STUDIES ON NEW FORMS OF PORTABLE BRIDGES FOR DISASTER RELIEF

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ABSTRACT

The study was to develop a novel design of portable bridges for disaster relief such that they can span a river rapidly without piers. We reviewed the design concepts of past movable bridges and select suitable mechanisms such as a simple assembly of linkages which are exploited as parts of bridge of new form to quickly deploy bridge bodies. According to the need for disaster relief in rural areas in Taiwan, the bridge was designed based on the proposed new form of bridges. The research results may provide domestic engineering consultants with innovative design concept and methodology of portable bridges for disaster relief.

Keywords: Disaster relief, portable bridges.

1. INTRODUCTION

Bridge systems often fail in natural disaster events such as earthquake, typhoon and tsunami. Enhancing bridge resilience to disasters becomes critical for quickly providing transportation for displaced people and delivery of food and medical supplies. For developing lightweight, short-span and portable bridges, advanced composite materials such as fiber-reinforced-polymer have been applied to reduce the weight of bridges and to increase load-carrying capacity in some studies (Robinson and Kosmatka 2008; Sedlacek et al. 2004; Wight et al. 2006). In addition, how to design bridges that can be expanded to span a river rapidly without piers and stored in minimum space until reused is very challenging for bridge engineers. Some design concepts of past movable bridges and mechanism of deployable structures in engineering may inspire us to create new forms of bridges for disaster relief. Some researchers have presented the kinematic principles of movable bridges and improved the sustainability of movable bridges by finding their new forms that integrate structural and mechanical systems (Gantes 2001; Thrall et al. 2012; Wallner and Pircher 2007). In this study, a portable pedestrian bridge for disaster relief was designed. There are two main ideas in this bridge design. One is that pantograph mechanism is exploited to quickly expand and form bridge pylon and deck. The other is that the erection of the bridge pylon and deck and the rigid body rotation of the bridge deck through a cable and pulley system are utilized to span a river

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rapidly without piers. A prototype bridge was made of hollow steel sections. The static and dynamic behaviors of the bridge were investigated numerically.

2. CONCEPTUAL DESIGN

In order to reduce the time needed to assemble a bridge and the space required to package one, pantograph mechanism known as scissor mechanism was applied in the design of the proposed rescue bridge. The mechanism commonly used in lift machines and roof structures consists of three noded bars which are connected at two nodes at their ends and at the hinge at the intermediate node (Gantes 2001). Figure 1 shows how a deployable structure transforms from a small packaged state to a final form by applying pantograph mechanism. Firstly, the plane unit is composed of a series of scissor-like elements. Secondly, the assembly of the two plane units forms a three-dimensional space structure which can be expanded rapidly to the designed length. Thirdly, in order to stabilize the structure in its final state, horizontal bars are connected to the ends of crossing patterns by pins. Finally, the deployed and stable structure can be employed as bridge pylon and deck.

In addition, how to construct a bridge that can span a river rapidly without piers only by manpower is very challenging. To achieve the goal, the idea of bascule bridges which pivot vertically about a horizontal axis was mimicked. The construction process is introduced as follows and shown in Figure 2. Firstly, the horizontally deployed bridge pylon and deck are erected. Secondly, pulleys are placed at the top of the pylon, and cables go through the pulleys to connect to the deck. Thirdly, the bottom ends of the pylon are fixed to the ground, and one of the bottom ends of the deck acts as a pivot such that the deck can rotate vertically. Finally, the opening or closing of the deck is controlled by hand-power through the cables, and the deck spans over a river when closed.

3. FOOTBRIDGE DESIGN AND ANALYSIS

To demonstrate the practical possibility of the proposed design concepts, a short-span footbridge for disaster relief was designed. Because the footbridge is used for temporarily transporting displaced people and delivering necessary supplies, a live load of 100 *kg* including human and backpack weight over the bridge was considered in the design stage. Also, the deflection of the bridge due to the pedestrian live loading should not exceed 1 / 360 of the span length. To prevent from unacceptable performance due to vibration caused by people walking or running, the fundamental frequencies of the bridge in vertical and lateral directions should be greater than 5 Hz and 3Hz respectively, which are referred to the standard in US (AASHTO 2008).

The crossing members forming the plane unit were built up from hollow square tubes with three holes, and hollow round tubes passed through these holes to connect the two plane units by pins to assemble the space structure as shown in Figure 1. The specifications of the hollow square and round tubes are summarized in Table 1. All of them were made of stainless steel. For fabrication convenience, the horizontal members used to stabilize the structure were identical to the crossing members. Thus, the triangle relation between the horizontal and crossing members and the number of crossing patterns determined the final length of the deployed pylon and deck. For the design of the bridge with rotation of one segment, the pylon and deck were composed of 8 and 12 crossing patterns respectively. When the pylon and deck were packaged, the lengths of the pylon and deck were 0.34 *m* and 0.51 *m* respectively. When they are deployed, their lengths were 2.16 *m* and 3.24 *m* respectively. The layout of the deployed bridge is shown in Figure 3.

The structural analysis has been conducted by use of finite element analysis program (Marc 2007). The deployed deck was assumed to be simply supported. For static analysis, the self-weight of the deck was distributed to joints on the top chords and the concentrated live load of 100 *kg* was applied at the middle point of span. The maximum deflections of the proposed bridge due to the dead load and the live load were computed and summarized in Table 2. In addition, by modal analysis, the results of natural frequencies of the bridge were listed in Table 3. One may find that the maximum deflection of the bridge do not exceed 1 / 360 of its span length, and the fundamental frequencies of the bridge in vertical and lateral directions are greater than 5 Hz and 3Hz respectively. All specified design criteria are satisfied for the proposed bridge. Regarding portability, the weight and length of the largest deployable structure used as the deck consisting of 12 crossing patterns are 25.6 *kg* and 0.51 *m* at a packaged state. Therefore, it is convenient to carry by a rescue team. When the structure is deployed, due to added horizontal members, its weight becomes 39.15 *kg*, and its length increases to 3.24 *m*. It is still easy to erect and rotate by few people for installation.

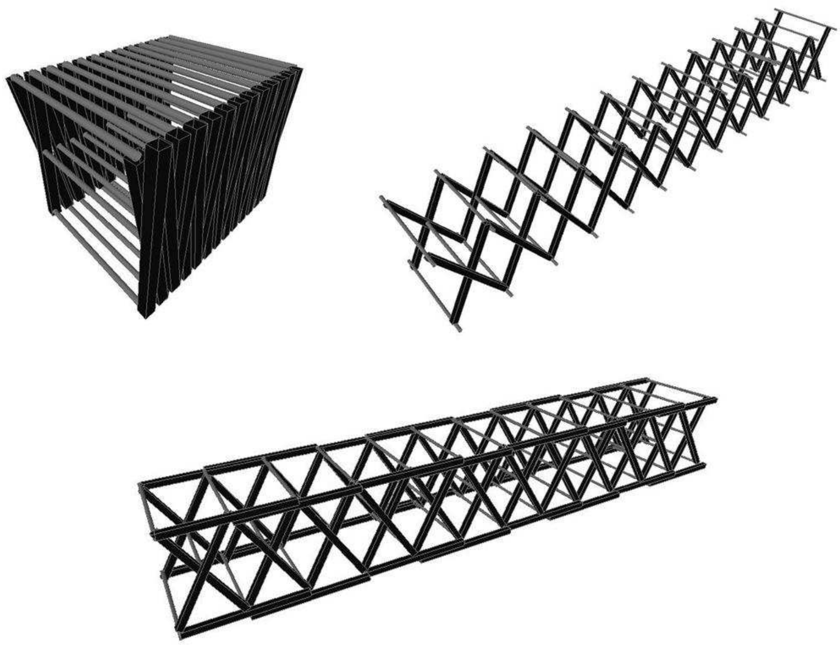


Figure 1: A deployable structure transforms from a small packaged state to a final form by applying pantograph mechanism.

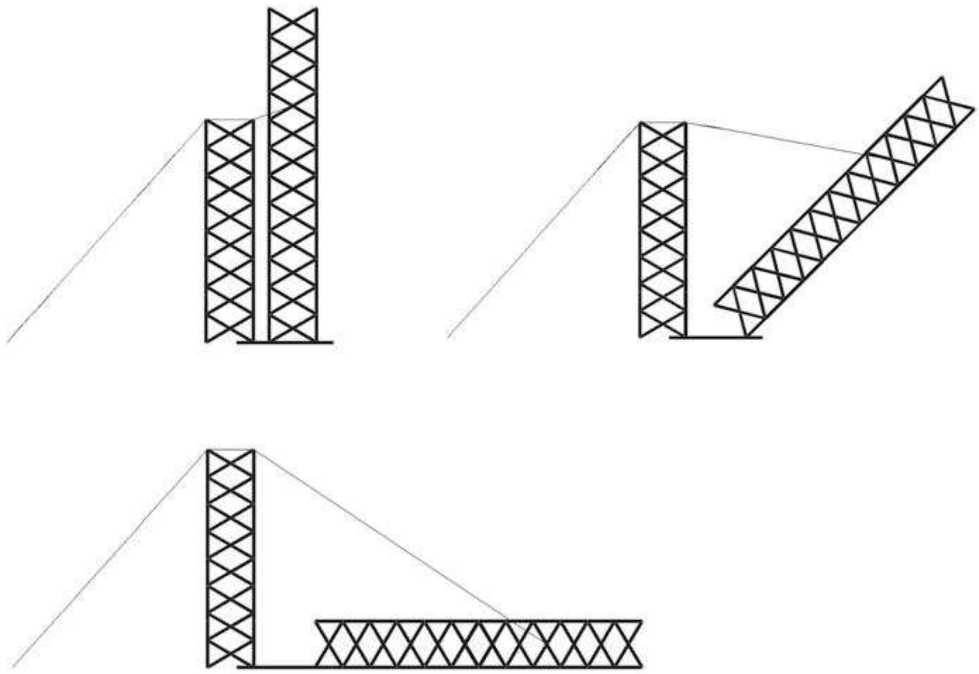
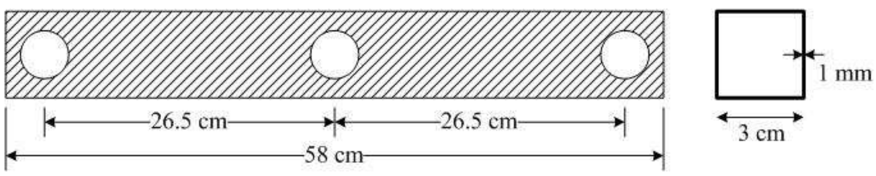
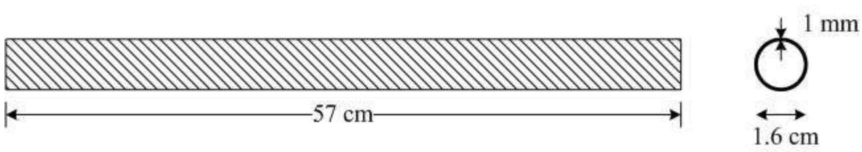


Figure 2: Sketch of deployment of a bridge with one deck.

Table 1: Design specifications of hollow square and round tubes

Items	Geometry dimension
Square tube	
Round tube	

4. CONCLUSIONS

In this study, the design and analysis of portable pedestrian bridges for disaster relief were described. In addition, two main ideas in the design of the bridge were presented, which include pantograph mechanism exploited to expand bridge structures and rigid body rotation of the bridge deck utilized to span a river without piers. Numerical simulation showed that the designed bridge meets the specified design requirements including the limitations of deflection and frequencies of bridges. This study may provide domestic engineering consultants with innovative design concepts of rescue bridges that are convenient to carry, assemble, and install.

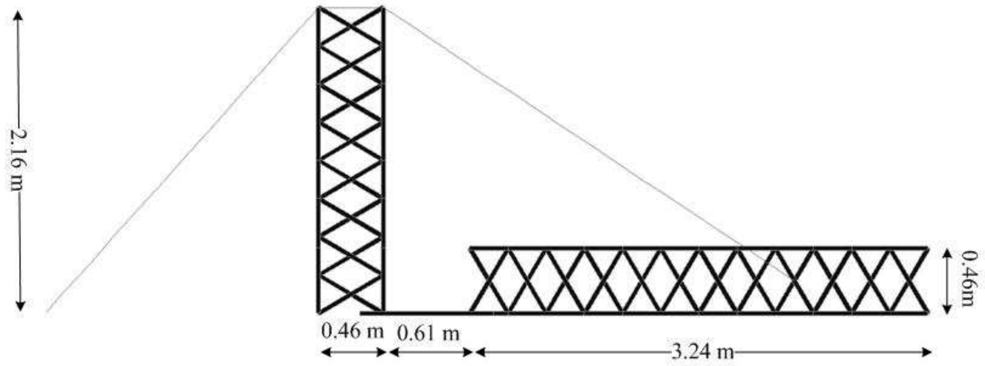


Figure 3: Layout of the deployed bridge with one deck.

Table 2: Maximum deflections of the proposed bridge due to the dead and live loads

Maximum deflection	Due to dead load	Due to live load
The bridge with one deck	1.5 mm	4.1 mm

Table 3: Natural frequencies of the proposed bridge by modal analysis

Natural frequencies	First mode (Lateral mode)	Second mode (Vertical mode)	Third mode (Torsional mode)
The bridge with one deck	9.4 Hz	16.5 Hz	18.2 Hz

5. ACKNOWLEDGMENTS

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