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Analytical Estimation on Remaining Load Bearing Capacity of Aging Truss Bridge by Using Whole Bridge Modeling

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Abstract: Considering the life extension of aging steel bridge, it is important to estimate accurately the remaining load bearing capacity. Even if the bridge with low-traffic state, it is difficult to decide to remove or to stop the bridge because it is an important life infrastructure for users. For the reason, it is considered that estimate the strength against traffic volume and traffic needs will more reasonable and economic maintenance basing on the remaining load bearing capacity. In this study, the finite element analyses focusing on the following two points were conducted for actual pony truss bridge.

1) Confirmation of the safety of the 4-ton truck load which was the result of resident's questionare of actual usage and traffic needs.
2) Grasp of corrosions and members to be emphasized in maintenance management.

In the analysis, the model of the whole bridge by the shell element was used, and the actual corrosion was reflected on the whole bridge. The main conclusions in this study are as follows:

1) Assuming a 4-ton truck load, the stress concentration occurred in the groove-like corrosion at the upper chord member. The safety factor to the yield state of this bridge was estimated as 1.3.
2) It will be estimated that the ultimate load bearing capacity of this bridge has decreased by 24% due to extensive corrosion and severe corrosion accompanied like through holes.

1. Introduction

Recently, the maintenance of aging steel bridges becomes one of the important social problem in Japan. Especially, many local municipalities have strict conditions in terms of financial difficulties and human resources, and it is difficult to keep all the bridges in the good condition. However, even if low traffic volume and short span, regional bridge is the foundation of living and disaster prevention, removal or replacement will not able to be done easily. For the reason, it is considered that estimating the minimum required load bearing capacity against actual traffic volume and traffic needs may realize more practical and economic maintenance.

Fig. 1. Analytical model

Table 1. Analytical cases

Analytical cases	Live load	Corrosion dameges
Case-1	truckload (4,6,9,14)	Considered
Case-2	L load in JSHB	Not considered
Case-3		Considered

In this study, the finite element analyses using whole bridge model of an actual aging pony truss bridge which has severe corrosion damages were conducted to estimate the ultimate load bearing capacity and collapse behavior.

2. Whole bridge modeling for finite element analysis

2.1. Outlines of objective steel bridge

The main span of the bridge to be analyzed is simply-supported Warren truss with curved chords and used for 99 years at mountain area in present location. All structural members are constructed by rivet joints combined several simple-shaped steels and many racing bars. The main span is 29.3m and the clear width is 4.5m, respectively. It can be noticed that the maximum height of main truss is kept as low as 2.9m from the considering of pony truss without lateral members. For the traffic needs of this bridge, it is confirmed that up to 4-ton truckload is enough from the viewpoint of daily life and disaster prevention based on the results of the residents questionnaire (Koyama et al. 2017). 27 years have elapsed since the repainting repair last time, and various types of corrosion are distributed throughout the bridge. Especially, severe corrosion damages tend to concentrate on the upper chord members at center span such as groove-like corrosions at the boundary of splice plate and pitting corrosions on the upper flange.

2.2. Whole bridge modeling and analytical conditions

The non-linear finite element analyses in this study were performed by using ABAQUS/Standard 6.14-5. Fig. 1 shows the analytical model in this study. In this model, all main structural members are constructed by the shell element with 4 nodes, and the all rivet joints were modeled as the rigid connection. The size of each shell element was set to under 40mm square in order to consider the corrosion damages which have a certain area. Based on the tensile tests, the material properties were assumed to be elastic modulus E=203.5 [GPa], yield stress σ_y=312.3 [MPa], and Poisson's ratio ν=0.274 respectively. The stress-strain relation was assumed to the perfect elasto-plasticity. For the boundary conditions, the rotations and displacements in all directions are fixed based on the actual state, because all shoes are fixed directly to piers by using 4 anchor bolts in a base plate. The RC slab is not modeled, because it is not structural member for main loads. In the corrosion modeling, the maximum corrosion depth was applied to the entire corrosion area.

2.3. Analytical cases and loading conditions

In all analytical models, the dead load of steel members was acted to entire bridge as the body force. However, the dead load of RC-slab and live load were distributed as external force on all stringers based on the influence lines for reaction force of stringers. Also, 4 analytical cases were prepared depending on loading and corrosion condition as shown in **Table 1.**

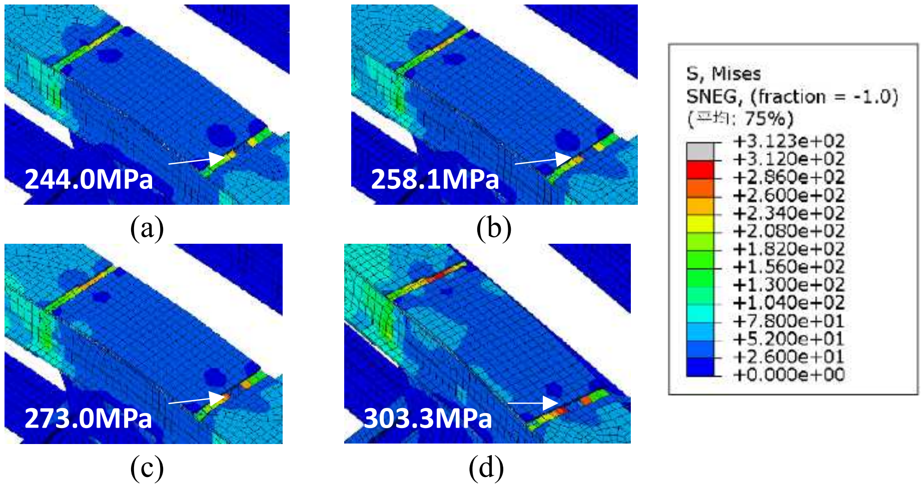

Fig. 2. Mises stress distribution around the groove-like corrosion (Case-1): (a) T-4 truckload; (b) T-6 truckload; (c) T-9 truckload; (d) T-14 truckload

In Case-1, 4 kinds of truckload (T-4~14) assuming severest state were loaded on stringers. T-4 (4-ton) truckload means the actual traffic needs which was based on the questionnaire results for local residents. The loading intensity of each truckload was calculated from the result of dividing the assumed vehicle weight of each load by the occupied area. The truckload was given to the side of road width for increasing the load share in one-sided main truss. Case-2 and Case-3 assumed the L load defined in JSHB (Japan Specifications for Highway Bridges). Here, L load p_1 which means the large-size trailer was excepted from loading condition, because such large vehicles cannot enter to this bridge from the problem on plan shape of connection road. Therefore, only L live load p_2(3.5 kN/m^2) was loaded to analytical model in Case-2~3. Also, the live load was multiplied by the magnification factor α, and α was gradually increased until the collapse of the whole bridge. The ultimate load bearing capacity of the whole bridge is estimated by the maximum magnification factor α_{cr} when the bridge collapsed.

3. Results and discussions

3.1 Truckload

Fig. 2 shows the Mises stress distribution diagram focusing on the groove-like corrosion occurring in the upper chord member at center span when T-4~14 truckload was loaded. The stress arround the groove-like corrosion increases as the truckload increases and concentrates particularly around the through hole. When T-14 truckload was assumed, the stress level reached to almost σ_y. Assuming a T-4 truckload which was the minimum required load for this bridge, the stress generated in this part was 244MPa, and the yield safety factor was 1.3. However, the corrosion damages in this analytical model were modeled larger than the actual state, and the traffic frequency of 3-ton truckload or more was low. So, it is thought that current state of this bridge will not be serious condition soon. If more life extending is considered, the load restriction of 4-ton and repair to the groove-like corrosion of the upper chord member may come in sight view.

3.2 Ultimate load bearing capacity and collapse behavior

In this section, the ultimate load bearing capacity and the collapse behavior were estimated from the analytical results for Case-2 and Case-3 in which the L load was increased to the ultimate state

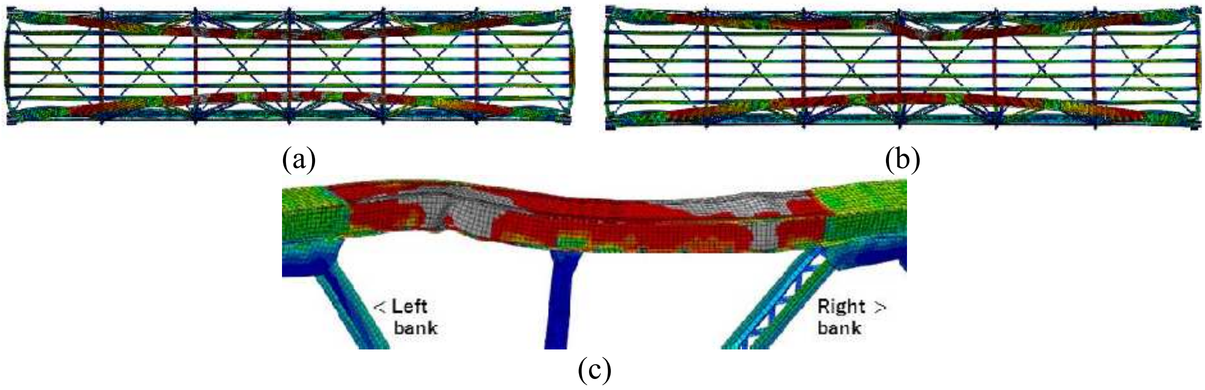

Fig. 3. Deformation (x 20) and stress distribution in ultimate state (Case-2): (a) α_{cr}=6.91 at peak load; (b) α=6.62 after peak load; (c) Out-of-plane buckling of upper chord member

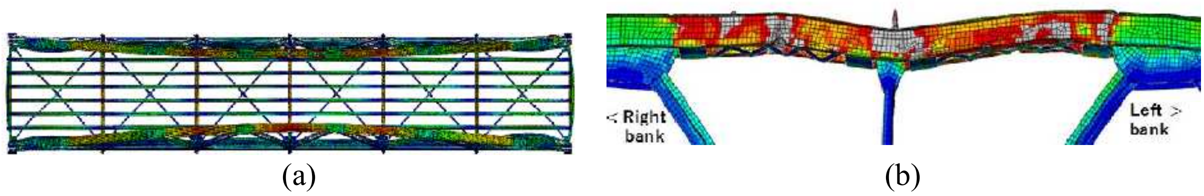

Fig. 4. Deformation (x 20) and stress distribution (α_{cr}=5.28) (Case-3): (a) Plan view; (b) In-plane buckling of upper chord member

by the magnification factor α. From Fig. 3 and Fig. 4, Case-2 without corrosion was disintegrated at α_{cr}=6.91, but Case-3 with corrosion damages collapsed at α_{cr}=5.28. These results will mean that load bearing capacity of whole bridge decreased by 24% due to corrosion for 99 years. Also, in both Case-2 and Case-3, though the buckling was occurred in the ultimate state on same upper chord member at the center span of downstream side, the direction of buckling was different each other. It could be confirmed that the buckling behavior will change from out-of-plane buckling caused by full cross-section yielding to in-plane buckling due to pitting corrosions on upper flange.

4. Conclusions

1) Assuming a 4-ton truck load, the stress concentration occurred in the groove-like corrosion at the upper chord member. The safety factor to the yield state of this bridge was estimated as 1.3. However, it is thought that current state of this bridge will not be serious condition soon.
2) It will be estimated that the ultimate load bearing capacity of this bridge has decreased by 24% due to extensive corrosion and severe corrosion accompanied like through holes.
3) The main collapse trigger of entire bridge was the local buckling toward in-plane direction on an upper chord member at center span. This buckling was caused by a lot of large pitting corrosions on upper flange.

5. References

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