General Report for Technical Session 1D: In-situ Testing

Jason T. DeJong
Department of Civil and Environmental Engineering, University of California, Davis, USA

1 OVERVIEW

Thirty-seven papers address the general topics of in-situ testing, with tools being utilized and the applications varying widely. The papers are presented in the following general themes though overlap between these themes inevitably exists: Site Characterization, Soil & Rock Properties, Foundation Settlement & Beariung Capacity, Soil Liquefaction & Ground Motions, and Construction QA/QC. Each section is further sub-divided herein. A summary of the theme each paper focuses on as well as the soil type(s) investigated and tool(s) utilized is summarized in Table 1. A discussion is presented following a short summary of all the papers.

2 THEME: SITE CHARACTERIZATION

Seven papers address the use of insitu tools for site characterization. Two papers focus on equipment performance given variations in test configuration/procedures while one paper presents new results for thin layer detection. The remaining four papers all focus on seismic measurements, ranging from improved measurement techniques to spatial seismic mapping.

2.1 *Tool Development*

Mondelli et al. (2009) examine the relative performance of a CPTu (peizocone penetration test) slot filter saturated with glycerine and grease through laboratory testing and insitu testing of tropical soils. Reduced sensitivity is observed in controlled laboratory pressure pulsing due to the higher viscosity of the grease. In situ this higher viscosity results in reduced desaturation above the water table (of particular note in tropical soils where ground water table can be deep) and possible detection of pore pressures in the capillary zone (Figure 1). Results substantiate and expand previous studies by Powell & Lunne (2005), Larsson (1995), and others.

Tonni and Gottardi (2009) present variable pe netration rate CPTu test results obtained in stratified silty Venetian soils at the Treporti Test Site. Penetration rates between 0.15 cm/s and 4 cm/s clearly influence penetration resistance, q_t, with the resistance increasing with a decrease in penetration rate (Figure 2). The partial drainage conditions present difficulties in using CPT data for estimation of OCR and S_u properties, among others, and the stratification of the deposit further complicates interpretation. While the additional data is difficult to interpret, it aptly demonstrates that the conventional correlations for undrained soil properties are not applicable due to partial drainage conditions.

Hryciw et al. (2009) combine FEM modeling with auto-adaptive remeshing and experimental VisCPT results to examine thin layer detection. The results of this unique approach is highlighted Figure 3. For layer thicknesses larger than 10 cm the layer thickness as estimated by CPT q_c generally underpredicts layer thickness by up to about 5 cm. However, thin layers less than 10 cm in thickness cannot be reliably detected with the CPT qc and often go undetected. The VisCPT demonstrates improved thin layer detection, but consideration that the VisCPT images are obtained within the disturbed zone of soil as well.

2.2 *Geophysical Applications*

Totani et al. (2009) present a unique and useful solution for obtaining shear wave velocity (V_s) measurements in non-penetrable soils. Results are obtained using a true-interval seismic dilatomter (SDMT) inserted into a pre-bored hole filled with sand and good agreement is obtained with down-hole V_s data at several sites. This rigorous study demonstrates the viability of this method, and it seems likely portable to the SCPTu and perhaps to other pseudo-interval testing configuration as well.

Bang et al. (2009) utilize SPT advancement as a seismic source for an array of geophones along the surface to map the V_s

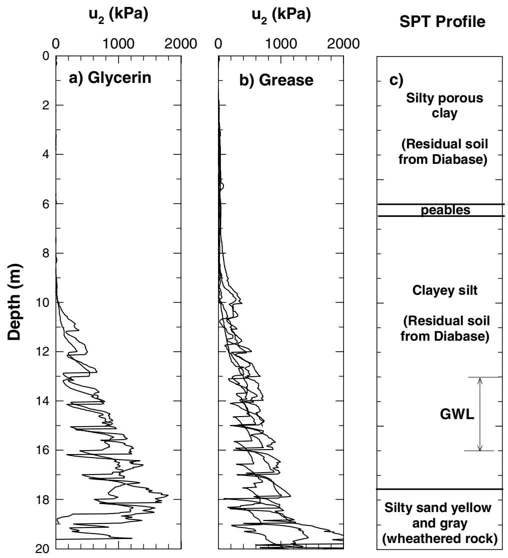

Figure 1. Pore pressure records from piezocone tests using grease and glycerin for Campinas-SP site.

distribution in the subsurface. This distribution of S- and P-wave content as a function of SPT depth and geophone offset

Proceedings of the 17[th] International Conference on Soil Mechanics and Geotechnical Engineering
M. Hamza et al. (Eds.)

doi:10.3233/978-1-60750-031-5-3278

Table 1. Summary of papers in technical session on in situ testing.

Theme	Authors	Soil Type				Tools													
						Insitu								Laboratory			Analytical		
		Sands / Gravels	Silts	Clay	Rock	CPT	DMT	PMT	SPT / DCP	Plate Load Test	FWD	Geophysics	New Tool	Triaxial Test	Oedoemeter	Index Tests	Numerical Modelling	Learning Algorithms	Probability
Site Characterization	Bang et al.				X				X			X	X						
	Chiu et al.				X							X							
	Hryciw et al.	X				X							X				X		
	Mondelli et al.	X	X	X		X													
	Tonni & Gottardi		X			X													
	Totani et al.				X		X					X	X						
	Whiteley & Stewart				X							X							
Soil & Rock Properties	Andrada & Andrada	X			X					X			X	X					
	Henoegl et al.	X											X						
	Katzenbach et al.	X	X	X									X						
	Kurup & Griffin			X		X								X	X			X	
	Lee et al.	X				X	X												
	Li & Zhang			X															
	Lobo et al.	X							X								X		
	Massad			X		X									X				
	Mlynarek et al.	X				X													
	Papic		X			X									X				
	Piantedosi et al.			X		X										X		X	
	Reiffsteck et al.	X	X			X							X						
	ul Haq et al.			X						X									
	Umezaki et al.			X		X							X						
	Yimsiri et al.			X								X		X					
Foundation Settlemnt & Bearing Capacity	Ali et al.	X	X	X		X							X						
	Ampadu & Dzitse-Awuku				X				X										
	Baguelin et al.		X	X				X											
	Caputo	X							X										
	Fortunato et al.	X	X	X					X	X									
	Mets & Ruben	X				X				X									
	Rito & Sugawara		X	X		X			X				X						
Soil Liquefaction & Ground Motions	Ahmadi et al.	X	X			X													
	Alonso et al.		X	X		X										X			
	Condarelli et al.				X														
	Gutierrez & Eddy	X	X																X
	Sawada et al.	X	X			X							X						
Const-ruction QA/QC	Conde et al.		X	X							X		X						
	Ho et al.				X								X						
	Tompai	X	X								X		X						

from the borehole is examined, laying the ground work for separation of the vertical and horizontal wave components. The method is demonstrated through two field trials, both of which show good agreement against indirect measures of V_s. A direct side-by-side comparison with other established methods will further validate this method.

Whiteley and Stewart (2009) utilize surface and borehole seismic imaging for mapping of karst and analyzing the effect of subsurface features on building performance. This is clearly demonstrated through a case study in Kuala Lampur where the subsurface consists of material classed as Extreme Karst, class kV (Zabidi & DeFreitis 2006). Seismic data clearly indicates that the building is founded on limestone overlying a filled sinkhole. Nearby dewatering for another construction project contributed to the observed settlements as well.

Chiu et al. (2009) utilize seismic wave and electromagnetic wave computed tomography to comprehensively examine the subsurface at a proposed construction site for three high-rise

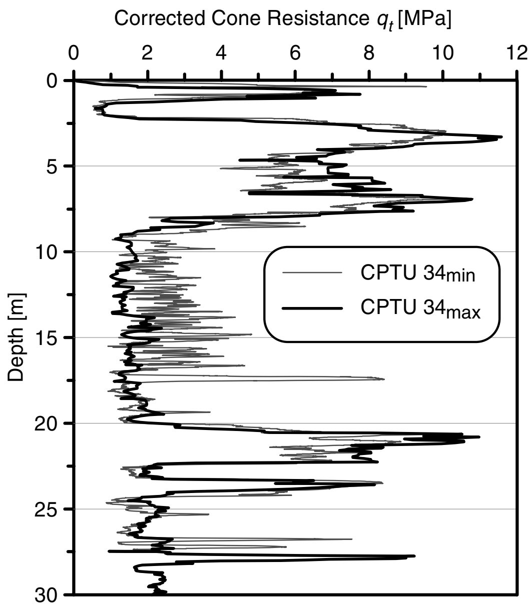

Figure 2. Comparison between cone resistance of adjacent CPTu tests performed at different penetration rates.

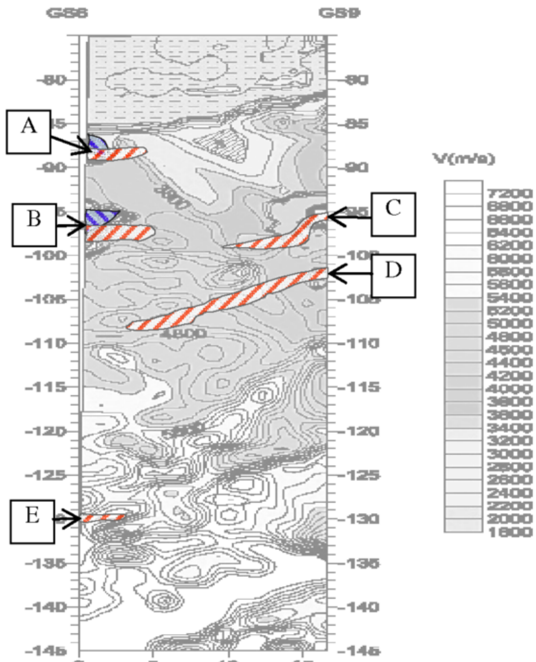

Figure 4. Comparison of Results of EM-Wave and Seismic-Wave CT Methods.

buildings. 43 borings to depths up to 150 m were performed to obtain geotechnical/geologic samples and to enable mapping of the subsurface with the geophysical tools. Results were utilized to design an efficient foundation system and to perform a targeted grouting program of solution features and fissure zones (Figure 4). The study clearly demonstrates the increased efficiency gained in foundation design for large structures that can be realized today.

3 THEME: SOIL & ROCK PROPERTIES

Fifteen papers address the estimation of soil properties using in situ test methods. Two areas particularly of interest are the characterization of cemented sands and assessment of thermal properties, the latter of which is of increasing importance for sustainable construction. New tools developments are presented first, followed by papers on sands, silts, and clays.

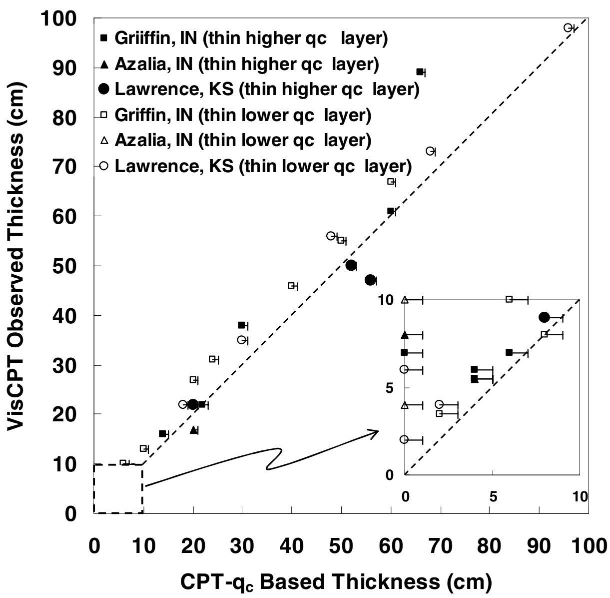

Figure 3. Comparison of layer thickness detection by CPT q_c compared with VisCPT.

3.1 *Tool Development*

Reiffsteck et al. (2009) present a development update of the Permeafor, an insitu device which estimates permeability during probe penetration, originally developed in the 1980's. Guidelines and results for laboratory calibration and from a field testing program in a range of soil types is presented. Results indicate reasonable capabilities of estimating the magnitude of permeability for a range of soils.

Umezacki et al. (2009) have successfully adapted radioisotope (RI) density logging with gamma rays to a CPT probe specifically for characterization of very soft sediments where the probe is advance by self weight. Of particular interest and promise is the sensitivity of measurements above and near the mud-line, a transition often difficult to resolve by conventional CPT systems. This is demonstrated in Figure 5 for results from a field campaign in the Ariake Sea.

Katzenbach et al. (2009) present the Geothermal Response Test (GRT) as an efficient and effective means to estimate the thermal conductivity at a site. The data obtained is particularly useful for the design of geothermal facilities, which contribute towards efforts for more sustainable systems. With a sound theoretical framework and numerical modeling (Figure 6), the paper documents equipment advances and outlines current activities for standardization of the test procedure.

3.2 *Sands*

Henoegl et al. (2009) also examine thermal propagation, but instead for improved insulation around in situ heat supply pipes. A new bedding material, "Thermosand", is examined through laboratory and field trials. The material's reduced thermal conductivity is attributed to its intra-particle porosity, wherein trapped air provides increased insulation. This unique application further demonstrates the increasing role of thermal soil properties in construction.

Mlynarek et al. (2009) study the secondary effect of sand particle shape on CPTu measurements and estimation of soil properties. Granular soil deposits from six different geologic origins are examined. The effect of particle shape is shown to

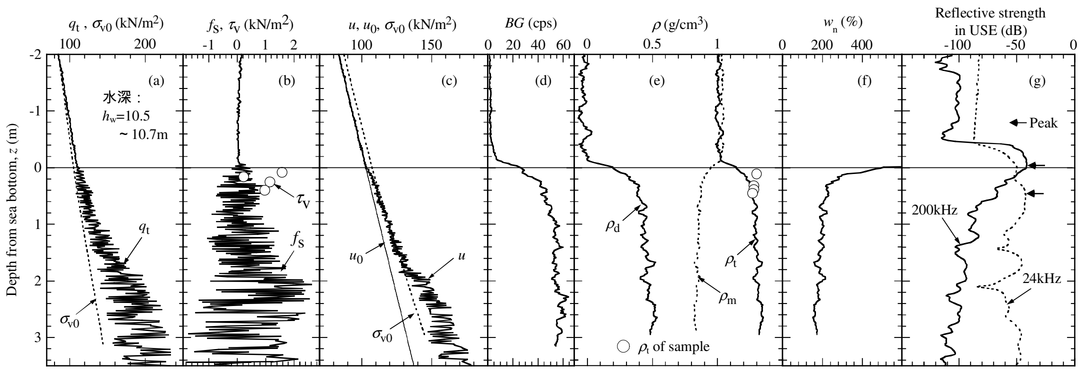

Figure 5. Results of RI-DL, CPT, (the Ariake Sea No. 1)

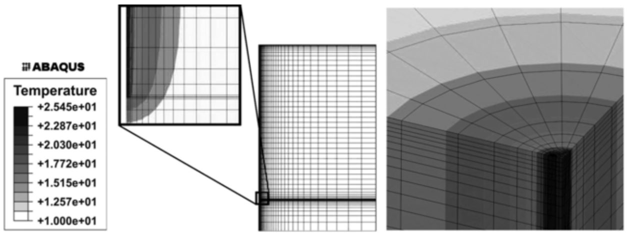

Figure 6. FE-models of a borehole heat exchanger for test interpretation; left: axisymmetric, right: tree-dimensional.

influence the estimation of relative density by up to 10% and the estimation of friction angle by up to 5%. While these observations may be expected and highlight the limited accuracy these correlations may have, a correction based on particle shape would require parallel sampling and laboratory testing that may be impractical in routine practice.

Lobo et al. (2009) present a new approach to estimate the internal friction angle of granular soils from dynamic penetration tests (such as SPT & LPT). Based on numerical simulation and the dimensional equation technique, this study analyzes the dynamic test as an inverse boundary value problem. Parameters for energy input (drop height, length, hammer efficiency, etc.) are resolved against the properties governing sampler-soil interaction (vertical effective stress, internal friction angle, small strain modulus) (Figures 7). This rather complex model for a dynamic penetration test and the use of dimensionless (π) parameters results in a straightforward equation for estimation of the internal friction angle. The primary limitation is the equation's dependence on parameters not obtained from the dynamic test itself, possibly limiting its use to sites where supplemental testing is performed.

Lee et al. (2009) address the important challenge of assessment of cementation in sand through in situ testing. They present a comprehensive and insightful study into the effect of cementation on CPT q_c and DMT indices (M_D, K_D). Testing was performed with a series of calibration chamber tests with K-7 sand cemented to varying degrees by gypsum (concentrations by mass ranging from 0% 10%). Example results are shown in Figure 8. As expected, all indices increase with cementation. The secondary effects of relative density on CPT q_c do not become significant until higher cementation levels while its effect on DMT indices (M_D, K_D) is comparable for the entire cementation range (gypsum concentrations from 5% to 10%). These effects are generally observed to be consistent over a stress range from 50 to 200 kPa. This data is used in turn to develop a relationship between DMT and CPT measures. This paper's insights possibly provide the groundwork to develop a method to assess the level of cementation when it is not known a priori.

Andrada and Andrada (2009) further address cementation through field tests on Asuncion's cemented sands. To complement laboratory results on soil samples and SPT refusal N values a portable plate load test type system is developed. Interestingly, the effect on water content (from 1.0% to 8.0%) has a significant impact load-displacement response. As an example, the strain to peak resistance for unconfined compression tests increases from 0.5% to 3% axial strain. Similar changes are observed for maximum bearing stress and elastic modulus. Unfortunately, the source/mechanism causing this significant dependence on water content is not discussed.

3.3 *Silts*

Papic (2009), through a CPT sounding and oedometer laboratory tests from an unsaturated silt deposit, examines Eurocode 7's recommendations on the correlation between the measured CPT q_c resistance and the modulus of compressibility as determined from an oedometer (E_{oed}). Results indicate that for unsaturated silts the recommended relations may over

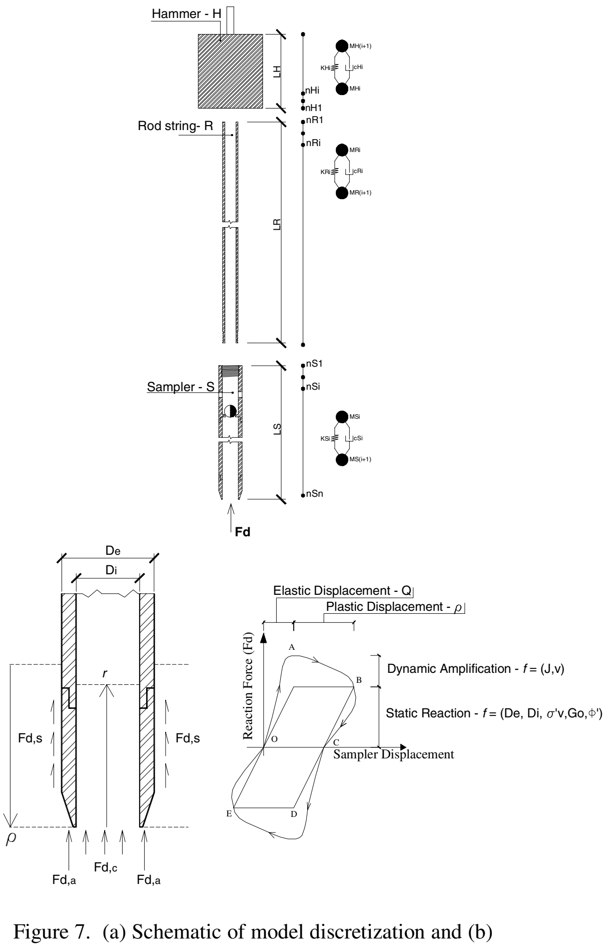

Figure 7. (a) Schematic of model discretization and (b) sample-soil interaction model.

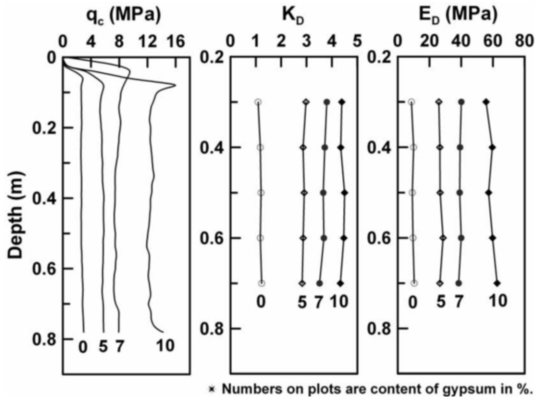

Figure 8. Typical profiles of q_c, K_D and E_D in chamber (Dr≈40%, σ_v'=100kPa).

predict E_{oed} though additional data from other sites is needed before a firm conclusion can be drawn. The study highlights the challenges of developing correlations for properties of intermediate soils based on in situ test data.

3.4 *Clay*

Yimsiri et al. (2009) highlight the anisotropic complexities of soft clays through laboratory and self boring pressuremeter tests (SBPMT) on Bangkok Clay. Isotropically consolidated triaxial tests instrumented with local axial and radial strain measurements and bender elements on undisturbed specimens prepared parallel and orthogonal to the deposition plane were performed. The axial and radial strains during consolidation were greater when oriented parallel to the bedding plane. A small degree of change in small-strain shear modulus was also observed. Overall, the behavior of near normally consolidated Bangkok clay was shown to exhibit less anisotropic behavior than heavily over consolidated London clay.

Massad (2009) performed a field study in the marine clays of Santos, Brazil. He provided further evidence that the preconsolidation pressure can be reliably estimated from CPTu q_t measurements using the comment equation of $\sigma_p' = (q_t - \sigma_{vo}) / N_{\sigma t}$ where σ_p' is the preconsolidation stress, σ_{vo} is the in situ vertical stress, and $N_{\sigma t}$ is an empirical factor. Values of 3.3 (proposed by Mayne et al. 1998) and 3.4 (Demers and Lerouiel 2002) agreed well with the range observed (range of 3.0 to 3.9 attributed to soil heterogeneity).

Kurup and Griffin (2009) similarly examine the correlations for estimating overconsolidation ratio (OCR), coefficient of lateral earth pressure at rest (K_o), and undrained strength (s_u) from CPTu data. Their approach includes training of an artificial neural network (ANN) – based data fusion model to predict these parameters. The models predict the respective properties of the dataset analyzed without any trends in the residuals of predicted values. However, the physics behind which these models are based, their applicability to other data sets, and formulations of the models for others to implement are not provided in detail.

Piantedosi et al. (2009) similarly uses tree-based learning and data mining techniques to use CPTu data to estimate soil liquid (LL) and plastic (PL) limits. Data sets obtained in response to the 1999 Chi-Chi, Taiwan earthquake are utilized. Predictions within the data set used for training of the model were successful. The concerns for Kurup and Griffin (2009) discussed above are equally applicable.

Li and Zhang (2009) examine the spatial characteristics of surficial cracking during clay desiccation. This field study examines the change in crack opening and porosity during the drying process, which occurs over several days. Hysteresis in the crack formation is observed; initial cracking occurs at a higher water content and the degree of suction is hypothesized to reduce in subsequent wetting-drying cycles.

ul Haq et al. (2009) present an overview of rigid plate load tests and flatjack tests performed to characterize properties of the rock underlying the Diamer Basha Dam in Pakistan. An extensive number of boreholes and associated laboratory testing has been performed, enabling statistical characterization of the specific gravity, unit weight, water absorption, and porosity. Rigid plate load tests with multiple unload-reload loops in both the vertical (Figure 9) and horizontal direction within tunnels enable the anisotropy of the elastic modulus to be assessed.

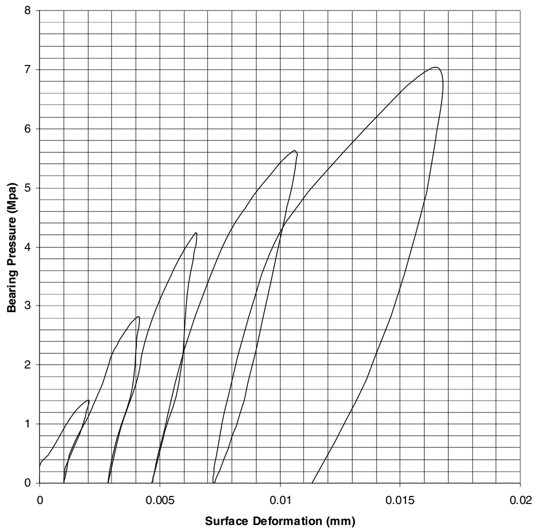

Figure 9. Example results from rigid plate load test with multiple cycles used to determine Modulus of Deformation.

4 THEME: FOUNDATION SETTLEMENT AND BEARING CAPACITY

Seven papers address the estimation of the settlement and/or bearing capacity of shallow foundations using in situ methods. Two of these methods utilize the conventional in situ techniques of the standard penetration test (SPT) and the pressuremeter (PMT) while the remaining papers present new results based on modified in situ tools or testing methodologies.

4.1 *Settlement*

Caputo (2009) reexamines previous work by Burland & Burbidge (1984) and by Berardi & Lancellotta (1991) for the settlement prediction of structures founded on coarse grained using the SPT N value. Reexamination of 125 case histories clearly demonstrates that the Burland & Burbidge method is more the conservative method. Caputo develops additional guidelines to improve the settlement prediction by linking the coefficient constants in Berardi & Lancellotta's settlement equation with the normalized bearing pressure and the magnitude of the N_1 value. Reanalysis of the set of case histories indicates that this new method may be more conservative than earlier methods.

Baguelin et al. (2009) propose two new sets of settlement predictions using pressuremeter (PMT) data; one method for embankments and the second for footings. Both methods are shown to perform well against databases of field case histories and are relatively simple and elegant in their formulation. In particular, the conventional estimation of Youngs Modulus, E, from E_M/α is shown to not apply beneath footings due to the 3-D plastic volumetric strains the soil undergoes.

Ali et al. (2009) utilize a CPT type probe to perform a static load test at depth. This method, termed the Cone Loading Test, provides load-displacement curves for the tip resistance. As

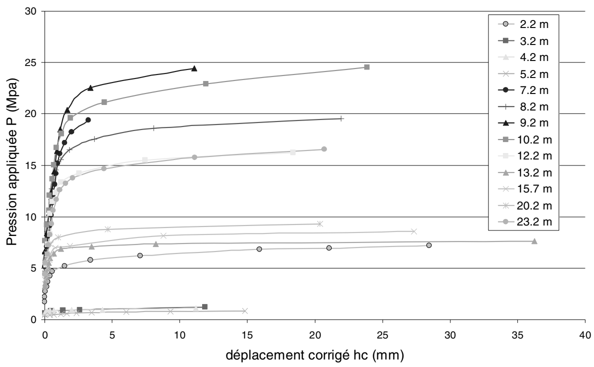

Figure 10. Example results from Cone Loading Test.

may be expected, the resistance increases with embedment depth (Figure 10). Ali et al. utilize this data set to propose new factors using the Cone Loading Test data to estimate the deformation moduli for settlement calculations.

Fortunato et al. (2009) examine the use of the dynamic cone penetrometer (DCP) as an alternative to the plate load test (PLT) for estimating the railway subgrade stiffness. Field test results from an ancient railway between Lisbon and Porto that was being upgraded for high speed rail is presented. The authors consider the pertinent parameters of soil type and depth of DCP data to be averaged for comparison with PLT data. In conclusion, they demonstrate good agreement between the deformation modulus in the second loading cycle of a plate load test, EV_2, with the dynamic cone penetration index, DCPI, averaged over specific depths for both fine-grained and coarse-grained soils (Figure 11).

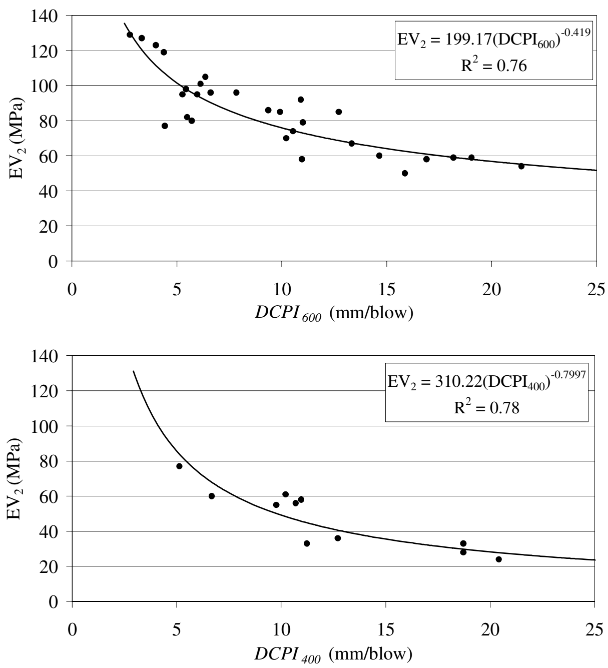

Figure 11. (a) Relation between $DCPI_{600}$ and EV_2 for coarse-grained soils and (b) Relation between $DCPI_{400}$ and EV_2 for fine-grained soils.

4.2 *Bearing Capacity*

Ampadu & Dzitse-Awuku (2009) explore the use of the dynamic cone penetrometer (DCP) as a simple, rapid, and inexpensive tool for bearing capacity estimation where more advanced technique are uneconomical. They present a sound study of laboratory element tests, model footing tests, and DCP data to examine the primary factors linking DCP data to the measured bearing capacity for foundations supported on lateritic soils. Further, they compare their observed trends with Terzaghi's bearing capacity equations and other methods and conclude the model footing to have a lower allowable stress than predicted (Figure 12).

Rito & Sugawara (2009) provide an update in the Combination Cone Penetration equipment (CPTC) equipment development and present methods for estimation of bearing capacity using CPTC data. The CPTC method consists of a conventional CPT (less pore pressure and sleeve friction measurements) and is advanced at a steady penetration rate in soft soils and dynamically in stiff soils. The measured tip resistance, q_c, can then be used to estimate the yield pressure and unconfined compressive strength. The potential of this method is compared with the conventional CPT method and the Swedish weight sounding tests (WST) at a test site. The application objective for this method is for housing land bearing capacity. Performance of CPTC appears comparable, or better, to other alternatives for this application though extension of this methodology to more complex foundation designs (e.g. where consolidation may be significant) has yet to be investigated.

Mets & Ruben (2009) hypothesize that bearing capacity of sand is largely influenced by the diagensis and settlement of sand and *not* by its density and granular condition. Additional factors such as cement, organic matter, bacteria, etc. do influence the behavior of sands. Mets & Ruben propose that their effect is greater than that of density and granular condition (grain size, shape, gradation). This hypothesis does highlight the importance of understanding these additional factors better. However, the reasoning and evidence presented is not sufficient to overturn the accumulated knowledge of the primary importance of density and granular condition on bearing capacity.

5 THEME: SOIL LIQUEFACTION AND GROUND MOTIONS

Five papers address aspects of soil liquefaction and its associated consequences. One paper addresses the design of input ground motions to examine local loading conditions, two papers examine the potential for liquefaction, and two papers examine the behavior and/or consequences when liquefaction occurs.

5.1 *Input Motion*

Condarelli et al. (2009) present an innovative method to estimate design ground motion time histories in a relatively accurate manner. The method uses a heuristic transfer function that is calibrated to site-specific microtremor measurements to modify a selected bedrock accelerogram. The modified accelerogram then serves an input to seismic site response

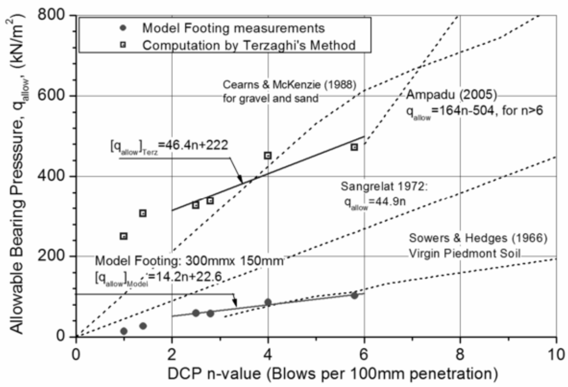

Figure 12. Summary of correlations between DCP n-value and allowable bearing pressure.

analysis (either 1D linear or equivalent linear). The two example applications presented demonstrate this technique. Of particular interest is the site amplification estimated since current techniques tend to underestimate the amplification factor.

5.2 *Liquefaction Occurrence*

Ahmadi et al. (2009) present an alternative approach to predict the liquefaction potential of soils using CPT data classified using the Eslami & Fellenius (2004) soil classification chart. This method is compared against the more common Robertson (1990) Soil Behavior Type chart using 10 CPT soundings from locations where liquefaction has occurred during recent seismic events. As shown in Figure 13, general zones where liquefaction did or did not occur are identified. The zones indicated where liquefaction may occur generally fall within zones identified by previous research (e.g. Idriss & Boulanger 2008). However, it *is* possible for liquefaction to occur outside of the circular zones indicated. Further evaluation of these zones against a broader database would improve definition of these boundaries and enable broader applicability.

Alonso et al. (2009) utilize a quay failure in the Port of Barcelona to examine the liquefaction potential of fine-grained hydraulic fills. The comprehensive study included SCPTu, SDMT and complimentary laboratory tests. Guidelines provided by Seed et al. (2003) and Andrews & Martin (2000) do not provide clear detection of natural soil deposits versus the hydraulic fill (Figure 14). Similarly, the Robertson & Wride (1998) and the Senneset & Janbu (1985) criteria as well as others only indicate a few locations where liquefaction may be possible. The method by Andrus et al. (2004) based on shear wave velocity and cyclic resistance ratio provide the clearest delineation of liquefiable soils since the shear wave velocity of the hydraulic fill is significantly less than the natural soil deposits (Figure 14).

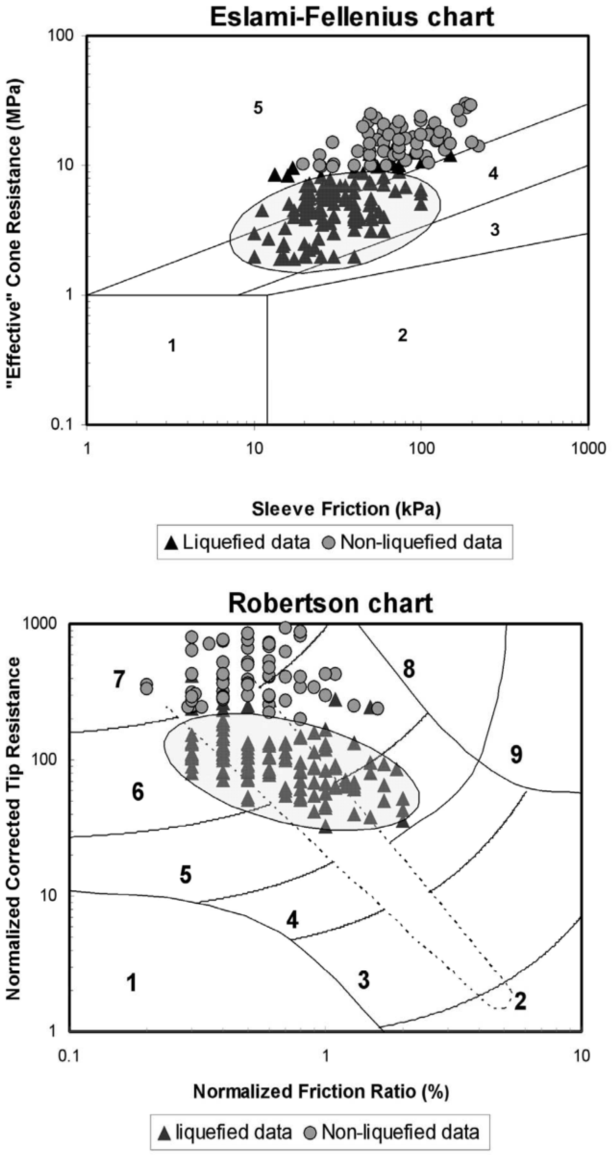

Figure 13. Summary of case history data for liquefied and non-liquefied conditions.

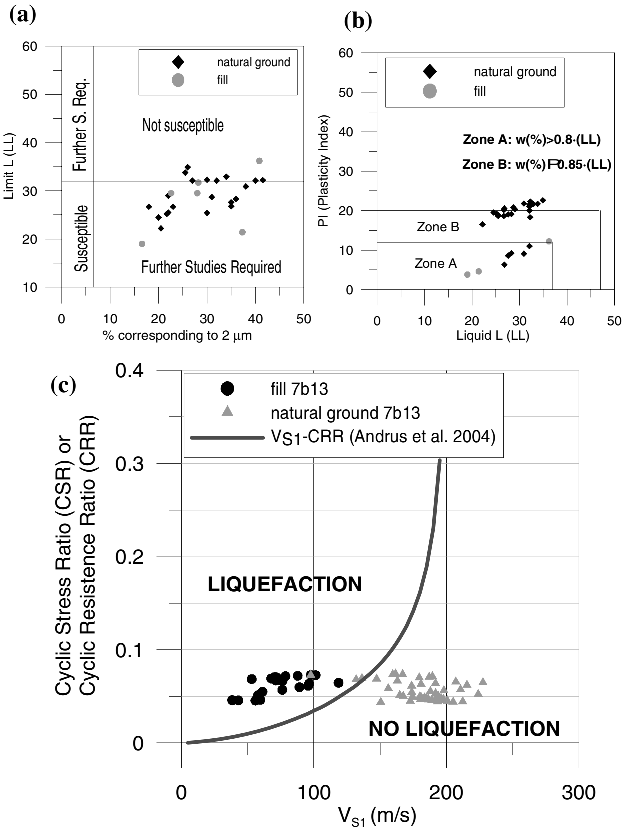

Figure 14. Identification of 'liquefiable' soil types. (a) Recommendations by Seed et al. (2003), (b) Criterion of Andrews & Martin (2000), and (c) Relationship by Andrus et al. 2004).

5.3 *Liquefaction Consequences*

Sawada et al. (2009) present a new Piezo Drive Cone (PDC), a modified CPT type probe with button pore pressure sensors on the cone tip that is advanced with dynamic impacts into the soil, to improve estimation of post-liquefaction settlement. PDC pore pressure measurements are utilized along with corrections for layer thickness, penetration resistance, and fines content to estimate post-liquefaction volumetric strains. The method is applied at a blast-induced liquefaction field test program on Hokkaido Island, Japan. As evident in Figure 15, the predicted results agree reasonably well with measured surface settlements.

Gutierrez and Eddy (2009) propose a probabilistic method to estimate the liquefied shear strength. Estimation of this parameter is very difficult and the potential consequences of inaccurate estimation of the liquefied strength significant (particularly for sloping ground). A deterministic relationship between the measured SPT $N_{1(60)}$ value and the liquefied shear strength (S_{U-LIQ}) is proposed based on 38 case histories (Figure

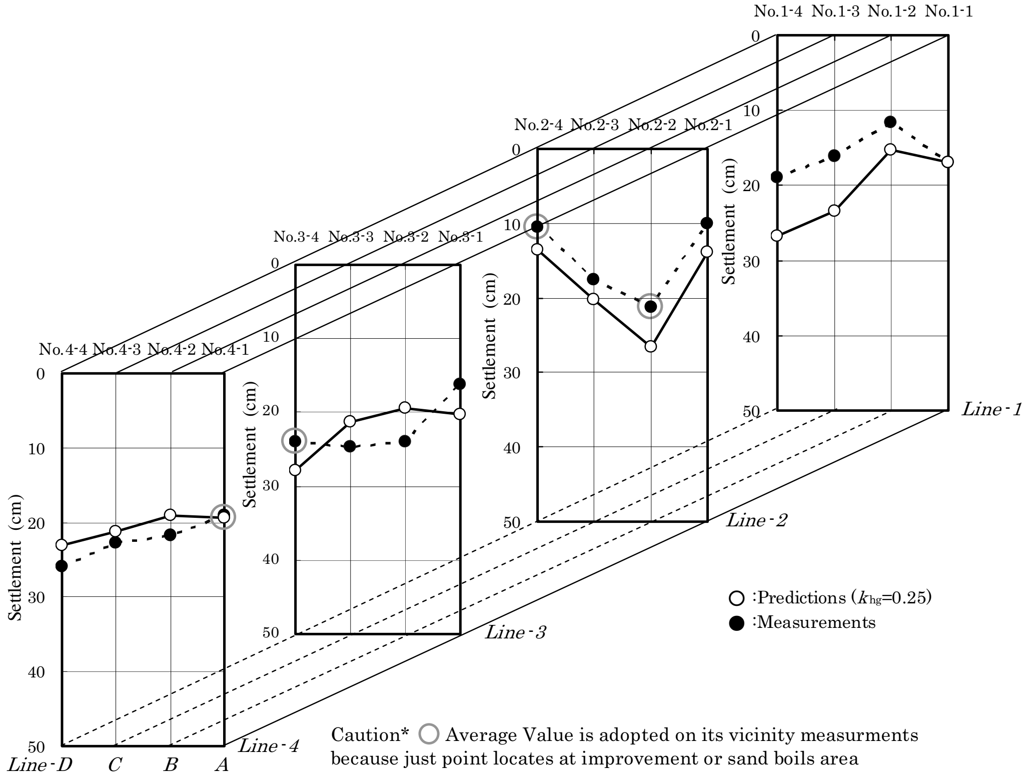

Figure 15. Comparison between prediction and measurements in *Area*-1.

16). Probabilistic analysis of the case histories is then used to consider uncertainties and formulate a probabilistic relationship. As shown in Figure 16, the contour corresponding to a 50% probability of failure agrees closely with the deterministic relationship. This provides an improved method to estimate the liquefied shear strength using a probabilistic approach.

6 THEME: CONSTRUCTION QA/QC

Three papers address issues related to quality assurance (QA) and control (QC) in construction. Two utilize the falling weight deflectometer device (FWD) while the final paper presents a new device for real-time monitoring of soil-nail drilling operations.

6.1 *Falling Weight Deflectometer*

Conde et al. (2009) demonstrates the feasibility of using a portable falling weight deflectometer device (P-FWD) for quality control of compaction. The P-FWD is compared against the GeoGauge and Light Dynamic Cone Penetrometer in its ability to reliably predict the soil dry density and water content. The sand cone density and nuclear gage tests are used as reference data. The ability to predict the water content and dry unit weight from P-FWD measurements is presented in Figure 17. As evident, additional research is needed to conclusively assess the utility of P-FWD for compaction control.

Tompai (2009) presents a laboratory evaluation of a B&C light falling weight deflectometer device. Results from a laboratory study of silty fine sand prepared in a large chamber are presented. The B&C modulus, E_d, is shown to compare favorably at nearly a 1:1 ratio with the measured static load test moduli, E_2. Agreement with the German Dynamic Plate (GDP) test is less favorable. Finally, the final dynamic compaction measured by the B&C FWD, T_{rd}, and relative compaction measured by conventional mass density measurements, T_{rd}, are presented in Figure 18. The B&C FWD method consistently predicts a dynamic compaction of about 95% for soils prepared at relative compaction values of 75% to 98%.

6.2 *Real-Time Construction Monitoring*

Ho et al. (2009) present an interesting study on the development and implementation of the Drilling Process Monitoring (DPM) method developed for soil nailing works. The system monitors in real-time critical factors for installation, including percussion pressure, thrust and rotation movement, and drill chuck position. Two case histories are presented to exemplify data output and performance features. Figure 19 presents drilling depth versus time monitoring records and borehole images from selected depths. This study demonstrates the opportunities and importance of real-time construction monitoring methods for improving the quality of construction.

7 DISCUSSION

The collection of papers represents our profession's continuous challenge of improving the characterization of soil and rock properties in the spatial context of a project site and within the constraints of cost and time. The numerous new devices and modification to existing devices presented indicates that the ultimate tool for in situ testing has yet to be realized, and very likely it will not be a single tool, but many. Recent technological advances will inevitably continue to provide new opportunities for tool development. This must be balanced with our industry's need for improved standardized testing tools and methods that can become established; if this does not occur dated techniques (e.g. SPT) will continue to persist though improved techniques (e.g. CPT) are available.

Many papers herein highlighted the increasing importance and potential of certain technologies and applications that will likely consume much of our future efforts. These include mapping of spatial variability with geophysics, characterization of problematic soils (e.g. cemented soils, intermediate soils –

silty sands, clayey sands, etc.), characterization of recycled materials (e.g. fly ash, mine tailing), quantification of the thermal properties of soils for use as a sustainable thermal resource, material behavior under extreme loads (e.g. liquefied strength of sands), and improved "certainty of execution" (i.e. development of QA/QC techniques to ensure design is realized in situ).

The body of and access to knowledge on in situ testing has grown tremendously in recent years, and much insight and guidance is readily available. Utilization of this knowledge in geotechnical practice and research provides the opportunity for new designs and tools that are economical, sustainable, and reliable.

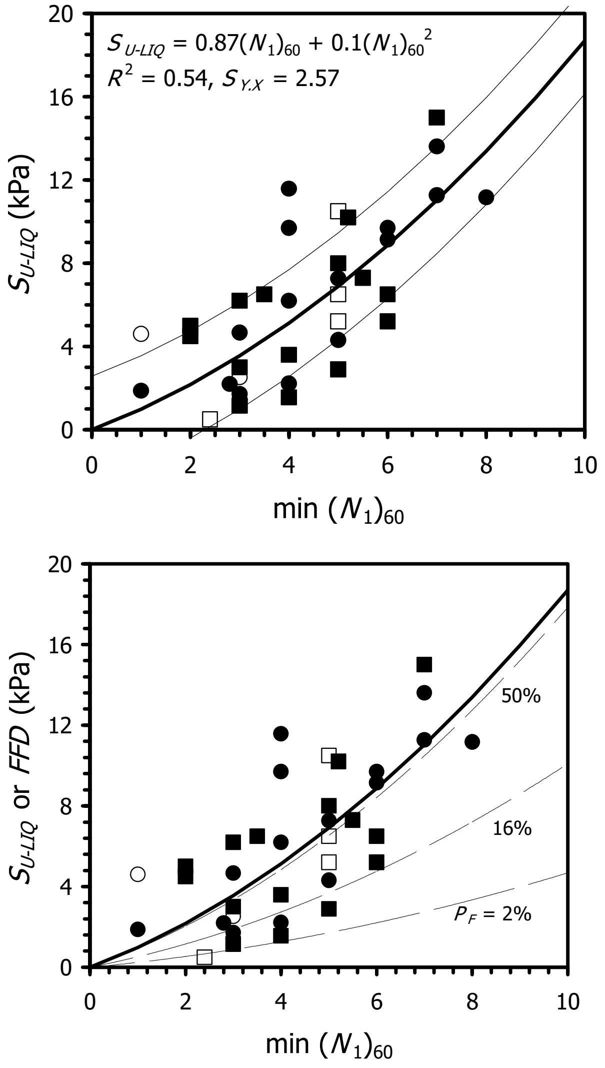

Figure 16. (a) Relationship between liquefied shear strength and SPT blow count from case histories of flow liquefaction. Squares correspond to cases analyzed with Spencer's method and circles correspond to infinite slope cases. Solid symbols indicate that SPT data was measured at the site and open symbols indicate that SPT data was estimated. (b) Contours of probability of failure, P_F, computed with the liquefied shear strength relation including model uncertainty.

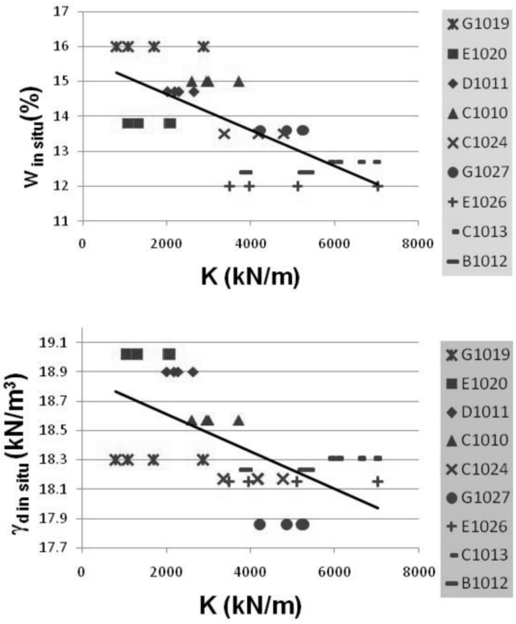

Figure 17. Correlation between K, in situ water content ($w_{in\ situ}$) and dry unit weight ($\gamma_{d\ in\ situ}$).

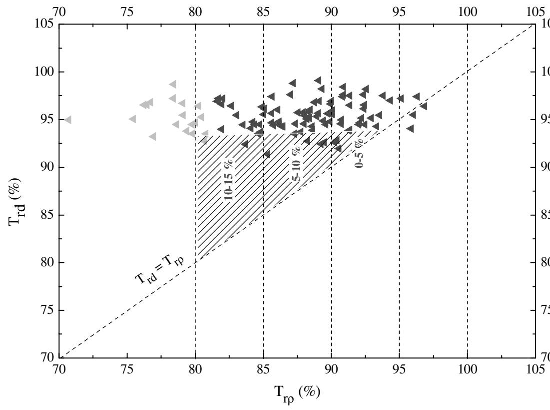

Figure 18. Compaction values measured by B&C (T_{rd}) and by conventional method ($T_{r\rho}$)

REFERENCES

Andrews, D.C.A. & Martin, G.R. 2000. Criteria for liquefaction of silty soils. *Proc. of the 12th World Conference on Earthquake Engineering*, Auckland, NZ. Paper 0312.

Andrus, R.D., Stokoe, K.H., II & Juang, C.H. 2004. Guide for Shear-Wave-Based Liquefaction Potential Evaluation. *Earthquake Spectra*, 20(2), 285-305.

Berardi R. and Lancellotta R. 1991. Stiffness of granular soils from field performance. *Géotechnique*, 41 (1), 149-157.

Burland J.B.and Burbidge M.C. 1984. Settlement of foundations on sand and gravel. *Glasgow and West of Scotland Association Centenary Lecture.*

Demers, D. and S. Leroueil (2002): "Evaluation of Preconsolidation Pressure and the Overconsolidation Ratio from Piezocone Tests of Clay Deposits in Quebec," Canadian Geotechnical Journal, Vol. 39(1), pp. 174–192.

Idriss, I.M. and Boulanger, R.W. (2008) *Soil Liquefaction During Earthquakes*, Earthquake Engineering Research Institute, 237 pp.

Larsson, R. 1995. *Use of a thin slot as filter in piezocone tests. Proceedings of CPT'95* 2:35-40.

Mayne, P.W., Robertson, P.K., and Lunne, T. (1998): "Clay Stress History Evaluated from Seismic Piezocone Tests". First International Conference on Site Characterization, Vol. 2, Atlanta, 1113-1118.

Powell, J.J.M. & Lunne, T. 2005. *Use of CPTu data in clays/fine grained soils*. *Studia Geotechnica et Mechanica* 27:29-66.

Robertson, P. K., & Wride, C. E. 1998. 'Evaluating cyclic liquefaction potential using the cone penetration test. *Canadian Geotechnical Journal.*, 35(3), 442-459.

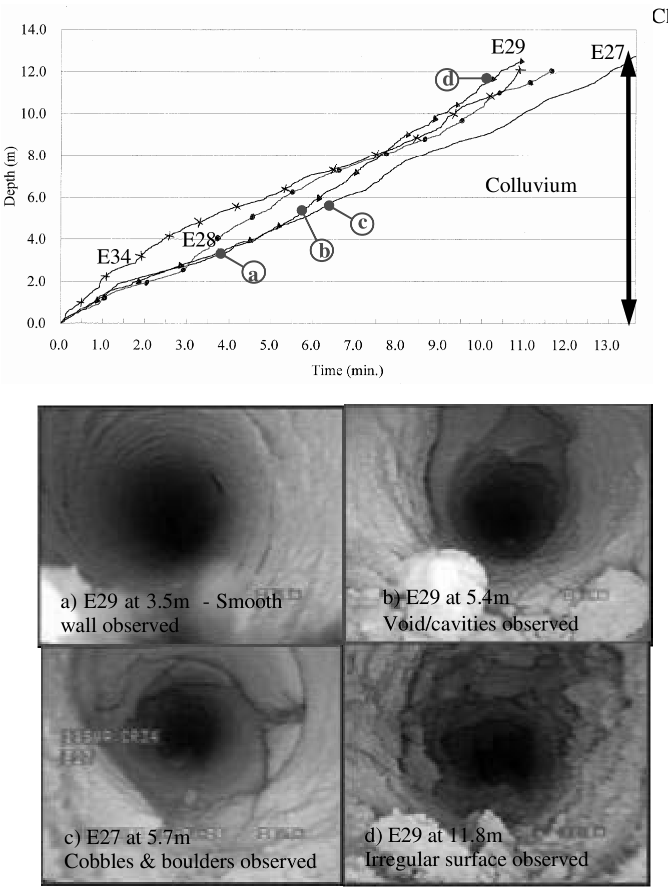

Figure 19. (a) Depth vs Time Graph of DPM Results for Feature No. 11SW-A/CR34 (Soil Nail Row E) (b) Photographs captured in CCTV survey.

Seed, R.B., Cetin, K.O., Moss, R.E.S., Kammerer, A.M., Wu, J., Pestana, J.M., Riemer, M.F., Sancio, R.B., Bray, J.D., Kayen, R.E. & Faris, A. 2003. Recent advances in soil liquefaction engineering: a unified and consistent framework. *26th annual ASCE L.A. Geotechnical Spring Seminar*, Long Beach, California. 71 pp.

Senneset, K., & Janbu, N. 1985. Shear strength parameters obtained from static cone penetration tests. *ASTM, Special Technical Publication SPT*, 41-54.

Zabidi, H. & De Freitias, M. H. 2006 Structural studies for the prediction of karst in the Kuala Lumpur limestone. IAEG 2006. The Geological Society of London 2006, Paper 264, 1-7.

PAPERS IN TECHNICAL SESSION 1D

Ahmadi, M.M., Eslami, A., and Kangarani, M.R. (2009) "Liquefaction evaluation based on CPTu soil classification chart."

Ali, J., Reiffsteck, P., Van de Graaf, H., van der Stoel, A.E.C., Gourves, R., and Bacconnet, C. (2009) "Cone loading test: Influence factors and deformation moduli determination."

Alonso, E.E., Gens, A., Tarrago, D., and Madrid, R. (2009) "Liquefaction potential of hydraulic fills."

Ampadu, S.I.K. and Dzitse-Awuku, D. (2009) "Model tests for bearing capacity in a lateritic soil and implications for the use of the dynamic cone penetrometer."

Andrada, J.C. and Andrada, R. (2009) "Behavior of Asuncion's cemented sands."

Bang, E.S., Kim, J.H., Choo, Y.W., and Kim, D.S. (2009) "Evaluation of shear wave velocity distribution map using SPT-uphole tomography method."

Batuelin, F., Lay, L., Ung, S.Y., and Sanfratello, J.P. (2009) "Pressuremeter, consolidation state, and settlement in fine grained soils."

Caputo, V. (2009) "Settlement predictions for coarse grained soils based on SPT results."

Chiu, S.L., Lam, T.S., and Yu, H.W.P. (2009) "Application of computed tomography technology for exploration of deep underground cavities and solution features."

Condarelli, D., Grasso, S., Maugeri, M., Langer, H., Pitilakis, K., and Manakou, M. (2009) "A methodology to design bedrock input motion using noise measurements."

Conde, M.C., Lopes, M.G., and Caldeira, L. (2009) "Stiffness methods for compaction control: the P-FWD device."

Fortunato, E., Pinelo, A., and Fernandes, M.M. (2009) "In situ characterization of an old railway platform with DCP."

Gutierrez, M. and Eddy, M. (2009) "Probabilistic liquefied shear strength criteria from case histories."

Henoegl, O., Leonhardt, R., Riedler, E., and Honarmand, H. (2009) "Thermal propagation around heat supply pipes – determining thermal conductivity of soil specimens."

Ho, N.L., Yau, K.M, Wright, M.J., and Wong, K.L. (2009) "Real-time drilling process monitoring for soil nailing works for slope upgrading works."

Hyrciw, R.D., Jung, Y., Susila, E., and Ibrahim, A (2009) "Thin soil layer detection by VisCPT and FEM simulations."

Katzenbach, R., Clauss, F., Waberseck, T., and Wagner, I. (2009) "Geothermal site investigation using the Geothermal Response Test (GRT) – test analysis and enhancements."

Kurup, P.U. and Griffin, E.P. (2009) "Data fusion technique for predicting shear strength and stress history from piezocone penetration tests."

Lee, M.J., Lee, W.J., Choi, S.K., and Hong, S.J. (2009) "Effect of cementation on cone tip resistance and DMT indices."

Li, J. and Zhang, L., (2009) "Formation and repeatability of crack network in soil."

Lobo, B.O., Schnaid, F., Rocha, M.M., and Odebrecht, E. (2009) "An approach to evaluation internal friction angle from dynamic penetration tests."

Massad, F. (2009) "Stress history and preconsolidation pressure evaluation from SCPTU."

Mets, M., and Ruben, T. (2009) "The effect of natural factors on bearing capacity of sands."

Mlynarek, Z., Wierzbicki, J., and Stefaniak, K. (2009) "The effect of sand grain roundness on the interpretation of CPTu penetration characteristics."

Mondelli, G., De Mio, G., Giacheti, H.L., and Howie, J.A. (2009) "The use of slot filter in piezocone tests for site characterization of tropical soils."

Papic, J.B. (2009) "Appendix to correlation between E_{oed} and q_c for silts."

Piantedosi, M.C., Livingston, G.R., Kurup, P.U., and Griffin, E.P. (2009) "Predicting soil liquid limit and plasticity index using tree-based learning."

Reiffsteck, P., Dorbani, B., Khay, M., and Haza-Rozier, E. (2009) "Hydraulic profiling tool."

Rito, F. and Sugawara, N. (2009) "Development and field application of static cone penetrometer combined with dynamic penetration."

Sawada, S., Yoshizawa, D., Hiruma, N., Nagase, M., Sugano, T., and Nakazawa, H. (2009) "Evaluation of differential settlement following liquefaction using Piezo Drive Cone."

Tompai, Z. (2009) "Laboratory evaluation of new B&C light falling weight deflectometer."

Tonni, L. and Gottardi, G. (2009) "Partial drainage effects in the interpretation of piezocone tests in Venetian silty soils."

Totani, G., Monaco, P., Marchetti, S., and Marchetti, D. (2009) "Vs measurements by seismic dilatometer (SDMT) in non-penetrable soils."

ul Haq, I., Munir, K., and Farooq, K. (2009) "Rock testing at Daimer Basha Dam project."

Umezaki, T., Kawamura, T., and Yoshimura, M. (2009) "Investigation of sediment environments in closed water body using RI-density log."

Whiteley, R.J. and Stewart, S.B. (2009) "Enhanced site characterization of covered karst with surface and borehole seismic imaging."

Yimsiri, S., Ratananikom, W., and Likitlersuang, S. (2009) "Investigation of some anisotropic characteristics of Bangkok clay."