Static Methods for Redundancy Analysis of Steel Truss Bridges

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1. Introduction

Linear static method is usually employed for redundancy evaluation, but it is limited accuracy. Nonlinear method, a higher accurate one, is not much investigated in current studies. This study attempts to investigate then compare linear and nonlinear redundancy approaches for steel truss bridges following Japan Specification for Highway Bridges (JRA 2002).

2. Finite element analysis

FE models

A typical steel truss through bridge was employed in the research. **Fig. 1** plotted the finite element model of the bridge. Both steel and concrete were simulated in elasto-plastic material as in **Fig. 2** & **Fig. 3.** The bridge was tested with effect of dead load D and live load L.

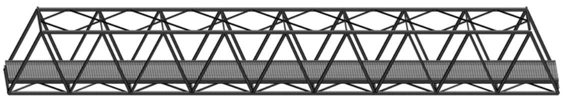

Fig. 1 FE model in 3D

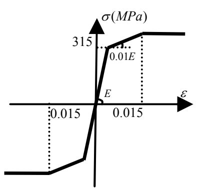

Fig. 2 Steel SM490A

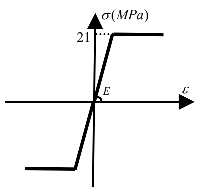

Fig. 3 Reinforced Concrete

Cases of study

In three cases of study, three candidates including two tensile diagonals D2, D4 and one compressive upper chord U4 were assumed to be failure as virtual break at *1D+0.5L,(* **Fig. 4***).* Loading firstly was applied until level just before appearance of virtual break. Then the virtual break, one by one was simulated by superposition of intact structure subjected 1D+0.5L with damaged structure which removed totally virtual break member then applied release force equaling to axial force of break members in opposite direction. The dynamic effect of sudden member failure was also consider by multiplying effect in damaged structure with load factor *I=1.854.*

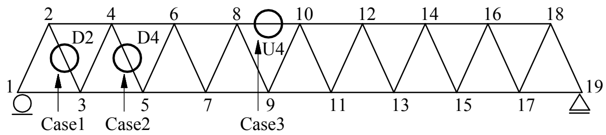

Fig. 4 Cases of study

Static redundancy evaluation methods

Linear redundancy: The bridge resistance is evaluated by member-strength checking through sectional forces from FE linear analysis. The tensile & compressive members are treated separately by formula (1) and (2) as prescribed in Japan Specification for Highway Bridges. If any member gives $R \geq 1$, that member is considered as failure, so whole bridge is collapse consequently.

$$R = \frac{N}{N_p} + \left(\frac{M}{M_p}\right)_{out\text{-plane}} + \left(\frac{M}{M_p}\right)_{in\text{-plane}} \tag{1}$$

$$R = \frac{N}{N_u} + \left(\frac{1}{1-\frac{N}{N_E}}\right)\left(\frac{M_{eq}}{M_p}\right)_{out\text{-plane}} + \left(\frac{1}{1-\frac{N}{N_E}}\right)\left(\frac{M_{eq}}{M_p}\right)_{in\text{-plane}} \tag{2}$$

Nonlinear redundancy*:* If the bridge response in nonlinear analysis in second plastic order passes the peak, it concludes that the bridge collapses by load at the peak.

3. Results

Linear redundancy analysis

Table 1 Summary of linear redundancy

Cases	*I=1.00*		*I=1.854*	
	*N^o^*	R max	*N^o^*	R max
Case1	*5*	*1.22*	*9*	*1.97*
Case2	*0*	*0.96*	*4*	*1.55*
Case3	*3*	*1.05*	*14*	*2.09*

N^o is number of members have R>1

Strength checking of members in post virtual break showed that some members became subsequent strength-failed. The subsequent failure members located

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mostly near by the virtual damage (**Fig. 5**). **Table 1** counted total number of subsequent failure members as well as maximum R index. It found that the dynamic effect, *I=1.854*, induced much larger R index than the index in cases of without dynamic effect, *I=1.0*.

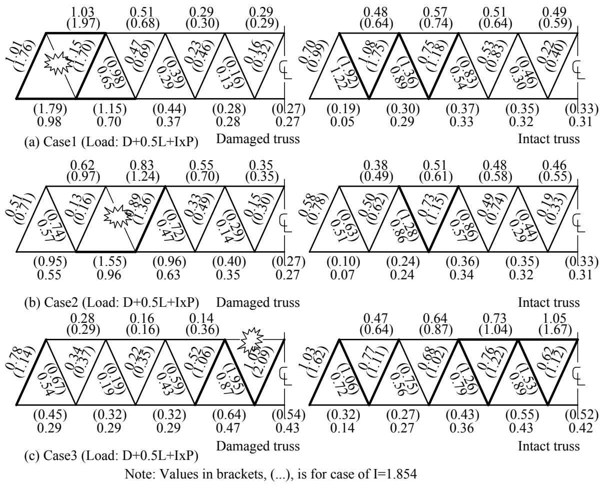

Fig. 5 R values in studied cases

Nonlinear redundancy analysis

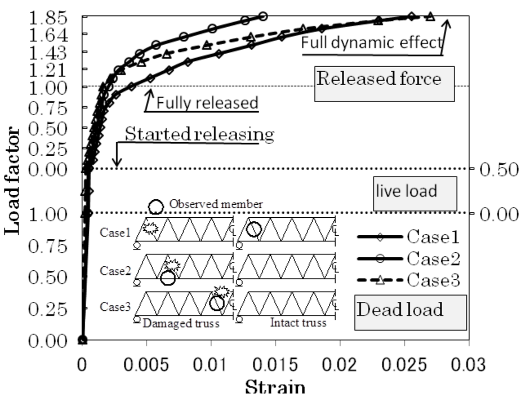

Fig. 6 Strain curves in observed members

The member strain was observed during analysis. **Fig. 6** drew the strain curves in largest strain-induced members. In these curves, through phased analysis, the loadings were incrementally applied until full of dead load 1D plus haft of live load 0.5L to express state before virtual break. Then the release force was incrementally loaded to introduce break. The load factor 1.0 of release force means the virtual break was fully removed without dynamic effect. The load factor 1.854 of release force expresses dynamic effect of sudden member failure was fully accounted. None of curves were passing the peak means that the bridge was not collapse due to break.

4. Discussions

Table 2 Comparison between two approaches

Cases	I=1.000		I=1.854	
	Linear	Nonlinear	Linear	Nonlinear
FCM	*D2 ,U4*	*None*	*D2,D4,U4*	*None*
Redundant	*No*	*Yes*	*No*	*Yes*

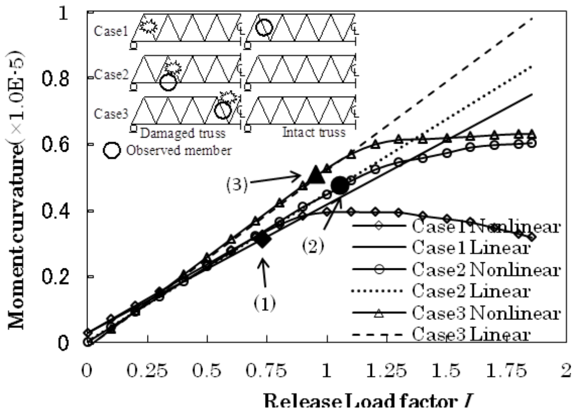

Fig. 7 Moment curvature curves in observed members

Table 2 showed a comparison of two approaches. Linear redundancy concluded the bridge was not redundant and most of virtual break were FCM, but nonlinear redundancy said in an opposite result. Sectional forces in same members in **Fig. 6** were observed. It found that axial forces proceeded in same lines. However moments became divergence after yielded due to redistribution process (**Fig**. 7). It showed the levels of first failure in strength member in linear redundancy, points (1) (2) (3) corresponding, located lower than moment divergence points. Hence, the formula for linear redundancy may underestimate the strength of member.

5. Conclusion

Both linear and nonlinear redundancy methods are investigated in this study. A comparison between them shows that two approaches result in different identification of FCMs. The linear redundancy method gives a lower redundant rating than nonlinear method does. The linear redundancy criteria underestimate strength of members.

6. References

[1] Japan Road Association (JRA), Specification for highway bridges- Part I &II, 2002.

[2] URS, "Fatigue evaluation and redundancy analysis, Bridge No.9340, I-35W over Mississippi river", Draft report, 2006.