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RESEARCH AND DEVELOPMENT OF THE UBC CONE PRESSUREMETER

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ABSTRACT

The research and development performed at the University of British Columbia (UBC) on the cone pressuremeter is reviewed and described. The cone pressuremeter combines the already successful electronic piezometer friction seismic cone and the pressuremeter into one instrument to support the needs of offshore site investigations. The instrument is pushed into the ground and continuously records tip resistance, sleeve friction and pore pressures with depth. At selected intervals based on the cone data, the pushing is stopped and the pressuremeter element expanded to provide stress-strain properties of the surrounding soil. Also, downhole seismic tests are performed to measure in-situ shear wave velocity.

The concept of the cone pressuremeter is presented along with some criteria and considerations for design and the objectives of the overall development program.

INTRODUCTION

In the last decade, resource development in the offshore environment has produced several major improvements in the area of in-situ testing for the determination of geotechnical parameters. The electronic cone penetration test (CPT) was introduced into offshore soil investigations in the early 1970's and is now the most dominant in-situ tool. The most notable recent improvement is the measurement of pore pressures during cone penetration testing which is now standard practice for all major soil investigations in the Norwegian sector of the North Sea (Lunne et al, 1985). However, challenging new offshore projects combined with an improved appreciation within oil companies of the importance of good soil investigations has led to remarkable developments in the state of the art of offshore in-situ testing.

The piezometer friction cone is generally regarded as the ideal instrument for evaluating soil stratigraphy, soil type and shear strength. Methods have been developed for directly applying cone data to design problems, such as driven piles, shallow footings, and the assessment of soil liquefaction due to earthquake loading.

The pressuremeter has been shown to be an ideal instrument for evaluating static soil stress-strain characteristics. However, existing pressuremeters are difficult to install, especially offshore.

During the early 1980's several in-situ testing centres independently developed the concept of combining the cone penetrometer with the pressuremeter. In France, a pressuremeter was developed for offshore use (Jezequel, et al., 1983). The French probe is 89 mm in diameter and is installed using a vibrating hammer device. The vibration reduces the installation force but can make interpretation of the cone and pressuremeter data difficult. The probe was designed specifically to model offshore piles.

Fugro in Holland and the University of British Columbia (UBC) have independently investigated the feasibility of developing a small pressuremeter mounted behind a 15 cm^2 (44 mm in diameter) electronic cone penetrometer which is pushed in a quasi-static manner similar to the standard CPT.

This paper describes the research and development performed at UBC on the concept of a cone pressuremeter.

HISTORICAL REVIEW

In 1981 research was under way at UBC that included studies of the piezometer cone and the self-boring pressuremeter. The self-boring pressuremeter (SBPM) research was conducted with the assistance and equipment of Dr. J.M.O. Hughes. During a phase of self-boring pressuremeter work, the possibility of installing the pressuremeter by pushing the probe closed-ended into the soil was investigated. A 60° solid cone tip was placed on the base of a 75 mm diameter self-boring pressuremeter probe (Robertson, 1982). This work was performed to evaluate the potential of using the pressuremeter to obtain P-y curves for the design of laterally loaded driven displacement piles. The use of the pressuremeter data for design of laterally loaded piles proved to be extremely successful (Robertson, et al., 1983).

However, it was observed that the shape and size of the pressure-expansion curves in sand obtained from a pressuremeter, which was pushed closed-ended, was remarkably similar to the data obtained from self-boring pressuremeter tests at the same site. Further study showed promising results concerning the use of the closed-ended pressuremeter or Full Displacement Pressuremeter (FDPM) to determine the static shear modulus in sands (Hughes and Robertson, 1985). Further testing has been performed to evaluate the concept of pushing a closed-ended pressuremeter or cone pressuremeter into clay soils.

Several pressuremeter design concepts have been evaluated for use as a cone pressuremeter. Both the Menard and Roctest Pencel (1984) pressuremeter probes were evaluated by pushing closed-ended into various soils (O'Neill, 1985). However, problems were encountered with the membrane design and the level of accuracy of the displacement measurements.

In the latter part of 1985, Fugro, Holland, provided a prototype of their cone-pressuremeter (full-displacement pressuremeter, FDPM) to UBC for evaluation and comparison with existing FDPM and SBPM test data. Details of the Fugro probe are given by Withers, et al. (1986).

Research at UBC has also been performed on a seismic cone penetrometer. The seismic cone penetrometer is a standard piezometer friction cone that incorporates a miniature seismometer (Campanella and Robertson, 1984). During a pause in the cone penetration a shear wave is generated at the ground surface and the arrival time recorded at the cone tip. Excellent comparisons have been recorded (Robertson et al., 1985) between the shear wave velocities obtained from seismic CPT downhole techniques and conventional cross-hole methods. The shear wave velocity can be used to obtain the dynamic shear modulus (G_{max}) at the small strain levels of $10^{-4}\%$. In 1985 the seismic CPT was evaluated for use offshore in the Beaufort Sea. Experience gained at four sites near Tuktoyaktuk, N.W.T., is described in a companion paper at this conference (Campanella, et al., 1986).

In 1984 the In-situ Group at UBC obtained an NSERC University-Industry Cooperative R&D Grant to develop a seismic cone pressuremeter for offshore applications with the deployment and logistical support of Foundex Explorations Ltd.

THE CONE PRESSUREMETER

The concept of the cone pressuremeter is to enable pressuremeter tests to be performed as part of cone penetration test operations. The pressuremeter element is included in the string of cone rods and is of the same diameter as the cone tip. The instrument is pushed into the ground in a similar manner to conventional CPT and continuously records tip resistance, sleeve friction, and pore pressure with depth. At selective intervals, based on the CPT data, the pushing is stopped and the pressuremeter element expanded to investigate the static stress-strain properties of the surrounding soil. Cone penetration is resumed when the pressuremeter membrane has been deflated to its original diameter.

During the pause in cone penetration to perform a pressuremeter test, the downhole seismic test can also be performed to determine the shear wave velocity and, thus, the dynamic stiffness of the soil.

The major advantages of the cone pressurmeter with seismic measurements are,

- i) ease of operation and installation
- ii) soil disturbance caused by insertion is repeatable and operator independent
- iii) maximum amount of data collected in one sounding.

UBC CONE PRESSUREMETER DEVELOPMENT

A schematic diagram of the conceptual design for the seismic cone-pressuremeter, which is under development at UBC, is shown in Fig. 1.

At the tip of the instrument is a 15 cm^2 electronic cone module. The cone module contains the tip and sleeve friction load cells, several pressure transducers to record pore pressures at different locations, a slope sensor to monitor verticality of the probe, a temperature sensor and seismic sensors. The cone design is similar to that described by Campanella and Robertson (1981). Above the cone module is an electronics module for the cone sensors. Above the cone electronics is a module that contains the pressuremeter and developmental module electronics. These electronics include D.C. regulation, conditioning and amplification, multiplexing,

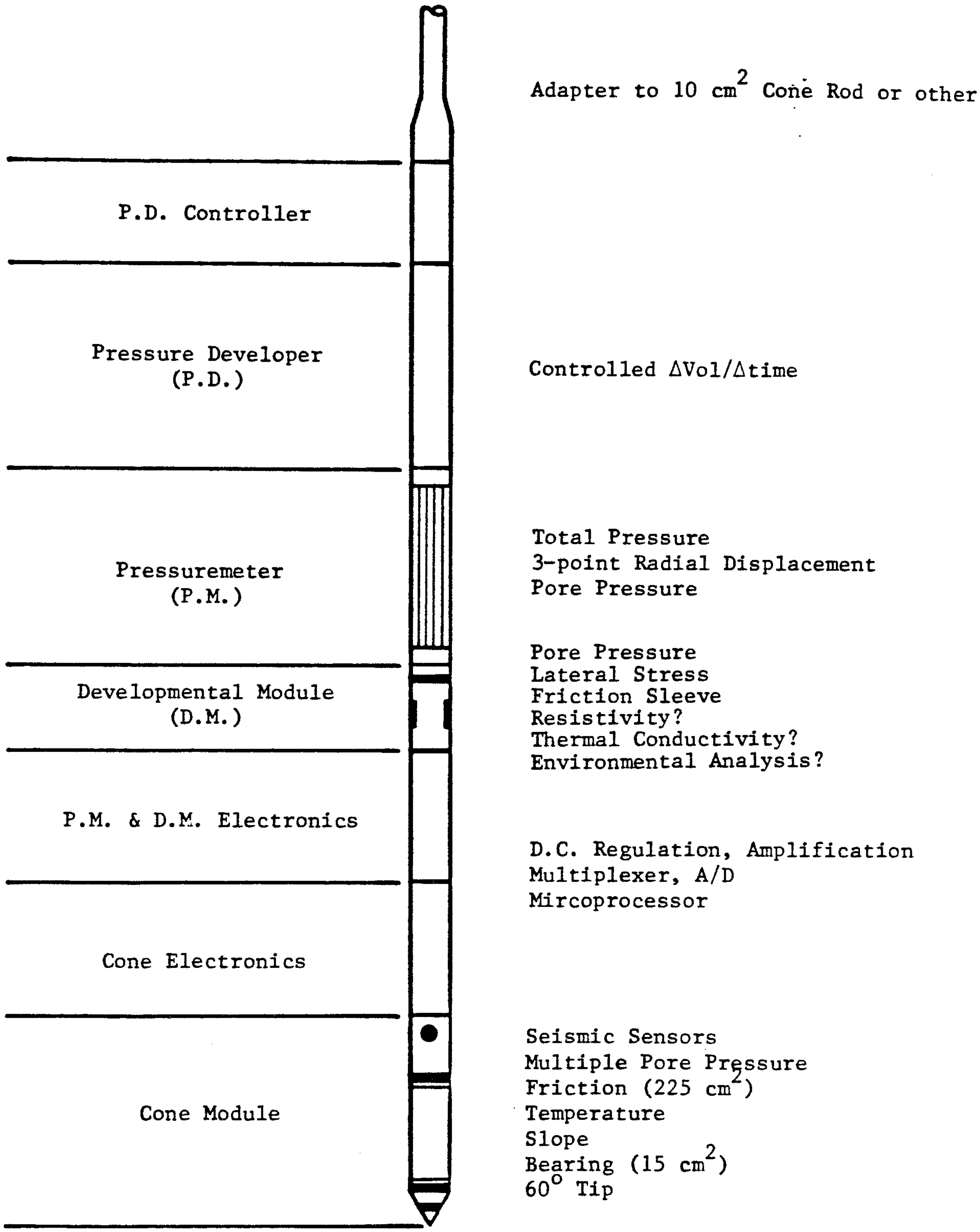

Fig. 1. Conceptual Design: UBC Cone Pressuremeter.

analogue to digital (A/D) conversion and microprocessor control through computer communication.

Between the electronics and the pressuremeter element is a developmental module (D.M.). Currently the developmental module contains a lateral stress cell, a friction sleeve load cell and a pore pressure sensing element. This developmental module is designed to be replaced by other modules which, for example, might measure thermal conductivity or resistivity, or specific ion concentration or conductivity or even take a water sample, etc. Thus, the D.M. could be changed according to the information required. Also, as different or new parameters become of interest, they could be investigated as part of the D.M.

The pressuremeter element follows immediately behind the D.M. and is, in turn, followed by the pressure developer and its controller. The expanding pressuremeter has a stainless steel Chinese lantern type protective covering. Only a very small, repeatable pressure should be needed to expand the pressuremeter at zero soil resistance in order to have sufficient sensitivity in soft soils. Sensors within the pressuremeter include expansion pressure, three radial displacement arms, and pore pressure. The pressure developer pumps fluid into the pressuremeter and is controlled to run constant strain rate, load increment, variable load or variable displacement tests, all under a computer controlled feedback system.

A fluid pressure test chamber is currently being built to submerge the entire seismic cone pressuremeter to calibrate it over a range of external fluid pressures to 7.5 MPa at various temperatures from 0° to 30°C.

Some of the design problems yet to be resolved and requiring additional research include:

1. Optimum length of pressuremeter module.
2. Optimum location of the pressuremeter module with respect to the tip and the rear adapter where rod area decreases.
3. Optimum radial strain rate and capacity.
4. Effect of creep deformations during pressuremeter testing.
5. Development of a seabed seismic shear source.

The design of the seismic cone pressuremeter will emphasize ease of maintenance such that any module could be replaced in the field. For example, the D.M. could be easily replaced or changed without requiring disassembly of other modules. Thus, each module could have a back-up. Replacement of the entire tool would not be necessary if part of a module malfunctions. Also the P.M. module is being designed so it can easily be disassembled, cleaned and reassembled after each sounding.

OBJECTIVES

The development of a tool which incorporates many sensors and tests in one device, is driven by the needs of offshore in-situ site investigations where the very high mobilization and daily support costs make such a tool both cost effective and viable. The objective is to obtain as much stratigraphic detail and as many geotechnical parameters as possible in one sounding and for all soil types encountered.

As a logging test the Piezo-cone will give detailed stratigraphy and empirical estimates of angle of friction, undrained shear strength, over-consolidation ratio and moduli. As a specific test the FDPM may yield measurements of lateral stress, angle of friction, undrained shear strength, large strain shear modulus and stress strain behaviour. The P and S wave seismic tests could yield measurements of small strain shear modulus and Young's modulus with an indication of damping characteristics for the sediments as well as possible gas content within the void space of the soil.

As can be seen from the conceptual design, the proposed instrument has a large measure of built-in redundancy. This redundancy allows the measurement of the same parameter by several methods in order to evaluate repeatability, accuracy, resolution and ease of interpretation. For example, the lateral stress cell in the D.M. should agree with the lift-off pressure for the pressuremeter. The pore pressure on the D.M. should closely correlate with the pore pressure at the P.M. The 3-point radial displacement in the P.M. should closely correlate with the volume change measured at the pressure developer (P.D.). Once the characteristics of the redundant measurements are understood for different soils and test procedures, the design will be optimized. The ultimate device will likely have little, if any, redundancy, be considerably simpler and easily adaptable to onshore site investigations.

Probably, the most significant advantage of having a multi-measurement tool with built-in redundancy is to be able to obtain a full range of correlation data for various sensors in the same soil or soil layer in the same 'hole'. This is potentially of great importance since in in-situ testing we do not have the luxury of knowing the "correct" value and must rely on correlations with large chamber tests, lab tests or other in-situ tests. The correlations obtained by this development tool at well documented field research sites should provide a higher degree of confidence and add immeasurably to the calibration of in-situ test tools for reliable interpretation of in-situ soil behaviour.

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