Linear Redundancy Analysis on A Steel Truss Bridge

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1. Introduction

In the 60s and 70s of 20th Century, Japan had been developing at top speed. Especially in the domain of civil engineering, large amount of bridges, tunnels were built during these 20 years. From now on, those bridges will reach their design period (50 years in Japan) in succession. Therefore how to settle these aged bridges becomes one of the significant challenges in Japan. To resolve this issue, the safety of integral bridge should be considered, which is the idea of bridge redundancy. The bridge redundancy generally can be defined as the capability of a bridge's superstructure to continue to carry loads after damage or failure of one of its members. This study will investigate the redundancy of the former Choshi Bridge based on linear numerical analysis results.

2. Research Approach and Bridge FE Model

2.1 Introduction of the Bridge FE model

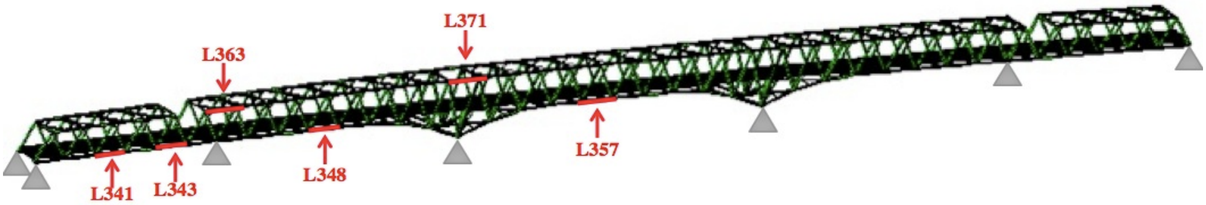

Fig. 2.1 FE model of the former Choshi Bridge

The former Choshi Bridge was located at choshi-shi, chiba-gen, Tokyo. It was a five-span truss bridge, which extended 406m in length and 8.2m in width. The longest span was 107m and deck was 7m in width. The construction of former Choshi Bridge was completed in 1962.

The bridge FE model is consisted of two parts. The bridge deck is modeled by using shell elements, and other parts of the bridge model (steel material) are simulated by using beam elements. The bridge FE model is shown in Fig. 2.1.

2.2 Field Test and Numerical Simulation

Before the former Choshi Bridge was dismantled, field tests were performed to determine the structural behavior of the aged truss bridge. The field test includes 8 cases. Case 1 and case 8 were under the dead load, and case 8 was the situation that after all the loading cases have been done. The displacement data was measured from the lower chord gusset plate. Filed test results were provided to verify the present numerical model. The loading locations of Case2 to Case7 are shown in Fig. 2.2 and maximum displacements of each field test and simulation results are shown in Table 2.1.

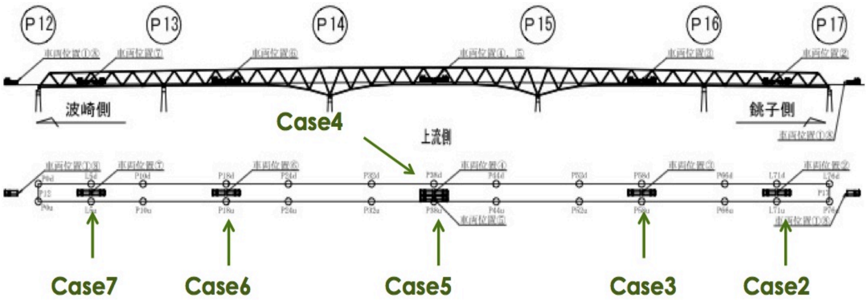

Fig. 2.2 Loading locations of Case2 to Case7

As shown in Table 2.1, maximum displacements of simulation results of 8 cases agreed well with field tests. Thus, it is reasonable to conclude that the bridge FE model performs high similarly with real bridge and further analysis can be executed.

Table 2.1 The maximum displacements of all the field test and simulation results

	Case 1(mm)	Case 2(mm)	Case 3(mm)	Case 4(mm)	Case 5(mm)	Case 6(mm)	Case 7(mm)	Case 8(mm)
Field test	0.0	9.0	13.5	13.5	15.0	15.0	10.5	2.5
Simulation	0.0	11.6	13.5	12.1	15.3	13.5	11.6	-

3. Linear analysis Method

Linear analysis was performed by using finite element method and *DIANA* software.

3.1 Possible Critical Member

A member whose failure could cause bridge collapse or loss of its serviceability is defined as a critical member in the present study. And possible critical members (PCM) are those members that have high possibility to be a critical member. Compare to the failure of compression members, tensile members' failure is more brittle. Furthermore, the typical failure mode of compression members is buckling failure in which situation that buckled members still has some resistance. Conspicuous displacement happens before the buckled members forfeit bearing capacity completely. For these reasons, compression members are not accounted as possible critical members in present redundancy study. Therefore, truss members (from all the upper chord members, lower chord members) that have relative large tensile stain under dead load are considered as PCMs. Meanwhile, members that meet the following two conditions are also considered as PCM. First, members that is severely corroded or damaged in the real bridge. Second, members those are at pivotal location, whose failure could let the whole bridge in danger. According to above conditions, 6 members are (L341, L343, L348, L357, L363&L419and L371&L427 as shown in Fig. 2.1) considered as PCMs and further simulation and analysis on these 6 PCMs are accomplished.

Keywords: Linear numerical simulation, Truss bridge, Redundancy, FE Model, Field test
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Each case is separated into two secondary cases including, intact and damaged cases. In damaged cases, PCMs are attached with a dummy material (Young's modules near 0) so that the stiffness of damaged members is much lower than intact members. According to the influence line the least favorable loading distribution for each PCM is added in two secondary cases.

3.2 Plastic strain ratio (R factor)

The R factor is calculated by the following formulas. When R ≥1, then the member is judged as reaching the ultimate state. For tensile members, R is calculated by equation (1). For compression members, R is calculated by equation (2).

$$R = \left(\frac{P}{P_p}\right) + \left(\frac{M}{M_p}\right)_{ip} + \left(\frac{M}{M_p}\right)_{op} \quad (1) \qquad R = \left(\frac{P}{P_u}\right) + \frac{1}{1-(P/P_E)_{ip}}\left(\frac{M_{eq}}{M_p}\right)_{ip} + \frac{1}{1-(P/P_E)_{op}}\left(\frac{M_{eq}}{M_p}\right)_{op} \quad (2)$$

where subscript 'ip' means in plane; 'op' means out of plane. P, M is axial force and moment. P_p, M_p is fully plastic axial force and fully plastic moment. P_u is the load-carrying capacity in axial compression as a column, P_E is the Euler buckling strength, and M_{eq} is the equivalent bending moment of the member.

4.Results and discussion

The maximum R factors of lower chords, upper chords and vertical bracings of all the cases are shown in the Table 4.1(the numbers given in parenthesis are done in damaged cases, the numbers without parenthesis are done in intact cases).

Table 4.1 Maximum R factor of all the cases

	L341	L343	L348	L357	L363	L371
LOWER CHORDS	.820(.819)	.823(.817)	.768(.876)	.959(1.078)	.695(.675)	.933(.976)
UPPER CHORDS	.857(.826)	.738(.742)	.864(.779)	.957(.907)	.652(.809)	.798(1.234)
VERTICAL BRACINGS	.503(.480)	.499(.489)	.495(.467)	.473(.446)	.589(1.160)	.527(.531)
MAXIMUM	.857(.819)	.823(.817)	.864(.876)	.959(1.078)	.695(1.160)	.527(1.234)

Those cases with some members' R factor are larger than 1. Then the PCM is determined as a critical member. For most of the chords, the maximum R factor has a tendency to be larger after the PCM damaged. Taking the case of L371 as an example to explain in detail how the failure of a PCM affects R factor of the former Choshi Bridge. The location of L371 is upper chord between second and third span. The result is shown in Fig. 4.1.

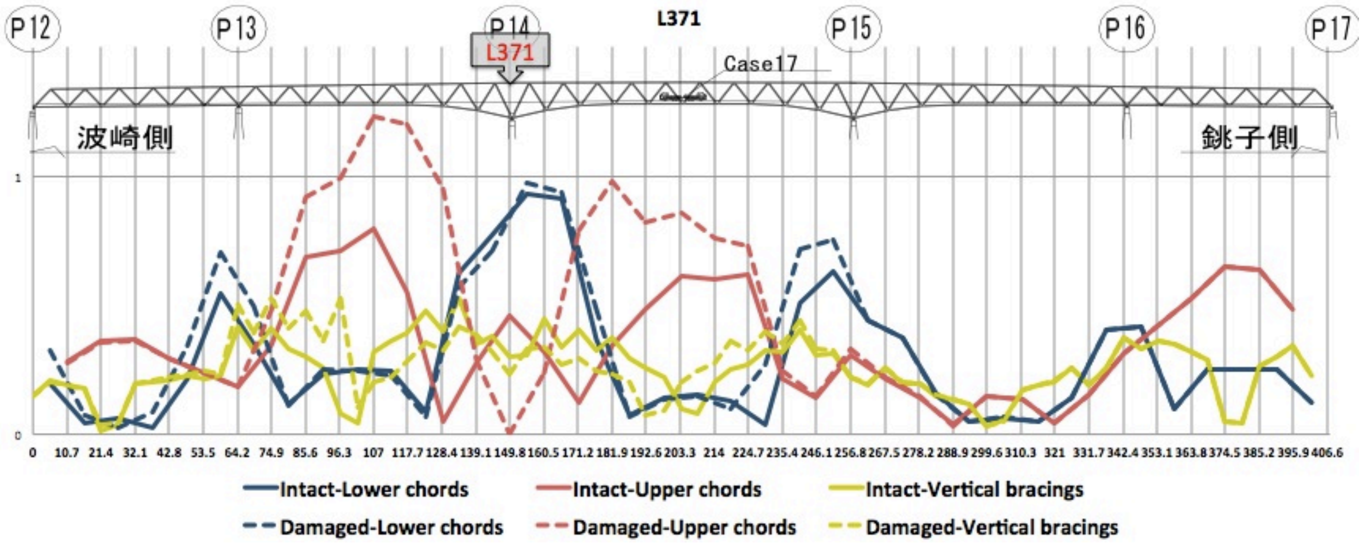

Fig. 4.1 The results of case L357

The failure of member L371 has relatively significant influence on upper compression chords and vertical bracings of second and third spans. In the intact case, member L371 and other upper compression chords of second and third spans have relatively large R factors. Compare to the intact case, the R factors of upper chords of second and third spans increase markedly in damaged case, more importantly a few members' R factors even beyond 1. Moreover, because of the failure of L371, loading resistance of the part around member L371 becomes lower, so that the loads distributed to this part become smaller. Meanwhile, an obvious increase of R factor is found in the neighboring members closing to the distributed loading locations. Therefore, no obvious changes of R factors of lower chords beside P14 are observed. And the lower chords beside P13 and P15 increase evidently, but remain safe because R factors stay smaller than 1. For vertical bracings, R factors are fluctuant however peak value remains smaller than 1. Consequently vertical bracings can be concluded as safe.

5. Conclusion

1. In the cases L357, L371 and L363, a few members' R factors even beyond 1, so these three members are determined as possible critical members.

2. Compare to intact cases, generally the R factors of compression members in neighboring members of PCM increase markedly in damaged case.

3. When span of a truss bridge is large (over 100m), lower chords in the middle of span has high possibility to be a critical member. However if span is smaller than 85m, failure of a lower chord usually do not affect bridge's safety.

4. For a truss bridge, the upper chord on each pier is of high possibility to be a critical member. These chords need more attention in design and redundancy research.

References 1. Hideki NAGATANI et al. (2009). "Structural Redundancy Analysis For Steel Truss Bridges in Japan." Journal A of Japan Society of Civil Engineers, Vol65 No.2, 410-425.