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Analytical Study on the Seismic Response of an Lohse Bridge during the Nankai Trough Earthquakes

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1. Introduction

Public infrastructure such as bridges and highways are considered to be the important ways of transportation during the earthquake relief. As a result, it is important to ensure that the bridges can survive without huge damage and are able to be open to traffic quickly after exposed to severe earthquakes.

Arch bridge is one of the most popular types of bridges in the world and with the help of modern materials, arch bridges can be divided into several types. In this study, the Lohse arch bridge is the target bridge of the dynamic analysis.

In Japan, it was predicted that the probability of a magnitude 8 or 9 earthquake occurring in the Nankai Trough is 70 to 80 percent within 30 years[1)]. Nankai Trough earthquakes are great megathrust earthquakes that occur along the Nankai Trough, which is the surface expression of the subduction zone between the Philippine Sea and Amur plates, with a return period of about 90–200 years. Therefore, nowadays, it is necessary to consider the effects of massive earthquakes when conducting seismic analyses.

With regards to seismic design, it is important to verify the safety of the structures. Recently, researchers have been conducting several researches focusing on improving the seismic performance of the bridges during earthquakes. Ishikawa et al.[2)] investigated the effects of shear panel dampers on the arch bridge by using the dynamic analyses with the design ground motions. The results showed that the seismic performance of the target arch bridge can be improved by the shear panel dampers. Santo et al.[3)] conducted similar analyses on the truss bridge and obtained the similar results. However, both studies only employed the design ground motions in the specifications, but not the simulated ground motion.

For this reason, it is essential to employ the simulated ground motion of the Nankai Trough earthquake in the analyses. In this study, the dynamic analyses of the Lohse steel arch bridge using the Nankai Trough earthquake ground motions and the design ground motions are carried out. Based on the analytical results, the characteristic of the seismic response of steel arch bridge subjected to the Nankai Trough earthquake is investigated.

2. Dynamic analysis of a steel arch bridge

In this study, SeanFEM[4)] is used to conduct the dynamic analysis. The target bridge is the Lohse steel arch bridge. Two types of ground motions are input as the disturbance for the analysis. One of the ground motions is the design ground motions indicated in Japanese seismic design specifications[5)], including three earthquake ground motions of Type I and Type II, respectively. Ground type I was employed for the dynamic analyses. The other is the earthquake ground motion simulated from the Nankai Trough earthquakes.

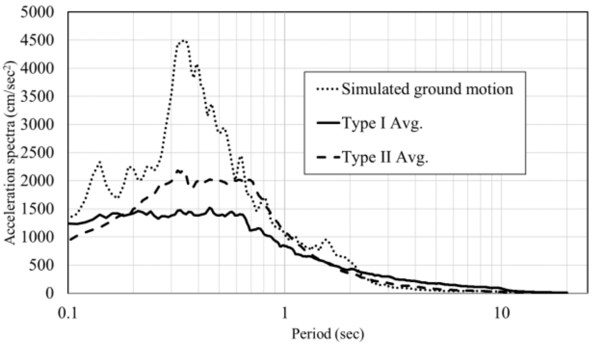


Fig.1 Acceleration spectra of earthquake ground motions

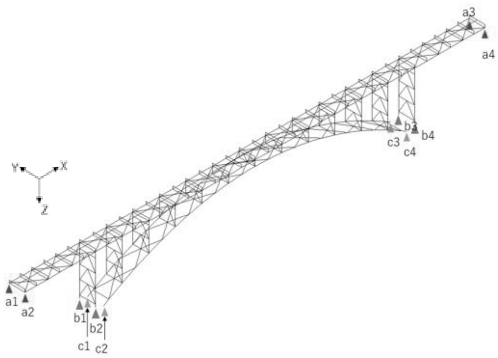


Fig.2 Overview of the analytical model

Fig.1 shows the acceleration response spectra of each earthquake ground motion which were input in both longitudinal direction and transverse direction. Rayleigh damping was applied for the dynamic analyses and the damping ratio is set as 0.02 for all steel members.

(1) Analytical model

A Lohse steel arch bridges was selected as the target of this study, as shown in **Fig.2**. Details of the analytical model are shown in **Table 1** and the boundary conditions are shown in **Table 2**. Since arch ribs play a relatively important role in the seismic performance of steel arch bridges, their behaviors will be focused on this study. For the analytical model, steel members and superstructures are modeled by fiber model and the bearing model is set as linear spring. **Fig.3** shows an example of the cross section of the arch rib, which is divided into 10 pieces in width and 2 pieces in thickness. For the material properties of the steel, linear stress-strain relationship was adopted, as shown in **Fig.4**.

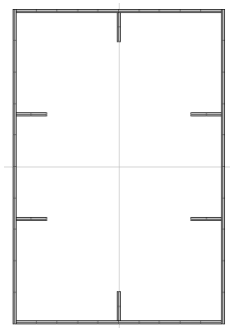


Fig.3 Cross section

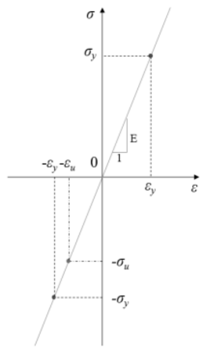


Fig.4 Steel material properties

(2) Real eigenvalue analysis

Before inputting the earthquake ground motions, the natural frequencies and mode shape of the structure with damping neglected were firstly determined. These results characterize the basic dynamic behavior of the steel arch bridge and indicate how it will response to dynamic loading. In the longitudinal direction, mode shape 7th and 6th are characteristic while in the transverse direction, mode shape 2nd and 8th are characteristic vibration mode. Details of the vibration modes during the analysis are shown in **Table 3**.

Table 1 Details of the analytical model

Construction type	Deck arch bridge (Lohse type)
Length	173 m
Span	26.5 m+120.0 m+26.5 m (Arch span:114 m)
Total width	8.2 m
Effective width	7.0 m
Steel material	SMA490W, SMA400W, SS400

Table 2 Boundary condition of the analytical model

Support	Longitudinal	Transverse	Vertical
a1, a2, a3, a4	Free	Pinned	Pinned
b1, b2, b3, b4	Fixed	Pinned	Fixed
c1, c2, c3, c4	Pinned	Pinned	Pinned

Table 3 Vibration mode of the structure

Mode	Frequency f (1/s)	Period T (s)	Participation factor	Damping ratio
2	1.156	0.865	-34.83	0.02174
6	2.858	0.350	21.59	0.02103
7	3.746	0.267	-26.94	0.02104
8	4.022	0.249	-15.13	0.02427

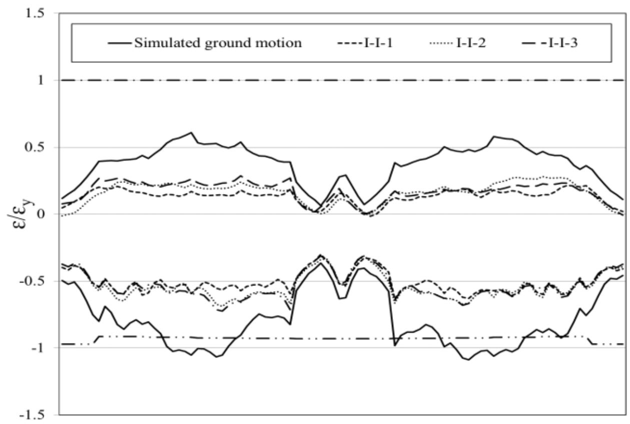
3. Analytical results

To investigate the effect of earthquake on the target bridge, results of the maximum strain response compared with yielding strain and the buckling strain along the arch rib are shown in **Fig.6** and **Fig.7**. **Fig.6** and **Fig.7** represent the strain response when earthquake ground motions were input in longitudinal direction and transverse direction, respectively. **Fig.6(a)** and **Fig.7(a)** show the results of the simulated ground motion and the earthquake ground motion Type I indicated in Japanese seismic design specifications while **Fig.6(b)** and **Fig.7(b)** show the results of the simulated ground motion and the earthquake ground motion Type II indicated in Japanese seismic design specifications. The vertical axis indicates the maximum strain of each element divided by the yielding strain ε_y.

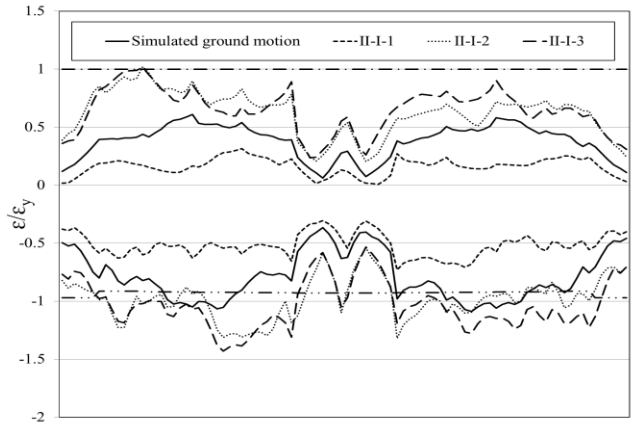
In the longitudinal direction, as shown in Fig.6, there is no significant difference among the distributions of the maximum strain of each earthquake ground motions. Results show that the maximum strain of the simulated ground motion along the arch rib are around +0.5 times and -1.0 times of the yielding strain. Strain results at the middle point are around +0.3 times and -0.5 times of the yielding strain.

In the transverse direction, as shown in **Fig.7**, similar distributions of the maximum strain of each earthquake ground motions were observed. However, the values of the maximum strain become higher compared to the longitudinal ones. The highest value of the maximum strain occurs at the point close to the supports, and the value of the design ground motion Type II is around two times larger than that of the simulated ground motion.

Based on the results shown below, there is no huge difference between the distributions of the maximum strain along the arch rib in both longitudinal and transverse direction. However, the reason of the relatively high values of the maximum strain in the transverse direction will be examined in detail in the future.

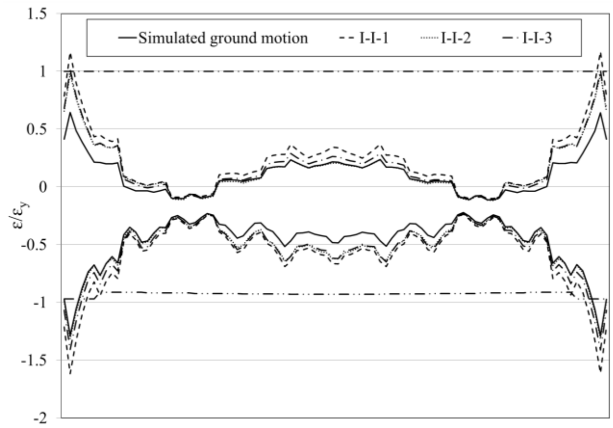


(a) Simulated ground motion and Type I

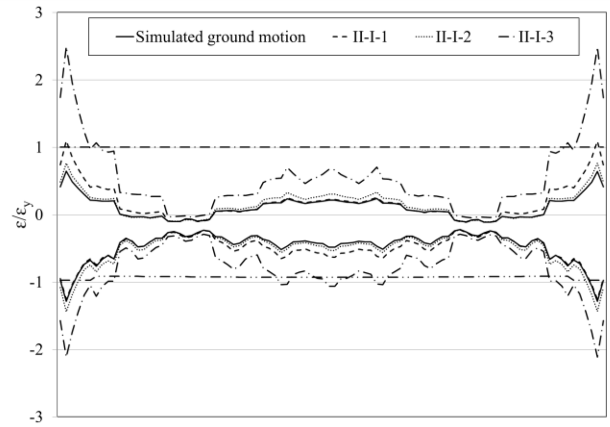


(b) Simulated ground motion and Type II

Fig.6 Strain response in longitudinal direction



(a) Simulated ground motion and Type I



(b) Simulated ground motion and Type II

Fig.7 Strain response in transverse direction

4. Conclusions

Dynamic response analyses of the Lohse arch bridge using the simulated ground motion of the Nankai Trough earthquakes and the design ground motions are carried out in this study. Strain results show that in both longitudinal direction and transverse direction, the distributions of the maximum strain along arch rib are in a close relationship. A further investigation of the reasons for current results will be examined in detail in the future.

References

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