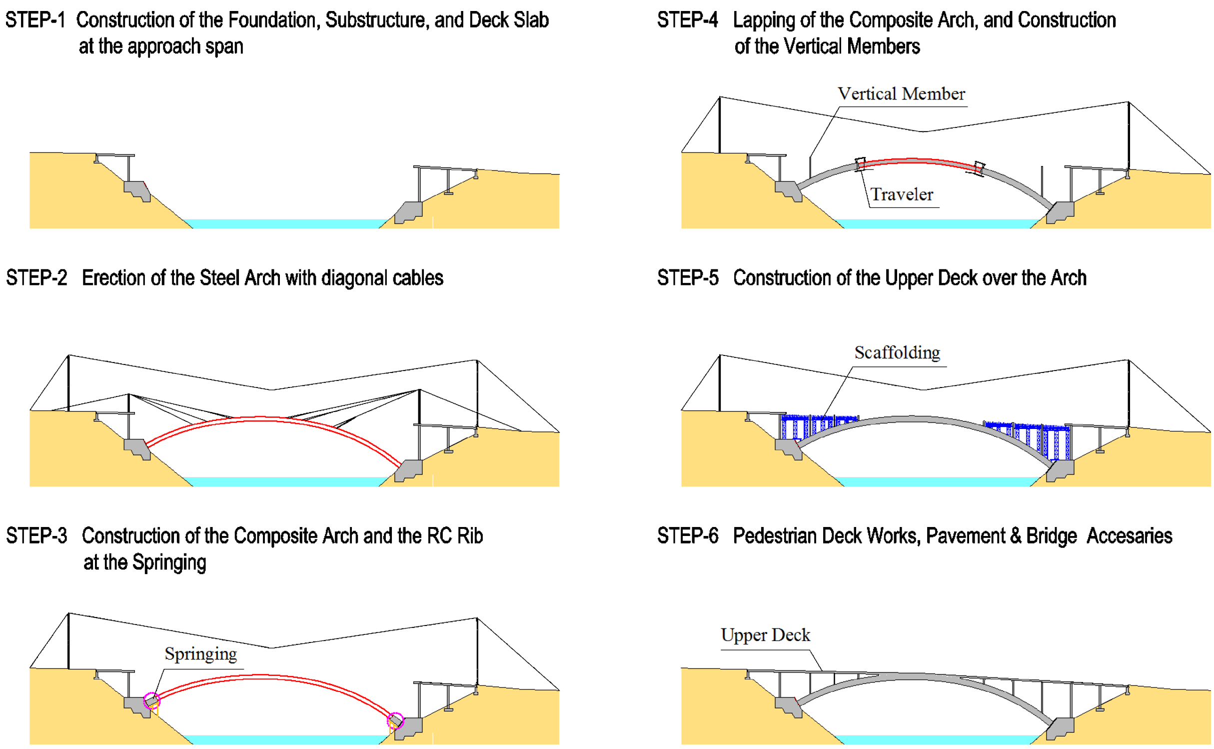

Fig.5 Construction procedures

using travelers (**Fig. 7**), then the concrete arch rib was completed. The length of cast-in-situ segment of the concrete arch rib was 4.0 m. The average cycle time of concrete lapping for a segment was 11 days.

(3) Construction of the deck

After the construction of spandrel columns, the prestressed concrete hollow slab was constructed. (**Fig. 8**). DYWIDAG Post-Tensioning system for multiple epoxy coated strands was adopted for the longitudinal tendon. The triple-layer protection was employed against salt attack; it comprises epoxy coated strands, polyethylene sheaths, and cement grout.

4. Thermal stress analysis of concrete

Thermal stress analysis was carried out for the following components. The constructionability, cost, environmental condition, and efficacy of the measures were synthetically evaluated. Measures for each component were implemented in order to control cracks.

Analysis components:

- Arch abutment
- Arch springing
- Cross beam in arch rib
- Arch crown
- Upper deck at construction joint

The implemented measures:

- Additional rebar arrangement
- Addition of an expansive additive
- Subdivisions of the placing ranges

The analysis result of springing is shown in **Fig. 9** as an example. Thermal cracking index is improved from 0.7 to 1.28 by using an expansive additive.

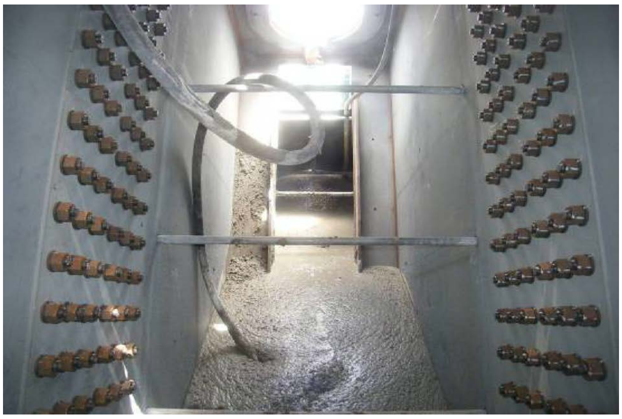

Fig.6 Filling concrete into steel box arch

Fig.7 Concrete lapping of composite arch

Fig.8 Installation of tendon and rebar

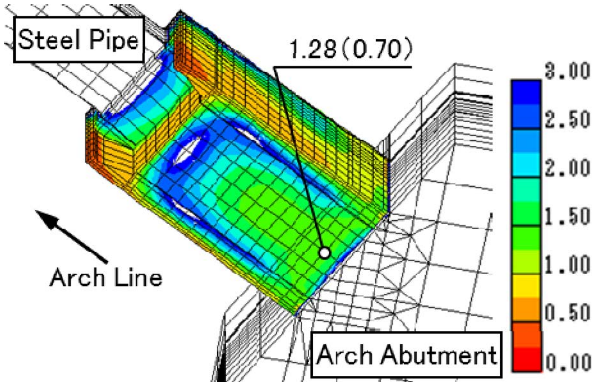

Fig.9 Thermal cracking index of springing

5. Measurement of arch rib stress

The stress transfer of arch rib constructed by CLCA is complicated, because the arch rib changes its structural form; “steel arch”, “composite arch”, and “reinforced concrete arch”. The inner steel box arch members of arch rib are disregarded as permanent structural members; they are only considered as temporary members during construction.

The stress measurement of the arch rib was carried out in order to verify the safety of construction, grasp actual stress of arch rib, and elucidate the stress transfer mechanism of arch rib.

6. Conclusion

The Warumi-Ohashi Bridge was opened for traffic in December, 2010. The bridge contributes to vitalization of local community as an sightseeing spot and an event site of such as Nordic walk events and marathon events from the Nakijin Castle, the UNESCO World Heritage Site. They became one of the tourist attractions of the north of Okinawa.

CLCA was employed for arch rib construction for its economical and safety merits. The arch span of the bridge is 210 m, and turned into the largest arch bridge constructed by CLCA in Japan. The arch span by this method exceeded 200 m for the first time.

The experience of this bridge suggests that CLCA can become a rational construction method for further huge arch bridges.

References

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Fig.10 Side view of the Warumi-Ohashi Bridge

概 要

ワルミ大橋は，北部沖縄の海岸国定公園内の鳥獣保護区域に指定されているワルミ海峡に架かる橋梁である。その構造形式の選定に当たって橋種選定委員会が設置され，航路限界等を考慮した13案の中から，特に風光明媚な景観との調和を考慮して，構造的にスマートな上路式 RC 固定アーチ橋が選定された。

設計では，塩害地域を考慮して，一般的なかぶりの確保に加え，エポキシ被覆鋼材，多重防食ケーブルシステムの採用といった配慮により高耐久性を確保した。

アーチリブの架設方法には，経済性と安全性を考慮し，『合成アーチ巻立て工法※』を採用した。本橋のアーチ支間長は210m であり，同工法で施工するアーチ橋としては，日本国内最長の支間長となる。同工法では初めて支間長200m を超えるもので，さらなる長大アーチ橋への合理的架設工法となり得ることが示された。

※鋼管アーチを先行架設後，鋼管内にコンクリートを充填（合成アーチを形成）し剛性を高めて，それを支保工にしながら外周にコンクリートを巻立ててアーチリブを構築する工法。