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The Subseabed Disposal Program (SDP) of the Department of Energy, managed by Sandia National Laboratories, Albuquerque (SNLA), is studying the feasibility of disposing of high-level radioactive wastes by burial in fine-grained deep-sea sediments. The thermo-mechanical response of these sediments to the thermal gradient and temperatures generated by the decaying radionucleides in a buried waste container is being determined by the SDP-supported In Situ Heat Transfer Experiment (ISHTE). The Naval Ocean Research and Development Activity (NORDA) is responsible for the development and fielding of piezometer probes for measuring the pore water pressure gradients induced by the thermal gradient in the sediment. Pore pressure gradients measured in ISHTE will permit validation of theoretical models predicting the rate of radionucleide leakage from a buried waste container to the overlying seawater column.

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NORDA Contribution to the In-Situ Heat Transfer Experiment: FY84 Annual Report

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November 1985

NORDA CONTRIBUTION TO THE IN-SITU HEAT TRANSFER EXPERIMENT (ISHTE): FY84 ANNUAL REPORT

Philip J. Valent, Richard H. Bennett,
Huon Li, and John T. Burns

November 1985

sponsored by Sandia National Laboratories,
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MARINE GEOTECHNICAL BRANCH
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NSTL, MS 39529

ABSTRACT

The Subseabed Disposal Program (SDP) of the Department of Energy, managed by Sandia National Laboratories, Albuquerque (SNLA), is studying the feasibility of disposing of high-level radioactive wastes by burial in fine-grained deep-sea sediments. The thermo-mechanical response of these sediments to the thermal gradient and temperatures generated by the decaying radionucleides in a buried waste container is being determined by the SDP-supported In Situ Heat Transfer Experiment (ISHTE). The Naval Ocean Research and Development Activity (NORDA) is responsible for the development and fielding of piezometer probes for measuring the pore water pressure gradients induced by the thermal gradient in the sediment. Pore pressure gradients measured in ISHTE will permit validation of theoretical models predicting the rate of radionucleide leakage from a buried waste container to the overlying seawater column.

This report of NORDA FY84 progress in ISHTE describes the results of a laboratory simulation of ISHTE, conducted at SNLA, in which sediment cracking due to probe insertion was determined to not be a problem to the experiment. Specialized equipment developed for ISHTE, in particular a pressure transducer calibrator for ambient pressures to 69 MPa (10,000 psi), is described. Preliminary results gleaned from excess pore pressure data obtained during the ISHTE component test cruise, Sept 84, confirm that sediment cracking due to probe insertion will be slight and will have an insignificant influence on the measured excess pore pressure dissipation rates. Excess pressures generated by insertion of the piezometer probes vary by a factor of two; the reason for this large difference is not known. No significant faults in the NORDA piezometer system were detected either in the laboratory simulation at SNLA or in the component test in 5800 m water depth north of Hawaii.

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The authors thank Charles Hickox, Joel Lipkin, Mark Percival, Les Shepard, and Dave McTigue, all of Sandia National Laboratories, Albuquerque, for making the ISIMU-II tests possible. Charles Hickox prepared the sediment sample used in the test, and made all arrangements for the necessary equipment. We thank Jack Miller and John Backes of the Applied Physics Laboratory, University of Washington, for helping us during the component test cruise in identifying and correcting our errant oscillator; Vern Miller, APL, for helping us in checking and recycling our probes; and Tom Aufrance, APL, for preparing the data plotting software for us on the MELVILLE. Lastly, we acknowledge the expert machining work of David Young, NORDA, in fabricating the transducer calibrator, and those efforts of Lee Nastav, NORDA, in preparing the illustrations for this report.

TABLE OF CONTENTS

NORDA CONTRIBUTION TO THE IN SITU HEAT TRANSFER EXPERIMENT

INTRODUCTION

Objective of Subseabed Disposal Program

The Subseabed Disposal Program (SDP) is evaluating the feasibility of emplacing high-level nuclear wastes in fine-grained deep-sea formations of the ocean basins (Hollister et al., 1981). The SDP is funded by the U.S. Department of Energy and managed by Sandia National Laboratories, Albuquerque (SNLA). The SDP supports the In Situ Heat Transfer Experiment (ISHTE) to gather data describing the in situ response of deep-sea sediments to a thermal gradient.

NORDA Contribution to SDP

The Naval Ocean Research and Development Activity (NORDA) is participating in the SDP by developing, fielding, and analyzing data from a set of deep-ocean porewater pressure probes. Three probes were fielded on the component test platform in September 1984 and five probes were fielded on the prototype platform in September 1985. The NORDA probes measure the excess porewater pressures induced by the thermal gradient set up by the heat dissipating from the simulated radioactive waste cannister. These excess porewater pressures describe the porewater pressure gradient driving the porewater flow in the vicinity of the radioactive cannister, and permit a reliable prediction of the rate of radionucleide leakage to the overlying seawater column in the event of cannister leakage.

NORDA's FY84 contribution to the SDP was performed under SNLA Order No. 58-5880.

Scope of Report

This report presents an overview of the NORDA contribution to ISHTE.

LABORATORY SIMULATION OF ISHTE

ISIMU-I

<u>Piezometer Data Analysis.</u> During the latter part of 1981, a laboratory simulation of ISHTE, named ISIMU-I, was conducted at the David Taylor Naval Ship Research and Development Center in Annapolis, Maryland. A 0.287-scale, electric-powered model of a radioactive heat source was embedded in an instrumented container of reconstituted sediment dredged from the MPG-I Pacific experiment site. The entire assembly, including two NORDA designed and operated piezometer probes, was placed in an environmental test chamber and the pressure and temperature maintained at 550 bars and 4°C to simulate

seafloor conditions at MPG-I. Analysis of the piezometer data was delayed by development problems with the NORDA high-pressure transducer calibrator (development of the calibrator will be discussed later in this report). The ISIMU-I piezometer transducers were calibrated in FY84 at 550 bars ambient pressure and these calibrations were used to reduce the ISIMU-I experiment data.

Some early ISIMU-I piezometer results were presented in Bennett et al., 1985, and a final report is in preparation. Undrained shear strengths derived from the insertion pore pressures measured by each piezometer were found to be in reasonable agreement with the undrained shear strengths measured by miniature vane shear tests on sediment cores from the test tank. The low insertion pore pressure measured by Piezometer Probe 1 (that probe 15 mm from the 23.7 mm diameter heater probe) suggests a 51% reduction in undrained sediment shear strength in the near-field of the heater probe, as compared to the far-field sediment strengths, due most likely to remolding of the sediment during the insertion of the heater probe. Piezometer Probe 1 also measured a much more rapid decay of this insertion excess pore pressure, as compared to the far-field probe, strongly suggesting a much shorter drainage path for Probe 1. Severe cracking of the surficial sediment was observed during heater insertion and this cracking was aggravated by insertion of the other sensor probes used in ISIMU-I. The coefficients of permeability and consolidation derived from the piezometer data decay curves were also of the same range as those measured on core samples. Detailed results will be presented in the NORDA final report on ISIMU-I piezometer probe and transmission electron microscopy results.

Microstructure Studies. Clay samples collected from the ISHTE simulation test and selected subsamples from RAMA were investigated by electron microscopy techniques. This was a cooperative study coordinated by NORDA (R. Bennett and H. Li) and included Sandia National Laboratories (L. Shepard), Texas A&M University (W.R. Bryant and P.J. Burkett), and Reserviors Inc. (W. Chiou). Transmission Electron Microscopy was carried out at TAMU and Scanning Electron Microscopy was completed by W. Chiou (Reserviors Inc.) and G. Romero (NORDA). Details of the subsample locations in reference to the ISHTE simulation cores are found in Bennett et al., 1984. A draft report of the initial results of the study was completed in FY83 at TAMU. A final report of the clay microstructure effort is currently near completion and is expected to be finalized by the first quarter of FY86. This final report will include both descriptive and semi-quantitative analysis of the clay fabric and the significance and relationships of the fabric to mechanical disturbance (probe insertion and sediment remolding effects), relationships of RAMA control samples to remolded samples, and the influence of high temperatures on the clay microstructure.

ISIMU-II

Purpose of Experiment. As noted above, ISIMU-I produced two unexpected results. First, for a given heater power level, the measured heat delivered to the surrounding sediment was approximately 25% lower than that predicted based on pretest measurements of the sediment properties (Percival, 1983). The second unexpected result was that the excess pore pressure probe in the near-field (15 mm from the wall of the heating element) was approximately onehalf that at the far-field pore pressure probe (342 mm from the heating element) (Bennett et al., 1984). To help clarify the reasons for these unexpected ISIMU-I results and, in particular, to help determine whether or not sediment cracking about the heater and the probes might contribute to these results, a second laboratory simulation of ISHTE, this one called ISIMU-II, was conducted at Sandia National Laboratories, Albuquerque, on 2-5 April 1984. The results of ISIMU-II are reported in Riggins et al., 1985, the highlights of which are described below.

Description. The sediment used in ISIMU-II was the same illitic pelagic clay, from MPG-I, used in the ISIMU-I experiment. The test tank assembly and sediment sample preparation was carried out by SNLA (Hickox and McTigue, 1983). The consolidated sample was 0.43 m in diameter by 0.71 m high. Measurements made on peripheral sediment cores taken after the probe tests showed the sediment water content to be fairly uniform, averaging 88.0%, and the undrained vane shear strength to average 4.1 kPa (0.59 psi). Two piezometer probes 7.9 mm (5/16 in) in diameter and one heater probe 23.7 mm (0.94 in) in diameter were used in this experiment. First one piezometer was inserted vertically into the sediment specimen and the excess pore pressure decay observed, then the heater was inserted and again decay was monitored, and then the second piezometer was inserted on the side of the heater opposite the first piezometer and decay was monitored. The clear space between the heater and each piezometer was 15 mm as in ISIMU-I (Figure 1). After the insertion pressures had essentially dissipated, the heater probe was powered up to 29.4 watts and maintained for 251 min while the impact of the changing thermal field on the excess pore pressures was monitored. The complete pore pressure experiment history is shown in Figure 2.

Cracking due to Insertion. Some surficial cracking of the sediment was observed generated by the probe and heater insertions, but this cracking appeared due to a near-surface "spalling" of the sediment. This cracking appeared to penetrate to a sediment depth of less than one probe diameter. No evidence of sediment cracking to an extent measurable by the piezometer probe transducers, i.e., ± 0.3 kPa (± 0.05 psi), could be found in the data (Riggins et al., 1985).

Insertion Pore Pressure Model. The probe insertion problem was modelled as the expansion of a cylindrical cavity, using solutions developed by Soderberg (1952) and Randolph et al. (1979). The procedures used are the same as those presented in the FY83 Annual Report (Bennett et al., 1984) and in Bennett et al. (1985), except for the addition of a "smear factor" proposed by Scott (1963). The smear factor, m, accounts for the reduced permeability of the remolded sediment along the piezometer probe wall. The smear factor modifies the rate of excess pore pressure dissipation described by

$$u/u_{max} = e^{-\beta t} \quad \text{..........} \quad (1)$$

by modifying the parameter β from

$$\beta = (1/m) \times (c_h/r_o^2) \quad \text{..........} \quad (2)$$

The smear factors, m, necessary to achieve a calibration of analytical model to the measured data from ISIMU-II were 2.3 and 4.6 for the two piezometers.

The sediment horizontal coefficient of consolidation obtained by curve fitting procedures for the two piezometers were 3.21×10^{-4} and 2.34×10^{-4} cm^2/sec The reader is referred to Riggins et al. (1985) for further information.

Thermal Pore Pressure Model. Riggins et al. (1985) presented an original, empirical model of the excess pore pressure history around the heater probe resulting from the thermal field. This model first predicted the increment in excess pore pressure due to an increment in temperature increase at the heater, and then superimposed the horizontal dissipation of excess pore pressure with time. The comparisons of model predictions with measured data from ISIMU-II are shown in Figures 3 and 4. These figures show the calculated excess pore pressures as the heater warmed the surrounding sediment with no pore pressure dissipation, then the excess pore pressure with dissipation included in the calculation, and finally the data measured by the piezometer probes. The developed model described the thermally induced excess pore pressures very well. However, further checking revealed that the model predicted sediment temperatures at the piezometer probe locations that are far lower than expected. Therefore, the model of Riggins et al. (1985) cannot be considered a validated tool.

Dave McTigue, SNLA, has developed a more descriptive model of the thermal pore pressure problem (McTigue, 1985), however, this model too requires further validation and calibration.

In short, the thermally induced pore pressure model remains an outstanding issue of the ISHTE project.

PREPARATION FOR ISHTE COMPONENT TEST CRUISE

Transducer Calibrator

Description. The high pressure transducer calibrator (Figure 5), designed and built at NORDA to calibrate differential fluid-pressure measuring transducers to an accuracy of 0.35 kPa (0.05 psi) at ambient gage pressures of 0 to 68.9 MPa (0 to 10,000 psi), was improved during FY84. After the correction of a few minor problems, the calibrator was successfully used to calibrate the three transducers used in the September component test cruise.

The transducer calibrator is a one-of-a-kind unit designed to operate inside a Benthos High Pressure Chamber in NORDA's High Pressure Test Facility (Figure 6). The calibrator applies ten 6.89 kPa (1.00 psi) increments of differential pressure to the transducer being calibrated by placing weights (1) on a piston (2) connected hydraulically to the positive side of the transducer (Figure 5). The present ten weights give the calibrator a range of 0 to 69 kPa (0 to 10 psi), although weights of different mass could be fabricated to alter the calibration increments and range.

Improvements. The transducer calibrator has as one of its components a small solenoid valve having as one of its attributes a negligible volume change on opening or closing. This valve is installed on the positive side of the transducer and is used to maintain this hydraulic circuit open to the ambient pressure in the pressure vessel during pressurizing. During the calibration of the transducer this valve is closed and must maintain a tight seal; otherwise, a slight leak will appear in the measured data as transducer drift.

In November - December 1983, two of these valves, of the LFYX series manufactured by the Lee Company, Westbrook, CT, started to leak after being immersed in a dielectric fluid (FC-40 manufactured by 3M) for 1000 hours and 150 hours respectively. During its life, neither valve was cycled more than 25 times. The problem appeared to stem from an incompatibility between the FC-40 fluid and plastic components in the valve. To correct the problem and to maintain the project schedule, a two part effort was initiated: (1) design of a solenoid - actuated ball valve, where the components were known to be compatible with the FC-40 fluid, was begun, while (2) an investigation into the causes of the failures of the LFYX series valves was carried out. A suitable ball valve design driven by a linear-acting solenoid, with satisfactory electric power demands, was developed to the sketch and materials list level. In the meantime, the two failed valves were examined by The Lee Company. The Kalrez sealing surface was found to be swollen to such an extent that the plastic had ruptured. The swelling was attributed to the saturation of the base polymer of the Kalrez by the active fluorine chain of the FC-40, displacing the fluorine in the polymer, and causing the plastic to swell (Simonich, 1984). Given this identification of the problem, we then proceeded to look for a dielectric fluid that would be compatible with the Kalrez sealing surfaces and with the other materials in the calibrator and transducers. A suitable candidate was found in the DC-200 series fluids manufactured by Dow Corning.

Transducer Calibration. The three differential pressure transducers to be used in the ISHTE component test cruise were calibrated using the calibrator in the high pressure test facility. Each transducer was first calibrated in the closed pressure vessel but at ambient atmospheric pressure. Three complete loading and unloading cycles, from 0 kPa to +69.0 kPa and back to 0 kPa, were run. Weights were applied and removed one at a time, in 6.90 kPa increments. Then the transducers were brought to an ambient pressure of 60 MPa (19,000 ft water depth) in ten steps. The system was maintained at this pressure for two hours to dissipate the heat generated by compression of the system (temperature rise estimated to be about 2° C). (Note: The temperature rise is a calculated value; the facility presently does not have the capability to monitor temperature within the pressure vessel, but this capability is planned). After the two hour period for temperature equalization, the transducer calibration procedure used at atmospheric pressure was repeated. After reducing the pressure in the vessel to atmospheric, the transducer calibration was again run three times.

The calibration curve for each transducer exhibits linearity to within the design specification of ±0.05 psi (±0.35 kPa). The calibration curves, of which the data in Figure 7 is typical, do show however that pressurization of the DP-9 model variable reluctance differential pressure transducer made by Validyne does result in a zero shift in the calibration in response to the first loading to 60 MPa. This zero shift is believed due to permanent deformation of the epoxy matrix in which the sensing coils of the transducer are potted. The zero shift is a one-time occurrence; no significant additional shift is observed on subsequent pressurizations. Thus the zero shift noted is not a problem because it is removed during the initial calibration before the transducer is fielded.

Some slight "creep" of the system occurs after the application of each load increment, whether at atmospheric pressure or at 60 MPa (Figure 8). A minimum of 5 min interval was maintained between the application of successive load increments to ensure that the rate of creep had essentially reached zero. The creep effect noted in the data is believed due to stretching of the neoprene bellows-type diaphragm used beneath the piston of the calibrator (Figures 5 and 9). This fabric-reinforced neoprene bellows appears to deform predominantly in an elastic mode on application or removal of a loading. However, there appears to take place some additional deformation, suggesting that the load of the applied weight is not immediately totally transferred as a hydraulic pressure to the transducer, but rather the bellows initially supports some of the applied load. Other options for transferring the weight of the loading weights to the hydraulic system have been sought, but no improved technique has been identified.

Electronic Interface

Description. Fabrication and testing of the electronic interface between the NORDA piezometer sensors and the APL control and data acquisition systems was completed in FY84; the interface was successfully fielded with the piezometers on the component test cruise. The interface controls the piezometer probe electronics for proper data transmission to the APL data acquisition systems, resetting all of the digital integrated circuits to a known condition with each order to power up, and converting the analog data from the piezometers to digital data for APL master system acquisition and storage. A more detailed description of the electronic interface function is given in Bennett et al., 1984.

Testing and Modification. The piezometer system electronic interface was tested at The Applied Physics Lab., University of Washington (APL/UW) during the last week of March 1984. The transfer of data signals between the NORDA piezometer system and the APL control system was performed successfully; however, the interface appeared to be responsible for some cross talk between channels and to be producing an excessively high noise level. The identified problems were corrected by changing a suspected integrated circuit chip. The piezometer electronic interface and voltage source were returned to APL on 25 - 26 April, where Jack Miller found all problems to be corrected. The piezometer system pressure cases, one to house the interface, the other to house the piezometer system battery pack, were pressure tested at the Benthos pressure testing facility in Falmouth, Massachusetts, on 13 - 14 April 1984. The two cases were tested to 66 MPa (9,500 psi) with no sign of leakage or case failure. After the tests, large surface irregularities, or surface ripples, were discovered; however, close inspection indicated that the ripples were the result of poor machining rather than deformation during the pressure test. John Burns, NORDA, participated in the fresh water wet test of the assembled component test platform in June; the piezometer system behaved properly in this test. The piezometer system electronic interface did develop a problem in an oscillator circuit during set-up for the component test cruise. A solid state oscillator proved to be unstable, doubling its output frequency. The change to a more stable component required a new subcircuit design which was supplied by APL/UW.

Piezometer Probes

The mechanical performance of one assembled piezometer, including the hydraulic latch mechanism and hydraulic drive system, was checked during the mechanical fit tests at APL during late March 1984. Some minor assembly problems were identified and solutions to all identified by APL. A question arose regarding the adequacy of the hydraulic drive system to insert the piezometer probes. John Burns measured the force required to move the 8 mm (5/16 in.) diameter probes through the two O-ring seals in the nodule knocker and into the pelagic clay sediment at the MPG-I site. A piezometer probe with nodule knocker was set-up over a core of a pelagic clay of about the strength expected at MPG-I, and dead loads were applied to the top of the probe. Movement of the probe was initiated at an added load of 39 N (8.8 lb) but movement stopped after 50 mm travel. Movement was sustained by a load of 49 N (11 lb). During this test the probe surface and O-ring seals were lubricated by fresh water only. All three piezometer probes were exercised in the fresh water wet test of June 1984, and performed as planned. Performance of the piezometer probes during the FY84 component test cruise will be reserved to the next section.

Core Processing Plan

NORDA (Phil Valent) participated with URI (Armand Silva) in the development of a core processing plan for the FY84 component test cruise. NORDA requested that hydraulic permeability of the MPG-I samples be measured both in the vertical and in the horizontal directions. The permeability data are necessary as a check on the performance of the excess pore pressure dissipation model being used. Both vertical and horizontal permeabilities should be measured because the magnitudes may be significantly different. A request for these data, measured on core samples taken from elevations at the heater mid-point and slightly above and below the heater, was transmitted to URI.

Valent assisted Silva in the development of the core processing plan at the ISHTE Project Planning Group meeting of 25 - 26 April 1984. This core processing plan was modified slightly, issued (Silva and Levy, 1984), and followed during the component cruise.

PARTICIPATION IN COMPONENT TEST CRUISE

Participation

Phil Valent and John Burns participated in the FY84 ISHTE Component Test Cruise during the period 6 Sept through 7 October 1984. All aspects of piezometer system function were tested during the second lowering of the ISHTE platform, except three probes were used instead of the full suite of five to be used in the one-year deployment, and the second pressure case with added batteries to power the piezometer electronics was not needed and not fielded.

The piezometer probe driving sequence was arranged so that two probes, one at a wall-to-wall distance of 0.13 m from the heater probe, and a second at 0.64 m, were driven first to measure the excess pore water pressures generated by insertion of the probes in undisturbed sediment. The third piezometer probe was driven in the near-field, 0.13 m from the heater wall, after the heater probe had been driven, to measure the impact of prior sediment disturbance on the excess pore pressures generated by insertion.

Equipment Performance

During checkout of the large component test platform electronics system, an intermittent data reception problem was detected. The problem was traced to an oscillator in the piezometer electronics interface; i.e., the oscillator would not maintain one frequency but would intermittently double its output frequency. The oscillator circuit was modified to use a higher frequency, more stable oscillator, and no further problems were encountered with the NORDA piezometer electronics system.

During assembly of the piezometers, one of the three was noted to be leaking dielectric fluid from the negative side reservoir. Electrical tape was wrapped over the leaking joint as a field fix; this solution did perform adequately with the problem piezometer system showing no more fluid loss than the other two when checked before and after deployment. Change of this seal to a new design was considered to prevent potential repeat problems; however, the decision was made to cope with this sealing problem by providing several replacement O-ring seals because the leakage appeared due to difficult-to-avoid damage to the O-ring during probe assembly. The selected solution is cost effective and appears adequate. A final judgement of the adequacy of the leakage solution will be made after reviewing probe performance in the Sept 85 ISHTE platform test.

While partially disassembling the piezometers to check the reservoir fluid levels and to reset the displacement measuring system, it was noted that the Delrin plastic nodule knockers were sticking in their exterior tubes. Sticking of the nodule knockers is not easily detected until after the probe tip has been pulled from its sealed area in the nodule knocker, at which time piezometer saturation on the positive side of the piezometer system has probably been lost. The sticking problem arose from three observed conditions: (1) slight ovalling of the exterior piezometer implant tubes by the U-bolt clamps used to fasten the piezometers to the platform, (2) very close fabrication tolerances between the exterior tube and the nodule knocker, and (3) swelling of the Delrin plastic nodule knocker in sea water. APL decided that the problem was best corrected by changing the clamp design to reduce ovalling of the tube and by changing the nodule knocker design to a two piece design to eliminate the potential for losing piezometer saturation.

The system for locking the probe tip in the nodule knocker also showed need for improvement. The locking system consisted of two set screws set at opposite sides of the nodule knocker and intended to be tightened down and prevent relative movement between the probe tip and the nodule knocker. The two opposing set screws caused the probe tip to displace laterally in the knocker and caused a loss of seal around the porous stone. Two more set screws were added to the lock design, to give four set screws set at 90° from each other around the tip axis to limit unwanted deflection within the seals.

Preliminary Results

Insertion Pressures. All three piezometers produced reasonable data. The data from piezometer probe PP-1, the first driven, presented in Figure 10, shows the excess pore pressure response due to insertion of PP-1 itself followed an hour later by the response due to insertion of the heater probe at a wall-to-wall distance of 108 mm (4.2 in). The third group of data shows the response of PP-1 to the insertion of piezometer probe PP-2, on the opposite side of the heater at the same wall-to-wall distance, some 2.8 hours after PP-1 insertion -- PP-2 insertion has no identifiable influence on PP-1 data. Note here that the maximum stable excess pore pressure due to insertion is about 15 kPa (2.2 psi).

Piezometer probe PP-3 (see Figure 11), inserted 39 sec after PP-1, exhibits a much higher insertion excess pore pressure of 30 kPa (4.3 psi) than measured at PP-1. The reason for this factor of two difference in insertion pressures is not known, although other behavioral differences point to PP-1 data as being abnormal (see following data for PP-2). Also note the slight impact of the heater insertion on the excess pore pressures measured at PP-3, 670 mm (26.3 in) wall-to-wall from the heater probe.

Data from piezometer probe PP-2, presented in Figure 12, shows the inactive status of that probe during the first two pore pressure events followed by its response to insertion approximately 2.8 hours into the pore pressure experiment sequence. PP-2 shows an insertion excess pore pressure of about 17 kPa (2.4 psi) in this sediment zone disturbed by the heater probe insertion. Note that the dissipation curve has been shifted to correct for the effects of pore pressure dissipation from the heater probe insertion, which the measured data include.

Dissipation Curves. Dissipation curves for PP-1, PP-3, and PP-2 are expanded in Figures 13, 14, and 15 to highlight the quality and consistency of the data obtained. Although the magnitudes of the insertion pressures vary from probe to probe, the shapes of the dissipation curves are similar indicating like dissipation rates and indicating that no cracking or conduits for accelerated dissipation of excess pore pressures to the surface were created or existed naturally. The dissipation curve for piezometer probe PP-1 responding to insertion of the heater probe is presented in Figure 16. Heater probe insertion had begun 83 sec before the first data point of this series and insertion had been completed 49 sec before the first data point taken. The hump in the excess pore pressure curve measured at PP-1 in response to the heater probe insertion has obviously been missed during the intervening 49 sec.

The insertion pore pressure dissipation data can be used to determine the coefficient of consolidation, c_v, and the coefficient of permeability, k, of the sediment in situ. Soderberg, 1962, has obtained a non-dimensional solution for the excess pore pressure dissipation at the piezometer probe skin, radius of r_o, as a function of the non-dimensional time T, where:

$$T = c_v t / r_o^2 \qquad (3)$$

The non-dimensional time, T_{50}, can be determined from Soderberg's solution at 50% consolidation, and the time of 50% dissipation, t_{50}, at each piezometer probe can be obtained from the piezometer dissipation curves, Figures 13, 14, and 15. Knowing the radius of the piezometer probe, r_o, then the coefficient of consolidation is obtained from the restructured Equation (3):

$$c_v = T_{50} r_o^2 / t_{50} \quad \text{. . . . .} (4)$$

The coefficient of permeability, k, can be obtained from the dissipation data by using a relationship from consolidation theory:

$$k = \gamma_w m_v c_v \quad \text{. . . . .} (5)$$

where γ_w = wet unit weight of water, and m_v = coefficient of volume change of the sediment.

The coefficient of volume change, m_v, was estimated from the results of one-dimensional consolidation tests on MPG-I cores reported by Silva et al., 1981. Coefficients of consolidation, c_v, and coefficients of permeability, k, determined from piezometer insertion pressure dissipation curves are:

Piezometer Probe	c_v cm^2/sec	k cm/sec
PP-1	8.2×10^{-4}	3.6×10^{-7}
PP-2	1.06×10^{-3}	4.7×10^{-7}
PP-3	1.79×10^{-3}	7.9×10^{-7}
Average	1.2×10^{-3}	5.4×10^{-7}

Preliminary comparison of these permeability values determined from piezometer probe data to data measured in consolidation tests on sediment cores taken from the ISHTE platform (Brandes and Silva, 1985) show that the piezometer determined values are about one order of magnitude smaller than those from consolidation tests. The source of this difference is under study.

Dynamic Pressures During Insertion. Pressures were measured at the rate of 240 times per minute during the insertion of the piezometer probes providing a picture of this phase of the event possibly never before so clearly defined and also probably providing the best measure of piezometer insertion duration. Please note, these insertion period data appear also in Figures 10 through 15 as the vertical spattering of points at the beginning of each insertion dissipation curve. In these plots, the insertion data are so compressed on the time axis that they appear as a vertical line.

Insertion phase data from piezometer probe PP-1 appears in Figure 17. The insertion period appears to begin at 6 sec and continue to about 29.5 sec for a duration of 23.5 sec. The deep dip in the curve at 9 sec is believed to represent data taken while the porous stone was still in the nodule knocker but below the bottom saturation seal. In this position the porous stone could likely be sensing the "zero" differential pore pressure. Shortly thereafter the porous stone enters the sediment. In the sediment the excess pore pressure follows a rough sinusoidal variation superimposed on a gradually increasing baseline. The data from PP-3 (Figure 18) shows a similar pattern with an insertion duration of 24 sec, and PP-2 (Figure 19) likewise with insertion duration of 23 sec.

One must note that the insertion phase curves for PP-3 and PP-2 differ significantly from that of PP-1 in the form of the curves after the end of insertion travel. PP-3 and PP-2 both climb to higher values as the excess pore pressures climb in the 5 sec after the end of travel. The excess pore pressure of PP-1 however makes no such climb. At this time the cause of this difference in observed performance is not known. It may arise from a difference in the sediment or from hardware or electronics differences.

Electron Microscopy Samples

Two oriented sediment specimens were taken, one from a near field and one from a far field core by A. Silva during core subsampling on the MELVILLE. They were hand-carried back to NORDA where they will be examined under the transmission electron microscope. A series of oriented specimens will be prepared, the fabric or structure of these specimens examined, and conclusions drawn regarding the influence of remolding due to heater insertion on the sediment fabric.

SUMMARY

NORDA's involvement in ISIMU-II in April 84 served to allay fears regarding the extent of the sediment cracking arising from probe insertion and the impact of cracking on the phenomena being observed. Further, the excellent data set obtained while the heater was powered offered the opportunity to have a professor from the Colorado School of Mines, Prof. Michael Riggins, join the Seabed Program and develop a simplified pore pressure response prediction program.

FY 84 saw NORDA's first operational use of the high pressure transducer calibrator. The calibrator is now a fully functional tool. With development of the calibrator also came improved understanding of the performance of the Validyne differential pressure transducers during pressurization to 60 MPa (8,800 psi), and during application of the 69 kPa differential pressure. Linearity of the transducers was established.

The ISHTE Component Test Cruise during Sep 84 proved to be a highly successful exercise, demonstrating correct functioning of the piezometer system and the associated APL control and data storage systems. Data measured were of very good quality. The component test cruise did identify two minor mechanical problems for which viable design changes to the piezometer clamps and nodule knocker have already been identified.

REFERENCES

Bennett, R.H., P.J. Valent, H. Li, J.T. Burns, D.N. Lambert, and F.L. Nastav, 1984. NORDA's Activities in the In Situ Heat Transfer Experiment (ISHTE), FY83 Annual Report, Informal Technical Transmittal, NORDA, NSTL, MS, pp. 26-33.

Bennett, R.H., H. Li, P.J. Valent, J. Lipkin, and M.I. Esrig, 1985. In Situ Undrained Shear Strengths and Permeabilities Derived from Piezometer Measurements, in Strength Testing of Marine Sediments: Laboratory and In-Situ Measurements, ASTM STP 833, R.C. Chaney and K.R. Demars, ed., American Society for Testing and Materials, Philadelphia, pp. 83-100.

Brandes, H. and A.J. Silva, 1985. ATLAS-84 Core Samples - Results of FY85 Geotechnical Laboratory Tests, unpublished report, University of Rhode Island, Narragansett, RI, October, 31 p.

Hickox, C.E. and D.F. McTigue, 1983. Memo to ISHTE distribution, Sandia National Laboratories, Albuquerque, NM, 24 Aug, 9 p.

Hollister, C.D., D.R. Anderson, and G.R. Heath, 1981. Subseabed Disposal of Nuclear Wastes, Sciences, v. 213, pp. 1321-1326.

McTigue, D.F., 1985. Memo to C.M. Percival, Sandia National Laboratories, Albuquerque, N.M., 18 Mar, 13 p.

Percival, C.M., 1983. The Subseabed Disposal Program In Situ Heat Transfer Experiment (ISHTE), Sandia Report SAND80-0202, Sandia National Laboratories, Albuqerque, NM, 47 p.

Randolph, M.F., J.P. Carter, and C.P. Wroth, 1979. Driven Piles in Clay - the effects of installation and subsequent consolidation, Geotechnique, vol. 29, no. 4, pp. 361-393.

Riggins, M., P.J. Valent, H. Li, J.T. Burns, and C.E. Hickox, 1985. Pore Pressure Response to Probe Insertion and Thermal Gradient: ISIMU-II, NORDA Technical Note 259, Naval Ocean Research and Development Activity, NSTL, MS, 80 p.

Scott, R.F., 1963. Transient Flow: Mathematical Analysis, in Principles of Soil Mechanics, Addison - Wesley Publishing Co., Reading, MA, pp. 188-206.

Silva, A.J., S.A. Jordan, and W.P. Levy, 1981. Geotechnical Aspects of Subseabed Disposal of High Level Radioactive Wastes, Marine Geotechnical Laboratory, University of Rhode Island, DOE/SLA Contract Nos. 13-9227 and 74-1098.

Silva, A.J. and B. Levy, 1984. Core Processing of ISHTE Component Cruise Cores. Memorandum from URI to ISHTE Distribution, 16 July.

Simonich, M.F., 1984. Letter from M.F. Simonich, The Lee Company, 2 Pettipaug Rd., Westbrook, Conn., to J. Burns, NORDA, dated 10 May.

Soderberg, L.O., 1962. Consolidation Theory Applied to Foundation Pile Time Effects, Geotechnique. vol. 12, pp. 217-225.

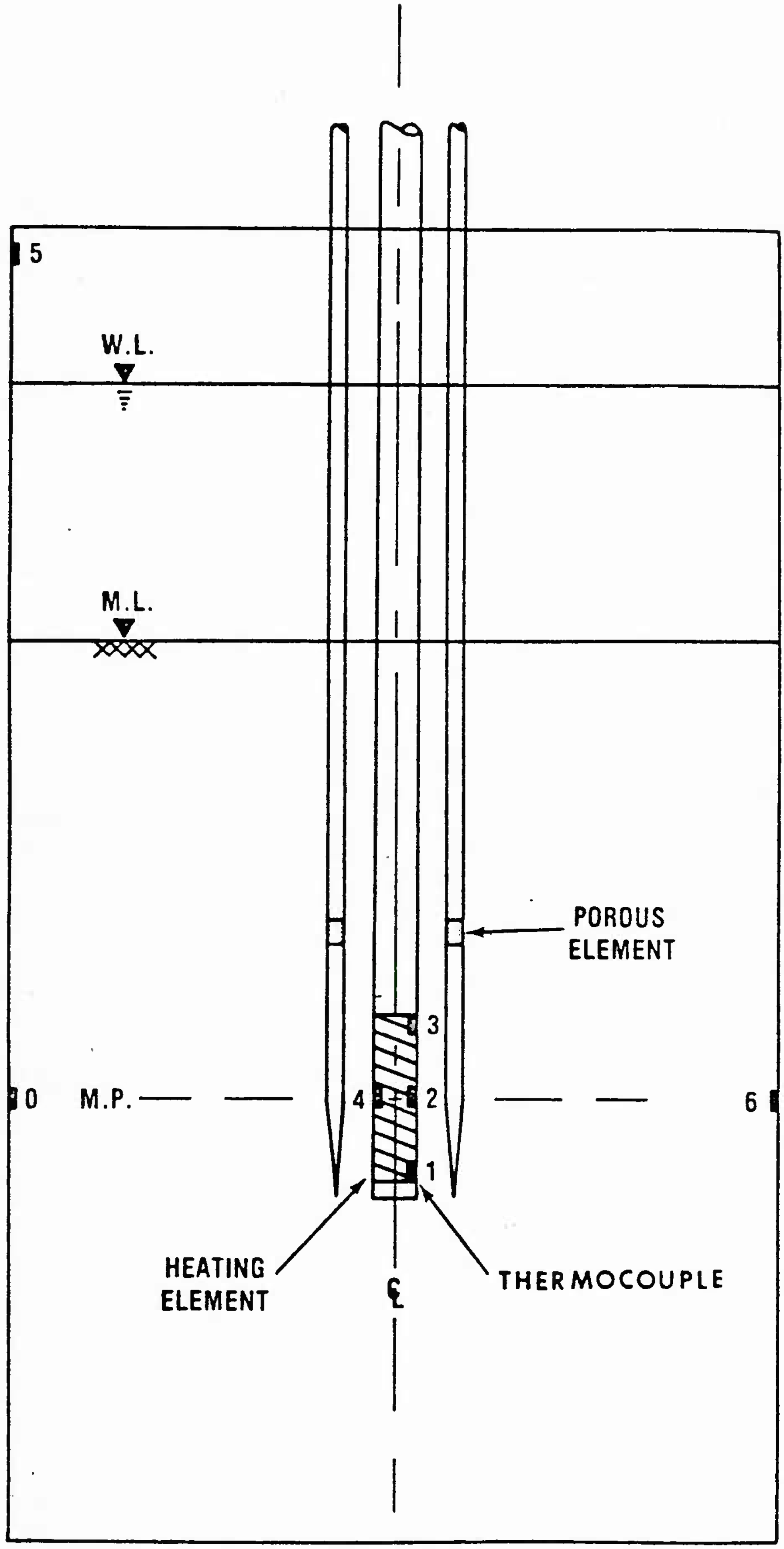

FIGURE 1. PLAN VIEW OF ISIMU - II TEST ARRANGEMENT (SCALE 1: 4)

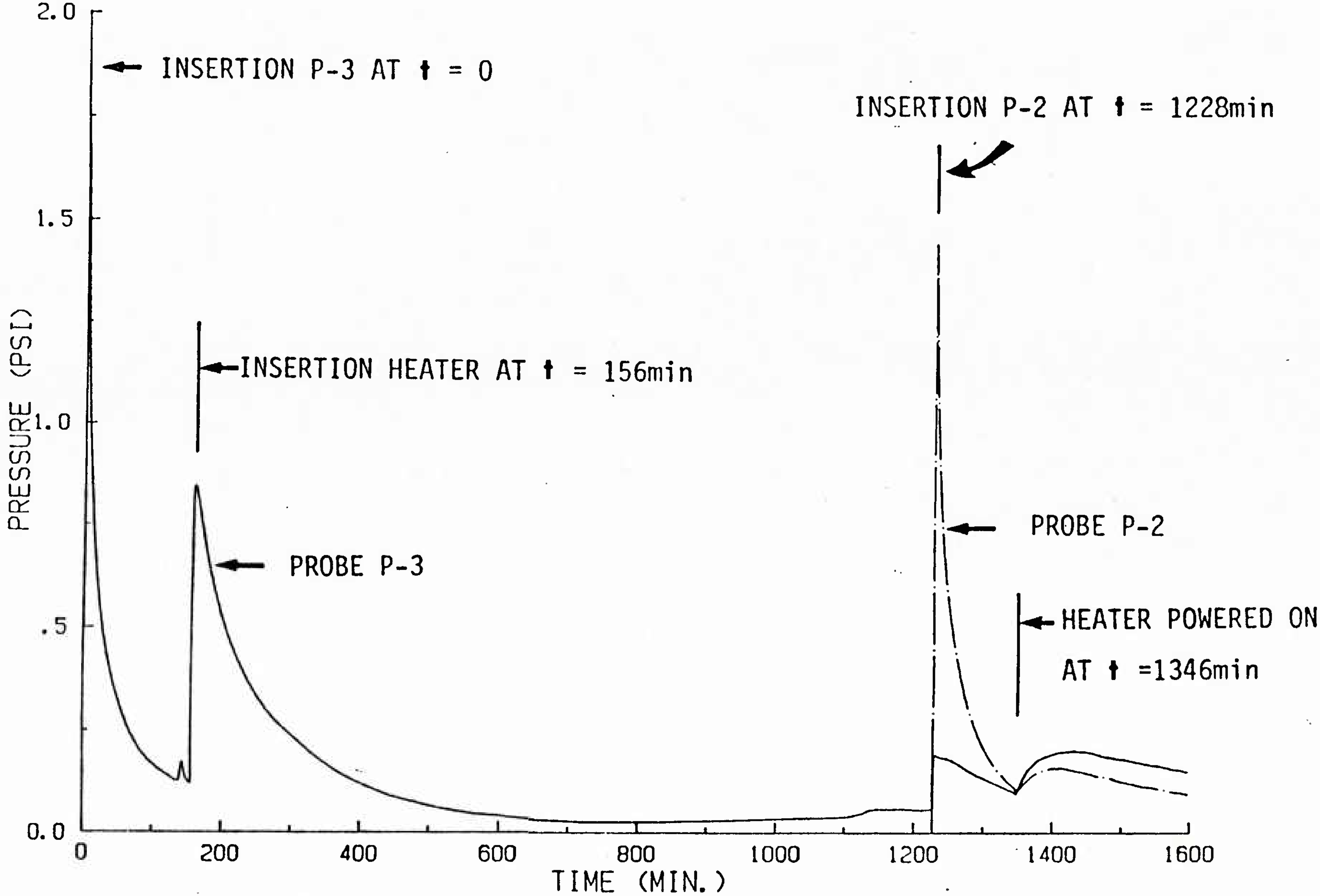

FIGURE 2. PIEZOMETER PORE PRESSURE RESPONSE FOR THE COMPLETE ISIMU - II TEST PERIOD
(1PSI = 6.895KPA)

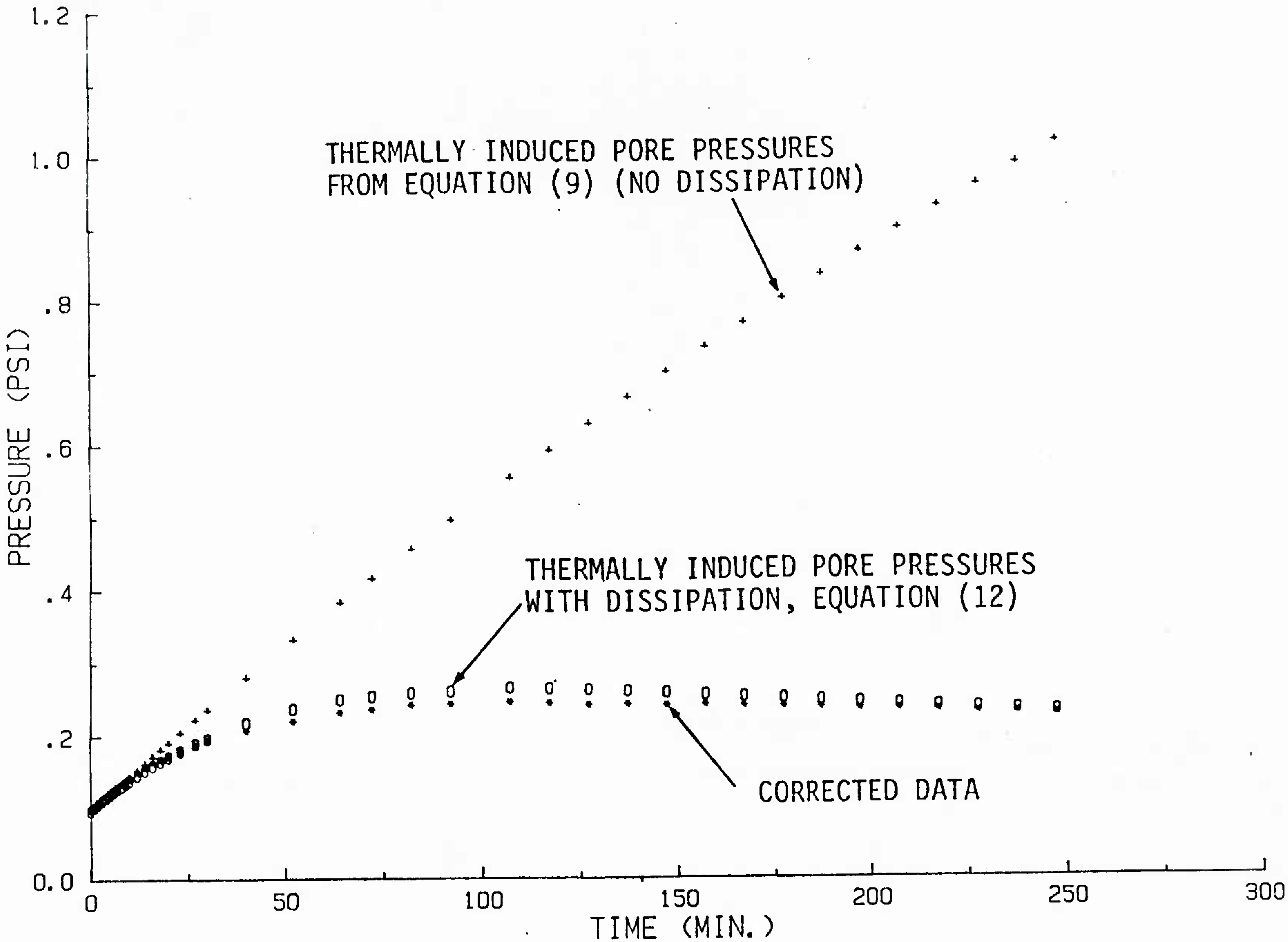

FIGURE 3. MODEL PREDICTIONS AT PROBE P-3

(1PSI = 6.895KPA)

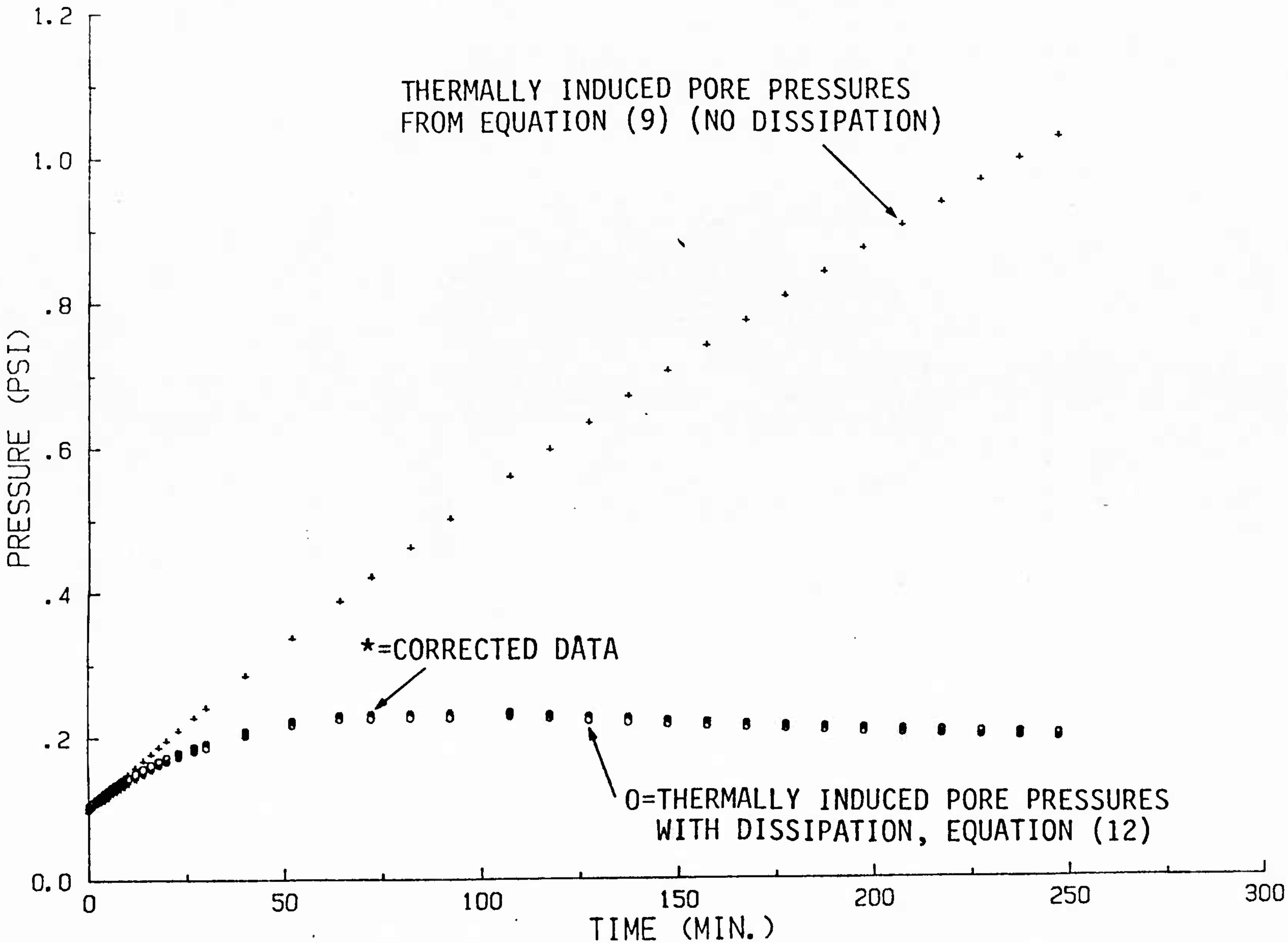

FIGURE 4. MODEL PREDICTIONS AT PROBE P-2
(1PSI = 6.895KPA)

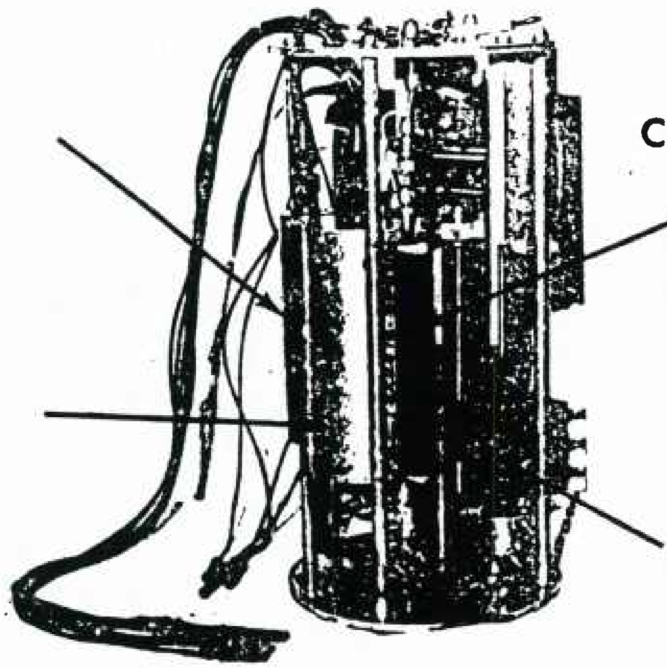

FIGURE 5. NORDA HIGH PRESSURE CALIBRATOR

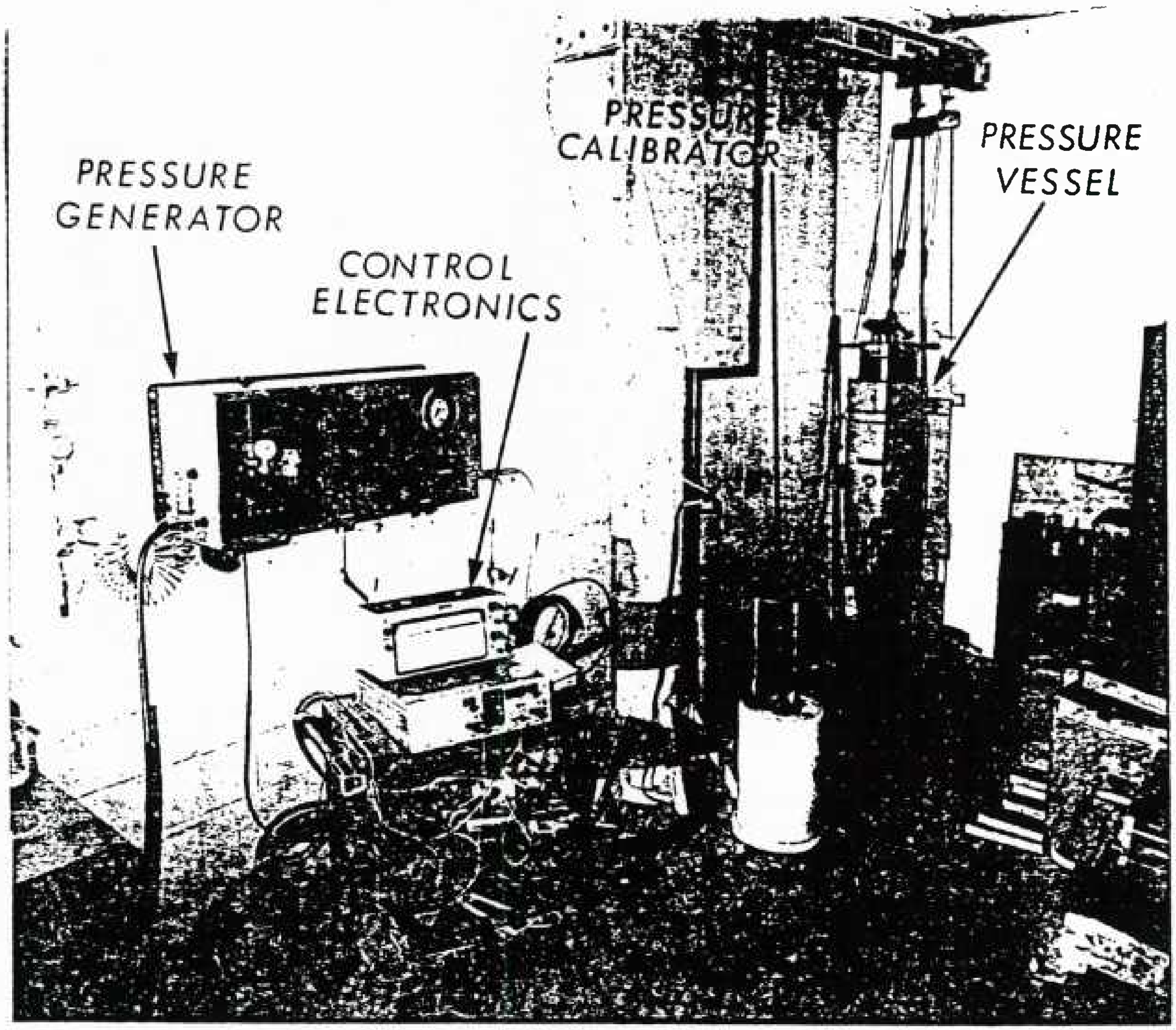

FIGURE 6. COMPONENTS, NORDA HIGH PRESSURE TEST FACILITY

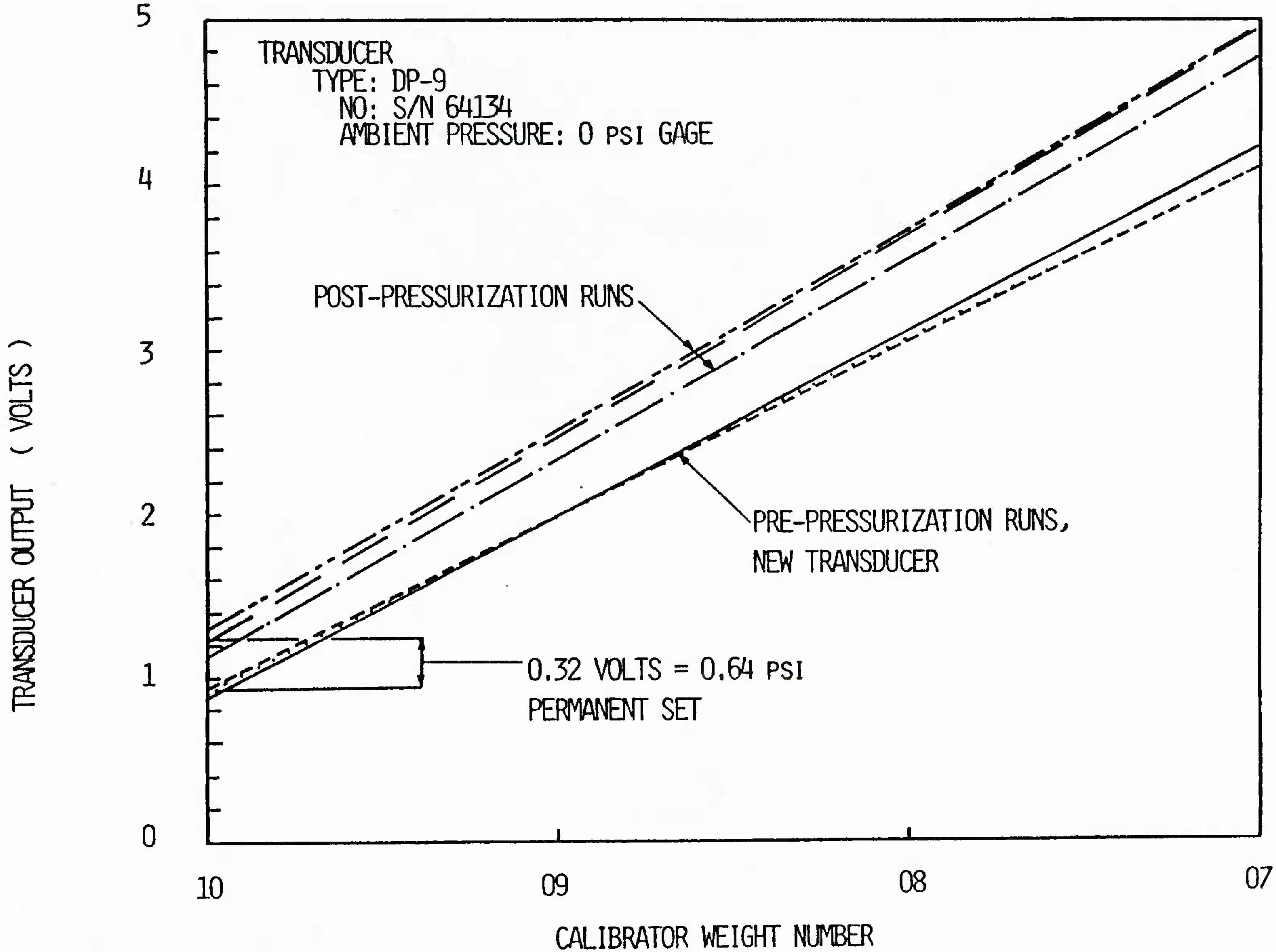

FIGURE 7. CALIBRATION CURVES FOR ISHTE TRANSDUCER BEFORE AND AFTER PRESSURIZATION TO 60MPA (9,000PSI) ILLUSTRATING PERMANENT SET RESULTING FROM PRESSURIZATION

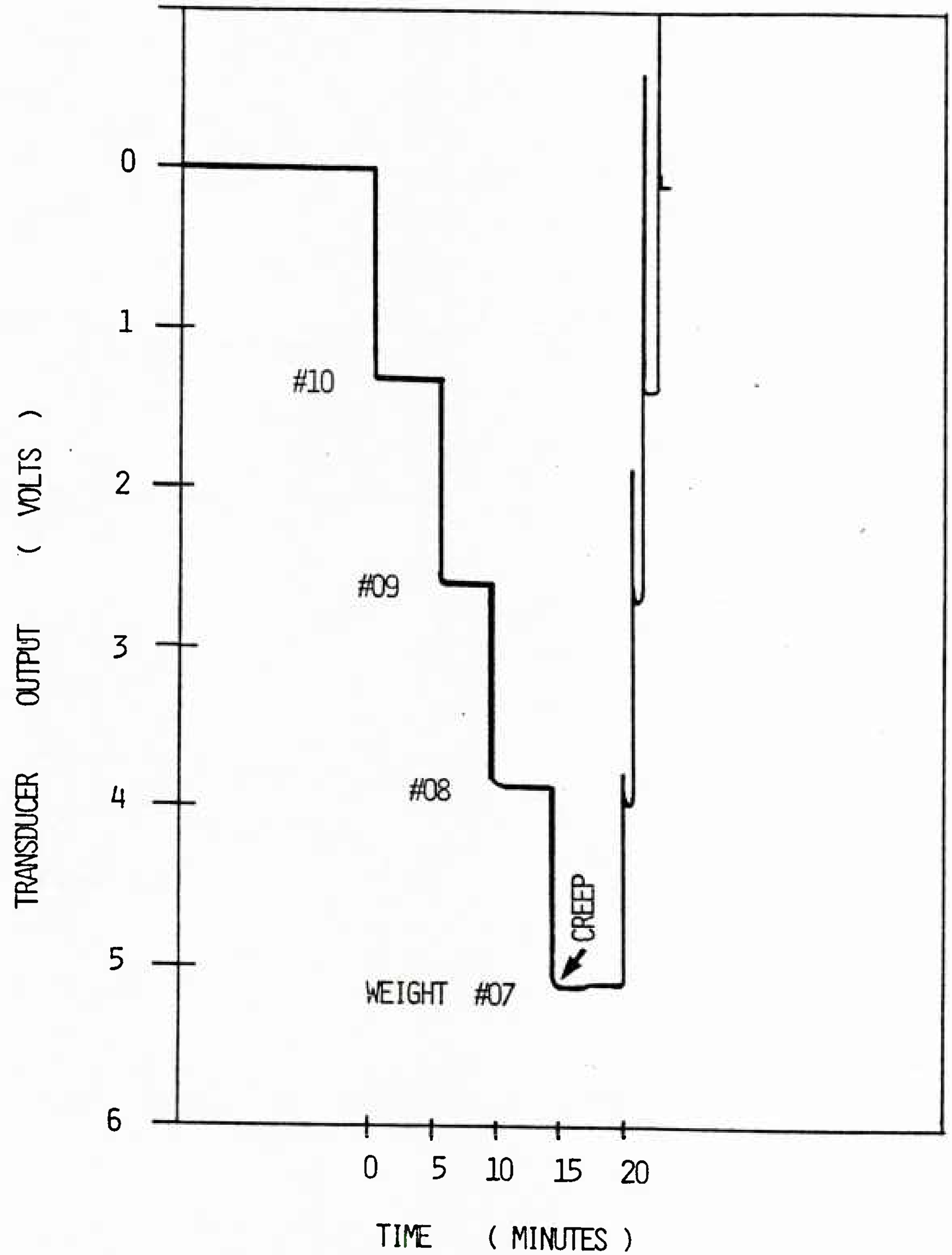

FIGURE 8. CREEP OF CALIBRATION SYSTEM AFTER APPLICATION OF EACH LOAD INCREMENT.

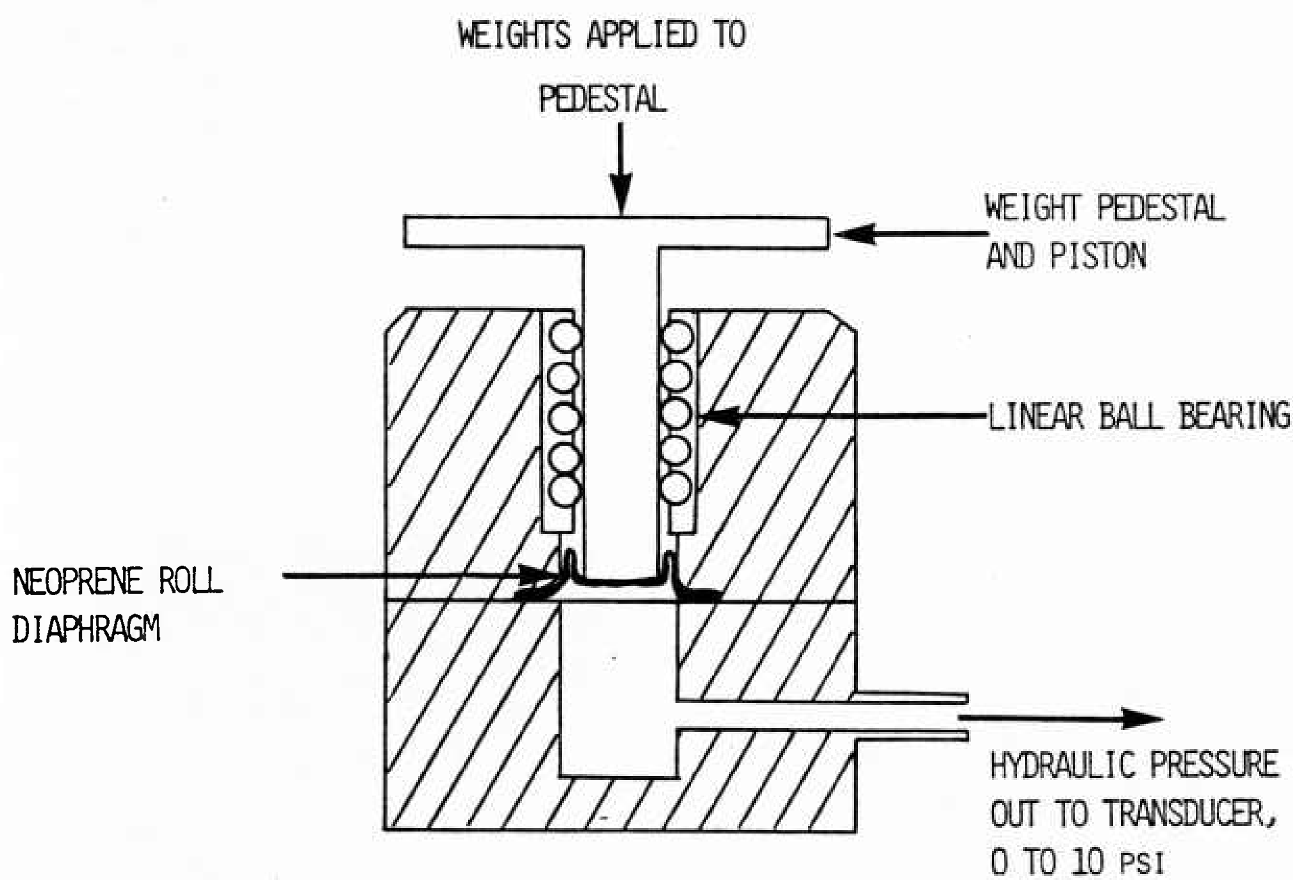

FIGURE 9. HYDRAULIC LOADING UNIT OF THE HIGH PRESSURE CALIBRATOR

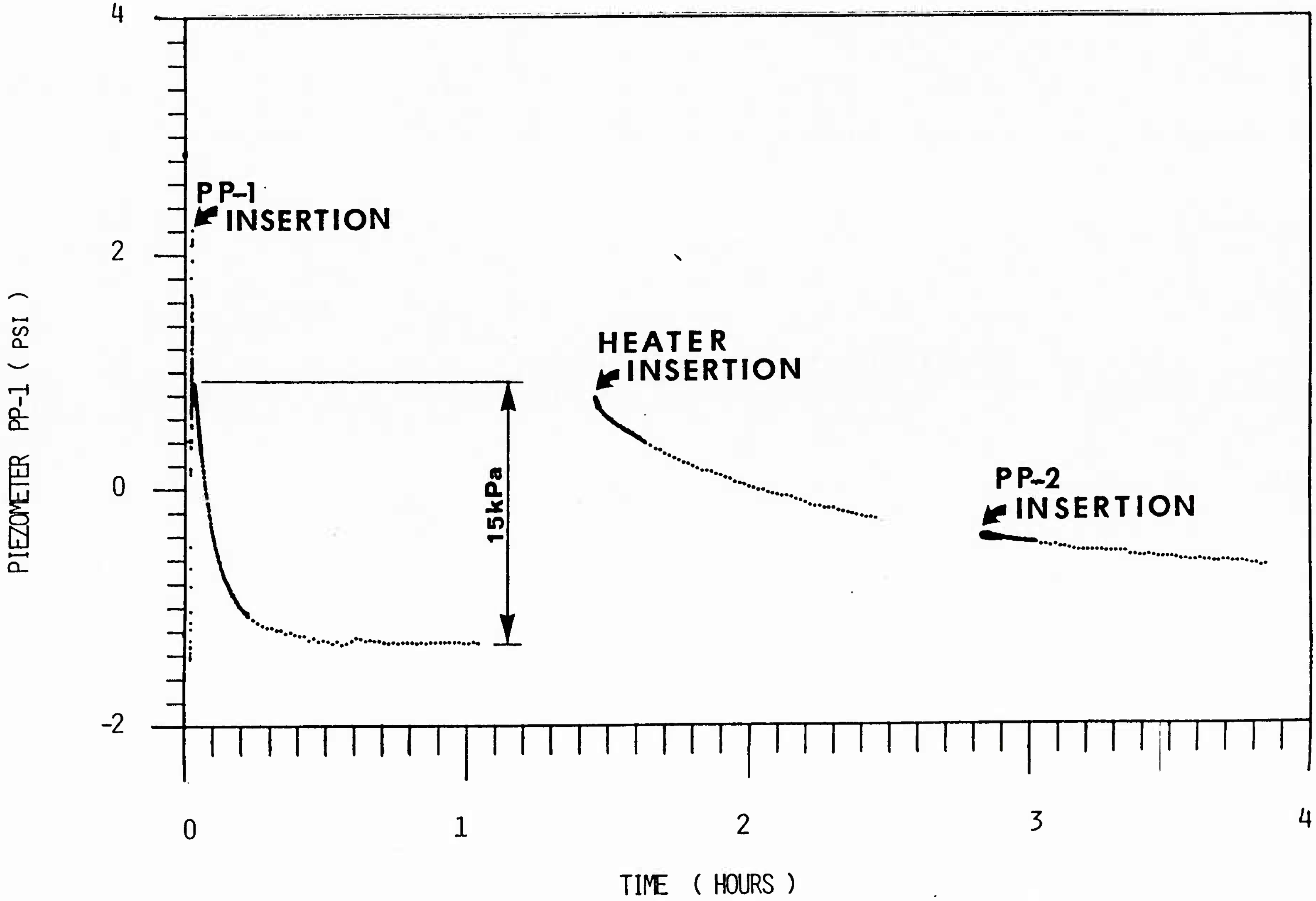

FIGURE 10. ON-BOTTOM DATA HISTORY FOR PIEZOMETER PP-1 (1984)

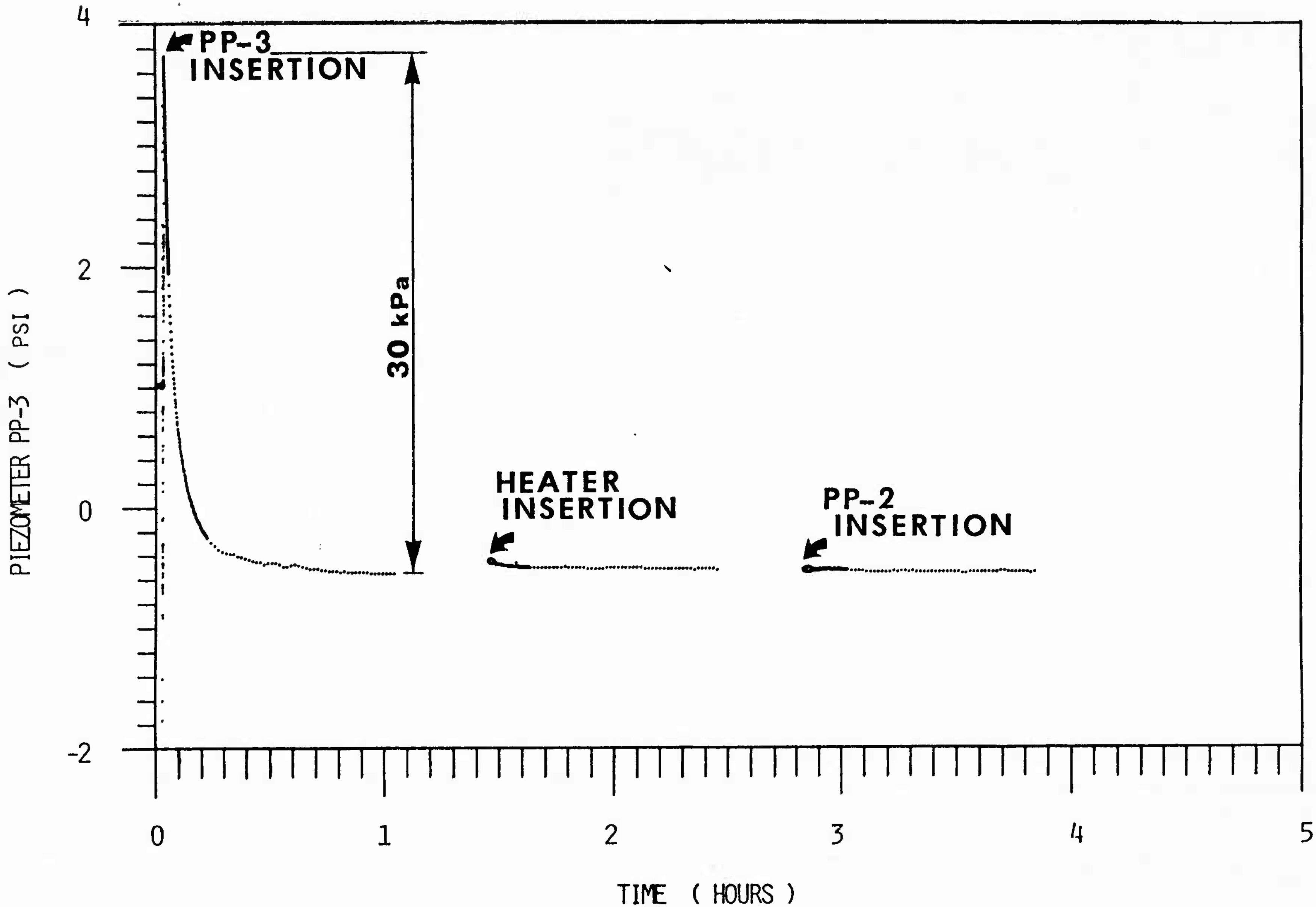

FIGURE 11. ON-BOTTOM DATA HISTORY FOR PIEZOMETER PP-3 (1984)

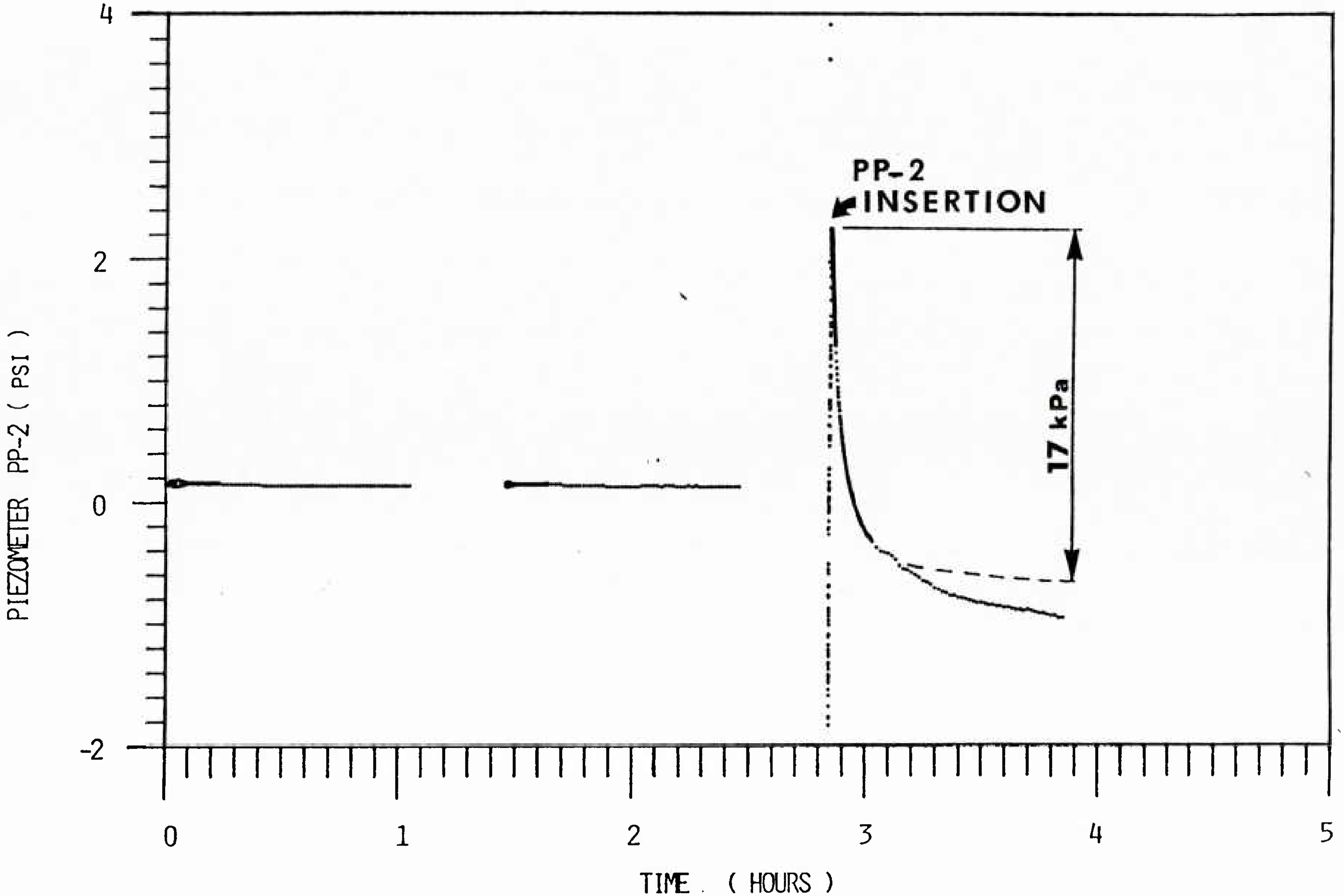

FIGURE 12. ON-BOTTOM DATA HISTORY FOR PIEZOMETER PP-2 (1984)

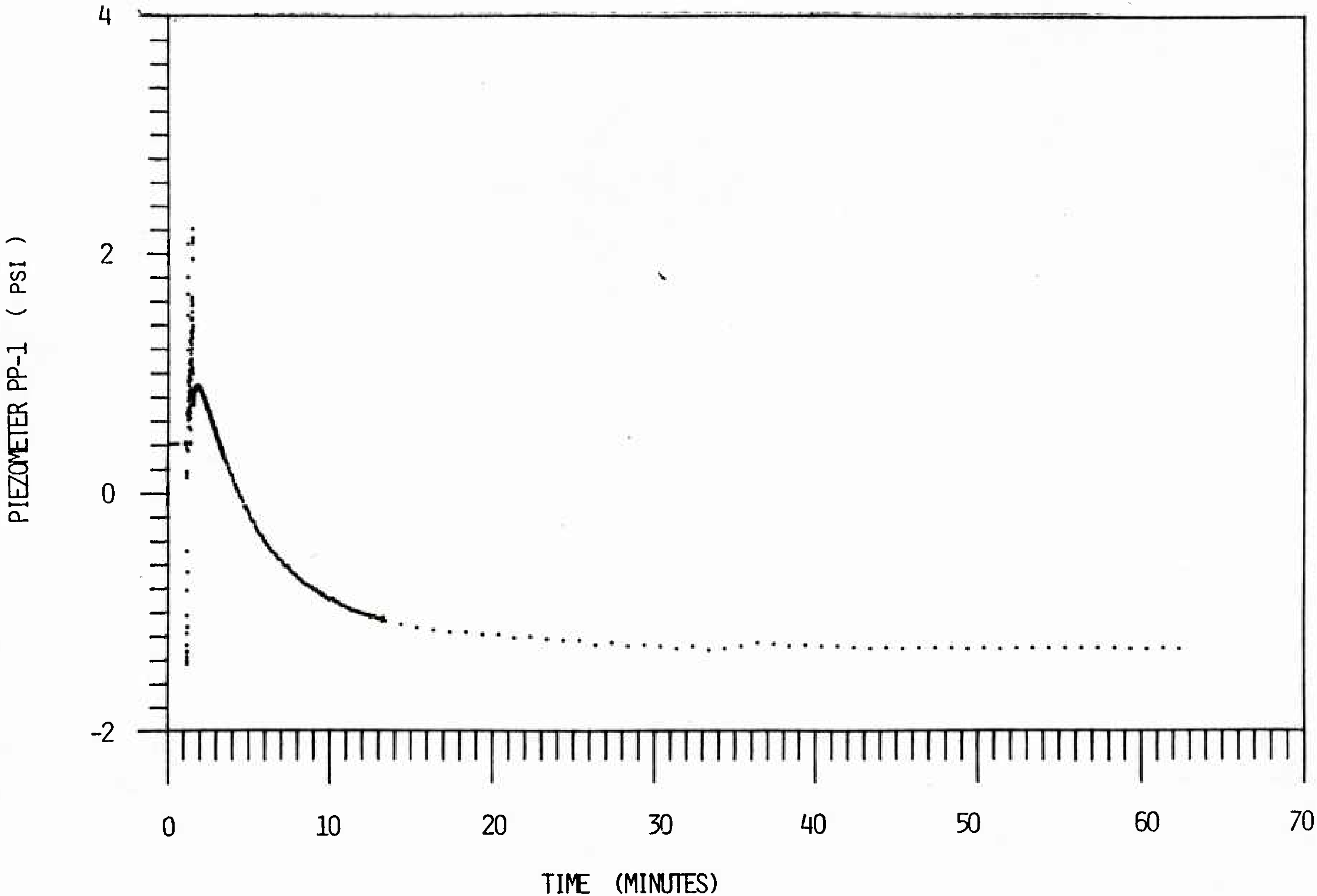

FIGURE 13. INSERTION DISSIPATION CURVE FOR PIEZOMETER PP-1

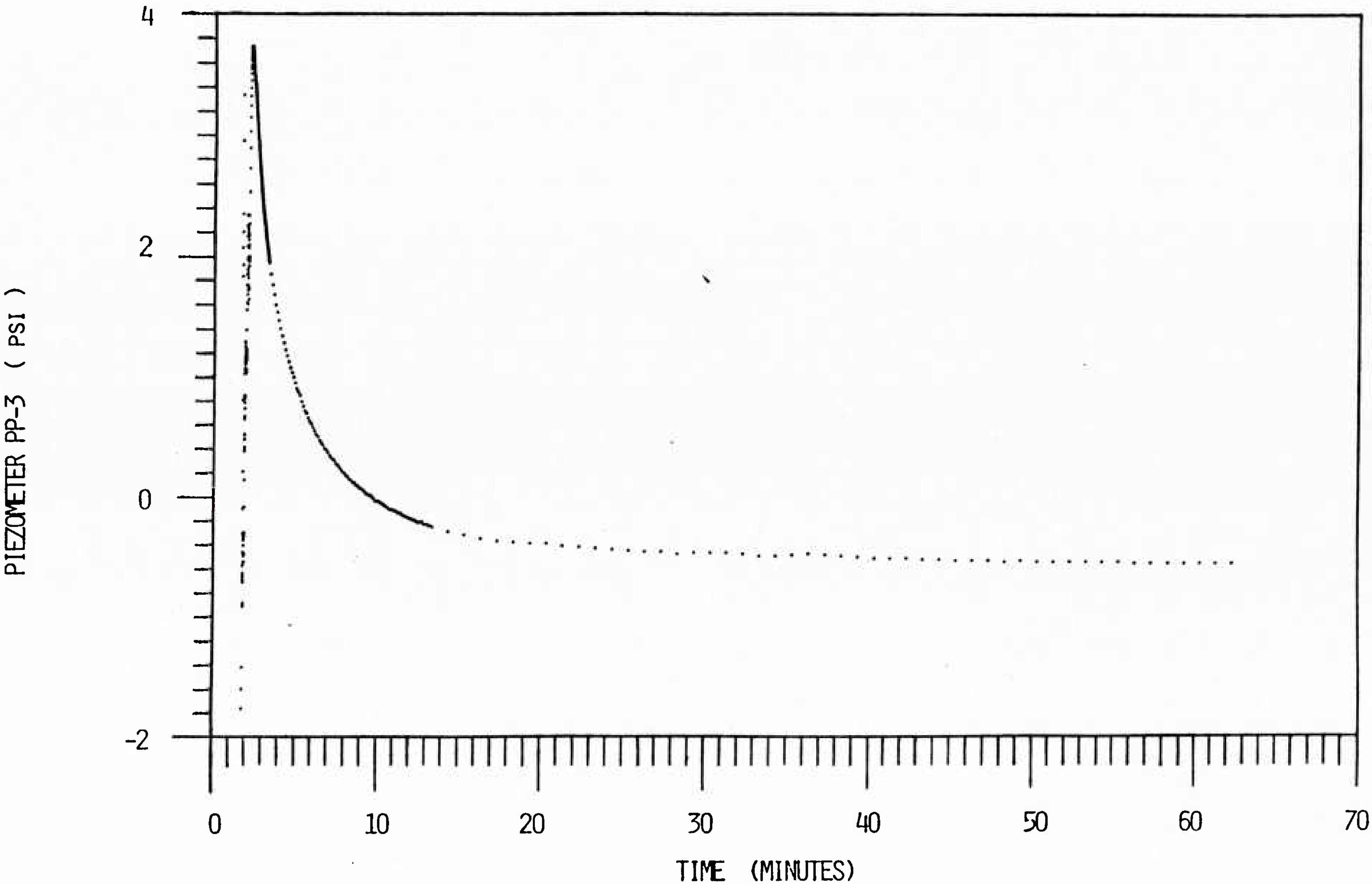

FIGURE 14. INSERTION DISSIPATION CURVE FOR PIEZOMETER PP-3

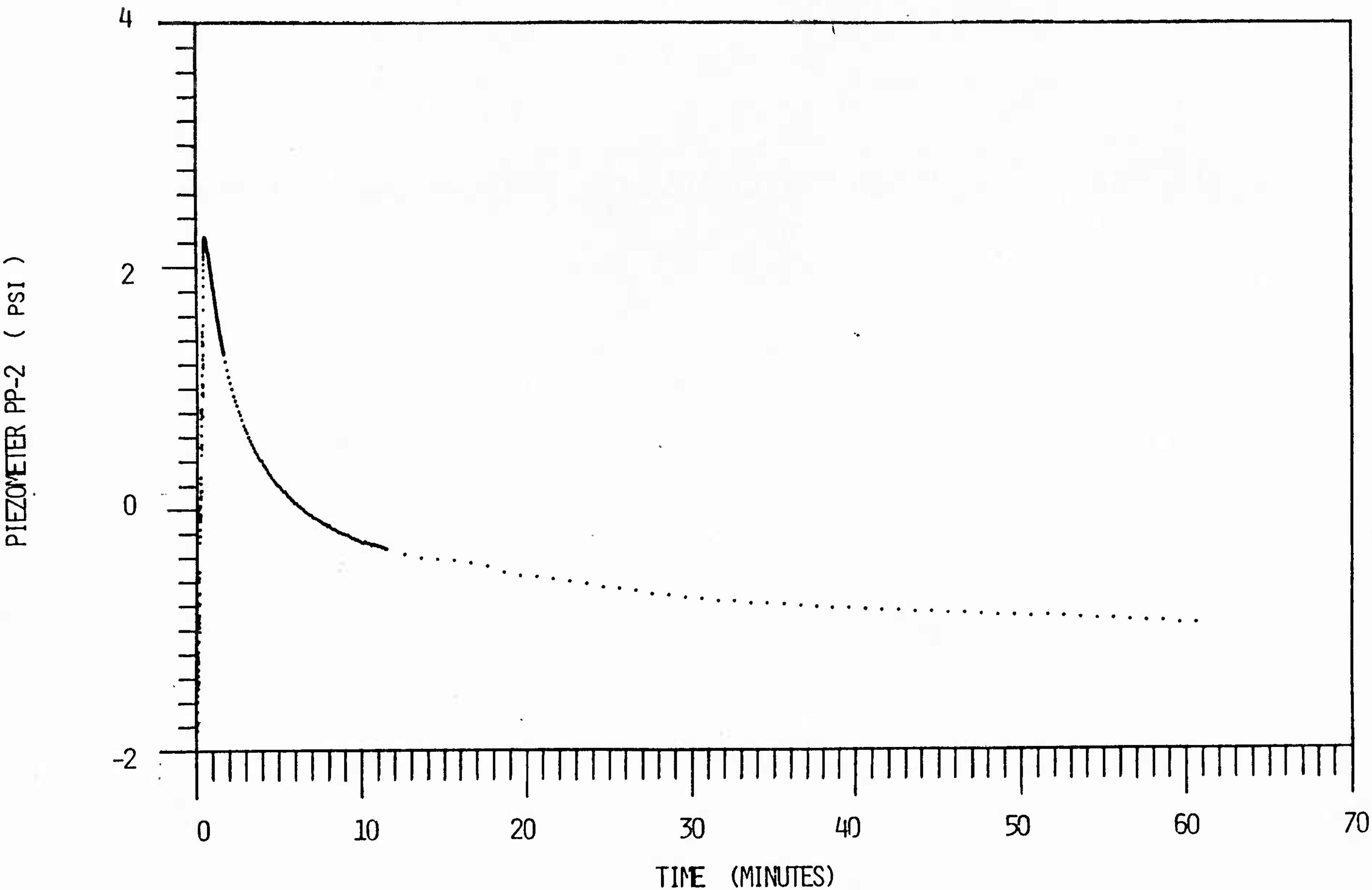

FIGURE 15. INSERTION DISSIPATION CURVE FOR PIEZOMETER PP-2

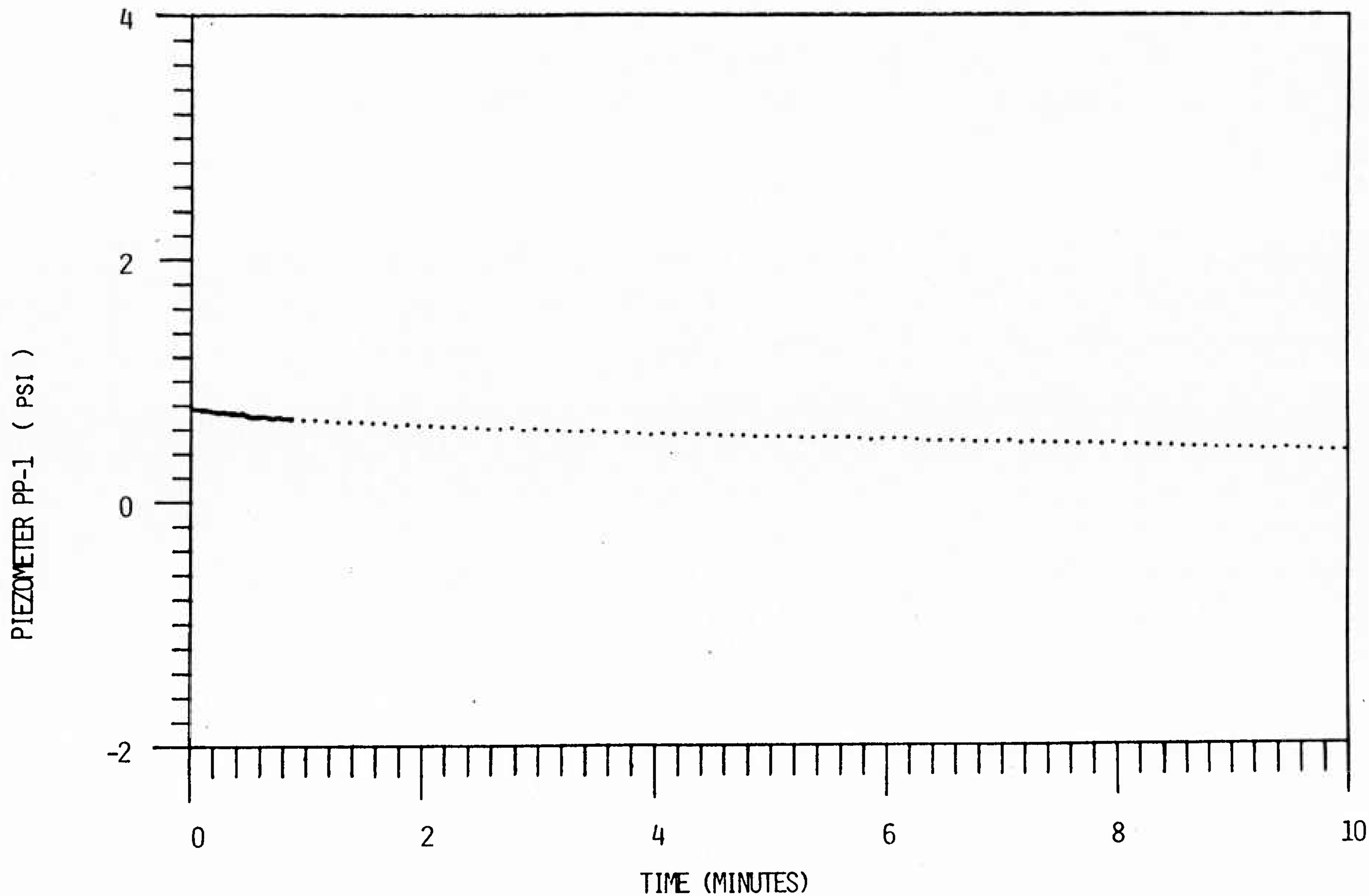

FIGURE 16. INSERTION DISSIPATION CURVE FOR HEATER PROBE AS RECORDED AT PIEZOMETER PP-1

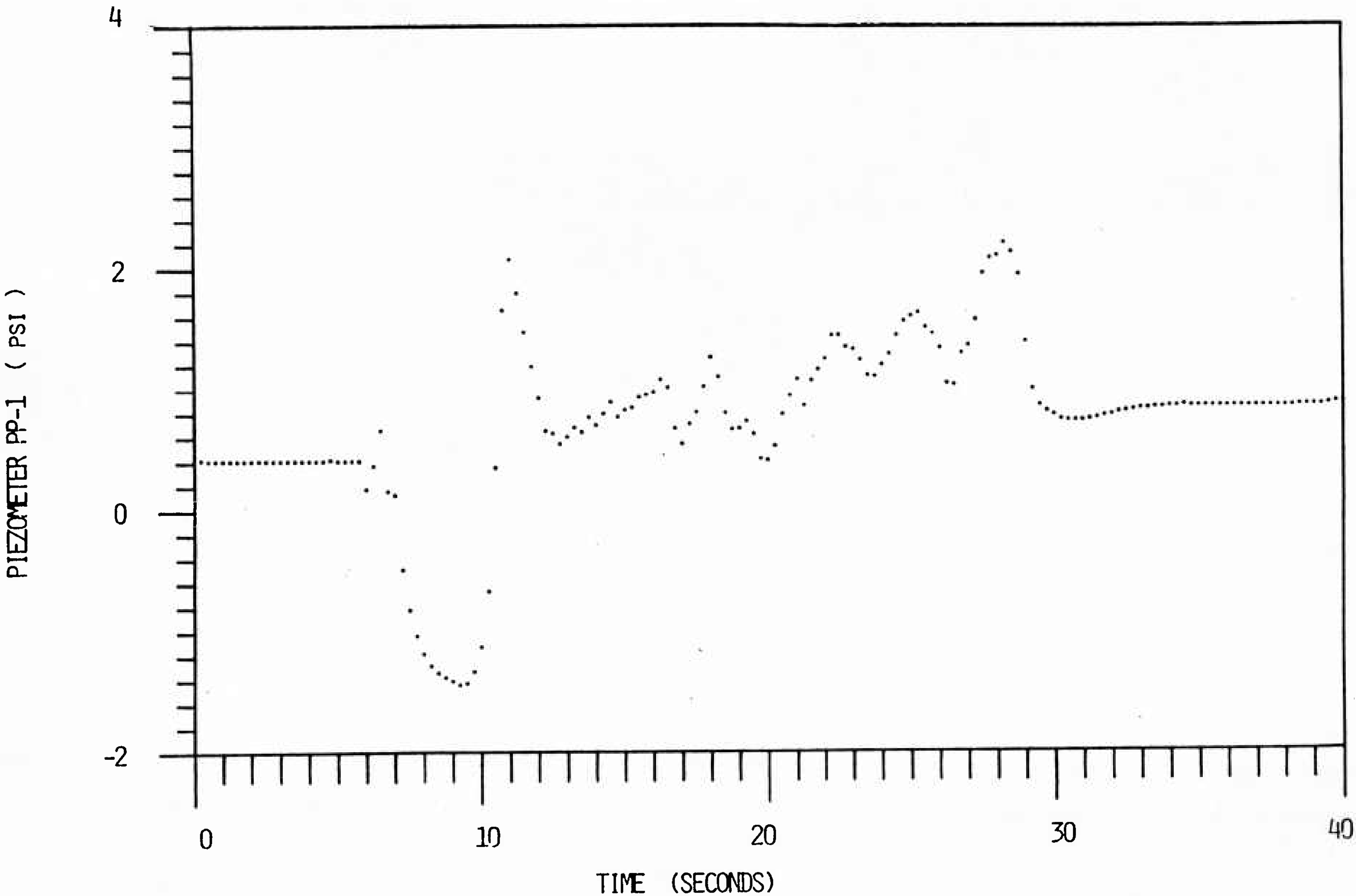

FIGURE 17. INSERTION HISTORY FOR PIEZOMETER PP-1

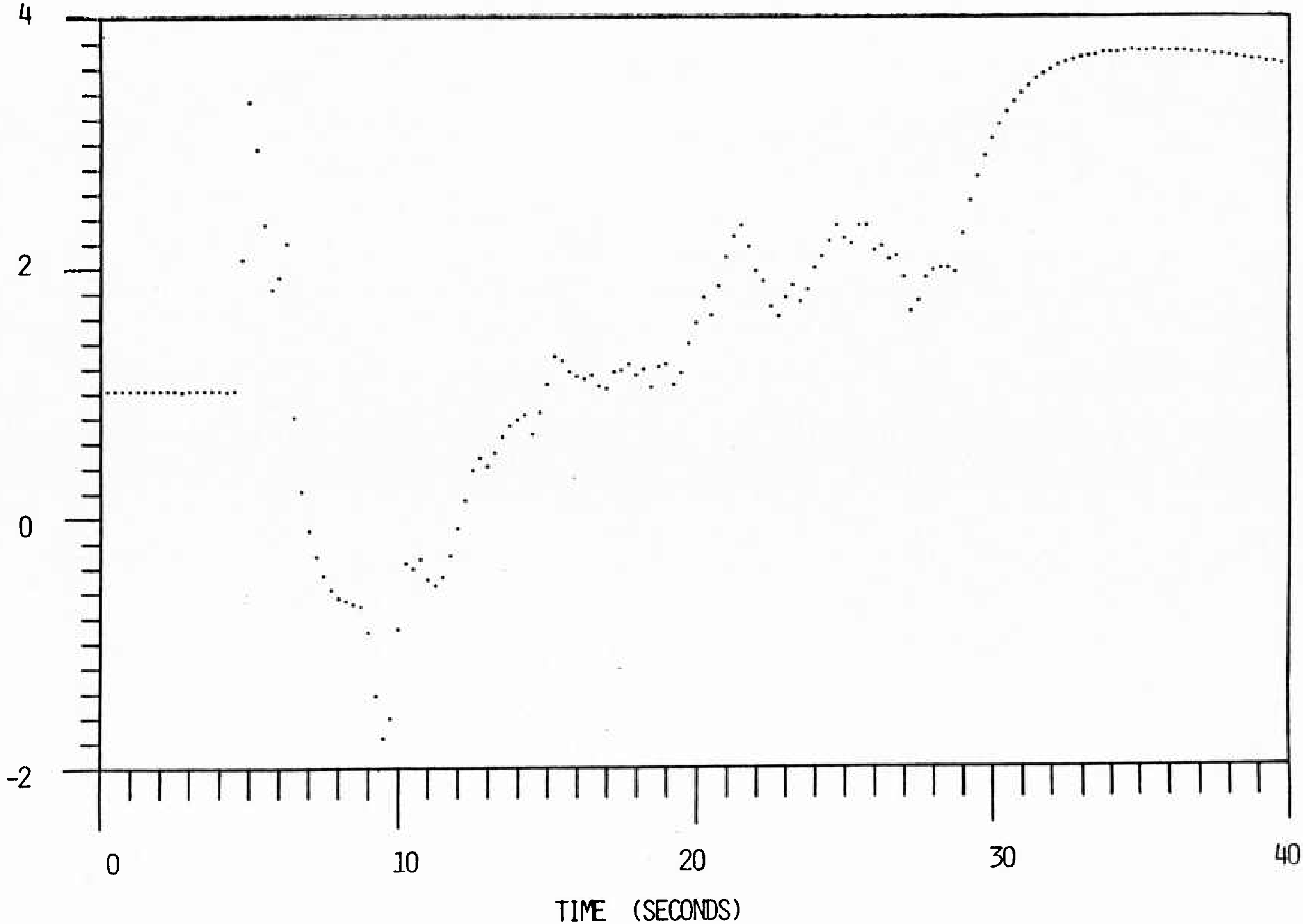

FIGURE 18. INSERTION HISTORY FOR PIEZOMETER PP-3

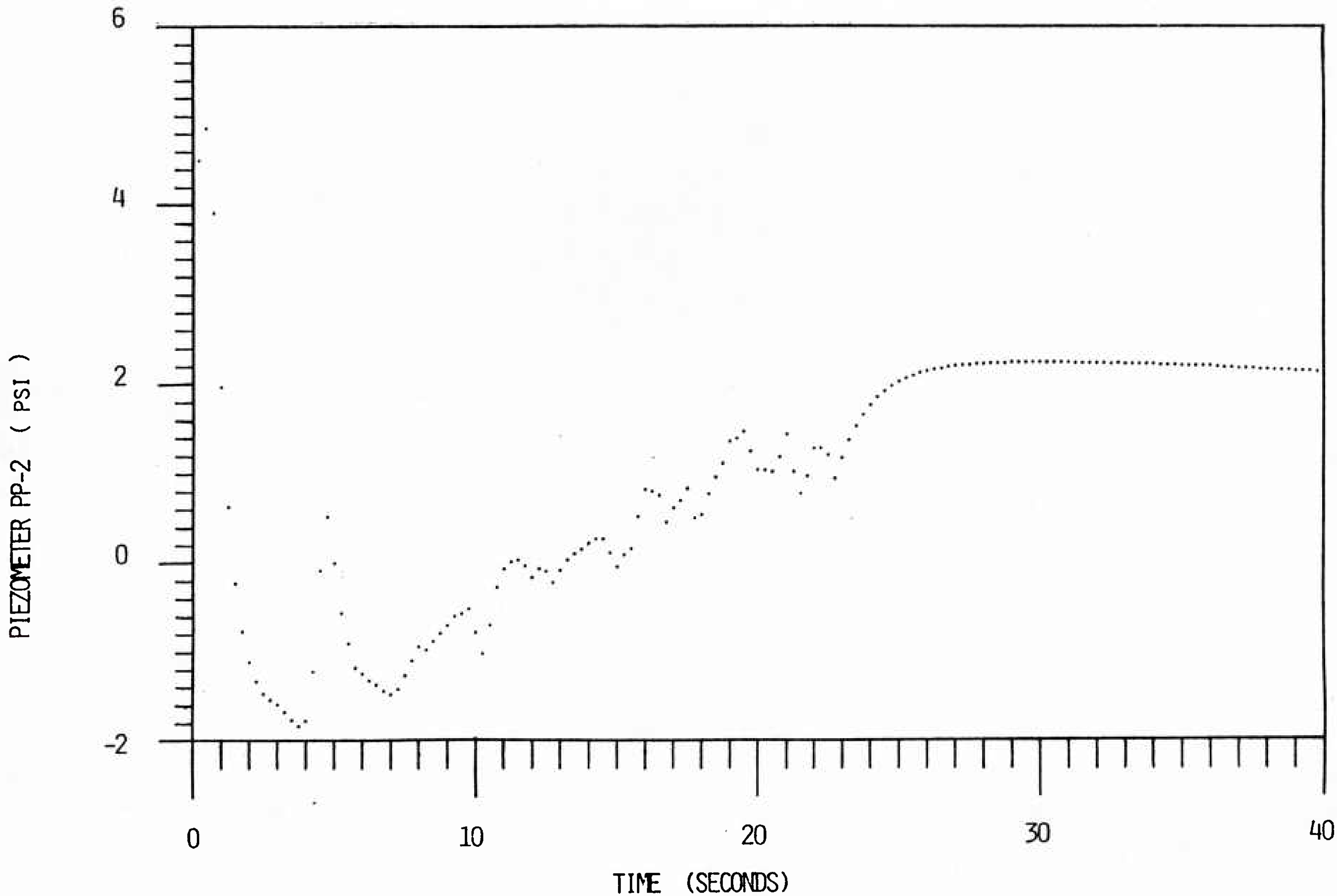

FIGURE 19. INSERTION HISTORY FOR PIEZOMETER PP-2