Effect of Pier Height on Seismic Response of Isolated Curved Highway Bridges

Hokkaido University	Fellow member	Toshiro Hayashikawa
Hokkaido University		○ Javier Gil Belda
Hokkaido University	Student member	Carlos Mendez Galindo
Hokkaido University	Member	Takashi Matsumoto
Hokkaido University	Member	Xingwen He

1. INTRODUCTION

During the last decades horizontally curved viaducts have become an important component in modern highway systems.

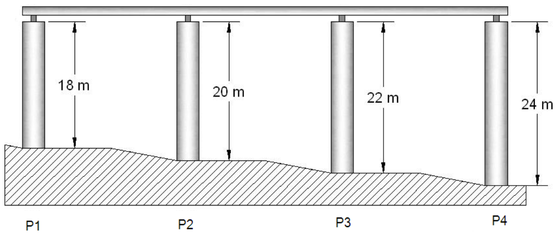
However, bridges with curved configurations may sustain severe damage owing to rotation of the superstructure or displacement toward the outside of the curve line due to complex vibrations occurring during an earthquake[1]. Besides, the performance of this kind of structures under great earthquakes presents a variation in terms of seismic behavior when the piers present different height.

Bridges can be seismically upgraded through the use of seismic isolation devices. The LRB's are steel reinforced elastomeric bearings in which a lead core is inserted to provide hysteretic damping as well as rigidity against minor earthquakes, wind and service loads[2].

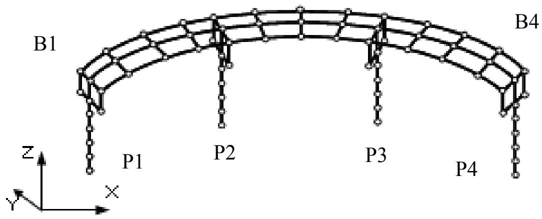
2. ANALYTICAL MODEL OF VIADUCT

The highway viaduct considered in the analysis is composed by a three-span continuous seismically isolated deck, consists of a concrete deck slab that rests on three I-shape steel girders. The overall viaduct length of 120 m has been divided in equal spans of 40 m, as represented in **Fig. 1**. The bridge alignment is horizontally curved in a circular arc. LRB's, as represented on **Fig. 2**, are installed on top of each pier for seismic isolation.

The bridge seismic performance has been evaluated on three different pier disposition patterns, as shown on **Table 1.** The analysis on the highway viaduct model is conducted using an analytical method based on the elasto-plastic finite displacement dynamic response analysis[3]. 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 implicit time integration Newmark scheme is formulated and used to directly calculate the responses, while the Newton-Raphson iteration method is used to achieve the acceptable accuracy in the response calculations. To assess the seismic performance of the viaduct, the nonlinear bridge model is subjected to a strong ground motion records from Takatori (TAK) and Kobe (KOB) stations during the 1995 Kobe Earthquake, as well as from Rinaldi (RIN) Station from the 1994 Northridge Earthquake.



a) Elevation view of viaduct



b) Detail of curved viaduct finite element model

Fig.1 Model of curved highway viaduct

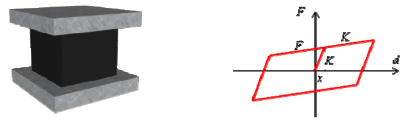


Fig. 2 Representation and analytical model of LRB bearings supports

Table 1 Viaduct pier heights

Case	Pier heights (m)			
	P1	P2	P3	P4
PD1	20	20	20	20
PD2	18	20	22	24
PD3	24	22	20	18

3. DECK RESPONSE

The effect of different pier dispositions is analyzed. In **Fig. 3** there is a representation of the obtained results from models. In this figure, the maximum deck displacements at the top of the bearings are shown, considering the three different pier disposition cases: PD1, PD2 and PD3.

At first the results obtained from TAK input earthquake. It can be seen that the worst condition is PD2 case, with similar displacements for the piers P2 and P3. It can be noticed that the use of non-equal piers increases the deck displacements. The highest values from the analyzed are the ones obtained from Takatori results input, with values in the range of 0.40m and 0.45m. For KOB input, the displacements

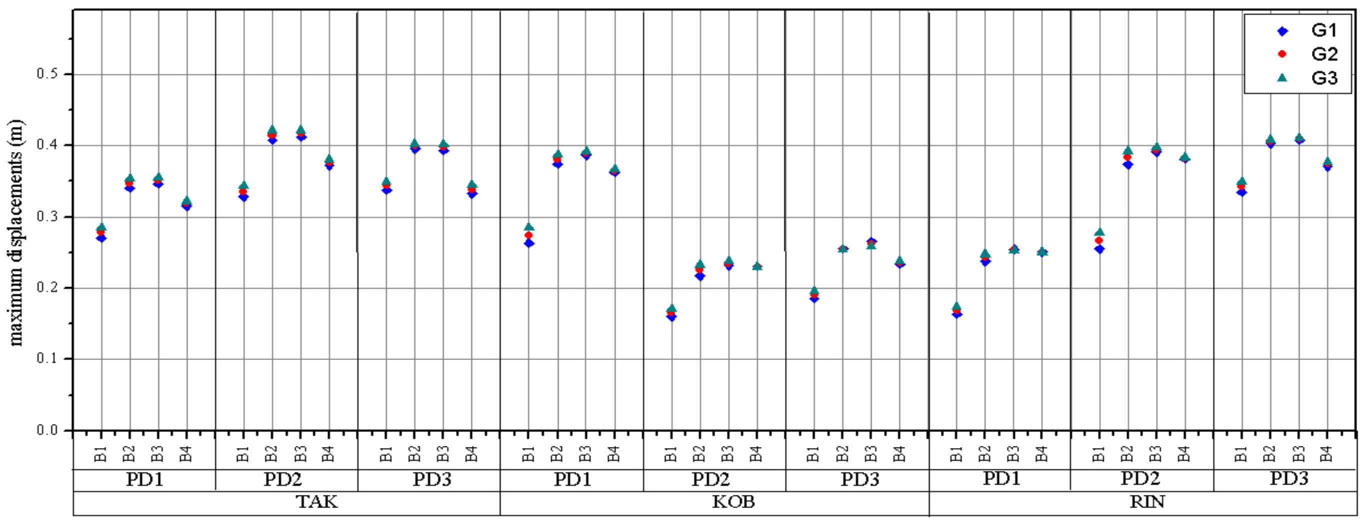


Fig. 3 Deck displacements for PD1, PD2 and PD3 in every girder

are lower when the piers have different height as can be seen on the graphic. There is a significant difference if the earthquake enters by the tallest or by the shortest pier. For the RIN input, once again the displacements on the deck increase by using different pier heights. The displacements significantly reach from a maximum of 0.25m in PD1, to a maximum of 0.40m in PD2 and PD3.

4. PIER DAMAGE

In order to know the way the damage that the earthquake causes on the piers, top pier displacements are represented in **Fig. 4**. Since the most severe condition has been TAK earthquake, as can be appreciated in the previous section, the analisys is focused on that earthquake input for obtaining more useful results.

Observing the results from PD1, can be seen that the displacements in the central piers are higher than in exterior piers, and always within and acceptable range, lower than 0.20m.

The results from PD2 show that with this disposition the displacements on piers P1 and P4 are different to each other, as well as the displacement values increase in the central piers, overpassing the value of 0.20m.

In the case of PD3, the worst of them, as can be appreciated on the figure, both P1 and P2 present high displacements. This time the displacements in P2 are around 0.25 m.

5. ENERGY DISTRIBUTION

In order to evaluate the energy distribution during the earthquake, **Fig. 5** shows the total energy absorbed by the structure during the earthquake, as well as the specific strain energy absorbed by the piers. For the TAK input the energy that has to be absorbed by the bridge is increasing in PD2 and PD3, compraing with PD1. However for KOB and RIN inputs it remains very similar.

The graphic of strain energy gives information about the absorbed energy by the piers. Can be noticed that for TAK input the amount of absorbed energy by the piers in case PD2 and PD3 is higher than for PD1. By contrast, for KOB input the amount of absorbed energy decreases in PD2 and PD3. Finally, for RIN input the energy remains in a similar value.

6. CONCLUSIONS

In this study the effect of using non-equal pier height disposition, compared with equal pier height disposition, using LRB bearings for three cases of Level II earthquakes, and taking into account the fact that a curved viaduct been analyzed. All the four bearings and the three girders have been analyzed for the purpose of getting satisfactory results.

The results clearly demonstrate that the use of LRB isolation devices is an appropriate solution for a viaduct with non-equal height piers. In terms of pier damage, there is a difference if the earthquake enters either by the tallest pier or by the shortest pier, being more harmful when it comes by the tallest pier. Besides, depending on the earthquake characteristics, the absorbed energy by the bridge will increase, as in TAK, remain the same as in RIN, or even decrease as happened in KOB, according to the pier disposition.

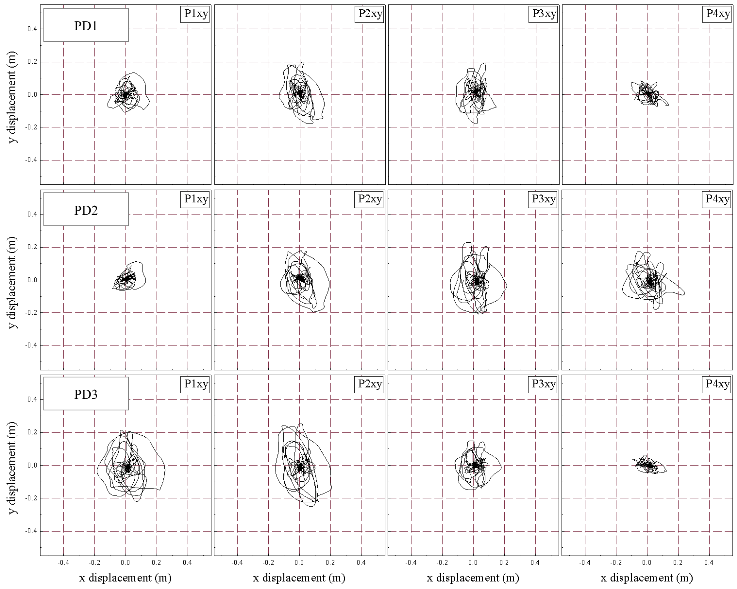
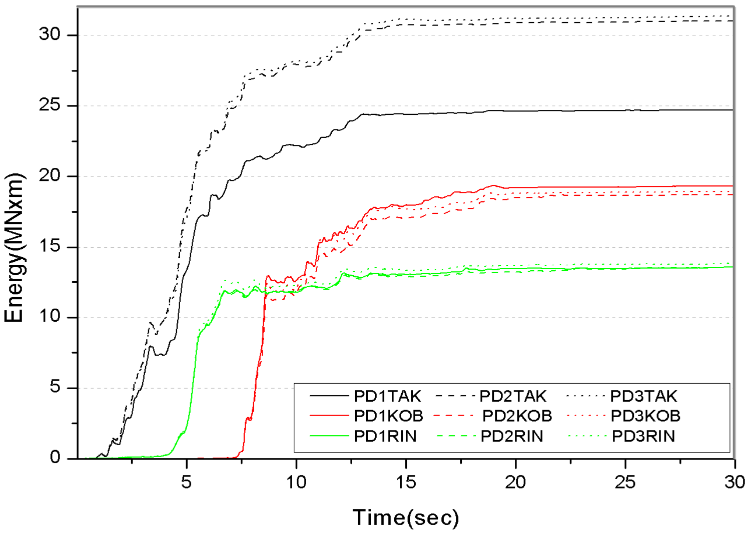
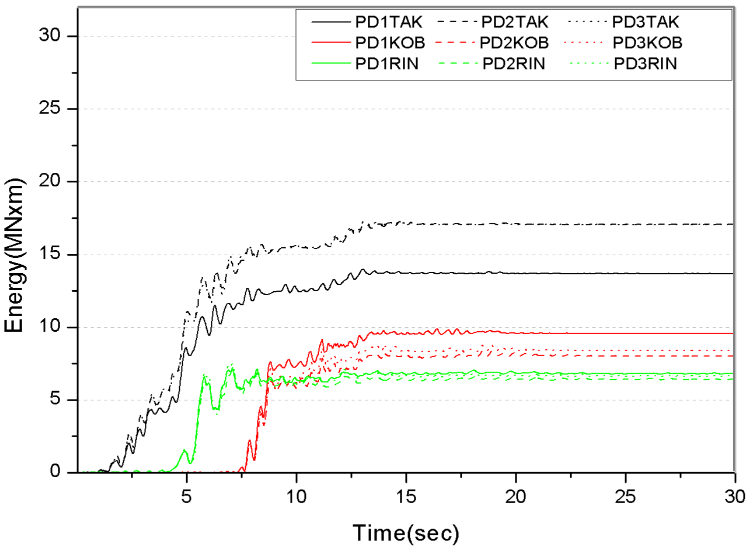


Fig 4. Top pier displacements for TAK



a) Total energy graphic



b) Strain energy graphic

Fig 5. Total energy time-history distribution at the end of the earthquake

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