Final Project Summary — PEER Lifelines Program

Project Title—**ID Number**	*Inertial & Kinematic Load Combinations on Pile Foundations in Liquefying and Laterally Spreading Ground*—**3F03**		
Start/End Dates	4/1/04 – 6/30/04	Budget/ Funding Source	$250,000 / Caltrans
Project Leader (boldface) and Other Team Members	**Boulanger (UCD)**		

1. Project goals and objectives

The objective of this project is to establish guidelines for inertial and kinematic load combinations to be used in simplified pushover analyses of pile foundations in liquefied and laterally spreading ground.

2. Benefits of the results of this project to develop technologies and protocols to mitigate the vulnerability of electric systems and other lifelines to damage directly and indirectly caused by earthquakes. Also, benefits to develop assessment techniques to evaluate damage to electric systems caused by earthquakes and to assess fiscal impacts due to the loss of electric service to the community.

The proposed project, combined with an expected follow-on project, will contribute to simplified design procedures for estimating loads on foundations due to lateral spreading.

3. Brief description of the accomplishments of the project

We completed the back-analyses of the inertial and kinematic load combinations that acted on the pile foundations in the dynamic centrifuge tests by Chang et al. (2003, as archived at the UC Davis Center for Geotechnical Modeling). A draft report describing the back-analysis procedures and findings has been written, but still needs to be reviewed and edited. This draft report formed the basis for the following paper:

> Chang, D., Boulanger, R. W., Kutter, B. L, and Brandenberg, S. J. (2005). "Experimental observations of inertial and lateral spreading loads on pile groups during earthquakes." GeoFrontiers Conference, Austin, Texas, Geotechnical Special Publication, ASCE, accepted.

Dynamic time-history analyses of the centrifuge tests by Chang et al. using OpenSees are in progress. Efforts to date have involved calibration of the soil material models, calibration of the soil-spring models, mesh generation, and initial dynamic analyses to evaluate numerical stability issues. The constitutive model by Yang and Elgamal has had some recent revisions which have required that we re-evaluate our material parameter selections and adjust our numerical solution schemes. We also experimented with the new coupled-flow elements that have been implemented in OpenSees, but have returned to the fully-undrained elements for the first round of analyses.

4. Describe any instances where you are aware that your results have been used in industry

None at this time.

5. Methodology employed

This project involves performing dynamic time-history analyses of published centrifuge experimental data to validate the numerical approach, and then using that numerical approach to perform parametric studies for the derivation of more general design guidelines. The numerical approach involves two-dimensional modeling of the soil profile with the foundation's structural components (piles, pile cap) connected to the soil mesh through soil spring elements, thereby allowing relative displacements between the soil profile and the piles (3D effects).

6. Other related work conducted within and/or outside PEER

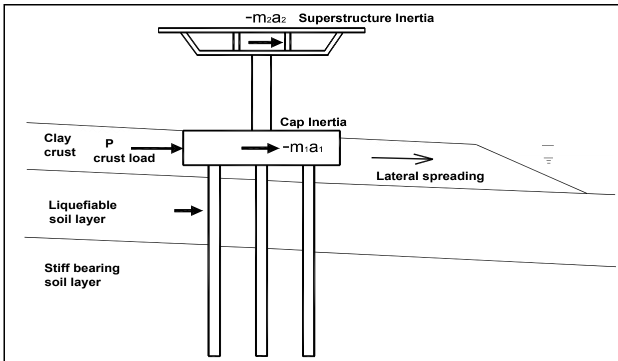
This project will utilize results from the US/Japan Centrifuge-Shaketable comparison project (3F02), and has strong synergy with the PEER Bridges and Transportation Systems thrust area's demonstration of the PEER methodology for a representative bridge configuration subject to liquefaction and lateral spreading. In addition, results from 3G02 (Improved estimates of lateral deformation) will also contribute to the proposed guidelines for design of pile foundations in laterally spreading ground.

7. Recommendations for the future work: what do you think should be done next?

The most serious limitation of emerging design methodologies for pile foundations in laterally spreading ground is the absence of experimental data to evaluate the mechanisms by which pile foundations may restrain lateral deformations of abutments. This coupling of deformations between the pile foundation and surrounding ground has been shown to have a major effect on design decisions for representative bridges (NCHRP 472). Consequently, a proposed amendment to this project was submitted that would directly address this issue of validating design methodologies for this "pile pinning" effect.

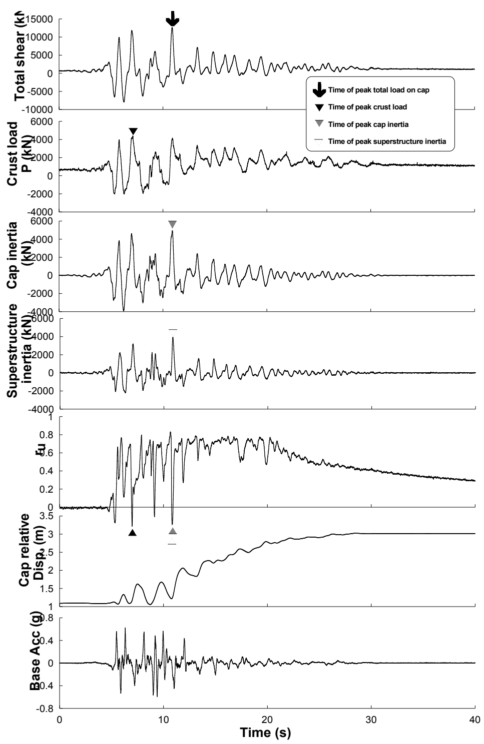
8. <u>Author(s), Title, and Date</u> for the final report for this project

The final report for the amended project would be submitted by May 30, 2006.

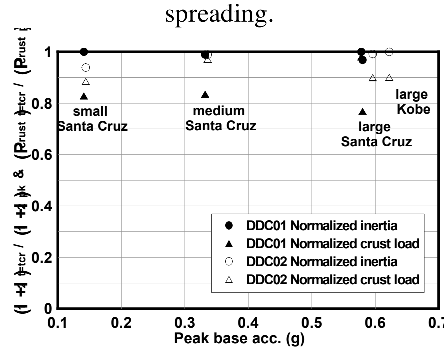


(a) Schematic of lateral spreading & inertial loads

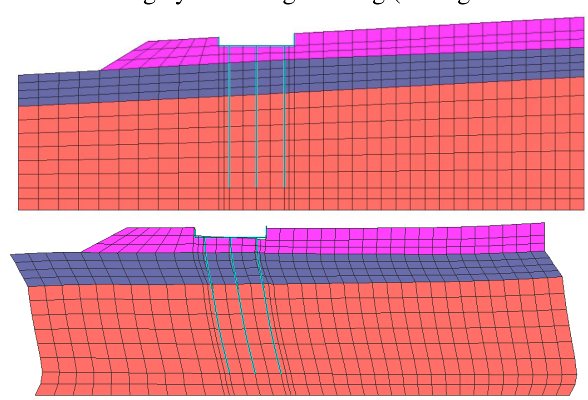
(b) Centrifuge pile group with passive bulge & lateral spreading.



(c) Back-calculated loads a on pile group during centrifuge testing.



(d) Inertial & lateral spreading load combinations at critical loading cycle during shaking (Chang et al. 2005)



(e) Initial and deformed FE mesh of the soil profile and pile group from photo (b) during large Kobe motion (superstructure omitted for this example).