Dynamic Response Analysis of A Base-Isolated Bridge Considering Ageing of Rubber Bearing

Nagoya University Student Member ○Haosheng Gu
Nagoya University Fellow Member Yoshito Itoh

1. Introduction

The performance-based design requires that the seismic behavior should not exceed the structural capacity in order to ensure that the bridge can resume normal function as quickly as possible after a severe earthquake. However, it is known that ageing causes the shear stiffness of rubber bearing to increase. Consequently the global natural period will decrease and the earthquake force acting on the pier becomes larger. Therefore, the future performance of the pier cannot be guaranteed without considering the ageing of bridge rubber bearing. Through dynamic response analysis on a base-isolated continuous steel bridge, this paper studies the variation of the bridge's response by considering the increase of rubber bearing's shear stiffness due to the ageing.

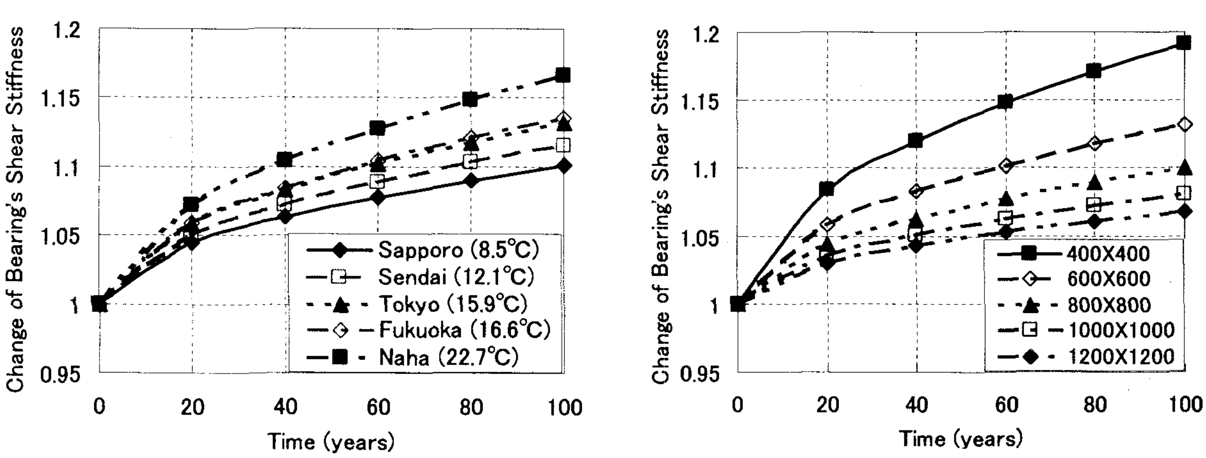
2. Ageing of Bridge Rubber Bearing

It has been clarified that rubber material stiffens due to ageing. The stiffness increases over the time and is mainly affected by temperature. Under higher temperature the ageing speed is faster. For thick rubber, because aged rubber will resist the oxidation progressing, namely the diffusion-limited oxidation effect, the outer surface of a rubber bearing is usually more affected by ageing than the interior region[1)]. The variation of small-sized rubber bearing is faster than large-sized because the proportion of the aged region is larger. The influences of the temperature and the size on nature rubber (NR) bearing are shown in Fig. 1. Itoh et al. predicted a 5-25% increase of shear stiffness of aged rubber bearing with different sizes from the coldest area to the hottest area in Japan[2)]. Thus, here the cases are examined with the equivalent stiffness K_b of rubber bearing increasing by 10%, 20% and 30%.

3. Dynamic Response Analysis of A Base-Isolated Continuous Steel Bridge

In this paper, a three-span base-isolated continuous steel bridge is studied. The analysis model is shown in Fig.2. The distributed vertical load of the superstructure is 118kN/m. The dead load of the neighbor span is considered, but the earthquake influence is neglected. The superstructure is simplified to a rectangle steel box section with the weight and sectional moment ($0.275m^4$) being the same. Height of the piers is 10m except for P2, which is 12m. The piers are also simplified to box sections without stiffeners. As for bridge rubber bearing, a bilinear model is adopted, as shown in Fig.3. The steel is the SM490 steel, with the material coefficients of E=206Gpa, σ_y=314MPa, ν=0.3, and E_p/E_e=1/100. The designed parameters of the piers and lead rubber bearings are shown in Table 1. It is assumed that the bridge is located on Ground Type I, and the JMA-NS earthquake (Level 2, Type I) is used in the dynamic analysis.

The analysis results are shown in Fig.4. It can be seen that with the increase of rubber bearing's shear stiffness due to the ageing, the displacement response of the bridge also increases. The maximum displacements of other piers increases about 9～16% when the shear stiffness of rubber bearing increases 30%. However, the maximum displacement of the superstructure only increases about 2% corresponding



(a) 600mm square NR bearing in various places (b) Different sized NR bearing in Tokyo (15.9℃)

Fig. 1 Long-term shear stiffness variation of natural rubber bearing due to ageing

Table 1 Parameters of the base-isolated highway bridge

1. Pier name	P_1	P_2	P_2	P_2
2. Pier height L (m)	10	12	10	10
3. Width of cross section b (m)	1.2	1.2	1.2	1.2
4. Thickness of cross section t (mm)	14	14	18	14
5. Axial force N (MN)	1.88×2	5.18	5.18	1.88×2
6. Yield horizontal displacement (mm)	69	92	66	69
7. The 1st stiffness of 4 LRB K_1 (MN/m)	54.4	58.3	53.3	54.4
8. The 2nd stiffness of 4 LRB K_1 (MN/m)	8.4	9.0	8.2	8.1
9. Yielding force of 4 LRB Q_y (kN)	198	151	198	198
10. Displacement of bearing (m)	0.101	0.069	0.109	0.101

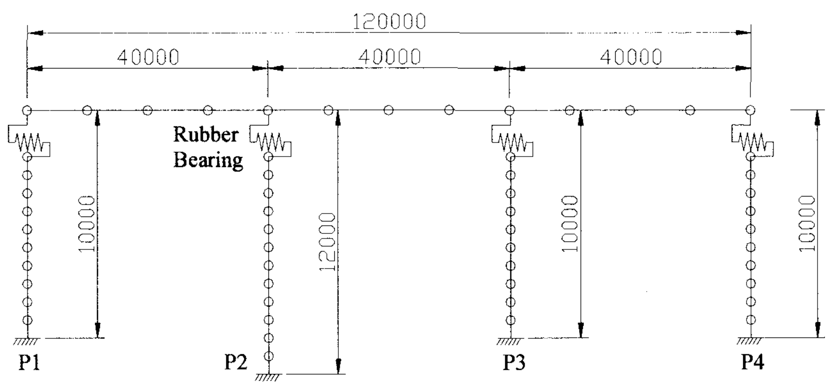


Fig.2 FEM model of continuous base-isolated highway bridge

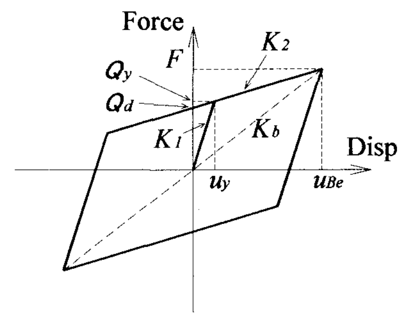


Fig.3 Bearing hysteresis curve

to 30% up of bearing's stiffness.

For example, from Fig.1(b) it is known that the equivalent stiffness of a 400mm square rubber bearing located in Tokyo increases by 20% after 100 years. In initial state the maximum displacement of P3 is 2.4 δ_y when attacked by JMA-NS earthquake. Then after 100 years the maximum displacement of P3 will increase by 12%, which will be 2.4 δ_y. Japanese Society of Steel Construction (JSSC 2004) prescribed that under Level 2 earthquake the limitations of the maximum displacement of a concrete-non-filled steel pier belonging to important structure is 4 δ_y[3]. Therefore, the serviceability of this bridge in 100 years can be ensured.

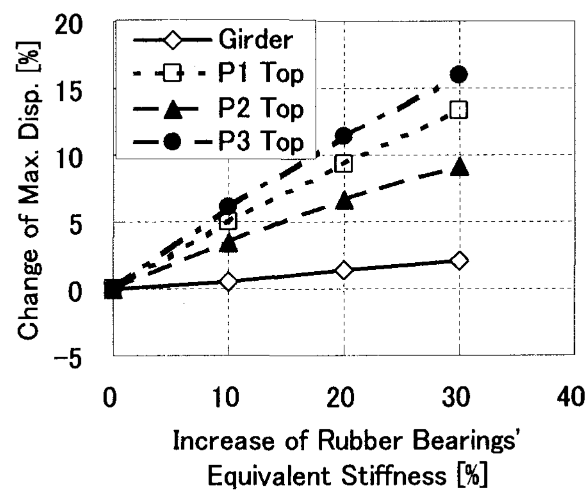


Fig.4 Variations of the maximum response

4. Conclusions

Through dynamic response analysis on a base-isolated continuous steel bridge considering the increase of rubber bearing's stiffness due to the ageing, it is known that the maximum displacement responses of the piers increase, however, the maximum displacement of the superstructure does not change much. Using this analysis method, the future performance of the base-isolated steel bridges can be estimated. It helps to establish proper maintenance strategy for the rubber bearing.

Reference

[1] Itoh, Y., Satoh, K., Gu, H. S. and Yamamoto, Y. 2005a. Study on the long-term deterioration of natural rubber of bridge bearings. *Journal of Structure Mechanics and Earthquake Engineering*, JSCE, No.801/I-73: 185-196 (in Japanese).

[2] Itoh, Y., Satoh, K., Gu, H. S. and Yamamoto, Y. Study on the deterioration characteristics of natural rubber bearings. *Journal of Structure Mechanics and Earthquake Engineering*, JSCE (tentatively accepted).

[3] Japan Society of Steel Construction. 2004. *Method of dynamic aseismatic performance inspection and advancement of civil steel structures*: JSSC (in Japanese).