A Nonlinear Redundancy Analysis Method for Steel Truss Bridges

Nagaoka University of Technology Student member ○Hoang Trong KHUYEN
Nagaoka University of Technology Regular member IWASAKI Eiji

1. Introduction

Redundancy analysis methods are studying by many researchers. However, most of their methods are a linear static method. It is well known that a linear analysis results in a lower accurate level than a nonlinear analysis does. Hence, this study aims to investigate a nonlinear approach which increases accurate level for assessment of redundancy for steel truss bridges.

2. Method

Fig. 1 Procedure of nonlinear redundancy analysis

Fig. 1 plotted a general procedure of nonlinear redundancy analysis [1]. Step 1 builds a finite element (FE) models which consider the varying of structural configuration during construction stages from erection of skeleton to installation of the deck. Step 2 identifies candidates for Fracture Critical Members (FCMs), tensile members, whose failure would be expected to results in the collapse of the bridge. Members whose failure leading yield in remaining members could be good candidates. Damages are simulated in FCMs candidates by one candidate at a time. For virtual damage simulation, the virtual damage member is first replaced by its sectional forces. Then, a so-called release force, which equals its sectional forces, is applied to eliminate the sectional force as shown in Fig. 2.

Increasing release load factor until 1.854 addressed the dynamic effect of sudden tensile member break. In truss bridges, because compressive members are failed by buckling due to the traffic collision, no dynamic effect exists in the case of compressive member failure. The whole analysis was carried in Phased analysis option of an FEM package.

Fig. 2 Simulation of virtual break

A second-order nonlinear analysis was employed in order to captures such geometry nonlinear as $P - \delta$ effect and $P - \Delta$ effect. The initial imperfection of truss members was accounted by an equation $l/1000 \times \sin \pi l/1000$, with $l$ is the length of the member. Initial imperfection is introduced in the direction so that it increases the stress in the target member. Plastic material model is employed to address nonlinear properties of materials. Fig. 3 displayed a typical collapse criteria for nonlinear redundancy. The structures are collapse either due to buckling of compressive or tensile break of members. If the buckling happens, the respond of the bridge, strain or displacement, passes the peak point. The tensile break of a member is defined as the state its strain reaches a certain level, 5% in this research. This 5% strain is the recommended value in the Standard Specifications for Steel and Composite Structures for safety verification [2].

Fig. 3 Collapse definitions of nonlinear redundancy

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3. Numerical application

**FE models:** A typical steel truss through bridge was employed in the research. Structural steel was modeled in beam elements and concrete deck was simulated by curve shell elements as shown in Fig. 4. Three plasticity models of steel were employed as in Fig. 5. Concrete was in elastic-plastic material as in Fig. 6. The loadings include both dead load $D$ and live load $L$. 

![Fig. 4 FE model in 3D](image)

![Fig. 5 Steel SM490A](image)

![Fig. 6 Reinforced Concrete](image)

**Cases of study:** This study investigated a method for redundancy analysis, not a single redundancy analysis of a particular bridge. Hence, only two candidates, one representative tensile member and another representative compressive member, were assumed to be virtual break at $1D + 1.0L$, (Fig. 7). Dead load $L$ and live load $L$ follows Specification for Highway Bridges [3].

![Fig. 7 Cases of study](image)

**Results:** The analysis recorded strain of all members. Fig. 8 and Fig. 9 drew the strain curves of the most critical members in cases of study. In Case1, strain curves diverged before the candidate was fully released with dynamic effect of sudden member failure due to different hardening patterns. Comparing to defined break strain of 5%, material model M1 and M2 results passed this limit strain. Therefore, the bridge was not redundant in Case1. On the other hand, strain curves proceeded in relatively same lines in Case2 because it had not yet reached hardening range. The bridge was redundant in Case2.

![Fig. 8 Strain curves in Case1](image)

![Fig. 9 Strain curves in Case2](image)

4. Conclusion

A nonlinear redundancy method was investigated in this study. The method was built from verified structural theories and was in conjunction with capacity of current available FEM packages. Even though, a nonlinear analysis takes time and consumes heavy work load, it is well known that its result is more accurate than conventional linear method. Hence, this method is an appropriate one for redundancy analysis when accuracy is the most concerned factor.

**References**

