EFFECT OF AGING OF RUBBER BEARINGS ON BASE-ISOLATED STEEL BRIDGE

Nagoya University, Student Member, ○ Paramashanti
Nagoya University, Member, Yasuo Kitane
Nagoya University, Fellow Member, Yoshito Itoh

1. Introduction

It is known that aging causes shear stiffness of rubber to increase. Rubber bearings commonly used as base-isolators also tend to increase their stiffness over time. In the current design specifications, this stiffness increase of rubber bearings due to aging is not considered. To examine the effect of aging of rubber bearings on the seismic response of a base-isolated bridge, a case study was conducted in this study. A base-isolated bridge with lead rubber bearings (LRB) and six-span continuous steel box girders owned by Nagoya Expressway Public Corporation was examined through dynamic analysis for 20, 40, 60, 80, and 100 years aging time.

The finite element (FE) model of the bridge is shown in Fig. 1. The bridge has T-type steel piers, and there are two main girders between Pier 47 and Pier 49, and three main girders between Pier 49 and Pier 53. The piers' heights vary from 15.4 to 15.8 m. Piers have stiffened box sections, and have concrete-filled sections at the bottom. Dimensions of the bearings and piers are shown in Table 1.

2. Long-Term Performance of LRB

Itoh et al.[1)] developed mathematical model to predict a change in the equivalent shear stiffness of a natural rubber (NR) bearing due to aging. Generally, the equivalent shear stiffness increases with aging time and temperature, and decreases with the bearing size. Based on the bearing size, the aging time, and the average yearly temperature at the construction site, property profiles of an NR bearing can be obtained. The equivalent shear stiffness of an LRB is determined by the shear stiffness of NR and the shear stiffness provided by lead plugs. Variations of the equivalent shear stiffness of LRBs due to aging calculated for an average temperature of Nagoya City (15.4˚C) for the longitudinal direction are shown in Fig. 2. In the figure, a ratio of the stiffness at a certain aging time to the initial stiffness, K_{Be}/K_{Be0}, is plotted for each pier. As can be seen from Fig. 2, the maximum change in the bearing equivalent shear stiffness is about 9%. Bearings on Pier 47 have the largest change because the bearings on Pier 47 have the smallest size among others. Itoh et al.[1)] showed the smaller the bearing size, the higher is the change of the bearing equivalent shear stiffness due to aging. The increase in the bearing equivalent shear stiffness results in a decrease in the global natural period. The global natural period decreased by 4% after 100 years.

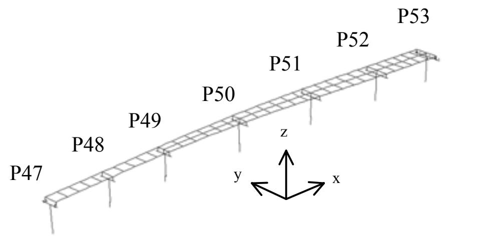

Fig. 1 FE model of the bridge

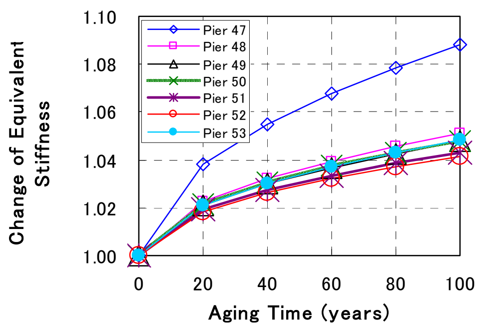

Fig. 2 Change of the bearing equivalent shear stiffness due to aging

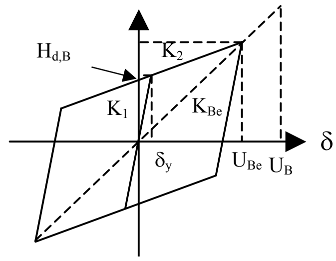

Fig. 3 Bilinear model of LRB

3. Seismic Response of Six-Span Base-Isolated Continuous Steel Bridge Due to Aging of Rubber Bearings

The general purpose finite element analysis program, ABAQUS, was used to perform dynamic analysis of the bridge. LRBs are modeled as truss elements with a bilinear force-displacement relationship as shown in Fig. 3. Mass elements are used to account for mass of girders, transverse beams, footings, and the influence of dead loads from the adjacent bridges on Pier 47 and Pier 53. However, seismic force from the adjacent bridges is not considered. Girders, transverse beams, and piers are modeled with beam elements. The soil profile of the site is classified as Type III. Earthquake records specified in Design Specifications of Highway Bridges[2)] for Level 2 Type II earthquake and Soil Profile III are used in the dynamic analysis.

Results from the dynamic analysis for the longitudinal direction of the bridge are shown in Fig. 4 through Fig. 6. Fig. 4 shows the comparison of force-displacement curves of LRBs on Pier 48 for the initial state (the condition of new bridge) and the state after 100 years aging time. It can be seen from the figure that the aging of rubber bearing results in an increase in the bearing shear stiffness, resulting in a decrease in the bearing displacement, and an increase in the

Keywords: rubber bearing, aging, base isolation, seismic performance, steel bridge
Contact Address: Department of Civil Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8603

Table 1 Dimensions of bearings and piers

Pier	Bearing				Pier				
	Length (m)	Width (m)	Thickness (m)	Static Shear Modulus of Rubber (kN/m^2)	Height (m)	Width of cross section (m)	Height of cross section (m)	Web thickness (m)	Flange thickness (m)
P47	0.66	0.66	0.165	800	15.5	2.8	2.5	0.027	0.03
P48	0.90	0.90	0.198	1,200	15.7	2.5	2.5	0.031	0.031
P49	0.90	0.90	0.189	1,000	15.7	2.5	2.5	0.041	0.041
P50	1.00	1.00	0.117	1,200	15.8	2.6	3.0	0.027	0.03
P51	1.05	1.05	0.144	1,200	15.8	2.6	3.0	0.042	0.042
P52	1.10	1.10	0.144	1,200	15.4	2.6	3.0	0.043	0.043
P53	0.92	0.92	0.187	1,200	15.5	2.8	3.0	0.047	0.041

horizontal force. At Pier 48, the maximum force increased by 6% after 100 years while the maximum displacement decreased by 7%. Since the increase of the bearing equivalent shear stiffness causes the global natural period to decrease and acceleration responses of the base-isolated bridge to increase, consequently seismic forces on the piers increase. Fig. 5 shows the change of residual displacements of the piers due to aging. The legend in the figure shows the residual displacements for the initial state in the parentheses. Residual displacements of the piers tend to increase with the aging time. The residual displacements of the piers increased by 150% at the most after 100 years at Pier 49. Allowable residual displacement is h/100, where h=height of the pier[2]. The maximum residual displacement is 0.038 m at Pier 50 at an aging time of 100 years, which is only 24% of the allowable value. All piers were found to satisfy the performance requirement for the residual displacement.

Fig. 6 shows a damage index for the stiffened steel box sections of the pier. The damage index is defined as a ratio between average compressive strain on the steel flange over effective failure length, $\varepsilon_{a,s}$, and failure strain for a stiffened box section, $\varepsilon_{u,s}$[3]. As can be seen in Fig. 6, the damage index tends to increase over time because the seismic force increases due to aging. The maximum change of the damage index is about 40% at Pier 49. However, all piers still satisfy the seismic performance requirement (damage index < 1.0) at the aging time of 100 years. The maximum steel damage index is 0.33 at Pier 50, which shows that the piers will have much redundancy against Level 2 earthquakes even when the aging effect of rubber bearings is considered for 100 years.

4. Conclusion

The equivalent shear stiffness of LRB increases due to aging of NR, which causes the seismic force on the bridge to increase. It is concluded that the base-isolated bridge analyzed in this study will still satisfy seismic performance requirements in 100 years without a replacement of rubber bearings. However, it is important to evaluate future seismic performance of a base-isolated bridge including the aging effect of rubber bearings so that an appropriate maintenance strategy for a life span of the bridge can be determined at the initial planning phase.

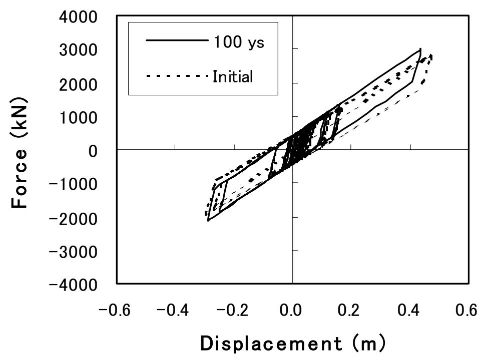

Fig. 4 Hysteretic curve of bearing on Pier 48

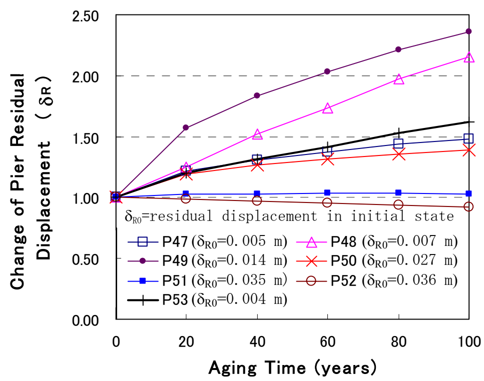

Fig. 5 Change of pier residual displacement

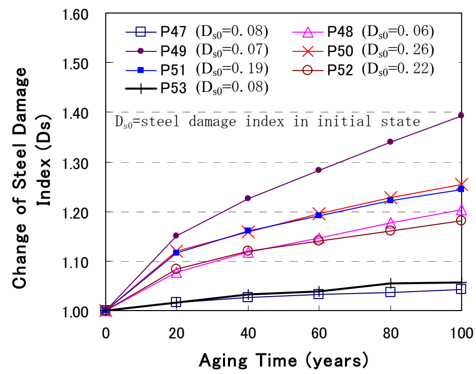

Fig. 6 Change of pier steel damage index

Reference

1) Itoh, Y. and Gu, H.S., Seismic Response of Steel Bridge Piers with Aged-Based Isolated Rubber Bearing, *Journal of Structural Engineering,* JSCE, Vol. 52A, March 2006.
2) Japan Road Association, *Design Specifications of Highway Bridges*, V, 2002 (in Japanese).
3) Zheng, Y., Usami, T., and Ge, H. B. Ductility Evaluation Procedure for Thin-Walled Steel Structures, *Journal of Structural Engineering,* ASCE Vol. 126, No.11, pp. 1312-1319, 2000.