

A MULTI-FUNCTION UNSEATING PREVENTION DEVICE FOR ISOLATED BRIDGES

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ABSTRACT :

A multi-function unseating prevention device is investigated to provide energy dissipation and to regulate the structural system properties other than the traditional function of unseating prevention devices for isolated bridges. The isolators in bridge structures are effective in mitigating the induced seismic force by a shift of natural period. However, the deck displacement becomes excessively large when subjected to an extreme earthquake. Such a large displacement may increase the hazard of deck unseating. Also it is difficult to design an expansion joint accommodating with such a large displacement. In the past studies, supplementary dampers have been shown to be useful on reducing seismic responses of isolated bridges. Considering that the space is generally limited for installing supplementary devices in bridges, a viscous damper is inserted into an unseating prevention device to dissipate energy during earthquakes. The multi-function unseating prevention device consists of a linear viscous damper and an elastic spring connected in parallel or in series. Typical continuous highway elevated bridges equipped with multi-function unseating prevention devices are analyzed. Parametric study is performed by using nonlinear structural dynamic analysis including the hysteretic behavior of the columns and isolators to examine the effectiveness of the multi-function unseating prevention devices under near-field earthquakes. It is found from the numerical simulation that the interaction of the energy dissipation between the columns, the isolators and the unseating prevention devices is important to modify the deck displacement. The damper dissipates energy effectively while the spring modifies the structural properties of two adjoining bridges.

KEYWORDS:

Isolated Bridge, Unseating Prevention Device, Seismic Response Control, Viscous Damping

1. INTRODUCTION

The unseating prevention devices play an important role the same as the other crucial components, such as columns and bearings, when the bridges are subjected to an extreme earthquake. During the 1995 Kobe earthquake in Japan and the 1999 Chi-Chi earthquake in Taiwan, a number of destructive bridges caused human casualties and property damage due to the unseating of the decks. However, unseating prevention devices have been regarded as attached devices and the regulations for the unseating prevention devices in seismic design codes have still been not detailed. The existing bridges have mostly been retrofitted by unseating prevention devices while the new bridges have implemented multiple unseating prevention devices in Japan and Taiwan since Kobe earthquake and Chi-Chi earthquake. However, the existing types of unseating prevention devices do not provide the function of energy dissipation (Liu and Chang, 2003). In this study, a multi-function unseating prevention device is investigated to provide energy dissipation under small-to-medium ground motions and to regulate the whole structural system properties under large ground motions other than the traditional function of unseating prevention devices for bridges.

The isolators in bridge structures are effective in mitigating the induced seismic force by a shift of natural period. However, the deck displacement becomes excessively large when subjected to a ground motion with large intensity or unexpected characteristics. Such a large displacement may increase the hazard of deck unseating. Also it is difficult to use an expansion joint which accommodates with such a large relative displacement. In the past studies, supplementary dampers have been shown to be useful on reducing seismic responses of isolated bridges (Kawashima and Unjoh, 1989, 1994; Lee and Kawashima, 2005, 2006). Considering that the space is generally limited for installing supplementary devices in bridges, a linear viscous damper is inserted into an unseating prevention device to dissipate energy during earthquakes herein. The multi-function unseating prevention device consists of a linear viscous damper and an elastic spring connected in parallel or in series. Typical continuous highway elevated bridges equipped with multi-function unseating prevention devices at the expansion joint are analyzed. Parametric study is performed by using nonlinear structural dynamic analysis, which includes the hysteretic behavior of the columns and isolators, to examine the effectiveness of the multi-function unseating prevention devices under various earthquakes.

2. TARGET BRIDGES AND ANALYTICAL MODELS

A typical isolated viaduct is analyzed to investigate the effectiveness of multi-function unseating prevention devices as shown in Figure 1. The superstructure consists of two adjoining three-span continuous steel I-girders and reinforced concrete decks with a total length of $6@40\text{ m} = 240\text{ m}$ and a width of 12 m, which are supported by reinforced concrete columns in height of 10 m. Five high-damping-rubber isolators per column support the decks. Two adjoining three-span segments are denoted as the target bridge and the adjoining bridge. The multi-function unseating prevention device is installed at the expansion joint between both bridges. The stiffness of the isolators remains constant in the target bridge while it varies in the adjoining bridge to study the effect of the multi-function unseating prevention device in terms of the ratio of the fundamental periods in two bridges.

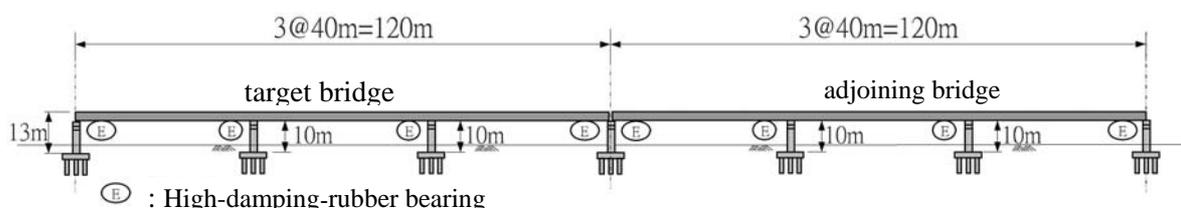


Figure 1 : An isolated viaduct consisting of the target bridge and the adjoining bridge.

The analytical model of the bridges is constructed by the SAP2000 nonlinear finite element software. The columns are idealized by using the multi-linear plastic nonlinear element. Pivot-type hysteretic loop is selected to simulate the nonlinear behavior of reinforced concrete columns. The isolators are assumed to be bilinear

elastoplastic. The linear soil springs is used to take the foundation and soil condition into account based on Japan Design Specifications of Highway Bridges (Japan Road Association, 2002). The structural damping is idealized by using Rayleigh damping with 5% damping ratios in the first two modes. Figure 2 depicts the analytical model which lumps a mass at the outmost columns to consider the effect of the adjacent bridges not idealized in the model.

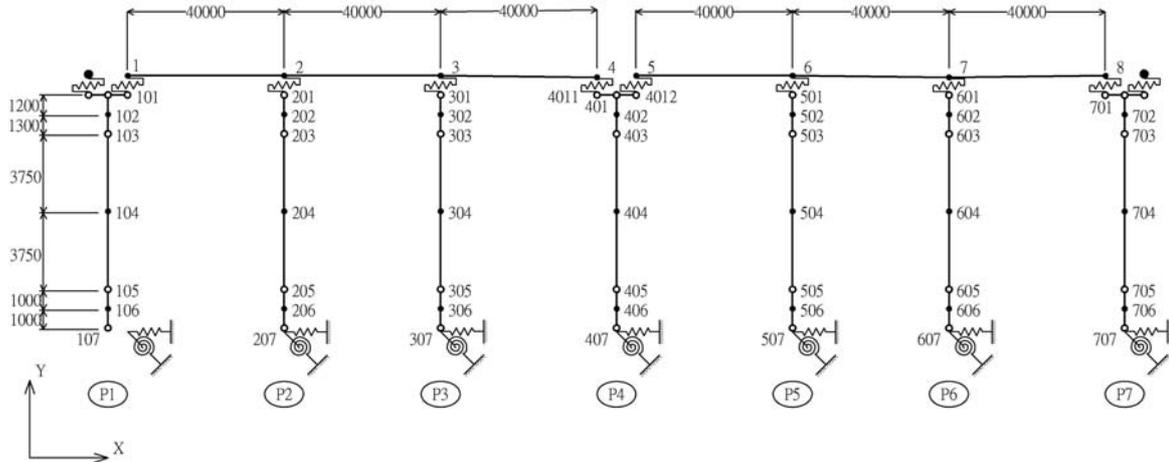


Figure 2 : Analytical idealization

In this study, it is suggested that the design of the isolators adopt the concept of balancing member stiffnesses, i.e. the equivalent stiffnesses of all columns are almost identical. Figure 3 shows part of the isolated bridges including the exterior and interior columns. The balancing member stiffnesses can be achieved as

$$\frac{1}{K_p^I} + \frac{1}{K_b^I} = \frac{1}{K_p^E} + \frac{1}{K_b^{E1} + K_b^{E2}} \quad (2.1)$$

where K_p^I and K_b^I are the stiffnesses of the column and the isolator at the exterior column, respectively; K_p^E and K_b^{Ei} ($i=1,2$) are the stiffnesses of the column and the isolator at the interior column, respectively.

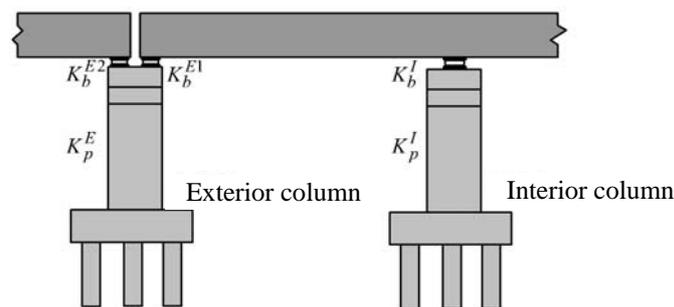


Figure 3 : Illustration of balancing member stiffnesses for exterior and interior columns

In simulation, the bridges are subjected to a near-field ground motion recorded at Sun-Moon Lake in the 1999 Chi-Chi, Taiwan earthquake. The fundamental periods of the bridges with balancing member stiffnesses is 1.36 sec while it without balancing member stiffnesses but with all isolators having the same stiffness is 1.24 sec. Figures 4 and 5 shows the hysteretic loops of the isolators and columns at the columns P1~P4 of the target bridge with balancing member stiffnesses while Figure 6 shows the hysteretic loops of the columns with all isolators having the same stiffness. The results reveal that the peak deck displacement with balancing member stiffnesses is 64 cm, which is larger than 55 cm with all isolators having the same stiffness. However, it is observed that the seismic force is distributed more evenly to both exterior and interior columns when the

isolators are designed based on the balancing member stiffnesses. When all the isolators are of the same stiffness, the exterior columns induce larger seismic force because the equivalent stiffness of the exterior columns is larger than that of the interior columns.

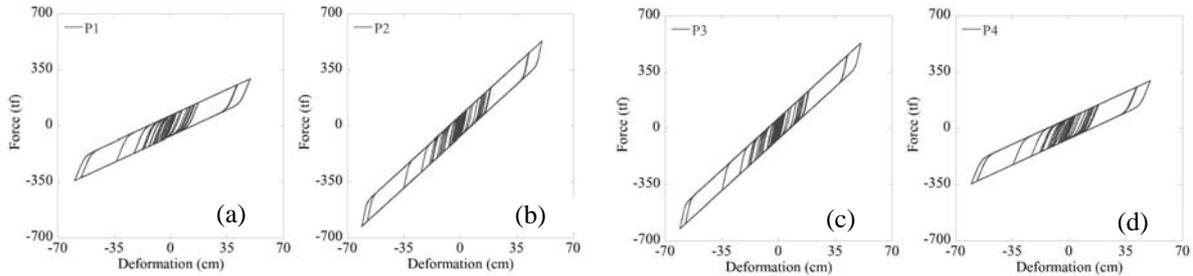


Figure 4 Hysteretic loops of the isolators at columns (a) P1 (b) P2 (c) P3 (d) P4 with balancing member stiffnesses

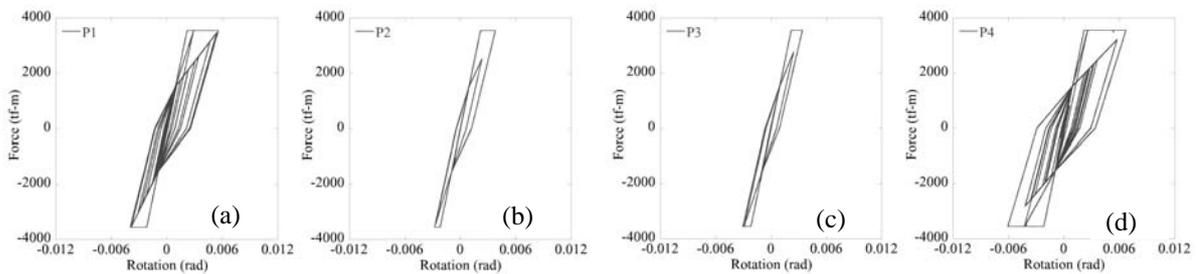


Figure 5 Hysteretic loops of the columns (a) P1 (b) P2 (c) P3 (d) P4 with balancing member stiffnesses

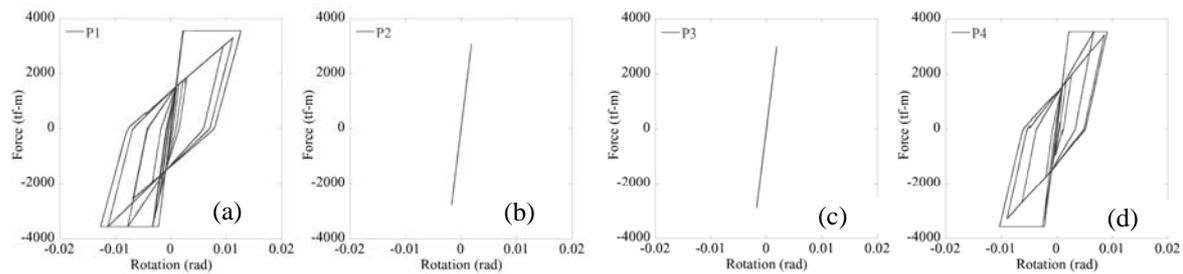


Figure 6 Hysteretic loops of the columns (a) P1 (b) P2 (c) P3 (d) P4 with all isolators having the same stiffness

3. RESULTS OF NUMERICAL SIMULATION

The multi-function unseating prevention device is installed at the expansion joint between the target bridge and the adjoining bridge. Since the devices installed at the expansion joint can work only when two adjacent bridges oscillate with relative motion, two adjacent bridges should be of different fundamental period. The stiffness of the isolators remains constant in the target bridge while it varies in the adjoining bridge to regulate the ratio of the primary periods in two bridges. The ratio of the fundamental period of the target bridge (T_1) to the adjoining bridge (T_2) varies at 0.9, 0.8, 0.7, 0.6 and 0.5. Two types of multi-function unseating prevention devices, a damper and a spring in parallel or in series, are studied parametrically. Prior to study the performance of the multi-function unseating prevention devices, a parametric study is first conducted to identify the effect of a pure damper and a pure spring.

3.1. A Pure Damper

The studied pure damper is assumed to be a linearly viscous damper. The damping coefficient C varies from 0 to 5000 kgf-sec/cm. Figures 7 shows how the peak deck displacement, the peak isolator displacement of the target bridge and the adjoining bridge, and the peak relative displacement between two bridges depend on the damping coefficient at different ratios of fundamental periods. It is observed that the deck displacement and the isolator displacement of both bridges decrease as the damping coefficient

increases and the period ratio decreases. However, the deck displacements of two bridges at all ratios of periods approach synchronization regardless of an increase of the damping coefficient. Also the isolator displacements of two bridges at all ratios of periods approach a constant as the damping coefficient is larger than a certain value. The results demonstrate that the damper dissipates much more energy due to the relative response at small damping coefficient. Once the damper coefficient increases largely, the damping force is so large that it synchronizes both deck responses.

3.2. A Pure Spring

The studied pure spring is assumed to be a linearly elastic spring. The spring stiffness K varies from 0 to 5000 kgf/cm. Figure 8 shows the spring stiffness versus the peak deck displacement, the peak isolator displacement of the target bridge and the adjoining bridge, and the peak relative displacement between two bridges at different ratios of fundamental periods. It is noted that the peak deck displacement of the target bridge increases while the other responses decrease as the spring stiffness increases at period ratios of 0.7~0.9. Stiffness of zero implies there is no link between the two decks; high value stiffness indicates strong links between two decks. In general, there is insignificant effect in the peak responses as the spring stiffness increases. Since the elastic spring cannot dissipate energy, it functions as a member transferring force between two decks.

3.3. A Damper and a spring in series

The multi-function unseating prevention device consists of a damper and a spring in series. Based on the previous results, two adjacent bridges are selected at the period ratio of 0.7 with the damping coefficient varying at 100, 300, and 500 kgf-sec/cm and the spring stiffness setting to 2000, 4000, 6000, 8000, 10000 kgf/cm and infinity. When the spring stiffness approaches infinity, the behavior of the multi-function unseating prevention is close to a pure damper.

Figure 9 shows the spring stiffness versus the peak deck displacement, the peak isolator displacement of the target bridge and the adjoining bridge, and the peak relative displacement between two bridges at the damping coefficient 100, 300, and 500 kgf-sec/cm. It is observed that to decrease the peak deck displacement or isolator displacement of the target bridge, any combination of the type in series is not better than a pure damper, i.e. the spring stiffness is infinite; to decrease the peak deck displacement and the isolator displacement of the adjoining bridge, the combination with high damping and low stiffness is beneficial.

3.4. A Damper and a spring in parallel

With the same parametrical analysis in the previous section, The multi-function unseating prevention device consisting of a damper and a spring in parallel is studied. When the spring stiffness is zero, the behavior of the multi-function unseating prevention is close to a pure damper. Also, when the damping coefficient is nothing, the behavior of the multi-function unseating prevention is close to a pure spring.

Figure 10 shows the spring stiffness versus the peak deck displacement, the peak isolator displacement of the target bridge and the adjoining bridge, and the peak relative displacement between two bridges at the damping coefficient 100, 300, and 500 kgf-sec/cm. It is presented that in order to decrease the peak deck displacement and isolator displacement of the target bridge, any combination of the type in parallel is not better than a pure damper, whereas to decrease the peak deck displacement and isolator displacement of the adjoining bridge, increasing the spring stiffness is valid. If the main goal is to decrease the peak relative displacement of two decks, the combination with high damping and high stiffness is beneficial.

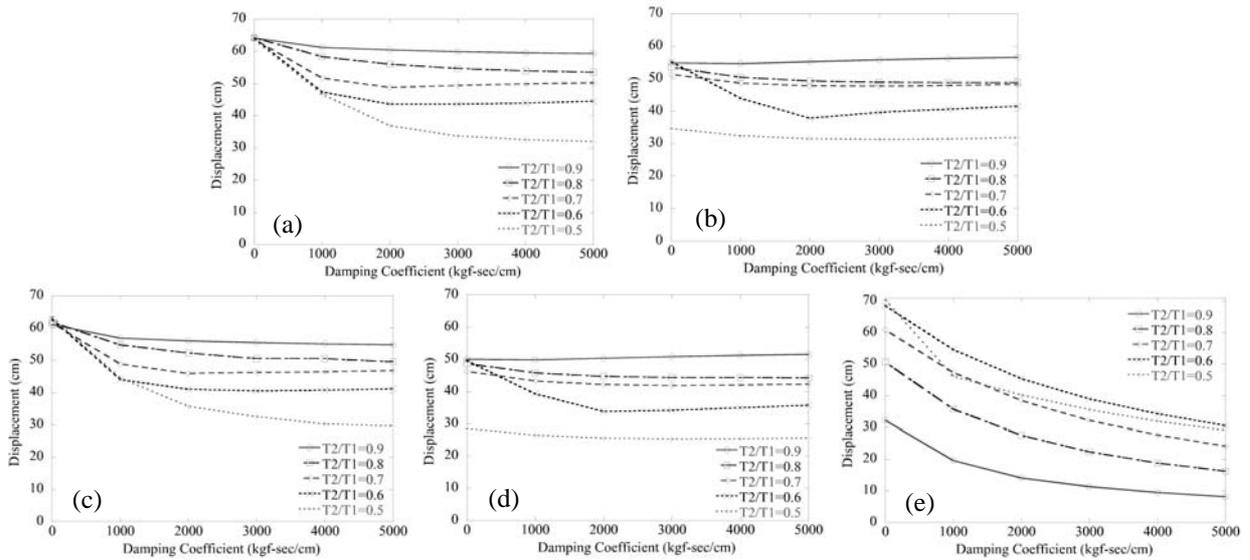


Figure 7 Peak deck displacement vs. damping coefficient of (a) target bridge and (b) adjoining bridge, and peak isolator displacement vs. damping coefficient of (c) target bridge and (d) adjoining bridge and (e) the peak relative displacement between two bridges at different ratios of fundamental periods with a pure damper

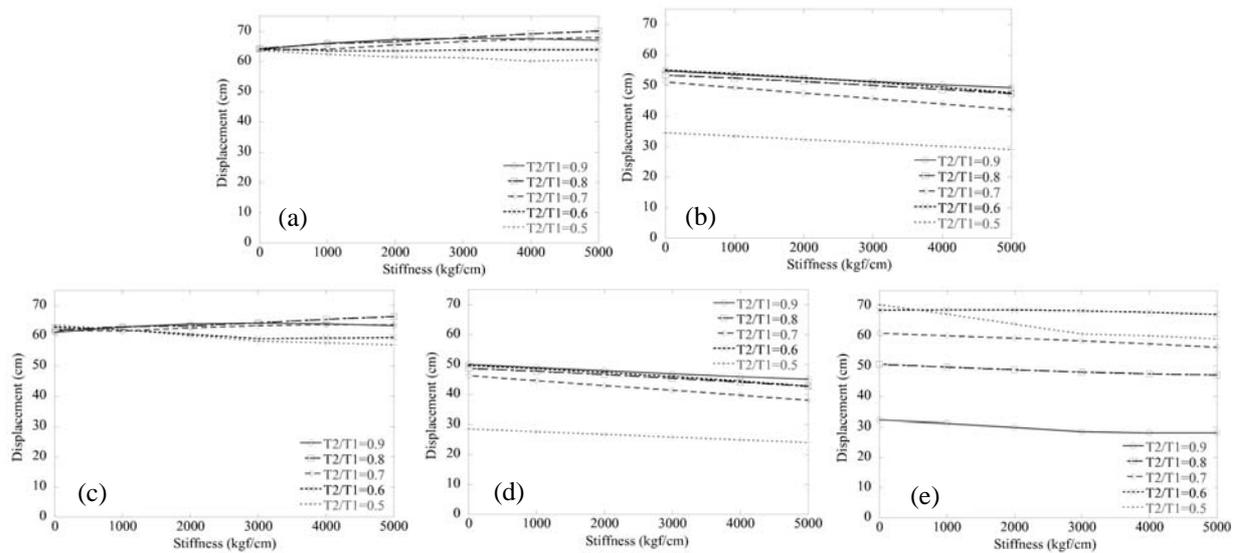
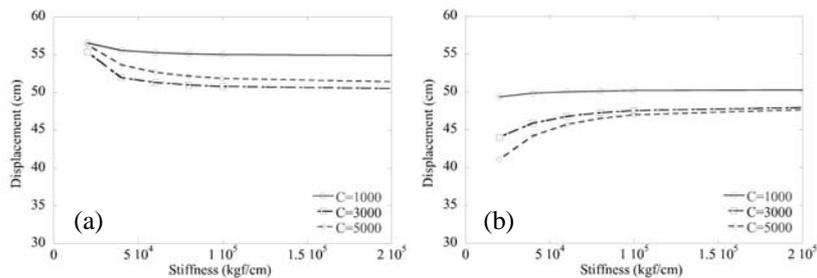


Figure 8 Peak deck displacement vs. damping coefficient of (a) target bridge and (b) adjoining bridge, and peak isolator displacement vs. damping coefficient of (c) target bridge and (d) adjoining bridge and (e) the peak relative displacement between two bridges at different ratios of fundamental periods with a pure spring



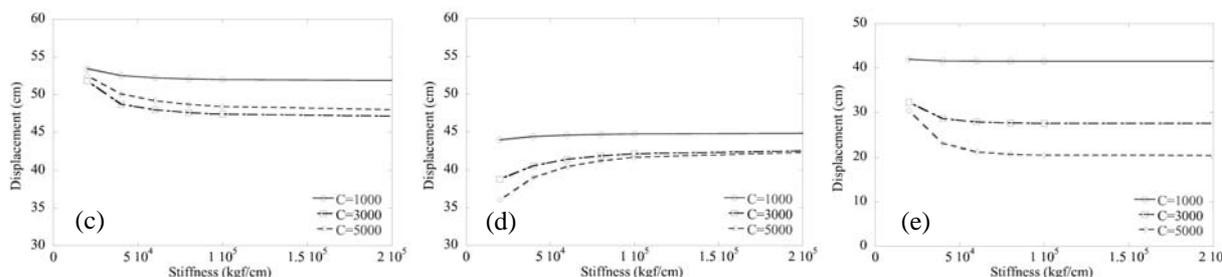


Figure 9 Peak deck displacement vs. damping coefficient of (a) target bridge and (b) adjoining bridge, and peak isolator displacement vs. damping coefficient of (c) target bridge and (d) adjoining bridge and (e) the peak relative displacement between two bridges at different ratios of fundamental periods with a damper and a spring in series

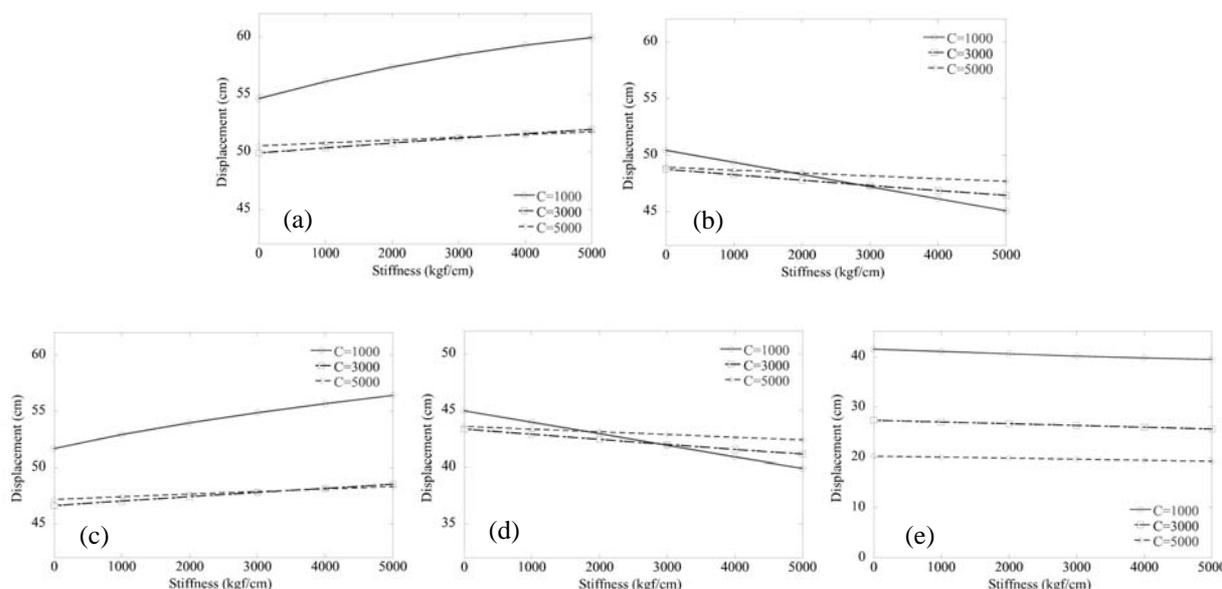


Figure 10 Peak deck displacement vs. damping coefficient of (a) target bridge and (b) adjoining bridge, and peak isolator displacement vs. damping coefficient of (c) target bridge and (d) adjoining bridge and (e) the peak relative displacement between two bridges at different ratios of fundamental periods with a damper and a spring in parallel

4. CONCLUSIONS

A multi-function unseating prevention device is investigated to provide energy dissipation and to regulate the structural system properties other than the traditional function of unseating prevention devices for isolated bridges. The multi-function unseating prevention device consists of a linear viscous damper and an elastic spring connected in parallel or in series. Typical continuous highway elevated bridges equipped with multi-function unseating prevention devices are analyzed. Extensive parametric study is performed by using nonlinear structural dynamic analysis including the hysteretic behavior of the columns and isolators to examine the effectiveness of the multi-function unseating prevention devices under near-field earthquakes. The following conclusions may be obtained from the results presented herein.

- (1) The method of balancing member stiffnesses is suggested to design the isolator stiffness at the exterior and interior columns. The main purpose is to distribute the seismic force evenly to every column.
- (2) It is found from the numerical simulation that the interaction of the energy dissipation between the columns, the isolators and the unseating prevention devices is important to modify the deck displacement. The damper dissipates energy effectively while the spring modifies the structural properties of two adjoining bridges. In general, the effect of a pure damper is superior to that of that of a pure spring, a damper and a spring in series or in parallel.
- (3) When the discrepancy of the periods of two adjacent bridges is larger, the multi-function unseating

prevention device setting at the expansion joint exhibits more effective performance in decreasing seismic responses.

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