A Study on Optimal Reinforcement of Scissor Type of Bridge with Additional Strut Members

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Introduction

In recent years, the world has seen many kinds of natural disasters, which caused many critical situations for resident's life by damage of an infrastructure. The rescue time is very important in emergency situations, therefore we have to consider new types of rescue systems and methods for rapid rebuilding of a damaged infrastructure. In order to solve this problem, we proposed a deployable emergency bridge (Ario 2006, Ario et. al. 2013), Mobile Bridge^{TM} (Herein called MB), based on the concept of the Multi-Folding Micro-structures (MFM) theory (Pawlowski et. al. 2013). The structural form of the MB is similar to a scissor system for its structural form. The design of the MB enables to reduce the construction time on site by deploying the structural frame directly over a damaged bridge or road.

In the previous projects (Chikahiro et. al. 2016), we succeeded to develop a real scale MB (Herein called MB1.0) for vehicles. The expansion of the scissor modules with deck boards from the folded state to the final position is shown in Fig. 1. The basic scissor module consists of a couple of members joined at a pivot providing a hinge-connection at their centers. In the fully deployed state the two members are in the shape of the character `X' creating a single scissor unit. This basic scissor unit is connected to a next unit by hinges.

In general, the scissor mechanisms are mostly applied in architectural field of temporary domes. Their strength and stability are improved arranging the scissor units as geodesic grid, or optimizing sectional area of the scissor components. In the case of emergency bridge, its design must assure construction speed and structural strength in order to provide safe passage for people and vehicles. In this paper, we propose a method of reinforcement of the MB based on additional strut members and prestressing forces, which minimizes stresses or displacements in the deployed state. The sectional area of strut members and prestressing forces can also be optimized for improving the limit load capacity of the bridge.

Fig. 1. The full-scaled experimental MB1.0 made by the MB's project of collaborate companies.

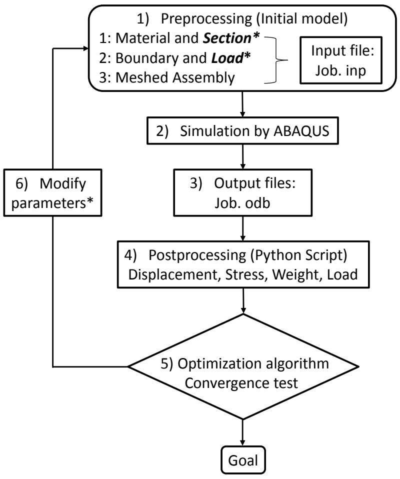

Fig. 2. Flowchart of optimization procedure.

Optimization methodology

One of optimization tasks considered in this paper is a limit load capacity problem, which is defined with constraints imposed on weight, stress and displacement in Eq. (1).

$$Maximize\ \ P_y,\quad s.t.\ \ W < W_i,\ \ \sigma < \sigma_y,\ \delta < \delta_y \qquad (1)$$

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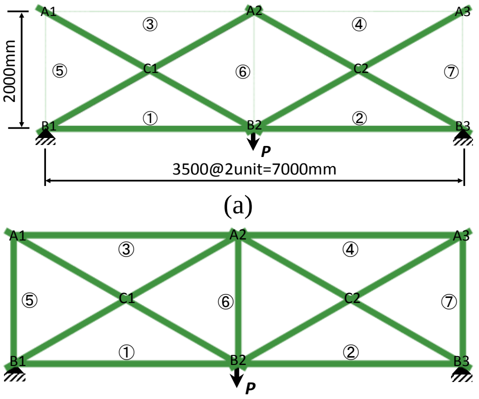

(a)

(b)

Fig. 3. Numerical models based on the MB1.0.

This optimization problem can be solved in many ways. At first, each sectional area of a strut can be optimized in order to these two approaches. The overview of the general optimization procedure, which can be applied for more complex problems, is presented in Fig. 2. An elastic analysis by ABAQUS 6.12 is iteratively called from algorithm which is programmed in Mathematica 9.0. The program generates new design variables, e.g. sectional area of struts or prestressing forces. This information is transmitted to ABAQUS preprocessing module and the calculation is carried out. The entire post-processing module is controlled by a Python language scripts that serves as the programming interface. Further explanation of this optimization method is found in author's previous paper (Chikahiro et. al. 2015).

Numerical example and results

Initial numerical model based on the MB1.0 is built up by ABAQUS 6.12 as shown in Fig. 3. The bridge in fully deployed state is simply supported and consists of two scissor units. The total length of the span is 7.0 m and the height is 2.0 m. The sectional properties of the main frame components, which are made using aluminum alloy A6N01, are A = 28.0 cm^2, I = 1146.3 cm^4, E = 62.5 GPa. The constraint conditions of σ_y and δ_y are assumed to 180.0 MPa and 14.0 mm, respectively. The weight is defined same frame weight in the initial model.

As an example numerical result, stress distribution of the optimized MB is shown in Fig. 4. Successful optimization procedure increase the limit load capacity of the MB1.0 more than 10 times that in the initial. It is considered that high bending stress within the initial model is reduced by additional strut members.

The change of basic dynamic properties was evaluated for the MB1.0 after optimization. The first natural frequency f of the model is 12.8 Hz, with dominant deformation mode in the vertical direction. From the point of view of the excitation by human and vehicle traffic in impact, the possibility of resonance phenomenon is negligible. These results allow to be mentioned that the proper reinforcement and structural optimization makes the MB a safe structure and a robotic bridge.

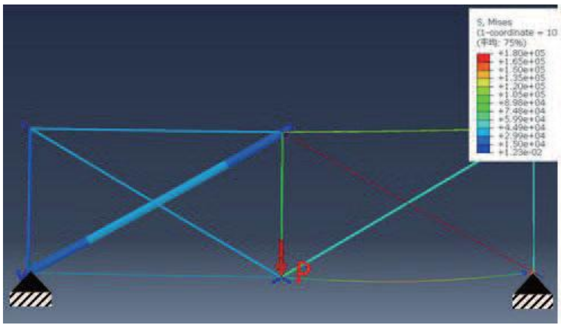

Fig. 4. Stress distribution of the optimal MB under the limit load P after optimization procedure.

Conclusions

The presented results allow for the following remarks:

1) The proposed methodology provides successful optimization result based on the developed MB.
2) The proposed solutions provide high maximum loads and satisfy imposed constraints. This high increase of structural stiffness is caused by higher resistance to global bending.

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