ABSTRACT

Huo, Hongbin. Ph.D., Purdue University, August 2005. Seismic Design and Analysis of Rectangular Underground Structures. Major Professor: Antonio Bobet.

There is compelling evidence that current engineering seismic design of rectangular underground structures needs to be improved. The recent failures of a number of underground structures and lifelines in recent earthquakes support this conclusion. The Daikai station collapsed during the Kobe earthquake of 1995 in Japan. The station belongs to the Kobe subway system and was built by the cut and cover method. The Daikai station is the first well documented underground structure not crossing an active fault that completely collapsed during an earthquake. What makes this case even more interesting is that adjacent similar sections of the station did not collapse. Dynamic finite element analyses have been conducted to investigate the load transfer mechanisms between the underground structure and the surrounding soil and to identify the causes for the different behavior of the sections of the station. A hysteretic non-linear soil model has been used for the analysis. The results from the analyses show that the stiffness ratio between the structure and the degraded surrounding ground and the frictional characteristics of the interface determine the response of an underground structure. The numerical model predicts larger deformations in the collapsed section because this section had a smaller stiffness, and thus triggered drifts in critical structural elements which were larger than at other sections.

A closed-form analytical solution employing complex variable theory and conformal mapping techniques has been developed for the seismic design of rectangular underground structures. It has been assumed that the ground and structure behave

elastically, it is deep structure with a tied interface with the surrounding ground, and that a pseudo-static approach can be used for seismic loading. Soil stiffness degradation with deformation has been incorporated through an iterative scheme where the soil shear modulus is reduced with increased shear strain. The results obtained from the analytical solution have been verified by a series of numerical tests which include the response of the Daikai station during the Kobe earthquake and the Los Angeles Civic Center Subway station subjected to the 1994's Northridge earthquake. The relative errors between analytical and numerical results are within 15%. The analytical solution indicates that the structure deformation is dependent on the stiffness ratio between the structure and the ground and on the shape of the structure, which is given by the ratio between its length and height. Even though depth and interface effects are neglected the solution still provides a good approximation because such effects compensate each other.