Annual Project Summary Report for 10/01/00 – 09/30/01

"Evaluation of Seismic Slope Stability Procedures Through Shaking Table Testing"
Award Number: 00HQGR0083
Research Project Period: 9/1/00-8/31/02

Jonathan D. Bray, Ph.D., P.E.
University of California, Berkeley
437 Davis Hall, MC-1710
Berkeley, CA 94720-1710
Tel. (510) 642-9843
Fax. (510) 642-7476
Email: bray@ce.berkeley.edu
URL: http://www.ce.berkeley.edu/~bray/

Program Element II. Research on Earthquake Occurrence and Effects
(Research Task: Processes, Theoretical, and Laboratory Studies)
Keywords: Geotechnical, Slope Failures

PROJECT DESCRIPTION

OBJECTIVE

The primary goal of this research project is to provide data and insight crucial to an objective evaluation of prevailing techniques for analysis and mitigation of earthquake-induced landslides produced by seismically induced ground deformations other than those resulting from liquefaction. Well-documented, realistic physical model tests offer the opportunity to evaluate available analytical techniques against defined conditions in a controlled laboratory environment.

SCOPE

To achieve the stated research objective, the results from the four already completed high-quality model slope experiments performed by Dr. J. Wartman (Wartman et al., 1998; Wartman, 1999) under a separate Caltrans-sponsored research grant will be back-analyzed during the first year to garner important insights. A report summarizing the findings from this study will be completed at the end of year one. Lessons learned from these back-analyses will be used to develop four new 1-g small-scale physical model clay slope experiments that are to be conducted at the beginning of the second year of the study. These new experiments will explore unresolved issues with well-defined model tests. Over the last six months of the two-year project, these four new experiments will be back-analyzed using prevailing slope deformation procedures, as was done for the other experiments by Wartman.

INVESTIGATIONS UNDERTAKEN

The results of four clay slope model experiments performed by Dr. J. Wartman (identified as Model Tests 2, 3, 4, and 6 in the recently completed University of California, Berkeley thesis by Wartman, 1999) have been reviewed. Two-dimensional finite element analyses using the equivalent-linear program QUAD4M (Hudson et al. 1994) have been completed for each of these four experiments. This effort included processing input shaking table base motions and developing soil model parameters (i.e. shear wave velocity, shear modulus reduction curves, material damping curves, unit weight, Poisson's ratio, and dynamic shear strength for evaluating large-strain properties) for these experiments. The data provided in the thesis by Wartman (1999) was used as the basis for these analyses.

In addition to completing these relatively sophisticated two-dimensional finite element dynamic analyses with the program QUAD4M, simplified seismically induced permanent deformation analyses (i.e. Newmark, 1965; Makdisi and Seed, 1978; and Bray et al. 1998) and one-dimensional SHAKE91 (Idriss and Sun, 1992) have been completed. Hence, prevailing simplified and advanced analyses of seismically induced permanent displacements of slopes and embankments have been completed. The results of this study are described in the University of California Geotechnical Report entitled “Evaluation of Seismic Slope Displacement Procedures through Back-Analysis of Physical Model Tests” by T. Travasarou, J. Bray, J. Wartman, R. Seed, and M. Reimer.

RESULTS

Analytical results for the back-analysis of the response of a representative model slope experiment are presented in this section. The details of the setup and results of Model Test 6 are described fully in Wartman (1999). The finite element model used for the two-dimensional back-analyses with the program QUAD4M is shown in Figure 1. A comparison of the calculated seismic displacements with the measured slope displacements of Model Test 6 is shown in Figure 2.

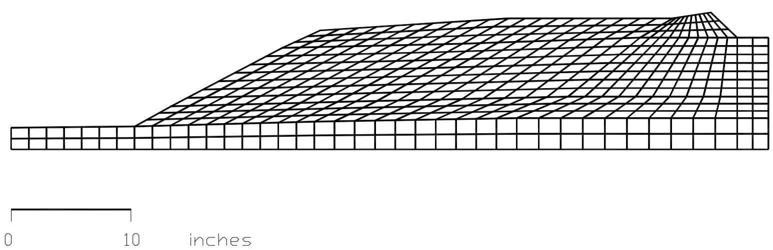

Figure 1. Finite element mesh for Model Test 6 of Wartman (1999).

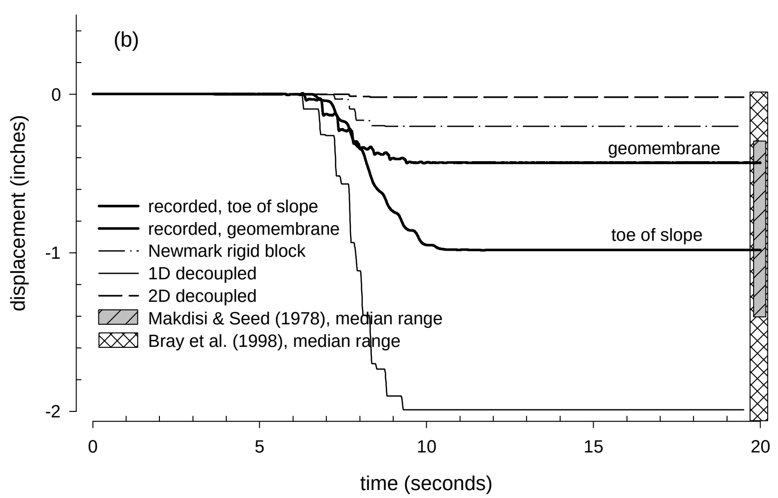

Figure 2. Results for Model Test 6 using several analytical procedures for estimating seismically induced permanent deformations.

The results of the back-analyses emphasize the difficulty in obtaining refined estimates of seismically induced permanent displacements for slopes due to the difficulty in capturing the dynamic response well at high strain levels using “state-of-the-practice” equivalent-linear dynamic analyses. Additionally, these small-scale models appear to have important three-dimensional response characteristics that are not captured by one- and two-dimensional analyses.

When the dynamic response of the slope as captured by the accelerographs embedded in the clay models experiments could be reproduced by the dynamic analyses, the slope displacements were estimated reasonably well. However, in two cases, the recorded response of the embedded accelerographs could not be reproduced by the dynamic analyses without “adjusting” the input parameters significantly (i.e. a forward analysis without knowing the results yields unreliable results). For these cases, the slope displacements calculated from “unadjusted, blind” forward analyses were not reliable.

In evaluating these experimental results, a number of issues were identified that need to be addressed in the additional slope experiments planned for year two of the project. The stiff clay that underlies the soft clay should be eliminated to reduce model parameter uncertainty. Well-defined slip surfaces should be used to better define the sliding block geometry. Additionally, the models should be made as large as possible to reduce model-scaling problems. The Wartman clay box model tests required accelerations in excess of 2 g to produce seismic displacements, because the yield accelerations for these small-height models was typically greater than 1 g. A larger clay slope will alleviate the difficulties of analyzing experiments at high acceleration levels, where induced shear strains are often excessive and outside the range of reasonableness for equivalent-linear dynamic analysis.

NON-TECHNICAL SUMMARY

A key element of California's Seismic Hazards Mapping Act is to identify zones containing potential earthquake-induced landslide hazards. Current evaluation/mitigation guidelines for these hazards are largely based on simplified analytical methods. Given that these methods have generally been calibrated to evaluate earth dam performance, and not the more general cases covered by this Act, these methods require re-examination. Due to the difficulties of obtaining well-documented full-scale case records, realistic physical model shaking table experiments represent a viable alternative for developing insight. This project will provide experimental data crucial to an objective re-evaluation of prevailing techniques for analysis of earthquake-induced landslides.

REPORTS PUBLISHED

Travasarou, T., Bray, J.D., Wartman, J., Seed, R.B., and Riemer, M.F. (2001) “Evaluation of Seismic Slope Displacement Procedures through Back-Analysis of Physical Model Tests” Geotechnical Engineering Report No. UCB/GT/01-04, University of California, Berkeley, June, 107 pp.

Wartman, J, Seed, R. B., and Bray J.D. (2001) "Physical Model Studies of Seismically Induced Deformations in Slopes", Geo-Engineering Report No. UCB/GT/01-01, Department of Civil and Environmental Engineering, University of California, Berkeley, September.

Wartman, J, Seed, R. B., and Bray J.D. (2001) "Experimental Data for Physical Model Studies of Seismically Induced Deformations in Slopes", Geo-Engineering Report No. UCB/GT/01-02, Department of Civil and Environmental Engineering, University of California, Berkeley, September.

DATA AVAILABILITY

Physical model test results data are available in Wartman et al. (2001) reports cited above. These reports are available from the U.C. Berkeley GeoEngineering Group (POC: Ms. Eileen Pearl, 440 Davis Hall, MC-1710, University of California, Berkeley, CA 94720-1710; (510) 642-1262; cegeot@newton.berkeley.edu).

REFERENCES

Bray, J. D., Rathje, E. M., Augello, A. J., and Merry, S. M. (1998) “Simplified Seismic Design Procedure for Lined Solid-Waste Landfills," *Geosynthetics International Journal*, Vol. 5, Nos. 1-2, pp. 203-235.

Hudson, M., Idriss, I.M., and Beikae, M. (1994) “User’s Manual for QUAD4M”, Center for Geotechnical Modeling, Department of Civil and Environmental Engineering, University of California, Davis, CA, USA.

Idriss, I.M. and Sun, J.I. (1992) "User's Manual for SHAKE91", Center for Geotechnical Modeling, Department of Civil and Environmental Engineering, University of California, Davis, CA, USA, 12 p.

Makdisi, F. I. and Seed, H. B. (1978) “Simplified procedure for estimating dam and embankment earthquake-induced deformations,” *J. Geotech. Eng. Div.*, ASCE 104(7), 849-867.

Newmark, N. M. (1965) “Effects of earthquakes on dams and embankments.” *Geotechnique*, London, 15(2), 139-160.

Wartman, J. (1999) “Physical Modeling of Seismic Slope Stability and Slope Deformations,” Ph.D. Thesis, University of California, Berkeley.

Wartman, J., Riemer, M.F., Bray, J. D., and Seed, R. B. (1998) “Newmark Analyses of a Shaking Table Slope Stability Experiment,” Proc., Geotechnical Earthquake Engineering and Soil Dynamics III, ASCE, Geotechnical Special Publication No. 75, Dakoulas, Yegian and Holtz, eds., Seattle, WA, pp. 778-789, August 3-6.