# "Evaluation of Seismic Slope Stability Procedures Through Shaking Table Testing"

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**Program Element II. Research on Earthquake Occurrence and Effects**

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## PROJECT OBJECTIVE AND SCOPE

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. To achieve the stated research objective, four new 1-g small-scale physical model clay slope experiments are to be conducted, and the results from these new experiments and 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 to garner important insights.

## 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 models for use with the program QUAD4M (Hudson et al. 1994) have been developed for each of these four experiments. Input shaking table base motions have been processed for use in these analyses, and equivalent-linear 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) have been estimated based on the results summarized in Wartman (1999). In addition to completing preliminary dynamic analyses with the two-dimensional 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.

## RESULTS

Preliminary 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. The agreement between the computed response and the measured response in terms of computer acceleration response spectra (5 % damping) is shown in Figure 2. A comparison of the calculated seismic displacements with the measured slope displacements of Model Test 6 is shown in Figure 3.

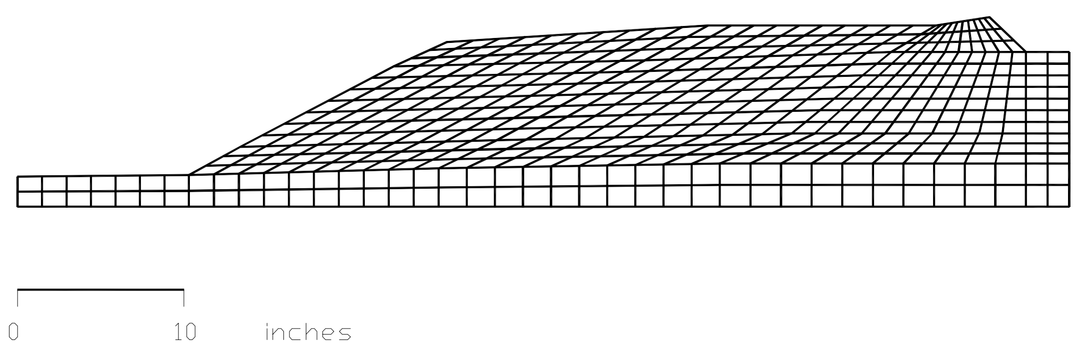


**Figure 1. Finite element mesh for Model Test 6 of Wartman (1999).**

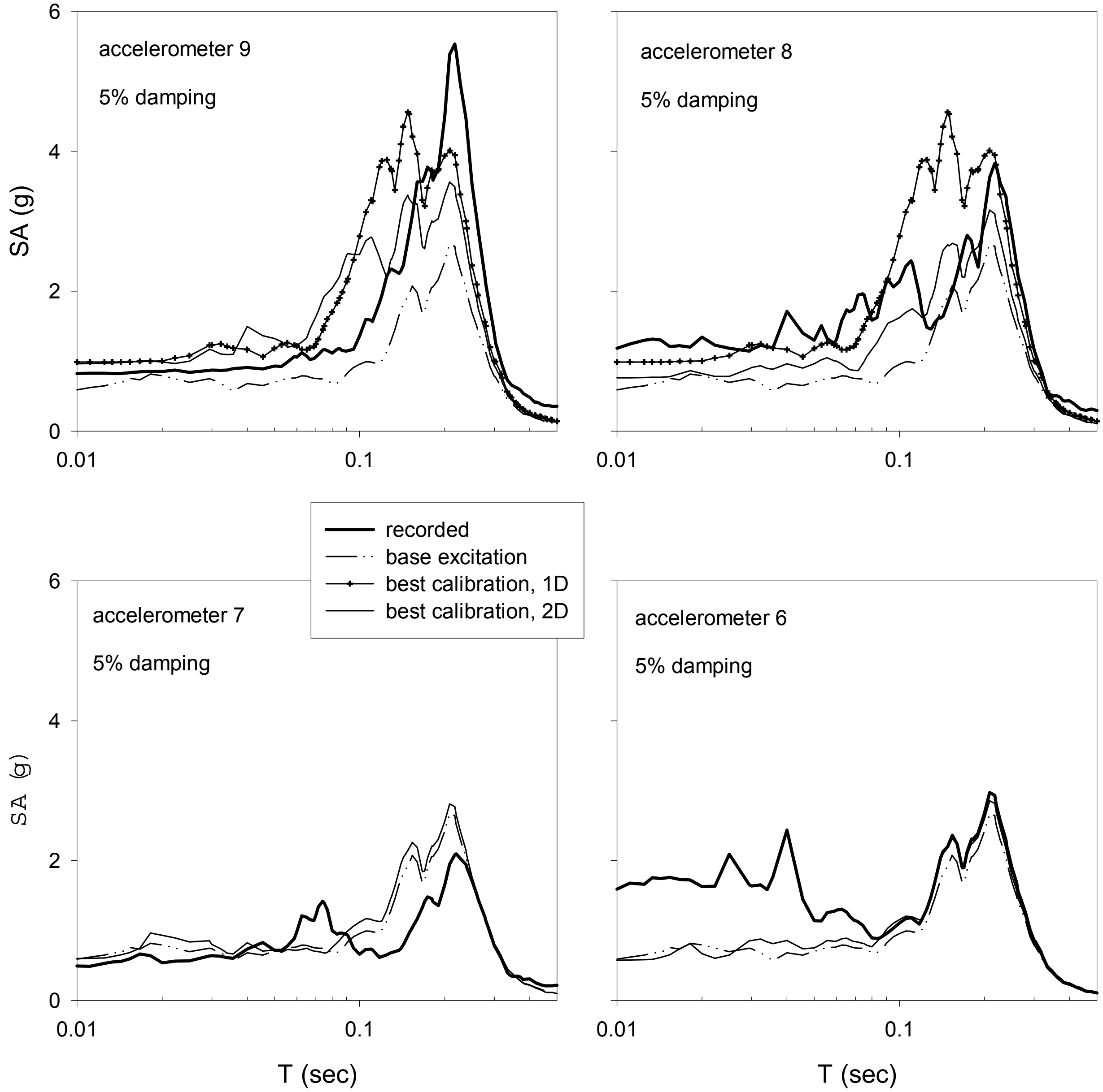


**Figure 2. Recorded and computed acceleration response spectra for 5% damping at selected locations of Model Test 6. The excitation at the base is the second large amplitude test motion. The best 2D calibration consists in decreasing the shear wave velocity of the soft clay by 20% and increasing that of the stiff clay by 10%. The best 1D calibration was achieved by using the initially measured properties. The shear modulus and damping reduction curves used are those interpolated to a PI=165 of Vucetic and Dobry (1991).**

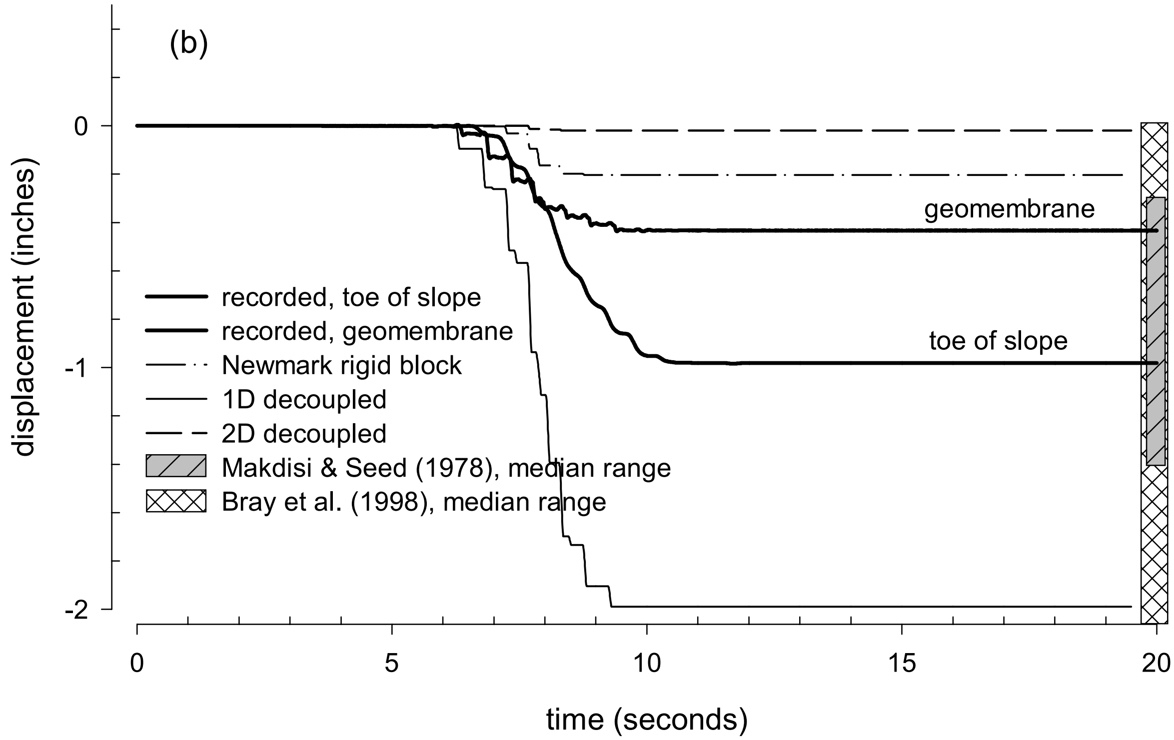


**Figure 3. Preliminary results for Model Test 6 using several analytical procedures for estimating seismically induced permanent deformations.**

## PRELIMINARY FINDINGS

The results of these preliminary 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 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 cannot be reproduced by the dynamic analyses, the slope displacements calculated from these analyses are not reliable. Hence, additional effort needs to be devoted to understanding the observed dynamic response of the Wartman (1999) slope experiments and to evaluating the capability of prevailing dynamic analyses programs used in practice to capture the observed response.

## 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

None at this time.

## DATA AVAILABILITY

None at this time.

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