

## Final Project Summary — PEER Lifelines Program

<b>Project Title—ID Number</b>	<i>Liquefaction Site Characterization in Taiwan—3A02</i>		
<b>Start/End Dates</b>	9/1/01 – 6/30/03	<b>Budget/ Funding Source</b>	\$78,217 / Caltrans
<b>Project Leader (boldface) and Other Team Members</b>	<b>Stewart (UCLA)</b> , Daniel Chu (UCLA), Emily Gugliemo (UCLA)		

### 1. Project goals and objectives

The principal objective of this research was to develop case histories for a liquefaction triggering database from the Chi Chi Taiwan earthquake. A second objective was to document soil conditions at sites where interesting liquefaction effects occurred, such as lateral spreading or soil bearing failures beneath building foundations.

### 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.

Well documented field case histories form the basis of contemporary procedures for analysis of liquefaction triggering and liquefaction effects. The Lifeline Program has for several years sought to develop improved probabilistic models for liquefaction triggering and liquefaction-induced ground deformations, and data such as that generated in this project is vital to the development of such models.

### 3. Brief description of the accomplishments of the project

We performed large site investigation programs in Nantou and Wufeng, Taiwan. We documented the results of those investigation programs, as well as other complimentary programs conducted in Nantou, Wufeng, and Yuanlin by others. Results are presented at: [http://peer.berkeley.edu/lifelines/research\\_projects/3A02](http://peer.berkeley.edu/lifelines/research_projects/3A02).

The seismic performance of the investigated sites include non-ground failure building and free-field sites, building sites with partial foundation bearing failures, free-field lateral spread sites, and free-field level ground sites with sediment boils. The web site presents field and laboratory investigation protocols for the sites, results of cone penetration testing (some with pore pressure and shear wave velocity measurements), and results of rotary wash borings with standard penetration testing (including energy measurements). An example of the type of data collected is presented in Figure 1.

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

None to report.

### 5. Methodology employed

Sites were selected for field exploration if there was high quality field reconnaissance data available. Among sites with such data, emphasis was given to building settlement sites, lateral spread sites, and non-ground failure sites. In each of these cases, there are significant needs for high quality case histories to support the development of semi-empirical or empirical models for liquefaction triggering or effects.

Most borings were limited to depths of 10-30 m. Drilling equipment consisted of a tripod-supported rotary wash rig. A typical rig setup over a hole is shown to the right. For SPT sampling, the percentage of the total theoretical energy delivered to the split-spoon sampler, or energy ratio, was controlled by following procedures in ASTM D6066-98 and ASTM D1586. We measured the actual delivered energy for each blow of the safety hammer using a rod section instrumented with accelerometers and strain gages.



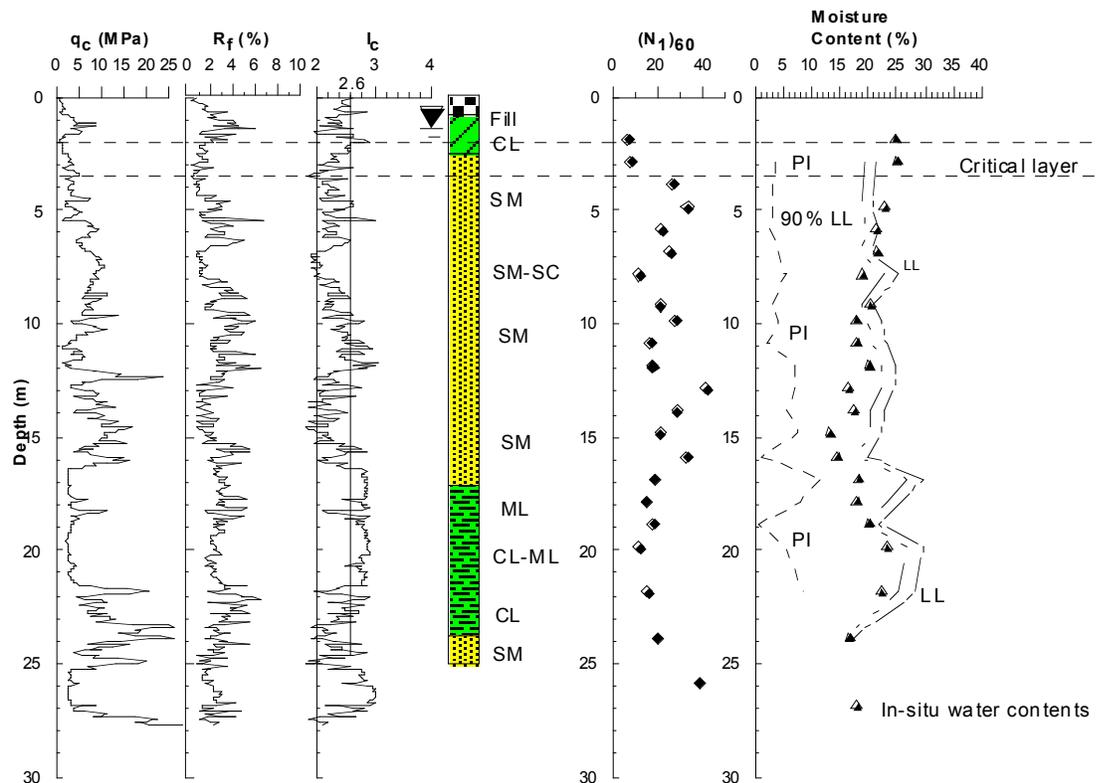


Fig. 1. Subsurface data for example site that experienced liquefaction (Wufeng Site C).

All retrieved soil specimens from the split spoon sampler were subjected to a full suite of laboratory index tests per ASTM standards including sieve, hydrometer, liquid limit, plastic limit, density and water content. In addition, in-situ vane shear tests (ASTM D 2573) were performed at selected locations and depths to estimate the undrained shear strengths of clayey soils. A limited number of monotonic and cyclic triaxial tests have also been performed.

Cone penetration tests (CPT's) were performed using standard procedures. A piezocone was used that provided  $U_2$ -type pore pressure measurements. Downhole seismic velocity profiling was performed at selected sites using a cone instrumented with one geophone.

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

Similar work has been performed in Turkey by Jonathan Bray (UCB) and Les Youd (BYU). Similar work was performed in Taiwan by NCREC. The results of that study are included on the web page for this project.

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

Site reconnaissance and investigation programs should be continued after future major earthquakes.

#### 8. Author(s), Title, and Date for the final report for this project

Stewart, J.P., Chu, D.B. and Guglielmo, E. (2003). "Documentation of Soil Conditions at Liquefaction Sites from 1999 Chi Chi (Taiwan) Earthquake," Report to Pacific Earthquake Engineering Research Center.