Final Report for Period: 10/1999 - 09/2002

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Award ID: 9978630

Organization: GA Tech Res Corp - GIT

Title:

Revolutionizing Friction Pile Design Through the Development of a Multi-Friction Sleeve Device for Direct In-situ Measurement of Interface Strength

Project Participants

Senior Personnel

Name: Frost, J. David

Worked for more than 160 Hours: Yes

Contribution to Project:

Post-doc

Graduate Student

Name: DeJong, Jason

Worked for more than 160 Hours: Yes

Contribution to Project:

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

Applied Research Associates

Applied Research Associates (ARA) were contracted to fabricate the attachment being developed as part of this project. In addition, they provided access to a test site and the use of a rig to permit field testing to be conducted at no cost to the project. ARA personnel also provided logistic support and trouble-shooting during initial use of equipment.

Other Collaborators or Contacts

Project personnel have displayed the attachment developed on the project at a trade show.

Activities and Findings

Research and Education Activities:

This project involved the development and evaluation of a multi-sleeve attachment for the CPT to permit direct in situ measurement of the relationship between interface strength and surface roughness. Current industry ability to determine the magnitude of interface strength between geotechnical structure elements and the surrounding soil is limited, primarily relying on empirical correlations. With this uncertainty, many geotechnical structures are significantly over-designed, resulting in expensive, inefficient geotechnical systems. Recent and ongoing research has successfully quantified the relationship between interface strength and surface roughness in the lab. The opportunity exists to transfer this knowledge to an in-situ test. Through measurement of the loads transmitted to multiple friction sleeves of increasing roughness assembled in series, the quantitative relationship between interface friction and surface roughness at specific measurement intervals will be obtained. This will result in the ability to directly measure the insitu interface strength, thereby opening the opportunity to revolutionize the design concepts, materials, methods and processes used in a range of geotechnical systems.

Findings:

A new multi-friction sleeve penetrometer attachment has been developed. This attachment provides the unique ability to obtain multiple sleeve friction measurements at each measurement depth within a single sounding compliments the data obtained by conventional CPT module readings with measurements of sleeve friction for different sleeve roughnesses. Innovative characteristics of the system include the ability to obtain seven simultaneous measurements at each measurement increment while monitoring verticality, full analog-to-digital conversion and multiplexing of signals downhole, the arrangement of four individual sleeve load cell sensors in series, the ability to rapidly exchange sleeves between consecutive soundings, and a diamond texturing pattern for sleeves which is 'self-cleaning' and induces shearing within the soil as opposed to at the interface.

The multi-friction sleeve penetrometer attachment was shown to have a high degree of repeatability, with the effect of breakdown and the presence O-rings for sealing being negligible. Shorter sleeves with texturing provided higher stratigraphic sensitivity than the conventional CPT fs and qc measurement, lending the possibility for improved methods of stratigraphic delineation with additional research. Furthermore, a more accurate estimate of insitu soil strength may be feasible since the textured friction sleeve obtains a more localized strength measurement than qc. With this development, the penetrometer attachment configured with an uninstrumented tip would also be advantageous in stiffer soils and partially weather rock where a CPT cannot be used because the qc capacity is exceeded. In addition, this penetrometer attachment provides the opportunity to develop improved insitu based correlation methods including soil classification and new design procedures for geotechnical structures with further development.

To fully quantify the capabilities of the multi-friction sleeve penetrometer attachment, a series of laboratory and field tests were performed to assess the operation of the device. A summary of this testing program follows.

Laboratory Calibration and Performance of Individual Load Cells

Prior to assembly of the penetrometer attachment, each load cell was calibrated individually without signal conditioning against an NTIS traceable load cell. This was followed by recalibration of each load cell through the fully assembled penetration system by loading each individual load cell and recording the measurements through the data acquisition system. In both calibration schemes, the R2 values were above 0.999 and the calibration factors differed by less than 2.5%. During calibration of each load cell in the fully assembled configuration, the remaining three load cells were monitored and cross-talk was less than 0.005% of the maximum calibration load in all cases. From this, it can be concluded that the multiple individual load cell system performs very well for obtaining four accurate, individual interface shear measurements during penetration.

Field Testing Program

A field testing program consisting of 39 soundings to 10 meters or more was conducted to: (1) determine the effect of assembly/disassembly on the system performance, (2) to investigate the similarity between measurements made with sleeves of the same texture in the same sounding and of measurements made with the same sleeves in consecutive soundings, (3) to evaluate the effect of each diamond design dimension variable on the measured sleeve friction, and (4) to assess the performance of the attachment when configured with a set of textured sleeves that increase consecutively in roughness.

Field testing was performed in the northeast United States in Vermont at a glacial outwash site. Soundings were performed at 1 m horizontal spacings and in accordance with ASTM standards at a measurement increment of 1 cm. The subsurface stratigraphy was delineated from the 15 cm2 CPT module using the classification method proposed by Robertson (1990). Clean sand exists to a depth of 6.3 m below which a thin sandy silt layer is followed by a sand to silty sand layer to a depth of 8.7 m. A second sandy silt layer exists between about 8.7 and 8.9 m followed by a sand layer to 12.5 m.

To compare the results of each measurement from all soundings, each measurement profile was detrended with linear regression from 1 to 10 m. The depth range was selected through consideration of the spatial variability and the increased sensitivity of the trendline over shorter depth increments. Though two layers with a higher fines content exist within the selected depth range, more rigorous detrending schemes (such as polynomial regression or a window layer detection) did not provide consistent results due to the significant differences between the soundings obtained with sleeves of different surface roughness. Furthermore, the trends detected by these did not consistently match the classification of the soil stratigraphy. An extensive evaluation of all the soundings performed in this research in addition to alternative detrending methods is beyond the scope of this paper and is provided elsewhere.

Training and Development:

The very nature of the project has ensured that participants have been challenged in a variety of ways. Even when based on solid fundamental concepts, the design, fabrication and validation of any instrument is invariably a challenging activity. In this respect, this project has been extremely successful. From the outset, the project team worked closely with the company selected to fabricate the equipment to ensure that the project could be successfully completed. For example, planning and design meetings were conducted to continuously assess the design process and progress.

Outreach Activities:

The project members have given numerous presentations at a number of national and international conferences and meetings about the developments. In addition, presentations at less formal 'brown bag' luncheons have been undertaken at a number of consulting firms. The project members have also prepared posters and distributed those at a number of the technical meetings and conferences. A summary of lectures given by the PI are included below:

Kentucky Geotechnical Engineering Group Distinguished Lecture, on 'Understanding Geotechnical Interfaces', 2000.

Invited lecture at Trinity College Dublin, Ireland, on 'Understanding Geotechnical Interfaces', 2001.

Invited lecture on 'Multi-Friction Sleeve Attachment for the Cone Penetrometer', ASCE Geotechnical Section, Atlanta, Georgia, 2001.

Invited lecture on 'Understanding Geotechnical Interfaces', California Department of Transportation, Sacramento, California, 2001.

Invited lecture at Polytechnic University, Brooklyn, New York, on 'Understanding Geotechnical Interfaces', 2001.

Invited Lecture on 'Effect of Pipe Surface Roughness on Jacking Forces', South Eastern Society for Trenchless Technology, Atlanta, 2002.

Invited Keynote Lecture on 'In Situ Testing û State of the Art', 17th Venezuelan Geotechnical Seminar, Caracas, Venezuela, 2002.

Journal Publications

J.T. DeJong, J.D. Frost and D.R. Saussus, "Measurement of Relative Roughness at Particulate Solid Interfaces", ASTM Journal of Testing and Evaluation, p. 8, vol. 30, (2002). Published

D.R. Saussus, J.D. Frost and J.T. DeJong, "Cone Penetrometer Friction Sleeve Length Effects - Part I: Soil Classification", Geotechnique, p. , vol. , ( ). Submitted

Frost, J.D., Saussus, J.D.,and DeJong, J.D., "Cone Penetrometer Friction Sleeve Length Effects - Part II: Interface and Anolamy Detection", Geotechnique, p. , vol. , ( ). Submitted

J.T. DeJong and J.D. Frost, "A Multisleeve Friction Attachment for the Cone Penetrometer", ASTM Geotechnical Testing Journal, p. 111, vol. 25, (2002). Published

J.D. Frost, J.T. DeJong and M. Recalde, "Shear Failure Behavior of Granular-Continuum Interfaces", Engineering Fracture Mechanics, p. 2029, vol. 69, (2002). Published

Frost J.D., and DeJong, J.T., "In-Situ Assessment of Role of Surface Roughness on Interface Response", ASCE Journal of Geotechnical and Geoenvironmental Engineering, p. , vol. , ( ). Submitted

Books or Other One-time Publications

J.T. DeJong and J.D. Frost, "Effect of CPT Friction Sleeve Roughness and Position on fs Measurements", (2001). Proceedings, Published
Editor(s): GEC/Parahyangan Catholic University
Collection: In Situ 2001
Bibliography: Conference Proceedings

J.T. DeJong and J.D. Frost, "Relating Quantitative Measures of Surface Roughness and Hardness to Geomaterial Interface Strength", (2000). CD-ROM, Published
Collection: GeoEng 2000
Bibliography: CD-ROM

J.D. Frost and J.T. DeJong, "A New Multi Friction Sleeve Attachment", (2001). Proceedings, Published
Editor(s): Balkema
Collection: International Conference on Soil Mechanics and Geotechnical Engineering
Bibliography: Vol. 1, pp. 91-94

Web/Internet Site

URL(s):

Description:

Other Specific Products

Product Type: Instruments or equipment developed

Product Description:

Multi-friction sleeve attachment for the cone penetrometer.

Sharing Information:

Technology has been licensed by Applied Research Associates.

Contributions

Contributions within Discipline:

The multi-friction sleeve penetrometer attachment has been shown to provide new unique insight and measurements of interface strength. Additional research based on the findings of this project is ongoing.

Contributions to Other Disciplines:

Insight/understanding developed in course of present study has led to development of alternative approach to quantify surface roughness which takes into account, the relative characteristics of materials at the interface. Research in this area is ongoing. Application of the instrument/methodology to a variety of applications including pile foundations, soil classification and trenchless pipe jacking is ongoing.

Contributions to Human Resource Development:

The principal graduate student to work on the project has completed his PhD. He has a position as an Assistant Professor of Civil Engineering at the University of Massachussetts - Amherst.

Contributions to Resources for Research and Education:

Physical device developed in course of project has and continues to contribute to research and education. Several additional graduate students are involved in research projects that are using the device. In addition, a follow-on proposal to continue development of the device has been submitted to NSF.

Contributions Beyond Science and Engineering:

Contributions beyond sciecne and engineering have resulted in that both the PI and the lead graduate student have learnt about the processes for invention disclosure, patent filing and patent review. In addition, they have used this knowledge in presenting to others the value of this effort.

Categories for which nothing is reported: