

DEVELOPMENT OF THE UBC SELF-BORING PRESSUREMETER

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Introduction

The Department of Civil Engineering at UBC has been involved with research investigations using self-boring pressuremeters for over ten years. All of this work was conducted in association with Dr. J.M.O. Hughes (Hughes et al,1977; Hughes et al,1980) using equipment (the HSB and HHP units) that he developed. Recently it was decided to develop an improved version to aid future research. The main areas of likely improvement that had been identified were instrumentation/data processing, membrane corrections, membrane protection, and installation methods.

A sectional assembly of the UBC pressuremeter is shown in Fig.1. The basic design follows that developed by Hughes. The overall length of the unit is about 1.43m, with a maximum diameter of 73mm. The single-cell membrane section has an L/D ratio of 6. The self-boring of the pressuremeter is accomplished by combined pushing and jetting with drilling mud. The membrane is expanded with air from a small compressor, which passes through a system of valves and

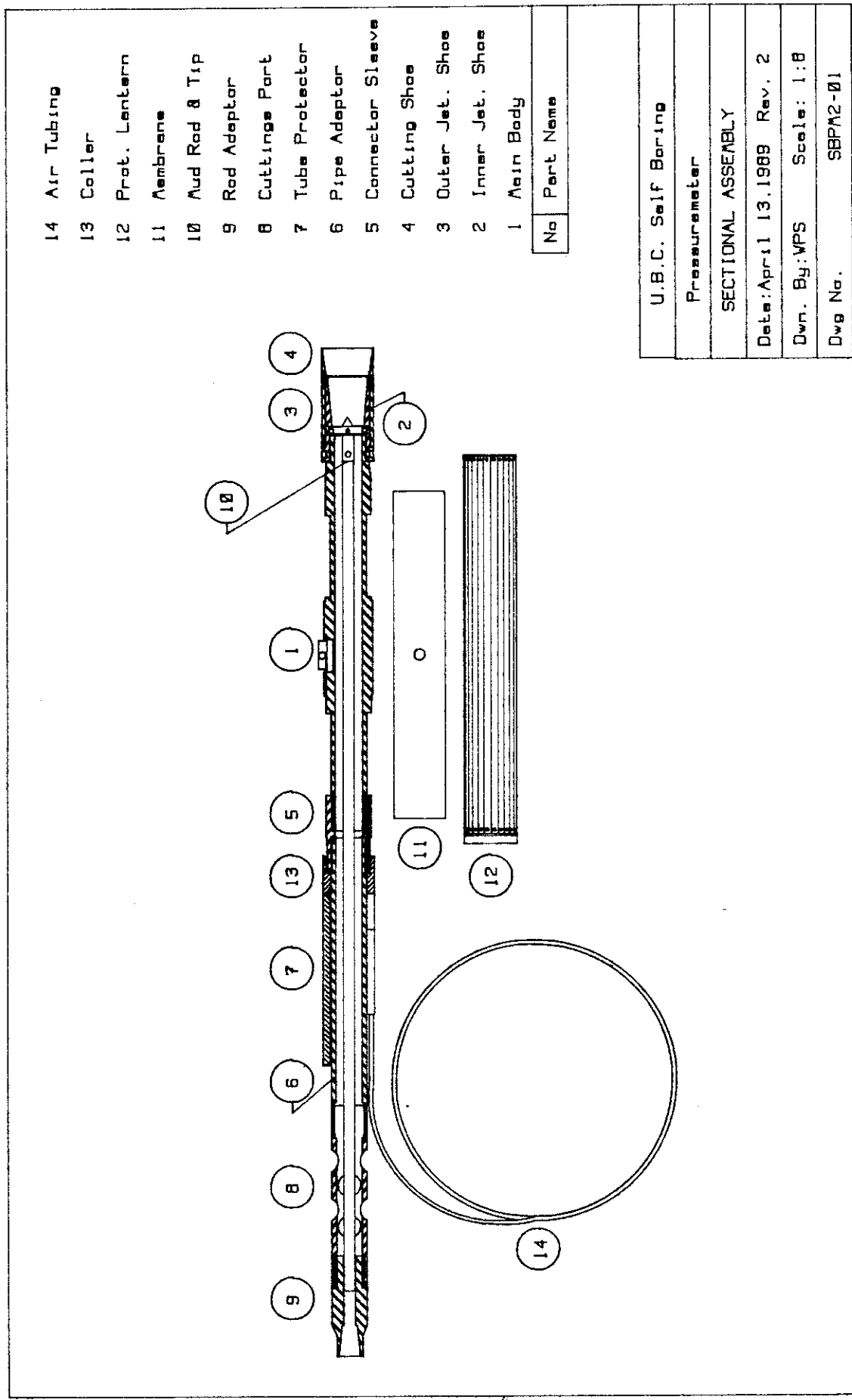


Fig. 1 Sectional assembly of UBC self-boring pressuremeter

meters which control both the pressure and flow rate for load and unload testing stages. The air tubing, which is taped to the drill rods, contains the wires for the electronics. Expansion of the membrane is measured by three strain-gauged cantilever arms.

Instrumentation

The UBC self-boring pressuremeter (SBPM) system consists of 5 transducers, downhole electronics including A/D converter and microcontroller, a DC power supply and a portable personal computer (PC) as shown in Fig.2.

Transducers

The SBPM has 3 cantilever type strain arm transducers for measuring the radial displacement and two pressure transducers, one measuring the inside or inflation air pressure and the other measuring effective soil stress which can be subtracted from the total pressure to obtain pore water pressure.

The displacement transducer consists of a bending beam which has been strain gauged. The beam is made from beryllium copper and is clamped to the pressuremeter body at one end (see Fig.3). Affixed to the free end of the beam is a plastic ball which makes a point contact with the brass

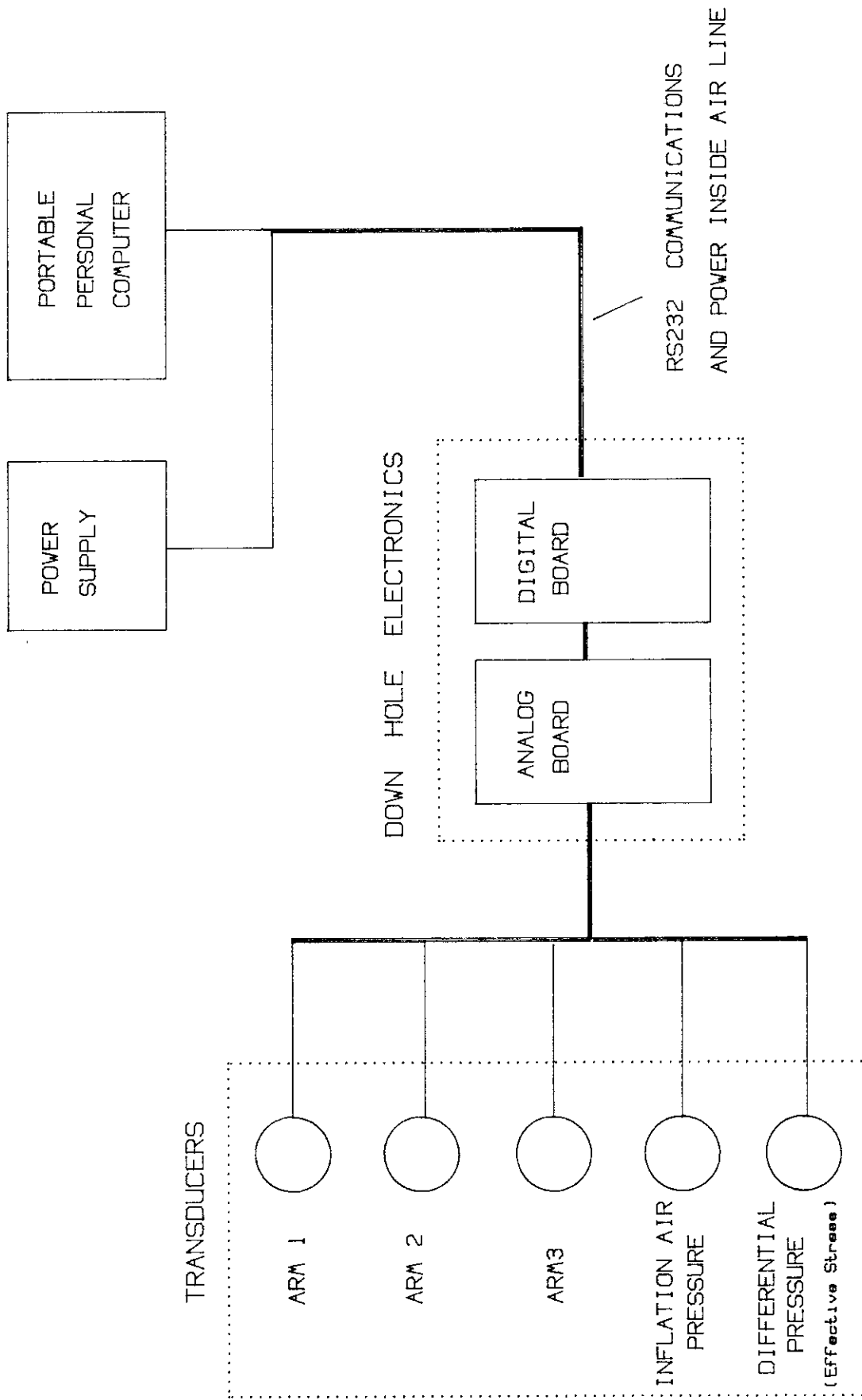


Fig.2 Self-Boring Pressurimeter Instrumentation System

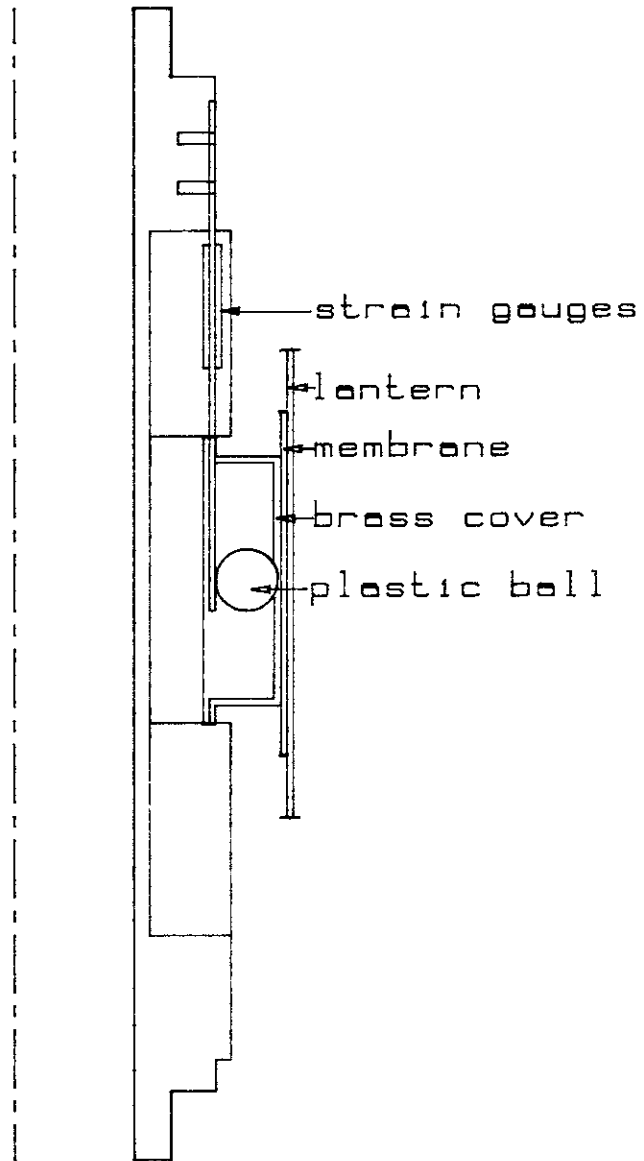


Fig.3 Radial strain arm

membrane follower. Four strain gauges, two on each side of the beam, make up a fully active 4-arm resistive bridge that is mounted near the clamped end. This arrangement is identical for all three strain arms which are mounted 120 degrees apart at the center of the inflatable membrane. Each transducer has an effective operating range of about 8 millimeters.

The inside air pressure transducer is a subminiature flat diaphragm type and is commercially available from Sensotec (Model F). It is calibrated for the 0 to 1800 kPa range and is mounted on the SBPM body near the end of one of the displacement transducers.

The effective stress transducer is a differential diaphragm type constructed from beryllium copper. A diaphragm strain gauge assembly converts the difference between the outside pore pressure and the inside total air pressure to a small differential output voltage. It is calibrated to work in the +1000 to -1000 kPa range. The transducer is clamped on the membrane and moves inside a cavity machined in the SBPM body. There is a small porous filter element that keeps the soil away from the diaphragm.

Down-Hole Electronics

There are two custom printed circuit boards down-hole; an analog board and a digital board. They are both about 35mm wide by 110mm long and are mounted on two of the three flats machined in the SBPM body.

The analog board contains the voltage regulation circuitry, 5 instrumentation amplifiers, and an analog to digital (A/D) converter that has a built in multiplexer. The voltage regulators provide 5 volts of excitation to all the transducers, a 2.5 volts reference for the A/D converter and separate supply voltages for the two electronic boards. The instrumentation amplifiers take in all the low level transducer signals and amplify them up to the conversion range of the A/D converter. The amplifier gains are set using Vishay resistors that have been trimmed to provide the appropriate gain for each transducer. The converter, a Linear Technology LTC 1090, is controlled by the microcontroller on the digital board. The LTC 1090 is programmed to resolve the 3 displacement transducer signals into 11 bits (1 part in 2048) and the pressure signals into 10 bits (1 part in 1024). The digital data is then sent to the microcontroller via a high speed serial interface.

The digital board contains an 8 bit microcontroller and some serial communications circuitry. The controller is a

Motorola 68HC811 which has been programmed to take A/D conversions on each channel, convert the raw data to an ASCII format and then send the data up to the personal computer (PC) via a RS232 serial link. The present data rate of 1200 baud allows for about 2 scans per second to be sent up to the PC.

DC Power Supply

The power requirements for the down hole electronics call for + 12 volts at 160 mA and - 12 volts at 20 mA. A Leader LPS-151, a linear type of DC power supply with low output ripple and noise has been used for this purpose. However, two 12 volt batteries would work equally well at a remote site.

Personal Computer (PC)

The serial communications cable from the down hole electronics connects directly into the RS232 port on any IBM or compatible PC. A Sharp PC-7000 portable, and a data collection and display program using Quick Basic, are used to collect data. This program displays the current values of all the transducers in engineering units as well as giving a graphical display. The data can be stored in a disk file and a screen dump of the graph may be printed in the field (see Fig.4).

UBC INSITU TESTING GROUP

File : bian-5b2-3
 Site : Annacis vc virgin2
 Test : 3M

Indicate the desired mode

- 1) Monitor
- 2) Take Baselines
- 3) Test/Cont
- 4) Start New
- 5) Print Screen
- 6) Quit

Enter Selection ? 5

Time	A-1	A-2	A-3	TP	EP
234	-41	-62	32	16	19
234	-41	-62	28	16	19
234	-41	-62	28	16	17
234	-37	-62	24	16	17
235	-41	-58	24	14	17
235	-37	-62	20	12	17
236	-37	-58	20	12	14
236	-37	-62	16	12	14
237	-37	-58	12	12	14

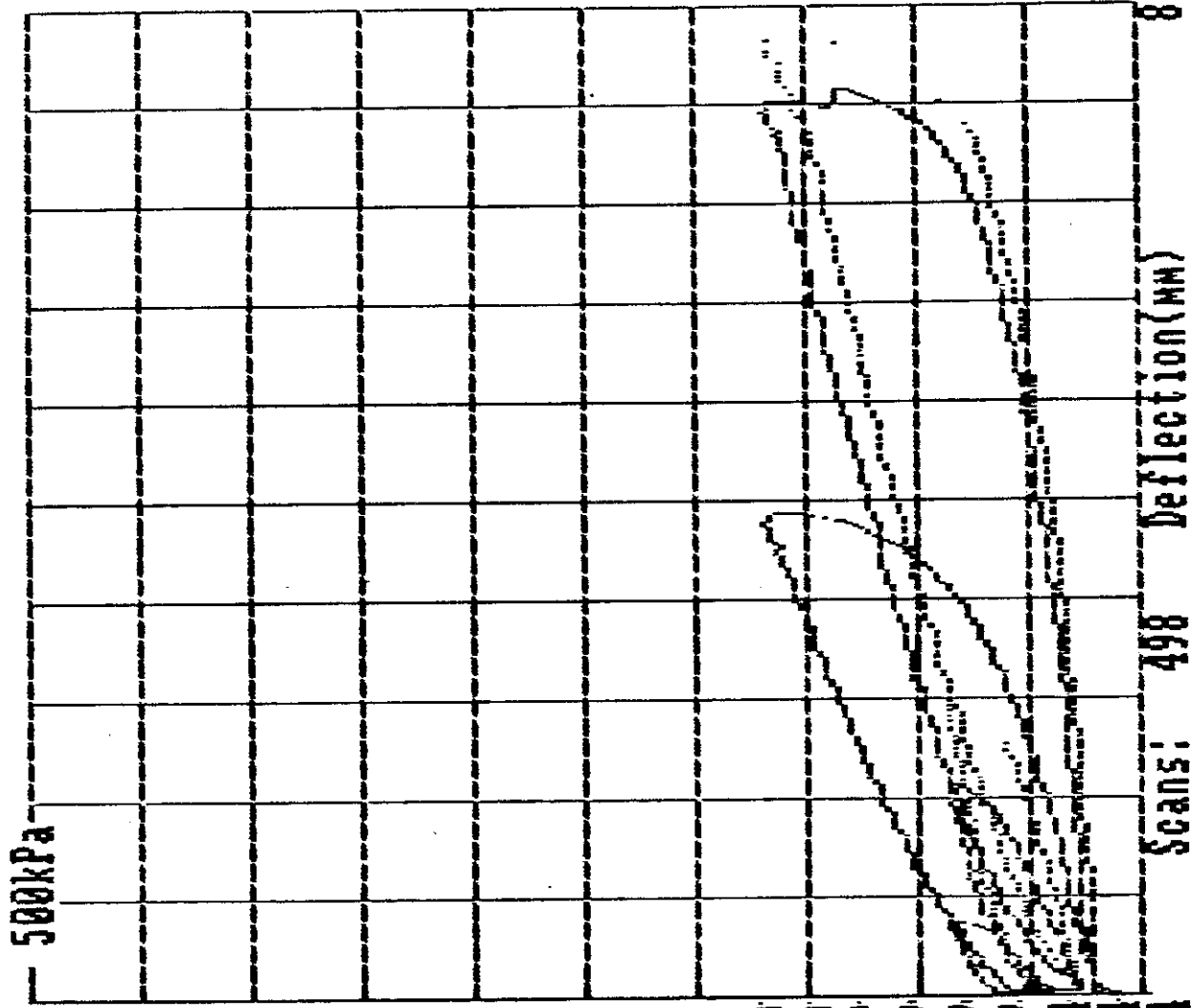


Fig.4 Typical screen printout

The screen dump includes the file name, site location and hole, and test depth in the upper left corner, followed by a series of questions used to control the program. The lower left section shows the latest nine scans of the five transducers. The data shown indicates the sensitivity of the system, about 4 micrometers for the lateral strain arms (A-1, A-2, A-3) and 2kPa for the pressure transducers (TP for total pressure and EP for effective pressure). The right side of the screen print is a plot of the inflation pressure versus the deflection of each arm. An alternate format is to plot against the deflection of just one arm. Data stored on the disk can be easily manipulated with a spreadsheet program to obtain membrane correction, averaging, strain, etc. and results can be plotted for viewing the results (see Fig.5).

Instrumentation Design Considerations

Some of the major factors involved in the electronics design were the amount of space available in the probe, the resolution of the data and the number of wires needed in the air line.

The space available in the probe was limited, the most imposing condition being the height. This limited the usage of some components in the design such as capacitors

Self Boring
Pressuremeter
McDonald's
Farm
MF8801
3.0m
Date: 10-24-88

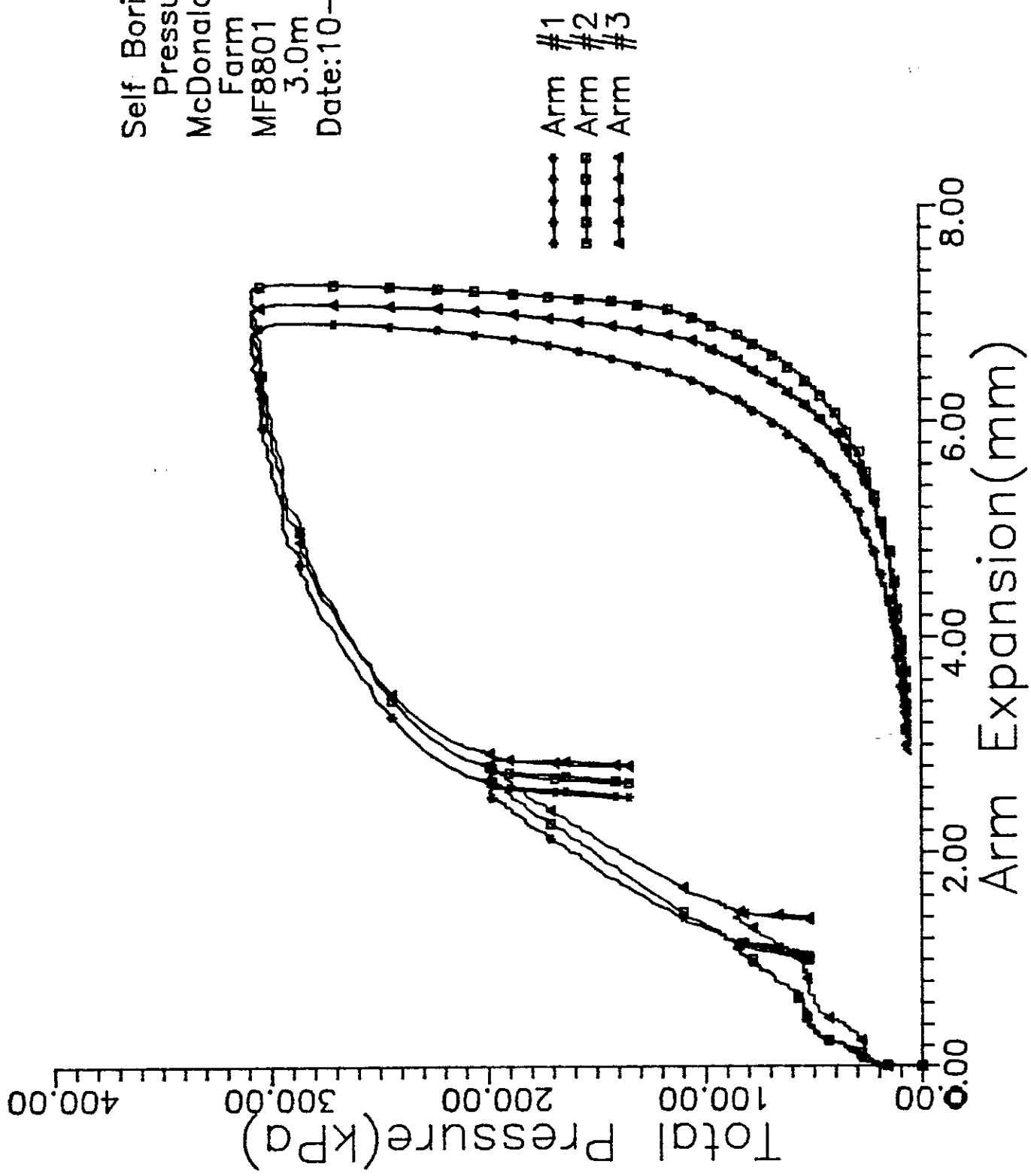


Fig.5 Typical final plot

and connectors. Most of the components used had to be carefully spaced out and some were surface mounted parts. Constraints of the LTC 1090 converter prevented the use of 11 bit resolution on all the channels. Therefore, based on previous pressuremeter research, it was decided to give the displacement transducers the maximum resolution. All resolutions used were found to be adequate.

The air line was also limited in size (6.4mm OD, 0.8mm wall). It was determined that only 6 - 24 Awg. wires could fit in the tube without impeding the air flow appreciably. This small number of wires was a factor in choosing to digitize the data downhole and send it up on a serial link.

Other factors considered in the design were the type of serial communication and the power consumption. The air line, in which the serial link is found, is 30 meters long and so RS-232 communications were used. A longer link would have required a differential serial interface such as a RS-485 interface. The RS-232 link is preferred since it can be directly input to a PC without going through a serial conversion unit (RS485 - RS232). By using the 68HC11 and the LTC 1090, the overall current consumption was kept quite low, about 160 mA overall. This makes future battery operation quite feasible.

Membrane Corrections and Protection

A variety of elastic materials have been used for pressuremeter membranes. The membranes are often robust for durability, but thicker materials also require much larger corrections for expansion in air. As well, more robust membranes often have a correction that varies with strain. Hers(1989) showed both linear and hyperbolic pressure-expansion variations with expansion pressure corrections exceeding 100 kPa.

A tubing of commercially available Gooch rubber, about 1mm in thickness and 58mm in diameter, was obtained for evaluation as a membrane material. Expansion in air gave a trilinear envelope, rising to about 12 kPa with 0.1mm expansion, about 17 kPa at 0.8mm and then remaining constant at about 17kPa, with little or no hysteresis (see Fig.6). Tests were also done with double membranes giving a similar shape and a maximum correction of 35 kPa. To estimate lift-off, the expansion initial variation should be considered, but the analysis of the balance of the pressuremeter curves can be done by simply subtracting the 17kPa correction. This low correction value gives greater confidence in measured radial soil pressures, especially in soft soils. For comparison purposes Fig. 6 shows a membrane calibration for a similar sized probe with urethane membrane (Withers et al, 1986). The non-linear shape and relatively large

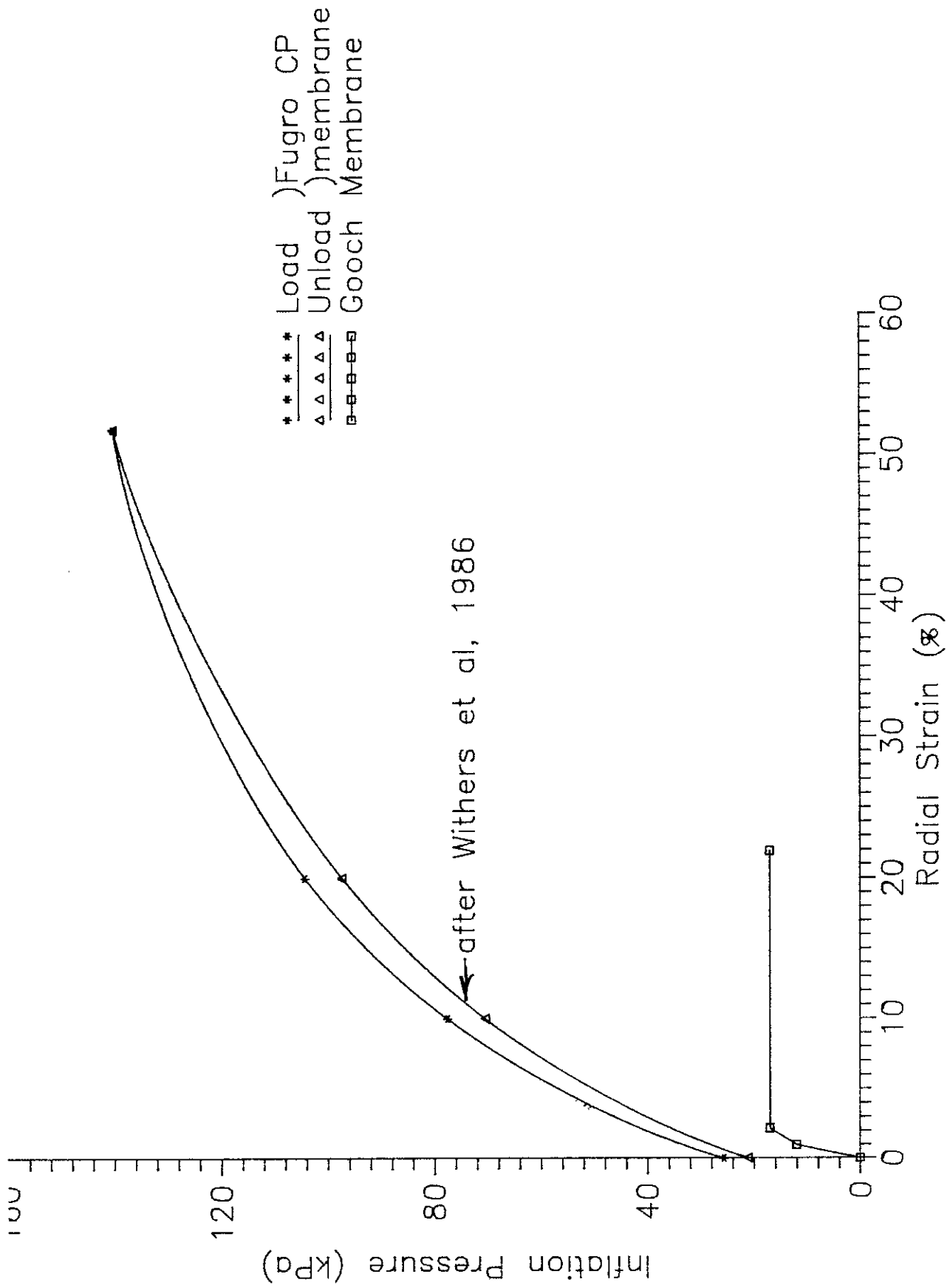


Fig.6 Membrane correction curves

corrections make it difficult to apply corrections to soil expansion curves.

During several tests in a large sand-filled pipe, the membranes broke at pressures of 400 to 600 kPa, and the punctures occurred consistently adjacent to the retaining rings at the top end of the membrane (see Fig.7). Different types of reinforcing tape were tried, but did not prevent the blow-out of the membranes. The original lantern design, similar to that of Hughes, consisted of 24 overlapping stainless steel strips, 16mm wide and 540mm long, riveted to a ring at each end (see Fig.8). In order to have bearing surfaces, the rings had to be placed beyond the ends of the membrane. The strips provided flexibility to the lantern past the end of the membrane, and it is believed that the membranes tended to fold over in the resulting space and break with increasing pressure as shown in Fig.7. An alternate style of lantern was constructed of stainless steel sheet about 0.5mm thick. Ten slots were cut in the plate stopping a short distance from the ends of the expanding portion of the membrane. These slots were backed with 16mm wide strips, which were spot-welded to the sheeting on one side of the slot, to prevent soil ingress. The lower end of the lantern was soldered to form a rigid cylinder and, at the upper end end, two of the slots extend through to the top end to allow mounting and removal. A cylindrical cap is placed over the top to complete the

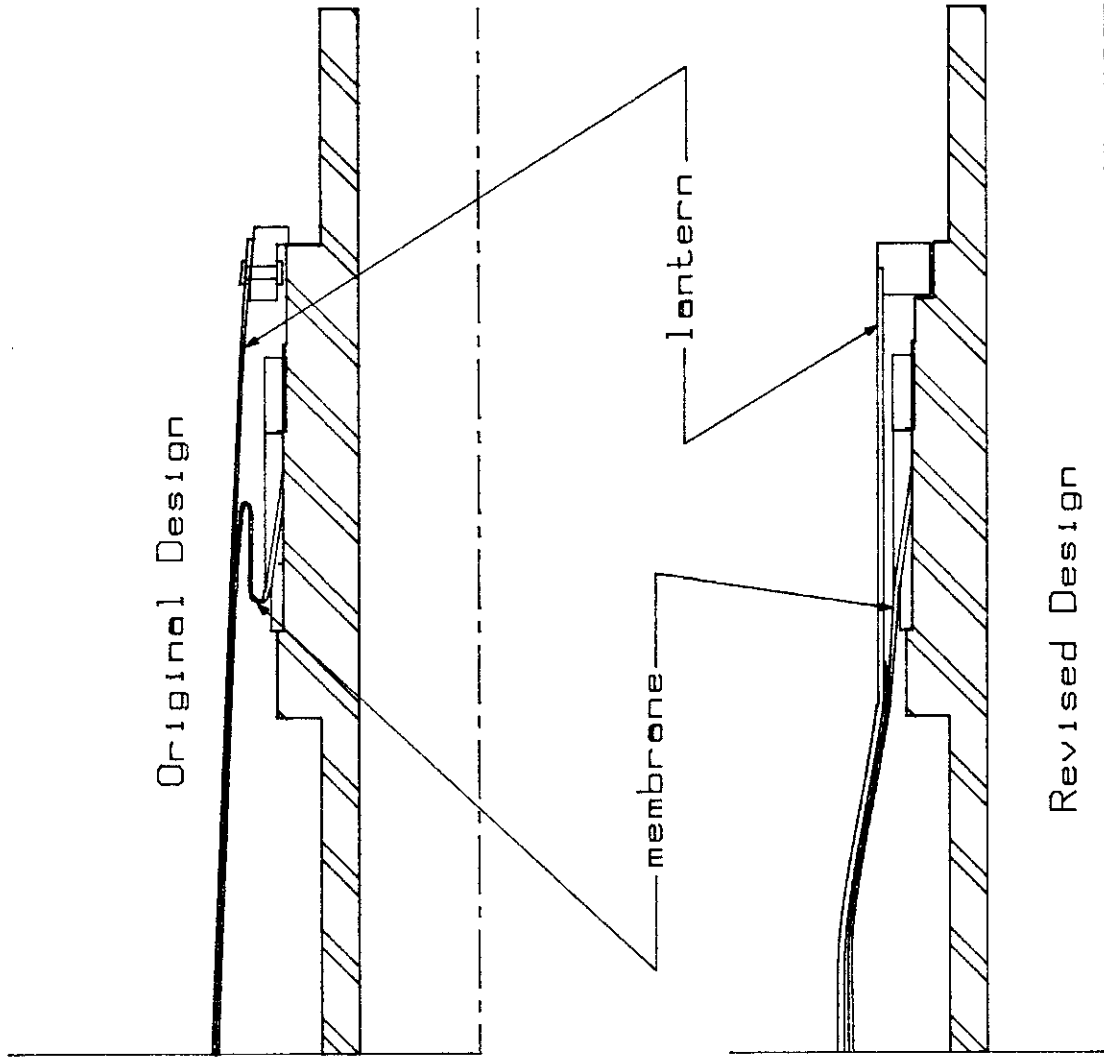


Fig. 7 Possible membrane shapes

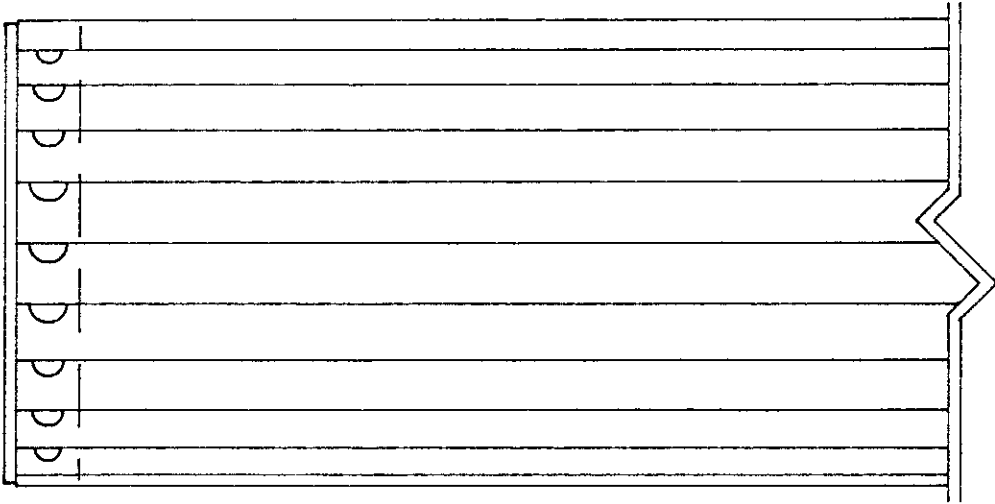
lantern. The new lantern layout is shown in Fig.8 and the expected membrane behaviour is shown in Fig.7. No further blow-outs of the membrane have occurred with this design.

Installation Methods

As a research tool, it is expected that several operators will eventually be using the pressuremeter and it is considered desirable to simplify the installation procedure as much as possible. For this reason it was decided, at least initially, to use only the jetting action of drilling fluid to break up the soil inside the cutting shoe and transport the soil to the surface. This technique is particularly effective in cohesionless soils.

A synthetic drilling mud is mixed with on-site water in barrels. The mud is forced down the centre of standard (35.7mm OD) cone rods by a low cost hydraulically-driven rotary mud pump designed for agricultural spraying. To reduce the wear on this system and to reduce clean-up problems on-site, it was considered preferable to use synthetic drilling additives. Two commercial products, both listed as non-particulate drilling muds or additives, GS550 and WDS120L, were evaluated. GS550 is a powder and is listed as a "granular copolymer of sodium acrylamides/acrylates". Although it mixed fairly readily, the resultant mud seemed to lead to worse clogging of smaller channels in the system

Original Design



Revised Design

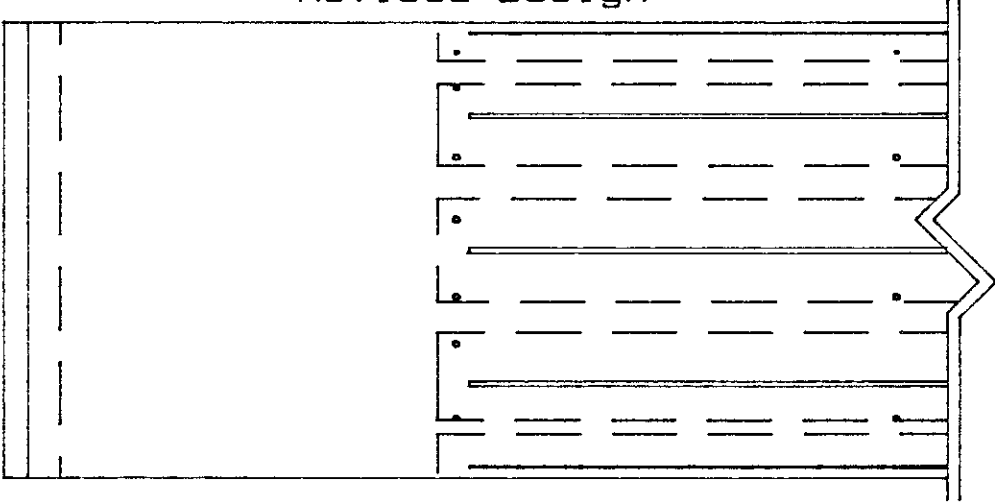


Fig. 8 Lantern Designs

than with plain water. WDS120L is a fluid and is listed as a "liquid avionic polymer". When mixed with water, the WDS120L seemed to provide improved flow characteristics.

At the top of the pressuremeter unit, the mud enters a small rod passing through the central cavity. Two alternate jetting systems have been developed. The initial design was a central jetting system as shown in Fig.9. The central rod is provided with 3 sets of small vanes for stability and a tip in which a series of 2.4mm holes have been drilled. Presently, 4 holes are drilled approximately horizontally, and 4 are at about 50° upwards from the horizontal. Because this rod is not fixed at the base the position can be adjusted in the cutting shoe. The alternate design has been called the "showerhead" (see Fig.10). Near the bottom of the pressuremeter, the mud passes to the outer wall through 4 radial holes, and then passes down 12 channels (4mm by 1.5mm) to form a circle of jets aimed inwards away from the cutting shoe. Presently the jets are about 40mm from the base, but this distance could be adjusted by changing the cutting shoe.

In both designs the mud system somewhat restricts the upward flow of removed soil. For the central jetting system, the maximum size of spheroidal particles is about 12mm, and, for the showerhead system, is about 11mm. Both systems have had limited use, and have had similar successes and problems.

centralizing
wing guide
(3 total)

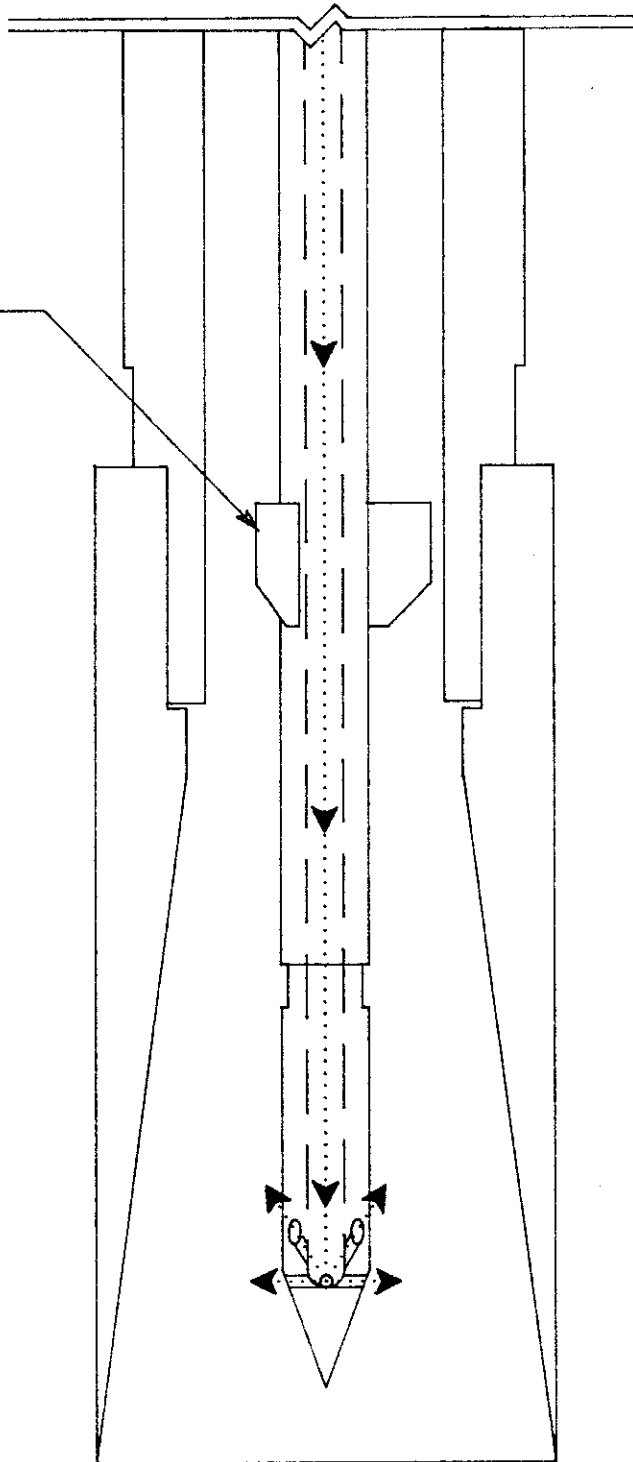


Fig.9 Central jetting system

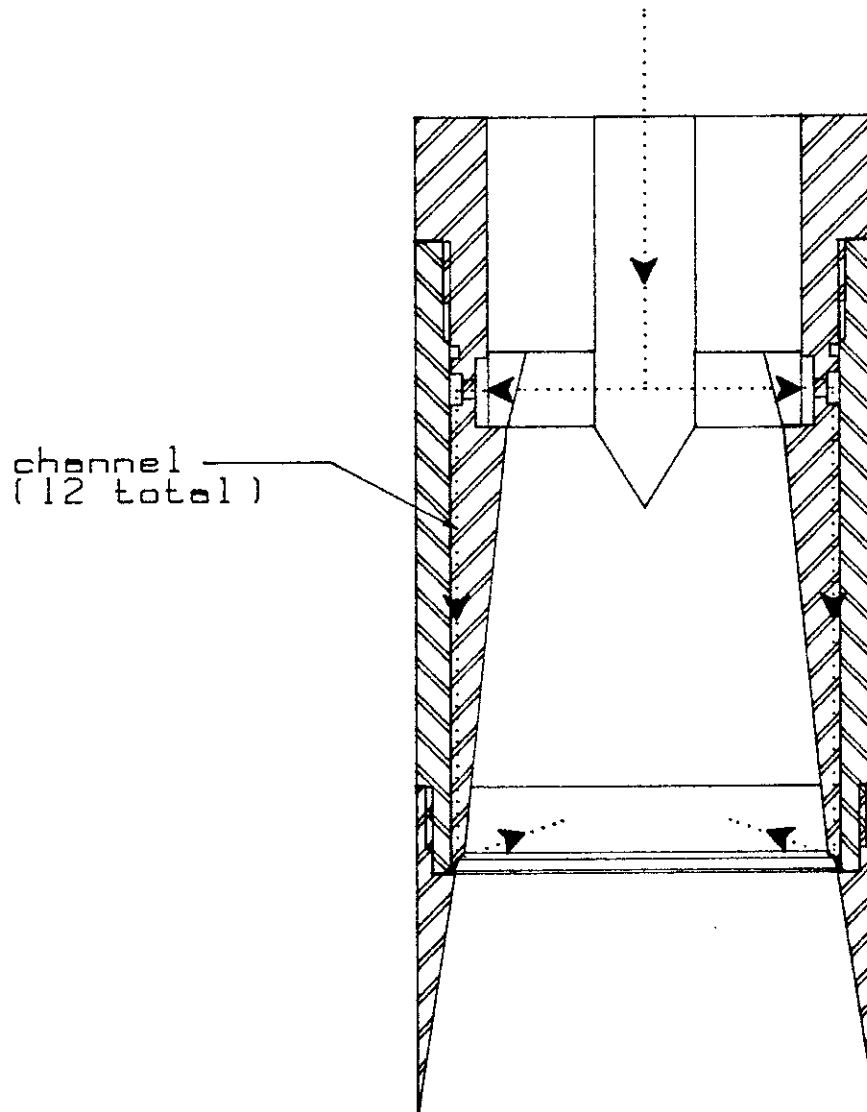


Fig. 10 Cutting shoe with shower jet

Further evaluation of the systems is continuing, to determine the optimal combinations of pushing rate, mud flow rate, bypass pressure, and jet positions.

Summary and Conclusions

Development of the UBC self-boring pressuremeter has led to improvements in several areas of the design. The downhole instrumentation provides a separate amplifier for each transducer, permitting the full use of the A/D converter for each channel. Data is transmitted to the surface in a digitized format thus eliminating the effects of transmission line noise. The surface PC allows viewing of the data in engineering units as the test proceeds, as well as providing a real-time graphical presentation of the test.

A new lantern has been designed that allows the use of thin membranes with a low membrane pressure correction. Two jetting systems have been constructed and are currently under evaluation. Field trials of the UBC self-boring pressuremeter are continuing.

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