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Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Westinghouse
Hanford Company Richland, Washington

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ABSTRACT

A new tool is being developed to characterize tank waste at the Hanford Reservation. This tool, known as the cone penetrometer, is capable of obtaining chemical and physical properties in situ. For the past 50 years, this tool has been used extensively in soil applications and now has been modified for usage in Hanford Underground Storage tanks. These modifications include development of new "waste" data models as well as hardware design changes to accommodate the hazardous and radioactive environment of the tanks. The modified cone penetrometer is schedule to be deployed at Hanford by Fall 1996.

At Hanford, the cone penetrometer will be used as an instrumented pipe which measures chemical and physical properties as it pushes through tank waste. Physical data, such as tank waste stratification and mechanical properties, is obtained through three sensors measuring tip pressure, sleeve friction and pore pressure. Chemical data, such as chemical speciation, is measured using a Raman spectroscopy sensor. The sensor package contains other instrumentation as well, including a tip and side temperature sensor, tank bottom detection and an inclinometer. Once the cone penetrometer has reached the bottom of the tank, a moisture probe will be inserted into the pipe. This probe is used to measure waste moisture content, water level, waste surface moisture and tank temperature.

This paper discusses the development of this new measurement system. Data from the cone penetrometer will aid in the selection of sampling tools, waste tank retrieval process, and addressing various tank safety issues. This paper will explore various waste models as well as the challenges associated with tank environment.

INTRODUCTION

BACKGROUND

Hanford was the site of a weapons grade plutonium production plant built during World War II as part of the Manhattan project. Since the plant stopped production in 1989, the mission at Hanford has shifted from weapons production to cleaning up the waste generated from such activities. The by products from the generation of weapons were stored in 149 single shell tanks and 28 double shell tanks. These tanks, located underground, were built to hold over 1 million gallons of hazardous and radioactive waste. Some of these tanks are as large as 70 feet in diameter and 50 feet in depth. Over time, some waste by-products have been reprocessed to reduce their volume, thus increasing the availability of tank storage room. Even though records were maintained on the materials originally stored in these tanks, the actual chemical/physical composition is mostly unknown.

Several methods are being implemented to characterize these unknown waste compositions, including core sampling and the use of in-tank instrumentation. Drilling core samples from the contents of the tank and sending these samples to laboratories for analysis is the standard method for obtaining certain chemical and physical data. In-tank instrumentation includes systems which gather temperature, liquid level and other measurements. Unfortunately no single method can obtain all the information required for safely remediating the tank waste. Since no one method is available, several methods are being considered to obtain all the needed data. One of the most promising methods uses the cone penetrometer to obtain chemical and physical properties data.

INSTRUMENT GENERAL DESCRIPTION

The cone penetrometer consists of an instrumented metal rod which is pushed through a material. The rod is supported by a guide tube which provides structural support to the rod. The rod is assembled by screwing hollowed rod sections into the instrumented tip as it is pushed, and penetrates the material. The basic instrument package consists of sensors to measure tip pressure, pore pressure and sleeve friction. Load cells at the tip (tip pressure) measure resistance of the materials ahead of the tip while side load cells (friction sleeve) measures the friction as the cone pushes into the material. Filtered hydrostatic pressure (pore pressure) is obtained using a sensing device also located within the tip. Classification charts are then generated by measurements taken from these three sensors. These charts are typically used to determine the type of soil or material being penetrated. Figure 1 depicts a typical data plot generated from a push through different soil types.

Other devices may be attached to the basic cone penetrometer by repackaging the tip, lowering another sensor down into the rod, or by a special rod tip. Many in-situ sensors are already available for the cone penetrometer, sensors to measure temperature, shear modulus, soil density, viscosity, pH, chemical species, moisture, radiation, hydrocarbon and resistivity. Resistivity measurements are used to determine the location and depth of groundwater. The resistivity probe has two electrodes mounted on an insulated sleeve above the cone. These two electrodes measure soil conductivity (resistivity) by passing an electrical current between them. Since mineralized water is very conductive, the sensor is ideal for locating water. Soil, gas and water samplers can also be attached to the rod by unscrewing the traditional tip and replacing it with a sampler tip.

Originally, cone penetrometers were developed for soil applications such as locating firmer soils in sea locked countries like the Netherlands. Since then, cone penetrometers have been used in soil identification, soil physical parameter determination, accessing soil bearing capacities and site characterization. Modern versions have the additional capacity of measuring physical and chemical characteristics without removing samples from the ground. Other capabilities include grouting of boreholes produced after samples have been taken. Grouting the boreholes is necessary to avoid introducing contaminants from the surface to possible aquifers.

BODY

HANFORD CONE PENETROMETER DEVELOPMENT

Hanford tank waste is a mixture of sludge and saltcake materials. The Hanford skid mounted cone penetrometer system will be capable of penetrating these tank waste materials to obtain physical and chemical data. Sludge waste is a very weak material while saltcake waste can be very hard. The data which will be obtained by the cone penetrometer includes: shear strength, compressive strength, yield stress, waste stratification, chemical speciations, and moisture. These derived measurements are in addition to the direct measurements of tip stress, sleeve friction, pore pressure, tip and side temperature, inclination, bottom detection, and waste tank temperature. Figure 2 shows a schematic of the probe.

Shear strength, compressive strength and yield stress are physical properties needed for the safe retrieval of tank waste. Knowledge of waste stratification profiles will aid other existing sampling tools in the tanks since it identify the material penetrated. From this information, the appropriate sampling mode can be selected. The sampling modes include the usage of auger, push mode or rotary core samples. The "hardness" of the sampled material can affect the recovery rate of these systems. Chemical speciation data will be used to determine the waste compatibility issues during the retrieval/processing of the waste. Moisture and tank temperature are required to answer many tank safety questions.

The operation of the skid mounted cone penetrometer is straightforward. As the tip of the cone penetrometer is lowered into the tank, information about chemical and material properties will be sent back to an on-board computer and analyzed. The computer, as well as the signal conditioning and processing equipment, is located in specially design skid on the tank. Once the tip reaches the desired location in a tank, such as the tank bottom, cables leading to the sensors in the tip will be removed to allow room for other instruments. A moisture sensor, for example, can be lowered with a winch to obtain the moisture content of the surrounding tank waste material. Once all data have been obtained, the cone penetrometer rod is removed from the tank.

Hanford tank waste presents an unusual challenge to instruments like the cone penetrometers. Tank interiors can only be accessed through risers protruding out of the top of the tank. Risers are pipes which are used to reach the tank interiors. Tank contents are not easy to sample since the waste contained within the tank is both hazardous and radioactive. As the cone penetrometer lowers its rod and guide tube down the riser, they will be unsupported until the waste is reached. The guide tube will provide structural support to the push rod as the push rod penetrates the waste. Due to the possibility of buckling, operating loads will be limited after completion of stress analysis and structural testing completion. In typical soil applications, the soil usually supports the cone and rod as it is lowered.

Other challenges pertain to the tank structure itself. The tank tops have limits to their load capacities. Cone penetrometers achieve the necessary reaction force to push the rod down into the soil by either anchoring the cone penetrometer support structure in the surrounding soil or by ballasting the support structure with the necessary weight. Since anchoring the cone penetrometer support structure onto the tank is not feasible, ballasting weight on the skid must be used to achieve the necessary reaction force to penetrate the waste within the tank. This reaction force is limited by the total weight which the top of the tank can withstand without failure. Dome loading limitations at Hanford tanks varies depending on the equipment loading and soil loading. The maximum reactive force which the cone penetrometer will be capable of exerting on the tanks will be 30 tons.

Another structural problem unique to the tanks is how to determine where the location of the bottom of the tank. Since chemical reactions have occurred within the Hanford tanks for decades, the bottom of the tank may be bowed due to the high heat associated with the reactions of the waste. Tank bottoms have also corroded with time. To compensate for these problems, an operational envelop limiting the forces applied to the bottom of the tank as well as a bottom detection system are being developed. The cone penetrometer bottom detection system is a magnetometer sensor which will stop the rod once the sensor has detected the bottom of the tank. The magnetometer detects the tanks ferrous material. Test indicate that the bottom of the tank can be measured within a feet of a steel plate. The closer the magnetometer is to the steel bottom, the stronger the signal. This new sensor has the potential of being used in other applications such as locating pipes and other ferrous structures in the soil applications.

DATA MODELS

Since the cone penetrometer has never been tested in Hanford type waste, waste simulants were developed to simulate the materials in the tank, such as salt cake and sludge. Tank waste mechanical properties were determined by empirical formulations based on soil theory. For each simulant, a waste classification chart was developed as a calibration guideline for future usage to determine what kind of the material the cone penetrometer was penetrating. Other data obtained during simulant testing included pushing requirements of the system.

Salt cakes and sludges are the major components of the tank waste.

Salt cake can be hard as cement while sludge can have the consistency of clays. The cone penetrometer must penetrate through both of these components to gather data on physical properties. The physical properties of interest were sludge yield strength, sludge shear strength and saltcake compressive strength. These measurements were obtained from tip pressure, sleeve friction, and pore pressure sensors. Waste classification charts were developed and are depicted in the Appendix.

The physical properties soil models used to develop the correlations between mechanical properties and the cone penetrometer sensor readings were based on the spherical cavity model. Estimates for the sludge shear strength employed the following equation:

$$\tau_{peak} = (q_t - \sigma_{vo}) / N_{kt}$$

where q_t = cone bearing (bearing force/bearing area)

σ_{vo} = overburden pressure (density of the material times the depth). In materials with 3 psi or less of shear strength, pore pressure over differential depth can be used.

N_{kt} = Cone factor (generally obtained from empirical correlations). In clays, it is normally between 10 and 20

The empirical correlations based on the test results were the following:

Yield strength	$\sigma_y = (q_t - \sigma_{vo}) /34$
Shear strength	$\tau = (q_t - \sigma_{vo})/15$
Compressive strength	$\sigma_c = .2\ q_t - 137$

These models were only valid for the simulants tested. The simulants were two clays for sludges (Kaolin and Bentonite) and K-Mag (a fertilizer or cattle supplement) for saltcake. All these materials are non-hazardous. Further testing will be completed so that the different waste types are classified and the accuracy of the instrument is accessed.

The test results indicate that the simulants occupied distinctive areas in the waste classification charts. The appendix shows the differences in the tip stress profiles and sleeve stress profiles. A preliminary waste classification chart has been created in which the weak sludges and strong saltcakes are displayed.

MOISTURE PROBE

The moisture probe is lowered in the cone penetrometer push rod inner diameter and programmed to automatically take readings every inch for 10 to 50 seconds. The testing results have shown that the surrounding 6 inches of material can be effectively measured. The technique used to measure moisture is through neutron thermalization. This techniques has been used in other applications to measure moisture on soil surface and within oil-logging holes. Neutrons are emitted by a source, Cf-252 source, in this case, onto the material of inspection. The source neutrons scatter and lose some energy. Neutrons lose most of its energy when scattering from a hydrogen nuclei (proton) because it has the same mass. Neutrons scatter several times and eventually slow down to thermal energies. A thermal neutron sensitive detector, located near the neutron source, detects source neutrons which become thermalized by the hydrogen within the waste and scatter back to the detector. The more water present, the more hydrogen and the greater the count rate in the thermal neutron detector. The count rate is correlated to moisture content in waste material. This technique is sensitive to the amount of hydrogen in waste, it is also sensitive to the amount of organic which contain hydrogen.

CONCLUSION

The cone penetrometer is scheduled to be deployed in the Hanford waste sampling process in 1996. This system will join several other measuring systems currently being used to characterize tank waste. Cone penetrometer usage in the tanks represents a new application that deviates from its traditional uses in soil analysis. For tank waste, the cone penetrometer will acquire physical and chemical waste properties required for remediation and processing as well as the resolution of tank safety questions.

ACKNOWLEDGEMENT

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NOMENCLATURE

q_c cone bearing
σ_{vo} overburden pressure

N_{xc}	Cone factor
σ_y	Yield strength
τ	Shear strength
σ_a	Compressive strength

APPENDIX

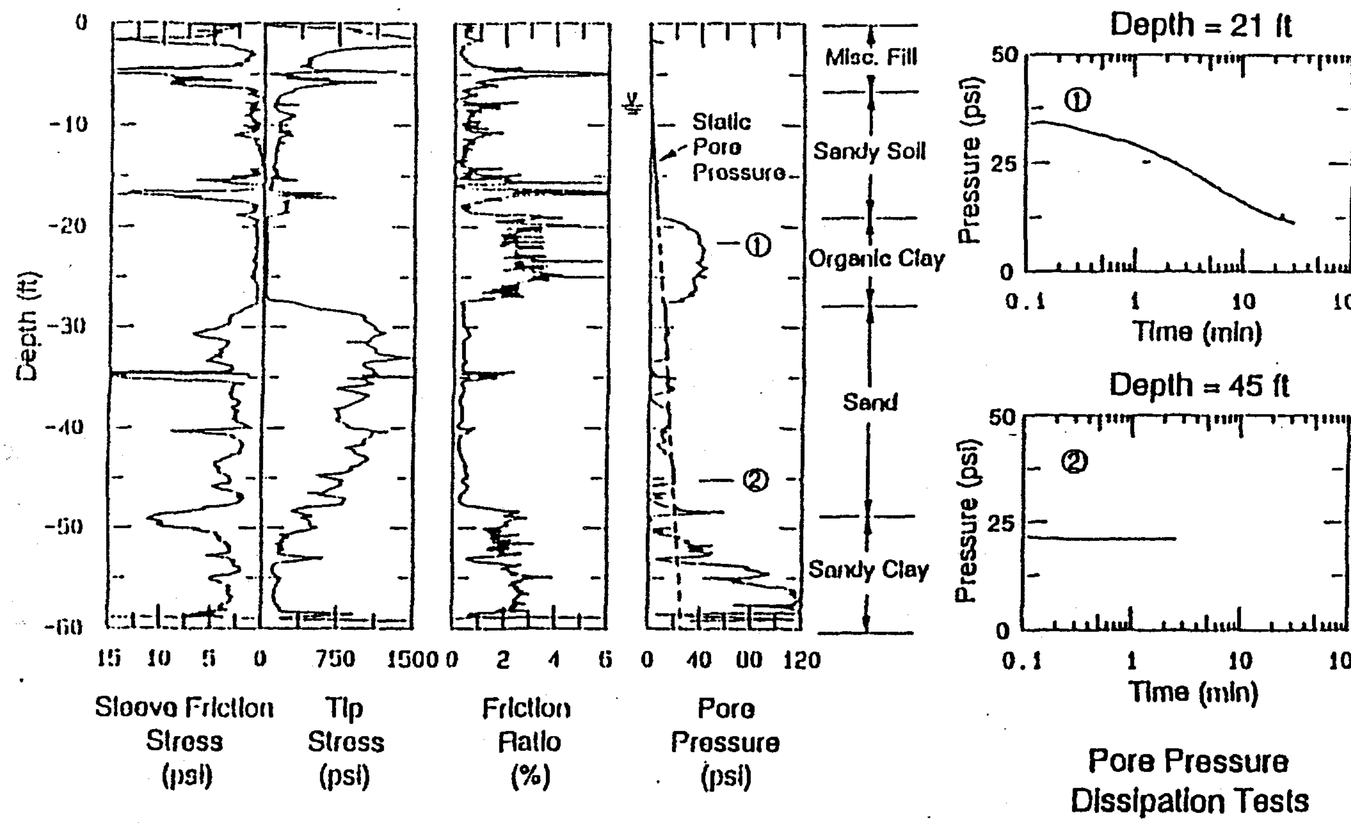


Figure 1: Typical Soil Cone Penetrometer Data

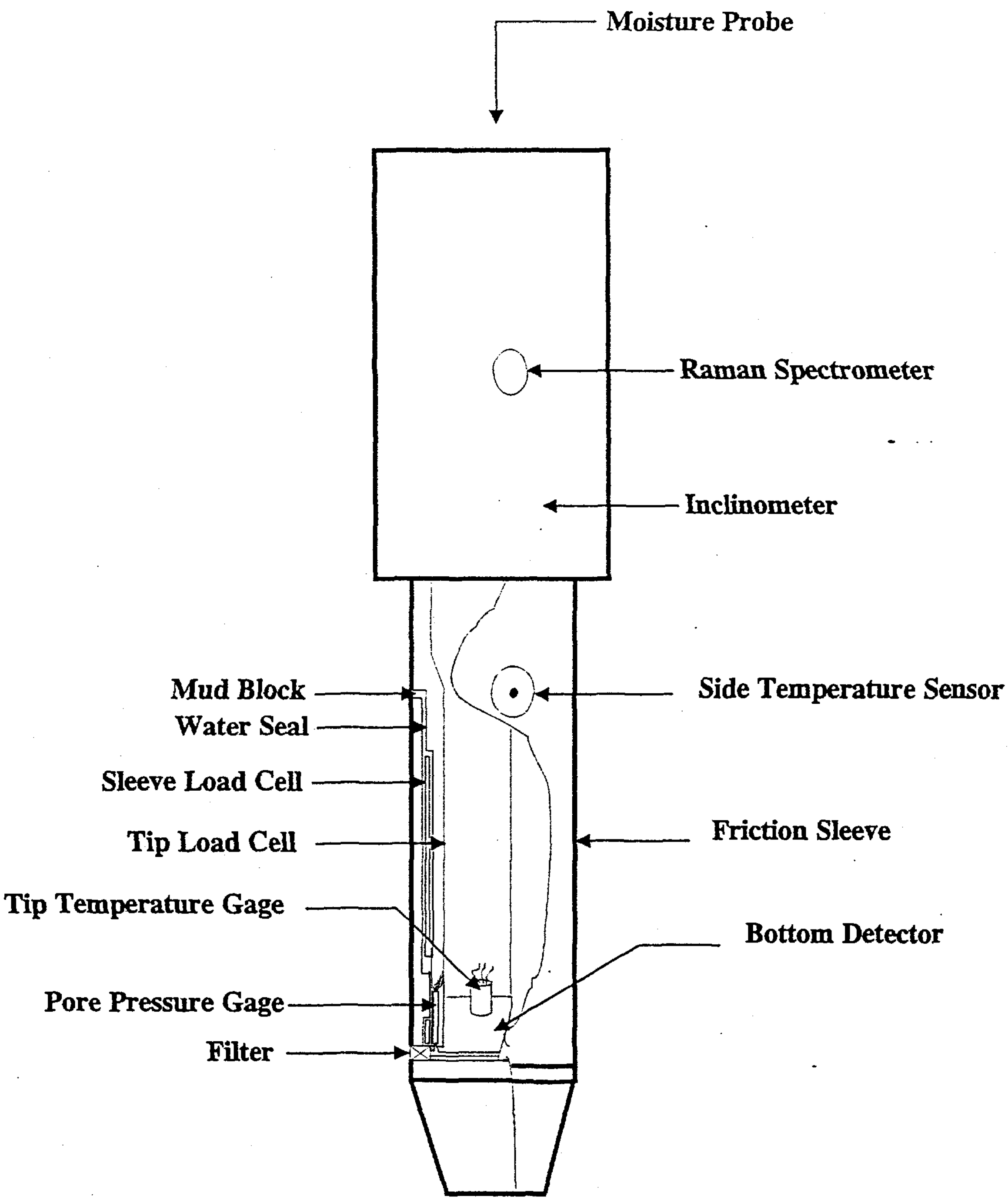
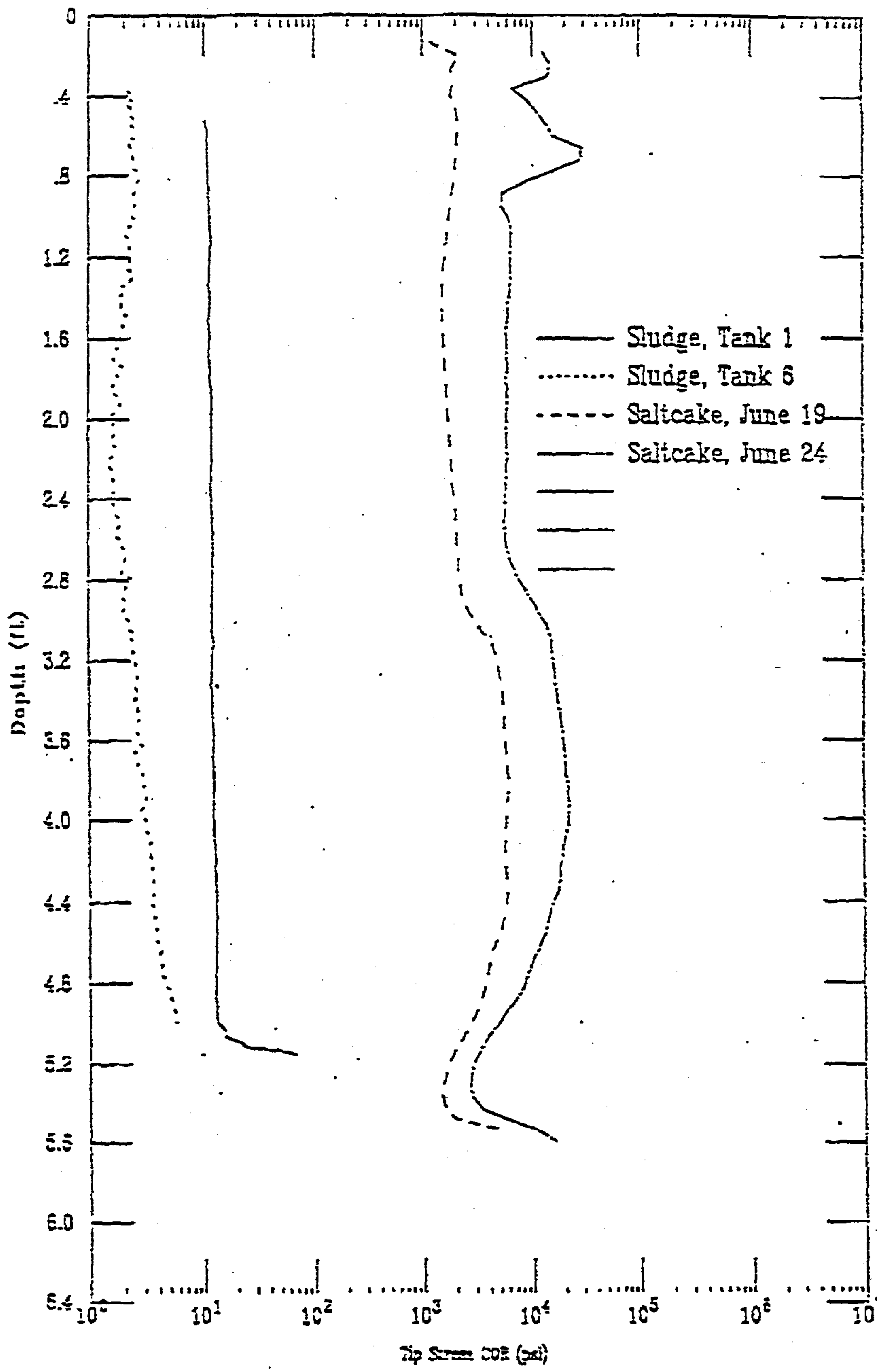
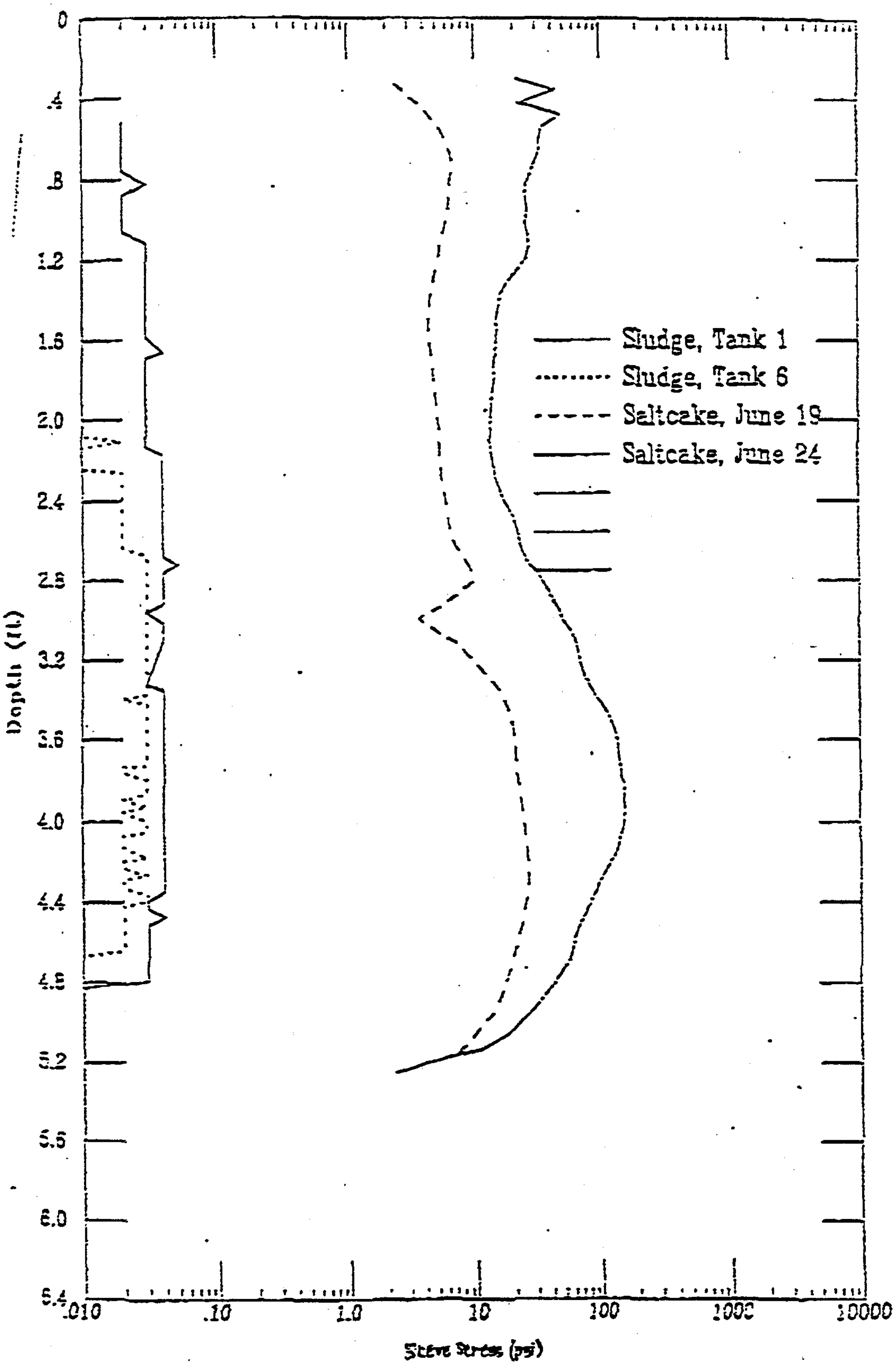


Figure 2: Cone Penetrometer Sensor Tip Schematic

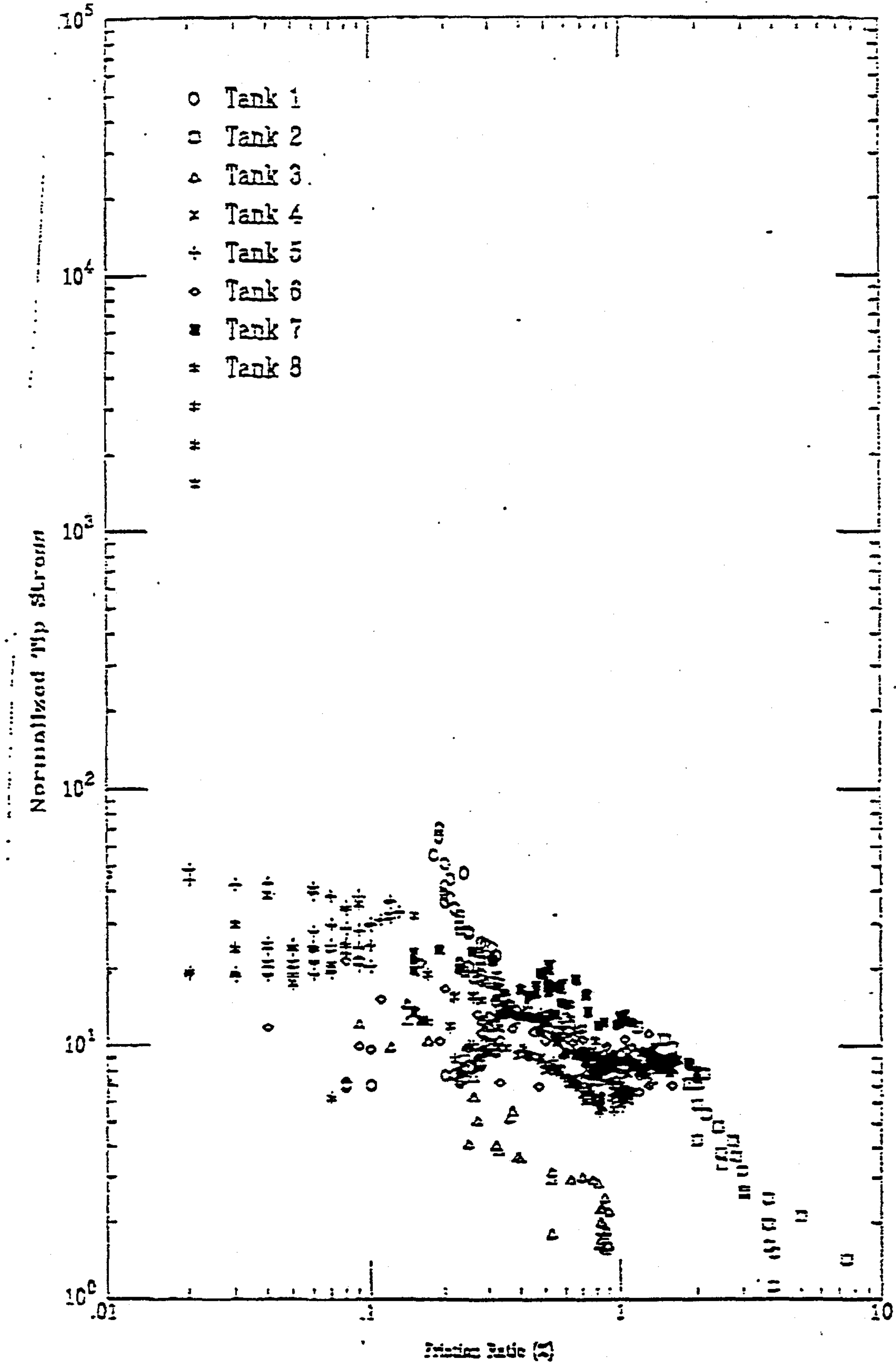
TIP STRESS PROFILES - SLUDGES AND SALTCAKES



SLEEVE STRESS PROFILES - SLUDGES AND SALTCAKES



SIMULANT CHARACTERIZATION - SLUDGES



SIMULANT CHARACTERIZATION - SALTCAKES