

Effect of Bearing Supports Configurations on Seismic Response of a Curved Viaduct with Integrated Sliding Bearing System

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1. Introduction

In the past decades, horizontally curved viaducts have become an important component in modern highway systems. They represent a viable option at complicated interchanges or river crossings. In addition, the curved alignments result in better aesthetics, an increase in traffic sight distances and economically competitive construction costs compared with straight bridges. However, bridges with curved configurations may sustain severe damage owing to rotation of the superstructure or displacement towards the outside of the curve due to the complex vibrations that occur during an earthquake^[1].

On the other hand, a new type of bearing system, integrated sliding bearing system has gradually began to be adopted. Unlike conventional bearing systems, this system separates bearings into those supporting vertical and horizontal loads so that allows flexible functionality and enables replacement as required of only the deteriorated part, resulting in reduction of life cycle costs. Sliding bearings are generally used for the vertical load, while dispersing and seismic isolating rubber bearings are used for the horizontal load^[2].

Therefore, the purpose of the present study is to analyze the seismic response of curved highway viaduct which equipped with integrated sliding bearing system under the 1995 Kobe earthquakes. The comparison among three different stiffness rubber bearings and three different restraint configurations of sliding bearings is presented. The study combines non-linear dynamic analysis with a three-dimensional bridge model in order to evaluate the seismic response accurately.

2. Analytical model of viaduct

The great complexity associated with the seismic analysis of highway viaducts means that a realistic prediction of the bridge structural responses is difficult. Therefore, the seismic analysis of the viaduct employs a non-linear computer model that simulates the highly non-linear response caused by level II earthquakes^[3]. Non-linearity is also considered for characterization of the non-linear structural elements of piers and bearings.

The highway viaduct considered in the analysis is composed of a three-span continuous superstructure. The overall viaduct length of 120 m is divided into equal spans of 40 m as shown in the Fig. 1(a) and (b). A radius of curvature 200 m, measured from the origin of the circular arc to the

centerline of the bridge deck are taken into consideration. Tangential configuration for both piers and bearing supports is adopted with respect to the global coordinate system for the bridge, as shown in the figure. The X- and Y-axes lie in the horizontal plane, the Z-axis is vertical.

2.1 Deck superstructure and piers

The highway viaduct superstructure consists of a reinforced concrete deck slab that rests on 3 I-shape steel girders, equally spaced at an interval of 2.1 m. The weight of the deck is supported on 4 hollow box section steel piers with 20 m height, 2.4m width and 0.05m thickness designed according to the Japanese seismic code^[1]. Characterization of structural pier elements is based on fiber element modeling where the inelasticity of the flexure element is accounted for by the division of the cross-section into a discrete number of longitudinal and transverse fiber regions with the constitutive model based on uniaxial stress-strain relationship for each zone.

2.2 Bearing supports

Since the viaduct model with three girders, outside and inside girders are equipped with friction sliding bearings, while the middle girder is equipped with rubber bearings as shown in the Fig. 2. The friction sliding bearings are represented by the bilinear force-displacement hysteric loop using high stiffness property to pre-yield stiffness and approximate zero to post-yield stiffness^[2] as shown in the Fig. 3 (a). The rubber bearings are represented by the linear

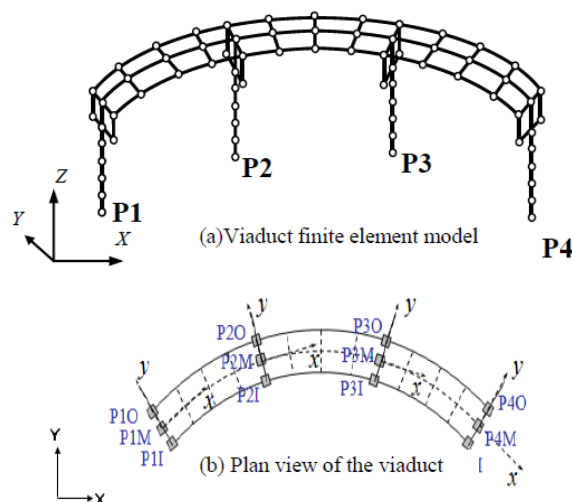


Fig.1 Analytical model of viaduct

displacement-load relationship^[2] as shown in the **Fig. 3(b)**. A sliding bearing with friction coefficient (μ) of 0.12 and three different stiffness rubber bearings and are discussed in the present study.

Displacements of sliding bearings in integrated sliding bearing system have been partially limited for some configurations as shown graphically in **Fig. 4**. Out-plane radial displacements are restricted in a-configuration (Case1) for all isolation units, representing the most commonly used method of bearing restraint in Japan. Sliding bearings in c-configuration (Case3) are such as to allow for free transverse movements. This is the simplest bearing arrangement, which has the advantage to distribute transverse forces in bridge transverse directions. This fact also makes the structure susceptible to large transverse displacements that may develop when the bridge is subjected to strong earthquake loading. An intermediate solution is adopted for b-configuration (Case2) to alleviate the lateral forces without inducing excessive radial displacements. The modification consists in providing stoppers to end-span sliding bearings to limit the joint displacements exclusively in the in-plane tangential direction; while the sliding bearings of intermediate piers are free two moves in both directions.

3. Method of Analysis

The analysis on the highway viaduct model is conducted using an analytical method based on the elasto-plastic finite displacement dynamic response analysis. The tangent stiffness matrix, considering both geometric and material nonlinearities is adopted in this study, being the cross sectional properties of the nonlinear elements prescribed by using fiber elements. The stress-strain relationship of the beam-column element is modeled as a bilinear type. The yield stress is 235.4 MPa, the elastic modulus is 200 GPa and the strain hardening in plastic area is 0.01^[4]. To assess the seismic performance of the viaduct, the nonlinear bridge model is subjected to the longitudinal, transverse and vertical components of a strong ground motion records from the Takatori Station during the 1995 Kobe Earthquake as shown in the **Fig. 5**. The longitudinal earthquake component shakes the highway viaduct parallel to the X-axis of the global coordinate system, while the transverse and vertical components are acting in the Y- and Z-axes, respectively. The large magnitude records from the 1995 Kobe Earthquake used in this study, classified as near-fault motions, are characterized by the presence of high peak accelerations and strong velocity pulses with a long period component as well as large ground displacements^[3].

4. Numerical results

4.1 Bearing supports response

This section clarifies the selection of the optimum stiffness of rubber bearings and configurations of sliding bearings in the integrated sliding bearing system by comparing the calculated results in terms of maximum bearing deformations,

maximum bearing displacements and maximum bearing forces. These deformations, displacements and forces are considered at the bearings resting on the top of the P1 and P3 piers in longitudinal direction (x) and transverse direction (y).

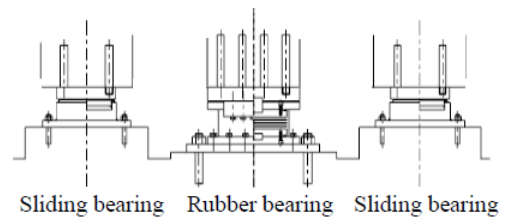


Fig.2 Arrangement of bearing supports

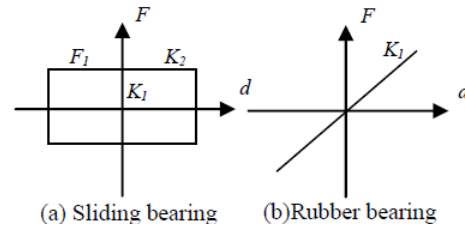


Fig.3 Analytical models of bearing supports

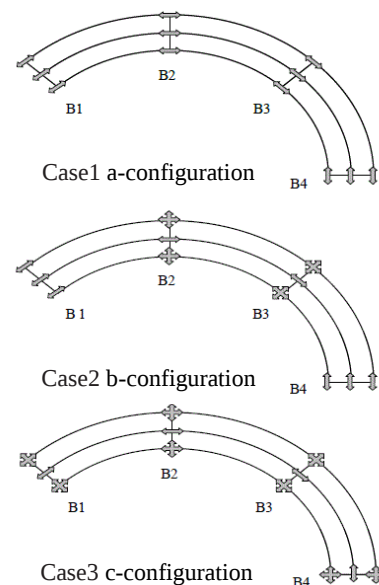


Fig.4 Restraint configurations of bearing supports

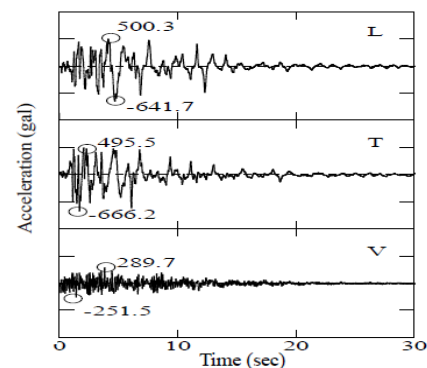


Fig.5 JR Takatori st. record 1995 Kobe earthquake

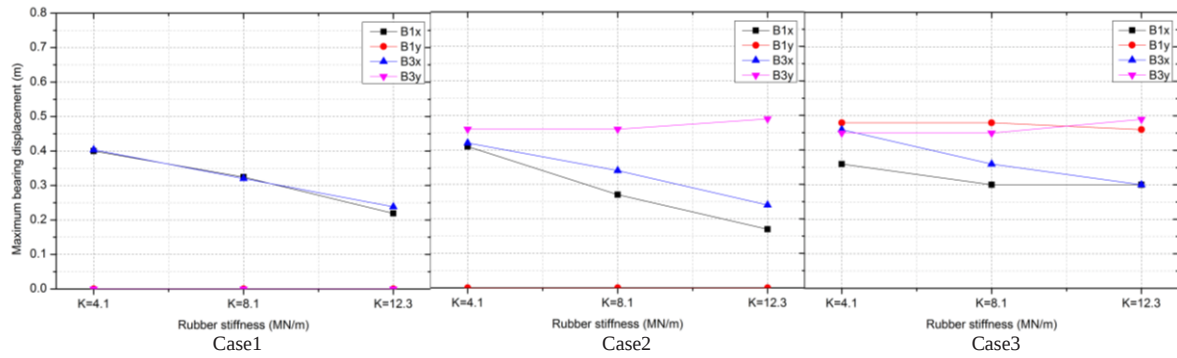


Fig.6 Effect of bearing supports configurations and rubber stiffness on maximum sliding bearing displacement

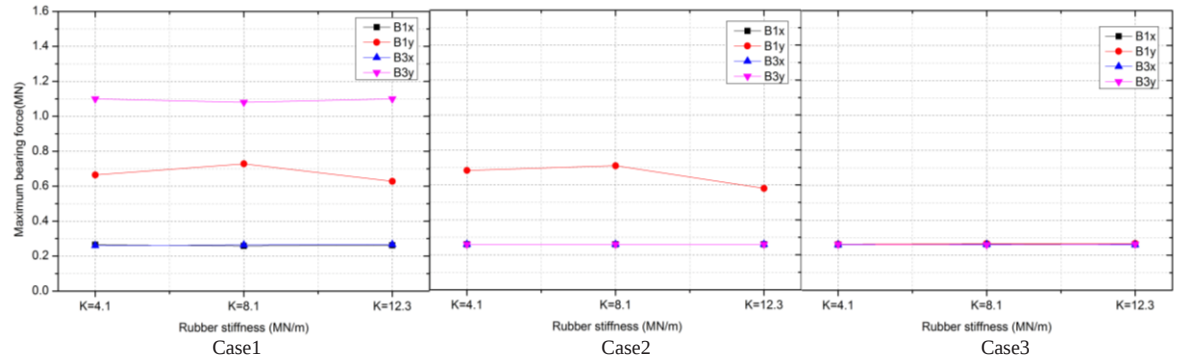


Fig.7 Effect of bearing supports configurations and rubber stiffness on maximum sliding bearing force

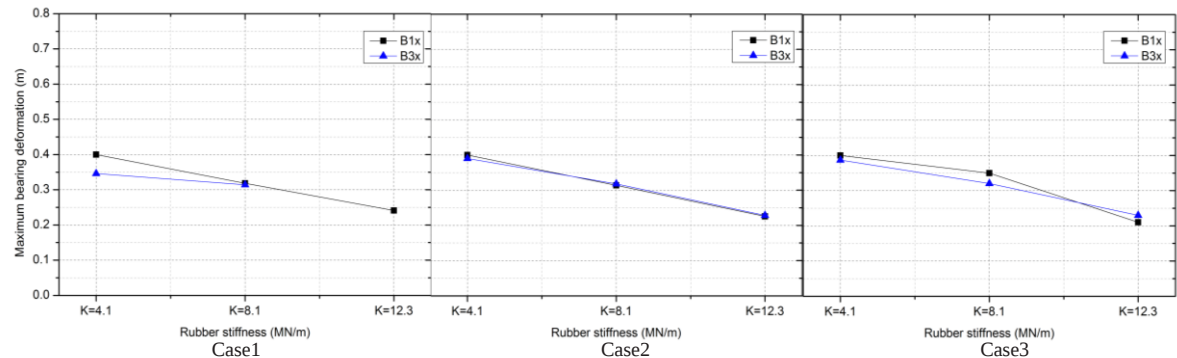


Fig.8 Effect of bearing supports configurations and rubber stiffness on maximum rubber bearing deformation

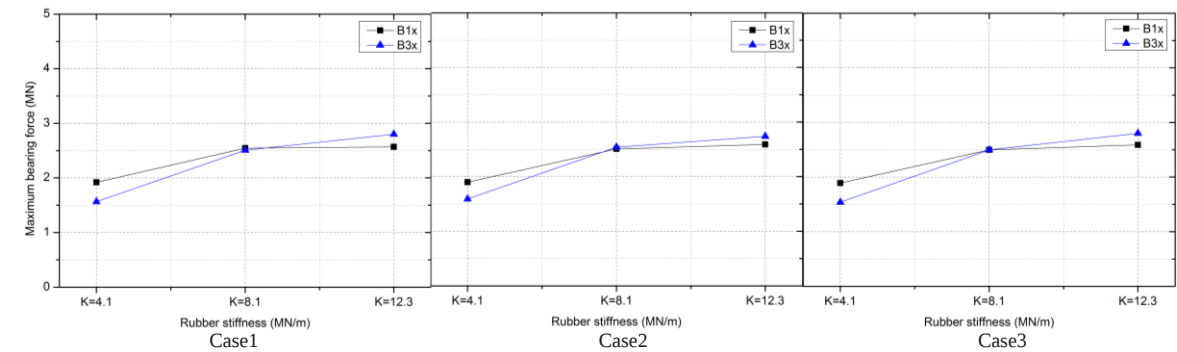


Fig.9 Effect of bearing supports configurations and rubber stiffness on maximum rubber bearing force

Firstly, the response of sliding bearings located on outside girders is analyzed and the calculated results are shown in the **Figs. 6 and 7**. In longitudinal direction, it can be seen that a significant increase tendency on the bearing displacements is observed with the decrease of the rubber bearing stiffness in the integrated sliding bearing system among all the cases. In transverse direction, the induced relative displacements to sliding bearings are different due to three configurations. In Case3, both B1 and B3 sliding bearings induced a larger relative displacement.

On the other hand, the sliding bearing force is analyzed. Since the dead load supported on the sliding bearings and the friction coefficient are constant values, the sliding bearing force would be expected to be a relatively uniformity value when the slide bearings start to slide during an earthquake. Therefore, in longitudinal direction, the sliding bearings in all cases have started to slide is confirmed. In the meanwhile, the sliding bearing forces of B1 and B3 in Case1 or B1 sliding bearings in Case2 in transverse direction are significantly larger than in longitudinal direction since the different configurations.

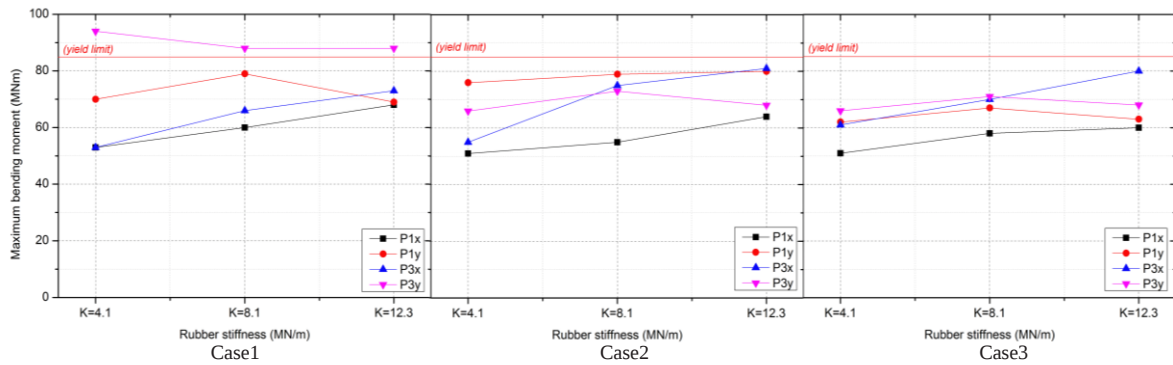


Fig.10 Effect of bearing supports configurations and rubber stiffness on maximum bending moment

Secondly, the calculated results of rubber bearings are shown in the **Figs. 8** and **9**. Only results in longitudinal direction were demonstrated since the rubber bearings configurations. An obvious increase tendency among all the cases on the bearing deformation is observed with the decrease of rubber bearing stiffness in the integrated sliding bearing system. On the other hand, the rubber bearing force is analyzed. An increment on the bearing forces is observed among the cases which equipped with larger stiffness rubber bearings in the integrated sliding bearing system.

4.2 Pier response

When a bridge is subjected to strong earthquake shaking, the supporting piers may suffer severe seismic damage at their bases. The maximum bending moment transmitted to the base of the pier can be considered to be an appropriate measure of seismic structural damage and been adopted as an important response factor in this study. Since the analytical model with a symmetric structure, only the results of P1 and P3 are shown in the **Fig. 10** for a better appreciation of the pier responses.

Firstly, in longitudinal direction, all of the bending moments are less than the yield limit, so that all the piers behaved elastically in this direction can be expected during a level II earthquake. Furthermore, an increase tendency on the bending moment is observed with the increase of the rubber bearing stiffness in the integrated sliding bearing system.

Secondly, the results in transverse direction are analyzed. In Case1, an increment on the maximum bending moment is observed comparing with the results in longitudinal direction, where the maximum bending moments of P3 overpasses the yield limit. It is clear that the increment on the bending moments due to the restricted of bearing supports in transverse direction. In addition, no obvious influence on the maximum bending moment is observed by changing the rubber stiffness in this direction. In Case3, since all the sliding bearings are such as to allow for free transverse movements, a significant decrement on the maximum bending moment of P1 and P3 is observed comparing with the results in Case1 and all of the bending moments are less than the yield limit. In Case2, since only B3 sliding bearings are to allowing for free transverse movements, only the decrement on maximum bending moment of P3 is observed comparing with the results in Case1, however all of the bending moments are still less than the yield limit. So

that to allow some flexibility of sliding bearings in transverse direction would possible to reduce pier damage is confirmed.

5. Conclusions

The effectiveness of integrated sliding bearing system on curved highway viaducts has been analyzed. The investigation results provide sufficient evidence for the following conclusions:

- (1)Bearings systems in curved viaducts are found vulnerable to damage during a level II earthquake. The possibility of exceeding bearing displacements and deformations increases by reducing the stiffness of rubber bearings in the integrated sliding bearing system. Allow flexibility of sliding bearings makes the bearings systems to large displacements.
- (2)It is observed that adopting integrated sliding bearing system is an effective method to protect the piers of curved highway viaducts from damage during a level II earthquake. For the purpose of reducing the pier damage, to allow some flexibility of sliding bearings in transverse direction would possible to be expected as a suitable solution.
- (3)Finally, the effectiveness of integrated sliding bearing system on curved highway viaducts is demonstrated, especially by adopting the medium stiffness rubber bearings with the b-configuration (Case2)which resulting in reducing the possible vulnerability of a viaduct during a level II earthquake.

References

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