The Effect of Live Load on the Seismic Response of Bridges

RESULTS: The presence of live load has a beneficial effect on the seismic response of ordinary bridges due to vehicle-structure interaction. Displacements, accelerations, and internal forces are reduced by modest amounts and the extent of crack formation and concrete spalling is less severe in the columns.

Background

Dynamic vehicle-bridge interaction has long been studied, but mainly with regard to the impact effect of live load, due to surface roughness and vehicle speed, and not the dynamic effect of sprung live load on seismic behavior. The objective of this study was to investigate this second effect and obtain insight into the consequences of vehicle-bridge interaction during earthquake excitation. This study consisted of both experimental and analytical investigations.

Why We Pursued This Research

Current bridge design specifications assume the likelihood of the full design live load occurring at the same time as the design earthquake is low. But traffic congestion has become a common situation in major cities and the occurrence of significant live load at the time of a major earthquake is much more likely than previously thought possible. It is clear that live load not only provides additional gravity load but also dynamic force effects due to its sprung nature. However the significance of these effects (adverse or beneficial) on seismic response is not so obvious.

What We Did

The experimental portion of the study took advantage of a separate study being conducted on the seismic response of curved bridges at the University of Nevada, Reno funded by the Federal Highway Administration. This study involved a series of shake table experiments on a 0.4-scale model of three-span steel girder bridge with a high degree of horizontal curvature. For the live load study, six trucks were placed on this bridge and performance was compared against an earlier experiment conducted without live load. These experiments were carried out on the NSF-supported NEES multiple shake table array at the University of Nevada Reno. Use of this array was funded under a Shared-Use Agreement with NEEScomm at Purdue University.

For the analytical portion of the study a 3D finite element model of the bridge and live load was developed and calibrated against the experimental results. It was then used to conduct a limited parameter study to determine if the observations found in the experimental phase extended to bridges and trucks of different mass and frequency ratios.
Research Results

For the bridge tested, the effect of live load was beneficial. It reduced the demand in the structure, as evidenced by a decrease in displacements, accelerations, and internal forces. For example, the figure at the right shows the envelope of maximum force and maximum displacement for the North Bent for increasing levels of excitation expressed as percentages of design earthquake (DE). It is seen that the column drift at each level of excitation is consistently less with live load on the bridge than without.

Live Load also delayed the formation of cracks and concrete spalling in the columns and reduced column damage for the same level of earthquake excitation. Girder uplift at the abutments and degradation of column torsional stiffness was less with live load on the bridge.

The 3D finite element model for vehicle-bridge interaction was able to replicate this behavior particularly with respect to peak values of displacement and force. Although this model could be refined to further improve accuracy, it is believed to be sufficiently accurate for use in parameter studies on live load effects.

The results of the parameter study showed that live load can give both beneficial and adverse effects on the seismic response of bridges. Factors affecting this response include vehicle-to-bridge mass ratio, vehicle period and damping, and earthquake ground motion (type and level). In general undamped vehicles give beneficial effects at mass ratios less than 10% and adverse effects at higher ratios for all vehicle periods and earthquake levels. However a modest amount of vehicle damping (5% of critical) can give favorable results for all mass ratios and vehicle periods particularly for the design level earthquake. These results are consistent with the experimental results reported above for a system which had a vehicle-bridge mass ratio of 19%, truck period of 0.8 s and truck damping of 10-15%, subject to two levels of the Sylmar ground motion.

The reason for the beneficial effect is most likely due to the ‘tuned mass damper (TMD) effect’ of the vehicles. TMDs are used to control wind vibrations in high-rise buildings, but their effectiveness for earthquake loads is not so clear. However, recent work on nonlinear energy sinks, which are essentially multiple nonlinear tuned mass dampers, has shown attractive results for controlling the seismic response of buildings. It is very possible that multiple trucks on a bridge, each with moderately damped nonlinear rear suspensions, are acting as a set of nonlinear energy sinks, with the same favorable results. Validation of this explanation was outside the scope of this study.

Recommendations

The following recommendations are made:

1. More detailed parameter studies should be carried out to confirm the above findings for a wide range of structures and truck types to extend the database beyond the bridge and vehicle type used in this study. For example, long span box-girder bridges, short span PC-girder bridges, and bridges with seismic isolation devices should be investigated along with 3- and 4-axle tractor-trailer rigs.
2. The mechanics of vehicle-bridge interaction should be explored in greater detail to understand the observed phenomena. The theory for multiple nonlinear tuned mass dampers appears to be a good place to start.

Reference


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