

A preliminary study on the application of computer simulation in the progressive collapse of bridges

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Keywords: stone arch bridge, progressive collapse, simulation, deactivation element, critical region

Bridges are important lifeline projects in national traffic system, so the collapse accidents of bridges will cause significant loss. However, the collapse accidents of arch bridges repeatedly happened in China in recent years (Cheng M.X., 2008). Those horrible accidents not only results in significant casualties and properties losses, but also aroused the concern and thinking of bridge engineers. It is very important to correctly reproduce the process of bridges accidents, to analyze the possible reasons of collapse and to determine the most critical regions for the bridge safety, which could provide favorable references for the bridge design, construction and collapses prevention.

Based on a 3-span stone arch bridge, this paper firstly simulates the entire process of the progressive collapse with the general purpose finite element (FE) program MSC.Marc. During the simulation, the stone of the arch bridge are modelled as elasto-plastic-fracture material (Bazant and Planas, 1997; Jiang J.J et al., 2005). And “birth-death element” technology (MSC.Marc Documentation, Volume D) is used to simulate the elemental failure. Total strain is used as the elemental failure criterion. Instead of traditional fixed boundary conditions of the piers, Mohr-Coulomb friction contacts (MSC.Marc Documentation, Volume A) are used to simulate the interaction between the foundation and the piers.

Considering the possible collapse reasons in the real accidents, two load cases are simulated. Load Case 1: Collapse due to insufficient material strength (poor construction quality) of the first main arch; Load Case 2: Collapse due to horizontal slide in the foundation of the left abutment. The comparison of the two load cases indicates that the main difference is the positions of the initial damage. In Load Case 1, the initial damage occurs at the weakest position in the first main arch, while in Load Case 2, the initial damage occurs at the skewback of the first main arch.

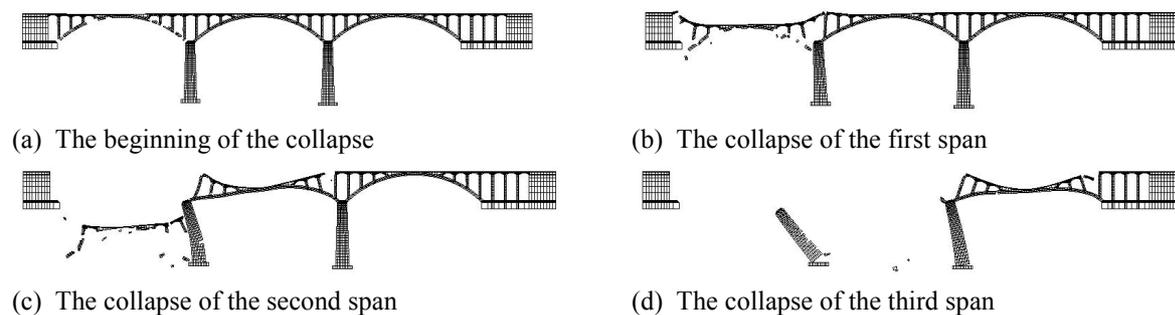


Figure 1. The simulated collapse process of Load Case 1

And then, this paper evaluates the importance indices of all components of the stone arch bridge. A literatures study shows that the importance indices of the structural components not only depend on the mechanical properties of structural system itself, but also depend on the characters of the external loads. Besides, they are influenced by the targets of the structures performance (Agarwal, et al., 2001; Nafday, 2008; Lin X.C., 2009; Liu C.M. and Liu X.L., 2005). Therefore, a generalized structural stiffness-based importance index I , which is proposed by Lin X.C. (2009), is adopted in this work. Both external load properties and stiffness properties are considered in Lin's index. Furthermore, a simply modification is made for Lin's index to eliminate the influence of the element size. The new importance index is expressed as follows:

$$\Gamma = \frac{1 - U_0 / U_f}{V} \quad (1)$$

in which, U_0 and U_f are the total strain energies of the healthy structure and the damaged structure, respectively. V is the corresponding elemental volume. The importance indices of all elements are sorted in descending order. The elements whose cumulative volume is in the first 10% of the total volume are defined as the critical regions of the stone arch bridge.

The analysis results show that the critical regions of the stone arch bridge are distributed at the following 5 regions: (1) the top of the piers; (2) the skewbacks of the main arches; (3) the upper and lower surfaces of the arch in 1/4 span near to the piers; (4) the skewbacks of spandrel arches; (5) the junctions between the transverse walls and the main arches.

Finally, the rationality of the critical regions obtained by above importance assessment method is verified via limit analysis (pushdown analysis). The ultimate load capacities of four typical structural systems are compared: (1) the original structure; (2) the structure whose material strengths in the critical regions are strengthened by 20%; (3) the structure whose material strengths in the least-critical regions are strengthened by 20%; (4) the structure whose material strengths in critical regions are reduced by 20%. The comparison shows that ultimate load capacity of the structure is extremely sensitive to the strengths of the critical regions and the defined critical regions of the stone arch bridge are reasonable.

Acknowledgements

This study is funded by National Science Foundation of China (No. 50808106) and West Transport Project of Ministry of Transport of China (No. 2008-318-223-43).

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