ANALYTICAL STUDY ON SEISMIC BEHAVIOR OF BASE ISOLATED BRIDGE SUPPORTED BY DOUBLE SPHERICAL SLIDING BEARINGS

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Abstract

Laminated rubber bearings have been adopted for many bridges and buildings in Japan, and researches have conducted to improve their performance. However, in 2011 Tohoku Earthquake and 2016 Kumamoto earthquake, it was found that laminated rubber bearings were damaged and some of them were fractured. Therefore, it is important to develop a different type of bearings from the laminated rubber bearings in order not to rely on one type of bearings for seismic application.

A spherical sliding bearing (SSB) is a pendulum type of seismic isolation bearings in which a movable body slides while being affected by friction over the concave spherical surfaces. A double spherical sliding bearing is movable at both sides of a slider, allowing larger displacement than a single spherical sliding bearing. And the friction coefficient can be changed on the upper and lower surfaces. The properties of the double spherical sliding bearing were investigated using model specimens [1] and a behavior of the model bridge with double spherical bearings were examined subjected seismic loadings [2]. However, seismic behavior of an actual base isolated bridge supported by the double spherical sliding bearings has not been well understood. Therefore, in this study, nonlinear dynamic analyses were conducted in order to simulate and investigate the behavior of an actual bridge with double spherical sliding bearings under earthquake ground motions.

Analysis results showed that horizontal force and displacement of double spherical sliding bearings were affected by a friction coefficient. Maximum displacement became smaller and maximum force became larger as a friction coefficient increased in the SSB model. In addition, maximum bending moment and curvature of SSB increased as a friction coefficient increased. It is concluded that seismic response of the model bridge with double spherical bearings were affected by a friction coefficient.

Keywords: double spherical sliding bearing, nonlinear dynamic analysis, bilinear model, equivalent linear method

1. Introduction

Laminated rubber bearings have been adopted for many bridges and buildings in Japan, and researches have conducted to improve their performance. However, in 2011 Tohoku Earthquake and 2016 Kumamoto earthquake, it was found that laminated rubber bearings were damaged and some of them were fractured. Therefore, it is important to develop a different type of bearings from the laminated rubber bearings in order not to rely on one type of bearings for seismic application.

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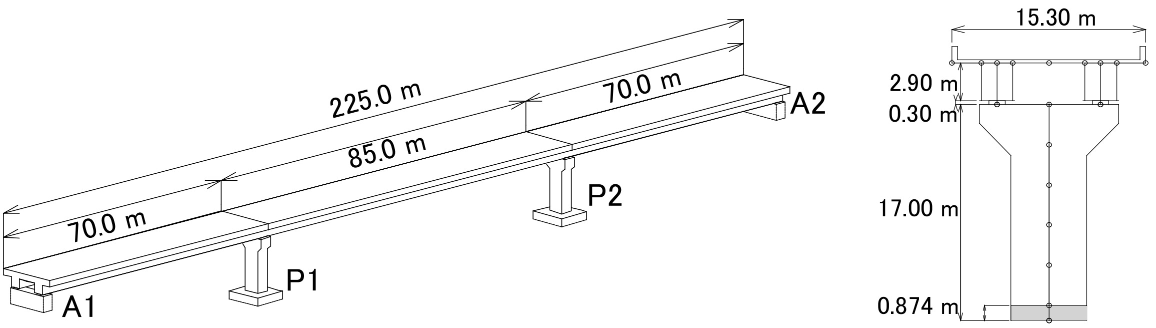
2. Nonlinear dynamic analyses

2.1 Target bridge for analyses

Fig.1 shows the schematic diagram of a target bridge to be analysed. The bridge is a base isolated bridge designed by specifications for highway bridges [3] with high-damping rubber bearings (HDR). The bridge is a three-span continuous and 225-m long bridge with steel box girder superstructure. The superstructure consists of two steel box girders and concrete slab being isolated by two bearings at each abutment and column location; a total of 8 bearings. The analyses were conducted for two different types of bearings; the HDR model and the SSB model.



(a) Layout of bridge (b) Elevation of P1, P2

Fig. 1 – Schematic diagram of bridge

2.2 Analytical model

The geometry and model of the bridge are shown in Fig. 2. The superstructure was modeled as a grid deck using elastic beam element. Only the plastic hinges at the column base were modeled using nonlinear fiber elements and the column outside of the plastic hinges were idealized as elastic beam elements. Combination of an envelope curve proposed by Hoshikuma et al. [4] and unloading and reloading paths proposed by Sakai et al. [5] were used for cover and core concrete. Menegotto-and-Pinto model modified by Sakai et al. to prevent the stress overestimation due to small unloading and reloading [6] was used for reinforcement. Concrete strength was 24 MPa and yield strength of longitudinal and tie reinforcements was 345 MPa.

Two different types of bearings; HDR and SSB, were modeled by bilinear spring elements for horizontal movement as shown in Fig. 2. The initial stiffness of the SSB model was taken as being large enough to be rigid in order to model a rigid-plastic behavior. Three different friction coefficients (μ = 0.05, 0.10 and 0.15) were used for the analyses to examine the effect of friction to the bridge behavior. As for the vertical movement, the uplift was allowed in the SSB model as shown in Fig. 2. The HDR was designed by specifications for highway bridges in Japan [2].

2.4 Analytical method

Nonlinear time-history analyses were carried out using recorded ground motions. The mass and stiffness proportional damping (Rayleigh damping) was used for damping. When setting the parameters of Rayleigh damping for a structure that has a high-stiffness member such as the initial stiffness of the SSB, the damping constant could not be calculated correctly. Therefore, when conducting an eigenvalue analysis, the non-linear characteristics of the SSB was considered by being treated as equivalent linear characteristics. The calculated equivalent linear characteristics are presented in Table 1 for both SSB and HDR models. The parameters of Rayleigh damping were determined based on the modal damping of the predominant modes in the longitudinal and vertical directions; primary and secondary modes, respectively.

The recorded ground motion used in the time-history analyses was JMA Kobe which is one of the records obtained from the 1995 Kobe Earthquake. The acceleration histories are shown in Fig. 3(a) and the acceleration response spectra for 5% damping is presented in Fig. 3(b) along with the Level 2 design response spectra in Japan. Three directional components of the wave were applied simultaneously to the bridge. The governing equations of motion were solved by using Newmark's method (β = 0.25).

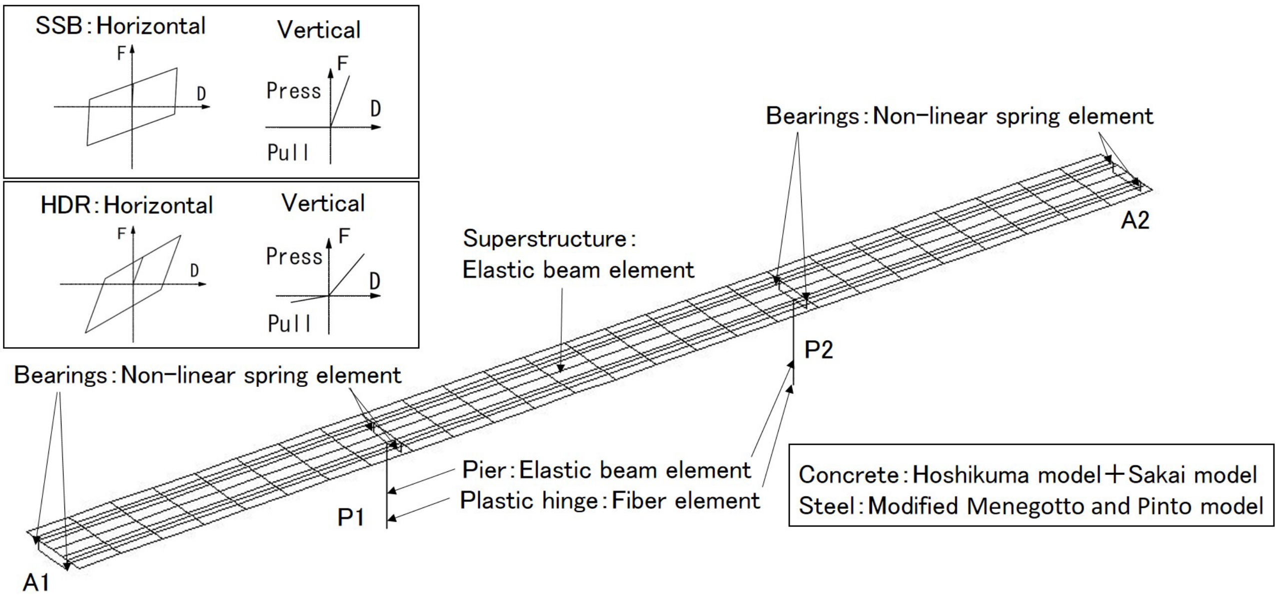
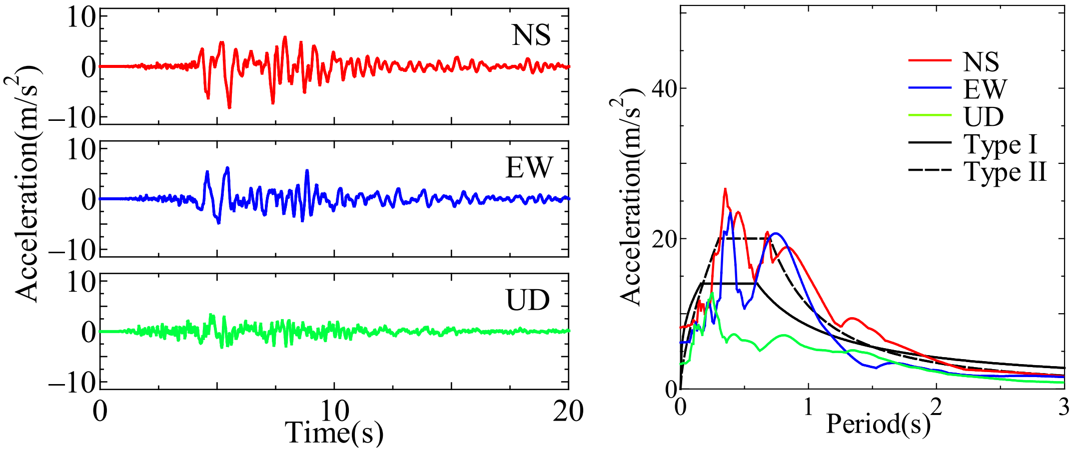


Fig. 2 – Analysis model

Table 1 – Equivalent linear characteristics

	SSB			HDR
Friction coefficient μ	0.05	0.10	0.15	N/A
Equivalent stiffness *Ke(MN/m)*	5.04	7.46	9.98	11.31
Equivalent damping coefficient *he*	0.21	0.35	0.43	0.17
Equivalent natural period *Te(s)*	2.71	2.23	1.92	1.75



(a) Recorded ground motions of JMA Kobe (b) Acceleration response spectra (for 5% damping)

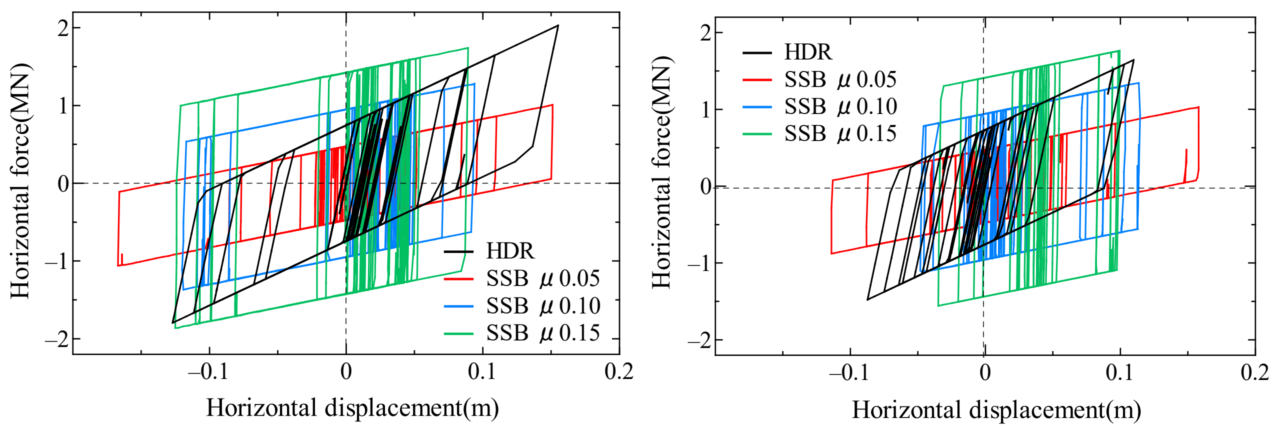
Fig. 3 – Input ground motion from 1995 Kobe Earthquake (JMA Kobe)

3. Analytical Results

Based on the time-history analyses, bearing response, residual displacement of the superstructure and column response were investigated to understand a behavior of the bridge with double SSBs under earthquake ground motions.

3.1 Bearing response

Fig.4 shows the hysteresis loops of the bearing located on P1 in the longitudinal and transverse directions. Fig.4 compares the hysteresis loop of HDR with that of SSB for three friction coefficients μ=0.05, 0.10 and 0.15. Maximum horizontal force tends to become smaller as the friction coefficient becomes smaller in the SSB model. The maximum force of HDR is larger than that of SSB with friction coefficient μ=0.05 and 0.10. This is because the natural period of SSB with μ=0.05 and 0.10 is longer than that of HDR, and less seismic force is attracted to SSB from the superstructure. As for the response of displacement, the maximum displacement tends to become smaller as a friction coefficient increases in the SSB model. This is from the effect of hysteresis damping which is associated with the area of the hysteresis curve.

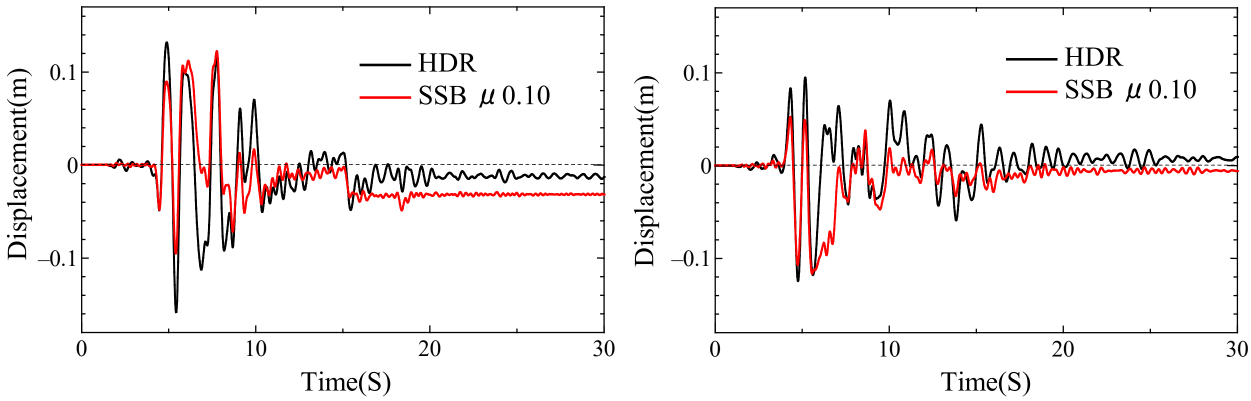


(a) Longitudinal direction (b) Transverse direction

Fig. 4 – Horizontal force-displacement hysteresis loops of bearing on P1

3.2 Residual displacement of superstructure

Since SSB is generally thought to have a recentering behavior due to the pendulum motion, displacement response of the superstructure was investigated to examine the residual displacement at the end of the earthquake excitation. Fig.5 shows the time-history displacement response of the superstructure and compares the response of HDR with that of SSB with friction coefficient μ = 0.10. From both graphs in two directions, the maximum displacement of SSB is smaller than that of HDR. The SSB tends to cause larger residual displacement than the HDR and the residual displacement of HDR is about 35mm in longitudinal direction. This is because the unloading stiffness of SSB is much larger than that of HDR as shown in Fig.4, which is from the effect of friction force.

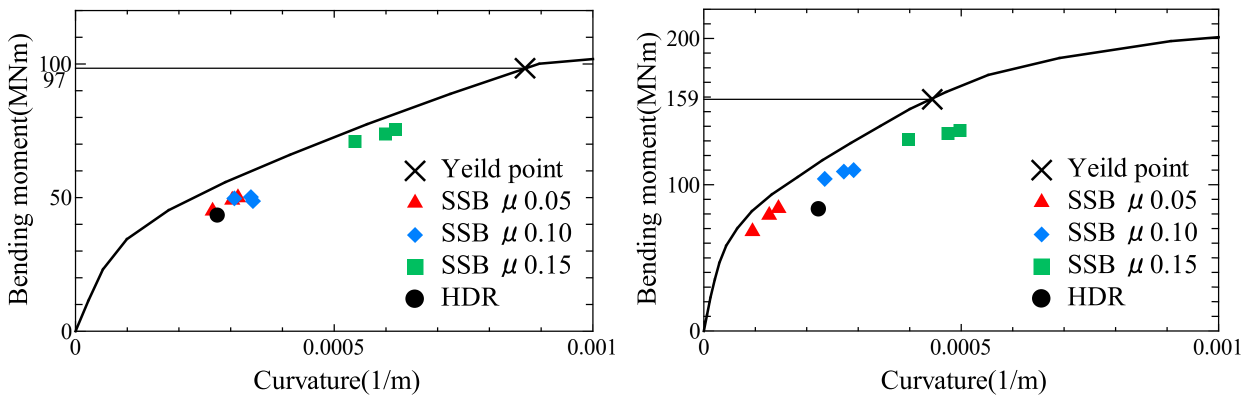


(a) Longitudinal direction (b) Transverse direction

Fig. 5 – The time history displacement response of superstructure on P1

3.3 Column response

The maximum response of the bending moment and its curvature in the plastic hinge of P1 column was plotted in Fig.6 to examine the horizontal forces transferred to the column from the bearings. There are results from a total of 10 cases; 3 spherical radius cases (1000mm, 1500m and 2000mm) of SSB with three friction coefficients (μ=0.05, 0.10 and 0.15) at each spherical radius and one HDR case. Fig.6 also presents the moment curvature relationship of the plastic hinge calculated by a pushover analysis. Fig.6 shows that the maximum bending moment and curvature of SSB increase as the friction coefficient increases. The spherical sliding bearing behaves as being rigid until the slider slides as shown in Fig.4. Therefore, the larger force is transferred to the column as a friction coefficient is larger, which increases the bending moment and curvature of the column.



(a) Longitudinal direction (b) Transverse direction

Fig. 6 – Maximum bending moment-curvature relationship of plastic hinge of P1

5. Conclusions

In this research, seismic behavior of a three span continuous bridge supported by double spherical sliding bearings as isolation was investigated based on the nonlinear dynamic analyses using JMA Kobe earthquake record. The results are summarized as follows;

1. Horizontal force and displacement of double spherical sliding bearings were affected by a friction coefficient. As a friction coefficient increased in the SSB model, maximum displacement became smaller and maximum force became larger.
2. Residual displacement of SSB was larger than that of HDR in this analytical case.
3. Maximum bending moment and curvature of SSB increased as a friction coefficient increased.

6. References

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