Concrete-arch Bridge
with Curved Girder to Aid Durability and Maintainability
— Agematsu Bridge —

維持管理性・耐久性に配慮した曲線桁を有する RC アーチ橋
— あげまつ大橋 —


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Synopsis
The Agematsu Bridge was designed as a concrete-arch bridge with a curved stiffening girder because (i) the bridge piers could not be placed in the river because of constraints on the impediment ratio of the river flow and (ii) the road alignment involved a horizontal curve. The bridge is part of an important arterial road for which there is no alternate route improving durability and maintainability are essential design considerations to minimize repair and renovation work. Hence, various schemes to improve durability and maintainability were used during the design and construction of this bridge, such as using of a box girder with a ribbed deck slab to realize a fixed reinforced concrete (RC) arch structure with a curved girder.

Structural Data
Structure: Deck-type fixed RC arch bridge
Bridge Length: 199.0m
Arch Span: 155.0m
Arch Rise: 18.5m
Width: 13.0m, effective width of roadway 9.5m + sidewalk 2.0m
Owner: Ministry of Land, Infrastructure, Transport and Tourism
Designer: Sumitomo Mitsui Construction Co., Ltd.
Contractor: Sumitomo Mitsui Construction Co., Ltd.
Construction Period: Apr. 2009 – Jan. 2013
Location: Nagano Prefecture, Japan

1. Introduction
The Kakehashi Improvement Project of which the Agematsu Bridge is a part was carried out to re-route the road to the opposite side of the river to prevent road closures in the event of rock falls or traffic accidents. The bridge is a design-build project integrating substructure and superstructure work with the theme of 100-Year Durable Bridge in Harmony with Nature. The bridge reported on herein is a concrete-arch bridge with a curved stiffening girder. Particular consideration is given to durability, maintainability, and aesthetics within the landscape (**Fig. 1**).

Fig.1 Agematsu Bridge

2. Design
(1) Structural Overview
The bridge spans the Kiso River. It would have been

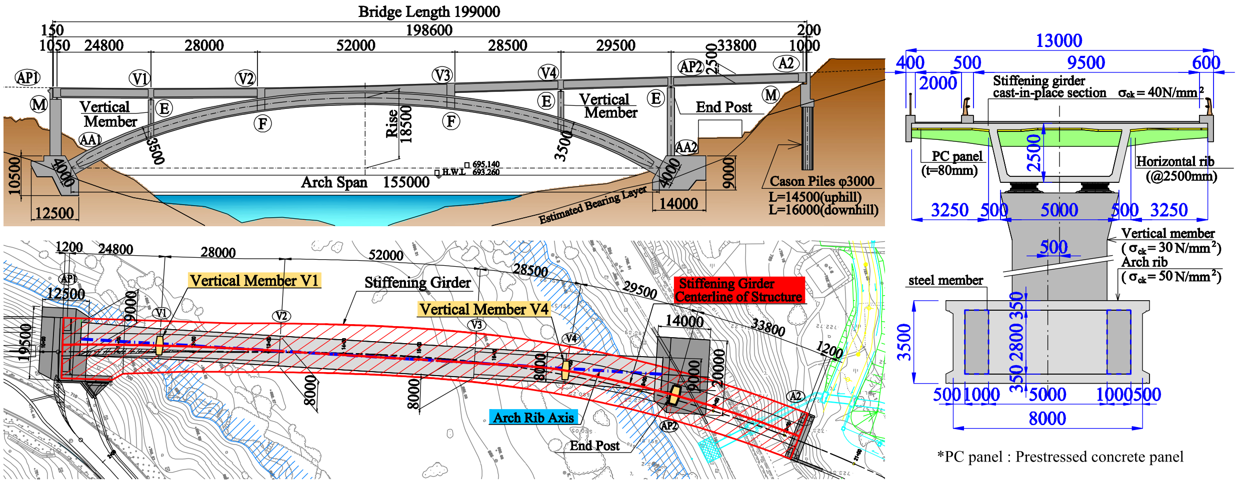

Fig.2 General drawing of the entire bridge

difficult to support the superstructure with bridge piers placed in the river because of a limitation on the impediment ratio of the river flow. Instead, an arch bridge was deemed suitable for this project. However, this presented a structural challenge because there were very few cases of an arch being used with a curved road alignment. This bridge was implemented as a structurally efficient arch bridge with a curved girder through the schemes discussed below. Furthermore, to improve their durability and maintainability, all structural components were designed as concrete structures.

(2) Addressing the Horizontal Alignment

The horizontal alignment of the bridge changes from a straight line at the initial point via a clothoid curve to a curve with a 335m radius. However, because arch structures are members under high axial compression, bending moments will arise in the transverse direction of the bridge if the arch rib is bent in the horizontal plane. For this bridge, the horizontal configuration of the arch rib is kept as a straight line and positioned such that it is located approximately on the centroid of the curvilinear road. Using the following techniques, the width of arch rib was configured to have the minimum width required for the stress.

(3) Seismic Design

The arch rib used 50N/mm^2 high-strength concrete and SD490 high-strength reinforcement bars. These were used with the intention of improving durability and reducing weight. Combined with not widening the arch rib despite the horizontal alignment of the road, this facilitated a flexible structure. Increasing the natural period reduced the inertial force during an earthquake and enhanced the seismic resistance. Under a level-2 earthquake specified in Japan, which is the critical level for the design of the arch rib, the section forces occurring at the springing section were reduced. This enabled the use of a spread foundation.

3. Construction

(1) Overview

The steps in the construction work are shown in **Fig.4**. First, open excavation was carried out for construction of the arch abutments, together with retaining walls for the left bank and using retaining walls for the right bank; the impact on traffic was minimized by using non-explosive methods. Afterward, the arch abutments were built and the cable cranes were erected. The arch rib was constructed using the new Melan method, whereby the steel members are left inside the concrete arch rib as a box-girder cross section[1]. This method enables shorter work schedules compared to the usual Melan method because the steel members are used as internal formwork, thereby eliminating the need to remove the lateral bracing and cross frames. Vertical members were constructed after constructing the arch rib, whereupon supporting falsework was assembled on top of the arch rib and the stiffening girder was constructed.

(2) Steel Member Erection

The steel member was fabricated as two main box girders divided into 27 blocks with a standard block length of 6.0m. The weight of the main truss for one block of the steel member was 9.0t. The steel member

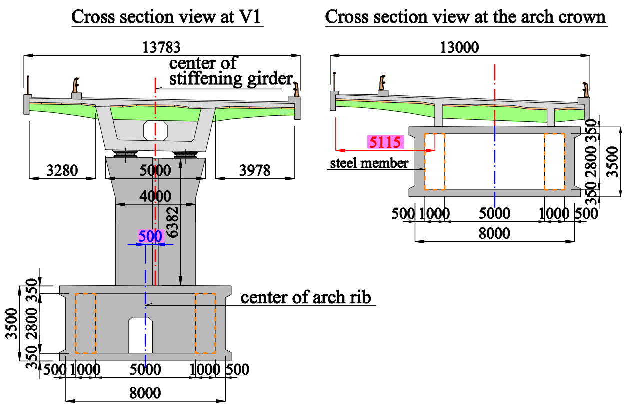

Fig.3 Cantilever lengths of stiffening girder

was erected using the cable erection method, making use of the existing cable crane equipment.

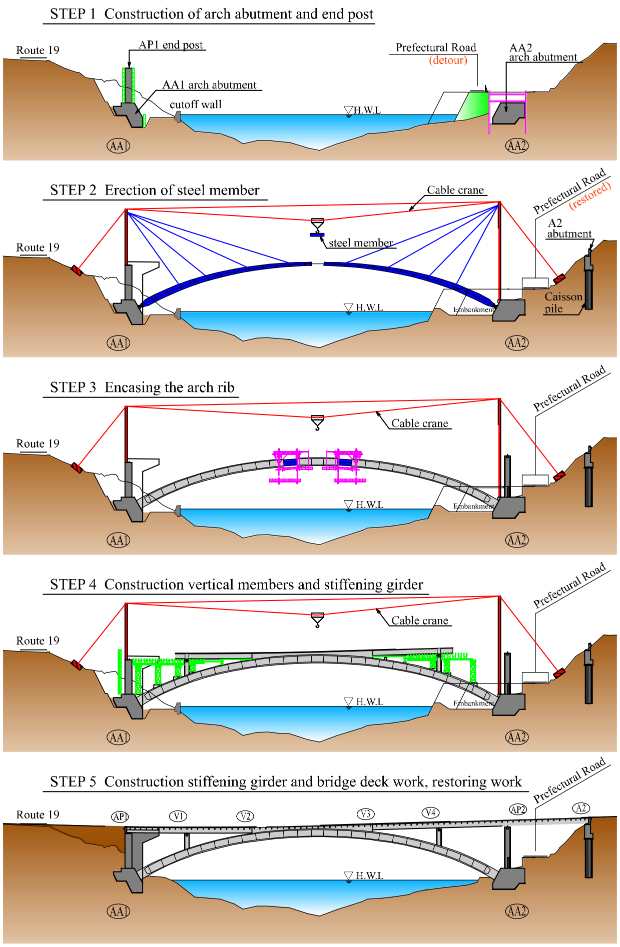

Fig.4 Construction step

Fig.5 Erection of steel member

(3) Arch Rib Construction

For the new Melan method, a concrete mix proportion with an 18cm slump was adopted in past projects to ensure workability to properly encase the underside of the steel member. However, because the arch rib in this bridge used highly viscous concrete with a design strength of 50N/mm^2 and D51 main bars within the 350-mm-thick bottom flange of the arch rib, workability was a concern. Hence, a full-scale cutout model of the underside of the arch rib including the steel member was fabricated to verify the workability experimentally. Based on this experiment, a mix proportion with a slump flow of 40cm was used. This ensured that the bottom part of the steel member could be reliably encased with concrete.

(4) Construction of Stiffening Girder

The construction procedure for the stiffening girder is shown in **Fig.6**. After installing the falsework for the bottom flange, webs and horizontal ribs at the top of the arch rib, the factory-fabricated horizontal ribs were secured in their positions (**Fig.7**). Then, the web and bottom-flange reinforcements and their formworks were assembled, after which the concrete for the web and bottom flange of the box girder was cast in place. Next, the precast panels were laid out on top of the horizontal ribs. Reinforcement and prestressing tendons were assembled, after which the deck slab was cast in place. Construction was made easier because no falsework was necessary for the cantilever deck slab using this method.

4. Durability Improvement Measures

This bridge is located in a cold region in which large quantities of anti-icing agent are applied during winter. To account for this, durability was improved by using

Fig.7 Installing the horizontal ribs

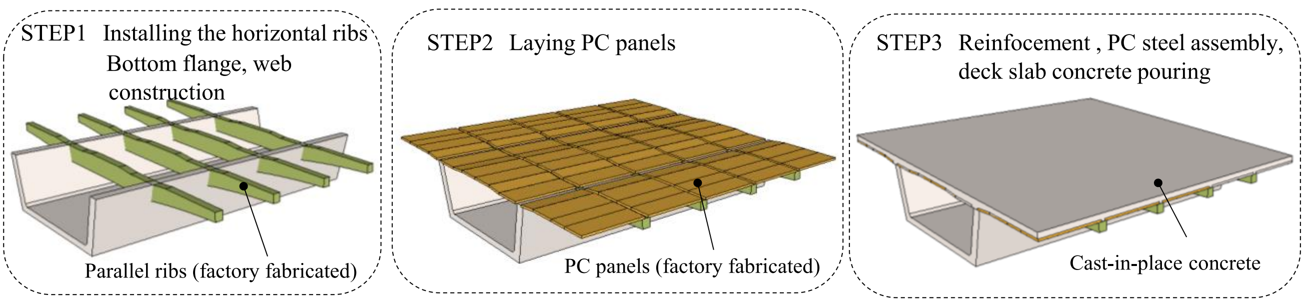

Fig.6 Stiffening girder construction procedure

concrete structures for all structural members including the arch rib and stiffening girder, as well as using high-strength concrete for the arch rib, the stiffening girder, and curb sections. In addition, measures to prevent deterioration were implemented: aluminum alloy was used for the railings, waterproof coating was performed on the curb sections, and stainless-steel pipes were used for the drainpipes (**Table-1**) .

Table-1 Durability improvement

Area	Measure
Drain	Stainless
Inspection corridor	Stainless
Curb	Use of epoxy coated rebars
	Use of High strength concrete
	3-layer waterproof coating
Railing	Aluminum alloy
Bearing	Multilayer anti-corrosive coating
Arch rib	Maintaining an outer cover of 60 mm
Stiffening girder	
Stiffening girder ends	3-layer waterproof coating
Springing sections	

5. Maintainability Improvement

In view of these conditions, an inspection corridor was built for the bridge, which takes into account the ease of inspection over the entire bridge through provision of accessibility, inspection spaces, and interior visibility (**Fig.8**) .

To facilitate walking safely on the bridge inspection corridor, both the sloping top surface and interior of the arch rib were provided with stairways and railings. Similarly on the arch-rib base, where the largest stresses are expected to occur during an earthquake, ladders were installed to enable access from the arch rib, and inspection spaces were provided at the underside of the arch-rib base for easy checking. Furthermore, for the stiffening girder, the external cables and cable anchorage, which are essential areas for inspection, were located inside the girder. Likewise for the arch rib, which is the principal structural member of this bridge, inspection immediately after a large-scale earthquake would be necessary as well as the required periodic inspections. Hence, lighting equipment was installed in both the stiffening-girder and arch-rib interiors to improve visibility during inspection.

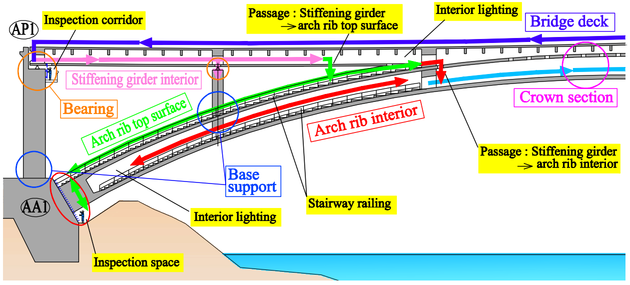

Fig.8 Inspection corridor system

6. Conclusion

The bridge is a concrete arch bridge with a curved stiffening girder, a type of bridge that is rare worldwide. To realize this, various schemes were utilized to improve the durability and maintainability[2], such as the use of a box girder with a ribbed deck slab. Many measures, some of which are not covered herein, were implemented to improve the durability and maintainability such as quality control and prevention of initial defects, and steps were taken to prevent deterioration.

Fig.9 View from underside of arch rib

References

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[2] Uchibori, H., Nagamoto, N., Nakajima, M., Akita, O.: *Design and Construction for Durability and Maintainability of Reinforced Concrete Arch Bridge with Curved Girder*, IABSE Conference Nara 2015, IABSE, Zurich, pp. 164-165, May 2015.

概　要

あげまつ大橋は，桟改良事業により対岸へルート変更される国道19号が木曽川を渡河する橋梁であり，設計施工一括発注方式にて発注された上下部一体の橋梁工事である。河川内に橋脚を設置することができず，補剛桁が平面曲線を有しているため，世界でも採用例が少ない補剛桁が曲線桁であるコンクリートアーチ橋である。

アーチリブの形状や配置は曲線桁の影響や地震力に配慮しており，補剛桁にはリブ付床版を有する箱桁を採用し，曲線桁を有するアーチ橋を合理的な構造として実現した。

本橋は，代替の利かない重要幹線道路上の橋梁であり，耐久性・維持管理性向上に配慮する必要があった。このため，耐久性向上のための材料面や構造面での対策を行うとともに，維持管理性を向上のために点検設備を充実させ、容易な点検が可能となっている。