Design of Takimi Footbridge locating the world heritage Shiraito Falls

Daisaku ISHIHARA
Civil Engineer
Pacific Consultants co.,ltd.
Tokyo, Japan
daisaku.ishihara@tk.pacific.co.jp

Daisaku Ishihara, born 1982, received his civil engineering master’s degree from Yokohama National University.

Fumio SEKI
Professor
Nihon University.
Tokyo, Japan
seki@civil.cst.nihon-u.ac.jp

Fumio Seki, born 1963, received his civil engineering doctor’s degree from Nihon University.

Yasushi ITOU
Project Manager
Pacific Consultants co.,ltd.
Tokyo, Japan
yasushi.itou@tk.pacific.co.jp

Yasushi Itou, born 1962, received his civil engineering degree from Nihon University.

Summary

This article reports the design of Takimi footbridge constructed near the Shiraito Falls in 2013. Shiraito falls is one of its component World heritage “Mt. Fuji: Object of Worship, Wellspring of Art.” This footbridge was required to meet the several constraints – fit to the cultural situation, fewer alternation of land and minimization of material – so that the authors approached the conceptual design and satisfy all requirements.

Keywords: PC arch bridge, conceptual design, Mt. Fuji, Shiraito falls, compact bridge.

1. Introduction

“Mt. Fuji: Object of Worship, Wellspring of Art.” was inscribed on the U.N agency’s prestigious World Heritage list in 2013. Mt. Fuji including Sengen Shrine at its foot, five major lakes, the Miho-no-Matubara pine grove and Shiraito Falls. Underground water of Mt. Fuji forms this waterfalls which is famous as a sightseeing area from long time ago in Japan.

Takimi Footbridge constructed on this site in 2013 as shown in Fig. 1. The design of this footbridge was required to meet several constraints and had to be elegant structure as a component of the World Heritage site.

Fig. 1: Takimi Footbridge and Shiraito Falls
2. Design Conditions

2.1 Site Conditions

Site conditions of this footbridge includes the following: Cultural situation, Geotechnical condition, Construction condition, and Misty condition.

2.1.1 Cultural situation

This site has a long cultural history as represented in Fig. 2 depicting the wide impressive scene of waterfalls. Minamoto no Yoritomo (1147 – 1199), the shogun of the Kamakura Shogunate of Japan, wrote a song about the beauty of Shiraito Falls. In addition, this site is famous as object of worship like Fujikou, folk religion of Mt. Fuji.

2.1.2 Geotechnical condition

The surface layer of geometry is gravel and silt and beneath the layer is Conglomerate that have over 50 N-value 1.75m under the surface. This geotechnical condition is favorable for supporting the footbridge.

2.1.3 Construction condition

There is only one narrow approaching road that is capable of carrying the construction materials. Therefore, the construction of this footbridge had to be done by small machines.

2.1.4 Misty condition

The provision for the splash of the waterfalls is one of main objects of the bridge design. Some measures to endure through the wet, humid, and misty condition for long time were required.

2.2 Design Standards

We apply two design standards, Japan’s Road Association and Fib footbridge guideline, in order to satisfy the world standard quality of bridge design.

2.2.1 Loads and frequency

In Japan’s Road Association design code, the load is specified as 3.5kN/m² only one grade [1], and the range from 1.5 Hz to 2.3 Hz frequency of the structure is permitted considering the pedestrian induced vibration [2]. However, one-sided live loads are one of special concern in footbridge design. So that we apply the Fib footbridge guideline. Fib guideline describes one-sided load must be concerned (Fig.3) [3]. Most of pedestrians on this footbridge likely to see the Shiraito falls on one-side of pavement, so we apply the asymmetric load.

2.2.2 Width of footbridge

In Japan’s Road Association footbridge design code, the width must be over 1.5m. Fib footbridge guideline specified that the width have to be over 2.5m. This footbridge is applied the Fib footbridge guideline so that the width is 2.5m.
3. Design of Takimi Bridge

In development of design concept we had to satisfy the following constraints:
- Fewer alternation of land
- Minimization of material
- Consideration for misty condition
- Colour suitable for surroundings
- Narrow approaching road

3.1 Design Concept

To achieve an optimum design taking into account the above mentioned constrains, “Compact bridge design” is adopted as design concept. This concept plays a vital role in satisfying the above constraints and also aesthetic considerations as described later.

3.2 Bridge Planning

3.2.1 Basic Structural System

Three types of structural system are studied on bridge planning (Fig. 4). Agency for cultural affairs prescribed us to compare with traditional bridge system – suspension bridge and girder bridge. Suspension bridge’s anchorage requires huge alternation of land. On the other hand, PC girder bridge’s height is 2.0m and it seems to be massive. Rahmen bridge’s volume is relatively compact and the alternation of the land is minimum in this three types of structural system, so the agency recommended this structural system.

3.2.2 Development of Structural System and Form

Raw Rahmen bridge proportion is so artificial that it doesn’t suit with the landscape of Shiraito Falls. Pi Rahmen is a first development of this structure that enables to decrease the height of girder from 1.5m to 0.9m. However, this structure’s proportion is rather suitable to the expressway than this site. Therefore, the points of diagonal members and girders are shifted to the center span and the axis of diagonal members is rounded to smooth the flow of forces. This structure is kind of Arch bridge, but also remains the character of Rahmen bridge, we calls this structural system “Balanced Flat Arch: BFA”.

In this structural system, the large amounts of horizontal forces are acted at its two points of springing. In order
to decrease these horizontal forces, diagonal back stay members are added. In addition, prestress forces are supplied to the diagonal back stay members, resulting 50% horizontal force decrease.

In general, the development of bridge form is separated from development of structural system. We design the both two elements considering the design concept at the same time.

3.3 Detail Design

3.3.1 Form of Arch Member

So as to achieve more compact bridge design, we study on the form of arch member. Fig. 6 shows the improvement that chamfering the edge of arch and the shade casting on the arch member. The amount of chamfering was determined by studying with models comparison of 500mm, 250mm, and 100mm.

3.3.2 Footbridge railings

The aluminium railings that never rust are adopted on account of misty condition. Its outer face is sharp form and inner face is flat. The shade of railings is impressive for the pedestrian (Fig. 7). And the colour of railing was determined to dark grey which fit for the environment.

3.3.3 Pavement material

The splash of Shiraito Falls make pavement wet anytime, the pavement have to be sufficient roughness not to slip. Local stone (Osawa Stone) adjusted its size for pavement is applied (Fig. 8). This pavement is also applied surround walk and we make much of sequence.

3.3.4 Measures against the misty condition

The misty condition will damage the concrete by supplying the water anytime. We consider the section of wheel guard. In addition, to reduce the effect of splash of waterfall, the outer face of wheel guard is painted with water-repellent coating (Fig. 9).
3.4 Construction

For the narrow approach road, the members are divided to the capable size that can carry from material provider. All staging method is selected as the construction method of this footbridge (Fig. 10). This construction is done in total 6 months.

![Fig. 10: Overview of Construction Situation](image)

3.5 Monitoring of Takimi Footbridge

3.5.1 Purpose of Monitoring and its Process

Vibration is special concern for footbridge and Fib guideline recommends the monitoring the vibration. In order to make sure of analysis, over 20 strain gauge is attached to the footbridge.

3.5.2 Results

The measured frequency is 7.23Hz and analysis result is 7.08Hz in Horizontal 1st mode [4] (Fig. 11). This means the accuracy of analysis and not likely to vibrate by pedestrians – as mentioned above, in Japan’s Road Association design code, 1.5 – 2.3Hz is the range of frequency easy to resonate with pedestrians.

![Fig. 11: Mode Shape of Vertical 1st](image)

<table>
<thead>
<tr>
<th>Table. 1: Frequencies of 1st mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical 1st</td>
</tr>
<tr>
<td>Horizontal 1st</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

4. Conclusions

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

- Total minimization of bridge volume including foundations
- High redundancy for vibration, flood, and earthquake
- The aesthetic of bridge attract the sight tourist and people comes to Shiraito Falls to see this footbridge.
- Consideration about aging
5. References


This article is a reprint and was originally published in the Proceeding: IABSE Conference Nara, 2015;Elegance in Structures, pp1-6(6);ISBN 978-3-85748-138-3