Rocking Isolation of Bridges

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In the conventional design, uplift of direct bridge foundations from the underlying ground is minimized in order to prevent overturning of the pier. However, post earthquake inspection of piers has revealed cracks on the underlying ground indicating that rocking of piers did take place during the earthquake. In this study the rocking response of piers is investigated through experimental response of models representing the footing-pier-deck system and analytical simulation of the experimental data.

The tests were conducted at the Earthquake Engineering Laboratory in Tokyo Institute of Technology, using a one dimensional shake table. A model idealizing the bridge pier consisted of steel top plates (deck), a column (pier), bottom plates (footing), and a rubber block (ground). The standard column pier was 840mm tall, 100mm wide and 6mm thick. The deck mass was 8.5kg. The footing with a section of 300mm and a thickness of 30mm was designed so that the deck displacement due to the rocking response of the footing was in the range of 30-60% of the total deck displacement. The rubber block had a section of 500mm, a thickness of 100mm, and a shear modulus of 0.6 MPa. The rubber block was laterally restrained to prevent shear deformation during the excitation.

When the model is excited, various modes of structural response occur. However since focus of this study is exclusively rocking response, sway motion of the footing was restricted. Rocking of the footing could take place freely thanks to two ball bearings fixed at each edge of the footing which could slide on two vertical smooth steel plates. These plates at the same time prevented sliding of the footing.

Both free oscillation and seismic excitation tests were conducted. Free oscillation tests provide important data on the equivalent viscous damping of the model bridge and on the dependence of model's natural period on footing's rotation.

The ground motions recorded at Japan Meteorological Agency Kobe Observatory (JMA Kobe) during the Kobe, Japan earthquake in 1995, near Bolu viaduct during the Duzce, Turkey earthquake in 1999 and Ojiya (NIG019EW) during the Niigata-chuetsu, Japan earthquake in 2004 were used. Intensity of the original ground motions was scaled down so that the response amplitude of the model reduced to suitable levels.

Experimental results revealed that when rocking of bridge piers occurs, response period increases leading to a clear seismic isolation effect. Moreover flexural deformation of the pier decreases resulting in lower ductility demand. However, consequence of footing's rotation is considerable increase of overall deck displacement. In addition large vertical acceleration developing at the edges of the footing during impact with underlying ground indicates danger of soil yielding. Based on experimental results it is also shown that as deck mass increases or footing's size decreases, footing's edges uplift increases. Contrary decrease of column height leads to significant decrease of footing's pier's rocking.

A discrete model simulating the experimental bridge was developed in order to study rocking effect of bridges analytically. The column was idealized with linear beam elements; the footing with linear beam elements of sufficiently high stiffness and the deck mass was lumped at the top of the column. The nonlinear contact between the footing and the ground was idealized by contact spring elements, which resist compression but not tension.

Analytical response correlates well the experimental response when uplift of footing obtains small or medium values. For large values of footing's uplift, P-δ effects cannot be ignored and must be taken into account by analytical tools otherwise footing's uplift and response period are underestimated.