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SYNOPSIS As engineering moves into deeper waters, measurements of soil properties in the laboratory may be highly suspect if the soils are gassy. Strength and pore-pressure data are presented and discussed. A suggestion is made for development of pore-pressure gauges to detect the presence of clathrates.

INTRODUCTION

Conventional methods of sample recovery and laboratory testing have possibly severe limitation in deepwater geotechnical engineering because of the apparently widespread existence of gasses in marine soils. The gasses expand because the pressure decreases as the sample is raised to the surface. The result is usually a sample expanded into a platey macrostructure like vermiculite. For example, such behavior was observed at Hole 6021 of the U.S.G.S. AMCOR project in 1976 (Hathaway, et al, 1979), where gas concentrations in excess of 400,000 ppm were measured in samples extracted from the voids between the expanded pieces of soil in the sample tube. The water depth was 1,000 ft, and the boring penetration was an additional 1,000 ft. The shipboard and laboratory nonremolded vane-shear strengths are shown in Fig. 1. Also shown are the results of three consolidated-undrained (CU) triaxial tests, and the range of likely strengths to be expected if the soil were normally consolidated (NC). If those measured shipboard and laboratory vane-shear strengths are correct, the area should be actively sliding on a plane at a sediment depth of 200 to 250 ft if the slope inclination is greater than about 1 or 2 degrees. The overall slope of the area is about 10 degrees, with local slopes as steep as 25 to 30 degrees. Thus, it appears that the measured strengths are too low, and by a substantial margin.

It is likely that, for gassy soils in very deep waters, the soil strengths measured on shipboard or in the laboratory will be controlled by the effects of expanding gasses rather than by the in-situ strength. Such situations are particularly critical to earthquake engineering and soil dynamics because it is not generally known whether or not the effects of gas expansion on measured properties are on the conservative side for dynamic response analyses. Therefore, as earthquake engineering moves into deeper water, it appears that better methods will have to be developed to determine soil properties.

One way to decrease the uncertainties of the situation is to determine the soil properties in-situ, acquiring samples only for water-content and index testing. Mitchell, et al (1978) have published an excellent summary of the present state-of-the-art of in-situ testing. The principal differences between in-situ testing in deeper waters, as opposed to shallow water or onshore, are: 1) the high-pressure environment; and 2) the gasses present. The high pressures impose obvious instrumentation problems: e.g. measuring an excess pore pressure of perhaps 10 psi at the bottom of AMCOR 6021, Fig. 1, where the ambient pressure is about 1,000 psi. It is assumed that those problems will be solved by instrumentation people. The purpose of this paper is to discuss the nature and effects of the gasses on the pore pressures and soil strengths.

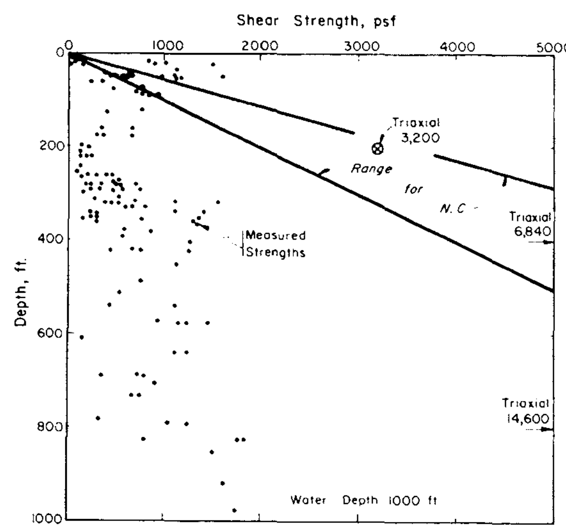

Fig. 1. Strength Data from AMCOR 6021
Water Depth = 1,100 ft
• Laboratory miniature vane and Torvane, from Richards (1977)
● CU Triaxial, from Swanson, et al (1977)

PORE GASSES

Pore gasses come mostly from local decay of organic matter, and methane is by far the most abundant gas in almost all the samples analyzed (Claypool, et al, 1974). These gasses can exist in several phases, depending on the temperature, pressure, and concentration of gas: 1) dissolved gas; 2) bubbles of gas; 3) clathrates; 4) in ice; and 5) combinations of the above.

Dissolved gas should have no effect on the in-situ soil properties; but it will have considerable effect on the laboratory soil properties if its in-situ concentration is greater than the solubility at the temperature and pressure conditions in the laboratory.

Bubbles of gas have the effect of raising the pore pressure, thus weakening the soil in-situ. The cyclic and dynamic behavior of soils with bubbles in their pore water are probably quite important to earthquake engineering, but they have not been extensively studied. The clathrate form of gas is less well known because marine clathrates normally exist only in waters deeper than those in which offshore construction and earthquake engineering have taken place. It is expected that construction will be undertaken in the next decade in areas where clathrates are likely to be found, so the important properties of clathrates will now be discussed briefly.

When the temperature is low or the pressure is high, or both, water in the presence of certain gasses will arrange its molecules in a crystalline structure, surrounding and capturing the gas molecules in a cage-like configuration.

We have not been able to find the results of any experiments on soils whose pore waters were in the clathrate state. Thus, we conclude that nothing is known about the fundamental static, cyclic, or dynamic properties of soils containing clathrates. The pressure-temperature conditions for formation of methane-seawater clathrates are given in Fig. 2. The vertical line represents the freezing phase of water: any situation to the left of that line will include ice. The diagonal line represents the clathrate phase: if there is adequate gas available, any situation above that line will include clathrate. Thus, at a soil temperature of 2°C, methane clathrate can form at about 33 atmospheres, or about 1,100 ft of seawater or seawater and sediment.

The clathrate is capable of holding much more methane than could be held in solution in water. Thus, when the clathrate decrystallizes due to a reduction in pressure, or an increase in temperature, or both, there is an effervescence as the excess methane comes out of solution. If the clathrate is in a closed system during this process, the resulting pressures can be very high (e.g., 100,000 psi, Hunt, 1979).

It would appear desirable to know if the pore gas is in the clathrate phase in-situ. Thus, there is need for a device to detect clathrates. One such device is suggested in Fig. 3. It is a wire-line piezometer with a temperature sensor and a micro-heater. When used with the heater off, the pore-pressure response will be the typical peak-and-decay shown by the solid line in Fig. 4. Then, when the heat is applied: 1) if no clathrates are present, there should be a small increase in pore pressure caused by thermal volume changes in the relatively closed system around the tip; or 2) if clathrates are present, the heat should decrystallize them locally to release the bound gas, thus sharply increasing the pressure in the relatively closed system around the tip.

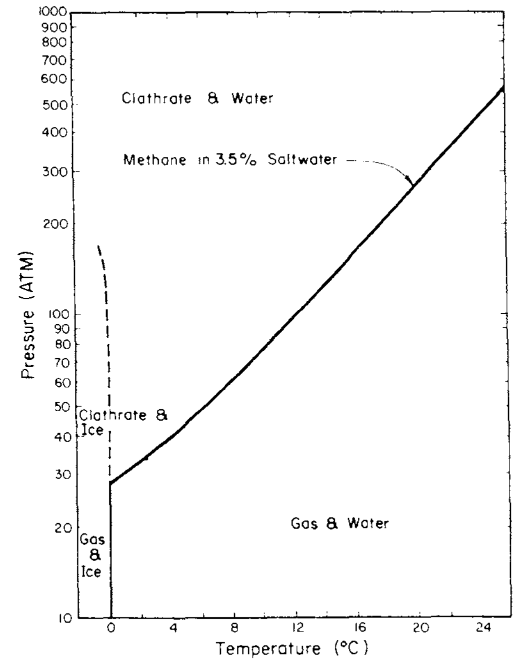

Fig. 2. Pressure-Temperature Phase Diagram for Methane-Seawater System
From Claypool, et al (1974)

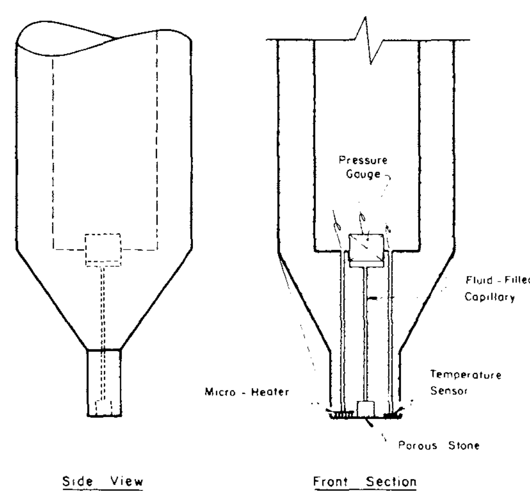

Fig. 3. Suggested Clathrate Detection System - Sandia National Laboratories

PORE PRESSURES

Two in-situ pore pressures are of interest to the geotechnical engineer: 1) the shearing pore pressure, U_s, generated by the insertion of the piezometer; and 2) the formation pore pressure, U_o, which is in excess of the hydrostatic pressure. A typical in-situ measurement of pore pressures in a soft clay is given in Fig. 5. The pressures shown are differential; that is, the excess over hydrostatic.

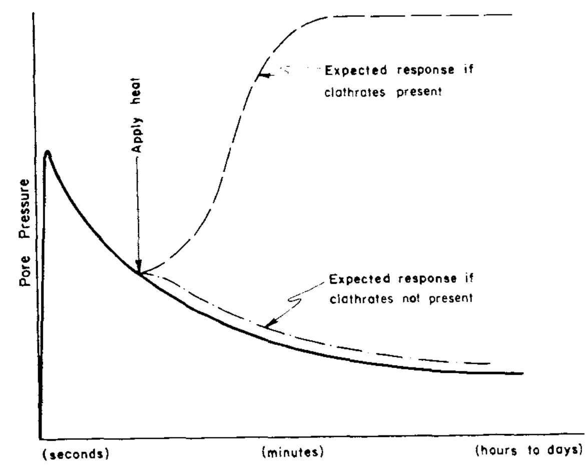

Fig. 4. Expected Response of Clathrate Detection System

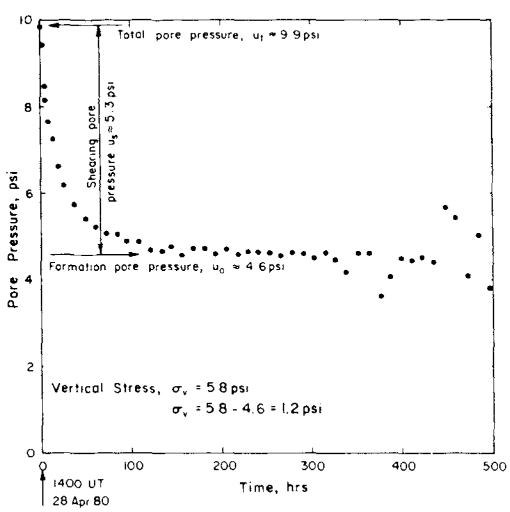

Fig. 5. Pore-Pressure Measurement

- Sandia National Laboratories GISP Device
- Location: South Pass, Block 28
- Water Depth = 44 ft
- Penetration = 31 ft

It took about 120 hr. for the pore pressure to stabilize to the formation value. The piezometer probe in this case was 3.25 in. in diameter. The stabilization time can in principle be reduced by reducing the probe diameter. For example, Wissa, et al (1975) report stabilization times of about 10 hr. in soft clay, using a piezometer probe with a tip diameter of about 1/2 in. Clearly such long stabilization times are unreasonable for borehole determinations, because of drillship costs. For this reason, formation pressures are not usually determined in borings, and it is therefore not usually possible to calculate the in-situ effective stress. This informational deficiency could be remedied by development of piezometers which decrease the pore-pressure dissipation time.

To allow waiting-out the dissipation times, multi-point piezometer probes have been developed, Dunlap, et al (1978). Such probes are inserted into soft clays using dead weights, so that their useful penetrations have been limited to a few tens of feet (e.g., 30-50 ft). The pore-pressure readings are transmitted by hard wire to a structure at the surface for recording. This has limited their use to areas where structures already exist, rather than use in frontier areas where data are lacking. To address this situation, Sandia National Laboratories developed a basic marine instrumentation system, Reece, et al (1978). The microprocessor-based system stores data accumulated over a period of time (e.g., a few weeks), and transmits the data acoustically on command to a small boat on the surface. In a paper presented at this conference, Reece et al (1981), describe the use of the basic system to measure seafloor earthquake motions. One configuration of the system for short- or long-term measurements of pore pressures offshore is shown in Fig. 6. In

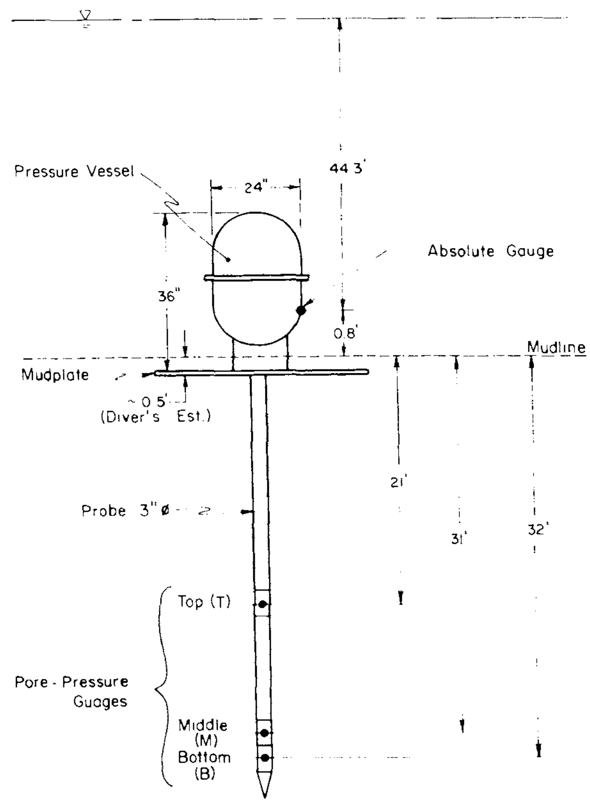

Fig. 6. Basic Marine Instrumentation System Configured for long-term pore-pressure measurements

this configuration, the 3.25-in probe was 33 ft long, and was provided with three pore-pressure gauges. The user can choose the probe diameter and length, and the type and number of pore-pressure gauges to suit the particular engineering or geologic situation.

The pressure vessel contains a microprocessor with signal-conditioning and storage electronics, and the batteries. The experimental model shown in Fig. 6 is capable of operating in water depths up to 1,000 ft. The mudplate on the configuration shown is 5 ft in diameter.

The data of Fig. 5 were acquired with the instrument of Fig. 6. The pore pressures during insertion were also acquired. These are shown in Fig. 7. The stones of the top and middle

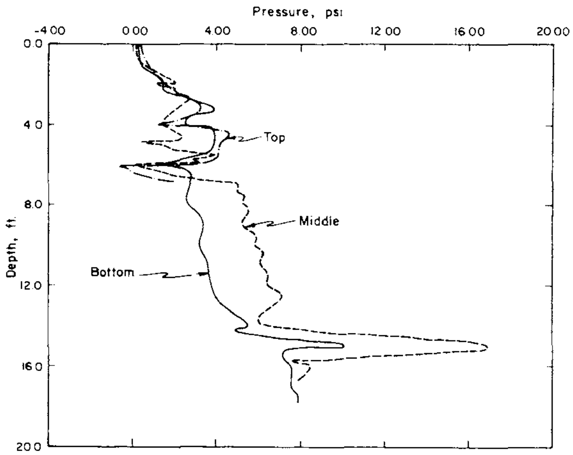

Fig. 7. Insertion Pore Pressures
- Sandia National Laboratories GISP Device
- Location: South Pass, Block 28
- Water Depth = 44 ft.

gauges were high-permeability corundum, but the stone of the bottom gauge was low-permeability ceramic. Thus, the time constant of the bottom gauge is substantially higher than those of the other two; and, for this transient situation, it therefore under-reads slightly. The data-acquisition system was programmed to a high data rate (10 rdgs/sec) for the first 210 sec, and then to 1 rdgs/sec. Due to delays in the operation, the readings went to the slower rate while the insertion was still in progress. Thus, the insertion data are partial for this experiment.

The insertion data, Fig. 7, show zones of higher permeability at 4 ft and 6 ft, as indicated by the drop in pore pressures at those depths. The log of a nearby boring, (Fig. 8), reports "faint laminations" at 4 ft and at 6 ft. The most interesting things about these data, however, are: 1) the gradual increase in pore pressure with depth, below about 9 or 10 ft (the gauges are differential to cancel the hydrostatic pressure); and 2) the large increase in pore pressure from 14 to 16 ft.

If the soil were sensibly uniform over these depths and if the formation pore pressure were zero, the pore-pressure readings are expected to be about constant, except for layers or lenses of lower permeability (e.g., 4, 6 ft). The log of the nearby boring, Fig. 8, also notes "possible flow-in disturbance", and "some gas" in the zone 14-16 ft. On this basis, it is hypothesized that: 1) the pore-pressure increase from 14-16 ft represents a gassy zone; and 2) the gradual increase in pore pressure with depth below 9 or 10 ft represents a gradual buildup of gas with depth, perhaps by permeation

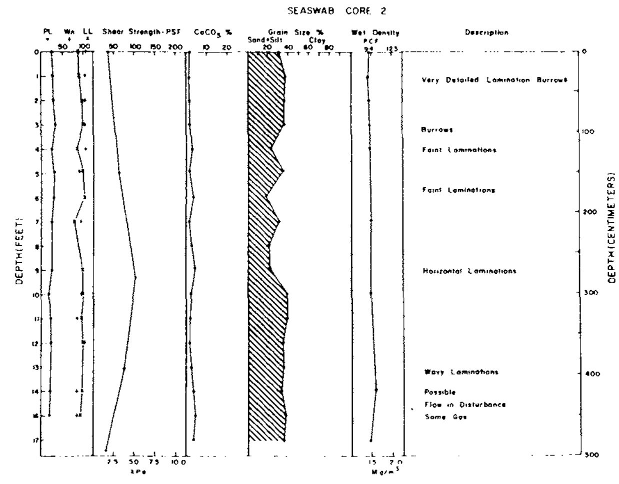

Fig. 8. Log of Boring Adjacent to Fig. 2
- from Hottman, et al (1978)

from the gassy zone at 14 to 16 ft. Thus, it appears that such a pore-pressure probe, if read during insertion, is capable of detecting and defining gassy zones, provided it can be determined that the supposed gassy zone is not significantly lower in permeability than the adjacent overlying materials. It appears that there is a need to develop a device which can detect when the gas is in the bubble state.

CLOSURE

The effects of gasses, especially in deeper waters, destroy the integrity of soil samples raised to the surface. It appears that in-situ methods will have to be developed. The in-situ methods should include instruments for determining the concentrations and phases (dissolved, bubbles, clathrates, frozen, combinations), of the gasses.

Fundamental work needs to be done on the static and dynamic properties of gas-bubble-charged soils, and of soils with clathrate pore fluids.

ACKNOWLEDGEMENTS

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