土木学会第53回年次学術講演会（平成10年10月）

I －B 331

Nonlinear Interactions between Pier and Isolator in a Seismically Isolated Bridge

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1. Introduction

The main purpose of installation of seismic isolations in a bridge is to protect the supporting piers from failure during a severe earthquake. However, it is not feasible that the piers are designed to remain linear in the case of a very large earthquake, instead they should be allowed to deform nonlinearly up to a certain limit. Therefore, during an extreme earthquake both the piers and the seismic isolations behave nonlinearly, dissipating energy through their hysteresis loops.

In this study, the nonlinear responses of a seismically isolated bridge are analyzed, where the effects of the variations in the stiffness of the pier and the yielding level of the isolator are examined. Several parameters that are critical for the design of an isolated bridge are discussed.

2. Model

Figure 1 shows the isolated bridge that is modeled as a two-degree-of-freedom system. The soil-foundation interactions are not being considered here. The pier is a reinforced concrete structure with a yielding displacement u_y^p of 5.04 cm, which has no post-yielding stiffness. The viscous damping ratio of the pier is taken to be 2%. The isolation system is a Lead Rubber Bearing (LRB) type with an initial stiffness k_1^b of 9883 tf/m and a post-yielding stiffness k_2^b of 1520 tf/m (1/6.5 of k_1^b). The hysteresis models of the pier and the isolator follow the Takeda and bilinear models, respectively. The masses of the deck m^d and the pier m^p are 815 t and 242 t, respectively.

The soil condition is assumed to be moderate, and the system is subjected to the design earthquake ground motion Type I (plate boundary earthquake). Type I ground acceleration consists of several moderate pulses with a peak ground acceleration of 365 gal and lasts for a long duration of about 50 s.

3. Results and Discussions

The responses of the system are calculated for several values of yielding forces of pier P_y^p and isolator Q_y^b. The yielding displacement of the pier and the initial stiffness of the isolator are kept constant, as shown in Figure 1. The responses are represented by the ductility of the pier μ^p, the residual displacement of the pier u_r^p, the maximum deformation of the isolator u_x^b, the maximum displacement of the deck u_x^d and the ratio of the hysteresis energy dissipated by the isolator η. These are the critical parameters in designing an isolated bridge. The ductility of the pier μ^p is defined as the ratio of the maximum displacement of the pier to its yielding displacement. The effectiveness ratio η is defined as the ratio of the hysteresis energy dissipated by the isolator to the total hysteresis energy.

The responses of the structure subjected to the input ground acceleration are shown in Figure 2. Figure 2[a] shows that for $2 < \mu^p < 4.5$, μ^p depends mainly on P_y^p, i.e. μ^p increases with the decrease of P_y^p. For $P_y^p <$ 500 tf ($\mu^p > 2$), u_x^b is not affected by the change of Q_y^b, but it increases with the increase of P_y^p, as indicated in Figure 2[b]. On the other hand, u_x^b increases with the decrease of Q_y^b, not affected by the variation of P_y^p, when P_y^p > 500 tf ($\mu^p < 2$). It shows that the ductility level of the pier affects the behavior of the isolator.

Figure 2[c] shows that the maximum displacement of deck u_x^d depends mostly on Q_y^b, i.e. it decreases with the increase of Q_y^b. The isolation effectiveness ratio η, shown in Figure 2[d], follows the ductility level of the pier. In the extreme case where $\mu^p = 1.0$ (pier remains linear), all the hysteresis energy is dissipated by the isolator. When μ^p increases, the ratio of the hysteresis energy dissipated by the pier increases, as the consequence, the effectiveness of the isolator becomes less.

Keywords: seismically isolated bridge, LRB, nonlinear interaction, ductility

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One of the critical criteria in aseismic design of bridge structures is the residual deformation of the pier. Figure 2[e] shows that u_r^p depends mostly on P_y^p, i.e. it decreases with the increase of P_y^p.

4. Conclusions

The characteristics of the seismic design criteria of an isolated bridge, μ_p, u_x^b, u_x^d and u_r^p, have been presented. Although the analysis was done only for a limited type of ground condition and input ground acceleration, general trends of the parameters were obtained, as shown in Figure 2. It is important to indicate that the parameters are not determined by the ratio of the yielding force Q_y^b/P_y^p only[1], but they vary with the changes of Q_y^b and P_y^p. The results also indicate that the ductility level of the pier affects the behavior of the isolator, which show the nonlinear interaction between the pier and the isolator. In seismic design process, contours, such as the ones presented in Figure 2, can be helpful in determining the ranges of yielding forces of pier and isolator that satisfied the design criteria

5. Reference

1) Kawashima, K. and Shoji, G.: Interaction of hysteretic behavior between isolator/damper and pier in an isolated bridge, *J. Structural Engineering*, JSCE, Vol. 44A, pp. 733-742, 1998.

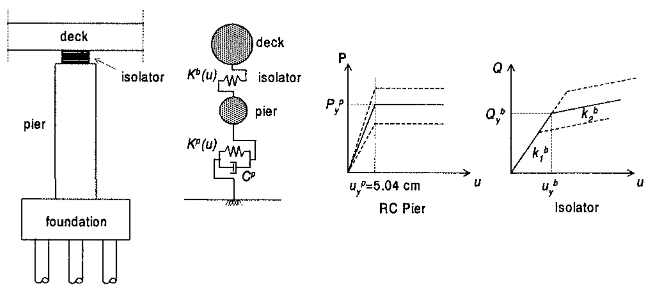

Figure 1 Model of seismically isolated bridge and force-displacement relationship of its pier and isolator

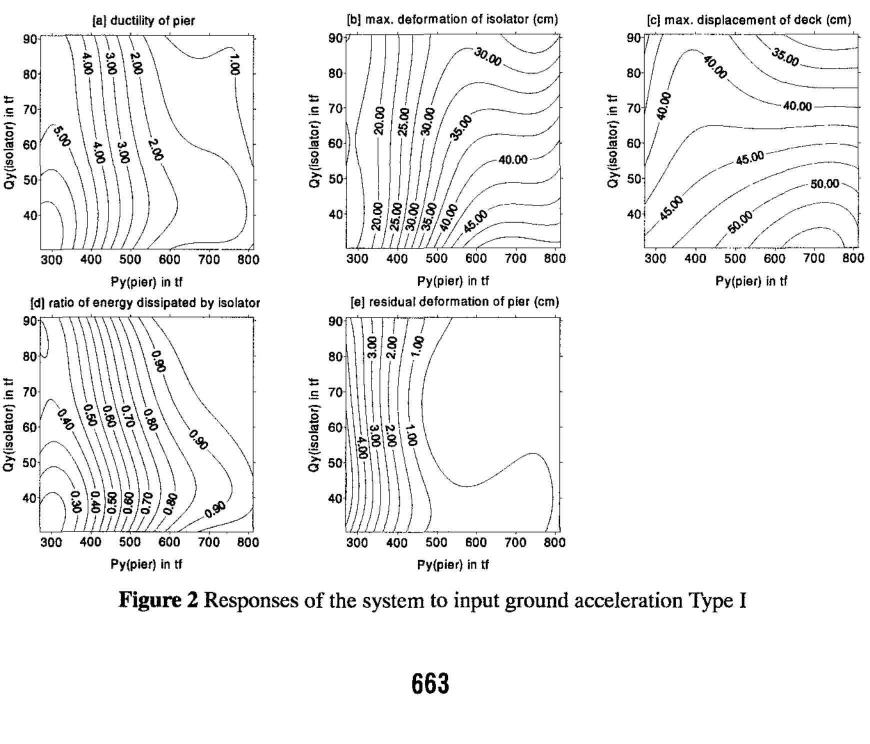

Figure 2 Responses of the system to input ground acceleration Type I