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

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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 and graduate students by active involvement in research and mentoring activities.

OBJECTIVES

In collaboration with the Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC) 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 specimen's undrained shear strength. The ratio of these quantities is the experimentally determined

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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/extension tests and by direct simple shear tests.

Probe Validation through Field Trials:
Field testing at onshore sites will be conducted 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 and graduate students in the research effort and to provide mentorship. The project involves three undergraduate and three graduate civil engineering students in research and mentoring activities throughout the duration of the project.

WORK COMPLETED

The *Laboratory Probe Calibration* testing in the Kaolin specimens was completed. A total of five full-scale Kaolin specimens (Specimens 1 through 5) were prepared and tested. Each specimen had final consolidated dimensions of approximately 1.1 m in diameter by 1.3 m in height. Each was prepared by mixing 2,700 pounds of Kaolin powder with 450 gallons of water and applying a consolidation pressure and allowing the water to drain at the top and bottom boundaries. Consolidating the specimens took about one to two months each to complete depending upon the applied pressure. Turnaround time for each specimen was about 4 months. The equipment and procedures developed to prepare uniform and homogenous large-scale clay specimens has been a key accomplishment for this project.

The readied specimens were tested by advancing a standard ball penetrometer (100 cm^2), mini-ball penetrometer (20 cm^2), cone penetrometer (10 cm^2), and vane shear device. A photograph of the probes is shown on Figure 1. The results were used to evaluate and compare the undrained shear strengths derived from each device. Core samples were retrieved for subsequent triaxial and direct simple shear testing. Digital imaging was used to observe the flow mechanism during shallow penetration. A photo of the soil flow mechanisms for the mini-ball and standard ball penetrometers is shown on Figure 2.

The *Probe Validation through Field Trials* phase is also complete. The field site was tested at a rock quarry site in Irwindale. Soft and fine grained tailings were tested in an old spreading pond at the site. A total of six spherical ball and cone penetrometer tests were performed over a two day period. Core samples were also retrieved. Unfortunately, permission was not granted to access a second site in the Port of Los Angeles West Channel at Cabrillo Beach.

The *Education Program* component is nearly complete. Two undergraduate civil engineering students have already completed their work on the project. One of the students graduated with her B.S. degree in Civil Engineering and the other is on track to graduate during the Spring. Both have expressed interest in pursuing their M.S. degree in Civil Engineering. Three graduate civil engineering students are also working on the project. One of the students completed his Master's thesis by analyzing more than two dozen direct simple shear tests he conducted on core samples retrieved from Specimens 1 through 3. He has since graduated and, aside from his full-time professional job, teaches the undergraduate soils mechanics laboratory course utilizing his experience with lab equipment gained from the project. The other graduate student has just completed the triaxial strength testing program and is now preparing his thesis, which should be completed by December. The third graduate student is currently conducting additional direct simple shear tests on samples retrieved from Specimens 4 and 5. He will use this information to complete his thesis which should also be complete by December. Publications related to their work on the project will be forthcoming.

RESULTS

As mentioned earlier, five tests (Specimens 1 through 5) have been completed. Each test represented a different clay consistency. For each test, four different types of probes were advanced side-by-side in order to allow a comparison of the recorded data.

The undrained shear strengths computed using all of the probes have been evaluated against the benchmark strengths from the triaxial and direct simple shear tests. The triaxial and direct simple shear testing is also complete. The research grant has allowed us the opportunity to purchase equipment to test specimens in complex modes of failure and has significantly upgraded our research lab capabilities. The results of the undrained strength profile from the probes compared to the laboratory strengths are shown on Figure 3 for the medium stiff clay specimen. The computed bar factor (N-values) are consistent and generally agree with data in the literature for deeper penetration. This data set is unique because it provides an important data set to determine undrained strength at shallow penetration.

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 at shallow penetration. 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

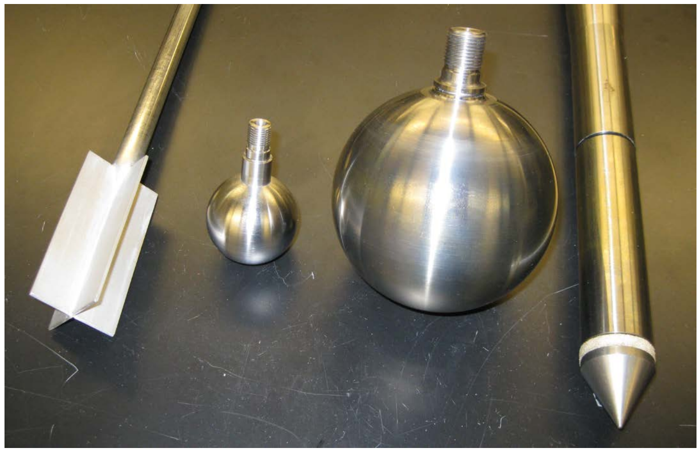

Figure 1: Photograph of probe types used in study. From left to right: vane shear, mini-ball, standard ball, and cone penetrometer.

Figure 2: Photograph showing the soil flow mechanism around the mini-ball (left) and standard ball (right) penetrometers.

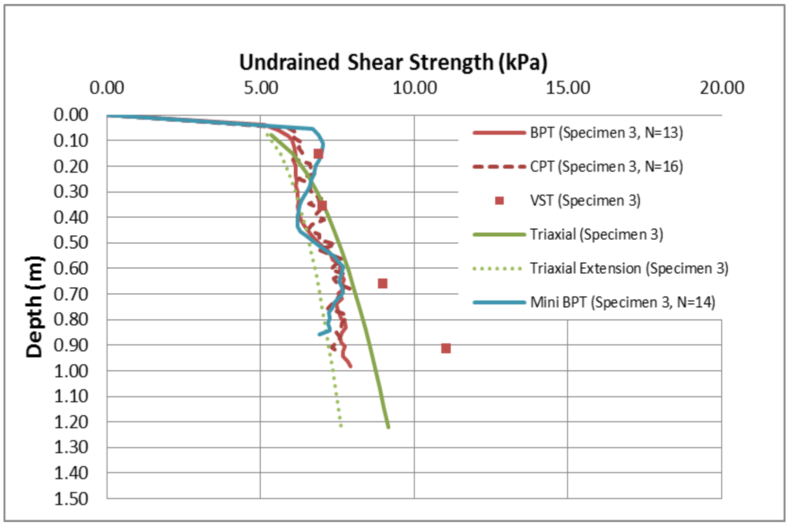

Figure 3: Graph comparing the undrained shear strength with depth for the mini-ball (Mini BPT), standard ball (BPT), Cone (CPT), and Vane (VST) compared to the undrained shear strength measured in the laboratory triaxial apparatus for medium stiff clay.