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TECHNICAL REPORT GL-82-8

THE PQS PROBE: SIMULTANEOUS MEASUREMENT OF PENETRATION RESISTANCE AND PORE PRESSURE

by

Stafford S. Cooper, Arley G. Franklin

Geotechnical Laboratory

U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

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20. ABSTRACT (Continued).

be both reliable and to provide consistent results. The evidence of this and earlier studies by other investigators indicates that induced pore pressures are linked to soil properties or conditions, rather than being controlled by test procedures.

PREFACE

This work was performed for the Office, Chief of Engineers (OCE), U. S. Army, under CWIS Work Unit 31619, "Development of a Technique and/or Device to Evaluate the Liquefaction Potential of In Situ Cohesionless Material," for which Mr. R. R. W. Beene was the OCE Technical Monitor.

The work was carried out by Mr. S. S. Cooper of the Field Investigations Group (FIG) and Dr. A. G. Franklin, Chief of the Earthquake Engineering and Geophysics Division, Geotechnical Laboratory (GL), U. S. Army Engineer Waterways Experiment Station (WES). The study was performed under the general supervision of Dr. W. F. Marcuson III, Chief, GL. This report was written by Mr. Cooper and Dr. Franklin.

COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE, were Commanders and Directors of WES during the period of this study. Mr. Fred R. Brown was Technical Director.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
feet	0.3048	metres
inches	2.54	centimetres
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms
tons (force) per square foot	95.76052	kilopascals

THE PQS PROBE: SIMULTANEOUS MEASUREMENT OF
PENETRATION RESISTANCE AND PORE PRESSURE

PART I: INTRODUCTION

Background

1. The cone penetration test (CPT), originally developed in Europe, has gained wide acceptance as a cost-effective means of determining soil stratigraphy and soil strength parameters. In Belgium and Holland, where soft soils generally prevail, CPT has been used for almost 50 years as the most popular means of subsurface exploration, often to the exclusion of other methods. However, acceptance in the United States has been limited due to the physical limitations of the original system and the belief that the standard penetration test (SPT) was a more useful tool. The relatively recent development of the instrumented electric probe for use in CPT has dispelled most of the early reservations and has introduced a versatile new tool for geotechnical exploration.

2. The design and use of pore pressure measuring devices, referred to as piezometer probes, was first detailed at the American Society of Civil Engineers (ASCE) Specialty Conference on in situ measurement of soil properties in Raleigh, N. C., in 1975.*,** The ability of the piezometer probe to assist in determining detailed stratification of soils was recognized. Later, research by Schmertmann† and Baligh,

* Bengt-Arne Torstensson. 1975. "Pore Pressure Sounding Instrument," Discussion, Session 1, Proceedings, ASCE Specialty Conference on In Situ Measurement of Soil Properties, Raleigh, N. C., pp 48-54.

** A. Wissa, R. T. Martin, and J. E. Garlanger. 1975. "The Piezometer Probe," Proceedings, ASCE Specialty Conference on In Situ Measurement of Soil Properties, Raleigh, N. C., Vol 1, pp 536-545.

† J. H. Schmertmann. 1978. "Study of Feasibility of Using Wissa-Type Piezometer Probe to Identify Liquefaction Potential of Saturated Fine Sands," Technical Report S-78-2, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Vivatrat, and Ladd* presented a considerable amount of data showing the value of correlations between CPT and pore pressure data. These data, however, and the correlations made were necessarily based on CPT and pore pressure data obtained at different times and locations since the piezometer probe used measured only pore pressure.

3. The need of the U. S. Army Corps of Engineers for rapid and reliable in situ testing to determine relative density and liquefaction potential of cohesionless soils has led to the development of a probe that simultaneously measures penetration resistance, friction resistance, and pore pressures induced in the soil by the advance of the probe. The probe has been designated the PQS probe to represent the three parameters being measured: pore pressure (P), axial load on the point or penetration resistance (Q), and the shearing force on the friction sleeve (S). The design of the probe follows in external geometry the American Society for Testing and Materials (ASTM) standard for 60-degree cones.

Purpose and Scope

4. This report documents the design, construction, and initial testing of the PQS probe. Included are discussions of the design concept, detailed drawings of the prototype device, descriptions of the calibration and operating procedures used, and limited data obtained in the initial field tests.

* M. M. Baligh, V. Vivatrat, and C. C. Ladd. 1979. "Exploration and Evaluation of Engineering Properties for Foundation Design of Off-shore Structures," Report No. MITSG 79-8, Massachusetts Institute of Technology, Cambridge, Mass.

PART II: DESIGN AND DEVELOPMENT

Design Criteria

5. A primary consideration in the design of the PQS probe was the need to adopt a standardized geometry so that direct comparisons could be made with data obtained by other investigators. For this reason the PQS probe was designed to conform closely with the exterior geometry for electric cones specified in ASTM Method D 3441-79. This method calls for a 35.6-mm-diameter by 60-degree cone tip (a projected cone area of 10 cm^2) and a friction sleeve having a surface area of 150 cm^2 . Other desired PQS features included interchangeable cone tips, an easily removable friction sleeve, independent measurements of point resistance and sleeve friction, a pore pressure measurement system with good transient response characteristics, and a penetration capacity q_c of at least 300 tsf* (29 MPa). The prototype unit, shown in Figure 1, has provided the desired features and has performed well in the limited series of field tests conducted to date.

Construction Details

6. As shown in Figure 2, the prototype unit is composed of six pieces, including a mandrel, gaged housing, friction sleeve, pressure cell, cell retainer, and cone tip. The pressure cell retainer was machined from bronze, the mandrel was machined from 1141 cold-rolled (CR) steel, and the remaining parts were machined from 304 series stainless steel selected primarily for its resistance to rust and corrosion during wet storage. The gage housing provides for independent measurements of sleeve friction and point resistance and locates the pressure cell as close as possible to the porous tip in order to minimize the internal water volume and enhance transient response. The skirt of the housing

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.



Figure 1. Waterways Experiment Station PQS probe

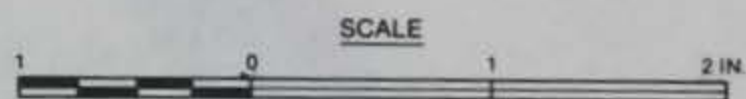
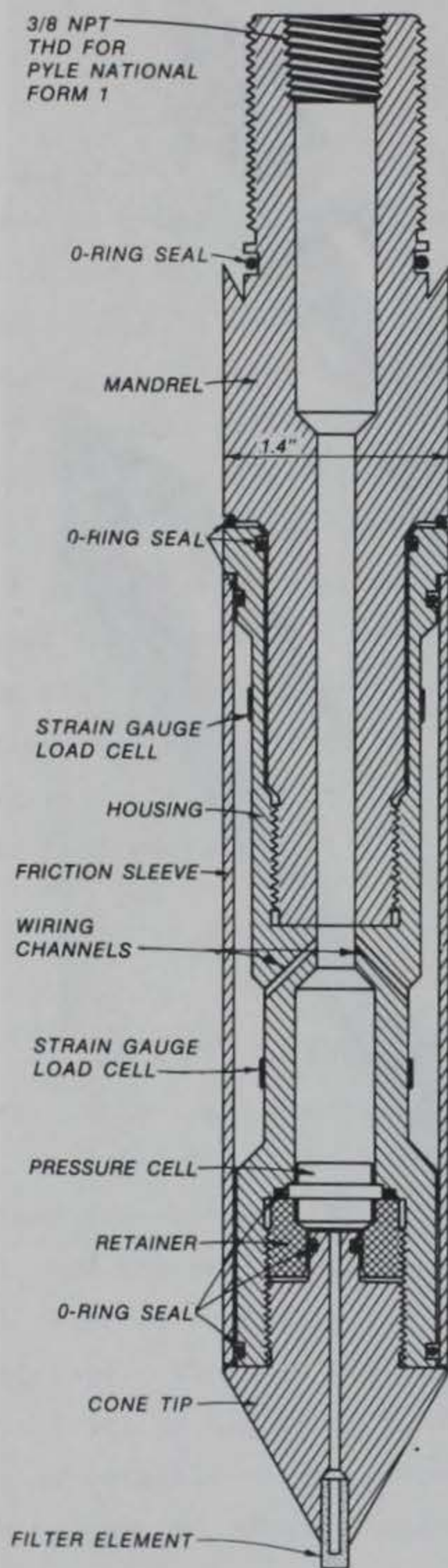


Figure 2. Cutaway view of the PQS probe

reacts to the frictional forces generated on the friction sleeve during penetration (sleeve plus exposed housing skirt surface area = 150 cm^2), and these forces are measured as tensile strain in the strain-gaged section of the housing which surrounds the mandrel. Axial forces are measured as compressive strains in the strain-gaged section of the housing immediately behind the pressure cell. Penetration loads, both frictional and axial, are transmitted to the mandrel at the flat-machined interface between mandrel and housing. Detailed drawings of the mandrel and housing are shown in Plate 1.

7. The friction sleeve is provided with sufficient clearance lengthwise so that the tip cannot transfer axial load to the friction sleeve, and sleeve "O" ring seals as well as a grease coating are used to protect the strain-gaged sections from groundwater. The interchangeable flanged tip transfers axial penetration loads directly to the machined face of the housing, and a short internal channel communicates pore pressure from the porous filter to the 150-psi (1.0-MPa) rated CEC (trade name of CEC Division, Bell and Howell) strain-gaged pressure cell. Various porous filter configurations are mounted in interchangeable tips. Stainless steel porous filter elements are readily available in pore sizes from one-half to 20 micrometres (μm), but a determination of optimal pore size(s) will depend on further evaluation. On the basis of field trials made so far, a 2- μm grade appears to be satisfactory for general use. Details of the friction sleeve, pressure cell retainer ring, and standard cone tip are shown in Plate 2. Plate 3 shows the details of alternative tips for the PQS probe.

8. All electrical wiring is brought through the center hole in the mandrel and exits the probe via a Pyle-National sealed fitting. A sealed adapter above the probe houses a cable connector, and the wiring from this connector is routed to the surface inside the jointed E-rod used to push the probe. Plate 4 gives details of the connector housing and E-rod subadapter.

9. The overall design of the probe was based on a maximum allowable stress of 20,000 psi (138 MPa) in the 304 stainless steel structural elements, and a 50,000 psi (345 MPa) maximum allowable stress in

the 1141 CR steel mandrel. This equates to a maximum total allowable force of 15,000 lb (67 kN), consisting of a maximum of 9000-lb (40-kN) force on the tip ($q_c = 400$ tsf (38.3 MPa)) and a maximum of 6000-lb (27-kN) force on the friction sleeve (Friction Ratio, $R_f = 4.4$ percent at max q_c).

Measurement System

10. The point penetration and friction sleeve load cells consist of 1/2-in.-long (1.3-cm-long) BLH strain gages wired as a full bridge (four active gages). Each half of the full bridge uses two gages arranged in a "T" configuration to minimize error due to Poisson's effect and to provide temperature compensation. The two half-bridges are 180 degrees apart on the circumference of the load cell in order to minimize response to bending.

11. The strain-gage bridges in the probe are connected to the surface signal conditioning equipment via a cable threaded through the jointed E-rod used to push the probe. A block diagram of the electrical system is presented in Figure 3. Common excitation is provided to all three bridges using one wire pair connected in parallel to the excitation side of each bridge. Output from the sensor bridges is read separately using three wire pairs, i.e., one pair each for the point load cell, sleeve friction load cell, and pore pressure transducer. After amplification, the sensor output signals are recorded on an oscillograph running at a paper speed of 0.1 in. (0.25 cm) per second. Depth of the probe tip below the ground surface is marked on the oscillograph record in equal depth increments, usually every 6 in. (15.25 cm), by means of a hand-held switch used to activate an event marker trace as each successive increment mark on the push rod reaches the ground surface.

Pore Pressure Saturation System

12. To make meaningful measurements of pore pressure response,

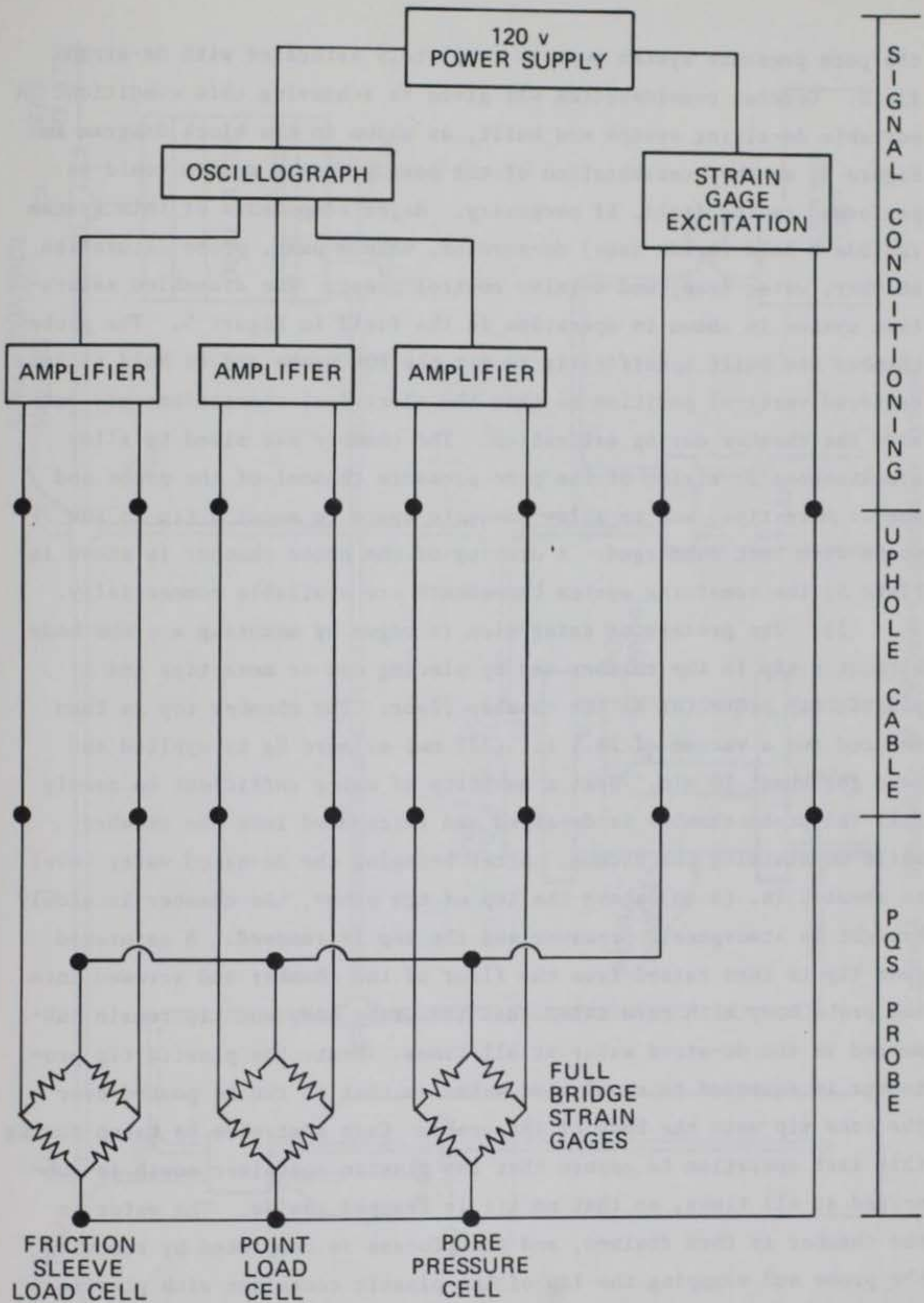


Figure 3. Schematic of PQS probe instrumentation

the pore pressure system must be completely saturated with de-aired fluid. Careful consideration was given to achieving this condition. A portable de-airing system was built, as shown in the block diagram in Figure 4, so that resaturation of the pore pressure system could be performed in the field, if necessary. Major components of this system include a Nold (trade name) de-aerator, vacuum pump, probe saturation chamber, water trap, and a valve control panel. The assembled saturation system is shown in operation in the field in Figure 5. The probe chamber was built specifically to fit the PQS probe and to hold it in a centered vertical position so that the electrical connections are outside the chamber during saturation. The chamber was sized to allow simultaneous de-airing of the pore pressure channel of the probe and one or more tips, and to allow adequate space to mount a tip to the probe with both submerged. A drawing of the probe chamber is shown in Plate 5; the remaining system components are available commercially.

13. The process of saturation is begun by mounting a probe body without a tip in the chamber and by placing one or more tips and a plastic tip protector on the chamber floor. The chamber top is then secured and a vacuum of 28.5 in. (727 mm) or more Hg is applied and held for about 10 min. Next a quantity of water sufficient to nearly fill the probe chamber is de-aired and introduced into the chamber while maintaining the vacuum. After bringing the de-aired water level to about 2 in. (5 cm) above the top of the probe, the chamber is slowly brought to atmospheric pressure and the top is removed. A saturated cone tip is then raised from the floor of the chamber and screwed into the probe body with care taken that the probe body and tip remain submerged in the de-aired water at all times. Next, the plastic tip protector is squeezed to expel some water so that it can be pushed over the cone tip onto the body of the probe. Care must also be taken during this last operation to ensure that the plastic container mouth is submerged at all times, so that no air is trapped inside. The water in the chamber is then drained, and the process is completed by removing the probe and wrapping the lip of the plastic container with plastic tape to prevent water/air leakage at the container-probe contact.

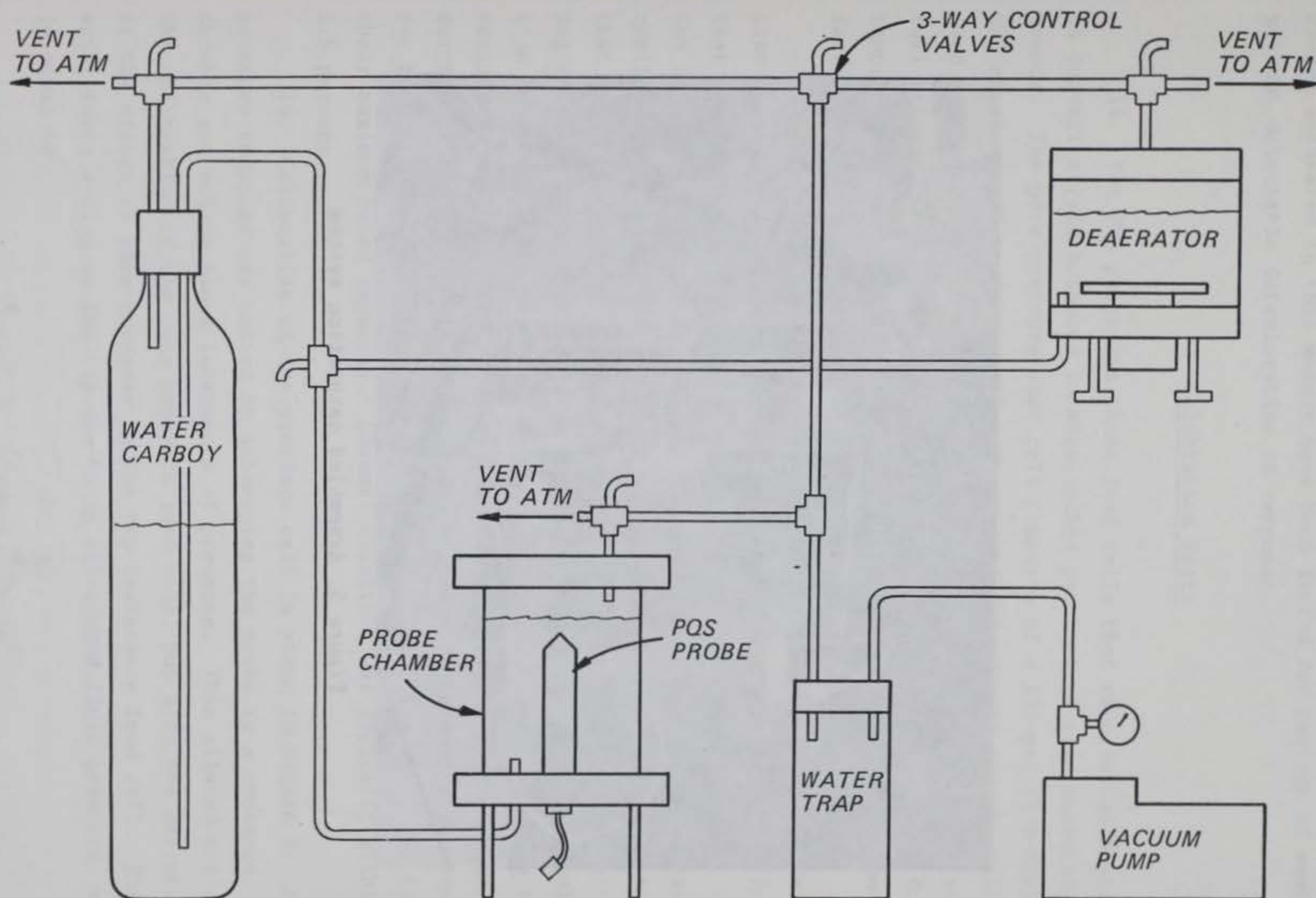


Figure 4. Schematic of PQS probe saturation system

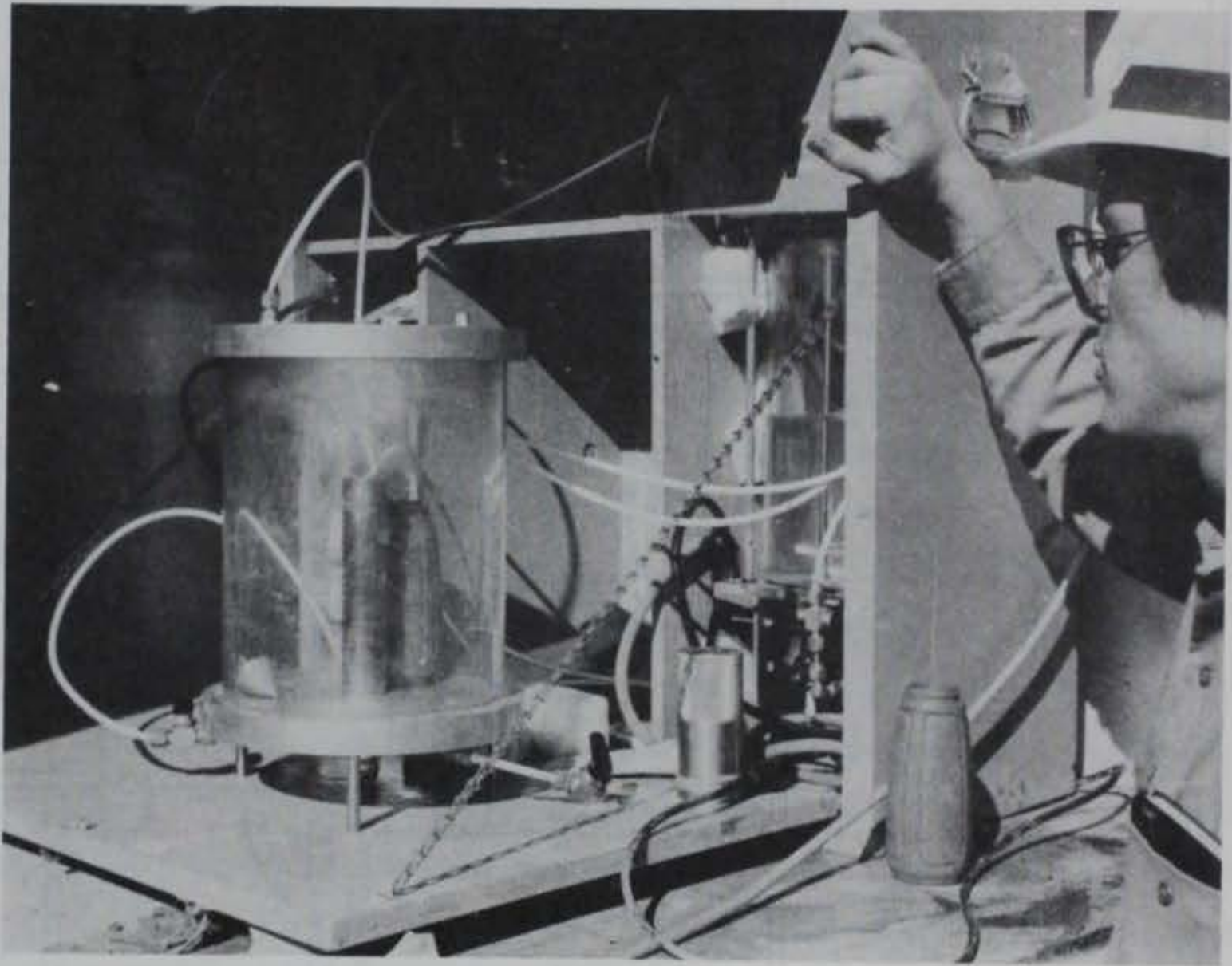


Figure 5. Assembled saturation system

Probes saturated in this manner have been stored for periods of weeks without detectable deterioration in response.

Calibration Tests

14. The PQS probe has three load cells that require calibration to convert strain measured in microinches per inch to load measured in pounds. The pore pressure load cell consists of a 150-psi (1.0-MPa) CEC strain-gaged pressure cell. The friction load cell and the point load cell both consist of 1/2-in. (1.3-cm) BLH strain gages wired as full bridges. Both BLH strain gages are configured to compensate for temperature, bending, and Poisson's effects. Since each probe manufactured is unique, calibration curves are required for use.

15. Calibration of the point resistance load cell and the friction sleeve load cell were accomplished using dummy tips designed for that purpose. These tips allowed independent loading of the point and the friction sleeve to isolate the load being measured. Loading was applied through a proving ring and all channels were monitored to ensure that crosstalk from one channel to another was not occurring. Monitoring was done with an SR-4 strain indicator, which allowed the correlation between load and strain to be made. Figures 6 and 7 show the tip resistance and the friction sleeve calibration curves, respectively, for PQS probe No. 2. Linear responses within $\pm 1/2$ percent were recorded for both the tip resistance and the friction sleeve load cells up to their maximum rated capacity. Channel crosstalk was typically within 1.5 percent.

16. Calibration of the pressure cell is shown in Figure 8. Pore pressure response was tested by submerging the probe in a pressure chamber and adding known increments of pressure. This allowed not only the calibration of the pore pressure load cell, but also the measurement of the effect of pore pressure on the tip resistance load cell. The net axial force acting on the tip due to an all-around fluid pressure u is equal to

$$F_{\text{tip}} = u \cdot (A_{\text{front}} - A_{\text{back}})$$

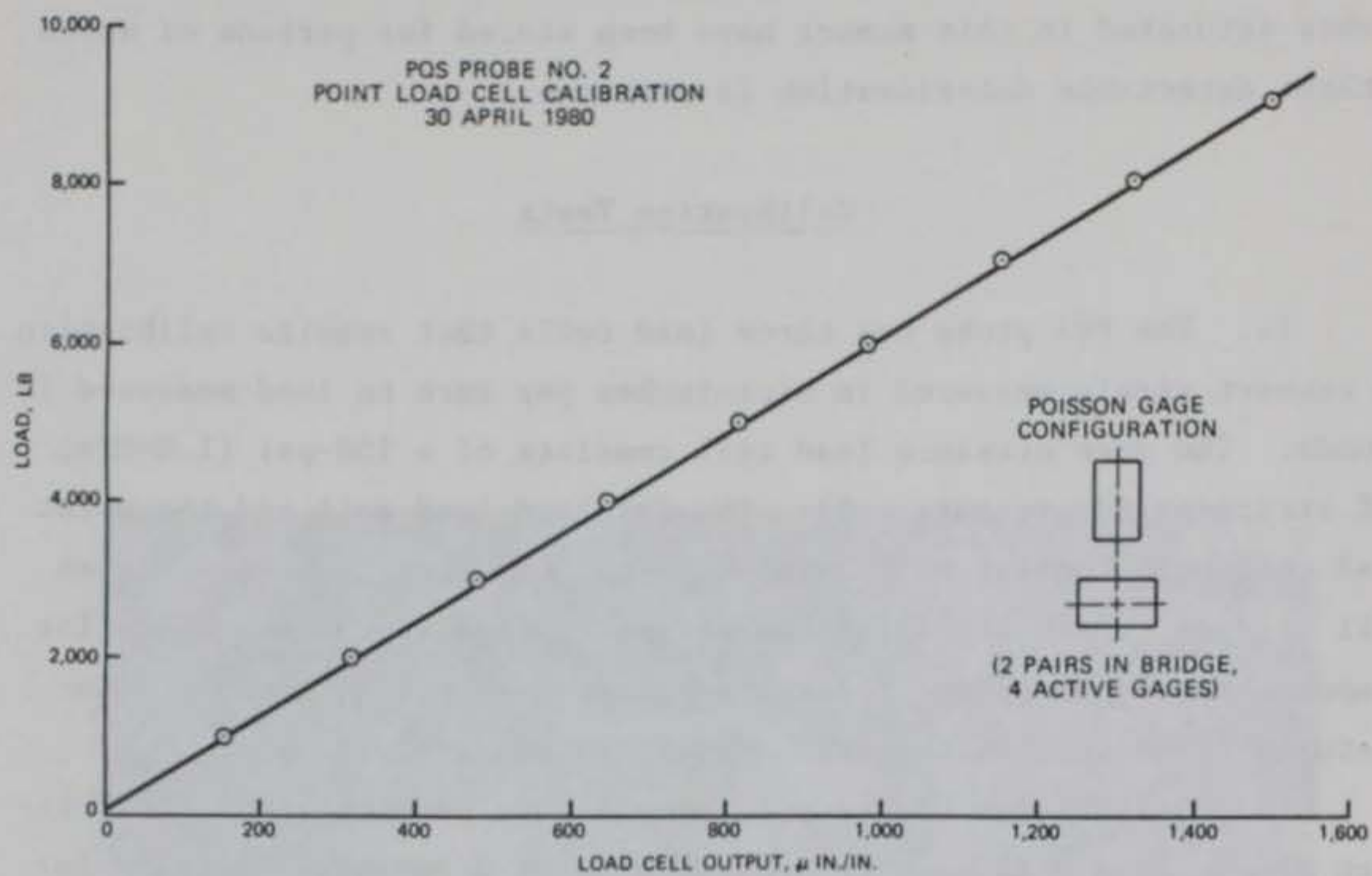


Figure 6. Calibration curve for point load cell

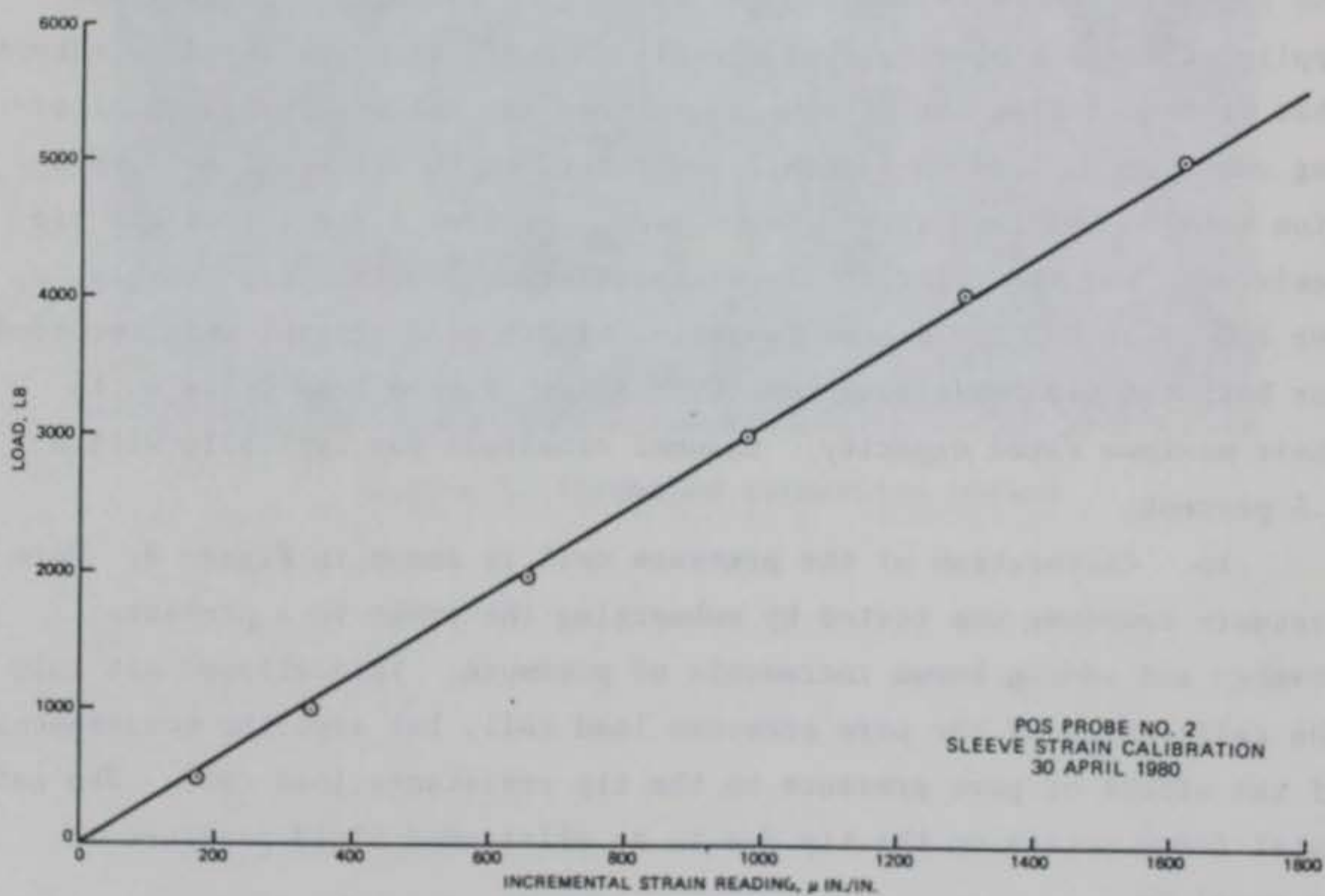


Figure 7. Calibration curve for friction sleeve load cell

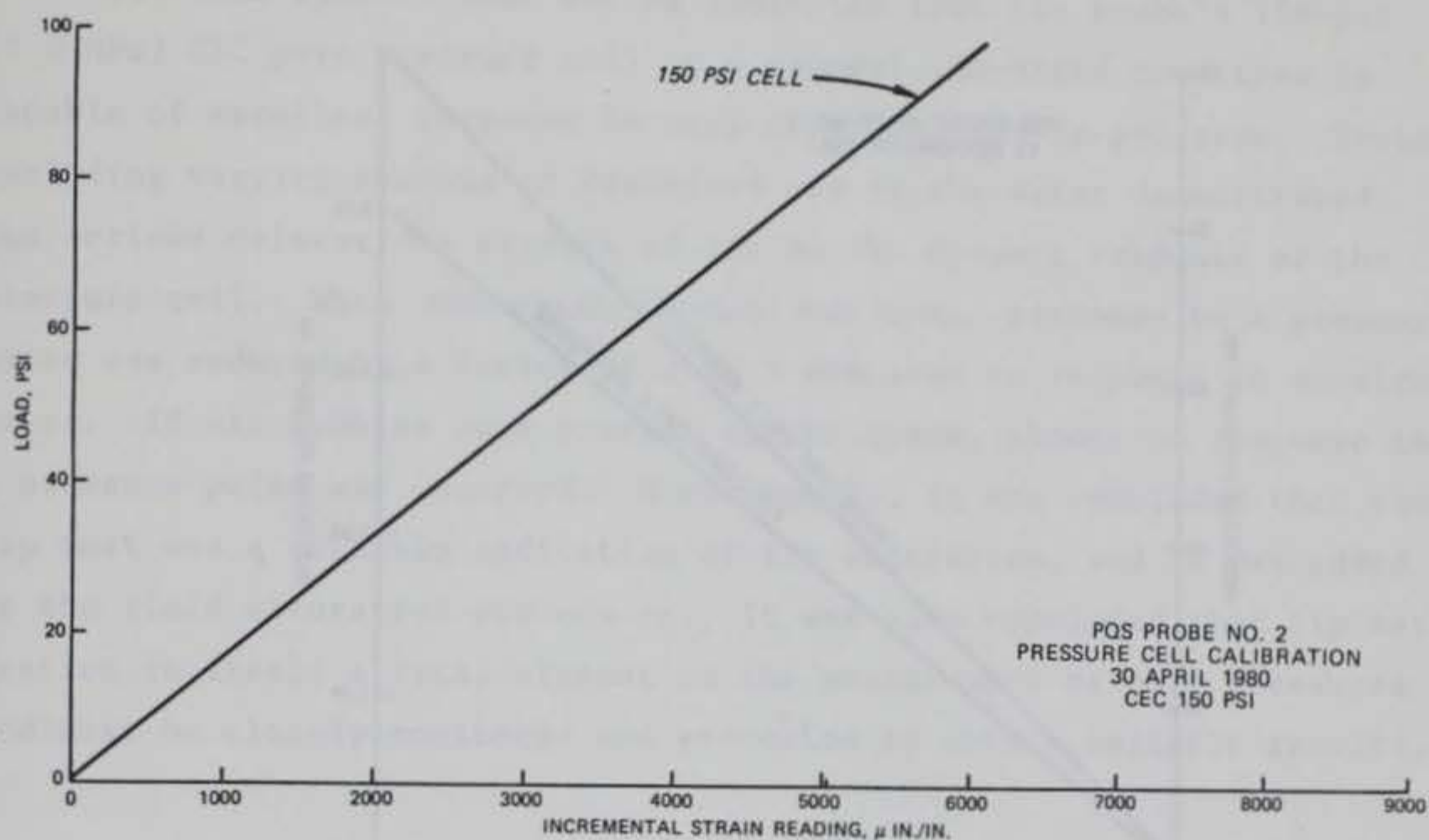


Figure 8. Calibration curve for pressure cell

where A_{front} is the frontal cross section area of the cone, 10 cm^2 , and A_{back} is the area at the back of the cone on which the fluid pressure acts through the space between the tip and the friction sleeve. The plot of tip load cell response shown in Figure 9 shows that the tip load response is about 81 percent of the chamber pressure, so that the area A_{back} is 19 percent of the frontal area. This value of the back area can be used, if required, in correcting the indicated tip resistance for pore fluid effects.

17. Dynamic calibration of the pore pressure response was accomplished by sealing a probe saturated with de-aired water into the open end of a plastic bottle that had been previously fitted with a 150-psi (1.0-MPa) CEC strain-gaged pressure cell in the base and filled with de-aired water. The pressure cells of both the probe and the plastic bottle were connected to a strip recorder for simultaneous monitoring. The dynamic response test consisted of sharply tapping the center of the plastic bottle and comparing the responses of the two pressure cells to the pressure impulse in the water. Figure 10 shows the response curve obtained for probe No. 2 using this procedure.

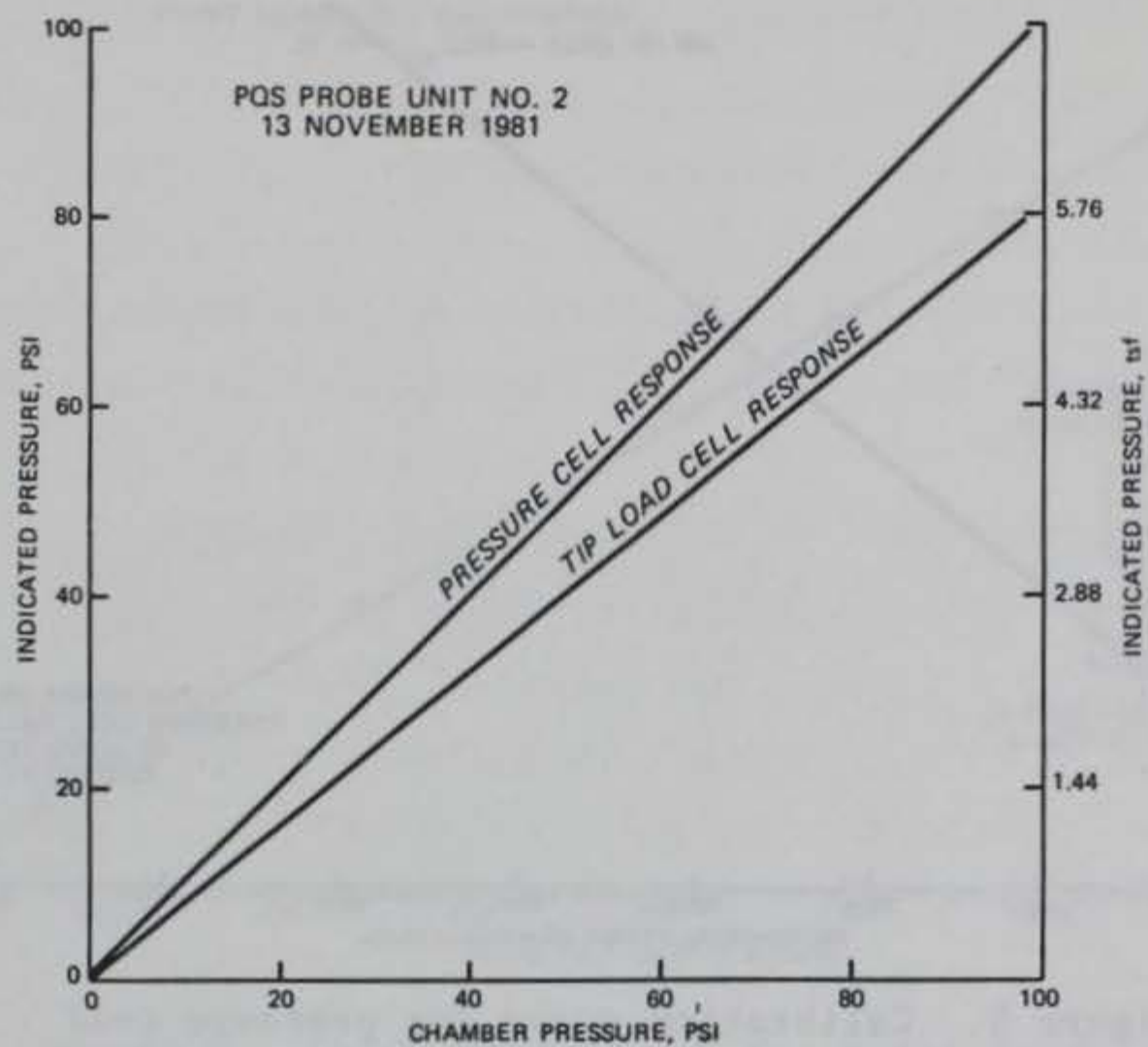


Figure 9. Tip load response to fluid pressure

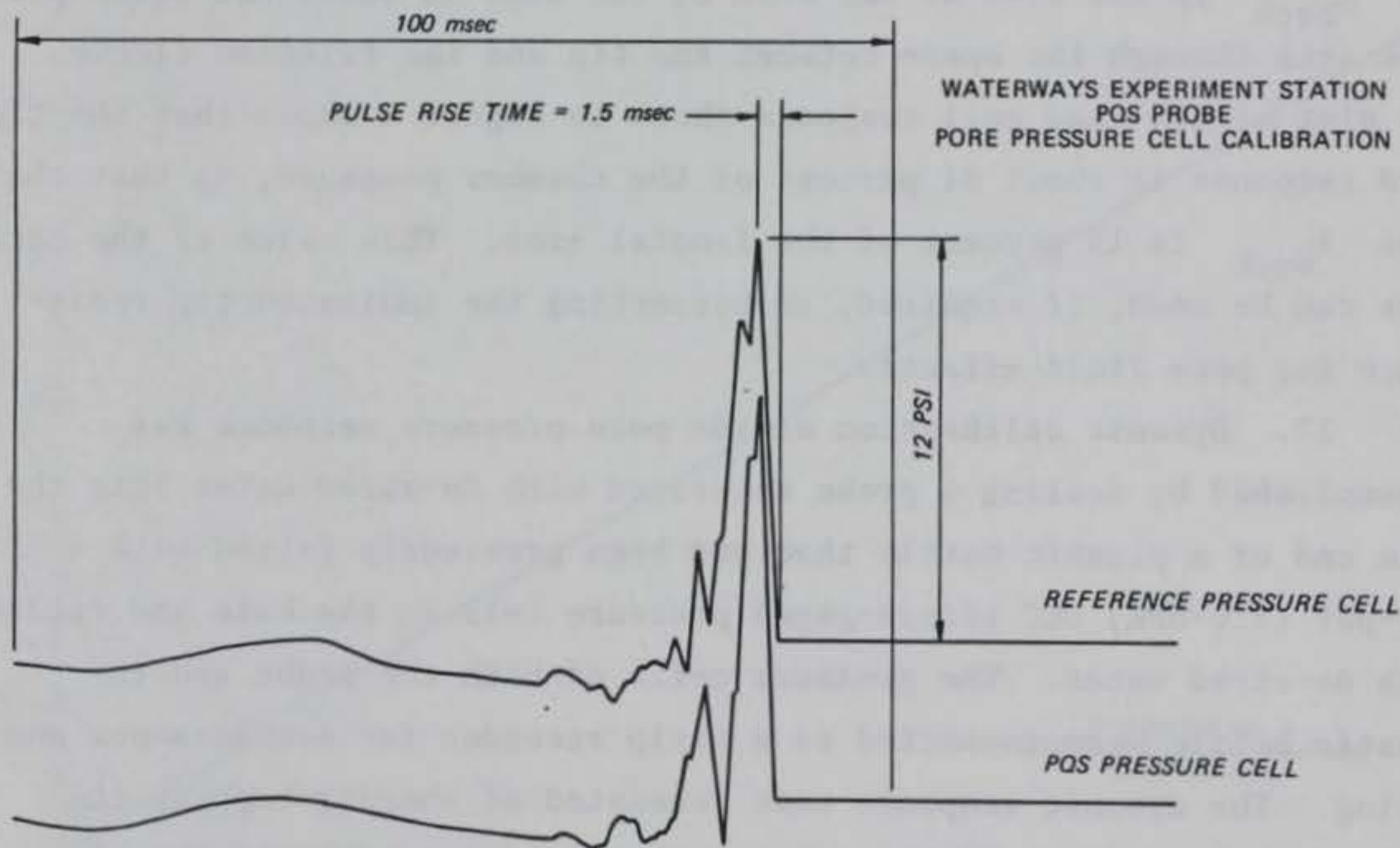


Figure 10. Dynamic response of pressure cell with 2- μ m porous tip

18. The dynamic test series indicated that the probe's 150-psi (1.0-MPa) CEC pore pressure cell in a properly de-aired condition is capable of excellent response to very rapid changes in pressure. Tests including varying amounts of dissolved air in the water demonstrated the serious deleterious effects of air on the dynamic response of the pressure cell. When nonde-aired water was used, response to a pressure pulse was reduced by a factor of 2 or 3 compared to response in de-aired water. If air bubbles were present in the system, almost no response to a pressure pulse was observed. Consequently, it was concluded that the tap test was a reliable indication of tip saturation, and it was added to the field saturation procedures. It was also concluded that tip saturation is itself a vital element in the measurement of pore pressures and must be closely monitored and protected to obtain reliable results.

PART III: OPERATING TECHNIQUES

Push Mechanism

19. Initial field testing of the PQS probe was carried out using the equipment shown in Figure 11. It consists of a trailer-mounted, 3000-psi (21-MPa) hydraulic system powered by a four-cylinder, air-cooled gasoline engine. The hydraulic ram used to push the PQS probe has a 34-in. (0.86-m) stroke and can deliver up to 30,000 lb (13,608 kg) of force, but the entire apparatus weighs only 9400 lb (4264 kg), so this is the limiting factor in reacting to the forces generated during pushing. Lead weights of up to 4000 lb (1814 kg) can be added to bring the fully ballasted weight to 13,400 lb (6078 kg). The device has proven to be adequate for preliminary tests, but a higher force capability will be required for many practical applications.

Probe Response Test

20. Before a push is begun, an expedient field test of the pore pressure sensor is desired. Otherwise, a loss of saturation or other defect might not be detected until considerable time has been lost in pushing. In early testing of pore pressure sensor response, it was discovered that tapping with a screwdriver handle on the cone tip plastic container produced a sharp pulse of short duration with a rise time of about 1.5 msec and a peak pressure of about 10 to 15 psi (69 to 103 kPa) when the probe and porous filter element were fully saturated. Such rapid response to pressure transients is not needed for pore pressure measurements, but the dynamic response is a sensitive indicator of the state of saturation of the probe and the filter element. Minor amounts of trapped air in the container resulted in a factor of 2 or 3 reduction in indicated peak pressure in these tests, but little or no pulse could be detected when saturation of the probe was lost. Additionally, field experience has shown that wear of the porous filter with use, accompanied by smearing of the metal of the filter, results in a loss of



Figure 11. PQS probe push apparatus

permeability, which also produces a diminished pressure response and longer response time in the tap test. The tap test, while crude, proved to be both repeatable and diagnostic of the probe pressure response. If in the tap test the pressure cell registered a peak pressure less than about 2 psi (14 kPa), then the pore pressure system did not perform satisfactorily during the push.

Push Operations

21. The push apparatus used in this study was provided with three secondary hydraulic rams, which are employed to level the apparatus

prior to pushing. A rack was provided to store up to 50 sections of 2- or 2-1/2-ft (61- and 76-cm) length E-rod size drill pipe which were prethreaded with the instrumentation cable (Figure 10). Sufficient pipe was secured to achieve a total push of 100 ft (30.5 m).

22. The push apparatus is capable of advance rates of up to 4 cm/sec, but hydraulic control valves were used to regulate the advance rate to either 1 or 2 cm/sec for purposes of this study. Depth of penetration was monitored by marking the drill pipe in 6-in. (15.2-cm) increments with chalk and by recording these increments on the oscillograph, using the hand-held switch as an event marker, as the push progressed. The push was typically halted for about 1 min after each 2.5 ft (0.8 m) of penetration in order to add pipe joints and to observe the response of the pore pressure sensor with time. After completing the push, the probe was held in position for sufficient time for the pore pressure to approach an equilibrium (hydrostatic) pressure, and then was withdrawn with only periodic halts to record the hydrostatic pressure at depths of interest, or as necessary to remove pipe joints.

Field Data

23. The PQS probe has been subjected to field trials at two sites on the banks of the Mississippi River in geologically recent point bar deposits. These deposits typically are fine quartz sands with intercalated bodies of fine-grained, plastic slough deposits. A portion of a record obtained at one of these two sites, Delta, La., is shown in Figure 12.

24. Data obtained in the field are recorded as functions of time on four channels of a strip chart recorder. Figure 12 shows the four traces after digitization and replotting to compress the time scale. Three analog traces are recorded: the P curve represents the total pore pressure p ; the Q curve, the cone tip resistance q_c ; and the S curve, the sleeve friction f_s . The fourth trace is an event marker, triggered by a hand-held push-button switch when a chalked depth mark on

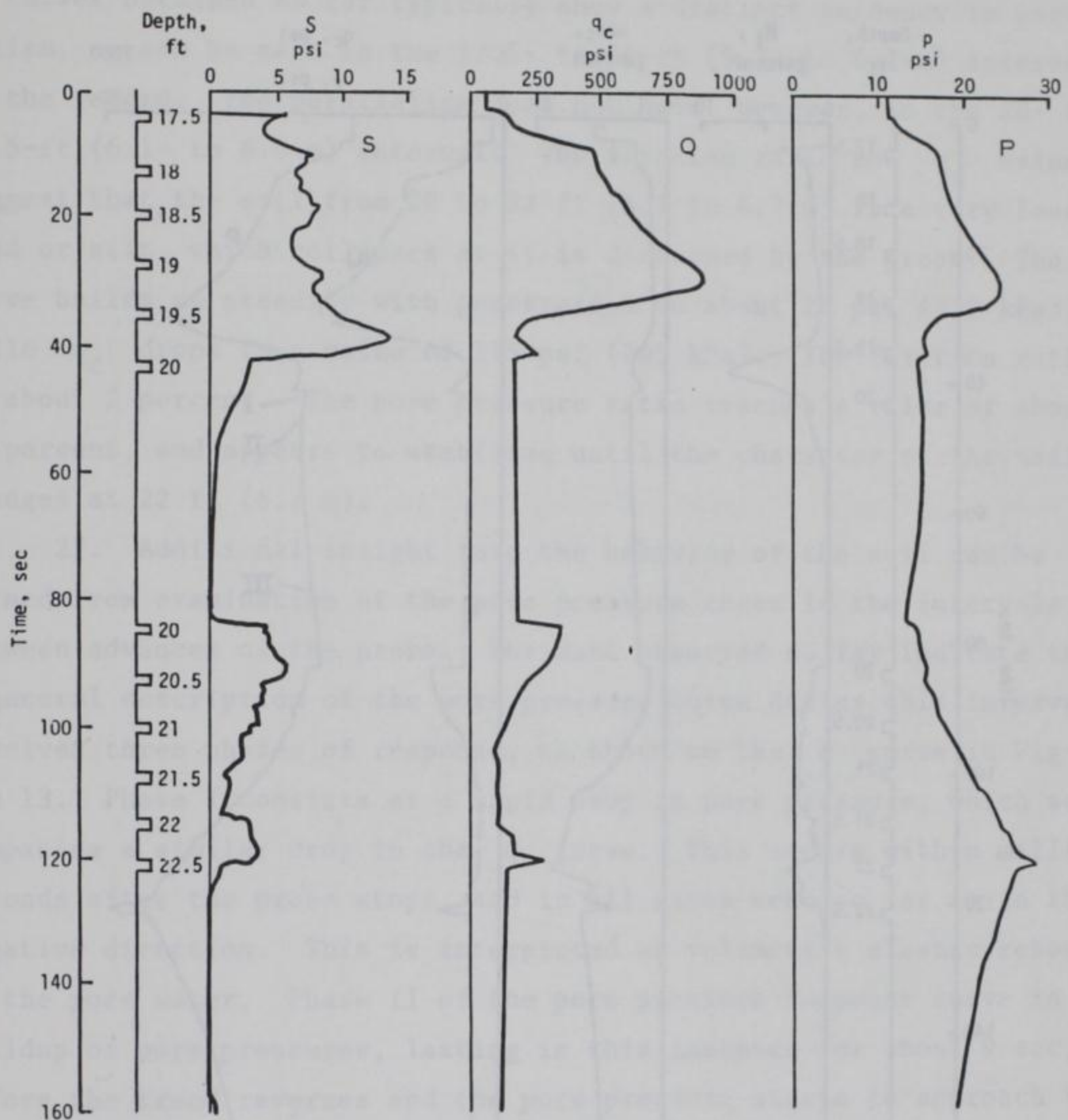


Figure 12. Typical example of penetration data obtained from field record

the drill rods passes a visual reference point.

25. When the field data have been digitized, computer-aided processing and plotting are possible. Figure 13 shows the data of Figure 12 converted to a form that facilitates interpretation. The P and Q curves are shown essentially unaltered except for a change of scale. The S curve is used to obtain a curve showing the friction ratio R_f ; i.e., the ratio of f_s to q_c , which can be correlated with soil type. A fourth curve shows the pore pressure ratio u/q_c ,

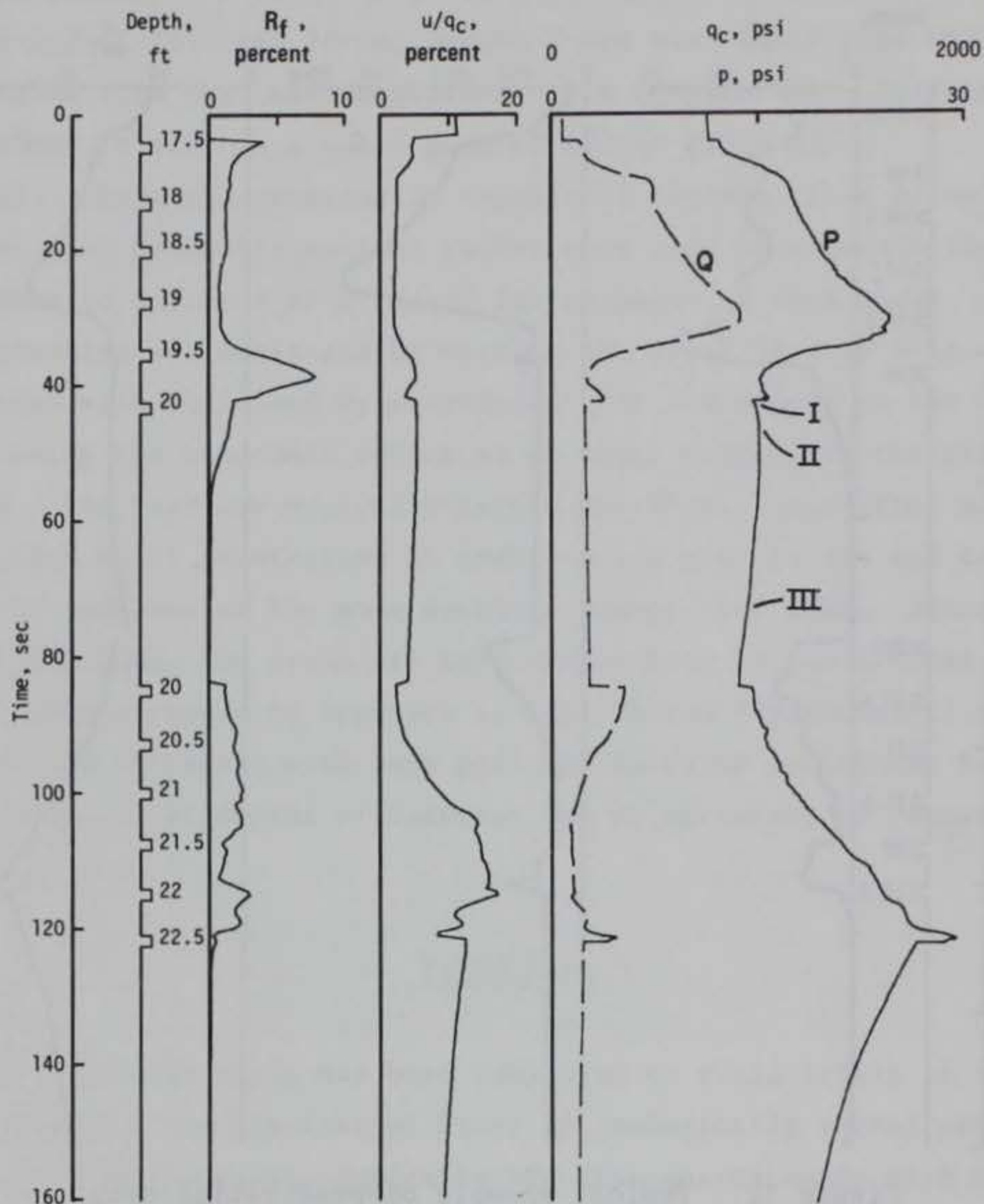


Figure 13. Record obtained after computer-aided transformation

where u is the excess pore water pressure, or total pore water pressure minus the hydrostatic water pressure.

26. There are several noteworthy features on this record. First, the pore pressure ratio u/q is generally quite low, on the order of 1 to 2 percent, in the sand intervals. Peaks as high as 5 to 7 percent occur in zones where low cone-bearing and high friction ratio values indicate cohesive soils. In sands of intermediate density, the P and

Q curves obtained so far typically show a distinct tendency to parallelism, as can be seen in the 17.5- to 20-ft (5.3- to 6.1-m) interval of the record. The parallelism does not hold, however, in the 20- to 22.5-ft (6.1- to 6.9-m) interval. The friction ratio and q_c values suggest that the soil from 20 to 22 ft (6.1 to 6.7 m) is a very loose sand or silt, which collapses as it is disturbed by the probe. The P curve builds up steadily with penetration to about 26 psi (179 kPa), while q_c drops to a value of 115 psi (795 kPa). The friction ratio is about 2 percent. The pore pressure ratio reaches a value of about 16 percent, and appears to stabilize until the character of the soil changes at 22 ft (6.7 m).

27. Additional insight into the behavior of the soil can be gained from examination of the pore pressure curve in the intervals between advances of the probe. The data observed so far indicate that a general description of the pore pressure curve during this interval involves three phases of response, as shown on the P curve in Figure 13. Phase I consists of a rapid drop in pore pressure, which accompanies a similar drop in the Q curve. This occurs within milliseconds after the probe stops, and in all cases seen so far is in the negative direction. This is interpreted as volumetric elastic rebound of the pore water. Phase II of the pore pressure response curve is a buildup of pore pressures, lasting in this instance for about 9 sec, before the trend reverses and the pore pressure starts to approach the hydrostatic value. The Phase II buildup represents about a 0.5-psi (3.5-kPa) increase in pore pressure. A sounding made about 5 ft (1.5 m) away, using a penetration rate of 4 cm/sec, or twice the rate represented by Figure 12, showed the same behavior of both P and Q curves, except that the Phase II buildup amounted to 7 psi (48.3 kPa) reached in 15 sec. It is believed that Phase II behavior is due to pore pressures in a zone of loose, collapsing sand below the cone. With the cone tip halted just above or in the top of the collapsing zone, the pressure buildup is communicated upward to the pressure cell.

28. In most cases, Phase II is absent and Phase I is immediately followed by Phase III, an asymptotic approach to the equilibrium pore

pressure (which normally is the hydrostatic pressure). This can be seen at the 22.5-ft (6.8-m) depth, where the typical shape of the dissipation curve, resembling a negative exponential curve, is shown. Torstensson* has related the time for 50 percent excess pore pressure dissipation in clay to the coefficient of consolidation. In sands, the permeability is greater than in clay and consolidation consequently more rapid. Typical times to 50 percent excess pore pressure dissipation are on the order of a few seconds in the point bar sands tested to date.

29. An alternative mode of presentation is to plot the penetration resistance and pore pressure data against depth as obtained from the event marker ticks on the strip chart record. Such a plot is shown in Figure 14. While this plot does not show the details of the pore pressure behavior in the intervals between advances of the probe, some indication of that behavior is given by the amount of pressure change during the intervals and the durations of the intervals, which are noted on the log.

* Torstensson, op. cit.

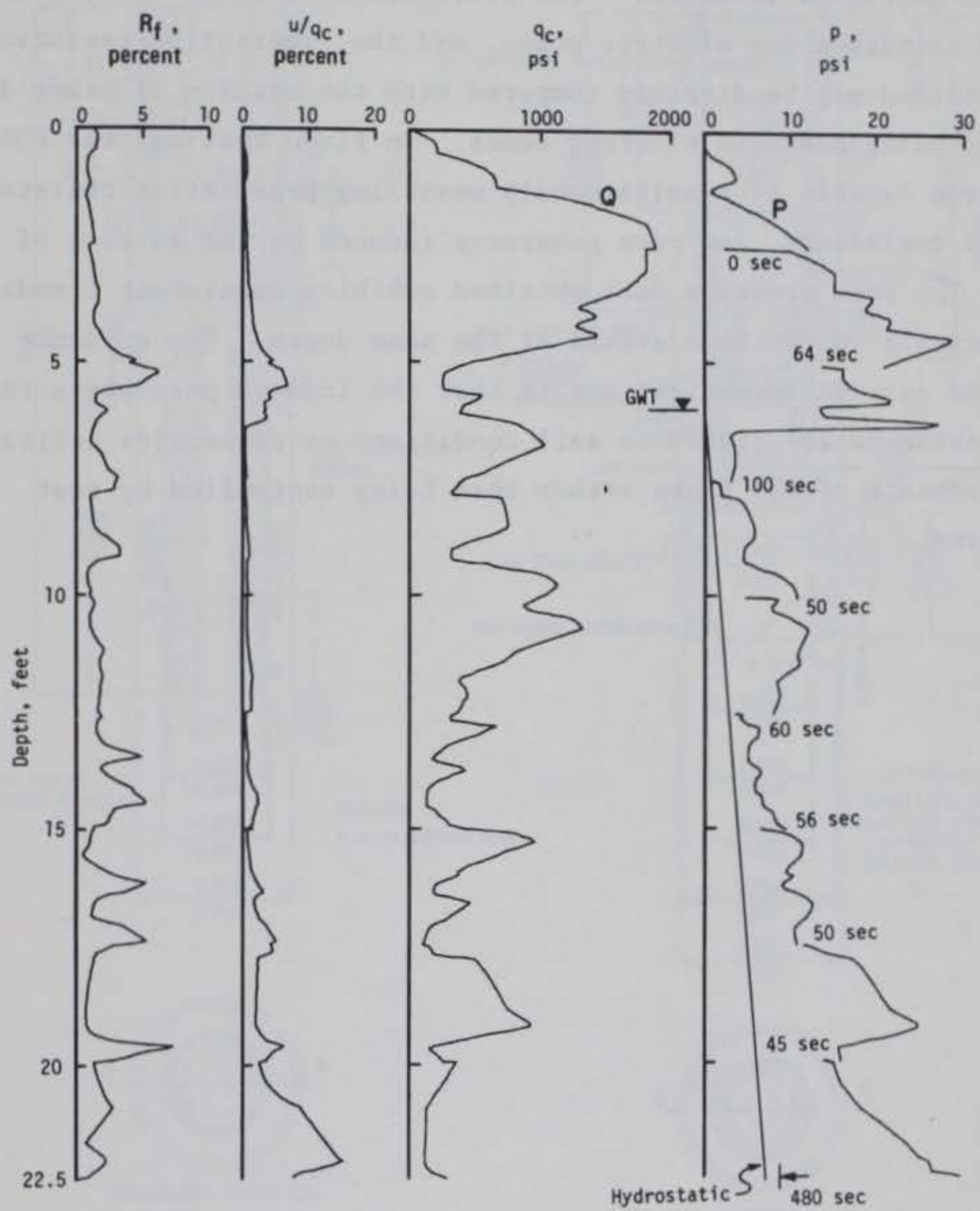
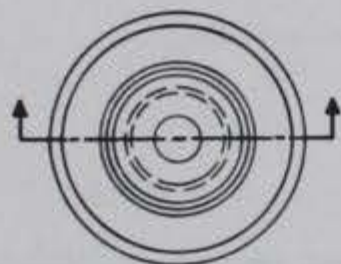
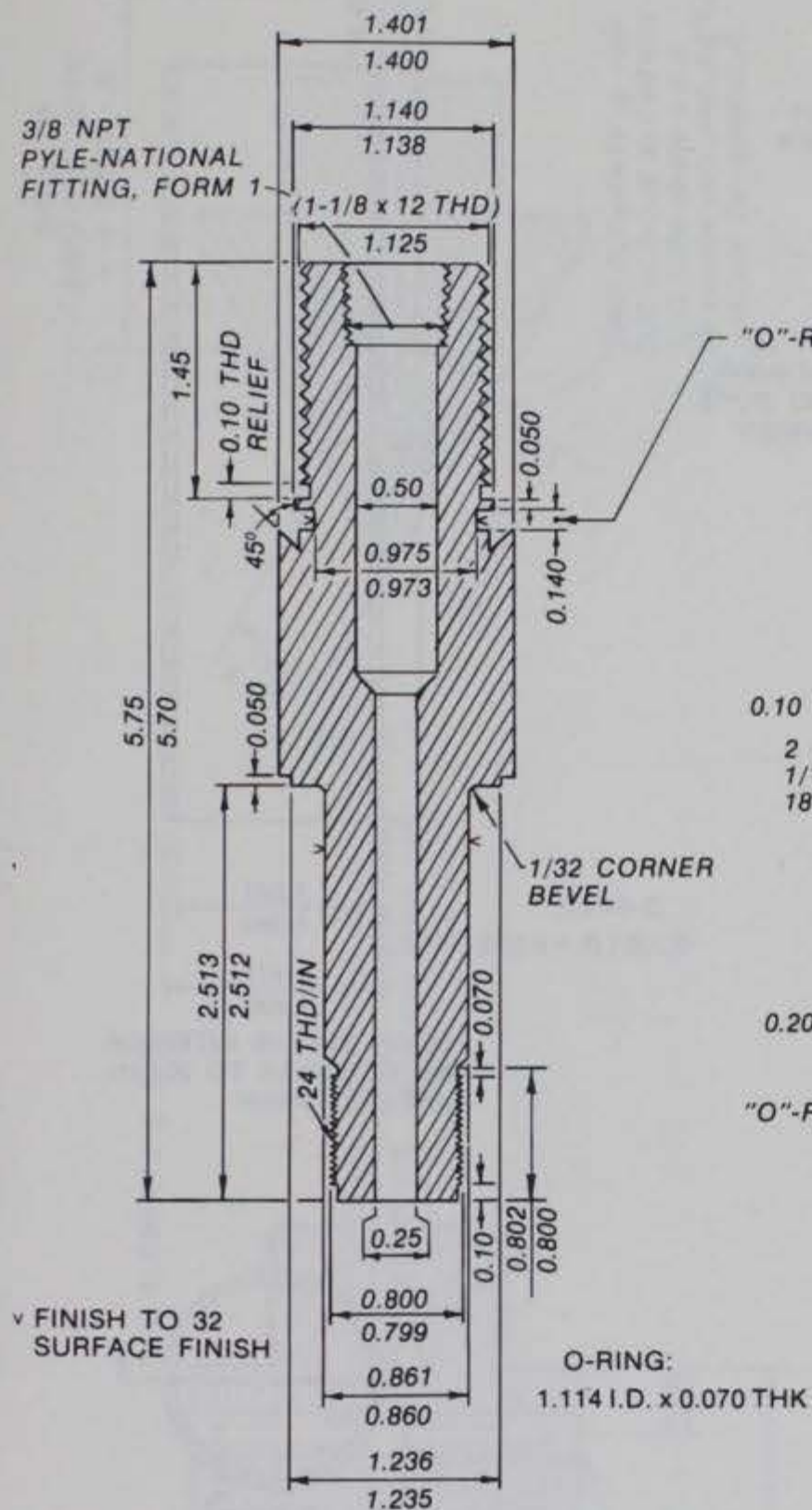


Figure 14. Log of sounding at Delta, La., plotted against depth

PART IV: SUMMARY AND CONCLUSIONS

30. In this report the design and construction of the PQS probe has been described in detail. The probe conforms in external geometry to ASTM standards for electric cones, and the penetration resistance data obtained may be directly compared with the results of other data obtained using standard electric cones. In field testing, the PQS probe has proven capable of simultaneously measuring penetration resistance, friction resistance, and pore pressures induced by the advance of the probe. The pore pressure data obtained exhibits consistent trends and is repeatable in the same strata at the same depth. The evidence of these and earlier investigations is that the induced pore pressures and resistances are linked to soil conditions or properties activated by the advance of the probe rather than being controlled by test procedures.

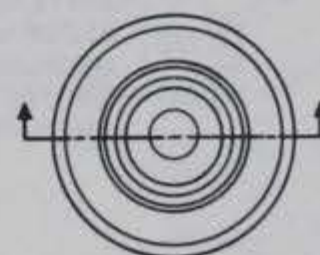
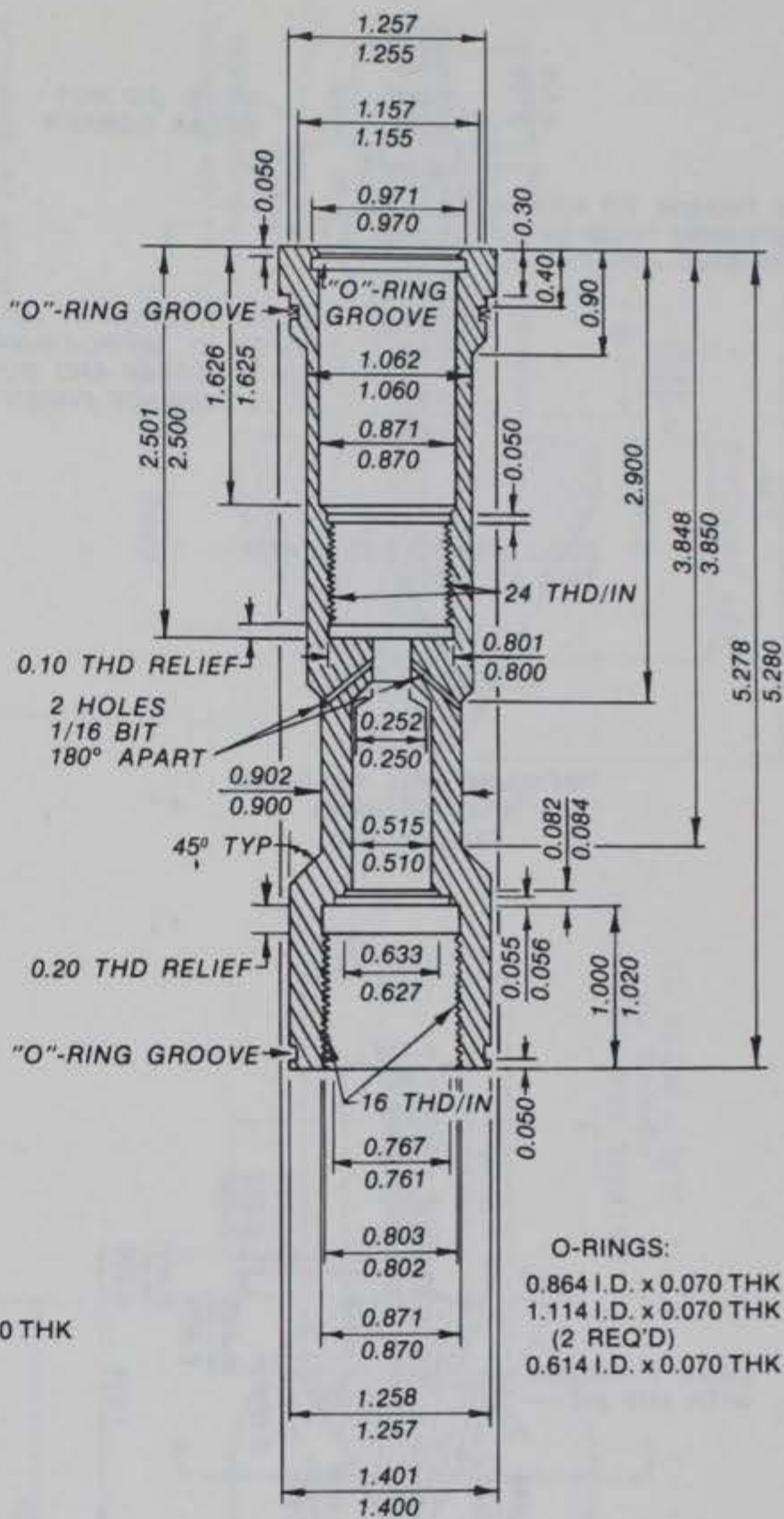
3/8 NPT
PYLE-NATIONAL
FITTING, FORM 1



MANDREL (1141 CR)
TOLERANCE IS ± 0.10 "
(UNLESS OTHERWISE
SPECIFIED)

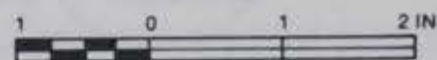


TYPICAL "O"-RING GROOVE
(ALL GROOVE SURFACES
32 SURFACE FINISH)



HOUSING
(STAINLESS)

SCALE



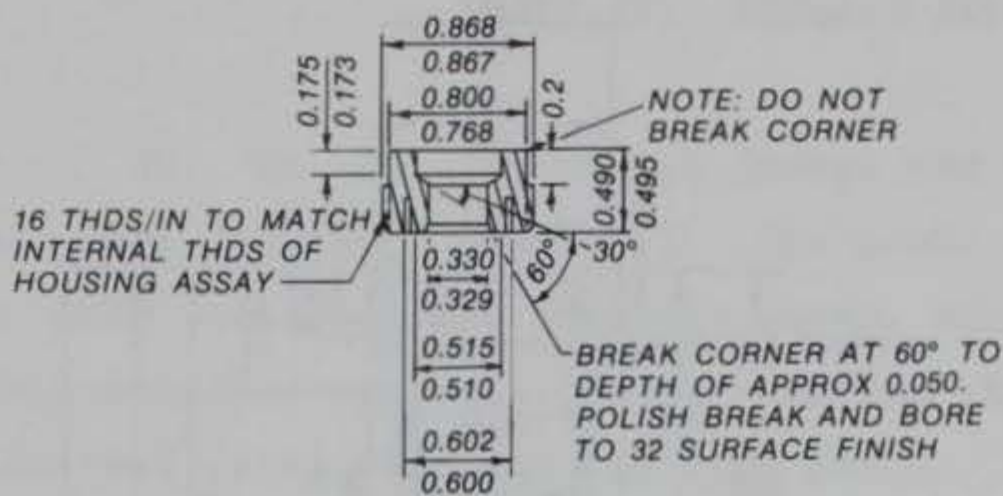
WATERWAYS EXPERIMENT STATION

PQS PROBE

HOUSING AND MANDREL DETAIL

S. S. COOPER

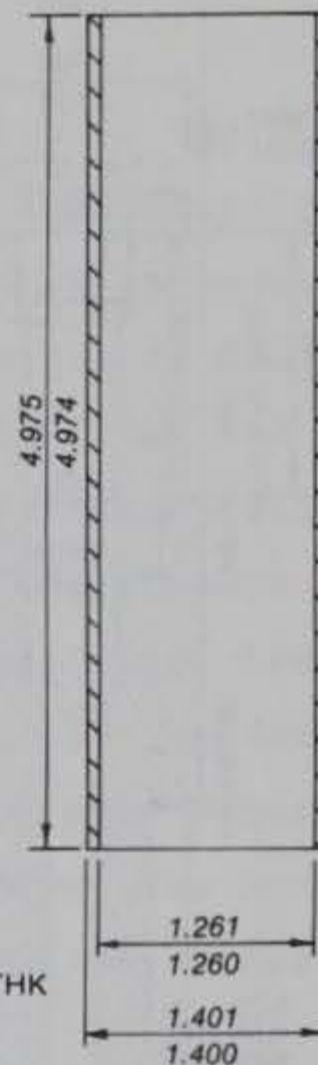
OCT 1979



DRILL 1/16 TO 0.20 DEPTH TWO AT 180°

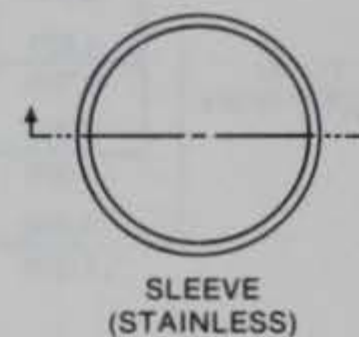
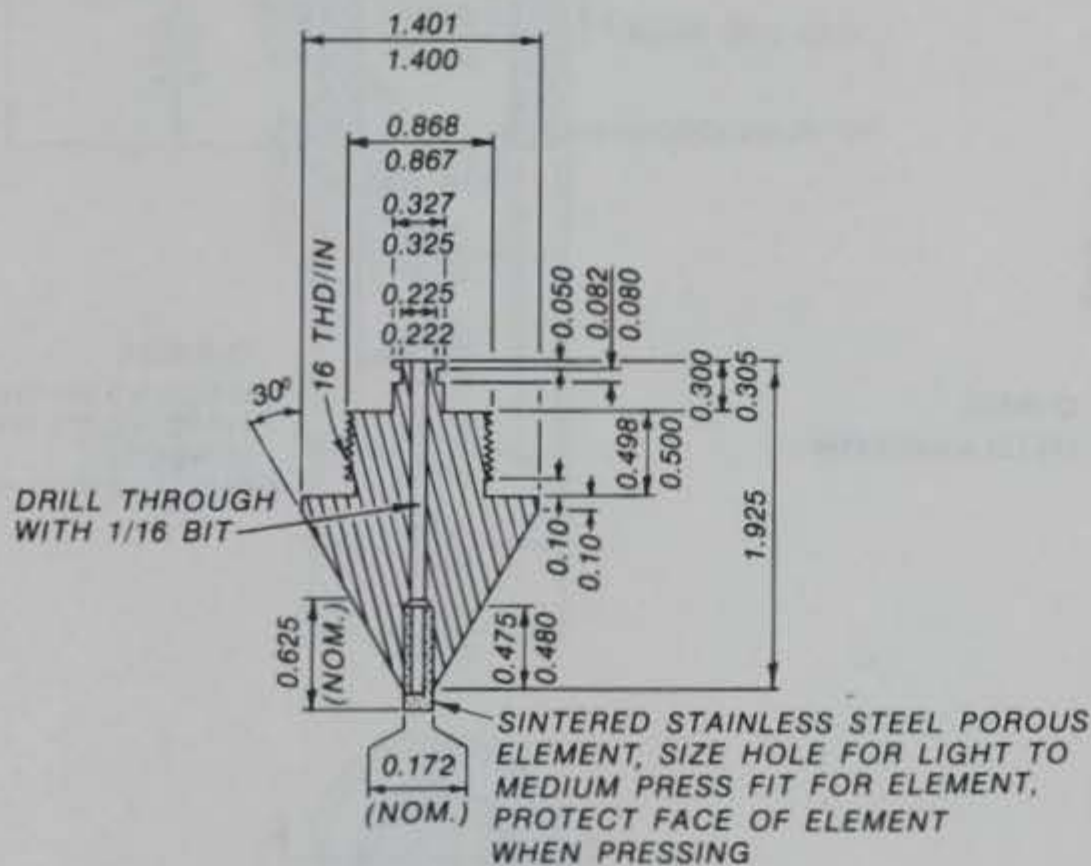


PRESSURE CELL RETAINER RING (BRONZE) SECTION B-B



O-RING:
0.208 I.D. x 0.070 THK

POLISH SLEEVE INTERIOR AND EXTERIOR TO 20 μ IN. SURFACE FINISH



SCALE



CONE PENETROMETER POROUS TIPS STAINLESS TIP #1 SECTION A-A

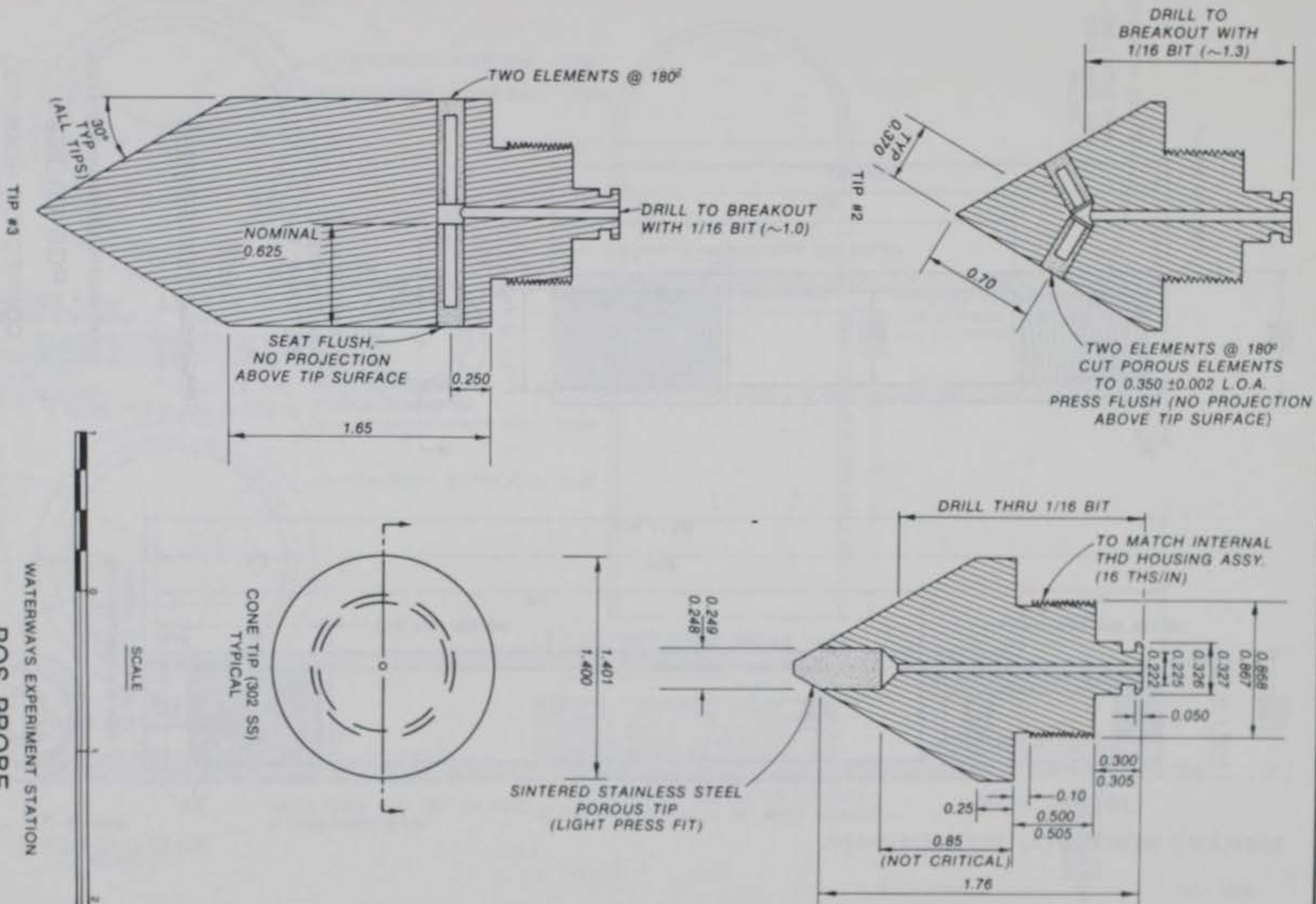
WATERWAYS EXPERIMENT STATION

PQS PROBE

FRICTION SLEEVE, RETAINER, AND TIP DETAIL

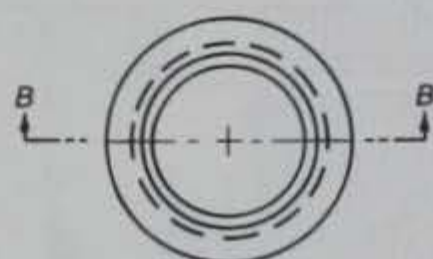
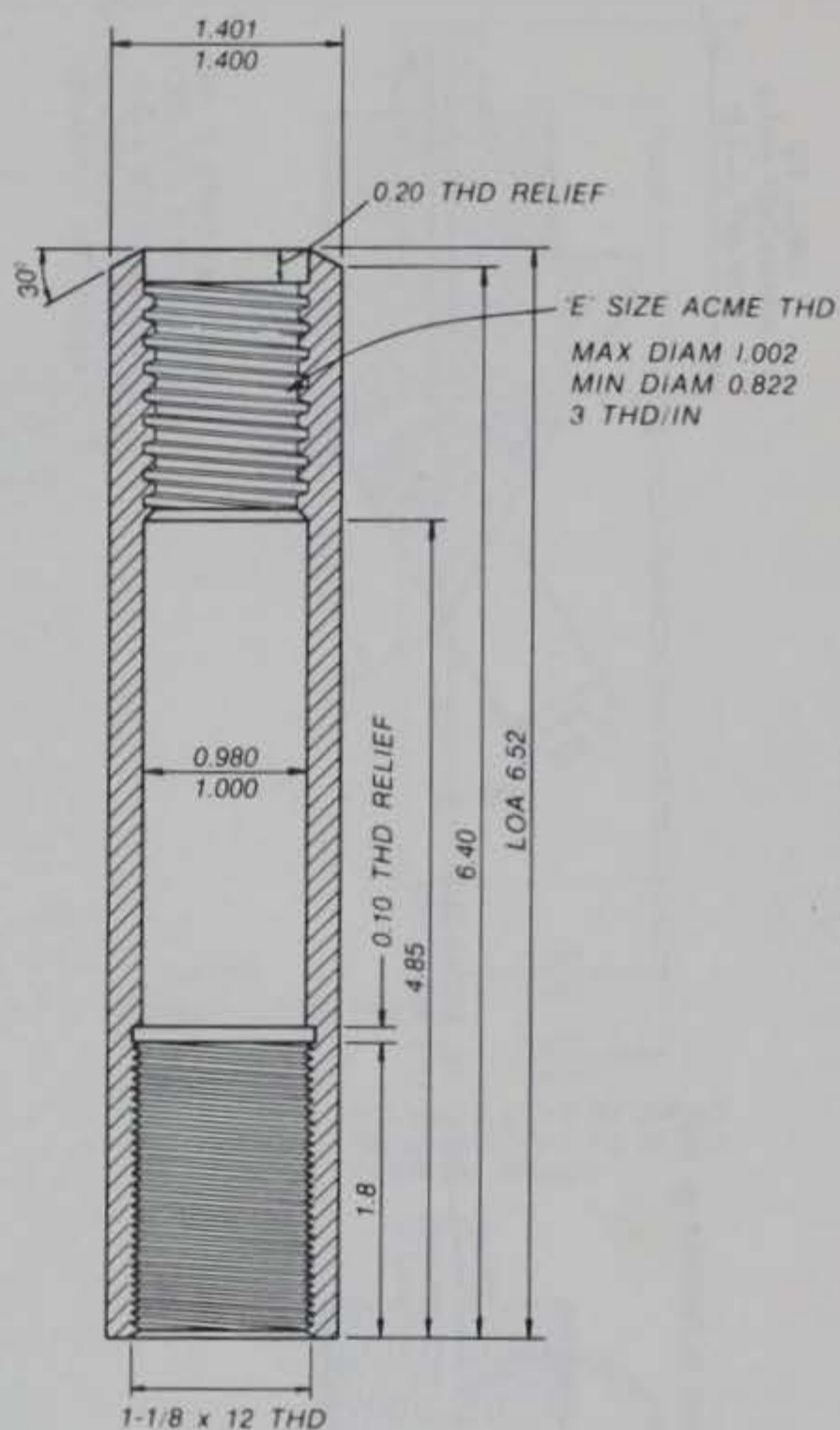
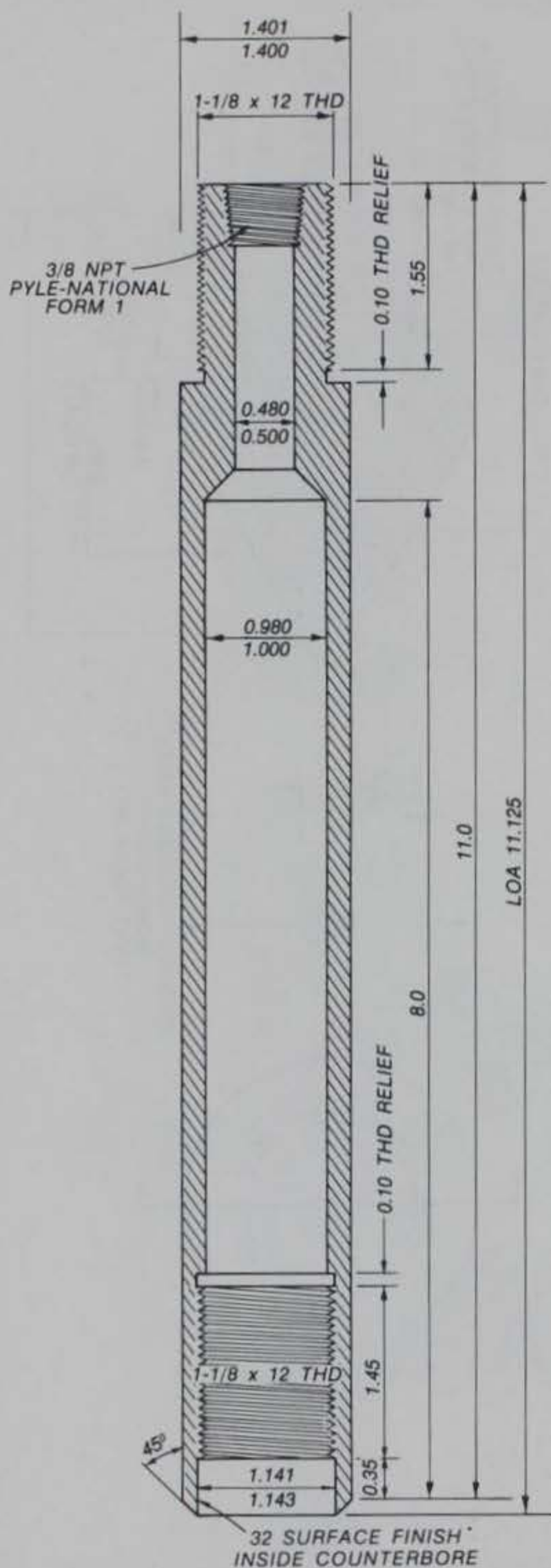
S. S. COOPER

OCT 1979



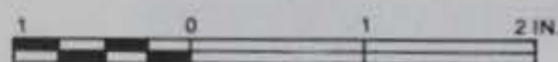
S. S. COOPER

OCT 1979



DOWNHOLE SUB
STAINLESS STEEL
SECTION B B

SCALE



WATERWAYS EXPERIMENT STATION

PQS PROBE

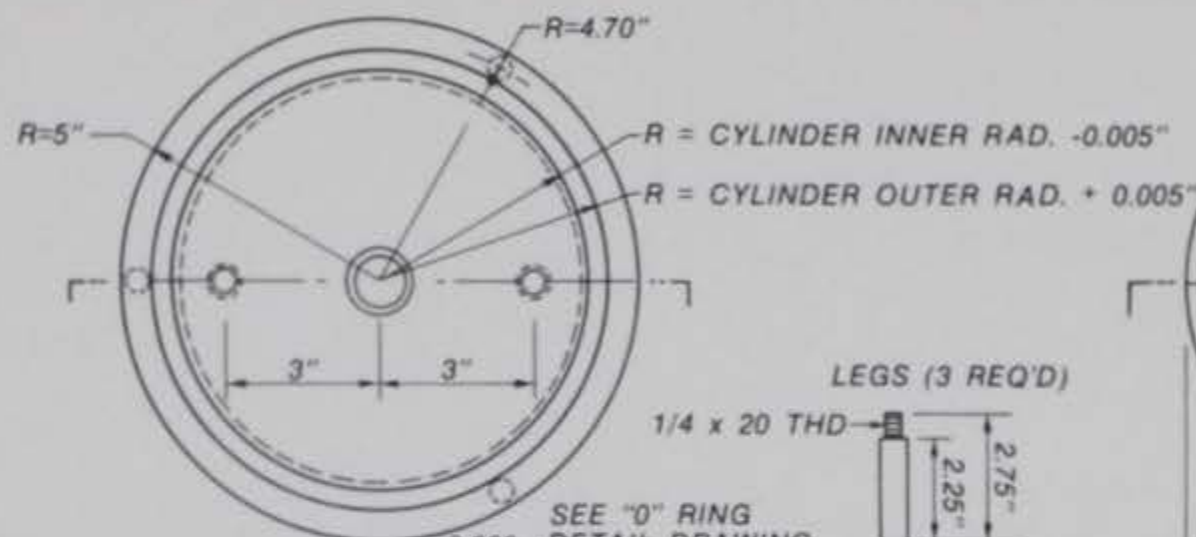
CONNECTOR HOUSING
AND E-ROD SUB
DETAIL

S. S. COOPER

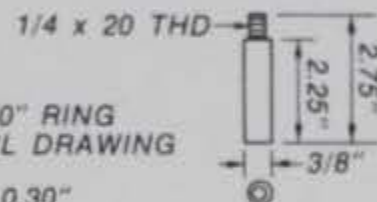
OCT 1979

ALUM. BASE PLATE (1 REQ'D)

PLEXIGLAS CYLINDER (1 REQ'D)



LEGS (3 REQ'D)

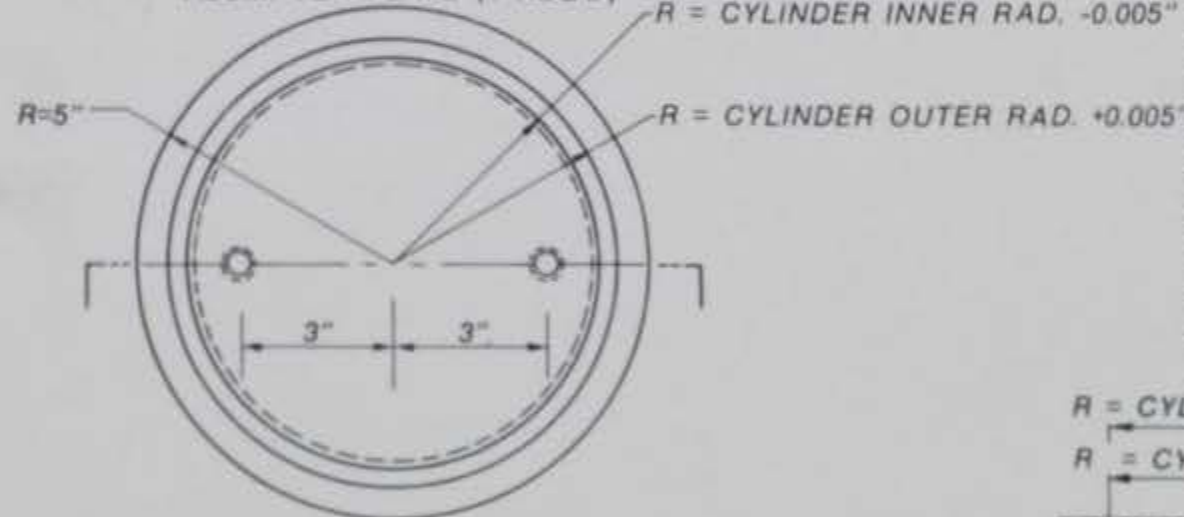


SEE "O" RING
DETAIL DRAWING

32 SURFACE FINISH
INSIDE COUNTERBORE

Drill 3/4" DEPTH
TAP FOR 1/4 x 20 THD
THREE LOCATIONS @ 120°

ALUM. TOP PLATE (1 REQ'D)

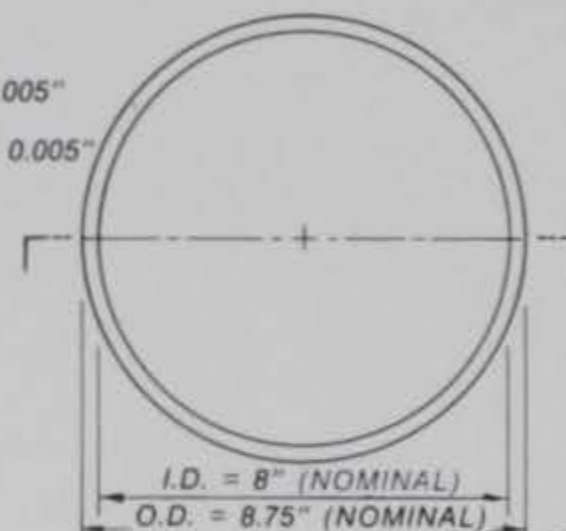


SEE "O" RING DETAIL DRAWING

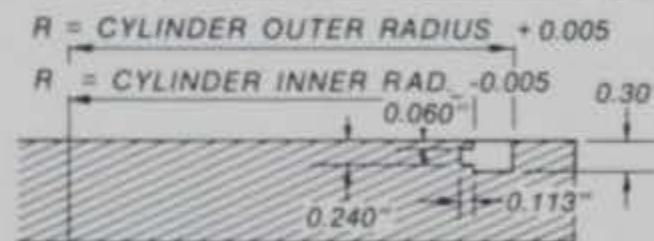


O-RING:
7.234 I.D. x 0.139 THK
(2 REQ'D)

DRILL THRU AND TAP 1/4 NPT
2 LOCATIONS @ 180°



MACHINE ENDS PROVIDE
1/32 CHAMBER @ 45° ON
ALL CORNERS



"O" RING DETAIL DRAWING
(TOP AND BOTTOM PLATES TYPICAL)
32 SURFACE FINISH IN "O" RING GROOVE

SCALE



WATERWAYS EXPERIMENT STATION

PQS PROBE

PENETROMETER SATURATION CHAMBER

S. S. COOPER

OCT 1979