Earthquake Damage Mitigation of Seismically Isolated Curved Viaducts

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Summary

This paper investigates the effectiveness of the use of seismic isolation devices on the overall 3D seismic response of curved highway viaducts with an emphasis on expansion joints. Furthermore, an evaluation of the effectiveness of the use of cable restrainers is presented. For this purpose, the bridge seismic performance has been evaluated on four different radii of curvature, considering two cases: restrained and unrestrained curved viaducts. Depending on the radius of curvature, three-dimensional non-linear dynamic analysis shows the vulnerability of curved viaducts to deck unseating and joint residual damage. In this study, the efficiency of using LRB supports combined with cable restrainers on curved viaducts is demonstrated, not only by reducing in all cases the possible damage, but also by providing a similar behavior in the viaducts despite of curvature radius.

Keywords: Nonlinear dynamic response, seismic damage, unseating prevention, curved viaducts.

1. Analytical Model of Viaduct

The highway viaduct considered in this study is composed by a three-span continuous seismically isolated bridge section connected to a single simply supported non-isolated span. The bridge alignment is horizontally curved in a circular arc. Four different radii of curvature are taken into consideration measured from the origin of the circular arc to the centerline of the bridge deck: 100m, 200m, 400m and 800m. The total viaduct length of 160 m is divided in equal spans of 40m. The bridge superstructure consists of a concrete deck slab that rests on three I-shape steel girders, equally spaced at an interval of 2.1 m. The three girders (G1, G2 and G3) are interconnected by end-span diaphragms as well as intermediate diaphragms at uniform spacing of 5.0 m. Full composite action between the slab and the girders is assumed for the deck superstructure model, which is treated as the three-dimensional grillage beam system presented in Fig. 1. The deck weight is supported on five hollow box section steel piers of 20m of height. Two cases have been considered, when the superstructure is supported on steel bearings (SB), and the second in which the continuous section has been seismically isolated (LRB). The non-isolated simply supported bridge section (S1) is supported by steel fixed (Fig.2 (a)) and steel roller (Fig. 2 (b)) bearings. Coulomb friction force is taken into account for the roller bearings, which allow movement tangent to the curved deck superstructure. The isolated continuous section (S2) is supported on top of four pier units (P2, P3, P4 and P5) by LRB bearings, which are represented by the bilinear force-displacement hysteresis loop given in Fig.2 (c).

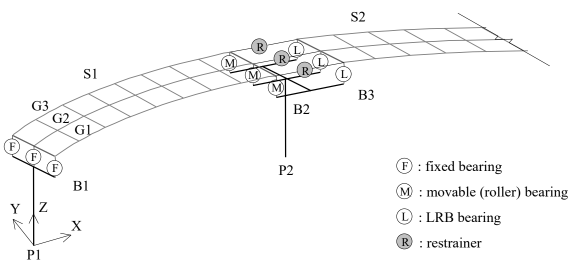

Fig. 1 Detail of viaduct finite element model

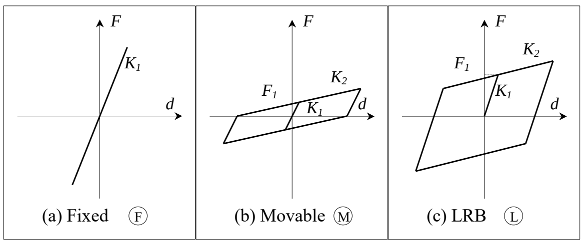

Fig. 2 Analytical models of bearing supports

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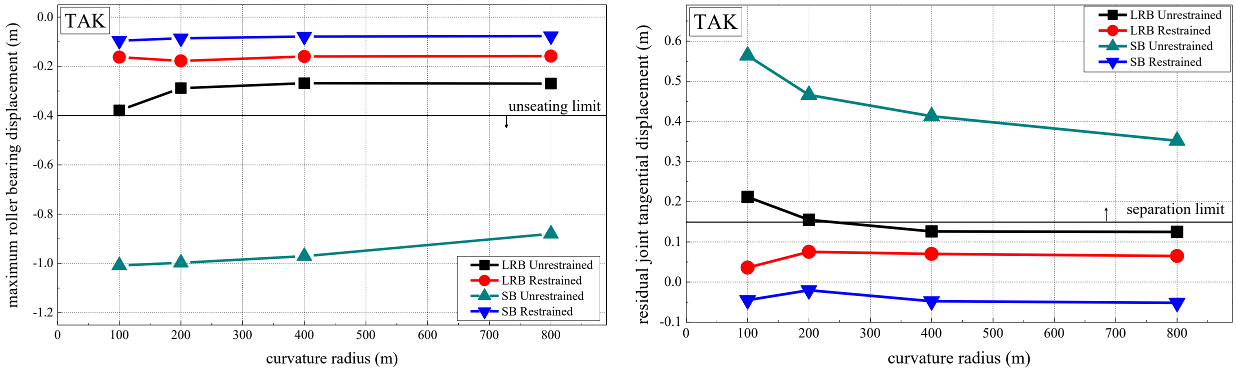

(a) deck unseating damage

(b) tangential joint residual damage

Fig. 3 Effect of seismic isolation and unseating prevention cables on seismic damage

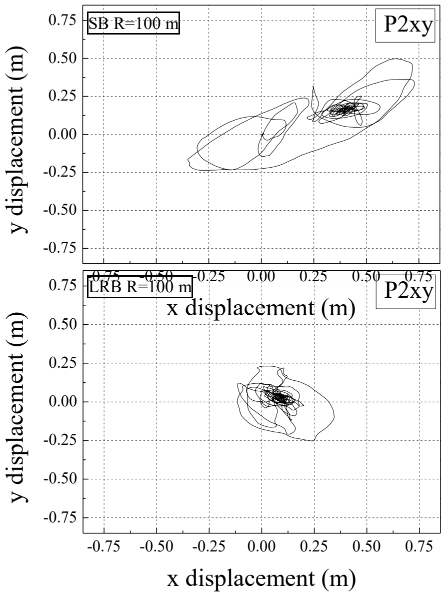

Fig. 4 Effect of seismic isolation on pier top damage from TAK

The analysis on the highway viaduct model is conducted using an analytical method based on an elasto-plastic finite displacement dynamic response analysis. 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. The longitudinal earthquake component shakes the highway viaduct parallel to the X-axis of the global coordinate system, while the transverse and vertical components are acting in the Y- and Z-axes, respectively.

2. Analytical Results

In all cases, the results indicate that TAK record, shown in Fig. 3, represents the worst scenario for the viaducts. In terms of deck unseating damage, the calculated results clearly demonstrate that curved viaducts are more vulnerable. However, this possibility can be reduced by the use of seismic isolation and by the use of restrainers. Moreover, the use of cable restrainers provide to the bridge a similar behavior in case of curved and straight bridges, as illustrated in Fig. 3 (a). Furthermore, the results show that curved viaducts are vulnerable to tangential joint residual damage. This damage increases in bridges with small curvature. In case of isolated and restrained viaducts, a significant reduction of this type of damage is appreciated and similar values are obtained (Fig. 3(b)). On the other hand, another important aspect analyzed in this study is the possibility of pier damage. The isolation provided by LRB's results in a remarkable damage reduction not only in terms of maximum displacements but also in terms of residual inclination, as presented in Fig 4.

3. Conclusions

The use of LRB's provides a significant reduction of seismic damage. Furthermore, even though the differences on the radii of curvature among the viaducts, the application of cable restrainers reduces the possibility damage. In this analysis, the effectiveness of seismic isolation combined with the use of restrainers on curved highway viaducts is demonstrated, not only by reducing in all cases the possible damage but also by providing a similar behavior in the viaducts despite of curvature radius.