Takimi Bridge as a Constituent Asset of a World Heritage Site
— Balanced Flat Arch Structure Minimizing Topographical Alteration —

世界遺産の構成資産に架かる滝見橋
— 地形改変を最小に抑えた扁平バランスドアーチ構造 —

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Synopsis

As a sacred place and a source of artistic inspiration, Mount Fuji was registered as a UNESCO World Heritage site in June 2013. Takimi Bridge (TB) is a pedestrian bridge cross-linked to Shiraito Falls (SF), a constituent part of the World Heritage site. Regarding the bridge position and bridge type, expert consideration had to be given to the surrounding environment. In locating the bridge as a new vantage point, the bridge position was chosen to be 40m downstream from the old TB. In the structural form, the form of a balanced flat arch (BFA) was conceived, based on the influence on the surrounding environment and aimed at reducing the amount of excavation required for the foundations.

Structural Data

Structure: Flat arch bridge
Bridge Length: 39.0m
Arch Span: 28.0m
Width: 2.5m
Owner: Fujinomiya City, Shizuoka Prefecture
Design Supervisor: Prof. Fumio Seki
Designer: Pacific Consultants Co., Ltd.
Contractor: DPS Bridge Works Co., Ltd.
Construction Period: Nov. 2012 – Dec. 2013
Location: Shizuoka Prefecture, Japan

1. Introduction

Because TB is located in one of the most scenic spots in Japan, near both natural monuments and a World Heritage site, it was necessary to minimize the extent to which the topography was altered and consider the view of the neighboring SF. In addition, the surrounding environment required a highly durable structure given the ecosystem diversity and the environment, where SF creates a large amount of misty water droplets. In the design, to avoid altering the topography, the authors considered a structure whose top and bottom are minimized and ultimately created a prestressed concrete (PC) BFA with a slender and compact form. This paper describes the design process, structural characteristics, design details, and test results after completion of TB.

Fig.1 Takimi Bridge (flat balanced arch structure)

Fig.2 Takimi Bridge and Shiraito falls (UNESCO World Heritage)

Fig.3 Location of Takimi bridge

2. Design

2.1 Sight Condition

(1) Cultural situation

This site has a long cultural history, as represented in depictions of its wide impressive waterfall scenery. Minamoto no Yoritomo (1147–1199), the shogun of the Kamakura Shogunate of Japan, wrote a song about the beauty of SF. This site is also famous as an object of worship, such as Fujikou, a folk religion of Mount Fuji.

(2) Geotechnical Conditions

The surface layer is gravel and silt. Beneath this layer (1 . 75m below the surface) is conglomerate that has an N-value of over 50. These geotechnical conditions are favorable for supporting the footbridge.

(3) Misty Conditions

Providing for the splashing of SF was one of the main objectives of the bridge design. Some measures were required for the bridge to endure for a long time under wet, humid, and misty conditions.

2.2 Design Standard

(1) Design Guidelines

It conformed to two design standards, Japan's Road Association and fib footbridge guideline, in order to satisfy the world standard quality of bridge design.

(2) Live Loads and Frequency

The JRA design code specifies the load as $3.5kN/m^2$ for all grades [1], and a structural frequency range of 1.5–2.3Hz is permitted, which considers pedestrian-induced vibration [2]. However, one-sided live loads are a particular concern in footbridge design, as laid out in the *fib* guidelines [3]. Pedestrians on this footbridge tend to view SF from only one side of the pavement, making it necessary to consider an asymmetric load and a torsional force perpendicular to the bridge axis [4].

3. Design of Takimi Bridge

(1) Design Concept

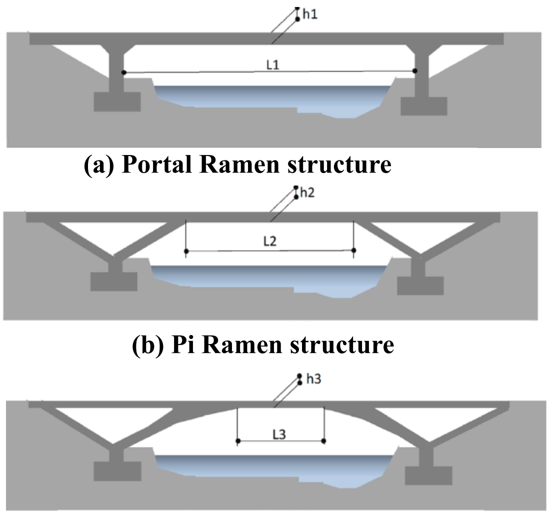
To achieve an optimum design given the aforementioned constrains, a compact bridge was adopted as the design concept. This concept plays a vital role in satisfying the constraints and the aesthetic considerations described later.

(2) Flow Line Plan for Viewpoint

Considering TB as a new viewpoint relative to the old TB, various viewpoints were provided for tourists by integrally designing the observation field and the boardwalk. The new TB is 40m downstream from the old one and affords a higher viewpoint. As such, it is now possible to have a wider view of SF from various heights, and a diversity of viewpoints has been realized.

(3) Development of Structural System

A Ramen structure was chosen as the basic structure because it offered the smallest foundations and the least amount of topographical modification. The proportions of a portal Ramen bridge are too artificial to suit the SF landscape. As a first development, a pi-shaped Ramen bridge would allow the girder height to be reduced from 1.5m to 0.9m, but the proportions of



(a) Portal Ramen structure

(b) Pi Ramen structure

(c) Balanced flat arch structure

Fig.4 Development of structural system

this structure are suited more to an expressway than to this site. Therefore, the point of connection between the diagonal member and the main girder were shifted to the center span and the axes of the diagonal members were rounded to smooth the flow of forces. This structure is a type of arch bridge that retains the character of a Ramen bridge. A flat structure with a span rise ratio of 1/12 was born (**Fig.4**), which is a BFA structural system.

In a BFA, large horizontal forces act at its two points of springing. To decrease these forces, diagonal back-stay members were added. In addition, prestress forces are supplied to the diagonal back-stay members, decreasing the horizontal forces by 50%.

Generally, a bridge's form is developed separately from its structural system. In this case, however, the authors designed both elements simultaneously to enact the design concept.

(4) Detail Design

Form of Arch Member and Fascia Line

To achieve a more compact bridge design, the authors studied the form of the arch member and fascia line. **Fig.5** shows the improvement achieved by chamfering the edge of the arch and demonstrates the shade cast on the arch member. Also shown is a study of the shape of the parapets, which determines the fascia line. The final shape of the study model and the actual completed bridge are shown in **Fig.6**. The final drawing is shown in **Fig.7**.

Footbridge Railings

Aluminum railings, which never rust, were adopted given the misty conditions. The form of their outer faces is sharp and that of their inner faces is flat (**Fig.8**). From this shape, in the external landscape railing is thin, there is no presence, internal landscape, railing is thick, giving the impression of presence. The railing color was determined as dark gray to match the environment.

Pavement Material

Splashing from SF makes the pavement constantly wet, and so the pavement must be sufficiently rough to prevent slipping. Osawa stone excavated from Mount Fuji was adjusted for shape and used for the pavement (**Fig.9**).

Anti-mist Measures

The misty conditions could damage the concrete by supplying water continuously. We consider the section of the parapets. In addition, to reduce the effect of splashing from SF, the outer face of the parapets is painted with water-repellent coating (**Fig.10**).

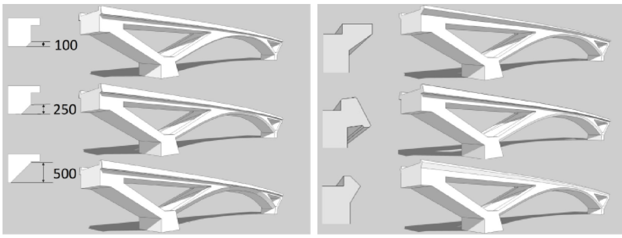


Fig.5 Form study of arch member and fascia line

Fig.6 Modeling studied shaping and actual bridge

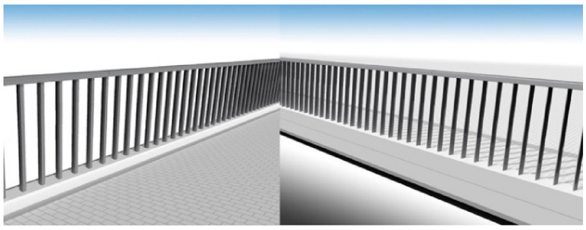


Fig.8 Railings C.G. (left: internal, right:external)

Fig.9 OSAWA stone

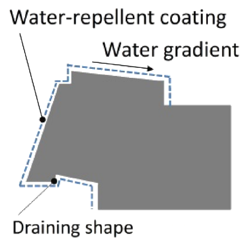


Fig. 10 Section of the parapets

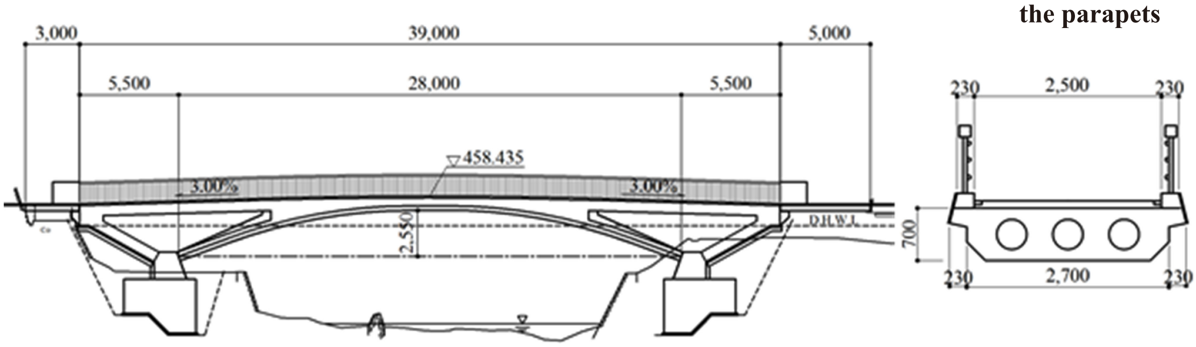


Fig.7 Side view of Takimi Bridge and cross section of main girder

Fig.11 Side view of Takimi Bridge and Shiraito falls

4. Construction

(1) Construction

Given the narrow approach road, the members were divided into a size that allowed them to be transported from the material provider. An all-staging method was selected to construct this footbridge,with construction done in six months (**Fig.11**).

(2) On-site Tests of Completed Bridge

Vibration is a particular concern for footbridges, and the *fib* guidelines recommend monitoring the vibration. To confirm the analysis, over 20 strain gauges were attached to the footbridge.

The measured frequency was 7.23Hz and the analysis result was 7.08Hz for the first vertical mode[5] (**Fig.12**). This means that the analysis was accurate in estimating that the bridge is likely to vibrate because of pedestrians. As mentioned above, the JRA design code suggests that a frequency range of 1.5–2.3Hz would likely have resulted in pedestrian-induced resonance (**Table-1**).

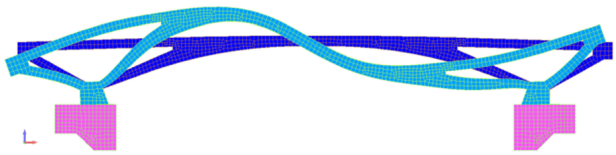


Fig.12 Shape of first vertical mode

Table-1 Frequencies of first mode

	Analysis	Experiments	Accuracy
Vertical	7.23 Hz	7.08 Hz	98%
Horizontal	7.25 Hz	5.98 Hz	82%

5. Conclusion

As described, we carried out a conceptual design and achieved the following:

- minimization of bridge volume including foundations;
- high redundancy for vibrations, floods, and earthquakes;
- the bridge aesthetics attracts tourists, and people come to SF to see this footbridge;
- consideration of aging.

TB won the Award of the Japan Prestressed Concrete Institute, the Award of the Japan Concrete Institute, and the Good Design Award of Japan Gmark. The redevelopment project around TB won the Japan Society of Civil Engineers Design Best Award in 2016.

References

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概　要

「富士山 – 信仰の対象と芸術の源泉」が，2013年６月にユネスコの世界遺産に登録された。滝見橋は，この世界遺産の構成資産である白糸の滝に架橋された歩道橋であり，架橋位置や橋種に関しては，専門家によって周辺環境への配慮が議論された。橋の位置は，新しい視点場として展開する観点から旧滝見橋より40m 下流に決定された。これによって，白糸の滝がよりダイナミックに見え，橋は，撮影スポットとしての機能を有することになる。橋の構造形式は，水飛沫に配慮し，自然景勝地であるため基礎の掘削の影響を最小に押さえなどから，コンパクトでスレンダーな扁平バランスドアーチ構造という形式が創出された。