CAPACITY AND STIFFNESS OF BRIDGE ABUTMENTS DURING EARTHQUAKES

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Most specifications and guidelines for earthquake design of highway bridges require that abutment-soil systems be included in the analytical model as discrete equivalent linear springs. In design applications, stiffness values of these springs are determined from one of the two iterative procedures:

- The procedure starts with an initial estimate of the abutment stiffness that is obtained from simplified rules involving abutment dimensions and soil properties. The analysis is repeated by successively reducing the stiffness until earthquake-induced force in the abutment becomes smaller than the abutment capacity.
- The procedure starts with the abutment stiffness that is calculated as ratio of the abutment capacity and an initial estimate of the earthquake-induced deformation. The analysis is repeated by updating abutment stiffness to reflect the abutment deformation calculated in the previous iteration until the abutment deformation at end of an iteration cycle becomes smaller than the value at beginning of the cycle.

It is not entirely clear how well the stiffness value thus determined represents the complex behavior of the abutment-soil system, which is influenced by soil-structure interaction and nonlinear behavior of the soil. Therefore, the objective of this investigation is to determine and compare the actual values of the stiffness and capacity of abutment-soil systems during earthquakes with their design values.

The actual values of capacity and stiffness of abutment-soil systems of a continuous two-span bridge with integral abutments are determined from its ground and structural motions recorded during a significant earthquake event. The bridge considered in this study is the US 101/Painter Street Overpass located in Rio Dell California; and recorded motions selected are those obtained during main shock of the April 25, 1992, Cape Mendocino/Petrolia earthquake. For this purpose, the bridge is idealized as a simple system consisting of the following:

- Road deck girder.
- Spring-dampers along the east abutment, normal to the east abutment, and along the west abutment. The spring represents the stiffness property and the damper accounts for material and radiation damping of the abutment-soil system.

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- Two linear elastic springs -- one normal to and the other along the bent -- at location of each column in the central bent; no damper is included because the energy dissipation in the bent should be negligible.

The actual stiffness and capacity values of each abutment are estimated from force-deformation relation of the associated spring-damper system. The forces in the three spring-damper systems are obtained by solving three equations of dynamic equilibrium, corresponding to two translational motions and one rotational motion about vertical axis of the road deck, at each instant of time. In these equations, inertia forces of the road deck are computed from its mass properties and recorded accelerations, and column forces are calculated from their known stiffness and deformation values. The deformations at desired locations are obtained by subtracting the free-field displacement from the total displacements calculated by appropriately transforming the recorded motions.

The actual capacity of the abutment-soil system is the yield strength displayed by a flat yield plateau in the force-deformation relation. The actual stiffness of the abutment-soil system is the slope of the force-deformation relation. For linearly visco-elastic behavior, the abutment stiffness is the slope of the major axis of the ellipse in an individual force-deformation loop. For nonlinear behavior, the abutment stiffness is the secant slope of the force-deformation loop.

The abutment capacity and stiffness thus obtained include all effects including those of soil-structure interaction and nonlinear behavior of the soil. These results are used to evaluate the CALTRANS, AASHTO-83, and ATC-6 procedures for estimating the abutment capacity and stiffness. This evaluation indicates that:

- CALTRANS procedure leads to a good estimate of the abutment stiffness in the direction along the abutment (transverse to the road deck) provided the deformation assumed in computing the stiffness is close to the actual deformation during the earthquake.
- CALTRANS procedure also leads to good estimate of the abutment capacity in the direction along the abutment.
- CALTRANS procedure may overestimate the capacity and stiffness normal to the abutment (along the road deck) by a factor of over two.
- The value of 7.7 ksf for the ultimate passive resistance of the soil used in the CALTRANS procedure may be too high.
- AASHTO-83 and ATC-6 procedure gives an initial estimate of abutment stiffness that is too large in both directions.
- AASHTO-83, ATC-6, and CALTRANS procedures give identical values for the final stiffness because the abutment capacities from these procedures are identical.

The conclusions in this investigation are based on results from recorded motions of one bridge during two earthquakes. It is strongly recommended that other similar bridges be investigated to verify these conclusions and to develop generally applicable conclusions that can be used to improve the current design procedures.