Alternative Penetrometers to Measure the Near Surface Strength of Soft Seafloor Soils

Mark R. Tufenkjian
Department of Civil Engineering
California State University, Los Angeles
5151 State University Drive
Los Angeles, California, 90032
phone:(323) 343-4434 fax:(323) 343-6316 email:mtufenk@calstatela.edu

Award Number: N00014-08-1-0353

LONG-TERM GOALS

Develop an alternative penetrometer to accurately measure the undrained shear strength of near surface soft seafloor soils. Further the education of participating undergraduate students by active involvement in research and mentoring activities.

OBJECTIVES

In collaboration with the Naval Facilities Engineering Service Center (NFESC) in Port Hueneme, assess the feasibility of using full-flow penetrometer technology to meet Navy requirements. Design, build, and test a full-flow penetrometer that will accurately measure the near surface shear strength of soft seafloor soils.

APPROACH

Review current full-flow penetrometer technology:
Review technical literature to evaluate the state-of-the-art in full-flow penetrometer technology. Discuss with end users and manufacturers the state-of-practice of full-flow penetrometers in scientific and engineering practice. Identify unresolved issues of flow-penetrometer technology and how they can be met to meet the needs of the Navy.

Probe design and construction:
Select probe type and size for design and construction. The probe will be designed to be compatible with the Navy's seabed cone penetrometer unit. The probe will be outfitted with load cells to measure penetration resistance, sleeve friction, and a pressure transducer to measure porewater pressures. Nearly all full-flow penetrometers in use today are either spherical (ball) or cylindrical (t-bar). The features and characteristics most critical to the needs of the Navy will dictate the selection of the probe type.

Laboratory Probe Calibration:
Calibration will be performed in the laboratory by pushing the full-flow penetrometer into prepared large-scale Kaolin specimens of known strength and comparing the measured resistance with the

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2010**	2. REPORT TYPE	3. DATES COVERED **00-00-2010 to 00-00-2010**

4. TITLE AND SUBTITLE **Alternative Penetrometers to Measure the Near Surface Strength of Soft Seafloor Soils**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **California State University, Los Angeles,Department of Civil Engineering,5151 State University Drive,Los Angeles,CA,90032**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

specimen’s undrained shear strength. The ratio of these quantities is the experimentally determined laboratory probe factor. Adjacent cone penetrometer and vane shear tests will also be performed in the specimens to allow side-by-side comparisons and evaluation of the penetration resistance and shear strength with depth; and to establish a baseline to assess the improvement in shear strength accuracy for the full-flow penetrometer. Also, undisturbed samples will be taken from the Kaolin specimens and tested by consolidated undrained triaxial compression tests and by direct simple shear tests.

Probe Validation through Field Trials:
The final phase of the project involves field testing at onshore sites to validate the recommended probe factors against real soils. The probe factors from the field trials will be calculated and compared with the theoretical and laboratory determined values. Ultimately, the potential of the full-flow penetrometer to more accurately determine the shear strength of soft soils (compared to the CPT and Vane Shear) will be evaluated. Parallel CPTs and vane shear tests will also be performed to allow side-by-side comparison and evaluation of the penetration resistance and shear strength with depth; and to establish a baseline to assess the improvement in shear strength accuracy for the full-flow penetrometer. High quality undisturbed clay samples will be obtained for laboratory strength testing (triaxial and simple shear).

Educational Program:
One of the main objectives of this project is to actively involve undergraduate students in the research effort and to provide mentorship. The project will involve three undergraduate civil engineering students in research and mentoring activities throughout the duration of the project. The mentoring activities are designed to provide the students with opportunities to interact with navy engineers professionally and socially.

WORK COMPLETED

The *Laboratory Probe Calibration* phase is nearly complete. Building upon last year’s successful design and fabrication of a large-scale consolidation tank (see Figure 1), two Kaolin specimens (each approximately 1.1 m in diameter by 1.3 m in height) were prepared and tested this fiscal year. The first specimen represented a medium-soft clay deposit and the second represented a soft clay deposit. A third clay specimen is currently in preparation and will represent a medium-stiff clay deposit. Once completed, these tests will represent three different soft clay consistencies by which the accuracy of a flow penetrometer to determine the undrained shear strength of soft clays at shallow penetration can be evaluated.

The clay specimens are prepared by slurry consolidation. This involves mixing clay soils (Kaolin) to high water content and then compressing the material until primary consolidation is complete. The slurry is consolidated by hydraulic pressure applied by a piston in direct contact with the slurry. The piston is driven by a main hydraulic cylinder (see Figure 1). The piston is actuated by a pressure compensated hydraulic pump powered by an electric motor. The piston utilizes a thin Teflon wear band as a seal between the piston edge and the tank wall. The tank bottom and piston are machined with grooves that are plumbed to outlet ports to drain water during consolidation.

The specimens are prepared by first placing a drainage filter at the bottom of the tank followed by the Kaolin slurry that is tremied into the tank as shown on Figure 2. Geotextile fabric is then placed on top of the slurry and the main cylinder and piston are bolted to the top of the tank and a target consolidation pressure is applied until primary consolidation is complete. The movement of the piston is monitored by an internal linear feedback sensor mounted inside the main cylinder. A photograph of a completed specimen after consolidation and ready for testing is shown on Figure 3.

The preparation and consolidation of a Kaolin specimen is a time consuming process taking nearly 2½ months to complete. However, the custom designed and fabricated equipment used to consolidate the specimens has and continues to work exceptionally well even after about 3,500 hours of use. The equipment and procedures developed to prepare uniform and homogenous large-scale clay specimens has been an important accomplishment for this project.

The *Probe Validation through Field Trials* phase is in the planning stages. There are currently two on-shore sites being considered for probe deployment. The first is a set of tailings ponds in the city of Irwindale, which is in close proximity to the University. The second is the mudflat areas near Freemont in northern California. Both sites contain near surface soft clayey soils and are accessible. Other potential sites in close proximity to the University are also being considered.

The *Education Program* component is ongoing and progressing well. Three undergraduate civil engineering students continue to work on the project. They entered into the program as freshmen and are now juniors. Two graduate civil engineering students have also been hired and will use the results of the research as a basis for their graduate M.S. thesis. The undergraduate students completed their summer internship at NFESC during the summer of 2010 as required by the program. Unfortunately, one of the students was not able to complete the entire internship due to health reasons. The undergraduate students reported that the experience and knowledge gained was beneficial to them and for their professional growth. They also expressed a greater appreciation of the depth and complexity of Naval projects and the important role the Navy plays in research and development. The undergraduate students were so inspired by their internship experience they prepared and presented a paper for the 2010 MTS/IEEE Oceans Conference in Seattle highlighting their summer opportunity at NFESC (Manuel et. al., 2010).

In June, the undergraduates arranged for Mr. Blake Jung from NFESC's Ocean Engineering Division to provide a guest lecture on Navy seafloor projects to the on-campus American Society of Civil Engineers student chapter. In December and again in June, Mr. Fred Arnold, an ocean engineering geologist with NFESC, conducted a series of probe drops using the Navy's Expendable Bottom Penetrometer into both of the Kaolin specimens; thereby leveraging infrastructure funded by ONR through this grant to other Navy commands.

In July, Dr. Mike Kassner, Director of Research for ONR, visited our campus, which provided us an opportunity to present our research findings and a venue to demonstrate our ONR funded equipment and capabilities.

RESULTS

As mentioned earlier, two series of tests (Specimen 1 and Specimen 2) have been completed this fiscal year. Specimen 1 was created as a medium soft clay while Specimen 2 was created as a soft clay. In each specimen, three different types of probes were advanced side-by-side in order to allow a comparison of the recorded data. The three probe types were a cone penetrometer (CPT), ball penetrometer (BPT), and a shear vane (VST). The CPT and BPT measure electronically a continuous profile of tip and sleeve resistance as well as the porewater pressure during advancement. The VST records the undrained shear strength of the soil at discreet depths. In addition, Shelby tube samples were collected for triaxial and direct simple shear testing. Photographic and video evidence were also recorded.

The net tip resistance profiles for the cone and ball for Specimens 1 and 2 are shown on Figure 4. The shape and magnitudes of the tip resistance profiles are consistent and in line with other soft clay tests reported in the literature. The cone profile appears to be more erratic than the ball, which is most likely due to the different soil deformation mechanisms around the probes and/or the smaller size of the cone compared to the ball. The smaller cone senses material changes more quickly whereas the larger ball senses a deeper oncoming front that tends to smooth out these boundaries. This is one advantage of the BPT.

The most striking feature is that the BPT resistances are about 30% to 40% less than the CPT resistances. This may not be surprising since similar tip behavior has been noted in other laboratory and field investigations when comparing full flow penetrometers with the cone. A possible reason for this behavior has been attributed to differences in soil flow mechanism around the cone and ball. This phenomenon will be studied in more detail.

The undrained shear strengths have been computed using the BPT and CPT test results and are compared with the VST shear strengths as shown on Figure 5 (Specimen 1) and Figure 6 (Specimen 2). The VST strengths compare favorably with the shear strength profiles derived from the BPT as well as the CPT tests. The probe strength profiles are currently being evaluated against test results from triaxial compression and direct simple shear tests conducted on the retrieved tube samples. Using a SHANSEP (Stress History and Normalized Soil Engineering Parameters) methodology a complete and accurate undrained shear strength profile will be obtained from the triaxial and simple shear tests. This will allow a direct comparison with the BPT test results and ultimately provide a means to assess the ability of the BPT to accurately capture the true picture of shear strength with depth. At least two more Kaolin specimens at varying consistencies are planned, which will provide a more complete data set.

Preliminary results from the testing were published with the Navy at the 2010 International Offshore (Ocean) and Polar Engineering Conference in Beijing (Tufenkjian and Thompson, 2010).

IMPACT/APPLICATIONS

The impact of the research is to increase the technical capabilities of the Navy by developing a tool to measure the strength of soft seafloor soils. Results of this research will provide immediate and practical information for use by Navy commands. The project will also further the education of undergraduate and graduate students by active involvement in research and mentoring activities. It will expose the students to research projects important to the mission of the Navy with the intent that they may consider naval careers

RELATED PROJECTS

None

PUBLICATIONS

Manuel, S., Acosta, R., and Tufenkjian, M., (2010), "A Summer Internship Experience at a NAVFAC Facility – An Undergraduate Engineering Student Perspective," MTS/IEEE Oceans 2010 Conference, Seattle, Washington, September, [published].

Tufenkjian, M., and Thompson, D., (2010), "Shear Strength of Soft Clay at Shallow Penetration using a Ball Penetrometer," *20th International Offshore (Ocean) and Polar Engineering Conference (*ISOPE), Beijing, China, June, [published].

Figure 1: Photograph of custom-designed and built consolidation tank for creating large-scale clay specimens. Note main hydraulic piston to the left of the tank.

Figure 2: Photograph of slurry placement into tank prior to consolidation

Figure 3: Photograph of final consolidated clay specimen prior to probe penetration

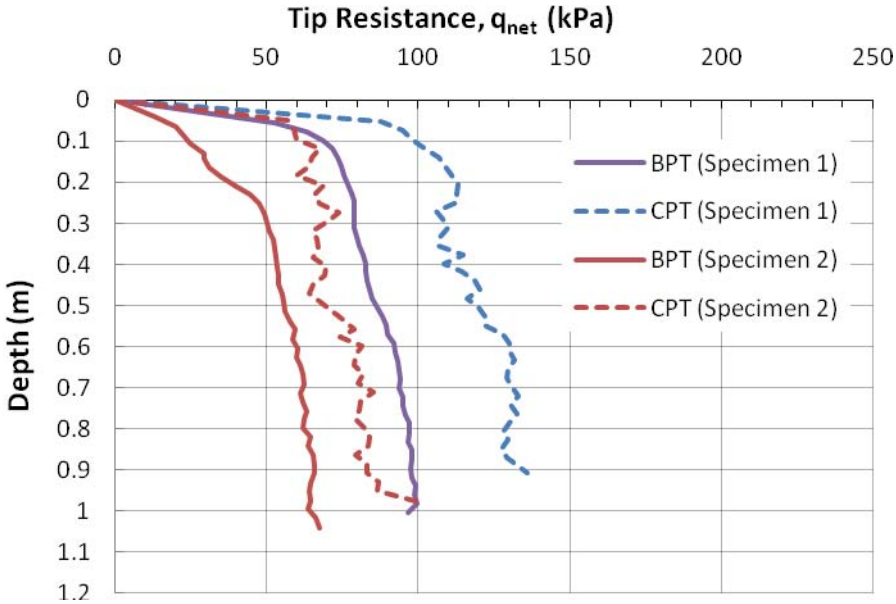

Figure 4: Graph showing profile of tip resistance with depth for the ball and cone penetrometers in Specimen 1 (medium-soft clay) and Specimen 2 (soft clay)

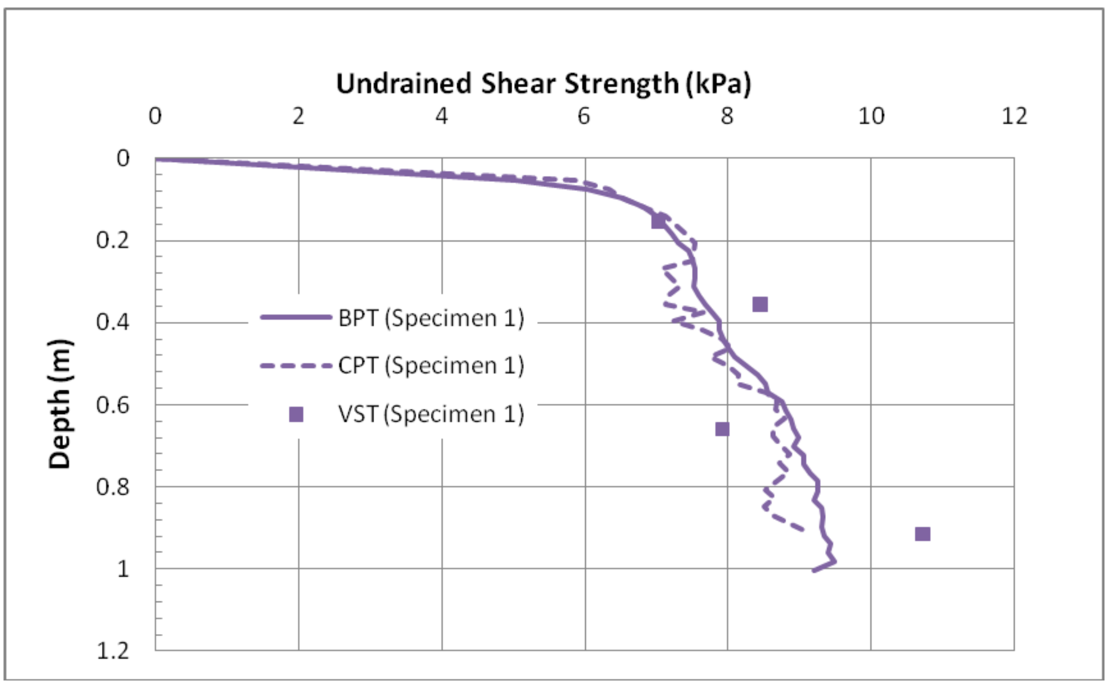

Figure 5: Graph showing profile of derived undrained shear strength with depth for ball, cone, and vane shear in Specimen 1 (medium-soft clay)

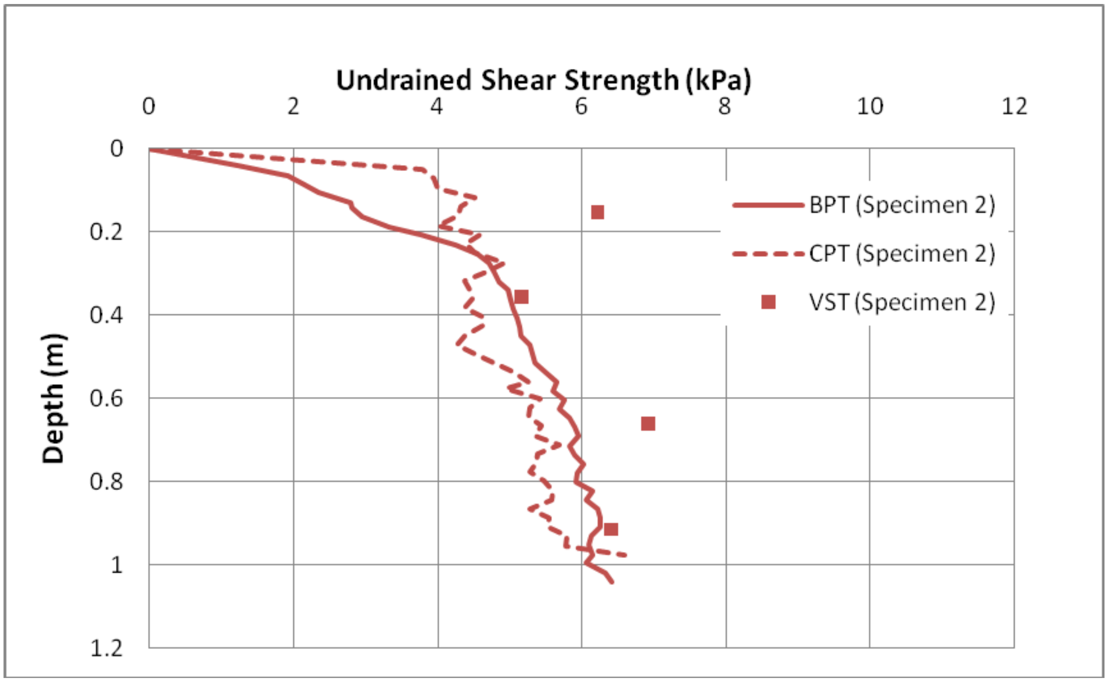

Figure 6: Graph showing profile of derived undrained shear strength with depth for ball, cone, and vane shear in Specimen 2 (soft clay)