OPTIMUM PASSIVE CONTROL OF IRREGULAR ISOLATED BRIDGES CONSIDERING ROCKING ISOLATION

Wen-Hsiao Hung¹ and Tzu-Ying Lee²

ABSTRACT

Rocking responses of spread foundations may occur during extreme earthquakes. Rocking responses result in the isolation effect on the bridges. When a bridge is designed using isolators and spread foundations, double isolation effects may further decrease the seismic-induced forces under extreme earthquakes. However, the deck displacement becomes excessively large when subjected to a near-field ground motion. Thus, passive viscous dampers are applied to the bridge for decreasing the displacement responses in this study. Compared with typical isolated bridges, the irregular isolated bridge has different stiffness at each column and abutment. The particle swarm optimization-simulated annealing (PSO-SA) hybrid searching algorithm is employed to find the optimum damping coefficients and the locations of viscous dampers.

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Introduction

Seismic isolation has been extensively applied to bridges for mitigating seismic-induced forces through the elongation of natural periods. Spread foundations are widely used to support bridges located in hard soil conditions. Rocking responses of spread foundations may occur during extreme earthquakes. In literatures, rocking responses result in the isolation effect on the bridges. When a bridge is designed using isolators and spread foundations, double isolation effects may further decrease the seismic-induced forces under extreme earthquakes. However, the deck displacement becomes excessively large when a bridge is subjected to a near-field ground motion. Thus, passive viscous dampers are applied to the bridge for decreasing the displacement responses. Compared with typical isolated bridges, the isolated bridge with irregular columns possesses different stiffness at each column. It is difficult to determine the locations and the corresponding damping coefficients of viscous dampers.

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Analysis Method and Optimum Design

In order to evaluate the dynamic response of irregular isolated bridge under near-field earthquake, vector form intrinsic finite element is employed for analyzing the structure [1]. Besides, the particle swarm optimization-simulated annealing (PSO-SA) hybrid searching algorithm is employed to find the optimum damping coefficients and the locations of the dampers [2]. The purpose of this study is to decrease the deck displacement and the column ductility such that the objective function is designated by using the both responses. Additionally, the peak shear forces and yielding moments are constrained to avoid overdamping situation.

Numerical Simulation

Target Bridge

A three-span isolated bridge with two columns of irregular height and two abutments as shown in Fig. 1 is studied in this research. To simulate the different height ratio of short column to long column, the height of pier $P_1$ is regulated with 5 m, 7.5 m, and 10 m. High damping rubber bearings (HDRBs) are used to be the isolators. The isolators are assumed here to be bilinear elastoplastic and the ratio of the post-yielding to pre-yielding stiffness is 0.19. The stiffnesses of isolators are shown in Table 1.

![Figure 1. A three-span continuous isolated bridge with columns of irregular height (A: abutment, B: bearing, C: damper, P: Pier)](image)

<table>
<thead>
<tr>
<th>Ratio of height ($P_1/P_2$)</th>
<th>B₁</th>
<th>B₂</th>
<th>B₃</th>
<th>B₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>24.25</td>
<td>43.78</td>
<td>48.51</td>
<td>24.25</td>
</tr>
<tr>
<td>0.75</td>
<td>24.25</td>
<td>45.63</td>
<td>48.51</td>
<td>24.25</td>
</tr>
<tr>
<td>1.0</td>
<td>24.25</td>
<td>48.51</td>
<td>48.51</td>
<td>24.25</td>
</tr>
</tbody>
</table>

Table 1. Stiffness of Isolators (unit: MN/m)

The superstructure consists of a five-span continuous deck with a total length of $3@40$ m = 1200 m and a width of 12 m, as shown in Fig. 2. The substructure is made of reinforced
concrete and idealized by the elastic beam element, as shown in Fig. 3.

When the bridge is subjected to extreme earthquakes, it may exhibit plastic hinge at the bottom of the column. The length of plastic hinge is evaluated by \( L_p = \frac{0.2H - 0.1D}{2} \) where \( H \) is the height of the column and \( D \) is the smaller dimension of the column section. The restoring forces of the column are assumed to be perfect elastoplastic.

![Figure 2. Lateral view of superstructure.](image)

![Figure 3. Lateral and side view of columns.](image)

**Ground Motion and Soil Springs**

A near-field ground motion recorded at Japan Meteorological Agency Kobe observatory in the 1995 Kobe, Japan earthquake is selected for the analysis. This study adopts the concept of a Beam-on-Nonlinear-Winkler-Foundation to model the soil-structure interaction behavior under large seismic loading, which is a nonlinear model and called Winkler-Based Model. Nonlinear Winkler springs can be used to simulate the soil vertical bearing forces, horizontal passive forces to the side of foundations, and vertical shear friction on the sides of foundations in the soil-structure interaction.

**Simulation Results**

Through performing the PSO-SA searching algorithm, the optimum damping coefficients can be obtained for different ratio of height of short column to long column with consideration of rocking response as shown in Table 2. For comparison, the optimum damping coefficients without consideration of rocking response are also obtained. Observed from the results, the optimum damping coefficients at short column with rocking are smaller than those without
Compared to the maximum displacement of the deck without dampers, the reduction ratios of the deck displacement with dampers are also shown in Table 2. The results show that the deck displacement can be largely decreased when the dampers are installed on the abutments.

Table 2. Optimum damping coefficients (unit: MN/m/s).

<table>
<thead>
<tr>
<th>Ratio of height (P1/P2)</th>
<th>Rocking</th>
<th>C₁</th>
<th>C₂</th>
<th>C₃</th>
<th>C₄</th>
<th>Reduction ratio of deck disp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>with</td>
<td>8.30*</td>
<td>2.70</td>
<td>2.62</td>
<td>8.30*</td>
<td>62.3%</td>
</tr>
<tr>
<td>0.75</td>
<td>with</td>
<td>8.30*</td>
<td>3.55</td>
<td>4.91</td>
<td>8.30*</td>
<td>63.5%</td>
</tr>
<tr>
<td>0.5</td>
<td>with</td>
<td>8.30*</td>
<td>4.72</td>
<td>8.30*</td>
<td>8.30*</td>
<td>63.5%</td>
</tr>
<tr>
<td>1</td>
<td>w/o</td>
<td>8.30*</td>
<td>2.91</td>
<td>3.29</td>
<td>8.30*</td>
<td>67.4%</td>
</tr>
<tr>
<td>0.75</td>
<td>w/o</td>
<td>8.30*</td>
<td>6.12</td>
<td>3.76</td>
<td>8.30*</td>
<td>68.3%</td>
</tr>
<tr>
<td>0.5</td>
<td>w/o</td>
<td>8.30*</td>
<td>8.30*</td>
<td>4.52</td>
<td>8.30*</td>
<td>69.5%</td>
</tr>
</tbody>
</table>

* Upper bond of the damping coefficient.

**Conclusions**

Excessive damping forces can impede the energy dissipation of isolators and may cause the shear failure of the abutments. When the dampers are set on the columns, the seismic responses decrease as the damping coefficient increases. Similarly, excessive damping forces result in large column deformations and residual displacements, even the permanent settlements of the footings. When the damping coefficients and allocations of the viscous dampers are determined using PSO-SA, the viscous dampers can effectively improve the seismic responses of the bridges with isolators and spread foundations, and avoid the residual displacements of the columns and the permanent settlements of the footings which are difficult to recover.

**References**
