NUMERICAL OPTIMIZATION OF DEPLOYABLE SCISSORS STRUCTURE WITH REINFORCING CHORD MEMBERS

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1. Introduction

A scissor structure is one of the well-known and most widely used deployable structure in the field of engineering. This type of structure enables to transform its configuration from the compact form to a large-size deployed state by extending in two or three directions [1], [2]. Generally, we can find applications of the scissor structures in architecture or space engineering. Very often they are used as light-weight temporary structures. The authors have proposed a scissors-type deployable bridge - Mobile Bridge$^{\mathrm{TM}}$ (MB) - based on the concept of the Multi-Folding Micro-structures [3] - [5]. The design concept of the MB enables to reduce the construction time on site by deploying the structure directly over a damaged bridge or a road without the need for any heavy machinery.

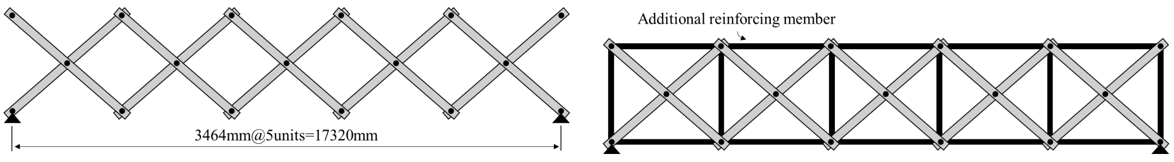
Our previous research was aimed at describing the fundamental mechanical properties of the MB. Several analytical methods were proposed based on the beam theory and equilibrium equations. At the current stage of the project, we have developed the full-scale experimental MB described in [6]. After successful initial tests we have concluded that in order to provide even higher level of safety in the disaster area, an effective reinforcing method and/or optimal bridge design should also be discussed. In this paper, we present the technique of reinforcement by the introduction of additional members, which can be added after the complete deployment of the bridge. Its optimal layout is evaluated by the combination of the FEM and the Differential Evolution (DE) optimization algorithm based on [7]. The optimal solution by weight minimization problem improves the performance of the bridge by selection of cross-sections of the scissor and reinforcing members.

2. Optimization methodology

This paper deals with the problem of minimization of the weight W, subject to the constraints imposed on the effective stress σ and the characteristic displacement δ, i.e

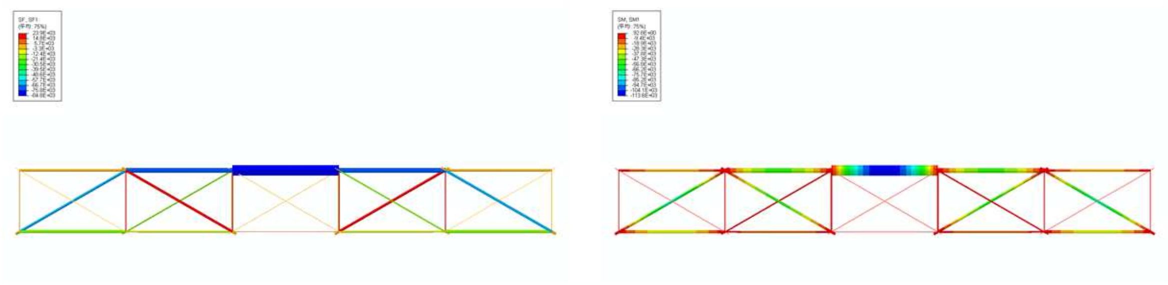
$$\begin{aligned} &\text{Minimize} && W, \\ &\text{s. t.} && \sigma_{\mathrm{max}} < \sigma_{\mathrm{y}},\ \delta_{\mathrm{c}} < \delta_{\mathrm{y}} \end{aligned} \tag{1}$$

where σ_{max} and δ_{c} are maximum stress and maximal allowable displacement in the center of the model. The problem is solved by changing each sectional area of the scissor and reinforcing components satisfying the constraint conditions based on the authors' previous paper [7].



(a) (b)

Figure 1: Outline of the numerical model. (a) The model without any reinforcing members, (b) The model with reinforcing members.



(a) (b)

Figure 2: Numerical results obtained for the operational state of the bridge. (a) Axial force distribution, (b) Bending moment distribution.

3. Numerical example

A simple 2D model of the mobile bridge implemented in ABAQUS 6.12 is shown in **Fig. 1**. After full expansion of the bridge, the total length of the span L is 17.3 m and the height η is 2.0 m. The bridge is analyzed in the operational conditions when simple supports are located on both sides of the lower span. The initial geometrical properties of all members of scissor structure and all reinforcing members are the same and equal: A = 28.0 cm^2, I = 1146.3 cm^4. The characteristics of the material are assumed to be linear elastic with Young's modulus E = 62.5 GPa and density ρ = 2.7 g/cm^3. The scaling of the geometry of the cross-sections required in the optimization procedure is conducted by introducing the coefficient factor γ. In the optimization procedure the scaling factor is assumed to be in the range from 0.01 to 2.0. The constraints imposed on yielding stress value σ_y and yielding deflection of the structure δ_y are assumed to be equal 180.0 MPa and L/500=34.6 mm, respectively. The applied loading includes both the dead weight and live load. The live load is caused by weight of the vehicle and is reflected in the numerical model by the point loads of 7.5 kN applied to the nodes located below the deck.

The conducted numerical simulations had revealed that initial design of the bridge is prone to large deformation due to large bending moment in the middle of the span. The optimized topology of the bridge is presented in **Fig. 2**. In the optimized topology the members of large cross-sections are present at the centre of the upper span, which corresponds to high compressive forces in this part of the structure. The top central part of increased thickness is supported by skew members such that the entire load bearing system of the bridge has the form of an arch. The presence of optimally sized reinforcing members causes that the bending moment in the scissor components is significantly reduced and deformation of the structure is considerably diminished.

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