FUNDAMENTAL STUDY ON DYNAMIC PROPERTY OF SCISSORING BRIDGE FOR DISASTER RELIEF

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Summary: The world has seen many kinds of natural disasters, which have critically influenced the residents' lives by causing damage to infrastructure. To realize rapid rescue efforts in an emergency situation, we propose a deployable emergency bridge, called Mobile Bridge™ [1], based on the theory of foldable structures[2] and the concept of Multi-Folding Microstructures (MFM) [3]. The current research presents the fundamental, numerical and experimental results obtained for the pedestrian and vehicle Mobile Bridges. In this paper, it is considered the localized linearization problem with the fixed an angle although this bridge contains a geometrical nonlinearity of scissors structure. Additionally, a seismic response analysis is conducted for the case where the Mobile Bridge is used in the disaster area as an emergency bridge. This allows for a better and safer structural design of the Mobile Bridge, which is patented in [4], [5].

Mobile Bridge based on the scissors mechanism

The design of the Mobile Bridge (henceforth called the MB) can realize reduced on-site construction time by deployment of the structural frame directly over a damaged bridge or a road. In previous projects [6]–[8], we successfully developed a pedestrian bridge (henceforth called the prototype) and a large-scale MB version 4.0 (henceforth called the MB4.0) for vehicles, as shown in **Fig. 1**. We also investigated the fundamental static properties of the MB based on the experimental tests and numerical simulations, which provided useful feedback for the design method.
In this work, we present the fundamental, numerical and experimental results for the MB based on the developed experimental bridges. Experimental testing included acceleration measurements under free and forced loading conditions, which supported the validation of numerical simulations. Additionally, the authors considered the seismic response analysis, which is important in the case of aftershocks, when the MB is used in the earthquake disaster area as an emergency bridge.

Numerical model

Numerical model based on the experimental MB

The FE numerical model is created using MSC Marc 2005 which is one of the major nonlinear finite element software. The prototype has a span of about 8.6m and a height of 0.5m. A person walks on the top deck of the bridge, as shown in **Fig. 1 (a)**. The main structural members of the bridge are fabricated using extruded aluminum alloy A6063. Therefore, the total weight of the bridge is less than 100kg. The most recent large model, the MB4.0, has a span of about 17.3m and a height of 2m. The main structural members of the bridge are made of extruded aluminum alloy while the frame of the hydraulic deployment system is made of steel SS400. The MB4.0 can be transported in the folded state on a single heavy platform lorry.

(a) MB for pedestrians developed in 2009 [7]　　(b) MB4.0 for vehicles developed in 2015

Figure 1. Experimental versions of different size of the MBs

Seismic load

The data from the Kobe earthquake (1995) observed by the Japan Metrological Agency was utilized to model the ground acceleration acting on the bridge. In this study, a relatively high acceleration, which resulted in severe damage to structures was observed in the North-South direction, and it was equal to $8.2\ \mathrm{m/s^2}$. This acceleration was applied to the considered FE model of deployable bridges as seismic excitation. The numerical analysis was conducted by using 3D models of the prototype and the MB4.0.

Numerical results

Eigenvalue analysis and vibration modes

The considered problem was the eigenvalue analysis aimed at finding the frequencies of free vibrations and the corresponding vibration modes. To address this problem, we applied the equation of free vibrations to the developed numerical model of the bridge. Although the MB has geometric non-linearity which affect to the stiffness of the bridge according to its expansion angle, in this paper, we present the results of the eigenvalue analysis for particular expanding angle as local linearization problem.

The numerical result for the prototype bridge showed that the frequencies for the 1^{st} and 2^{nd} modes for the vertical direction and horizontal direction were 3.8Hz, 14.3Hz and 1.8Hz, 3.7 Hz, respectively. Similarly, the 1^{st} and 2^{nd} modes for the MB4.0 are 3.3Hz and 14.8Hz in the horizontal direction and 11.1Hz and 28.0Hz in the vertical direction, respectively. These results indicate that in the case of the MB, the vibrations in the horizontal direction are stronger than those in the vertical direction when the length of the structure increases. Therefore, special attention has to be paid to the in-plane vibrations when a full-scaled MB is installed on-site.

Conclusion

This paper presents the fundamental, numerical and experimental results based on two prototypes of the MB. The eigenvalue analysis reveals the basic vibration modes of the MB and indicates that the scissoring bridge can easily vibrate in the horizontal direction due to small corresponding stiffness. This research allows for a better and safer design of the MB. The details of the experimental testing and numerical analysis of the seismic response will be presented at the conference.

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