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Development of an openable deck timber bridge to reduce snow loading

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ABSTRACT: In winter, the Akita Prefecture, located in northeastern Japan, receives a large amount of snowfall, causing pedestrian bridges in the mountainous areas to deform and collapse owing to snow loads on the bridges.. Therefore, we developed an openable deck timber bridge that can circumvent snow loads by changing the bridge structure solely during winter. Outdoor exposure tests were conducted at two locations in the Akita Prefecture to determine actual snow accumulation on openable deck timber bridge prototypes. For comparison, part of the deck was not rotated, thus forming a closed deck. Accumulated snow on the open deck slabs did not cover the bridges but was observed to be limited to the top of the girders and rotated deck slabs at a snow depth of approximately 1 m. The estimated snow load under existing snow accumulation conditions was reduced by approximately 50% compared to the closed deck slab (not rotated). We confirmed that the developed structure reduced the snow load and found that snow melted faster on the openable deck slab than on the closed deck slab.

KEYWORDS: timber bridge, snow load, exposure test, roated deck slab, pedestrian bridge

1 – INTRODUCTION

Akita Prefecture, located in northeastern Japan, experiences heavy snowfall in winter, with snow depths exceeding 4 m in some areas. During winter, when snow depths prohibit access into mountainous areas, pedestrian bridges in such areas may be deformed or collapse owing to the accumulation of snow on the deck slabs.

As shown in Figure 1, snow accumulates on the top surface of the bridge, piling up high and expanding sideways as snowfall progresses, eventually covering the entire bridge. The depth of this accumulated snow is approximately 2 m. However, not only the snow load acting on the top of the bridge should be considered but also that acting on the overhangs.

Based on Figure 1, snow load is assumed to be acting on both the bridge surface (width: 1 m, snow depth: 2 m) and overhangs either side (width: 0.5 m, snow depth: 1 m). The average unit volume weight of the snow load is 3.5 kN/m^3 [1], indicating that a snow load of approximately 10.5 kN/m along the bridge length should be applied.

This implies that the bridges should be designed using the winter snow load rather than the spring-to-autumn human traffic load (3.5 kN/m). Thus, structural calculations must be performed using loads that are present when pedestrians are not, a factor that reduces cost performance.

Therefore, we developed an openable deck timber bridge [2] that circumvents snow loads by changing its structure during winter. This study reports the results of exposure tests conducted to evaluate the load-reduction performance of an openable deck timber bridge.

2 – OVERVIEW OF OPENABLE DECK TIMBER BRIDGE

Figure 2 shows an overview of the developed openable deck timber bridge. The bridge can be used as a normal girder bridge from spring to autumn. In winter, when snow accumulates and no pedestrians are present, the deck slabs rotate 90° to prevent snow from accumulating on the deck.

Figure 3 shows a detailed view of the openable deck timber bridge. The bridge is a girder bridge consisting of two main girders (glued laminated timber) topped with structural plywood rotating decks (hereinafter referred to as “openable deck”). The girders are made of Japanese

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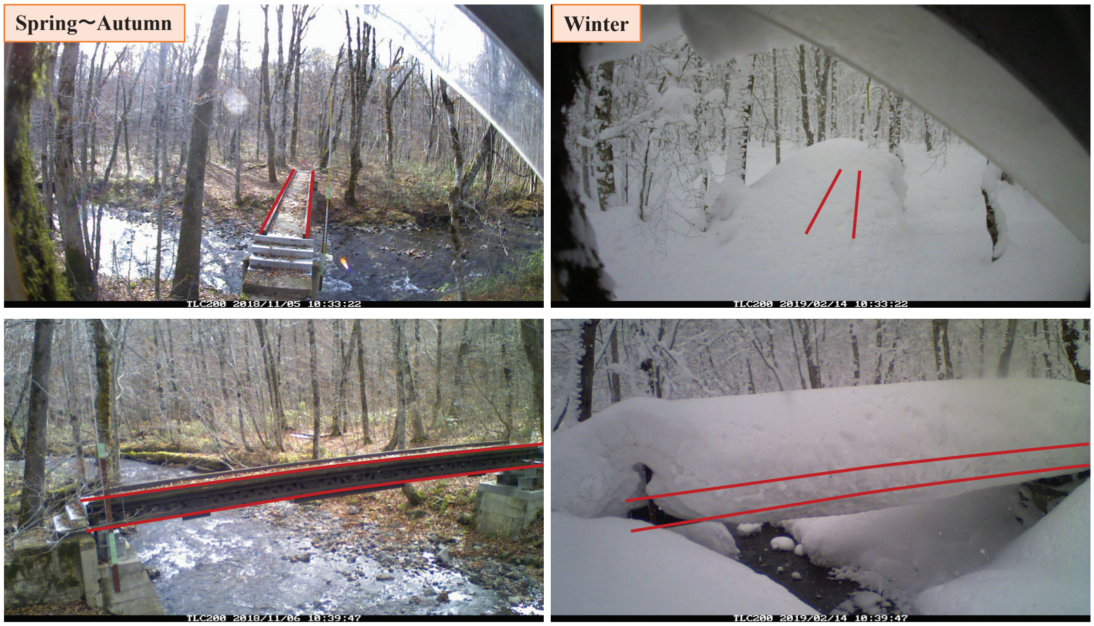

Figure 1. Snow accumulation on a pedestrian bridge

cedar laminated timber (E75-F240), with cross-sectional dimensions of 180 mm (width) by 300 mm (height), and 10 layers of 30-mm-thick laminate. The girders are connected by sway braces (SS400, PL6 × 250 × 650 mm) placed at the ends and centre of each girder. The openable deck is then installed on top of the girder and divided into 1000-mm-long sections in the bridge length direction.

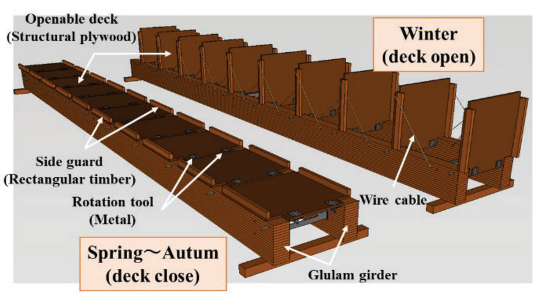

Figure 2. Overview of the openable deck timber bridge

Figure 4 shows a detailed view of the openable deck. The openable deck is made of structural plywood (t28 × 1000 × 1000 mm) and can be rotated using a rotation tool and steel rod. The openable deck can be easily rotated by hand. The rotated openable deck is secured to the eyebolts attached to the main girder using wire cables to prevent toppling as a result of wind and snow. Therefore, snow accumulates only on the girders and tops of the rotated deck slabs.

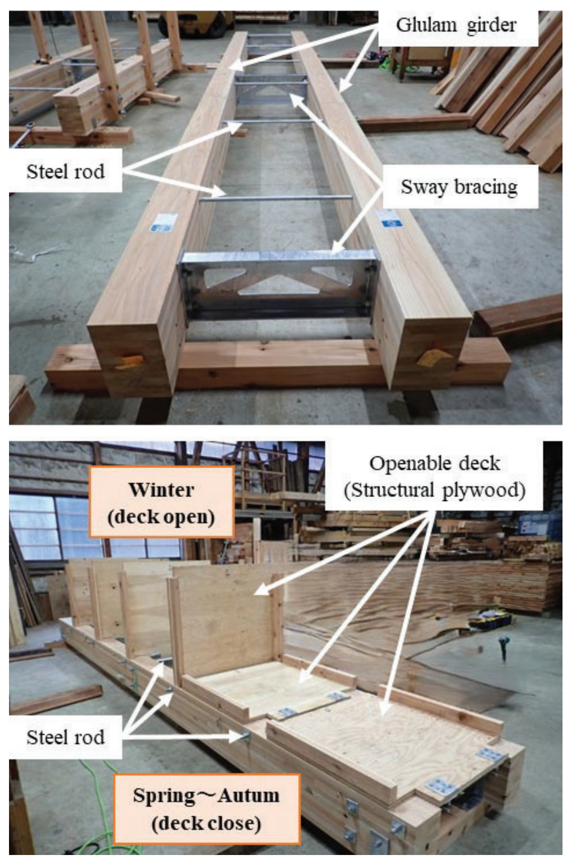

Figure 3. Detailed view of the openable deck timber bridge

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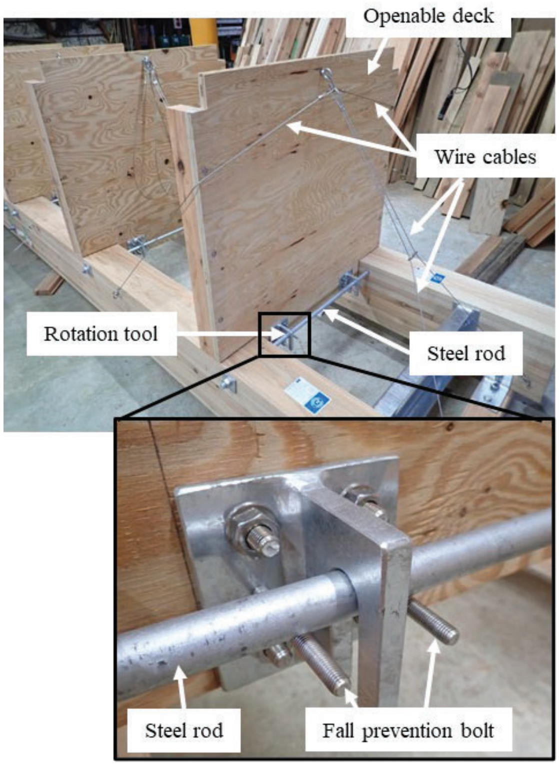

Figure 4. Detailed view of the openable deck

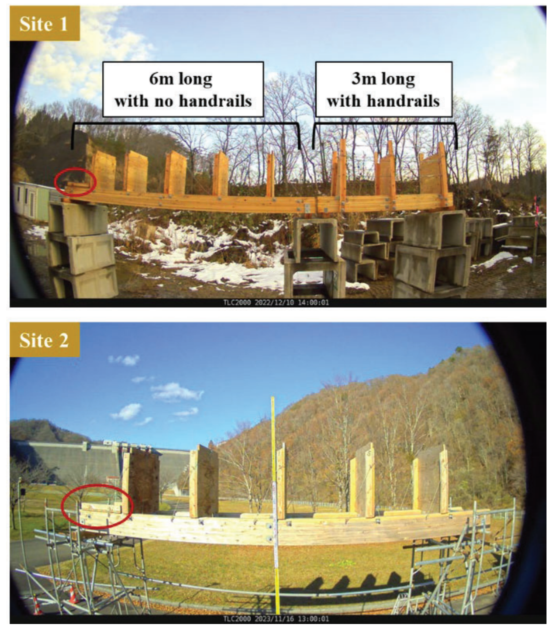

Figure 5. Exposure test conditions

3 – OUTDOOR EXPOSURE TEST

To evaluate the effectiveness of the openable deck timber bridge in reducing snow accumulation, we conducted exposure tests at two locations in the Akita Prefecture, where the snow depth is typically greater than 2 m. The exposure test period for site 1 was from December 2022 to March 2023, and that for site 2 was from December 2023 to March 2024.

Figure 5 shows the exposure test conditions. Two types of bridge prototype were prepared at site 1. One was 6 m long with no handrails, and the other was 3 m long with handrails. At site 2, exposure tests were conducted on the 6-m-long bridge prototype used at site 1.

To determine snow accumulation on the deck slab when closed, one span at the left end of the deck slab of the prototype was left closed (marked with a circle in the figure) at both sites. The prototypes were placed at least 2.5 m above the ground to prevent snow accumulation from the ground from affecting the prototypes.

Three cameras were installed around each prototype to monitor snow accumulation. Images were captured hourly from 7:00 am to 6:00 pm every day. In addition, a field survey was conducted on days with heavy snowfall to confirm the details of the prototype.

4 – RESULTS

Figure 6 shows the daily snowfall and snow depth during the exposure period recorded at the nearest AMeDAS station (Yuzawa) [3] to site 1. Each day represents a 24 h period from 1:00 am to 1:00 am. The maximum daily snowfall during this period was 52 cm/day (December 17th), and the maximum snow depth was 96 cm (December 20th). Snowfall became less frequent in March, with the snow depth reaching 0 cm by mid-March.

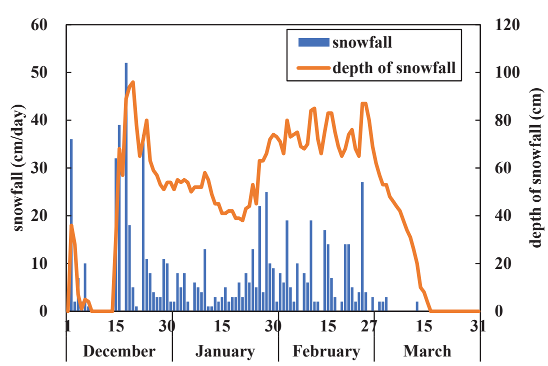

Figure 6. Daily snowfall and snow depth during the exposure period at site 1

Figure 7 shows a series of recorded maximum snowfall and snow depths. Snow began falling late night on December 15th and continued to fall intermittently at a rate of 1–5 cm/h, reaching a depth of 68 cm at 1:00 pm on December 16th. Thereafter, no snow fell on the 17th, but snow began falling again at 7:00 am on the 18th, with a maximum hourly snowfall of 6 cm and maximum snow depth of 89 cm at midnight on the 16th. Snow continued to fall intermittently on the 19th, with a maximum snow depth of 96 cm recorded at 2:00 am on the 20th.

Figure 8 shows the observed conditions during a field survey conducted on the morning of the 20th, when the maximum snow depth was recorded.

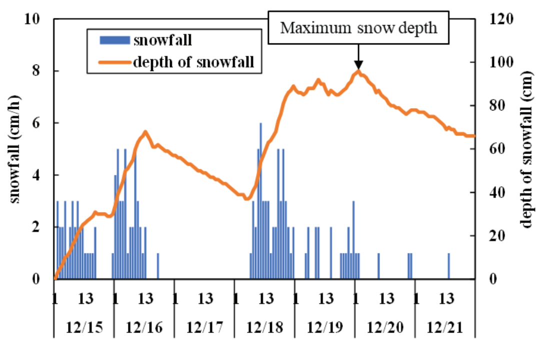

Figure 7. Snowfall and snow depth (December 15th to December 19th)

The snow cover on the girders was 60–80 cm and that on the top of the openable deck was approximately 20 cm, compared to a snow depth of 96 cm in the surrounding area. The maximum snow overhang on the girders was approximately 20 cm (Figure 9). In contrast, on the left end of the slab where the openable deck was not rotated, the snow accumulation was approximately 100 cm, suggesting that the snow accumulation on the girder, which had a small flat area, was not as large as that on the deck slab. No snow accumulation was found at the locations where the openable deck was rotated, indicating that snow accumulation on the deck slab could be reduced by the openable deck. These trends were similar at site 2. A difference in snow accumulation owing to the presence or absence of handrails could not be confirmed.

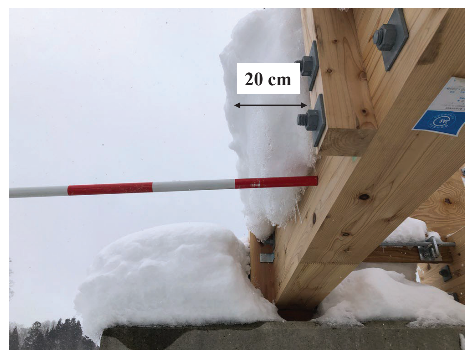

Figure 9. Snow overhang on girder sides

** The dimensions provided refer to the snow accumulation at each position.*

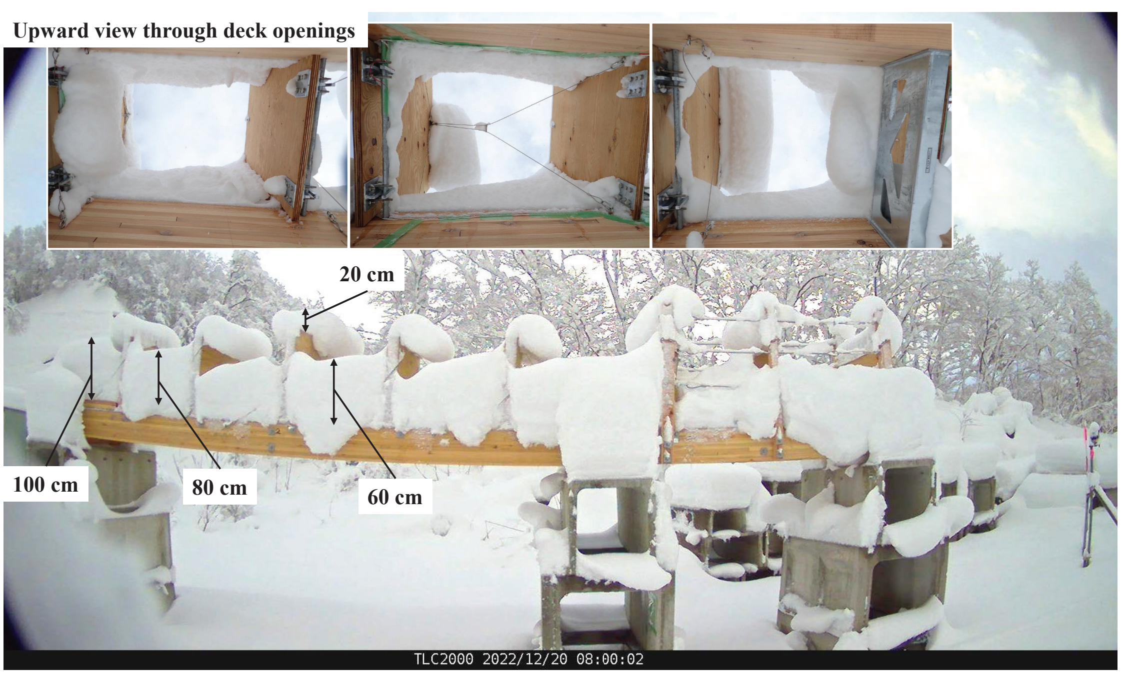

Figure 8. Snow accumulation on the bridge at site 1 (December 20th)
**The dimensions provided refer to the snow accumulation at each position.*

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Figure 10 shows the snow accumulation 4 days later (December 24). The snow on top of the openable deck had disappeared, and approximately 20 cm of snow remained on the girders. However, approximately 70 cm of snow remained on the openable deck that was not rotated. The results suggest that the openable deck not only reduced the amount of snow that accumulated on the entire bridge but also reduced the amount of snow that accumulated earlier. This also reduced the duration over which the snow load was borne by the bridge.

Figure 11 shows a model diagram of snow loads acting on an openable deck timber bridge based on the exposure test results. The model was based on the period of maximum snow depth during the exposure period. The snow on the top surface of the main girder was set to the girder width (0.18 m) and snow depth (0.80 m). The snow overhang on the outside of the girder was set to the overhang width (0.1 m) and snow depth (1.0 m) to account for snow protruding outside the girder. The snow on the openable deck was set to the deck slab width (1.00 m), snow depth (0.2 m), and length (0.10 m) to account for the snow overhang on the top surface.

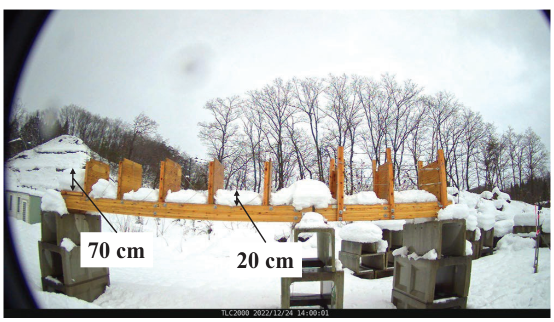

Figure 10. Snow on the bridge after 4 days (December 24th)

** The dimensions provided refer to the snow accumulation at each position.*

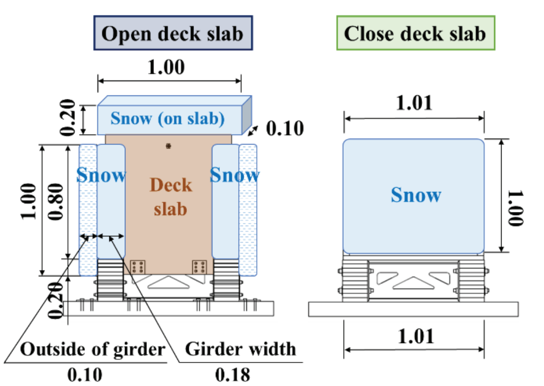

Figure 11. Model diagram of snow loads acting on openable deck timber bridge (dimensions: m)

The average unit volume weight of the snow load was assumed to be 3.5 kN/m^3 [1]. The estimation results are presented in Table 1. The snow load acting on the openable deck timber bridge was 1.778 kN/m along the bridge length. The snow load on the unrotated deck was 3.535 kN/m, indicating that the snow load could be almost halved by the openable deck.

The snow load acting on the openable deck timber bridge is smaller than the pedestrian crowd load (3.5 kN/m^2) used in the design, indicating that the determinant of the girder cross section is the pedestrian crowd load. Therefore, we inferred that there is no need to increase the bridge strength by increasing the cross-section of the member to accommodate the snow loads acting in winter when there are no pedestrians, as is the case with conventional bridge types.

Table 1. Estimated snow loads acting on the bridge

	Width (m)	Height (m)	Depth (m)	number	Snow load (kN)
Girder top	0.18	0.80	1.00	2	1.008
Overhanging girder	0.10	1.00	1.00	2	0.700
openable-deck top	1.00	0.20	0.10	1	0.070
Total					1.778
openable-deck was not rotated (conventional type)	1.00	1.01	1.00	1	3.535

6 – CONCLUSION

We developed an openable deck timber bridge that can avoid snow loads by converting its structure only during winter as an alternative to conventional structures that are designed to withstand snow loads. Using exposure tests, we verified the extent to which the bridge could circumvent snow loads. The results showed that the load could be reduced by approximately 50% compared to an unrotated openable deck.

However, the results were obtained at a snow depth of approximately 1 m; thus, clarity is required as to whether the same level of snow load reduction is possible at greater snow depths. Therefore, continued exposure tests are necessary to determine the conditions at greater snow depths. In addition, the bridge length was assumed to be a maximum of 6 m. For application in longer spans, the structural connection between girders must be further studied.

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