REDUCTION OF POUNDING OF SUPERSTRUCTURE SEGMENTS OF ELEVATED BRIDGE DURING EARTHQUAKES

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1. INTRODUCTION

Pounding between bridge superstructure segments and abutments as well as between adjacent superstructure segments was observed in elevated bridges during severe earthquakes. Collisions of structural elements of the bridge can cause expensive to repair damage to deck ends and in some cases a collapse of the superstructure. It is particularly important to incorporate pounding into the design of base isolated bridges since the elongation of the natural period results in large displacements of superstructures which inevitably leads to pounding. In this paper, several techniques to avoid or minimize pounding effects, triggered by seismic traveling wave, are discussed.

2. FORMULATION OF POUNDING OF ELEVATED HIGHWAY BRIDGE

The structure used in the analysis is an infinitely long, isolated RC highway bridge, consisting of superstructure elements with dimensions and cross section properties specified in "Manual for Menshin Design of Highway Bridges" [1]. The superstructures are supported on two high damping rubber bearings (HDRBs) design for the displacement of 18 cm. For the analysis, the bridge length is limited to 5 segments and the analysis is focused on the middle one. The surrounding bridge segments and the gap-spring elements on the beginning and end of the model (Fig. 1) are simulating the dynamic behavior of the neglected parts of the bridge.

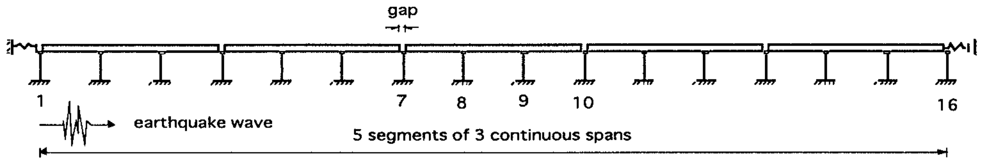

Fig.1 Full model of bridge

Pounding between adjacent superstructure segments in the longitudinal direction of the bridge is modeled by linear viscoelastic impact elements. These elements become active when the distance between adjacent masses is smaller than initial gap, *d*. The high damping rubber bearings are described by nonlinear model[2] (Fig. 2) which describes the variation of bearing stiffness and damping with the strain and strain rate level. The linear equivalent model of HDR describes the behavior of bearings only for the design displacement and for larger deformations the equivalent stiffness and damping are decreasing, thus the application of linear model can lead to significant changes in pounding patterns and underestimation of forces cause by pounding in piers (Fig. 3).

3. METHODS OF MINIMIZING EFFECTS OF POUNDING

The most natural way to prevent pounding is to ensure the sufficiently large spacing between adjacent superstructures. Fig. 3 shows the maximum shear forces transmitted to the piers form the middle segment of the bridge due to scaled to 800 gal El Centro earthquake and apparent wave velocity 1000 m/s. The reduction of the shear force for the gap larger than 0.14 m, i.e., when the influence of collisions can be neglected, is about 43% with respect to shear force for gap of 0.11 m. However, it is undesirable for

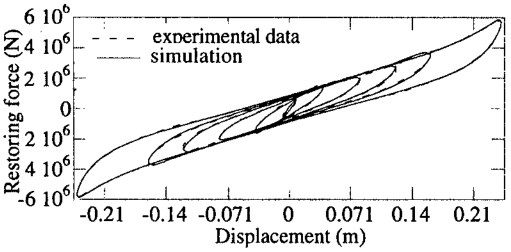

Fig.2 Experimental data and predication of HDRB hysteresis

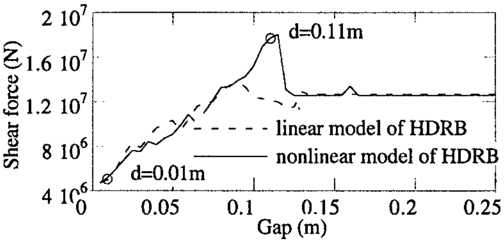

Fig.3 Maximum shear force vs. gap for linear and nonlinear models of HDRB

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bridges to have large expansion joints and moreover, the shear force can be decreased beyond the value of non-pounding case when the gap between the superstructures is very small. In case of applying very small gap, the analysis should take into account the required spacing between the decks and local damage of the deck ends due to large number of collisions. The idea of placing the laminated rubber elements in-between adjacent superstructures, so as the separation gap is artificially reduced and the deck is protected form direct collision, is under investigation.

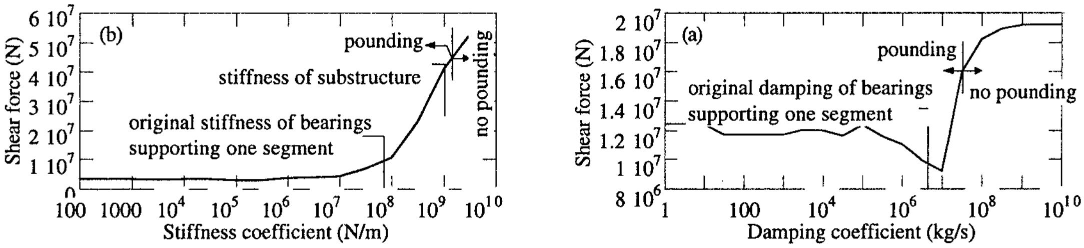

Fig.4 Maximum shear force with respect to various: a) damping; b) stiffness of bearings.

The occurrence of collisions between the adjacent superstructures segments can be also altered by varying the properties of the bearings. Fig. 4 shows the variation of the shear force due to increase of HDRB damping and stiffness for gap of size d=0.05 m. The increase of damping and stiffness of the bearings prevents pounding, however, since the connection between the piers and deck becomes rigid the shear force is significantly higher comparing to the bridge with standard HDRB. Minimization of pounding can be achieved by placing an additional damper or spring between adjacent superstructures (Fig. 6 and 7).

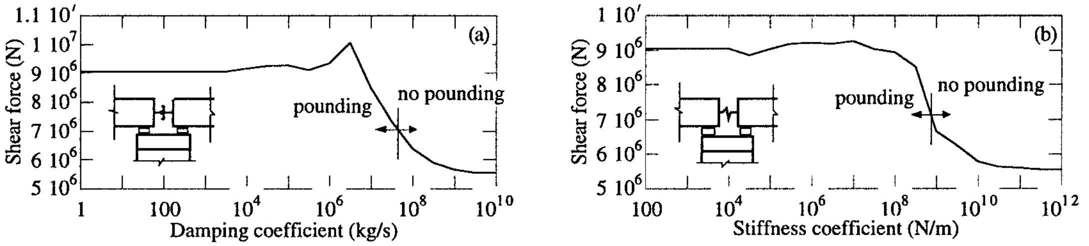

Fig.5 Maximum shear force with respect to: a) damping; b) stiffness of additional device.

The device inserted between the bridge decks is effective if either damping or stiffness is very large, thus, there are no collisions of the decks since the bridge behaves like a long continuous beam. The internal forces in the superstructure are higher, but the forces transmitted to the piers are much smaller. A shock transmission unit (STU) has the characteristics to realize this idea. STU behaves as a stiff connection for the band of frequencies exerted by earthquakes but has no rigidity for the slow motion resulting from thermal elongation , creep or shrinkage. The 5 tone STU was experimentally tested for harmonic excitation of different frequencies and the tests confirmed the benefits of STU application. The drawback of STU for pounding prevention is its capacity. The force induced between the decks can have very large magnitude, thus either a large number of the devices must be installed or single unit should have a capacity of several hundreds tons. Both solutions can be practically difficult to realize.

4. CONCLUSIONS

The methods of minimizing pounding between superstructures of elevated highway bridge due to traveling wave effect has been presented. The optimization of gap size between superstructures suggests two possible solution: small or large gap size. Although, the large gap prevents pounding, the maximum shear forces in piers are relatively large and big expansion joints are necessary. The small gap can be induced by placing e.g., laminated rubber members in-between deck ends so as the effective gap is decreased and deck ends are protected form direct collisions. The location of additional device between two superstructures is effective only when the stiffness or damping of the device is very high, which can be realized by shock transmission units.

REFERENCES

1) Kawashima, K., Okado, M. and Horikawa, M.: Design example of a highway bridge based on the Manual for Menshin Design of Highway Bridges, *Recent selected publications at Earthquake Engineering Division, Public Works Research Institute (No.2)*, pp.191-208, May, 1993.

2) Jankowski R., Wilde K., Fujino Y.,: Pounding in elevated bridges during earthquakes and reduction of its effects, *Proceedings of NCEER-INCEDE Workshop, Buffalo, New York*, March 1997.