I – Problem Statement Title (04-EQ026)

Determining the Effective System Damping of Highway Bridges

II - Research Problem Statement

Question: What effective system damping should be used to analyze bridges when structure and boundary elements with different damping ratios co-exist?

Traditional structure dynamic analysis uses a 5% system damping. While it is generally acceptable for ordinary concrete structures, it does not apply for steel structures or structures with significant influences from the foundation or other damping elements. The MTD 20-4 Attachment A has stated that for short bridges (less than 300 feet long with no hinges and non-skewed), it can be analyzed with a reduction factor for its higher damping inherited from the abutments. The equation shown in the MTD is based on the Japanese code without much reference. For seismic isolated bridges, Caltrans' current practice is to use the damping ratio from isolator as the system damping and modified response curve in isolation mode. This may overestimate system damping if the substructure is flexible.

III - Objective

Develop specification and examples covering the calculation of effective system damping when a bridge consists of higher or lower damping elements other than concrete members. The specifications should be prepared in both LFD and LRFD format.

IV - Background

Traditional structure dynamic analysis uses a system damping of 5% for concrete structures and 2-3% for steel structures. While this practice is acceptable in buildings, it does make a difference for a short bridge with lots of influence from abutment damping. For seismic isolated bridges, the damping ratio for the isolators is in the range of 20-30%. When it is combined with the rest of structure, the effective system is in the range of 15-25% depending on the isolator layout. Therefore the system damping is overestimated. Composite damping rule is based on energy dissipation as Ragget suggested it in 1975. After the 1989 Loma Prieta Earthquake, Caltrans funded research to study short span bridges by Dames and Moore. In their conclusion, it suggests the effective modal system damping can be increased for strong ground shaking. It also suggested using weighted energy method as applied in the nuclear power industries. Jennshin Hwang, who once worked for Caltrans and current Deputy Director of National Center of Earthquake Engineering Research in Taiwan, has verified the combination rules through shaking table for seismic isolation with various isolators. However, his layout is primarily for structure elements layout in parallel. For structure elements layout in serial or in combination, no verification has ever been performed.

To absorb more energy from earthquake excitation, flexible bridge may add energy dissipation devices to reduce overall motion. Can this so-called added damping to be included in the overall effective system damping?

V – Statement of Urgency and Benefits

A. Support of the Department's Mission/Goals

(Improving Mobility: Safety and Reliability) All bridges in California are subject to strong earthquake shaking and a dynamic analysis is required. Both strength and deformation demands are greatly influenced by system and element damping factor. A realistic damping factor can result in more efficient and reliable structures, reducing retrofit and foundation costs.

B. Return on Investment

The majority of bridges across California freeways are short with a total length less than 300 feet. Research contract 59Q122, finished in 1993, identified higher abutment damping from recorded strong motion records. The increased damping from abutments can reduce the overall seismic demand of substructures. Taking advantage of increased damping during analysis for new structures can reduce the number of piles or size of foundations required. For existing bridges performing analysis with increased damping can reduce retrofitting costs. Although the current Memo to Designers recognizes this effect, it does not directly instruct the designer how to calculate it. Rather, it lets the designer use a higher damping if he/she thinks it is appropriate. Lacking guidelines, many engineers conservatively use the minimum value. Assuming increased damping could be included in the analysis of even a quarter of our bridge projects, and if it resulted in only a 5% reduction in foundation costs, the cost savings would be nearly $10 million annually.

VI - Related Research

1. Goel,R.K. and Chopra, A. "Evaluation of bridge abutment capacity and stiffness during earthquake", Earthquake Spectra, Vol 13-1, 1997,
2. Dames & Moore, "Study of Caltrans's Seismic Evaluation Procedure for Short Bridge Overcrossing Structures", Contract 59Q122, August 1993.
3. Johnson, C.D. and Keinholz, D.A. "Finite Element Prediction of Damping in Structures with Constrained Viscoelastic Layers," AIAA Journal, vol. 20, No. 9, pp. 1284-1290, 1982
4. Ragget, J.D. "Estimating Damping of Real Structures." Journal of Structural Division, ASCE, Vol. 101, ST9, pp. 1823~1835, 1975.

VII - Deployment Potential

New design specification and Memo to Designers for damping calculation will be established. These documents will lead to improved safety of our highway bridge system.