On Increasing Accuracy of Linear Redundancy Analysis Method for Steel Truss Bridges

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1. Introduction

Bridge redundancy analysis evaluates bridge safety after a break occurs on one of its members. The conventional linear elastic method is widely used in redundancy analysis [1]. The robustness of the damaged structure associates with the term of redundancy index *R* which was determined by checking the strength of members in a linear elastic analysis. If *x* and *y* are strong and weak axis in a member cross section, the redundancy index is defined in Eq. (1) for tensile members and Eq. (2) for compressive members. If any member fails in strength, $R > 1$, the whole bridge collapses consequently.

$$R = \frac{N}{N_p} + \left(\frac{M_x}{M_{px}}\right) + \left(\frac{M_y}{M_{py}}\right) \tag{1}$$

$$R = \frac{N}{N_u} + \left(\frac{1}{1-\frac{N}{N_{ex}}}\right)\left(\frac{M_{eqx}}{M_{px}}\right) + \left(\frac{1}{1-\frac{N}{N_{ey}}}\right)\left(\frac{M_{eqx}}{M_{py}}\right) \tag{2}$$

These two equations may be simple. However, because the strength of the member is a nonlinear curve rather than simple linear, accuracy of current equations is low, especially when bending moments enlarge due to the loss of members. Hence, this study proposed more accurate nonlinear equations of member strength for redundancy analysis of steel truss bridge.

2. Proposed redundancy index

When one member is broken, the member moment in the damaged truss bridge is biaxial bending. In this paper, the strength of members proposed by Duan & Chen [3] was employed as Eq. (3) for tensile members and Eq. (4) for compressive members. If any member shows $R > 1$, the whole bridge collapses consequently.

$$R = \left(\frac{M_x}{M_{pcx}}\right)^{\alpha_x} + \left(\frac{M_y}{M_{pcy}}\right)^{\alpha_y} \tag{3}$$

$$R = \left(\frac{M_{eqx}}{M_{pcx}}\right)^{\alpha_x} + \left(\frac{M_{eqy}}{M_{pcy}}\right)^{\alpha_y} \tag{4}$$

For the I-shaped section

$$\alpha_x = 1.2 + 2\frac{N}{N_p};\ \alpha_y = 2 \tag{5}$$

$$\frac{M_{pcx}}{M_{px}} = \min\left(1.18M_{px}\left(1-\frac{N}{N_p}\right), 1\right) \tag{6}$$

$$\frac{M_{pcx}}{M_{py}} = \min\left(1.19M_{py}\left(1-\left(\frac{N}{N_p}\right)^2\right), 1\right) \tag{7}$$

For the Box shaped section

$$\alpha_x = \alpha_y = 1.7 + 1.5\frac{N}{N_p} \tag{7}$$

$$\frac{M_{pcx}}{M_{px}} = \min\left(1.20M_{px}\left(1-\frac{N}{N_p}\right), 1\right) \tag{8}$$

$$\frac{M_{pcy}}{M_{py}} = \min\left(1.20M_{py}\left(1-\frac{N}{N_p}\right), 1\right) \tag{9}$$

For compressive members in all types of cross section shapes

$$M_{pux} = M_{px}\left(1-\frac{N}{N_u}\right)\left(1-\frac{N}{N_{ex}}\right) \tag{11}$$

$$M_{puy} = M_{py}\left(1-\frac{N}{N_u}\right)\left(1-\frac{N}{N_{ey}}\right) \tag{12}$$

In the above equations, N, M_x, and M_y are sectional forces of a member. Strengths of member in uniaxial bending $M_{pcx}, M_{pcy}, M_{pux}$, and M_{puy} are computed in Eqs. (6-7) and Eqs. (8-12) [4]. Such strength components as plastic axial strength N_p, ultimate compressive strength N_u, Euler buckling load N_{ex}, N_{ey}, equivalent moments M_{eqx}, M_{eqy} and full plastic moment strength M_{px}, M_{py} can be computed by a standard procedure such as American or Japan specifications for highway bridges.

3. Numerical validation

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Case studies

A typical steel truss bridge in Niigata was employed to make the validation. This bridge is a simple span, steel truss bridge. Six members were assumed to be break as in Fig. 1. The dead load D and live load L by Japan Road Association [2] were employed. The bridge was analyzed in a 3D finite element model by elastic analyses.

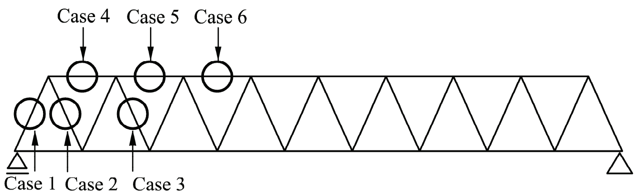

Fig. 1 Cases of study

Sudden member break simulation

The break was assumed at loading of 1.0D+1.0L. This study employed the widely accepted method by the URS [1] to address sudden member break. The member break is first replaced by its sectional force at member ends. Then a so-called release force which equals the sectional force is applied in opposite direction to eliminate the sectional force. Increasing the release force factor until α=1.854 addresses the dynamic effect of a sudden break.

Linear redundancy analysis

This study investigates the redundancy analysis methods, not a single redundancy analysis of a particular bridge. Hence, the study finds the collapse load at which the first member yielded $R=1.0$ while releasing the virtual break member by both convention equations and proposed equations. Such strength components were calculated following a Japan specification [2].

Nonlinear redundancy analysis

A second-order nonlinear analysis was conducted. The materials were assumed perfected plastic with yield stress of 315 MPa for steel and 21 MPa for reinforced concrete respectively. In order to be comparable to linear methods, nonlinear approach figured out the load factor at which first section was completed yield or buckling occurred. This load factor was considered the collapse load factor by the nonlinear redundancy

Comparisons

The collapse load factors in the linear redundancy were divided by the collapse loading factor in the nonlinear approach to find out the accuracy. Fig. 2 plotted the accuracy comparison for six studied cases. It shows that the conventional method yields about over 70% in accuracy while the proposed method gives very high accuracy, all over 90% compared to nonlinear redundancy analysis which is known as highly accurate method.

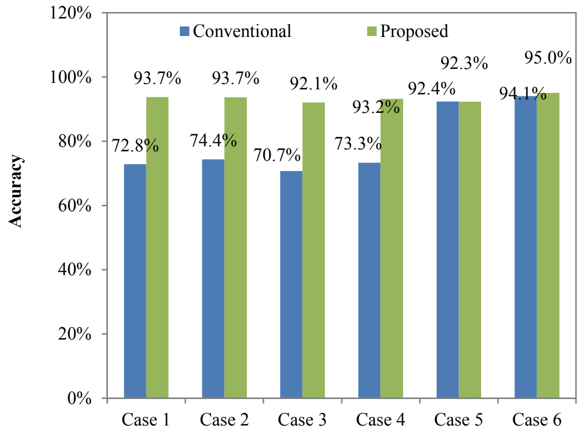

Fig. 2 Comparison of accuracy

4. Conclusions

In this study, the bridge redundancy analysis methods were reviewed. Conventional linear elastic redundancy has advantage of simplification, but low accuracy because of using linear equations to express the member strength. This study proposed some more accurate nonlinear equations to calculate the member strength in redundancy analysis of steel truss bridges. The validation with a nonlinear redundancy analysis shows that the proposed equations can increase the accuracy up to over 90% compared to nonlinear redundancy analysis. The proposed equations can be applied to common type of member sections in steel truss bridges.

5. References

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