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CONSTRUCTION TESTS OF A FOLDING TIMBER BRIDGE

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ABSTRACT: Serious disasters from earthquakes, typhoons, pouring rain, debris flow and so on often occur in Japan. Such disasters almost always cause roads and bridges to break. If the traffic and lifelines are shut off, citizens are isolated from the other areas and their daily life is damaged. It may be necessary to rescue injured persons rapidly. For the quick recovery from natural disasters, emergency bridges are sometimes constructed. In this case, the construction time should be as short as possible. This study presents a new emergency bridge with short construction time, which is a folding bridge. The bridge type is Howe truss, and the span length is 9.9m. The hinges which can make the bridge to fold are attached between truss panels. Outdoor tests of this bridge construction were executed on the ground in the Hakodate National College of Technology. In the tests, the bridge was assembled by modifying from folded condition to unfolded condition. A pseudo river and a construction site were settled in the ground and the unfolded bridge was erected by using 13tf rough terrain crane. It took only 2 hour and 30 minutes to complete this timber bridge.

KEYWORDS: timber truss bridge, emergency bridge, folding bridge, erection test

1 – INTRODUCTION

In Japan, natural disaster such as earthquakes, tsunamis, typhoons and so on occur in every year[1]. Noto Peninsula, in Hokuriku region in Japan, was damaged by a big earthquake on 1. 1. 2024, and a large number of people needed emergency reliefs. Since the transportation routes were blocked, some small villages were isolated from the other villages or cities.

It is important that the victims of the disaster are rescued within 72 hours because the survival rate decreases rapidly after the time. During from the occurrence of disaster to the rescue, it takes time to collect information, to move to the disaster site and to construct a bridge. To rescue the victims rapidly, an emergency bridge should be constructed as soon as possible [2].

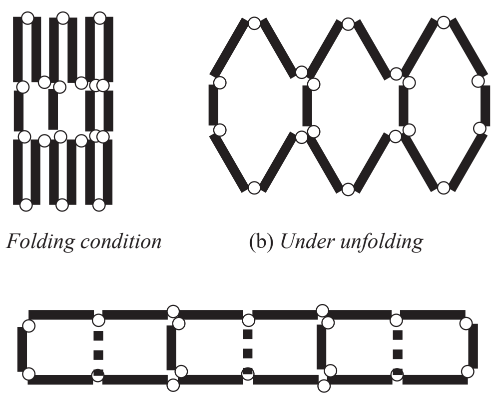
To construct a bridge quickly, the folding bridges are developed by the authors. Using an one-fifth scale model, the mechanical system was developed and discussed [3]. Using a half scale model, assembling the truss structure was confirmed and the strength of the model was checked by loading tests [4, 5].

The emergency bridge presented here is a full scale model bridge which can be easily transported in folded condition by a truck and can be easily assembled in the disaster site. In this paper, the outline of the presented bridge made of timber and the results of the construction test are shown.

2 – TEST SPECIMEN

2.1 FOLDING SYSTEM

Folding and unfolding are executed by rotating motion around the hinge plates attached to truss members. Figure 1 shows the mechanism of folding and unfolding of the bridge. These are the plane views of the bridge and the white circles are the hinges. Unfolded condition as shown in Figure 1 (c) is the same as Figure 2 which has 9.9m span, 1.402m width. In the folded condition as shown in Figure 1 (a), this structure can be put on the truck.



(a) *Folding condition* (b) *Under unfolding*

(c) *After unfolding*

Figure 1. Conditions of the folding bridge

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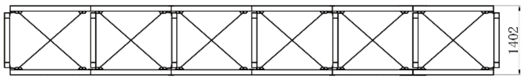
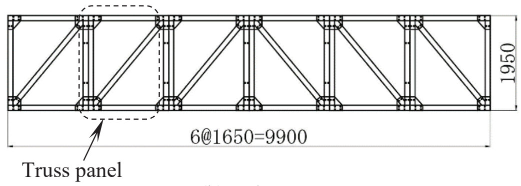


(a) *Plane view*



(b) *Side view*

Figure 2. Timber truss bridge

A truss panel as shown in Figure 2 (b) is composed of upper and lower chord members, vertical members and a diagonal member. Each member is connected by steel panel plates. Each truss panel is connected by hinge plates.

2.2 TRUSS PANEL AND TRANSVERSE PANEL

The timber material used in this bridge is Japanese cedar and the cross sectional size is 105mm × 105mm. Pick up the truss panel from Figure 2 (b), it is shown as Figure 3 largely. The end of each member is connected by Panel plate 1 or Panel plate 2, which are 3.2mm thick steel plates with bolt wholes.

The panel plate 1 connects the vertical member and the upper or lower chord member with 6 screws as shown in Figure 4 (a). The panel plate 2 connects three members, vertical member, diagonal member, upper or lower chord member, with 9 screws as shown in Figure 4 (b). In each connection point, two panel plates are used on both side of the timber truss members.

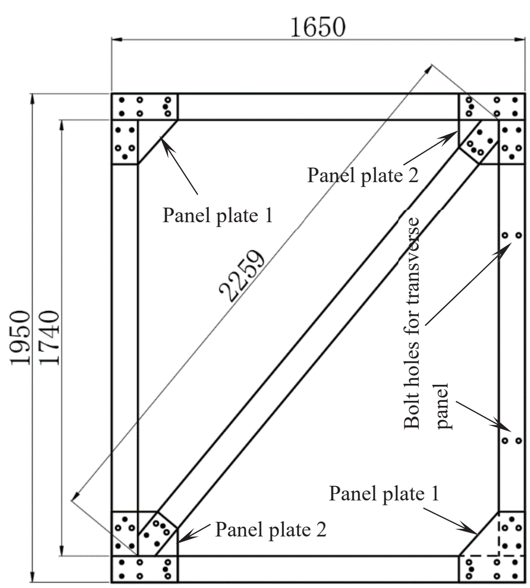
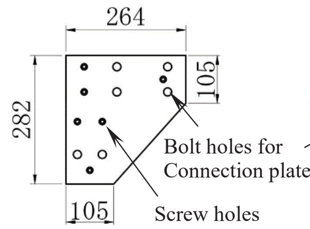
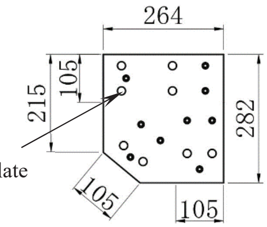


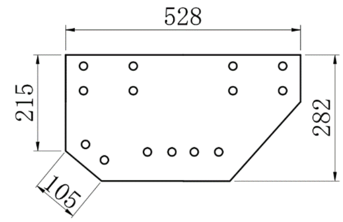
Figure 3. Trass panel



(a) *Panel plate 1*



(b) *Panel plate 2*



(c) *Connection plate*

Figure 4. Metal materials for connection

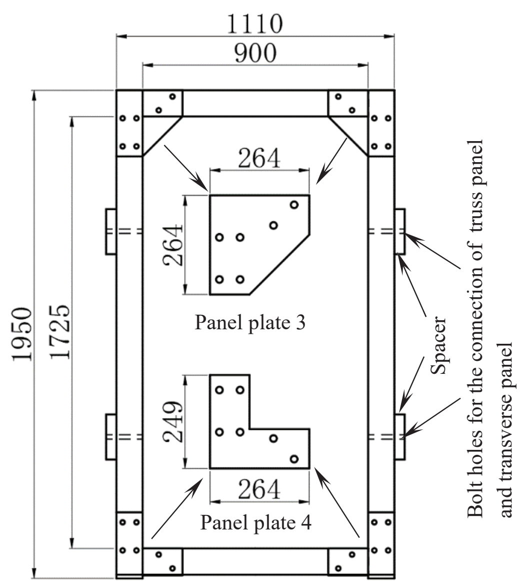


Figure 5. Transverse panel

The Connection plate as shown in Figure 4 (c) is used for connecting one truss panel and the next to truss panel. Although all truss panels are connected each other by hinge plates, the Connection plates are also used to strengthen the connection of the truss panel. The Connection plates are bolted together to the panel plate after unfolding work.

Figure 5 shows the transverse panel in the direction perpendicular to the bridge axis. The material of this frame is the same as the truss panel. The space among the horizontal and vertical members is walking space of pedestrians. The transvers panel is formed by Panel plate 3 and Panel plate 4.

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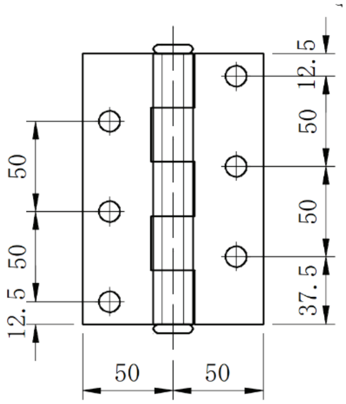

Figure 6. Hinge plate

Photo 1. Folded condition

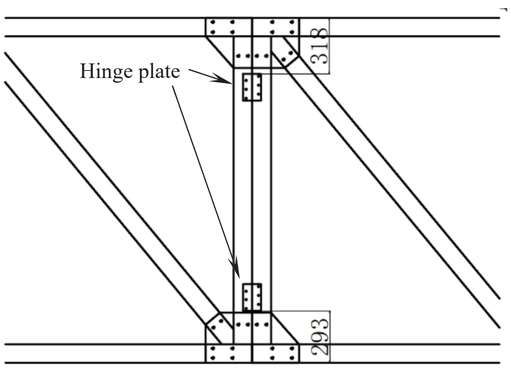

Figure 7. Hinge plates on vertical members

Photo 2. Loading the bridge on the truck

Figure 6 shows the hinge plate adopted in this study, which is a ready-made product composed of steel plates and a steel shaft. Six bolt holes are in the plate, and the bolts with 10mm diameter are used to fix to vertical members in the truss panels. Two points on the vertical member of truss panel are connected by these hinge panels as shown in Figure 7. These connected points are the location without panel plates.

3 – FIELD CONSTRUCTION TESTS

Field construction tests of the folding bridge developed in this study were executed in the ground of Hakodate national college of technology on October 2021. The bridge was folded before the test as shown in Photo 1. The width of this folded bridge is 4410mm, the length in the direction of bridge axis is 920mm and the height is 1950mm. The weight of this bridge in this folded condition is 822kgf (= 8.06kN) without the weight of slab.

In the construction tests, the number of worker was 7 students, 2 technical staffs and one supervisor. In addition, one truck driver and one crane operator participated in the test, but they did not do the assembling work.

Photo 2 shows the situation just after loading the bridge on the truck. This truck is 4 ton middle size one, and is good to carry the folded bridge with regard to the size of the cargo bed of the truck. To load the folded bridge on the truck, a rough terrain crane with 13 ton capacity was used. This crane can go through narrow road to the disaster site because it is four-wheel steering car. The materials in addition to the bridge, slab, wire ropes, steel Connection plates, bolts and so on were loaded on the truck.

An erection place, a position of the truck and crane, an erection yard were decided in the ground before the test. Figure 8 shows these places. Pseudo river in blue colored area was considered in the ground as the bridge to be placed. An erection yard was placed on the load along the river. The truck stopped along the erection yard. The erection support which is a timber structure to unfold the bridge was put on the the erection yard as shown in Photo 3. Next, the crane, at the point A shown in Figure 8, lifted up the folded bridge from the truck and lifted down to the erection support.

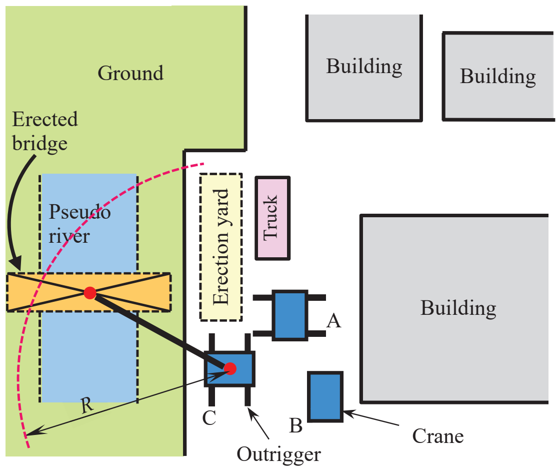

Figure 8. Location of the bridge erection

Photo 3. Erection support on the ground

In the erection support, there are two straight timber members as rails on which the bridge is unfolded. This erection support has 11.0m length and 0.9m width. The upper surface of the straight timber is smooth since the bridge moves easily at the unfolding.

Photo 4 shows that the crane lifted down the folded bridge on the erection support. After this crane work, the crane moved from point A to point B. On the erection support, the lower beam of the transverse panels touch with the surface of the rail. In this condition, truss panels overhanging right and left direction do not touch the rail.

After lifting down the folded bridge by the crane, the work of unfolding it started. Photo 5 shows this work which is made by human power, not any machines. Two workers pull one end of the bridge, the other two workers pull the other end. Another worker keeps the balance of the moving bridge beside of the bridge. The bridge is unfolded smoothly slipping on the erection support. When the workers pull the bridge, there is a friction force on the erection support, however, the force is not too strong to move the bridge. The time to unfold the bridge from the folded condition to the extended condition was only 4 minutes and 21 seconds.

If the bridge slips and gets out in transverse direction of the bridge axis, it will fall down from the erection support and it may not be unfolded. To avoid this accident, the protuberances are provided at the lower ends of the transverse panel as shown in Figure 5. The protuberances are very small, only 1.0cm, however, they play a role of stopper and stop the bridge moving outside of the erection support.

After the unfolding work, four corners of the truss panel were connected to the corners of the next truss panel by the Connection plates shown in Figure 4 (c). Two Connection plates and 14-16 bolts are used at one corner. Panel plate 1 and 2 are already put at the corner as shown in Figure 3, then the Connection plate is placed on the panel plate. The work to bolt the Connection plate was difficult because penetrating bolts to bolt holes was very hard. Therefore, it took one hour and 21 minutes to finish bolting the Connection plates.

After that, the lateral bracings in the top and the bottom of the bridge were fixed using wire ropes and turnbuckles in X-shape as shown in Figure 2 (a). Finally, 2-by-8 timber plates as the slab were arranged on the lower beams of the

Photo 4. Folded bridge on the erection support

Photo 5. Unfolding work

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Photo 6. Completion of unfolding work on the erection support

transverse panels. These works mentioned above were executed on the erection support. Photo 6 shows the completed state of the bridge on the erection support.

The completed bridge on the erection support was placed on the pseudo river in the ground. This was one-operation erection using crane. The crane moved from the point B to the point C and lifted up the bridge. The dead load of the bridge was 1271kgf (= 12.5kN) including slab, Connection plates, lateral bracings and so on. The lifting capacity of this crane is 13tf which is in the case of minimum radius of lifting work. Since the weight of this bridge is 12.5kN, the radius of lifting work R is restricted to 12m in using outrigger[6]. The dotted curve line in Figure 8 is the line of radius R = 12m. Since the middle point of pseudo river is inside of the dotted line, it is possible to do lifting work by this crane.

Photo 7 shows the situation of the bridge lifted up by the crane moving from the yard to the erection point on the pseudo river. Timber abutments were already put at both riverside. The abutment was simple and small size of 210mm height made from square timber. The situation of

Photo 7. Crane erection

Photo 8. Completion of the bridge erection

the bridge touched down on the abutment is shown in Photo 8. Crane working was for only 5 minutes 41 seconds.

Table 1 is the summary of working time of constructing this folding bridge. The elapsed time at the left side is the time from the arrival of truck at the erection site. It does not include the time of loading the material on the truck and running time, namely. Ten workers engaged in the same work in each work content basically except for the connecting work of Connection plates. In the latter half of the Connection plates work, the fixing work of lateral bracings was executed simultaneously.

Crane works were twice in this construction. One was the work of lifting the bridge from the truck, and the other was the work of lifting it to the pseudo river. It took only a few minutes in both crane works. The work of unfolding the bridge by human powers, which is a characteristic feature of this erection, also finished in a few minutes. It was the

Table 1. Working time (h:m:s)

Elapsed time	Work content
0:00:00	Arrival of truck. Start of the work.
0:15:00	Erection support settled
0:30:00	Erection support finished (0:18:32). Lift down the bridge on the erection support (0:03:35). Unfolding work (0:04:21).
0:45:00	Fix the transverse panels.
1:00:00	Finish fixing the transverse panels (0:23:24).
1:15:00	
1:30:00	Bolted connection of the Connection plates
1:45:00	Fix the lateral bracings
2:00:00	
2:15:00	Finish bolting the Connection plates (1:21: 16). Finish fixing the lateral bracings (0:19: 50).
2:29:37	Load slab (0:09:38). Crane erection (0:05:41).

work of Connection plates that takes the longest time. The total time from start to finish of this erection was 2 hours 29 minutes 37 seconds. This short time of the bridge construction will contribute to early recovery in the disaster area.

4 – CONCLUSION

Field construction tests using full scale timber emergency bridge were executed. The bridge with a folding structure system was developed to erect quickly. It is carried by a middles size truck under folded condition and is unfolded by human powers in the disaster site. In the tests, the disaster site was a school ground and pseudo river. Although the erection yard was arranged beside ground, the road near the river will be adequate as the erection yard.

Folding system of the bridge is made by using hinge plates between the truss panels. It is impossible to carry and unfold the bridge by human power because its weight is 822kgf. The unfold work can be done, however, by human power by pulling the bridge on the erection support of which the top surface is smooth.

In the test, the construction time from unfolding the bridge to crane erection was about 2 hours 30 minutes under works by 10 workers. It is very fast as a bridge construction. It is not necessary to prepare some temporary construction materials as staging because a crane is used to erect. Therefore, the bridge developed in this study is good to be used as emergency bridge.

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