Analytical Investigation of Seismic Performance of Viaduct Bridge System with Lead Rubber Bearings and another with Sliding Bearings

Utsunomiya University, Graduate School of Engineering Student ○Reem Al Sehnawi Fellow Akinori Nakajima
Utsunomiya City Ryota Sakai

1. Introduction

After Hyogo-ken Nanbu Earthquake (1995), isolation systems have been positively equipped in bridges in order to reduce the earthquake effects on their substructure. As typical types of isolation systems which can be set up in bridge structures, the lead rubber bearing and the sliding bearing have been developed. In this research, numerical analysis of viaduct bridge system with lead rubber bearings and another with sliding bearings was conducted to investigate the seismic performance of two bridge prototypes. First, push-over analysis was conducted for an optimal designing of the pier cross-section and the isolation bearing of the viaduct bridge system with lead rubber bearings. Second, nonlinear dynamic analysis was employed in order to investigate the dynamic behaviour of the two bridge prototypes, considering the friction coefficient of the sliding surface and the stiffness of the restoring system as parameters of the sliding bearing. Thereby, the response of two bridge prototypes were compared with each other and also compared with the design critical values to understand the behaviour of seismically isolated bridges with an indication of their range of applicability.

2. Bridge model

In this study, the considered viaduct bridge system is illustrated in **Fig. 1**, where, the viaduct bridge system consists of a superstructure which has a PC slab with three spans continuous two steel I-girders, two fixed RC piers, and two movable bearings at the both ends of the superstructure. Herein, the superstructure configurations are 40, 50, and 40m, and the pier heights are assumed as 20 and 50m. In addition, the cross sections of the piers are taken as a rectangular with width B that is constant at a distance of 6m in the transverse direction of the bridge axis. The height H of the cross-section and the amount of the reinforcement are taken as variables.

On the other hand, the analytical models are modeled as beam elements for the superstructure and the piers, while, the bearings are modeled as bilinear springs to simulate the bearings nonlinearities. Herein, the compressive strength of concrete is $f'_c = 30\mathrm{N/mm^2}$ and concrete young modulus is $E_c = 31\mathrm{kN/mm^2}$, the yield stress of steel is $f_y = 345\mathrm{N/mm^2}$, and steel young modulus is $E_s = 200\mathrm{kN/mm^2}$.

3. Ground motions

According to Japanese Specification for Highway Bridges, Part V: Seismic Design, the considered input acceleration motions were L1-I and L1-Ⅲ of ground motion level 1, and TI-I-1, TI-I-2, TI-I-3, TⅡ-I-1, TⅡ-I-2,

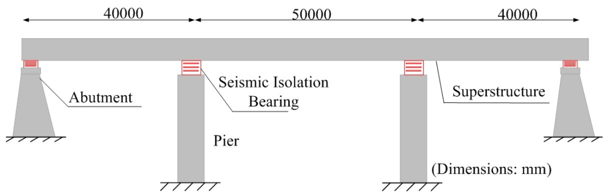

Fig. 1 Viaduct Bridge with Seismic Isolation Bearings

TⅡ-I-3, TI-Ⅲ-1, TI-Ⅲ-2, and TI-Ⅲ-3 of ground motion level 2. These ground motion were related to soil class I and to soil class Ⅲ in order to investigate the effect of long-period earthquake ground motion.

4. Response and design critical values

Here, the design methods were performed according to Seismic Coefficient Method in case of ground motion level 1, and Ductility Design Method in case of ground motion level 2. Since the superstructure of the viaduct bridge prototype has two steel I-girders, thus, two bearings were assumed for each pier, and each bearing has four lead plugs. As well as, the design criteria of the bearing refers to the horizontal displacements U of the isolation bearings should be within ± 10% of the design displacements U_B of isolation bearings, herein, the design displacement U_B is taken as 20% of the bearing thickness under ground motion level 1, and 200% of the bearing thickness under ground motion level 2. Furthermore, the optimal design should be determined by conducting an iterative calculation by changing the lateral force value until the response value approaches the critical value. Otherwise, the design criteria of the pier cross-section refers to the ultimate concrete compressive strain ε_{cu}=0.0035 in case of ground motion level 2, and to the yield tensile strain of the steel ε_y= 0.001725 in case of ground motion level 1.

5. Pier cross-section and bearing design

In this study, by conducting push-over analysis, the pier cross-sections of the viaduct bridge system with lead rubber bearings have been designed. Thereby, the seismic design results were shown in **Table 1**. By comparing the equivalent seismic coefficient k_{hc0} with the ultimate value, it can be noticed that the critical cross-sections design were by considering ground motion level 1. Moreover, according to the Japanese Specification for Highway Bridges, Part V: Seismic Design and Design Manuals of Base Isolation Bearing Design of Highway Bridges, the seismic design of the isolation bearing were presented in **Table 2**, considering ground motions level 1 and level 2. Since, the bearing displacements were not within 10% of the design displacement of the isolation bearing under ground motion level 2, thus, it can be said that, the

Key Words: *Viaduct Bridge System, Numerical Analysis, LRB, Sliding Bearing, Pushover Analysis, Nonlinear Dynamic Analysis*
7-1-2, Yoto, Utsunomiya city, Tochigi, 〒 321-8585, Japan Tel.028-689-6210 Fax.028-689-6210

Table 1 Parameters of Viaduct Bridge System with LRB

Pier height	m	20	50
Height of pier cross-section H	m	2.20	5.20
Total reinforcement steel area	m^2	0.1672	0.5026
Design lateral force coefficient k_{h0} (L1)	-	0.200	0.200
Equivalent seismic coefficient k_{hc0} (TI)	-	0.230	0.300
Equivalent seismic coefficient k_{hc0} (TII)	-	0.185	0.393
Tension strain of reinforcement steel ε_s	-	1.69E-03	1.64E-03
Ultimate equivalent seismic coefficient (L1)	-	0.275	0.304
Ultimate equivalent seismic coefficient (L2)	-	0.321	0.430

Table 2 Parameters of Isolation Bearings

Parameters	Unit	(level 1)		(level 2)	
Pier height	m	20	50	20	50
One side width a	m	1.25	3	1.25	3
Total thikness Σ_{te}	m	0.225	0.35	0.225	0.35
Lead plug diameter ϕ_{dp}	m	0.15	0.18	0.15	0.18
Yield force Q_d	MN	0.589	0.848	0.589	0.848
Primary stiffness K_1	MN/m	35.674	155.874	128.922	242.195
Secondary stiffness K_2	MN/m	5.488	23.981	19.834	37.261
Equivalent stiffness K_B	MN/m	7.358	25.712	38.534	54.572

seismic isolation bearings have been designed for ground motion level 1.

6. Sliding bearings characteristics

Here, the nonlinear dynamic analysis was conducted in order to investigate the dynamic behaviour of the viaduct bridge system with sliding bearings considering the friction coefficient of the sliding surface and the stiffness of the restoring system as parameters of sliding bearings. Moreover, by assuming the pier heights are 20 and 50m, the dynamic behaviour of the viaduct bridge system with lead rubber bearings and the other with sliding bearings were compared with each other, taking into account the maximum responses of strains of the cross-sections at the pier base and the maximum responses of bearings displacement. In this study, the variety of friction coefficient was assumed as low, medium, and high friction coefficient, the stiffness of the restoring system was assumed as $K_2 = 0, 0.5, 1.0, 2.0, 3.0$MN/m, while, the natural period was assumed to have the same value of the natural period of the viaduct bridge system with lead rubber bearing.

7. Study results

Since the friction coefficient of sliding bearing is varied widely, thus the purpose of this study is to mention the desirable range of the friction coefficient and bearing stiffness in order to obtain better seismic performance. Therefore, for instance, for pier height 20m in soil class I and seismic motion type I, **Fig. 2** illustrated the relationships of the maximum responses versus the friction coefficient, considering various restoring system stiffness, also, **Fig. 3** showed this relationships for pier height 50m, in soil class Ⅲ, and under seismic motion type I. Thereby, though all results were not shown in figures, the same relationships for all mentioned cases were drawn. As a result, it was confirmed that the sliding bearings characteristics were related with the pier heights, soil classifications, and ground motions. Furthermore, the maximum responses of strains of the cross-sections at the pier base and the maximum responses of the bearings displacements were generally in trade off relationship, regardless of the values of the two parameters. The maximum response of strains of the cross-section at the pier base was too small compared with the critical strains, while, the relative displacements between the superstructure and the pier were practically large, here, the reference value of the sliding bearing displacements was taken the design displacement. Additionally, for the both cases of pier heights, the desirable friction coefficient range was the medium friction coefficient in soil class I, and medium and high friction coefficient in soil class Ⅲ in case of pier height 20m, whereas, for pier height 50m and soil class Ⅲ the bearing displacements were impractical. Moreover, as the secondary stiffness changes, the tendency of response values was unclear. Although the maximum response of strains of the pier cross-section of the viaduct bridge system with lead rubber bearings were larger than that of the viaduct bridge system with sliding bearings, the maximum response of bearing displacements of the viaduct bridge system with sliding bearings were larger.

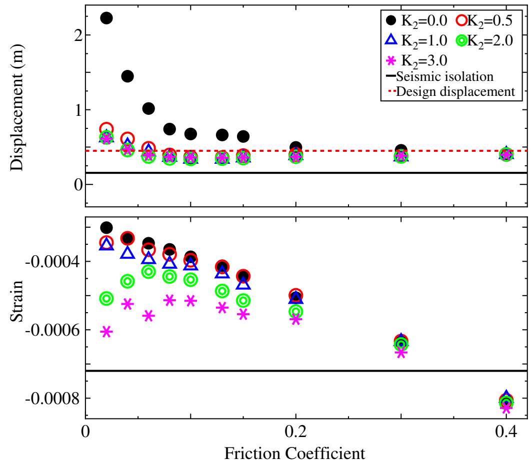

Fig. 2 Friction Coefficient versus Maximum Response Relationship (20m, Level 2, Soil Class I)

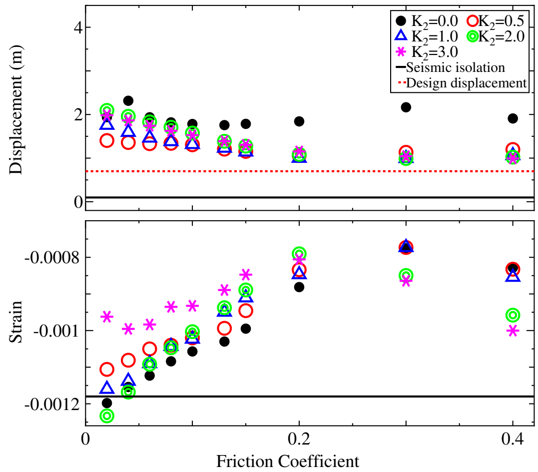

Fig. 3 Friction Coefficient versus Maximum Response Relationship (50m, Level 2, Soil Class Ⅲ)

8. Conclusion

In this research, the viaduct bridge system with sliding bearings were impractical in cases of tall pier bridges and in soft soil, and the maximum responses of strains of the cross-sections and the maximum responses of the bearings displacements were in trade off relationship[1]. Moreover, the bearings displacements response and the strains response at the pier base could be controlled by determining the friction coefficient of the sliding surface.

REFERENCES

1) Ryoichi Fujita, Atsushi Mori, Hidesada Kanaji, Kazuyuki Izuno: A Study on the Seismic Performance of a Sliding Typed Seismic Isolation System Applied for Bridges, 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada, August 1-6, 2004.