Shallow Penetration Resistance of a Mini-Cone Penetrometer in Sand

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LONG-TERM GOALS

Develop improved in-situ testing techniques of seafloor soils by using a mini-cone penetration test system to provide a fast and reliable method to determine seafloor soil properties within the upper 1 to 2 meters for the design of foundations and cable burial systems.

OBJECTIVES

To investigate the penetration resistance of a minicone in sand at shallow penetration depths in order to provide experimental information to correlate measured cone parameters with sand strength properties. Evaluate existing methods to predict relative density and friction angle with the measured cone data. Recommend most appropriate methods or develop new methods to predict sand strength properties based on cone data.

APPROACH

In-situ testing techniques have proven to be successful at improving the quality, reliability, and speed of marine geotechnical investigations. The most commonly used in-situ method for offshore investigations is the cone penetration test. Our collaborators, Dr. Kimo Zaiger and Mr. David Thompson of the Naval Facilities Engineering Service Center (NFESC), have recently acquired a custom-designed and built mini-cone penetration system that will be capable of obtaining accurate and reliable geotechnical information within about the upper 2 meters of the seafloor. The mini-cone has a tip base area of 2 cm^2, which is smaller than the conventional 10 or 15 cm^2 cone. The primary advantage of this configuration is the smaller downward thrust needed to advance the penetrometer into the seafloor and ability to identify very thin lenses. However, calibration information is needed to correlate the measured mini-cone parameters to soil strength properties. This will be accomplished through the following tasks.

Perform Mini-Cone Soundings in Controlled Sand Test Beds: Mini-cone soundings to shallow depths are being conducted in carefully prepared sand test beds where soil properties and boundary conditions are controlled. Side-by-side comparisons with the standard cone (10 cm^2) are also being investigated.

Conduct Laboratory Tests to Determine Test-Bed Soil Parameters: Parallel laboratory tests are being conducted on the sand to similar densities and under similar boundary conditions to the test beds. The test bed soils are being characterized by conducting appropriate laboratory index and strength tests such as grain size distribution, petrographic analysis, relative density, and drained triaxial compression testing.

Calibrate Mini-CPT Test Results with Laboratory Test Measurements: Conventional cone sizes have well-established correlations for identifying soil types and strength parameters. However, these correlations have not been extensively verified for mini-cone results and have been generally unreliable for soil depths less than about 2 meters. In this task, existing algorithms to interpret conventional cone test results for sands are being used to compare the mini-cone tests results with the results of the laboratory tests. Based on the results of this evaluation, refinements to the algorithms will be made to best fit the laboratory data. In this way, specific correlations for the mini-cone will be developed.

WORK COMPLETED

Laboratory Testing: Prior to preparing the sand test beds, the key parameters controlling the dry density of the sand by air pluviation were investigated in the laboratory. Simple tests using a system of stacked sieves and a variable height frame were used to evaluate the effect of deposition intensity and drop height on the density of the test sand. The test sand was further characterized by conducting grain size and petrograhic analysis, and determining the minimum and maximum dry densities. The shear strength parameters of the sand are being evaluated by direct shear and triaxial compression testing.

Sand Spreader: A major technical challenge was creating controllable and uniform dry sand test beds. The volume of soil needed to fill the trench (on the order of 55 metric tons) required a semi-automated and efficient delivery system that was capable of placing sand at uniform densities repetitively. Several concepts were considered but in the end an innovative air-pluviated streamout feed system was custom designed and built as shown on Figure 1.

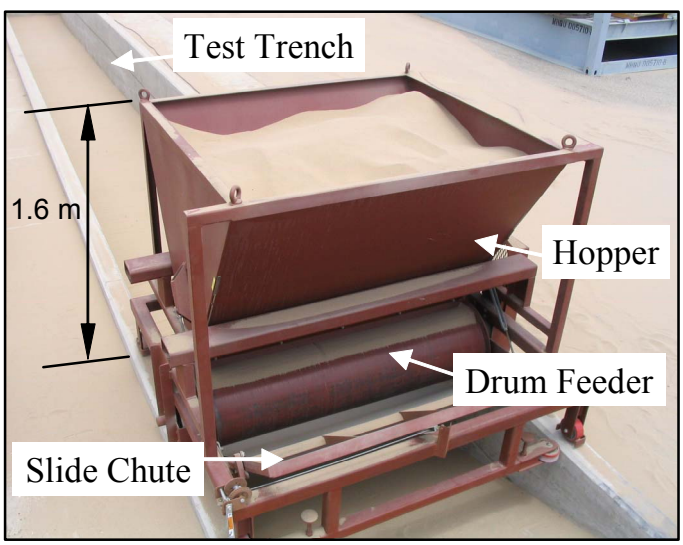

Figure 1. The sand spreader was used to create the test beds in the test trench by dry sand pluviation. Main components of sand spreader include the hopper, drum feeder, and slide chute

The main components of the sand spreader are the steel frame, hopper, electric motor, adjustable gate valve, rotary drum feeder, and slide chute. The sand spreader was mounted on two electrically driven load bearing wheels which tracked along the top of the trench. The rotary drum feeder discharges the

sand from the hopper by its rotation. When activated, the sand spreader traverses the length of the trench and deposits the sand along the full width of the trench. The deposition intensity of this sand "curtain" can be controlled by adjusting the gate valve opening, which can be incrementally adjusted from fully closed (no sand flow) to a wide open position of about 50 mm. The vertical drop height of the sand can be controlled by a retractable slide chute. To date, three sand test beds have been prepared and tested. The first test bed represented a loose in-situ condition. The second test bed was a duplicate of the first to demonstrate repeatability of the test results. The third test bed represented a medium-dense condition. Each test bed took anywhere from 2 to 3 days to prepare.

Test Bed Density Measurements: An important part of the calibration process is the accurate measurement of the in-situ dry density of the test beds. However, when dealing with dry sand conventional density measurement techniques are not applicable. A specially designed density scoop was built and calibrated to efficiently and accurately determine dry sand densities within the test bed. Specially designed density cans were also fabricated and used.

Cone Testing: A total of 51 cone penetration soundings (33 mini-cones and 18 standard cones) have been performed in three prepared test beds. The tip and sleeve resistance with penetration depth was measured.

RESULTS

Test beds representing loose and medium dense sand have been tested and the results analyzed. Figure 2 shows a comparison of the mean mini-cone tip resistance profiles in loose and medium dense sand. This tip resistance behavior is similar to studies using standard cones in homogeneous sand provided in the literature (e.g. De Beer, 1974; Mitchell and Lunne, 1978; Puech and Foray, 2002). Specifically, the tip resistance initially increased rapidly below the ground surface until a critical depth was reached where the tip resistance essentially reached a maximum or constant value thereafter. Increasing the density of the sand increased the value of the maximum tip resistance and deeper penetrations were required to reach the critical depth. The measured values of maximum tip resistance and critical depth compared well with other published data (Puech and Foray, 2002) on sands at shallow penetration.

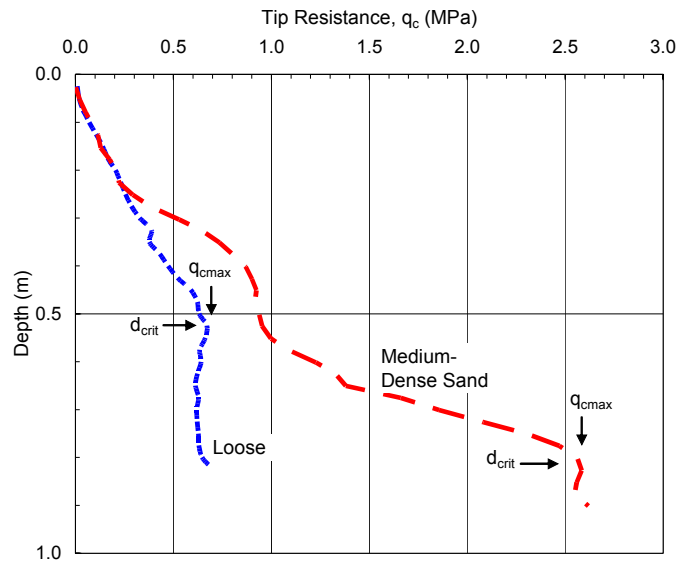

Figure 2. Mini-cone tip resistance profile in loose and medium dense sand at shallow penetration illustrating maximum tip resistance at the critical depth

IMPACT/APPLICATIONS

The custom designed sand spreader has demonstrated the ability to layer sand into the test trench uniformly (constant density), repetitively, and at a range of relative densities up to about 70%. This has improved the capability of the NFESC to conduct future experiments in their test trench.

The results thus far have added to the understanding of the minicone penetration response of sands at shallow depth. Further testing and analysis is ongoing in test beds of different relative densities to add to the existing data set. Concurrent laboratory testing is being conducted to determine the friction angle of the sand at similar densities and stress conditions in the test beds. Once completed, various analytical methods will be compared to correlate measured cone resistance with relative density and friction angle, and if needed, new correlations will be proposed.

RELATED PROJECTS

None

REFERENCES

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PUBLICATIONS

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