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"EVALUATION OF SEISMIC SLOPE STABILITY PROCEDURES THROUGH SHAKING TABLE TESTING"

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ABSTRACT

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, the results from the four already completed high-quality model slope experiments performed by Wartman (1999) under a separate Caltrans-sponsored research grant were first back-analyzed. Findings from these two-dimensional dynamic finite element analyses of the four 1-g small-scale physical model clay slope experiments using the equivalent-linear program QUAD4M (Hudson et al. 1994) are described in a comprehensive report by Travasarou et al. (2001). In addition to completing these relatively sophisticated dynamic analyses, 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) were performed. Hence, prevailing simplified and advanced analyses of seismically induced permanent displacements of slopes and embankments were applied.

The results of the back-analyses emphasized 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 the second phase of this research program, six new 1-g small-scale physical model clay slope experiments were prepared and testing on the UC Berkeley Davis Hall shaking table. Whereas the previous clay box model tests often required accelerations in excess of 2 g to produce seismic displacements, because the yield accelerations for these small-height models were greater than 1 g; the new tests were prepared with a larger, less stable clay slope to 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. The geometry of the slope and the properties of the clay were systematically adjusted until models with relatively low yield accelerations (i.e. less than 0.5 g) were possible. These models were instrumented and tested to record their response.

Back-analyses were completed with 2D dynamic finite element analyses, 1D wave propagation analyses, and with simplified analyses. It was found that 2D FEA captured the dynamic response of the model clay slopes well as described by the measured acceleration-time histories along the crest and within the slope. Conversely, 1D analyses could not capture the dynamic response of the model clay slopes. Correspondingly, seismically induced permanent deformation analyses using the equivalent acceleration-time history of the sliding mass calculated using the 2D FEA captured the measured seismic displacement of the slope well; whereas seismic displacement analyses using the results from the 1D analyses did not capture the observed seismic performance of the slope well. Thus, again, the importance of capturing the dynamic response of the slope was critical to calculating the resulting seismic displacements.

Relatively simple, Newmark (1965) rigid block analyses gave rough estimates of the measured seismic displacement of the slopes if the dynamic strength of the model clay, including its post-peak drop in strength, was modeled satisfactorily. Hence, a simple analysis where the input acceleration-time history is used as the dynamic loading and the yield acceleration of a sliding block is used as the dynamic resistance can give good insight, because this analysis focuses on two most important aspects of this problem, i.e. the importance of the earthquake shaking and the slope's dynamic resistance. However, it misses the third most important factor, which is the dynamic response of the slope itself. Hence, decoupled seismic analyses where the slope's response is captured is recommended for use in practice.

DETAILED DESCRIPTION OF WORK PERFORMED AND RESULTS OBTAINED

The technical contributions of this two-year study are delineated in the two comprehensive technical reports prepared as part of this study, i.e. Travasarou et al. (2001) and Chen et al. (2004). These two reports constitute the technical contribution of this study, and as such, they should be consulted to get a complete, detailed description of the work performed and results obtained through this research project.

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