Low Cycle Fatigue Assessment of Joint Structure in Steel Truss Bridges under Earthquake

Nagoya University Student member ○Chao Jiang Nagoya University Full member Takeshi Hanji
Nagoya University Fellow member Kazuo Tateishi Nagoya University Full member Masaru Shimizu

1. Introduction

The failure of joint structure in steel truss bridges can cause the collapse of the whole bridge which has been realized from the accident of the I-35W Mississippi River bridge. Joint structures have been carefully investigated in terms of load-carrying performance against static loads but little research has focused on its dynamic behavior. This study selected a deck truss bridge to confirm the performance and countermeasures against low cycle fatigue at joint structure under huge earthquakes.

2. Target truss bridge

The selected bridge is a three-span continuous truss bridge with concrete slab approach bridge, of which span distributions are 43.5, 64.4 and 46 m in the truss spans, 22.4 and 22.4 m in the approach spans as shown in Fig.1.

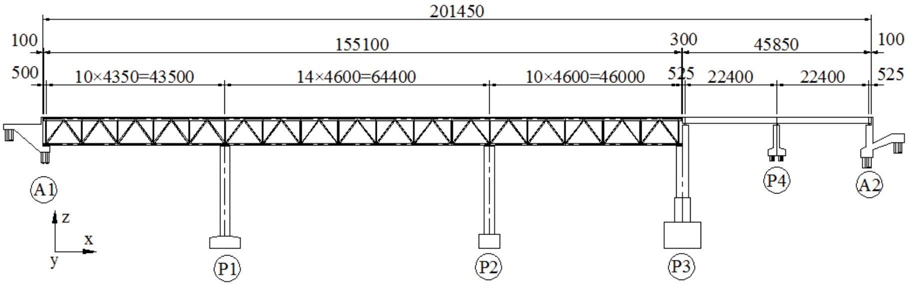

Fig.1 Overview of target deck truss bridge (unit: mm)

Three seismic waves shown in Fig.2 called Kobe wave, Double Kobe wave and Tohoku wave were used for seismic response analysis to represent different ground motions.

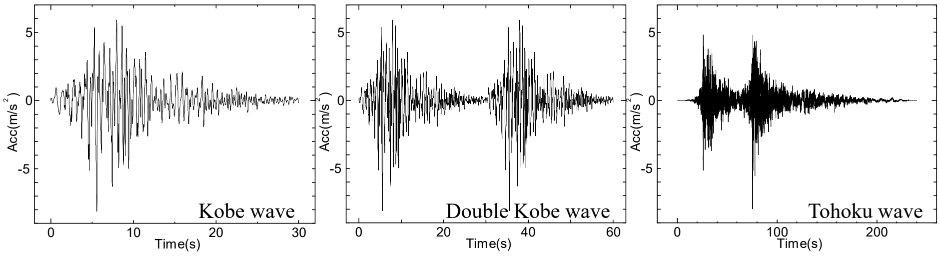

Fig.2 Time histories of seismic waves

3. Analysis flow

The analysis was divided into three steps (Fig.3) and conducted using a zooming technique; a whole bridge is modelled with beam elements (called whole bridge model) and seismic response analysis is conducted under different waves. Then, a joint structure where high strain occurs in the seismic analysis is selected as a possible fatigue damage part, and in the second step, the area surrounding the joint structure is extracted and modelled with coarsely meshed solid elements (referred to as joint structure model). From strain distribution in the joint structure model, the location where high plastic strain generated can be identified. As the third step, the strain concentrated area in the joint structure model is extracted and modelled with finely meshed solid elements (referred to as local model). Low cycle fatigue assessment is performed based on the local strain history from the local model.

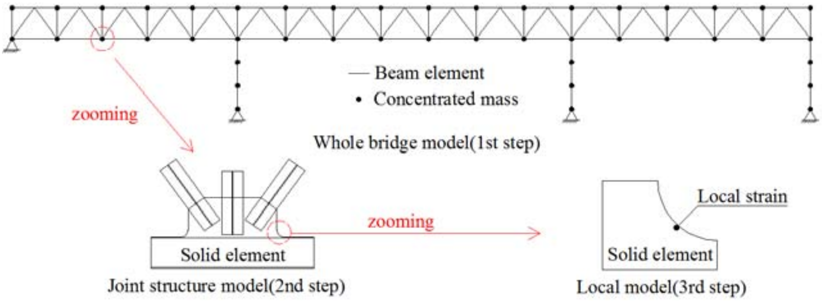

Fig.3 Schematic flow of three-step analysis

4. Low cycle fatigue assessment results

Fig.4 shows an example of equivalent plastic strain distribution in the joint structure model. It can be observed that the highest strain concentration generated at the boundary between a lateral gusset plate and a lower flange of main chord. Fig.5 shows an example of equivalent plastic strain distribution in the local models. The results indicate that highest plastic strain occurs

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Contact 〒464-8601 Furo-cho, Chikusa-ku, Nagoya Nagoya University Graduate School of Engineering TEL:052-789-4620

around a weld toe at the main chord side, and that strain concentration is also observed at a transition part of a main chord gusset plate but it is relatively small compared with that at the welded part of the lateral gusset plate.

Low cycle fatigue damage at a cracking point (highest strain point) can be calculated by the following formula:

$$D=\sum D_i=\sum\frac{n_i}{N_i}=\sum\frac{n_i}{(\frac{C}{\varepsilon_{li}})^{\frac{1}{k}}} \qquad (1)$$

where, N_i is fatigue life calculated with the fatigue strength curve, ε_{li} and n_i are the ith local strain amplitude and its number of cycles, D_i is the damage index for each strain amplitude, k (= 0.587) is constant and C is also constant depending on material. For base metal, C = 0.392, and for weld metal C = 0.261[1]. It is defined that low cycle fatigue crack of 0.5 mm will occur when the damage reaches 1.0.

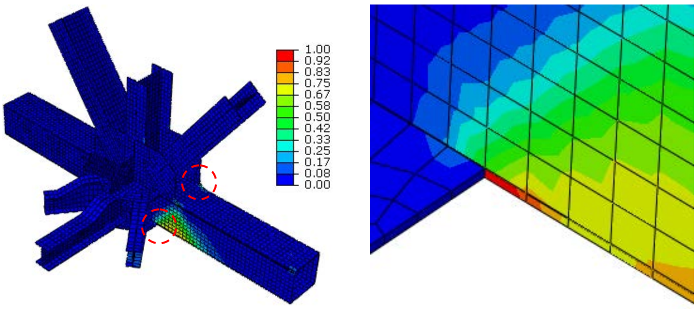
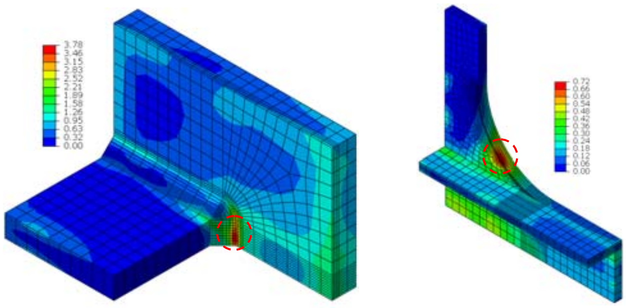


Fig.4. Equivalent plastic strain distribution around joint structure



(a) Welded joint (b) Transition part

Fig 5. Equivalent plastic strain distribution in local models

The fatigue damage calculated for the weld toe and the transition part are shown in Figs.6. The fatigue damage of the weld toe exceeds 1.0 regardless of the ground motions, meaning that welded joints at joint structures can be a crack initiation point. Therefore, it is important to consider the low cycle fatigue performance of the connection of such secondary members cautiously.

Seismic isolation bearing replacement can relieve the dynamic behavior of the bridge, and the weld toe treatment by grinding is a simple fatigue strength improvement technique which can enlarge weld toe radius and decrease stress concentration. Recalculated fatigue damage after applying the bearing replacement and weld toe grinding (finished groove radius ρ = 3.0, 6.0, 9.0 mm) shown in Table 1 reveals their effectiveness against low cycle fatigue under huge earthquakes.

5. Conclusions

In this study, low cycle fatigue assessments under huge earthquake were perform for a steel truss bridge as a case study, mainly focusing on its joint structure. The results reveal that welded connections to the joint structure need to be assessed against low cycle fatigue carefully even though they join secondary members, and show the effectiveness of seismic isolation rubber bearings and weld toe treatment as countermeasures.

Table.1 Fatigue damage in different countermeasures

Countermeasures	Kobe	Double Kobe	Tohoku
Bearing replacement	0.02	0.03	0.12
Grinding (ρ=3.0 mm)	1.09	2.41	0.85
Grinding (ρ=6.0 mm)	0.71	1.56	0.55
Grinding (ρ=9.0 mm)	0.55	1.21	0.43

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Reference 1) Tateishi, K., Hanji, T. and Minami K. (2007), International Journal of Fatigue, Vol.29(5), pp.887-896.

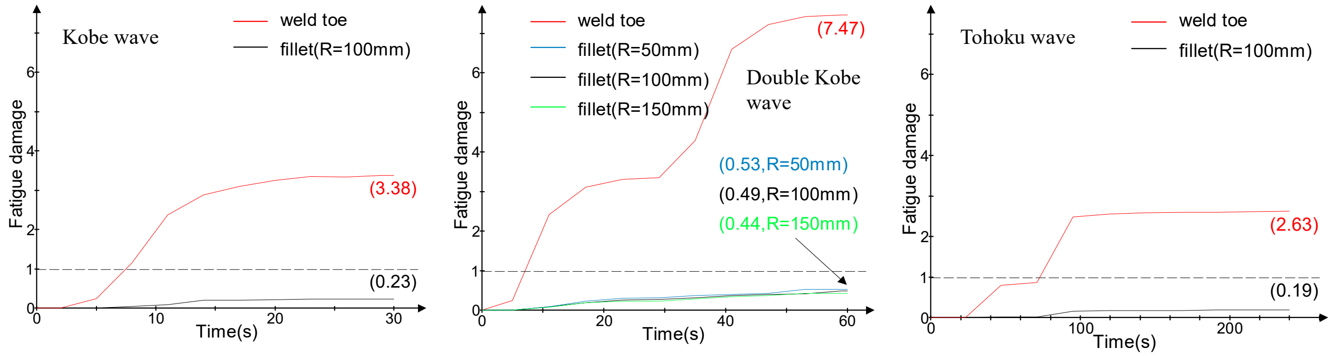

Fig 6. Time histories of fatigue damage under different seismic waves