Preliminary Report
FAIRBANKS FROST HEAVE TEST FACILITY

February 1981

Northwest Alaskan
PIPELINE COMPANY

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Branch of Pipeline Monitoring
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ABSTRACT

Recognizing the need to understand and quantify the effects of frost heave upon an operating chilled-gas pipeline, Northwest Alaskan Pipeline Company and Foothills Pipeline (Yukon) Limited constructed the Fairbanks Frost Heave Test Facility. Its operation has been virtually continuous since commissioning of the facility on October 13, 1979.

The location of the Fairbanks facility, some six miles from Fairbanks, Alaska, was chosen because it satisfied the requisite experimental and geotechnical criteria necessary to accommodate long-term frost bulb growth. The test site possesses thawed high-silt content soils (Fairbanks silt) together with a high-water table.

The ten full-scale test sections at the facility were designed to investigate the heave relationships between the sections, to test proposed mitigative solutions, and to advance the predictive capabilities of structural and empirical frost heave models.

Since early in 1980, the test sections have ordered themselves into two general groups: those that have demonstrated a decaying heave rate (Test Sections 1, 4, 5, 6 and 9) and those that have maintained a relatively constant heave rate (Test Sections 2, 7, 8 and 3). Test Section 10 and the east end of Test Section 9 are both installed in permafrost and have heaved approximately 0.3 inches. Additionally, as designed and placed at the site, Test Section 9 is demonstrating differential heave of a long-span length pipeline along its 400-foot length.

In the fall of 1979, prior to start-up of the facility, Northwest Alaskan commissioned EBA Engineering Consultants to prepare a performance prediction for the facility with their empirical frost heave model. The simulations were based upon intended operating conditions, historical climatological data for Fairbanks, Alaska; the various test section configurations at the facility; and

experimentally-derived Ice Segregation Ratio (ISR) values for remolded Fairbanks silt using NWA's standard frost heave test cell. Other than Test Section 2 which has heaved approximately 96 percent of the predicted value and Test Section 8 which has heaved sooner than predicted, all other simulated test sections have heaved 50 percent or less of their predicted value (e.g., Test Section 1, the bare reference section, has heaved 0.35 feet, as against 0.72 feet predicted). EBA is in the process of remodeling the test sections using actual operating temperatures and initial conditions, actual weather data, and ISR relations defined by Northwest Alaskan's evolved laboratory testing techniques.

In addition to up-grade programs, three new testing programs are planned for the test site. In the first program, two new 48 inch diameter Test Sections, 11 and 12, will be constructed early in 1981: both test sections will be restrained at both ends via artificial permafrost. The purposes of these "guillotine" test sections are to characterize further the relationships between pressure, heave, and structural response of the short and intermediate span-length pipes during frost bulb growth. In the second program, four 18-inch diameter, and four 48-inch diameter, 8-foot long concrete-filled steel test sections will be pulled out of the soil during the spring and summer of 1981. The purposes of these tests, and the on-going small-scale model uplift tests, are to provide force-deformation data for structural modeling. In the third program, two new Small-Diameter Test Sections, 13 and 14, will be constructed early in 1981. Together with existing test sections, these test sections will serve to define relationships between operating temperature, frost bulb growth, and frost heave.

This report, intended to be the first of bi-annual reports, describes the equipment, operational procedures, and presents the performance of the facility during its first ten months of operation. Subsequent reports will concentrate upon presentation of on-going analytical programs, correlations, and predictions.

FACILITY AND
PERFORMANCE PRESENTATION
FAIRBANKS FROST HEAVE TEST FACILITY
FOR THE FIRST TEN MONTHS OF OPERATION

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

SECTION PAGE

LIST OF FIGURES

LIST OF FIGURES (Continued)

1.0 INTRODUCTION

This report, intended to be the first of the bi-annual reports, presents the performance of Northwest Alaskan Pipeline Company's Fairbanks Frost Heave Test Facility. Although this report is not intended to present analyses of the performance of the facility, preliminary findings of ongoing structural analysis is included in an appendix to this report.

Section 2.0 of this report describes the geotechnical characteristics of the site and the rationale for choosing the Gettinger property for the frost heave facility; Section 3.0 describes the construction of the facility including the ditch configurations for all 10 test sections; Section 4.0 describes the facility's instrumentation, electronics and equipment; Section 5.0 presents the operating history of the facility; Section 6.0 presents comparisons of frost heave with frost bulb growth, including the field findings from the 1980 verification program; and Section 7.0 discusses other programs intended for the site; and Section 8.0 presents a summary and observations of facility performance.

2.0 FACILITY LOCATION

The Fairbanks Frost Heave Test Facility is located some 6 miles from Fairbanks, Alaska, at approximately 2.5 miles Chena Hot Springs Road. Subsequent to an intensive survey (Ref. 1, 2, 3) for a test site that accommodated the requisite geotechnical and experimental criteria, the present site, leased from Mr. Henry Gettinger, was chosen because of:

1. The heave characteristics of Fairbanks silt as demonstrated during frost-susceptibility tests by CRREL and others.

2. Adequate acreage of unfrozen, frost-susceptible ground to a depth sufficient to accommodate long-term pipe-induced frost bulb growth.

3. The presence of flat to gently sloping topography with a year-round water table generally closer than 12 feet to the ground surface.

4. The presence of a transition from frozen to thawed ground which was necessary so that the structural effects of differential frost heave on a pipe structure (i.e., Test Section 9) could be observed.

3.0 FACILITY CONSTRUCTION AND DITCH CONFIGURATIONS

3.1 Facility Construction

Construction began at the site during August, 1978. All 10 test sections were installed with their immediate instrumentation by February, 1979. Improvements in the instrumentation continued into April, 1979, with the automatic data gathering system being installed and tested during July, 1979. A plan view of the site is presented on Figure 3.1-1.

Start-up was delayed until October 13, 1979, to allow the seasonal frost, whose extent was aggravated by the winter construction, to thaw from the site. Polyethylene film (visqueen) was placed over Test Sections 1 through 5, 7, and 8, plus 9 up to the permafrost/thawed transition, to assist in warming the ground. Test Section 6, the Cryo-anchor "chill pipe" Section, was not covered as its operation was intended to be initiated within frozen ground.

Between July, 1979, and the start-up date of October 13, 1979, minor instrumentation improvements continued at the site to maximize instrumentation reliability.

3.2. Ditch Configurations, General

The facility has 10 separate sections of 48-inch diameter pipe. Combinations of soil replacement, pipe insulation, shallow pipe burial, chill pipes, and select bedding material are employed to characterize the most effective control measures. These configurations are presented in Figure 3.2-1.

Excepting Test Section 5, all test sections are buried 2.5 feet below natural grade with a 1 foot thick crown directly above the pipe, sloping to join the natural grade at the ditch walls. The top of Test Section 5, the shallow-burial section, is flush with the natural grade and is covered with a 3 foot thick layer of compacted granular fill.

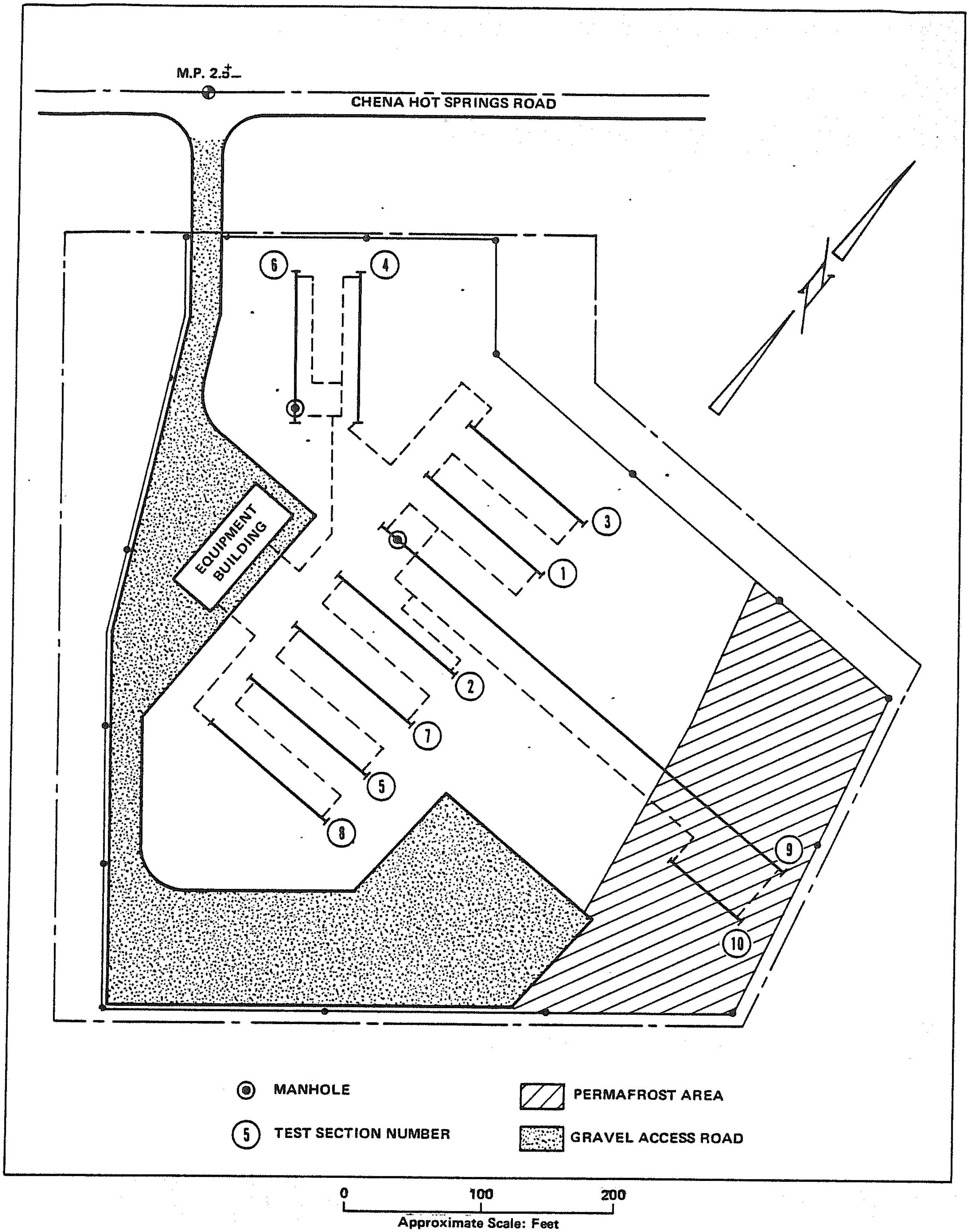
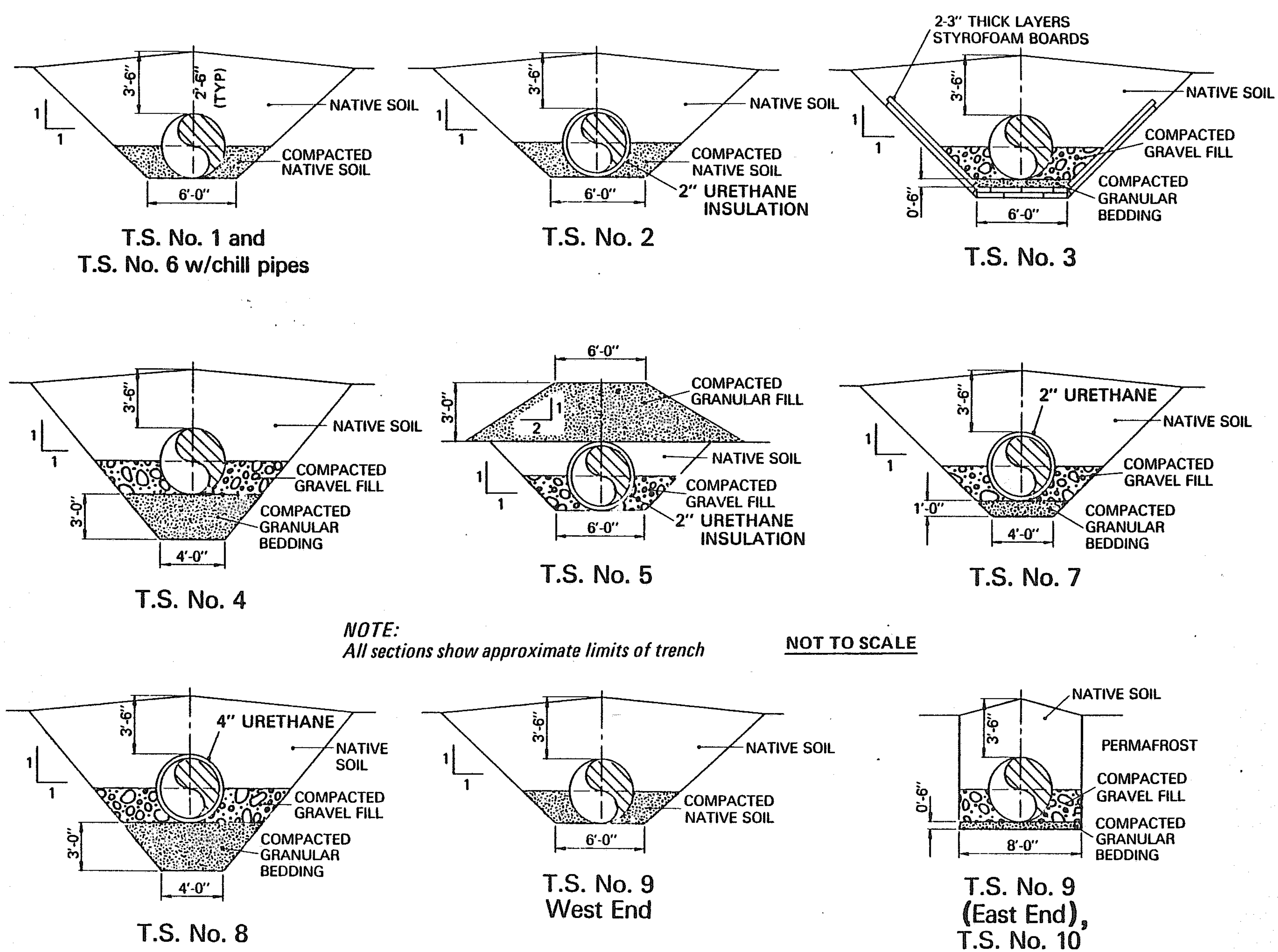


FIGURE 3.1-1 FAIRBANKS FROST HEAVE TEST FACILITY, SITE LAYOUT

FIGURE 3.2-1 FAIRBANKS FROST HEAVE TEST FACILITY, DITCH CONFIGURATIONS



Ditch walls for Test Sections 1 through 8 plus the west end (thawed soil) of Test Section 9 were constructed at a 1-to-1 slope. Ditch walls for the east end of Test Section 9 and Test Section 10, both of which are buried in permafrost, are vertical.

3.2.1 Ditch Configuration, Test Section 1

Test Section 1 is a bare, 120 foot long, uninsulated pipe installed in a trench backfilled with native soil (Fairbanks silt). The bottom of the pipe lies upon in-situ soil. Constructed with no frost heave mitigation measures, this section is intended to be used as a reference for the mitigative sections.

3.2.2 Ditch Configuration, Test Section 2

Test Section 2 is insulated with 2 inches of urethane insulation, is 120 feet long, and is installed in a trench backfilled with native soil. The bottom of the pipe, shielded by the insulation and its protective jacket, lies upon in-situ soil.

3.2.3 Ditch Configuration, Test Section 3

Test Section 3 is 120 feet long and is insulated from the in-situ soil by 6 inches of polystyrene board insulation which is placed on the bottom and sloped walls of the ditch. Six inches of compacted granular bedding separates the bare pipe from the board insulation underneath the pipe.

Between the springline of the pipe and its bottom, compacted gravel fill was used to separate the pipe from the insulated ditch walls. From the springline of the pipe to the ground surface, the ditch is backfilled with native soil.

3.2.4 Ditch Configuration, Test Section 4

Test Section 4 is a bare, 120 foot long uninsulated pipe installed in an overexcavated ditch. The pipe lies upon a 3 foot thick layer of compacted granular bedding. The ditch was backfilled with compacted gravel fill between the pipe's springline and bottom and with native soil from the pipe's springline to the ground surface.

3.2.5 Ditch Configuration, Test Section 5

Test Section 5 is insulated with 2 inches of urethane insulation, is 120 feet long, and is shallowly buried: the top of the pipe's insulation is at the same elevation as the natural ground surface. A 3 foot thick layer of compacted granular fill was used to cover the pipe. The bottom of the pipe, shielded by the insulation and its protective jacket, lies upon in-situ soil. The ditch was backfilled with compacted gravel fill between the pipe's springline and bottom and with native soil from the pipe's springline to the natural ground surface.

3.2.6 Ditch Configuration, Test Section 6

Test Section 6 is a bare, 120 foot long, uninsulated pipe installed in a trench backfilled with native soil. Chill pipes, using water and methanol as the convective heat transfer medium, extend (at an angle) approximately 15 feet beneath the pipe's bottom.

3.2.7 Ditch Configuration, Test Section 7

Test Section 7 is insulated with 2 inches of urethane insulation, is 120 feet long, and is installed in an overexcavated ditch. The bottom of the pipe, shielded by the insulation and its protective jacket, lies upon 1 foot of compacted granular bedding.

The ditch was backfilled with compacted gravel fill between the pipe's springline and bottom and with native soil from the pipe's springline to the ground surface.

3.2.8 Ditch Configuration, Test Section 8

Test Section 8 is insulated with 4 inches of urethane insulation, is 120 feet long, and is installed in an overexcavated ditch. The bottom of the pipe, shielded by the insulation and its protective jacket, lies upon a 3 foot thick layer of compacted granular bedding. The ditch was backfilled with compacted gravel fill between the pipe's springline and its bottom and with native soil from the pipe's springline to the ground surface.

3.2.9 Ditch Configuration, Test Section 9

Test Section 9 is a bare, 400 foot long, uninsulated pipe with approximately 270 feet (at the west end) buried in thawed soils and the remaining 130 feet buried in permafrost. This pipe demonstrates the effect of differential frost heaving of the pipe at the transition between permafrost and thawed soils, heave of thawed soils, and heave of initially frozen soils.

The west end of Test Section 9 is installed in a 1-to-1 side-slope ditch which is backfilled with native soil. The bottom of the pipe lies upon in-situ soil.

At the east end of Test Section 9, the bottom of the pipe lies upon 6 inches of compacted granular bedding within a ditch with vertical walls. The ditch is backfilled with compacted gravel fill between the springline of the pipe and its bottom and with native soil between the springline of the pipe and the ground surface.

3.2.10 Ditch Configuration, Test Section 10

Test Section 10 is a bare, 40 foot long, uninsulated pipe wholly installed in permafrost. The bottom of the pipe lies upon 6 inches of compacted granular bedding within a ditch with vertical walls. The ditch is backfilled with compacted gravel fill between the pipe's springline and bottom and with native soil from the pipe's springline to the ground surface.

3.3 Site Features

3.3.1 Supply and Return Piping

Chilled air supply to (and return from), each of the series-arranged test sections is conveyed by 12 inch diameter pipe insulated with 3 inches of urethane. In order to minimize structural loading of the test sections by the supply and return piping during the course of the test, a counter weight support system was devised that effectively adjusts itself as vertical displacement of a given test section occurs.

3.3.2 Field Electronics Housing

Twenty-two, approximately 4 by 3 by 8 foot buildings are used at test site to house the field (satellite) electronic multiplexers. The proper thermal environment is maintained in the insulated buildings by small electric heaters.

4.0 FACILITY INSTRUMENTATION, ELECTRONICS AND EQUIPMENT

4.1 Overview, Instrumentation and Electronics

Instrumentation at the facility is designed to measure: (1) the conditions of the operating system; (2) the thermal and groundwater environments around test sections and at select locations at the site; (3) the heave of the test sections, within the frost bulb, and adjacent areas; and, (4) the soil pressures and structural pipe responses. Table 4.1-1 presents a summary of instrumentation at the facility.

With the exception of heave rods and groundwater elevations, all sensor data are collected by two micro-processor computers. Half-hourly, a computer scans the alarm status of the operating system. If an alarm is set, the site operators are alerted via the onsite printer or, if the computer detects an alarm after working hours, the computer alerts a security service who in turn instructs an operator to return to the site.

Daily, the computers scan all automatically gathered data and update their memory. If the change in any datum is greater than a set variance (plus or minus a set value, common to the sensor type) the operators are alerted via the onsite printer; thereby, corrective maintenance actions are initiated.

Every Tuesday and Friday, the site operators manually collect heave rod and groundwater data at the facility. Using a Hewlett-Packard 3840 Total Station infra-red electronic distance measuring instrument, the operators follow a reading sequence designed to provide reliable and redundant data. Groundwater data are collected by lowering an electric probe down each piezometer/standpipe and measuring the depth to water contact. By computer prompt, the operators enter the manually collected data -- a variance comparison is also made between these new and former data.

TABLE 4.1-1
INSTRUMENT SUMMARY

INSTRUMENT TYPE		QUANTITY
Temperature Sensors		1850
Groundwater Wells		12
Heave Rods		59
Heave Plates		30
Frost-proof Benchmarks		3
Extensometers	LVDT	2
	C-Ring	6
Strain Gauges	Axial	78
	Triaxial Rosettes	8
	Hoop	8
Soil Pressure Gauges		42
Heat Flux Transducers		70
Electronically Addressed Piezometers		17
Pipe Pressure Gauges		1
Pipe Flow Rate Gauges		1
Chilled Air Temperature Sensors		5
Ambient Air Temperature Sensors		2
Snow Depth Gauges		4

After the manually collected data are entered, the computer writes these data and current automatically collected data to two (duplicate) cassette tapes.

A computer in NWA's Fairbanks office automatically compares the data from the two cassette tapes for accuracy before the data are reduced to engineering units and printed. One of these tapes is placed in a data archive in Fairbanks. The reduced data are transferred to a 9-track tape and transmitted to Irvine, California. After a microfiche is made of each tape, five of the tapes are consolidated on a larger 9-track tape. Two "identical" tape copies are made and the data are again compared for accuracy. One of these tapes is placed in another data archive and the other is sent to Battelle Columbus Laboratories' database management computer.

4.2 Instrumentation

4.2.1 Temperature Sensors

Approximately 1850 temperature sensors are used at the facility to monitor the environment of the pipes, some site areas "uninfluenced" by the pipes, and the operating system.

The majority of the temperature sensors are arranged on a 16-per-string (hexidecimal) basis. Located adjacent to and beneath the test sections, they serve to define an array necessary to monitor the progress of the frost bulb and seasonal frost.

From the refrigeration unit, through the series-arranged test sections and interconnecting piping, to the location at which the chilled air re-enters the mechanical building the temperature of the circulating air is measured five times.

Individual temperature sensors are located at select locations on external pipe surfaces, at select heave plates, on Test Section 9's external extensometers, on the upper and lower surfaces of Test Section 3's board insulation, adjacent to heat flux transducers along Test Section 6, and at electronically addressed piezometers beneath Test Sections 1, 2, 6, and 9.

4.2.2 Groundwater Wells

Each of the 12 groundwater standpipes, five of which were installed in 1978, are read twice a week. These slotted-PVC standpipes are placed around the site to provide water table elevations adjacent to the test sections and to facilitate analysis of groundwater movement.

4.2.3 Heave Rods and Plates

Vertical displacements of the test sections are computed by comparing the relative elevations of three frost-proof benchmarks at the site against heave rods mounted on the test sections. With the exception of Test Section 9, the differential heave section which has 32 heave rods, each of the test sections have 3 heave rods located near their quarter-points and mid-point.

Adjacent to Test Section 1, the reference section, are 20 heave plates located at various depths whose principal purpose is to measure relative vertical displacements of the 4 inch diameter steel plates within the frost bulb after the frost bulb has encompassed a given plate.

In order to measure the vertical displacement of the in-situ soil at various depths, three 4 inch diameter steel heave plates are located at: (1) one end of Test Section 5, and (2) the thawed-soil end of Test Section 9. Additionally, one heave plate is placed beyond the permafrost end of Test Section 9 to monitor the vertical displacement of the natural permafrost. At three locations on the site, shallowly buried heave plates (3 foot by 3 foot concrete slabs) are used to monitor displacement due, in major part, to seasonal refreezing.

The heave rods connected to the pipes and to the heave plates are protected from seasonal frost jacking by a PVC pipe shield extending from the rod's base to the ground surface.

4.2.4 Extensometers

Extensometers are used to measure internal vertical and horizontal asymmetric displacements ("ovaling") at one station within Test Section 6, at two stations within Test Section 9, and to measure the longitudinal movement of Test Section 9.

Internal displacement is measured using a strain gauge affixed to an approximately 3.5 foot diameter "C-ring" which is mounted within the pipe. One C-ring instrument measures displacement in the horizontal plane and one measures displacement in the vertical plane.

Longitudinal displacement at both ends of Test Section 9 is measured with an LVDT instrument connected between a reference pile and the test section.

4.2.5 Strain Gauges

Test Section 9 is equipped with 39 pairs (top and bottom) of axially oriented strain gauges, plus two stations where four gauges (top, bottom, and both sides) are used to measure hoop strain, and two stations where triaxial rosettes (top, bottom, and both sides) are used.

4.2.6 Soil Pressure Gauges

Four arrangements of soil pressure gauges are used at the facility:

Arrangement "A" is composed of two pressure cells located at the top and bottom of the pipe at two stations along Test Section 9. These cells are designed to have a 12-inch by 12-inch soil pressure surface and are machined to match the curvature of the pipe surface.

Arrangement "B" uses the same pressure cell as "A" above. At each of the five stations along Test Section 9, four cells are used to detect soil pressure at the top, bottom, and both sides of the pipe. This arrangement is also used at one station on Test Section 6.

Arrangement "C" uses a 9-inch diameter load cell mounted within a cast aluminum shoe which is machined to match the curvature of the pipe surface. The shoe was designed to reduce soil bridging and stress concentrations, to protect the pressure cell, and to facilitate mounting. At two stations along Test 9, three cells are oriented as follows: one cell is located on the top of the pipe and the other two cells are located along both sides of the upper surface of the pipe, at an angle of approximately 45 degrees from the top.

Arrangement "D" uses the same pressure cell as "C" above. At one station along Test Section 9, eight equally spaced (at 45 degree intervals) cells detect soil pressure around the pipe.

4.2.7 Heat Flux Transducers

Four arrangements of heat flux transducers are used at the facility:

Arrangement "A" is used at one station on Test Section 4's bare surface and at one station on Test Section 7's insulated surface. This arrangement uses 12 equally spaced (at 30 degree intervals) heat flux transducers.

Arrangements "B" and "C" are located at the same station on Test Section 6. Arrangement "B" uses 16 equally spaced heat flux transducers mounted along one of the chill pipes adjacent to Test Section 6. Temperature sensors (arrangement "K") are mounted at the same locations as each of these heat flux transducers. Arrangement "C" uses 16 heat flux transducers oriented parallel to the ground surface at a depth of approximately 10 feet. The variable-spaced heat flux transducers extend from the chill pipe to approximately 10.5 feet beyond the chill pipe (approximately 13 feet beyond Test Section 6). Temperature sensors (Arrangement "L") are mounted at the same locations as each of these heat flux transducers.

Arrangement "D" is used at two stations along Test Section 3. Located between the polystyrene board insulation and the in-situ soil, three heat flux transducers are used on the bottom of the ditch and two are used on each sidewall of the ditch.

4.2.8 Electronically Addressed Piezometers

The facility has 17 electronically-addressed piezometers located beneath or immediately adjacent to Test Sections 1, 2, 6, and 9. Grouped near the same station at various depths, five piezometers are located along Test Sections 1, 2, and 9 and two are located along Test Section 6.

4.2.9 Climatological Data

In addition to the data available through NOAA, U.S. Weather Service, Fairbanks International Airport, air temperatures from both weather stations at the facility are continuously recorded on strip-chart recorders. Twice a week, snow depths are also recorded at four locations at the facility.

4.2.10 Operating System Data

Circulating air temperatures, pipe pressure, and pipe flow rate are all continuously recorded by strip-chart recorders located at the facility.

4.3 Facility Electronics

4.3.1 Data Acquisition System

The Frost Heave Test Facility Data Acquisition System consists of two computers, one slave (B & F SY76), and one master (INTEL 8020).

The B & F SY76 collects data automatically from:

- o Strain gauges.
- o Internal extensometers.
- o External extensometers.
- o Pore pressure sensors.
- o Barometer.
- o Soil pressure girdles.
- o Pipe temperature sensors.
- o Weather temperature sensors.
- o Pipe pressure sensors.

The INTEL 8020 collects data automatically from:

- o All B & F SY76 data.
- o Temperature sensistors.
- o Heat flux sensors.

Manually collected data is entered into the INTEL 8020 via a CRT/Keyboard for:

- o All heave rod readings.
- o Some temperature sensor readings.
- o Some heat flux sensor readings.
- o All groundwater well readings.
- o All snow depth readings.

The INTEL 8020 is interfaced to its field data points via Petrotech Lavalin multiplexing equipment. An address/data cable runs from the computer interface to each of 22 junction boxes each contained in an insulated and heated building.

Each junction box containes a line driver board which interfaces that box with the address/data cable. In turn, each junction box has an internal address/data cable to connect its driver board with the enclosed temperature and/or heat flux multiplexer boards. Each temperature/heat flux board is a 16-channel multiplexer to which is attached a cable leading to the 16 individual sensors.

The address/data cable provides a 12-bit address bus and a 12-bit data bus. Thus, data points can be assigned addresses 000-FFF in hexidecimal (0000-4095 decimal). Data values may have the same range.

All data points in the system are assigned an address. Each multiplexer board (temperature/heat flux) is designed to recognize a unique range of 16 addresses. Thus, in a 3-digit hexidecimal address, the two most significant digits identify the multiplexer board and the last digit identifies the specific channel (sensor) to be read.

When a scan is initiated, the INTEL 8020 begins with sensor 000; sends that address out on the address bus; waits an appropriate time; reads the sensor on the data bus and stores the value in its memory. The address is incremented and the process is repeated until all automatically read data are collected. The full range (000-FFF) is not used and any manually read points are skipped.

The SY76 is attached to the address/data cable with a line driver as if it were a junction box. The SY76 automatically scans its field data points every 90 minutes, converts the raw data to engineering units and stores the values in its memory. The SY76 waits for a request from the INTEL 8020 for a sensor value and then transmits the value to the INTEL. Data points with hexidecimal addresses 000-1FF are contained in the SY76.

After completion of a scan, the current value of each sensor is compared with the value from the previous scan. Any differences which exceed set limits are printed to alert the facility operators. The data are then printed on a line printer and recorded on two cassette tapes. Conversion to engineering units is performed on the INTEL MDS 220 in the NWA office in Fairbanks.

4.3.2 Electronic Distance Measurement

A Hewlett-Packard 3820A Electronic Total Station is used at the test facility to measure vertical elevations of the test sections, heave plates, and the three frost-proof benchmarks. The instrument automatically computes horizontal and zenith angles, and horizontal and vertical distances. This instrument is ideally suited for use at the test facility because of its speed and specified accuracy of ± 0.016 feet.

Adjacent to the control and equipment building at the facility, a 6 inch diameter steel pipe attached to a 6 X 6 foot concrete pedestal (within a wooden shelter) is provided for mounting of the instrument.

4.4 Facility/Support Equipment

4.4.1 General

The control room, standby electrical power generation unit, Data Acquisition System, circulation and refrigeration equipment, and attendant support equipment are housed in a 40 by 100 foot insulated folding metal building. The building pad, as well as the access road and storage pad are constructed of nonfrost-susceptible gravel.

The control room, which also serves as the facility office is air conditioned to maintain a proper environment for the Data Acquisition System.

Electrical power is purchased from Golden Valley Electrical Association. This service is capable of supplying 500 KVA (at 480 V) of 3-phase, 60 hertz power.

4.4.2 Circulating Air Knock-Out Drum

Before the warmed air from the test loop is supplied to the circulating air compressors, it is passed through a knock-out drum. This drum, supplied by California Tank, protects the compressors by extracting scale and particles picked up in the loop.

4.4.3 Circulating Air Compressors

The facility has two full-size 150-hp Rotoflow centrifugal compressors each capable of providing 940 cfm of 675 psig air through the closed test loop. Due to system requirements and electrical service limits, only one of the manually-switched parallel-arranged compressors operates at any time.

4.4.4 Refrigeration Equipment

The refrigeration system was designed to provide 40.3 tons of refrigeration while cooling a stream of air from 9°F to 0°F. Air supply to the refrigeration units is at a pressure of approximately 675 psig and is dehydrated to a minus 50°F dewpoint at atmospheric conditions.

The packaged unit, supplied by Carrier Air Conditioning Corporation, is equipped with three 50-percent-size reciprocating-type compressors. The refrigeration system operates on a halocarbon refrigerant (R-502). The evaporator has the capacity to cool approximately 215,000 lbs/hr of circulating air.

The packaged unit's air-cooled condensor draws air from within the equipment building. Its design air temperature range of 40°F to 85°F is maintained by a combination of exhaust and supply ducting options.

4.4.5 Make-Up Air Compressors

Each of the two 75 hp RIX, self-cooled, reciprocating make-up air compressors are capable of providing 115 scfm of oil-free air at 675 psig to the make-up air dryer. Operation of these automatic units is dependent upon: (1) instrument air consumption; (2) circulating air compressor seal leakage; (3) regeneration air for the air dryer; and (4) miscellaneous leakage from the test loop itself (e.g., valve seals).

4.4.6 Make-Up Air Dryer

Before make-up air enters the test loop, it is desiccated to a dewpoint of minus 50°F. This air dryer, supplied by Pall Trinity, is capable of handling 200 scfm of make-up air supplied by the make-up air compressors. In the event that both make-up air compressors are required to operate at the same time (providing approximately 230 scfm), the moisture that is not extracted by the air dryer is eventually extracted from the circulating air stream by either the knock-out drum or the refrigeration unit's evaporator.

5.0 OPERATING HISTORY

5.1 Facility Operations, Reliability

Since start-up of the facility on October 13, 1979, its operation has been virtually uninterrupted. As part of the scheduled maintenance program at the facility, the circulating air and refrigeration units are shut-down for approximately two hours each week to allow the site operators to extract water from the chiller unit.

If the facility's circulating or refrigeration units fail (e.g., loss of purchased power) after normal working hours, the computer system will detect an alarm during its half-hourly scan. The computer then alerts a security service who in turn alerts a site operator to return to the facility. This sequence has occurred approximately six times since facility start-up. Typically, the duration between alarm detection and an operator arriving at the facility is less than two hours.

In the event of a power failure, the facility's standby power generator automatically comes on-line to provide power for some building lights, the Data Acquisition System, the above-ground low-pipe temperature heat tracing system, and for the heaters that protect the field electronics. Because standby power is not sufficient to supply the air supply, circulating, or refrigeration units, purchased power must be restored before operation of these units can resume. However, power outages have not been a problem as they have been infrequent and their duration has been short (typically less than one hour).

5.2 Facility Operations, Equipment

5.2.1 General

No major problems have been experienced with any of the air supply, circulating, or refrigeration equipment.

5.2.2 Refrigeration Package

The refrigeration package was designed to have one primary unit, one "peaking" unit, and one standby unit. For refrigeration demand less than its capacity, the continuously operating primary unit is capable of following the refrigeration load by unloading itself down to a certain point below which a hot-gas bypass faculty maintains compressor load while allowing the net refrigeration load to decrease. If the primary unit's capacity is exceeded, the second "peaking" unit automatically assists. At the control panel, any one of the units can be assigned primary, peaking, or standby responsibility.

Throughout the summer of 1980, the period when refrigeration demand was the greatest (excluding the start-up load in October, 1979), the primary load-following unit has been capable of satisfying demand.

5.2.3 Air Supply and Circulation

Make-up air to the test loop is supplied by one or both of the compressors located at the facility. Automatically actuated, these compressors supply oil-free, 675 psig, relatively cool (approximately 70°F) air to an air dryer before the make-up air enters the test loop just ahead of the refrigeration unit.

As explained in Section 5.1, water is extracted from the chiller unit on a weekly basis. The source of this water is from: (1) the amount of make-up air exceeding the capacity of the air dryer and/or (2) sublimated water from the test sections from ice resulting from incomplete extraction of hydrotest water.

No problems have been experienced with either the knock-out return air cleaning drum (located upstream of the circulating compressors) or either of the circulating compressors.

5.3 Facility Operations, Electronics

5.3.1 Data Acquisition System

The data acquisition system installed at the facility was a developmental system with limited field experience. Environmentally aggravated component failures of the field (satellite) electronics have necessitated near-regular electronic maintenance.

Detection and isolation of component failures are accomplished in major part by the main computer's datum comparison (variance) routine and in minor part by troubleshooting. Section 7.0, Planned Programs, describes programs underway to increase the reliability of the overall Data Acquisition System.

5.3.2 Electronic Distance Measurement

No problems have been experienced with the Hewlett-Packard 3840 Electronic Total Station distance measurement instrument at the facility. The instrument is kept in the control room when not in use and is kept warm when the readings are being taken during cold days.

Fogging of some of the corner-cube reflectors that the instrument interrogates has been experienced periodically; however, it is anticipated that desiccant (added to the back of problem reflector units) will eliminate the problem.

5.4 Facility Operations, Instrumentation

5.4.1 Temperature Sensors

Analyses of below-ground temperature sensor data have been generally difficult. Although the principal sources have not been satisfactorily isolated, steps are being taken to reduce the ambiguities.

Because the reported temperatures are not generally accurate but are generally consistent, a combination of computer graphics, statistics, and computer simulations has been employed to define frost bulb growth. Field verifications of these analyses were conducted in July and August of 1980 and are presented in Section 6.0.

5.4.2 Groundwater Wells

During the months of November, December and January (1980), four of the groundwater standpipes at the site developed a layer of ice which prevented the taking of their readings. In early February, the facility operators fabricated a Chem-lex self-limiting heat tape to keep these wells open for the remainder of winter. The heat tape was used as needed: typically it was placed within a problem well the evening before the next day's reading.

5.4.3 Heave Rods and Plates

Other than infrequent fogging of a few reflectors and the need to increase the height of one reflector so that it could again be seen (frost heave of the pipe had obscured the view of the reflector) no problems have been experienced with either the heave rods or heave plates at the facility. As stated in Section 5.3.2, a desiccant has been added to the problem reflector units to eliminate the fogging problem.

5.4.4 Extensometers, Strain Gauges, and Soil Pressure Gauges

Preliminary analysis of the data from these instruments are included in the structural report (Appendix).

5.4.5 Heat Flux Transducers

Presentation of data from these instruments will be included in a later report.

5.4.6 Electronically Addressed Piezometers

Presentation of data from these instruments will be included in a later report.

5.4.7 Climatological Data

No problems have been experienced with either the two air temperature weatherstations or the manual snow depth gauging procedure at the site. Additional climatological data for geothermal simulations are available from NOAA, U.S. Weather-service data for the Fairbanks area.

5.4.8 Operating System Data

No problems have been experienced with either the pipe flow rate sensor, pipe pressure indicator, or any of the continuous strip-chart recorders at the facility. Only minor difficulties have been experienced with calibration of the five circulating air temperature sensors.

5.5 Circulating Air History

Since commissioning of the facility on October 13, 1979, operation of the circulating air and refrigeration systems has been essentially continuous.

The circulating air system has provided an average mass-flow rate of approximately 182,600 lbs/hr at an average pressure of approximately 670 psig.

Circulating air temperatures at two locations within the test loop are presented in Table 5.5-1. Sensor TE-3 represents the air temperature immediately upstream of Test Section 8 -- the first of the series-arranged sections. Sensor TE-6 represents the air temperature after it has circulated through all but the last test section (Number 6, with chill pipes). As shown in Table 5.5-1, the circulating air temperature entering the test loop has fluctuated between approximately 12.8°F and 14.1°F, and through the test loop the air has been warmed to a range of approximately 14.1°F to 16.5°F (excluding start-up in October).

TABLE 5.5-1
AVERAGE CIRCULATING AIR TEMPERATURES

MONTH, YEAR		SENSOR TE-3 (°F)	SENSOR TE-6 (°F)
Oct.	1979	14.0	19.6
Nov.		13.1	15.5
Dec.		12.8	14.5
Jan.	1980	13.4	14.1
Feb.		13.6	14.4
Mar.		13.4	14.3
Apr.		14.1	15.2
May		14.1	16.0
Jun.		13.7	16.5
Jul.		13.7	16.0

NOTES

1. Chilled air circulation began on October 13, 1979.
2. Sensor TE-3 represents the circulating air temperature entering the test loop.
3. Sensor TE-6 represents the circulating air temperature after it has been warmed through the test loop.

6.0 FROST HEAVE AND FROST BULB GROWTH

6.1 Overview

In order to verify the extent and composition of the frost bulb for each of the test sections, Northwest Alaskan initiated a drilling, sampling and trenching program in July of 1980. The objectives and scope of this program are reported in Section 6.2. Data from this program are reported on the "Frost Heave vs. Frost Bulb Growth" figures, as the 1980 Field Verification Program points, and are presented on Table 6.1-1. A plot plan showing the location of boreholes, trenches, and permeability wells is included in the appendicies to this report.

Also within this section are tables and figures showing frost heave comparisons between the various test sections, tables and a figure showing frost heave within the frost bulb surrounding Test Section 1, data for heave plates and figures showing frost bulb growth and groundwater well hydrographs.

6.2 1980 Field Verification Program

6.2.1 Objectives

During late July and early August of 1980, Northwest Alaskan conducted drilling, trenching and groundwater investigations at the test site. The objectives of this program which included the drilling of 20 boreholes, 3 groundwater wells, and 10 trenchs were four-fold:

a. To verify the dimensions of the frost bulb and the location of the permafrost table as suggested by the installed temperature sensors.

TABLE 6.1-1
FAIRBANKS FROST HEAVE TEST FACILITY
1980 FIELD VERIFICATION PROGRAM, BOREHOLES

DATE	TEST SECTION	BOREHOLE NUMBER	BOREHOLE LOCATION STATION	BOREHOLE LOCATION REFERENCE	FROST BULB ENCOUNTERED[1,2] FIRST	FROST BULB ENCOUNTERED[1,2] LAST	PERMAFROST ENCOUNTERED
07/22/80	1	N69-3	64'	3' Rt of C/L	2.8'	to 12.9'	23.5'
07/24/80	1	N69-7	26'	3' Lt of C/L	2.8'	to 12.7'	24.2'
07/24/80	1	N69-8	97'	3' Lt of C/L	2.2'	to 12.9'	26.7'
07/25/80	2	N69-9	65'	3' Rt of C/L	4.8	to 8.5'	26.5'
08/04/80	2	N69-22	23'	3' Lt of C/L	5.0'	to 7.7'	25.5'
08/05/80	3	N69-24	56'	3' Lt of C/L	2.8'	to 9.9'	26.0'
07/29/80	4	N69-13	58'	3' Lt of C/L	2.5'	to 14.3'	24.5'
08/05/80	4	N69-23	89'	3' Lt of C/L	2.3'	to 14.3'	22.5'
08/01/80	5	N69-18	63'	3' Rt of C/L	7.0'	to 9.2'	27.2'
08/04/80	5	N69-21	19'	3' Lt of C/L	7.7'	to 9.1'	27.5'
07/29/80	6	N69-14	52'	4' Rt of C/L	2.5'	to permafrost, B.O.H at 26.9'	
08/01/80	7	N69-19	54'	3' Rt of C/L	4.5'	to 9.2'	27.4'
07/25/80	8	N69-10	51'	4' Rt of C/L	4.1	to 8.6'	23.0'
07/28/80	8	N69-11a	108'	3' Lt of C/L	5.6	to 10.3'	18.8'
07/21/80	9	N69-1	224'	4' Lt of C/L	4.0'	to 10.7'	18.5'
07/22/80	9	N69-2	241'	3' Lt of C/L	3.1'	to 12.8'	15.0'
07/30/80	9	N69-15	101'	3' Lt of C/L	3.1'	to 14.3'	25.5'
07/31/80	9	N69-16	261'	3' Lt of C/L	2.8'	to 13.4'	15.6'
07/31/80	9	N69-17	278'	3' Lt of C/L	3.3'	to permafrost, B.O.H. at 25.7'	
07/28/80	N/A	N69-12	Between Sections 1 & 9		NONE		23.5'

[1] First represents the top of the detected frost bulb, last represents the bottom of the detected frost bulb (i.e., frost bulb depth).

[2] Where the holes were drilled, the test section's base is approximately 7 feet beneath the ground surface.

b. To measure, photograph, classify, and test continuous core samples taken within the frost bulb to determine the ice-segregation ratio and its variations for the different thermal environments presented by the various test sections.

c. To identify the soil beneath the frost bulb (i.e., the soil that the frost bulb would eventually encounter) by recovering drive samples.

d. To conduct in-situ permeability tests at the site for on-going groundwater analyses.

6.2.2 Drilling Techniques

By careful maneuvering and the use of ramps, the Nodwell-mounted CME-55 drill rig was able to avoid the cable trays, electrical wires, and the chilled air supply and return piping at the test site.

A 2.5 inch inside diameter Modified Shelby sampler was used to obtain frozen frost bulb samples. Between the depths where the frost bulb was first and last encountered, consecutive 18-inch long frozen samples were taken. Only after a given sample was logged, photographed with two cameras, tagged, wrapped, and placed in either a cold box or the onsite freezer was the next sample taken.

Immediately beneath the frost bulb a 1.4 inch or 2.5 inch diameter drive sample was taken. Thereafter, until encountering permafrost, drive samples were taken at 5 foot intervals.

The permafrost table was generally easy to identify, principally because of the transition zone between the saturated soil medium (beneath the frost bulb) and the underlying frozen (permafrost) soil. In numerous cases, massive ice was recovered from the permafrost table.

In all cases a hole was begun using an 8 inch outside-diameter, 3 inch inside diameter hollow-stem auger. The auger would extend from the ground surface to the frozen soil interface to provide guidance for the sampling equipment. It was discovered early in the program that it was not necessary to extend this auger through the frost bulb (subsequent to the continuous frost bulb sampling) to open the hole for the PVC pipe. If carefully and systematically done, the hole in the saturated silt medium opened by the sampling equipment would stay open long enough to permit placement of the PVC pipe. Accordingly, backfilling was virtually limited to replacing the soil displaced by the few feet of augering.

A sealed 2 inch inside diameter PVC pipe was placed in each drill hole so that temperature sensor strings could be installed at a future date.

6.2.3 In-situ Permeability Testing

At three locations on the test site groundwater wells were drilled for in-situ permeability testing using a "falling head" method. After a 3 inch inside diameter steel casing was driven to approximately 17 feet below the ground surface, a 2.5 inch inside diameter (approximately 2.75 inch O.D.) Modified Shelby was used to clean-out the casing to its bottom. The casing was pulled up about 3 feet after a volume (equivalent to a 3 foot column within the 3 inch casing) of 3/4 inch gravel was secure at the bottom of the cleaned-out casing.

After stabilization of the groundwater table, its elevation was recorded. The casing was filled with water to its top -- greater than 10 feet above the groundwater table. The falling water elevation was then recorded at prescribed intervals for use in standard equations to derive the in-situ permeability.

6.2.4 Trenching

To complement the drilling and sampling investigations of the frost bulbs, a small rubber-tired backhoe was used to open 10 trenches at the test site. The objectives of this program were to verify the shape of the frost bulb, the depth of the unfrozen cover over the test sections, and to expose the in-situ soil stratigraphy.

In all cases the trenches were begun perpendicular to the axis of the test sections, slightly beyond the test section's centerline. In some cases, due to physical limitations (e.g., cable trays, chilled air supply and return piping, etc.), the trenches had to be angled as the trench progressed farther from the test section.

Trenches were not open adjacent to Test Sections 3, 5 or 10 because: (1) Test Section 3 has board insulation placed on the ditch boundaries which it was not deemed advisable to disturb; (2) Test Section 5 is placed beneath a gravel berm which also it was not deemed advisable to disturb and it also had access limitations; and, (3) due to its areal similarity with a trench opened along Test Section 9, a trench was not opened along Test Section 10.

6.2.5 Laboratory Testing Program

Laboratory testing of the samples taken during the 1980 Field Verification Program has begun concentrating in the following areas:

a. Visual confirmation of the field-recorded data noting exceptions as evidenced.

b. Sketching each sample noting locations of ice lenses and soil features.

c. After cutting each sample longitudinally (returning half of the frozen sample to storage), a record will be made of the dimensions, inclinations, and locations of any ice lenses as well as a record of the soil/ice classifications. Additionally, photographs will be taken of each sample.

d. After the sample is cut into short segments, each segment will be tested to reveal its bulk density and water content, and gradation.

e. Drive samples taken below the frost bulb, some core samples taken within the frost bulb, and some grab samples taken of backfill and bedding materials will be tested for gradation.

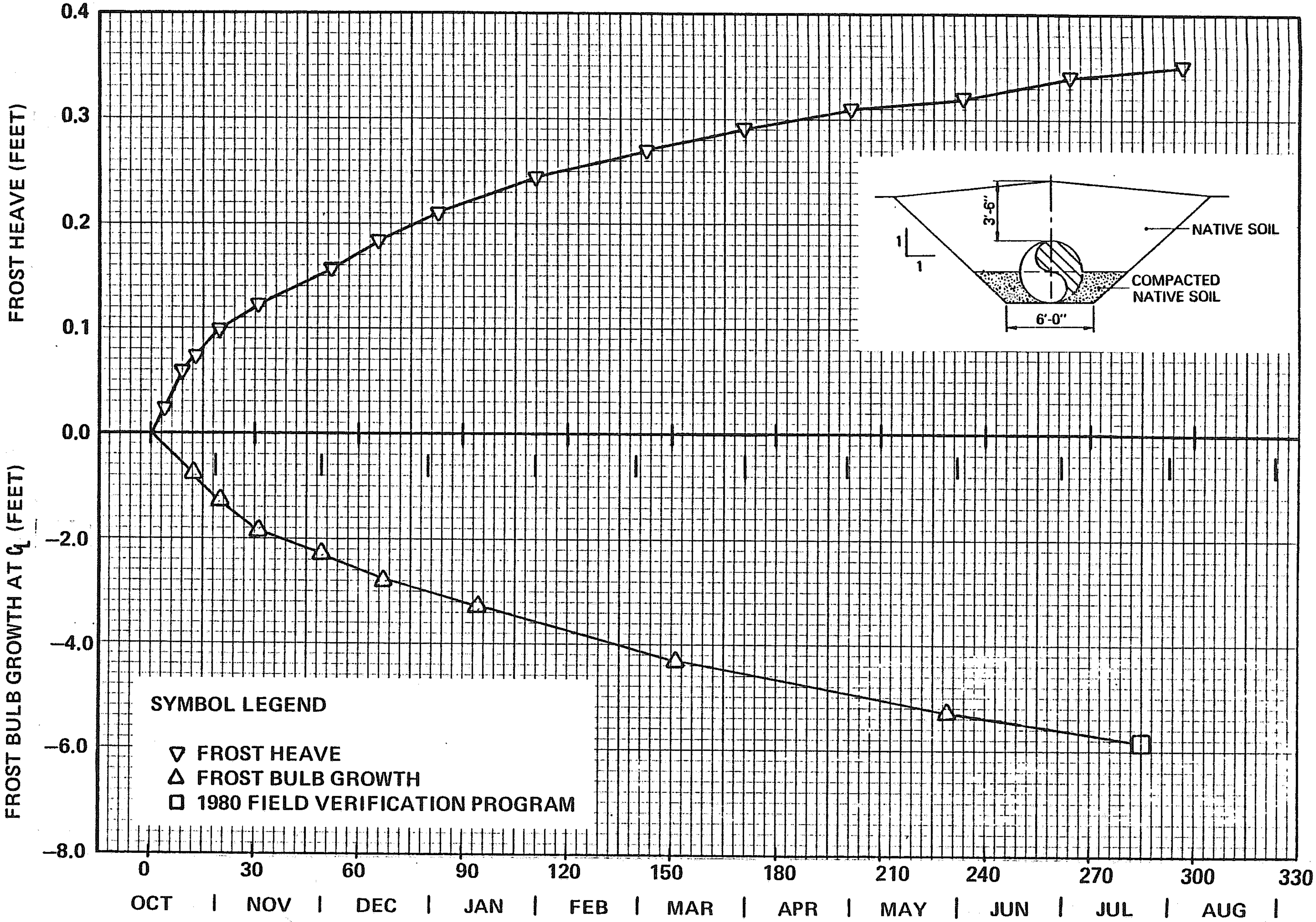
6.3 Tabular and Graphical Presentation

In this subsection, a table of the vertical displacements since facility start-up is given for each of the 10 test sections. With the exception of Test Section 10 (wholly installed in permafrost), figures accompanying the tables present average vertical displacements along each test section and frost bulb growth versus time.

Figure 6.3-10 in this subsection presents the vertical displacement profile versus time along Test Section 9 and Figure 6.6-5, presenting the vertical displacement versus time for Test Section 10 is included in subsection 6.6

Frost bulb growth data for Test Sections 3, 5, and 8 are not presented at this time. It is anticipated that these data will be presented in the next report when ongoing analyses are concluded.

FIGURE 6.3-1
FROST HEAVE & FROST BULB GROWTH VS. TIME
TEST SECTION 1

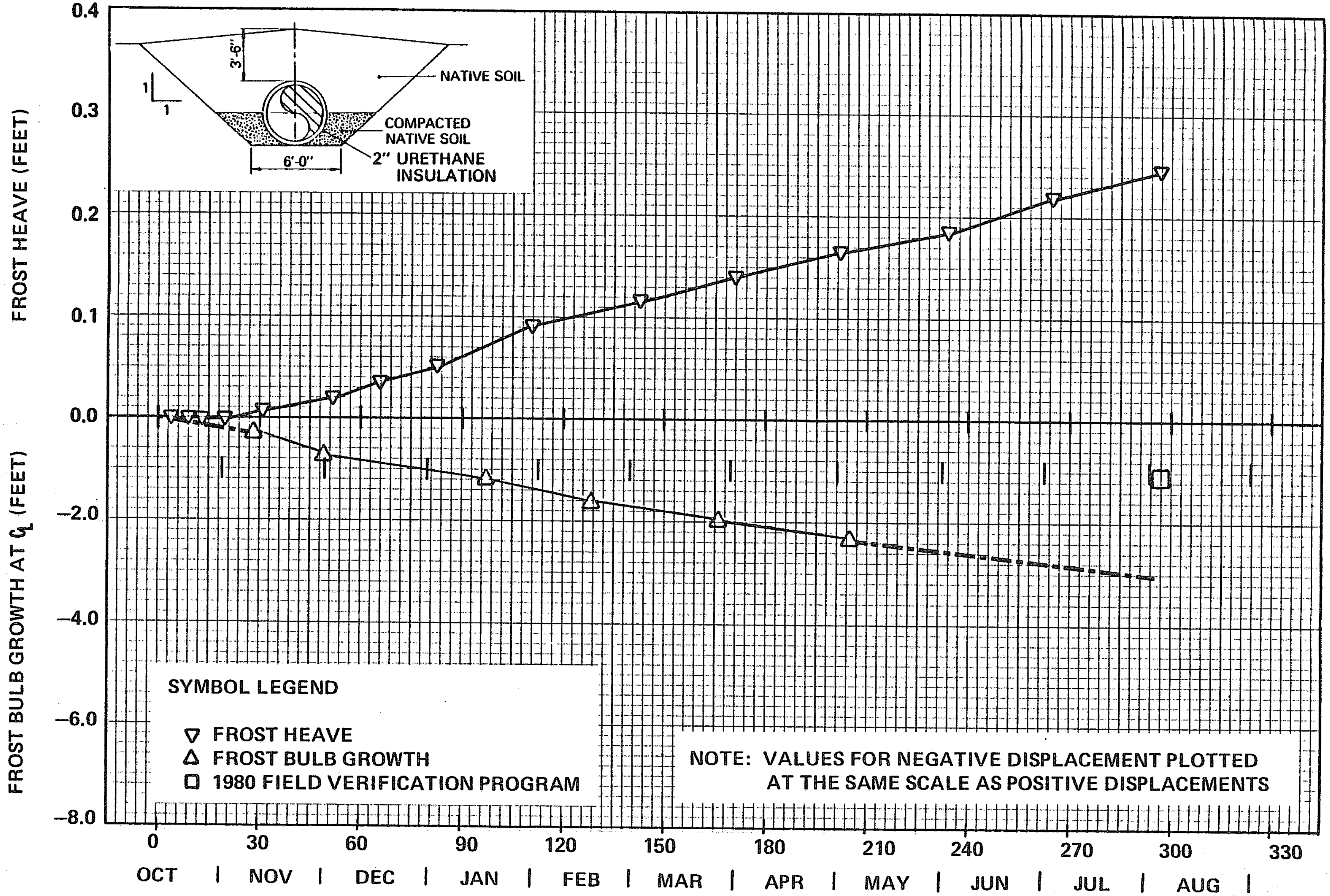


NOTE: DAY ZERO IS OCTOBER 13, 1979

TABLE 6.3-2
VERTICAL DISPLACEMENT SINCE FACILITY START-UP
TEST SECTION 2

DATE	DAYS SINCE START-UP	VERTICAL DISPLACEMENT $B4E STA. 32 (ft)	$B4D STA. 62 (ft)	$B4C STA. 92 (ft)	AVERAGE (ft)
10/13/79	0	0.000	0.000	0.000	0.000
10/17/79	4	-0.004	0.000	-0.002	-0.002
10/22/79	9	0.001	-0.001	-0.003	-0.001
10/26/79	13	-0.006	-0.002	-0.002	-0.003
11/02/79	20	-0.003	-0.001	-0.001	-0.001
11/13/79	31	0.006	0.008	0.010	0.008
12/04/79	52	0.023	0.023	0.014	0.020
12/18/79	66	0.041	0.039	0.024	0.035
01/04/80	83	0.061	0.053	0.040	0.051
02/01/80	111	0.109	0.099	0.068	0.092
03/04/80	143	0.142	0.124	0.086	0.117
04/01/80	171	0.166	0.149	0.107	0.141
05/02/80	202	0.197	0.172	0.124	0.165
06/03/80	234	0.223	0.196	0.144	0.187
07/04/80	265	0.260	0.227	0.171	0.220
08/05/80	297	0.287	0.254	0.197	0.246

FIGURE 6.3-2
FROST HEAVE & FROST BULB GROWTH VS. TIME
TEST SECTION 2

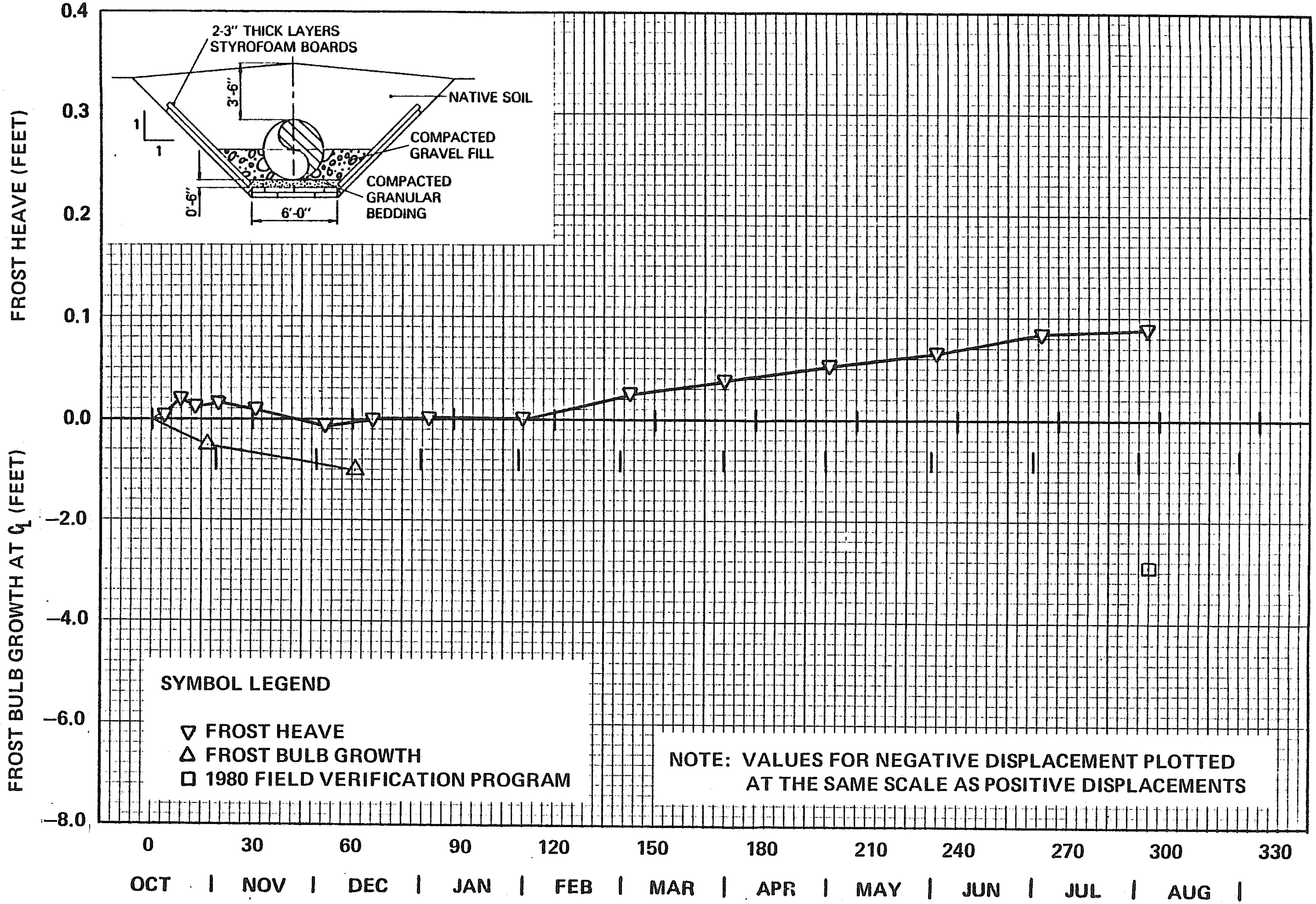


NOTE: DAY ZERO IS OCTOBER 13, 1979

TABLE 6.3-3
VERTICAL DISPLACEMENT SINCE FACILITY START-UP
TEST SECTION 3

DATE	DAYS SINCE START-UP	VERTICAL DISPLACEMENT $B43 STA. 32 (ft)	$B44 STA. 62 (ft)	$B45 STA. 92 (ft)	AVERAGE (ft)
10/13/79	0	0.000	0.000	0.000	0.000
10/17/79	4	0.005	--	-0.002	0.002
10/22/79	9	0.008	0.014	0.010	0.011
10/26/79	13	0.007	0.011	0.002	0.007
11/02/79	20	0.006	0.012	0.006	0.008
11/13/79	31	0.007	0.006	0.002	0.005
12/04/79	52	-0.006	0.001	-0.003	-0.003
12/18/79	66	-0.001	0.003	-0.002	0.000
01/04/80	83	-0.004	0.004	0.003	0.001
02/01/80	111	0.005	0.004	0.013	0.001
03/04/80	143	0.010	0.015	0.014	0.013
04/01/80	171	0.015	0.020	0.021	0.019
05/02/80	202	0.029	0.025	--	0.027
06/03/80	234	0.032	0.031	0.035	0.033
07/04/80	265	0.039	0.042	0.044	0.042
08/05/80	297	0.047	0.047	0.042	0.045

FIGURE 6.3-3
FROST HEAVE & FROST BULB GROWTH VS. TIME
TEST SECTION 3

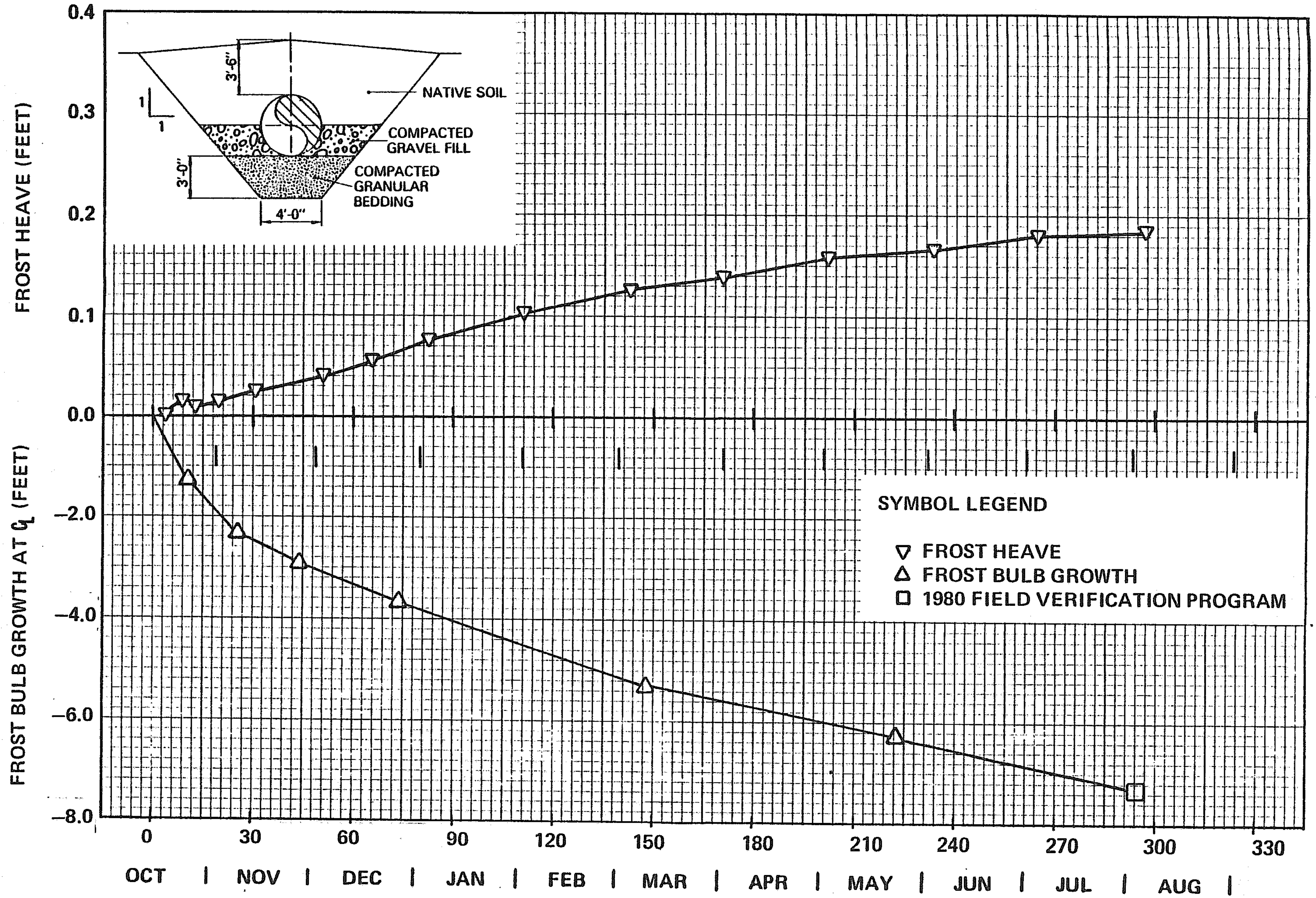


NOTE: DAY ZERO IS OCTOBER 13, 1979

TABLE 6.3-4
VERTICAL DISPLACEMENT SINCE FACILITY START-UP
TEST SECTION 4

DATE	DAYS SINCE START-UP	VERTICAL DISPLACEMENT $B5B STA. 32 (ft)	$B5C STA. 62 (ft)	$B5D STA. 92 (ft)	AVERAGE (ft)
10/13/79	0	0.000	0.000	0.000	0.000
10/17/79	4	0.003	0.008	0.001	0.004
10/22/79	9	0.019	0.017	0.013	0.016
10/26/79	13	0.009	0.010	0.011	0.010
11/02/79	20	0.014	0.013	0.020	0.016
11/13/79	31	0.022	0.015	0.040	0.026
12/04/79	52	0.040	0.039	0.046	0.042
12/18/79	66	0.051	0.054	0.065	0.057
01/04/80	83	0.079	0.076	0.089	0.081
02/01/80	111	0.100	0.099	0.115	0.104
03/04/80	143	0.122	0.123	0.138	0.127
04/01/80	171	0.139	0.130	0.150	0.140
05/02/80	202	0.154	0.148	0.173	0.159
06/03/80	234	0.164	0.159	0.179	0.167
07/04/80	265	0.177	0.171	0.195	0.181
08/05/80	297	0.183	0.176	0.199	0.186

FIGURE 6.3-4
FROST HEAVE & FROST BULB GROWTH VS. TIME
TEST SECTION 4

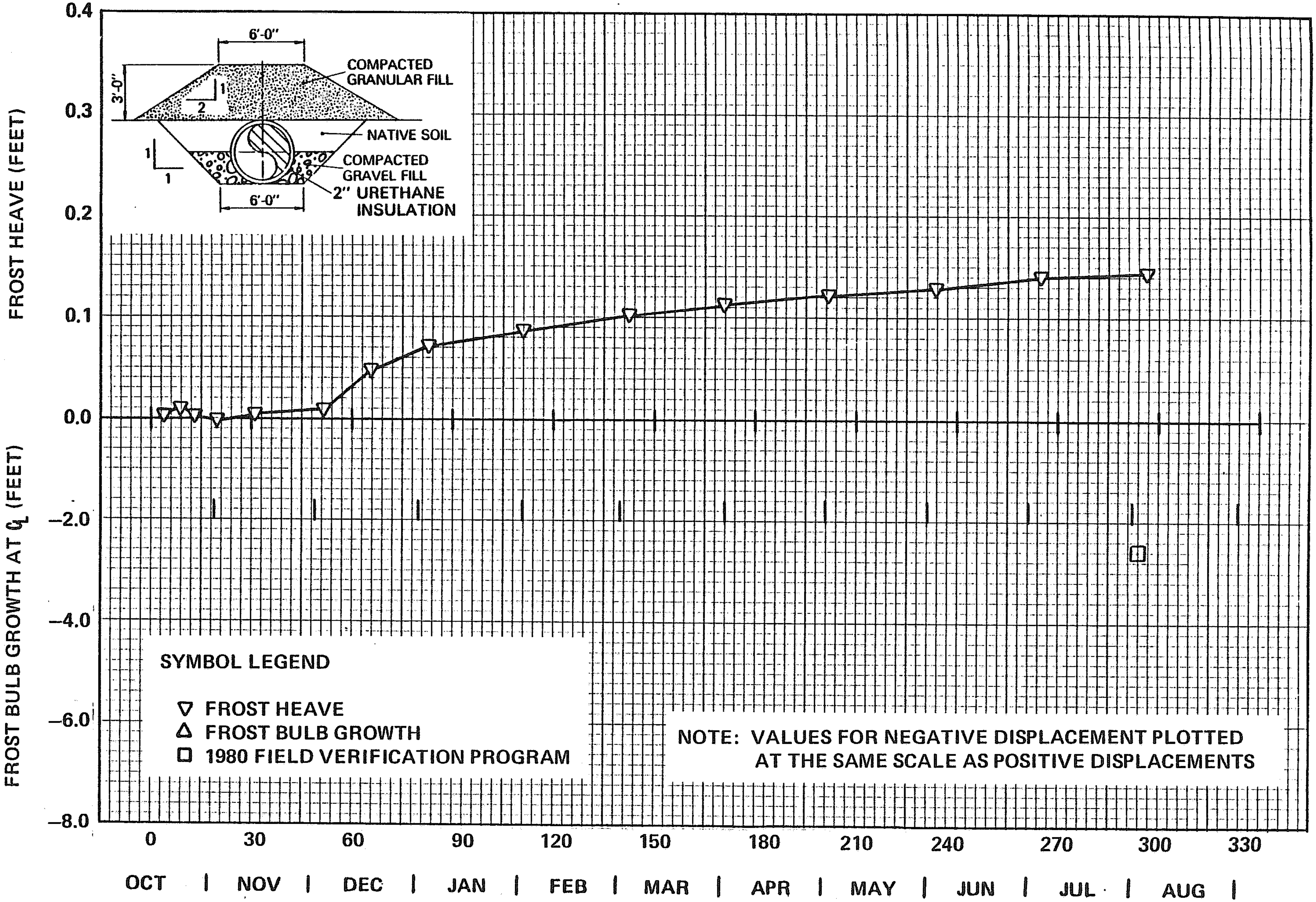


NOTE: DAY ZERO IS OCTOBER 13, 1979

TABLE 6.3-5
VERTICAL DISPLACEMENT SINCE FACILITY START-UP
TEST SECTION 5

DATE	DAYS SINCE START-UP	VERTICAL DISPLACEMENT $B54 STA. 32 (ft)	$B53 STA. 62 (ft)	$B52 STA. 92 (ft)	AVERAGE (ft)
10/13/79	0	0.000	0.000	0.000	0.000
10/17/79	4	0.008	0.001	0.006	0.005
10/22/79	9	0.018	0.005	0.009	0.010
10/26/79	13	0.004	0.001	0.006	0.004
11/02/79	20	0.003	-0.006	0.001	-0.001
11/13/79	31	0.009	0.001	0.004	0.005
12/04/79	52	0.017	0.007	0.005	0.010
12/18/79	66	0.054	0.043	0.043	0.047
01/04/80	83	0.080	0.062	--	0.071
02/01/80	111	0.106	0.081	0.073	0.086
03/04/80	143	0.125	0.100	0.085	0.103
04/01/80	171	0.128	0.108	0.102	0.113
05/02/80	202	0.139	0.115	0.113	0.123
06/03/80	234	0.143	0.120	0.121	0.128
07/04/80	265	0.154	0.134	0.134	0.141
08/05/80	297	0.153	0.138	0.139	0.144

FIGURE 6.3-5
FROST HEAVE & FROST BULB GROWTH VS. TIME
TEST SECTION 5

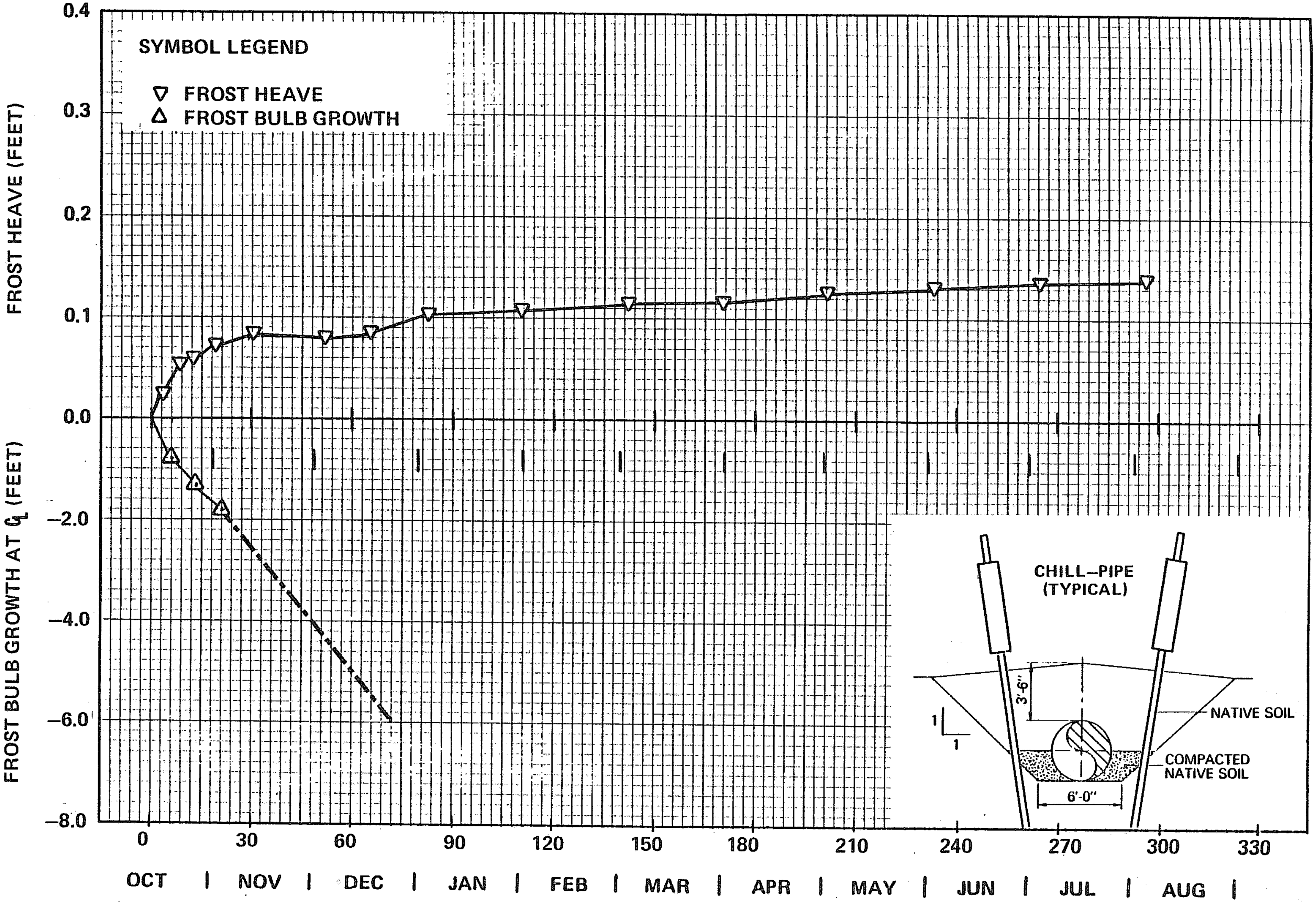


NOTE: DAY ZERO IS OCTOBER 13, 1979

TABLE 6.3-6
VERTICAL DISPLACEMENT SINCE FACILITY START-UP
TEST SECTION 6

DATE	DAYS SINCE START-UP	VERTICAL DISPLACEMENT $B5A STA. 32 (ft)	$B59 STA. 62 (ft)	$B58 STA. 92 (ft)	AVERAGE (ft)
10/13/79	0	0.000	0.000	0.000	0.000
10/17/79	4	0.026	0.021	0.029	0.026
10/22/79	9	0.049	0.050	0.066	0.055
10/26/79	13	0.062	0.054	0.068	0.062
11/02/79	20	0.075	0.071	--	0.073
11/13/79	31	0.080	0.079	0.095	0.085
12/04/79	52	0.074	0.075	0.094	0.081
12/18/79	66	0.084	0.078	0.099	0.087
01/04/80	83	0.099	0.096	0.120	0.105
02/01/80	111	0.104	0.100	0.125	0.109
03/04/80	143	0.109	0.109	0.130	0.116
04/01/80	171	0.112	0.110	0.132	0.118
05/02/80	202	0.121	0.119	0.143	0.128
06/03/80	234	0.128	0.125	0.147	0.133
07/04/80	265	0.128	0.134	0.155	0.139
08/05/80	297	0.131	0.132	0.158	0.141

FIGURE 6.3-6
FROST HEAVE & FROST BULB GROWTH VS. TIME
TEST SECTION 6

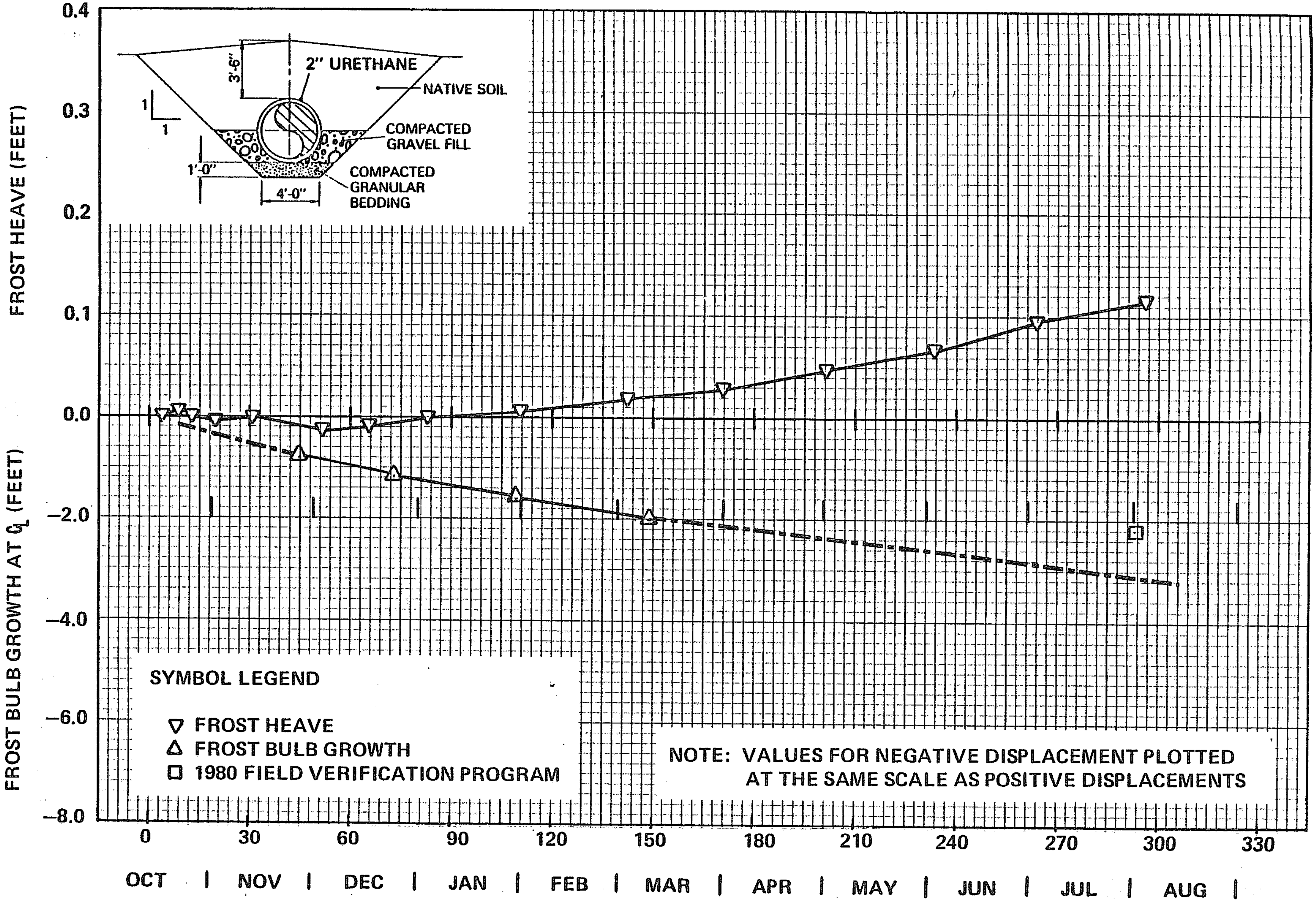


NOTE: DAY ZERO IS OCTOBER 13, 1979

TABLE 6.3-7
VERTICAL DISPLACEMENT SINCE FACILITY START-UP
TEST SECTION 7

DATE	DAYS SINCE START-UP	VERTICAL DISPLACEMENT $B51 STA. 32 (ft)	$B50 STA. 62 (ft)	$B4F STA. 92 (ft)	AVERAGE (ft)
10/13/79	0	0.000	0.000	0.000	0.000
10/17/79	4	0.002	0.002	-0.002	0.001
10/22/79	9	0.010	0.003	0.005	0.006
10/26/79	13	0.002	-0.001	-0.002	-0.000
11/02/79	20	-0.001	-0.004	-0.004	-0.003
11/13/79	31	-0.000	0.001	-0.003	-0.001
12/04/79	52	-0.008	-0.012	-0.014	-0.011
12/18/79	66	-0.009	-0.011	-0.006	-0.009
01/04/80	83	-0.004	-0.002	0.004	-0.001
02/01/80	111	0.008	0.001	0.009	0.006
03/04/80	143	0.032	0.009	0.016	0.019
04/01/80	171	0.042	0.019	0.026	0.029
05/02/80	202	0.064	0.031	0.041	0.046
06/03/80	234	0.086	0.052	0.060	0.066
07/04/80	265	0.115	0.081	0.085	0.094
08/05/80	297	0.137	0.105	0.102	0.115

FIGURE 6.3-7
FROST HEAVE & FROST BULB GROWTH VS. TIME
TEST SECTION 7

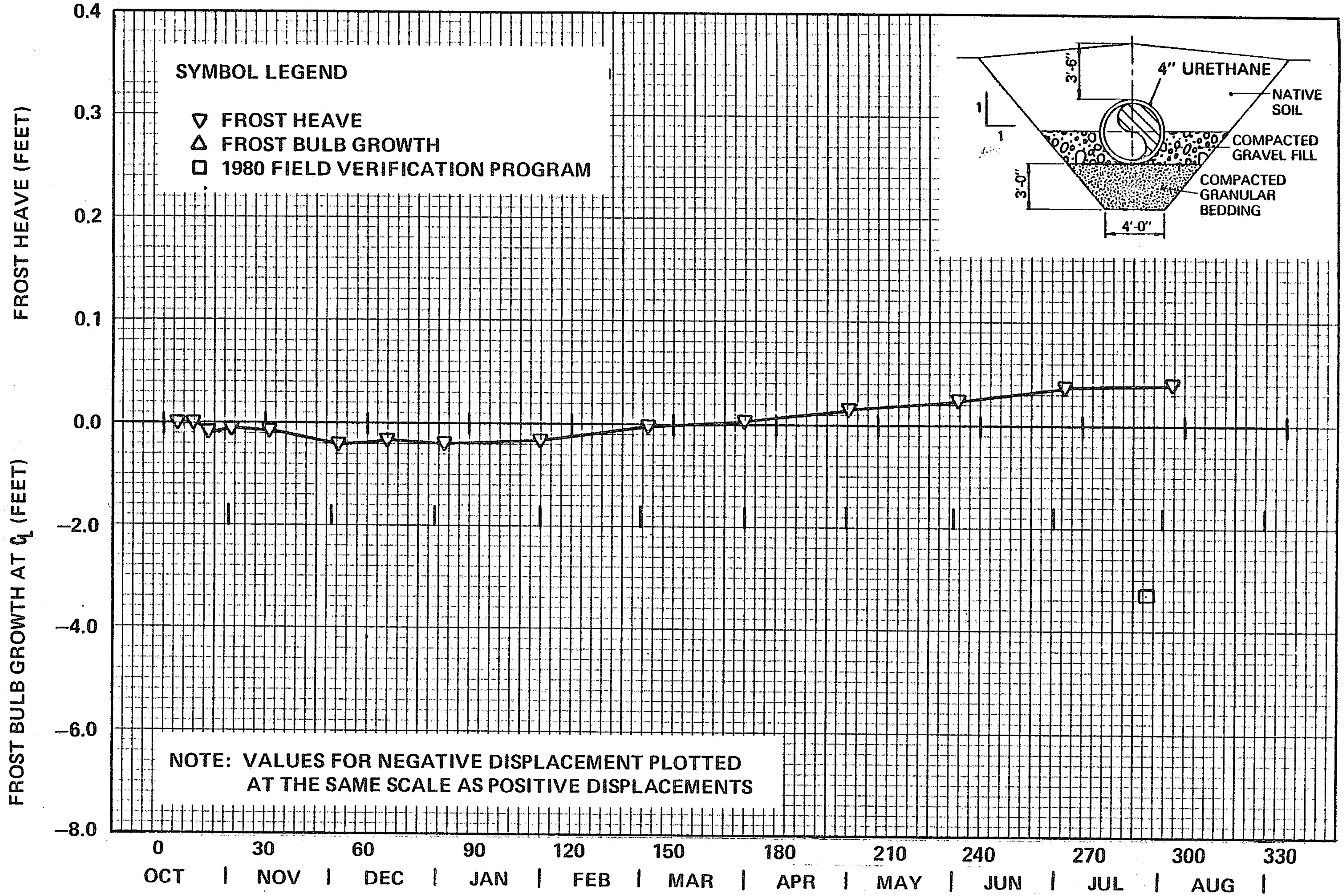


NOTE: DAY ZERO IS OCTOBER 13, 1979

TABLE 6.3-8
VERTICAL DISPLACEMENT SINCE FACILITY START-UP
TEST SECTION 8

DATE	DAYS SINCE START-UP	VERTICAL DISPLACEMENT $B57 STA. 32 (ft)	$B56 STA. 62 (ft)	$B55 STA. 92 (ft)	AVERAGE (ft)
10/13/79	0	0.000	0.000	0.000	0.000
10/17/79	4	-0.003	0.001	0.007	0.002
10/22/79	9	-0.007	0.011	0.003	0.002
10/26/79	13	-0.011	-0.006	-0.003	-0.006
11/02/79	20	-0.002	-0.008	-0.004	-0.004
11/13/79	31	-0.005	-0.009	--	-0.007
12/04/79	52	-0.017	-0.023	-0.020	-0.020
12/18/79	66	-0.013	-0.017	-0.016	-0.015
01/04/80	83	-0.023	-0.019	-0.013	-0.018
02/01/80	111	-0.012	-0.016	-0.022	-0.017
03/04/80	143	-0.001	-0.005	-0.001	-0.002
04/01/80	171	0.006	-0.002	0.003	0.003
05/02/80	202	0.023	0.004	0.015	0.016
06/03/80	234	0.036	0.016	0.023	0.025
07/04/80	265	0.054	0.028	0.031	0.038
08/05/80	297	0.060	0.039	0.022	0.041

FIGURE 6.3-8
FROST HEAVE & FROST BULB GROWTH VS. TIME
TEST SECTION 8



NOTE: DAY ZERO IS OCTOBER 13, 1979

TABLE 6.3-9
VERTICAL DISPLACEMENT SINCE FACILITY START-UP
TEST SECTION 9

DATE	DAYS SINCE START-UP	VERTICAL DISPLACEMENT $B64 STA. 4 (ft)	$B65 STA. 50 (ft)	$B66 STA. 65 (ft)	$B67 STA. 95 (ft)	$B68 STA. 110 (ft)	$B69 STA. 125 (ft)	$B6A STA. 142 (ft)	$B6B STA. 148 (ft)
10/13/79	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10/17/79	4	0.029	0.023	0.022	0.023	0.022	0.018	0.016	0.012
10/22/79	9	0.059	0.053	0.055	0.057	0.042	0.040	0.029	0.033
10/26/79	13	0.074	0.076	0.076	0.071	0.058	0.044	0.044	0.046
11/02/79	20	0.089	0.101	0.100	0.103	0.079	0.067	0.054	0.059
11/13/79	31	0.119	--	0.136	0.140	--	0.096	0.089	0.086
12/04/79	52	0.142	0.158	0.161	0.178	0.139	0.125	0.111	0.106
12/18/79	66	0.163	0.167	0.178	0.194	0.157	0.139	0.130	0.127
01/04/80	83	0.181	0.184	0.189	0.208	0.177	0.166	0.191	0.133
02/01/80	111	0.216	0.215	0.228	0.252	0.213	0.201	0.180	0.178
03/04/80	143	0.238	0.234	0.248	0.274	0.242	0.224	0.199	0.205
04/01/80	171	0.253	0.252	0.263	0.289	0.261	0.241	0.219	0.220
05/02/80	202	0.268	0.268	0.280	0.309	0.285	0.257	0.235	0.236
06/03/80	234	0.280	0.282	0.295	0.323	0.302	0.276	0.247	0.252
07/04/80	265	0.298	0.304	0.315	0.337	0.323	0.292	0.263	0.269
08/05/80	297	0.309	0.315	0.328	0.354	0.333	0.304	0.276	0.280

TABLE 6.3-9 (Continued)

VERTICAL DISPLACEMENT SINCE FACILITY START-UP

TEST SECTION 9

DATE	DAYS SINCE START-UP	VERTICAL DISPLACEMENT $B6C STA. 155 (ft)	$B6D STA. 163 (ft)	$B6E STA. 170 (ft)	$B6F STA. 178 (ft)	$B70 STA. 185 (ft)	$B71 STA. 193 (ft)	$B72 STA. 200 (ft)	$B73 STA. 208 (ft)
10/13/79	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10/17/79	4	0.018	0.023	0.024	0.026	0.021	0.021	0.028	0.019
10/22/79	9	0.038	0.042	0.040	0.049	0.051	0.057	0.044	0.043
10/26/79	13	0.046	0.051	0.056	0.063	0.062	0.060	0.065	0.061
11/02/79	20	0.061	0.070	0.072	0.082	0.073	0.087	0.084	0.076
11/13/79	31	0.089	0.097	0.100	0.112	0.113	0.123	0.123	0.113
12/04/79	52	0.119	0.120	0.121	0.139	0.133	0.145	0.143	0.145
12/18/79	66	0.132	0.132	0.143	0.149	0.153	0.167	0.170	0.160
01/04/80	83	0.142	0.152	0.155	0.170	0.183	0.191	0.185	--
02/01/80	111	0.186	0.191	0.203	0.221	0.214	0.235	0.236	0.239
03/04/80	143	0.210	0.217	0.230	0.245	0.244	0.264	0.265	0.269
04/01/80	171	0.229	0.232	0.245	0.264	0.259	0.277	0.282	0.290
05/02/80	202	0.248	0.250	0.264	0.281	0.279	0.300	0.301	0.303
06/03/80	234	0.260	0.261	0.286	0.295	0.292	0.318	0.322	0.323
07/04/80	265	0.277	0.279	0.297	0.313	0.309	0.335	0.344	0.343
08/05/80	297	0.286	0.293	0.310	0.327	0.326	0.349	0.355	0.354

TABLE 6.3-9 (Continued)

VERTICAL DISPLACEMENT SINCE FACILITY START-UP

TEST SECTION 9

DATE	DAYS SINCE START-UP	VERTICAL DISPLACEMENT $B74 STA. 217 (ft)	$B75 STA. 223 (ft)	$B76 STA. 230 (ft)	$B77 STA. 238 (ft)	$B78 STA. 245 (ft)	$B79 STA. 248 (ft)	$B7A STA. 260 (ft)	$B7B STA. 268 (ft)
10/13/79	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10/17/79	4	0.020	0.025	0.025	0.014	0.019	0.016	0.015	0.008
10/22/79	9	0.057	0.047	0.041	0.042	0.034	0.032	0.027	0.010
10/26/79	13	0.070	0.063	0.062	0.051	0.041	0.044	0.028	0.021
11/02/79	20	0.083	0.080	0.074	0.072	0.063	0.057	0.053	0.031
11/13/79	31	0.125	0.119	0.098	0.102	0.089	0.082	0.065	0.049
12/04/79	52	0.151	0.145	0.128	0.122	0.113	0.106	0.078	0.067
12/18/79	66	0.183	0.160	0.148	0.142	0.136	0.115	0.087	0.068
01/04/80	83	0.207	0.185	0.170	0.162	0.151	0.133	0.103	0.082
02/01/80	111	0.237	0.234	0.215	0.191	0.183	0.167	0.132	0.099
03/04/80	143	0.267	0.265	0.241	0.230	0.199	0.191	0.153	0.116
04/01/80	171	0.281	0.276	0.257	0.242	0.218	0.205	0.158	0.118
05/02/80	202	0.304	0.297	0.275	0.255	0.238	0.218	0.166	0.131
06/03/80	234	0.325	0.318	0.301	0.279	0.250	0.235	0.183	0.144
07/04/80	265	0.337	0.337	0.320	0.291	0.267	0.250	0.185	0.152
08/05/80	297	0.354	0.348	0.330	0.300	0.272	0.259	0.195	0.160

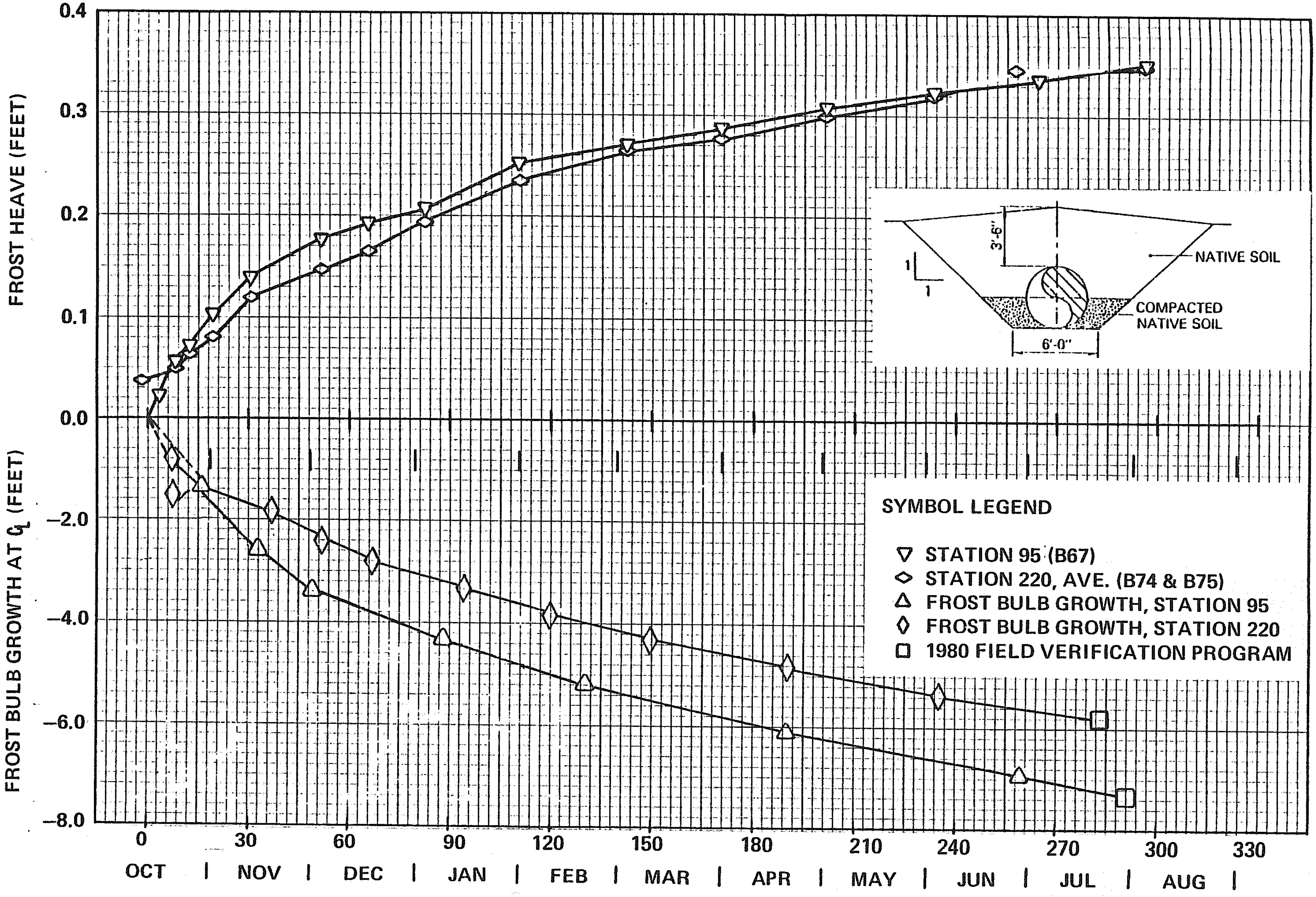
TABLE 6.3-9 (Continued)

VERTICAL DISPLACEMENT SINCE FACILITY START-UP

TEST SECTION 9

		VERTICAL DISPLACEMENT							
DATE	DAYS SINCE START-UP	$B7C STA. 275 (ft)	$B7D STA. 283 (ft)	$B7E STA. 292 (ft)	$B7F STA. 305 (ft)	$B80 STA. 324 (ft)	$B81 STA. 335 (ft)	$B82 STA. 350 (ft)	$B83 STA. 396 (ft)
10/13/79	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10/17/79	4	0.001	0.008	-0.007	0.012	0.010	-0.002	0.004	-0.006
10/22/79	9	0.004	0.017	0.001	0.018	0.016	0.012	0.005	-0.014
10/26/79	13	0.016	0.016	0.007	0.020	0.008	0.011	0.016	-0.008
11/02/79	20	0.017	0.027	0.012	0.033	0.021	0.014	0.008	0.014
11/13/79	31	0.031	0.033	0.018	0.029	0.019	0.022	0.019	0.002
12/04/79	52	0.056	0.040	0.006	0.033	0.025	0.021	0.014	0.000
12/18/79	66	0.063	0.045	0.012	0.018	0.024	0.019	0.012	0.010
01/04/80	83	--	0.052	--	0.031	0.028	--	0.013	0.010
02/01/80	111	0.083	0.056	0.017	0.024	0.028	0.013	0.020	0.011
03/04/80	143	0.089	0.061	0.026	0.031	0.032	0.023	0.021	0.009
04/01/80	171	0.106	0.072	0.023	0.033	0.039	0.031	0.032	0.019
05/02/80	202	0.110	0.076	0.022	0.037	0.033	0.027	0.025	0.007
06/03/80	234	0.115	0.083	0.037	0.052	0.043	0.036	0.031	0.021
07/04/80	265	0.116	0.079	0.037	0.044	0.046	0.037	0.037	0.018
08/05/80	297	0.125	0.087	0.029	0.043	0.042	0.025	0.025	0.014

FIGURE 6.3-9
FROST HEAVE & FROST BULB GROWTH VS. TIME
TEST SECTION 9



NOTE: DAY ZERO IS OCTOBER 13, 1979

FIGURE 6.3-10
COMPARISON OF VERTICAL DISPLACEMENTS
SINCE FACILITY START–UP
TEST SECTION 9 PROFILE

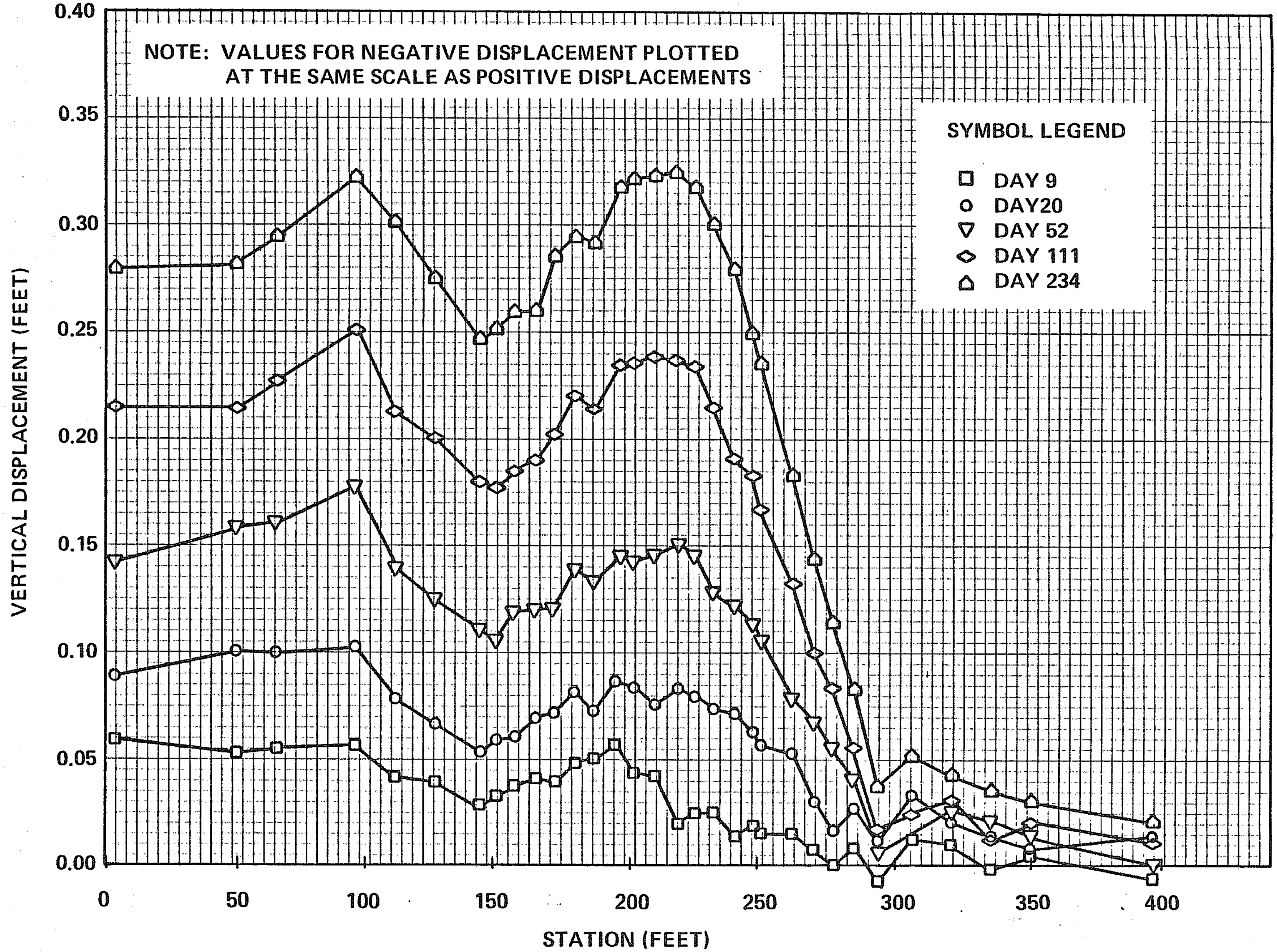


TABLE 6.3-10
VERTICAL DISPLACEMENT SINCE FACILITY START-UP
TEST SECTION 10

DATE	DAYS SINCE START-UP	VERTICAL DISPLACEMENT $B4A STA. 10 (ft)	$B49 STA. 20 (ft)	$B4B STA. 30 (ft)	AVERAGE (ft)
10/13/79	0	0.000	0.000	0.000	0.000
10/17/79	4	-0.001	-0.008	0.010	0.000
10/22/79	9	0.007	-0.002	0.007	0.004
10/26/79	13	-0.003	-0.010	0.010	-0.001
11/02/79	20	0.009	-0.004	0.022	0.009
11/13/79	31	0.009	0.006	0.015	0.010
12/04/79	52	0.011	0.006	0.010	0.009
12/18/79	66	0.023	0.001	0.014	0.013
01/04/80	83	--	--	--	--
02/01/80	111	0.007	0.017	0.012	0.012
03/04/80	143	0.008	0.014	0.027	0.016
04/01/80	171	0.008	0.014	0.027	0.016
05/02/80	202	0.018	0.020	0.021	0.020
06/03/80	234	0.020	0.027	0.031	0.026
07/04/80	265	0.029	0.027	0.038	0.031
08/05/80	297	0.019	0.027	0.033	0.026

6.4 Seasonal Variations

6.4.1 Heave Plates

Table 6.4.1-1 presents vertical displacements for shallow heave plates at six locations around the test site. The depth below natural ground surface of the 3 foot square by 8 inch thick concrete pedestals (plates) that support the heave rods are also given in this table.

Table 6.4.1-2 presents vertical displacements of deep heave plates. Their depths and locations are also presented in this table.

It should be noted that, unlike other vertical displacement data presented in this report, the data in Tables 6.4.1-1 and 6.4.1-2 are for a one-year period beginning on August 16, 1979.

TABLE 6.4.1-1
VERTICAL DISPLACEMENT OF SHALLOW HEAVE PLATES

From August 1979 to August 1980

	VERTICAL DISPLACEMENT					
	$BA4	$BA5	$BA6	$BA1	$B9E	$BA7
DATE	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)
08/16/79	0.000	0.000	0.000	0.000	0.000	0.000
09/13/79	-0.045	-0.011	-0.085	-0.036	-0.015	-0.028
10/13/79	-0.046	-0.022	-0.102	-0.058	-0.020	-0.041
10/13/79	-0.039	-0.005	-0.130	-0.066	-0.014	-0.061
12/18/79	0.021	0.016	-0.044	-0.075	-0.013	-0.055
01/04/80	0.039	0.001	--	--	-0.022	--
02/01/80	0.111	0.027	0.049	-0.036	-0.002	-0.018
03/04/80	0.132	0.027	0.081	-0.017	-0.006	-0.006
04/01/80	0.142	0.021	0.105	-0.004	-0.012	0.006
05/02/80	0.026	-0.029	0.098	0.004	-0.012	0.023
06/03/80	-0.101	-0.056	-0.075	-0.042	-0.017	-0.012
07/04/80	-0.099	-0.085	-0.202	--	-0.012	-0.046
08/05/80	-0.092	-0.093	-0.215	--	-0.014	-0.065

$BA4 is located near the site access road at about 15 inches below the ground surface.

$BA5 is located near the site fence, roughly perpendicular to Test Section 3 (approximately 50 feet from Station 120), at about 9 inches below the ground surface.

$BA6 is located along Test Section 8's axis approximately 25 feet beyond its end, at about 25 inches below the ground surface.

$BA1 is located along Test Section 5's axis approximately 10 feet beyond its end, at about 3 feet below the ground surface.

$B9E and $BA7 are located along Test Section 9's axis, about 3 feet below the ground surface, at Stations 10 (thawed) and 410 (permafrost), respectively.

TABLE 6.4.1-2
VERTICAL DISPLACEMENT OF DEEP HEAVE PLATES

From August 1979 to August 1980

	VERTICAL DISPLACEMENT			
	$BA2	$BA3	$B9F	$BAO
DATE	(ft)	(ft)	(ft)	(ft)
08/16/79	0.000	0.000	0.000	0.000
09/13/79	-0.008	-0.013	-0.016	-0.058
10/13/79	-0.014	-0.015	-0.016	-0.091
11/13/79	-0.003	-0.010	-0.009	-0.129
12/18/79	-0.008	-0.016	0.028	-0.167
01/04/80	--	--	0.018	-0.169
02/01/80	-0.002	-0.006	0.038	-0.112
03/04/80	-0.006	-0.012	0.031	-0.089
04/01/80	-0.005	-0.011	0.022	-0.074
05/02/80	-0.014	-0.006	0.012	-0.061
06/03/80	-0.006	-0.007	0.009	-0.092
07/05/80	-0.004	-0.001	0.009	-0.152
08/05/80	-0.007	0.001	0.007	-0.181

$BA2 and $BA3 are located along Test Section 5's axis approximately 10 feet beyond its end at depths of 12 and 20 feet below the ground surface, respectively.

$B9F and $BAO are located along Test Section 9's axis approximately 10 feet before its "thawed" end at depths of 12 and 20 feet below the ground surface, respectively.

6.5 Frost Heave within the Frost Bulb

In order to quantify displacements within and below the frost bulb, heave plates were placed adjacent to Test Section 1. Arranged in groups of five, the 4 inch diameter plates are buried at 3 or 4 feet off-centerline at depths of 0.5, 2.0, 3.5, 5.0 and 6.5 feet below the pipe's bottom at four locations along Test Section 1.

Referenced to October 13, 1979 (facility commissioning), Tables 6.5-1 through 6.5-5 present vertical displacements of these plates as a function of time. These data are also plotted on Figure 6.5-1.

Figure 6.5-1 shows that when a heave plate at depth is encompassed by the growing frost bulb, the trend of its vertical displacement is parallel to the test section.

These curves also show that when the frost bulb encompasses a pair of vertically separated heave plates, the differences in displacements between the plates remains relatively constant indicating that heave in already frozen soils is minimum.

TABLE 6.5-1
VERTICAL DISPLACEMENT SINCE FACILITY START-UP

Heave Plates Adjacent to Test Section 1, 6 Inches Below Bottom-of-Pipe, 3 Feet off Centerline

DATE	DAYS SINCE START-UP	VERTICAL DISPLACEMENT $B8C STA. 32.5 LEFT (ft)	$B91 STA. 32.5 RIGHT (ft)	$B96 STA. 92.5 LEFT (ft)	$B9B STA. 92.5 RIGHT (ft)	AVERAGE (ft)
10/13/79	0	0.000	0.000	0.000	0.000	0.000
10/17/79	4	--	--	--	--	--
10/22/79	9	0.015	0.005	0.006	0.009	0.009
10/26/79	13	0.023	0.005	0.003	0.011	0.011
11/02/79	20	0.024	-0.002	-0.002	0.010	0.008
11/13/79	31	0.030	0.028	0.007	0.016	0.020
12/04/79	52	0.039	0.059	0.046	0.048	0.048
12/18/79	66	0.060	0.082	0.066	0.073	0.070
01/04/80	83	0.085	0.103	0.093	0.097	0.095
02/01/80	111	0.120	0.136	0.128	0.131	0.129
03/04/80	143	0.147	0.163	0.152	0.153	0.154
04/01/80	171	0.167	0.187	0.174	0.173	0.175
05/02/80	202	0.188	0.205	0.194	0.194	0.195
06/03/80	234	0.199	0.219	0.205	0.209	0.208
07/04/80	265	0.222	0.235	0.223	0.226	0.227
08/05/80	297	0.235	0.244	0.235	0.238	0.238

TABLE 6.5-2
VERTICAL DISPLACEMENT SINCE FACILITY START-UP

Heave Plates Adjacent to Test Section 1, 2 Feet Below Bottom-of-Pipe, 4 Feet off Centerline

DATE	DAYS SINCE START-UP	VERTICAL DISPLACEMENT $B8D STA. 33.5 LEFT (ft)	$B92 STA. 33.5 RIGHT (ft)	$B97 STA. 93.5 LEFT (ft)	$B9C STA. 93.5 RIGHT (ft)	AVERAGE (ft)
10/13/79	0	0.000	0.000	0.000	0.000	0.000
10/17/79	4	--	--	--	--	--
10/22/79	9	0.003	0.005	0.008	0.006	0.006
10/26/79	13	0.005	--	0.004	-0.001	0.003
11/02/79	20	0.001	-0.001	0.002	0.000	0.001
11/13/79	31	0.010	0.014	0.007	0.010	0.010
12/04/79	52	0.009	0.014	0.002	-0.002	0.006
12/18/79	66	0.008	0.017	0.003	-0.007	0.005
01/04/80	83	0.011	--	0.003	0.008	0.007
02/01/80	111	0.023	0.037	0.018	0.047	0.031
03/04/80	143	0.049	0.061	0.044	0.072	0.057
04/01/80	171	0.071	0.083	0.064	0.090	0.077
05/02/80	202	0.096	0.104	0.083	0.111	0.099
06/03/80	234	0.108	0.112	0.096	0.124	0.110
07/04/80	265	0.127	0.131	0.118	0.140	0.129
08/05/80	297	0.140	0.141	0.122	0.153	0.139

TABLE 6.5-3
VERTICAL DISPLACEMENT SINCE FACILITY START-UP

Heave Plates Adjacent to Test Section 1, 3.5 Feet Below Bottom-of-Pipe, 3 Feet off Centerline

DATE	DAYS SINCE START-UP	VERTICAL DISPLACEMENT $B8E STA. 34.5 LEFT (ft)	$B93 STA. 34.5 RIGHT (ft)	$B98 STA. 94.5 LEFT (ft)	$B9D STA. 94.5 RIGHT (ft)	AVERAGE (ft)
10/13/79	0	0.000	0.000	0.000	0.000	0.000
10/17/79	4	--	--	--	--	--
10/22/79	9	0.008	-0.002	0.009	0.023	0.010
10/26/79	13	0.011	0.004	0.003	0.015	0.008
11/02/79	20	0.007	0.000	0.007	0.013	0.007
11/13/79	31	0.014	0.012	0.011	0.032	0.017
12/04/79	52	0.011	0.006	0.005	0.029	0.013
12/18/79	66	0.009	0.009	0.004	0.035	0.014
01/04/80	83	0.022	-0.005	0.005	0.035	0.014
02/01/80	111	0.008	0.001	0.002	0.026	0.009
03/04/80	143	0.027	0.017	0.002	0.041	0.022
04/01/80	171	0.045	0.037	0.024	0.062	0.042
05/02/80	202	0.065	0.057	0.046	0.084	0.063
06/03/80	234	0.077	0.068	0.059	0.097	0.075
07/04/80	265	0.094	0.086	0.077	0.117	0.094
08/05/80	297	0.106	0.095	0.089	0.124	0.104

TABLE 6.5-4
VERTICAL DISPLACEMENT SINCE FACILITY START-UP

Heave Plates Adjacent to Test Section 1, 5 Feet Below Bottom-of-Pipe, 4 Feet off Centerline

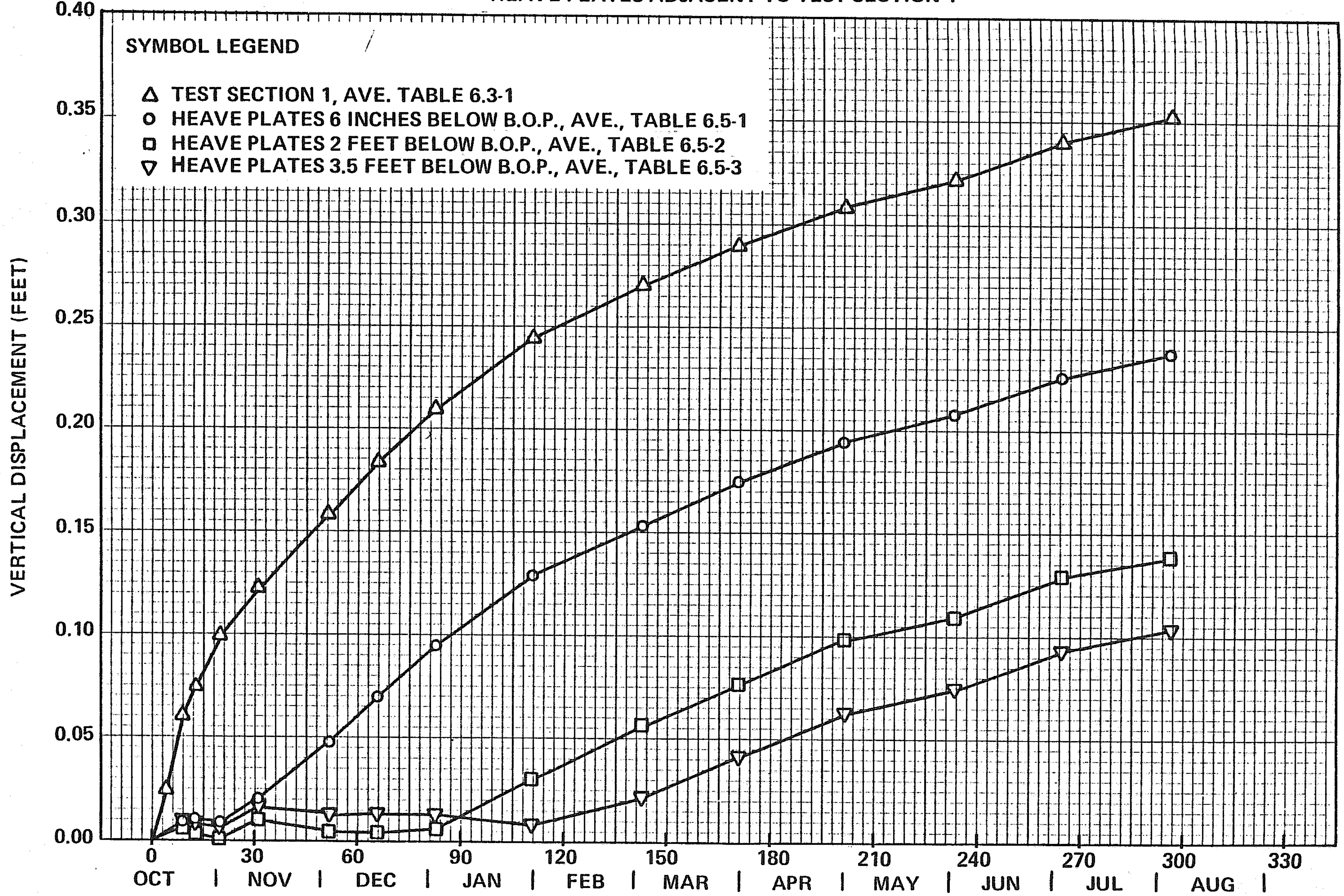
DATE	DAYS SINCE START-UP	VERTICAL DISPLACEMENT $B8B STA. 31.5 LEFT (ft)	$B90 STA. 31.5 RIGHT (ft)	$B95 STA. 91.5 LEFT (ft)	$B9A STA. 91.5 RIGHT (ft)
10/13/79	0	0.000	0.000	0.000	0.000
10/17/79	4	--	--	--	--
10/22/79	9	0.010	0.002	0.004	0.002
10/26/79	13	0.010	-0.000	0.001	-0.001
11/02/79	20	0.003	0.000	-0.009	0.002
11/13/79	31	0.012	0.006	0.002	0.009
12/04/79	52	0.003	0.029	-0.002	0.007
12/18/79	66	0.002	0.047	0.015	0.004
01/04/80	83	0.005	0.072	0.022	--
02/01/80	111	0.008	0.098	0.021	0.009
03/04/80	143	0.000	0.093	0.017	0.008
04/01/80	171	-0.002	0.080	0.014	0.002
05/02/80	202	-0.001	0.042	0.018	0.006
06/03/80	234	-0.002	0.034	0.010	0.006
07/04/80	265	-0.002	0.030	0.006	0.011
08/05/80	297	0.001	0.037	-0.003	0.016

TABLE 6.5-5
VERTICAL DISPLACEMENT SINCE FACILITY START-UP

Heave Plates Adjacent to Test Section 1, 6.5 Feet Below Bottom-of-Pipe, 3 Feet off Centerline

DATE	DAYS SINCE START-UP	VERTICAL DISPLACEMENT $B8A STA. 34.5 LEFT (ft)	$B8F STA. 34.5 RIGHT (ft)	$B94 STA. 94.5 LEFT (ft)	$B99 STA. 94.5 RIGHT (ft)
10/13/79	0	0.000	0.000	0.000	0.000
10/17/79	4	--	--	--	--
10/22/79	9	-0.001	0.009	0.008	0.016
10/26/79	13	-0.002	0.011	0.009	0.024
11/02/79	20	-0.001	0.002	0.005	0.035
11/13/79	31	0.008	0.010	0.019	0.064
12/04/79	52	0.004	0.002	0.024	0.094
12/18/79	66	0.011	0.009	0.029	0.102
01/04/80	83	0.016	0.011	0.040	0.124
02/01/80	111	0.013	0.006	0.046	0.137
03/04/80	143	0.007	-0.007	0.045	0.132
04/01/80	171	0.002	-0.022	0.046	0.124
05/02/80	202	-0.001	-0.033	0.046	0.119
06/03/80	234	-0.003	-0.040	0.047	0.018
07/04/80	265	-0.004	-0.041	0.051	0.020
08/05/80	297	-0.007	-0.046	0.043	0.020

FIGURE 6.5-1
COMPARISON OF VERTICAL DISPLACEMENTS
SINCE FACILITY START—UP
HEAVE PLATES ADJACENT TO TEST SECTION 1



NOTE: DAY ZERO IS OCTOBER 13, 1979

6.6 Graphic Frost Heave Comparison

In this subsection, graphic comparisons of vertical displacements since facility start-up are presented for selected combinations of Test Sections.

Figure 6.6-1 presents a comparison between Test Sections 1 through 8. Figure 6.6-2 presents a comparison between bare Test Sections 1, 4 and 6. Figure 6.6-3 presents a comparison between insulated Test Sections 2, 3, 5 and 7. Figure 6.6-4 presents a comparison between overexcavated Test Sections 4 and 8.

Figure 6.6-5 presents a comparison between one station along the "thawed soil" end of Test Section 9 and Test Section 1 and between Test Section 10 and one station along the restrained "frozen soil" end of Test Section 9.

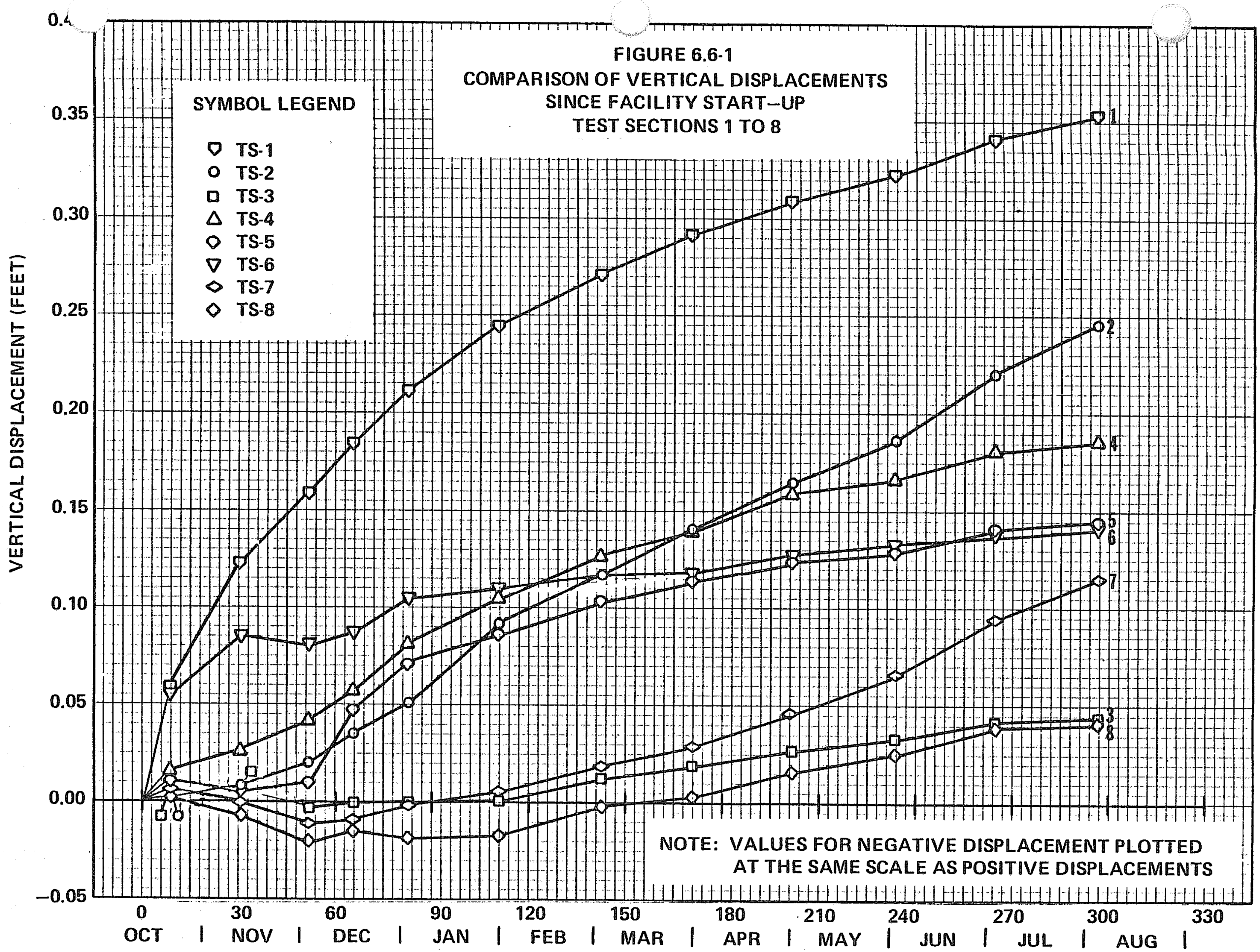
Since early in 1980, the test sections have ordered themselves into two general groups: those that have demonstrated a decaying heave rate, and those that have maintained a relatively constant heave rate.

In the decaying heave-rate group are bare Test Sections 1, 4, 6, and 9, and insulated Test Section 5, which is configured with two inches of urethane insulation and is buried beneath a gravel berm. In decreasing order of heave, Test Sections 1 and 9 (at 9's most rapidly heaving station) are closely paralleling each other. Next is Test Section 4 with, since early in 1980, a heave rate of approximately 72 percent of Test Section 1. Next is Test Section 5 with, since early in 1980, a heave rate of approximately 49 percent of Test Section 1. Last in the decaying heave-rate group is Test Section 6 which is now nearly frozen-in under the influence of its chill pipes and has virtually ceased heaving.

In the relatively constant heave rate group are insulated Test Sections 2, 7, 8, and 3 in order of heave response. During July, 1980, Test Section 2's heave rate was approximately twice that of Test Section 1, the facility's bare reference section. Although many influences will serve to modify the relative performance of these test sections, if their present trends persist, Test Section 2 will overtake Test Section 1 early in 1981.

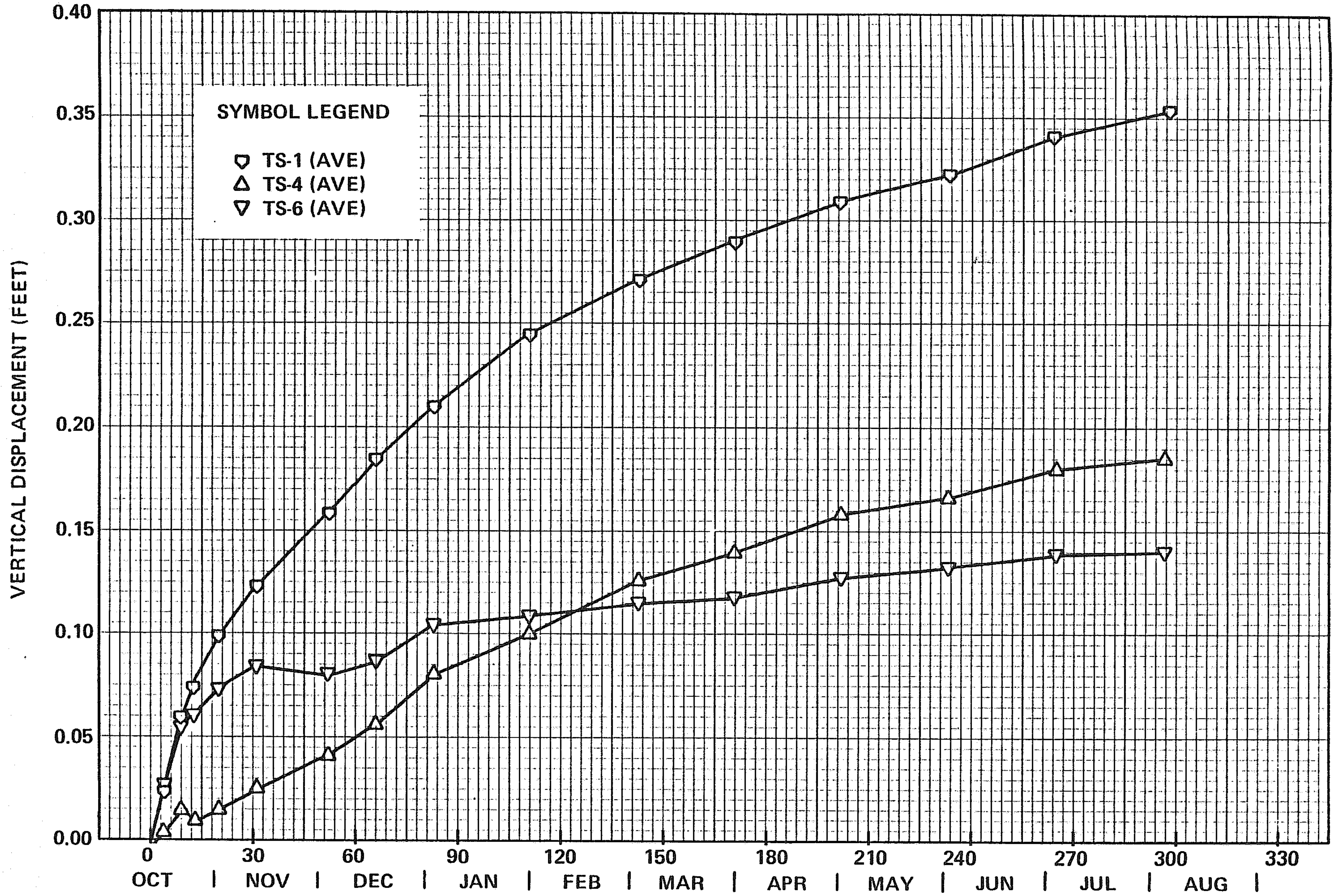
As of August, 1980, Test Section 6, installed with chill pipes, has virtually ceased heaving. As shown in Figure 6.6-1, the heave of Test Section 6 paralleled that of Test Section 1 (the bare reference section) for a limited period after facility start-up. This trend was expected as chill pipes do not normally operate during summer months to promote or maintain frozen soils; therefore, thawed frost-susceptible soils existed beneath the base of the test section, prior to start-up, due to normal seasonal thawing of the active layer. Subsequent heaving, similar to a total of approximately 0.3 inches of heave observed at Test Section 10 and at the east end of Test Section 9 (both installed in permafrost), is principally due to freezing of unfrozen moisture in the frozen soils.

Test Section 9 continues to demonstrate differential frost heave of a long pipeline structure. Where this test section was buried in initially thawed soils (approximately 270 feet), its heave has closely paralleled that of Test Section 1 -- the bare reference section. Where Test Section 9 was buried in permafrost soils (approximately 130 feet), its heave has closely paralleled that of Test Section 10 -- the test section wholly installed in permafrost.



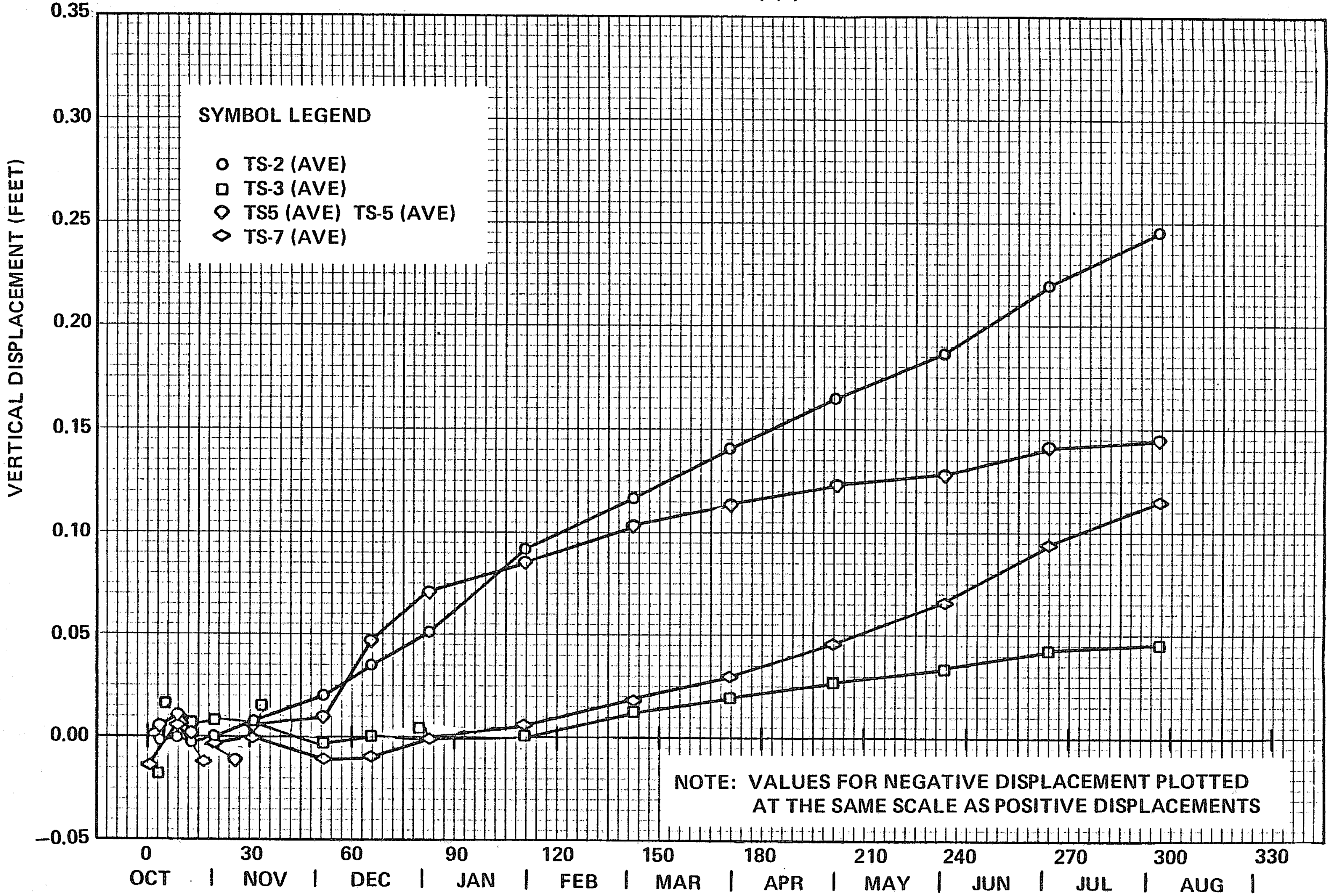
NOTE: DAY ZERO IS OCTOBER 13, 1979

FIGURE 6.6-2
COMPARISON OF VERTICAL DISPLACEMENTS
SINCE FACILITY START–UP
TEST SECTION 1,4,6



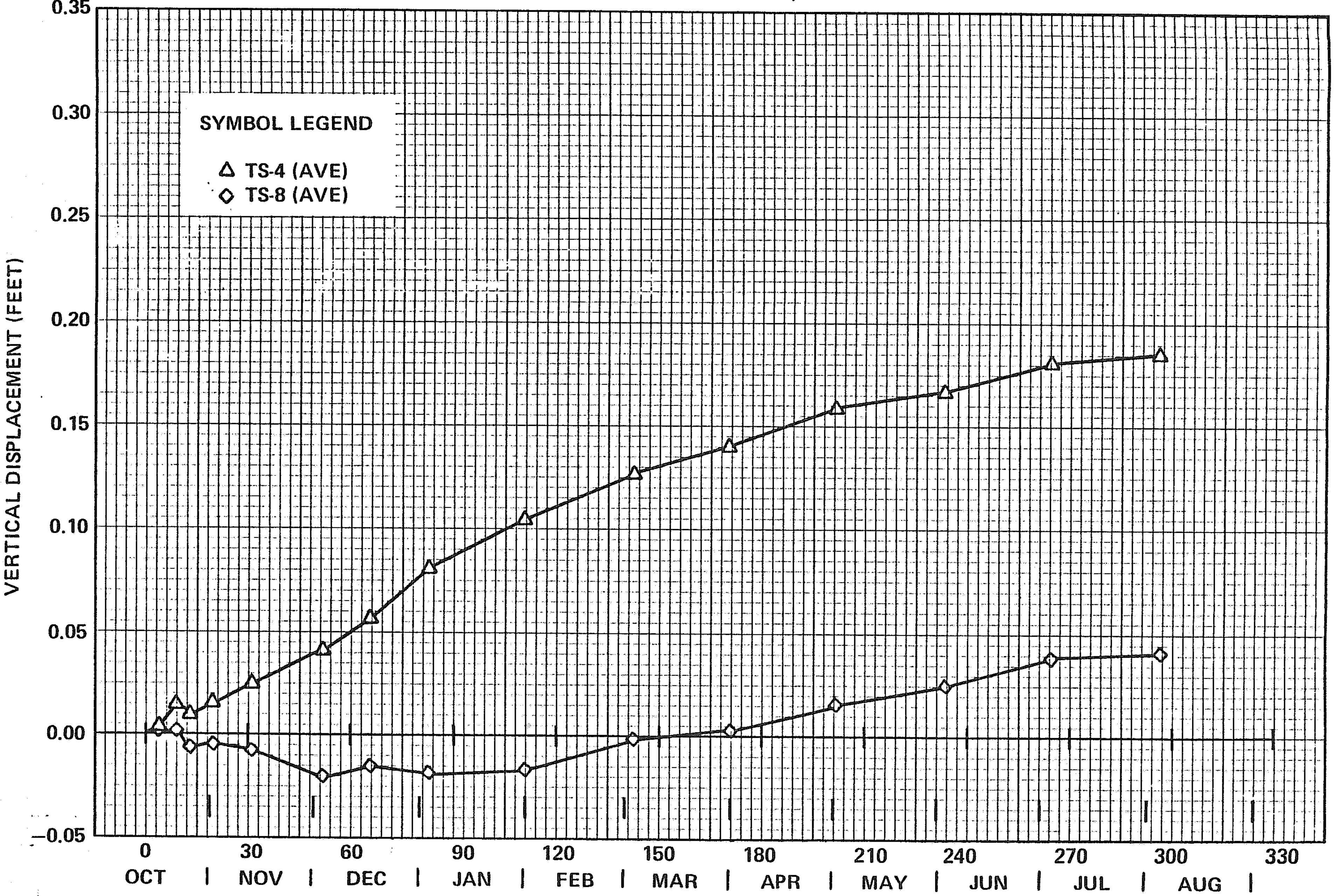
NOTE: DAY ZERO IS OCTOBER 13, 1979

FIGURE 6.6-3
COMPARISON OF VERTICAL DISPLACEMENTS
SINCE FACILITY START–UP
TEST SECTIONS 2,3,5,7



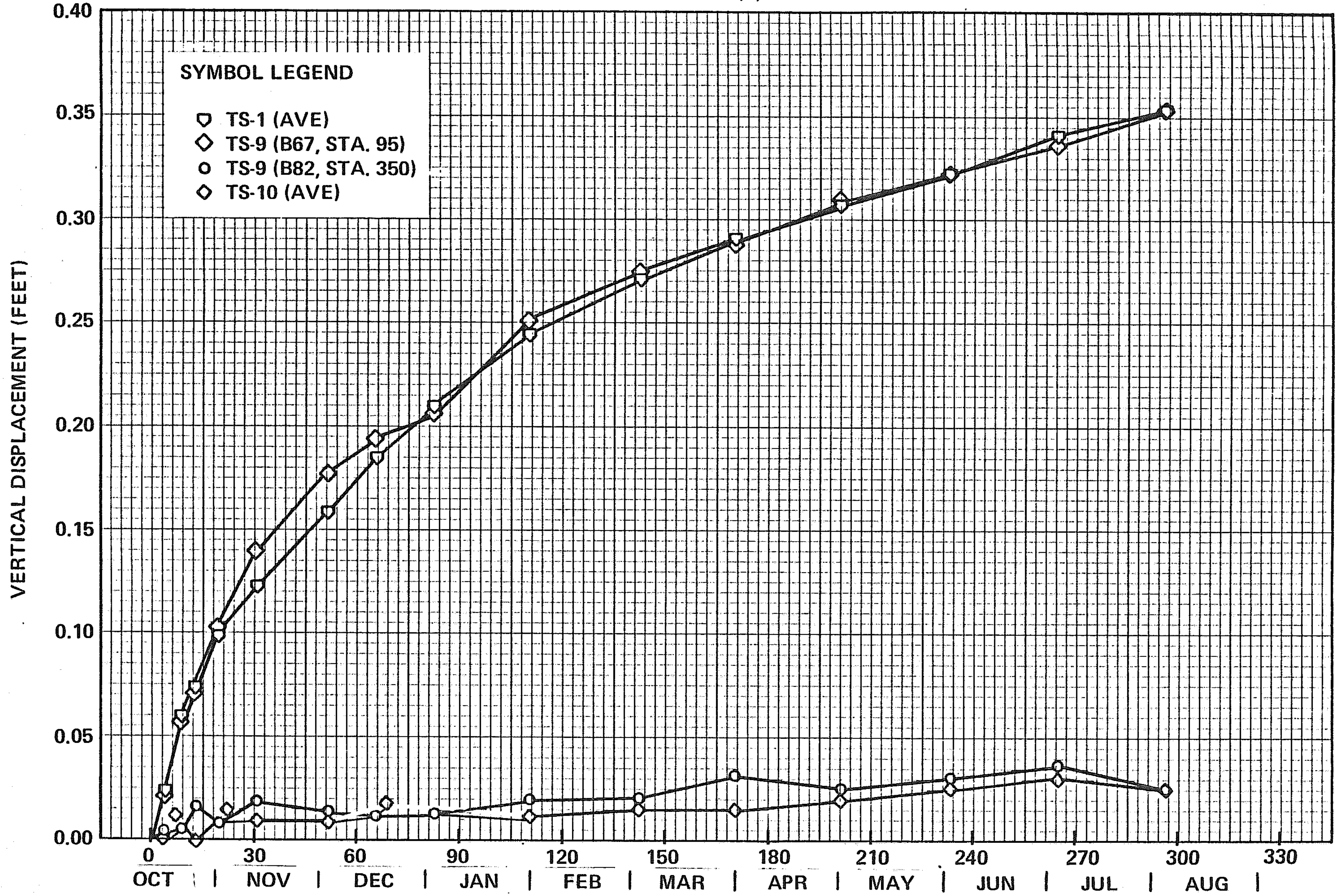
NOTE: DAY ZERO IS OCTOBER 13, 1979

FIGURE 6.6-4
COMPARISON OF VERTICAL DISPLACEMENTS
SINCE FACILITY START—UP
TEST SECTIONS 4,8



NOTE: DAY ZERO IS OCTOBER 13, 1979

FIGURE 6.6-5
COMPARISON OF VERTICAL DISPLACEMENTS
SINCE FACILITY START–UP
TEST SECTIONS 1,9,10



NOTE: DAY ZERO IS OCTOBER 13, 1979

6.7 Frost Bulb Growth and Groundwater Well Hydrographs

In this subsection, graphic comparisons of frost bulb growth and groundwater well hydrographs are presented for Test Sections 1 through 9 (Test Section 10 is wholly installed in permafrost). Figure 6.7-1 presents the relative locations of the groundwater wells and the test sections. Subsequent reports will present a higher density of groundwater data which will serve to smooth the profile of the hydrographs. As shown on the figures, the groundwater table has been sufficiently close to the frost bulb to avoid "starving" of the frost bulb during its growth.

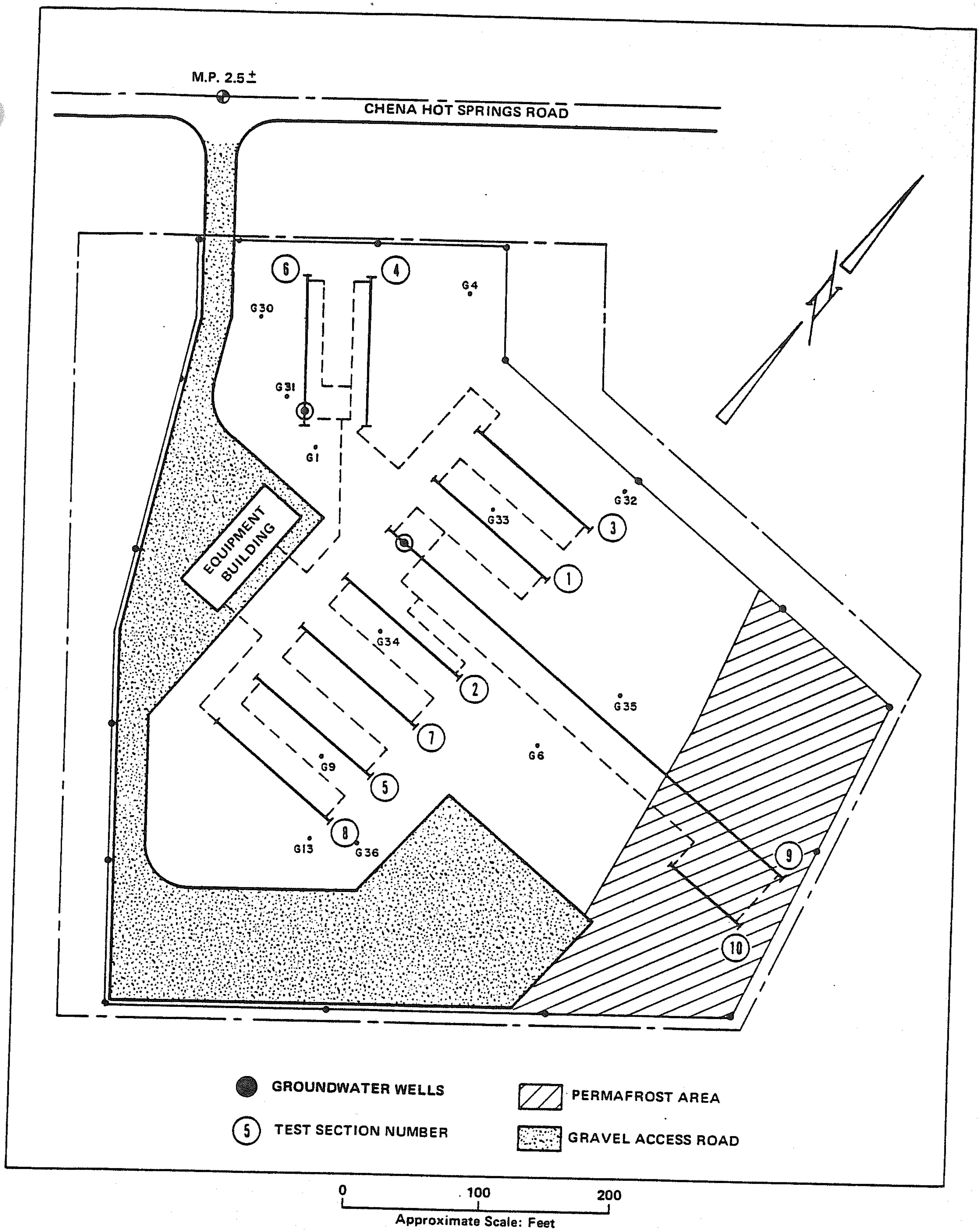
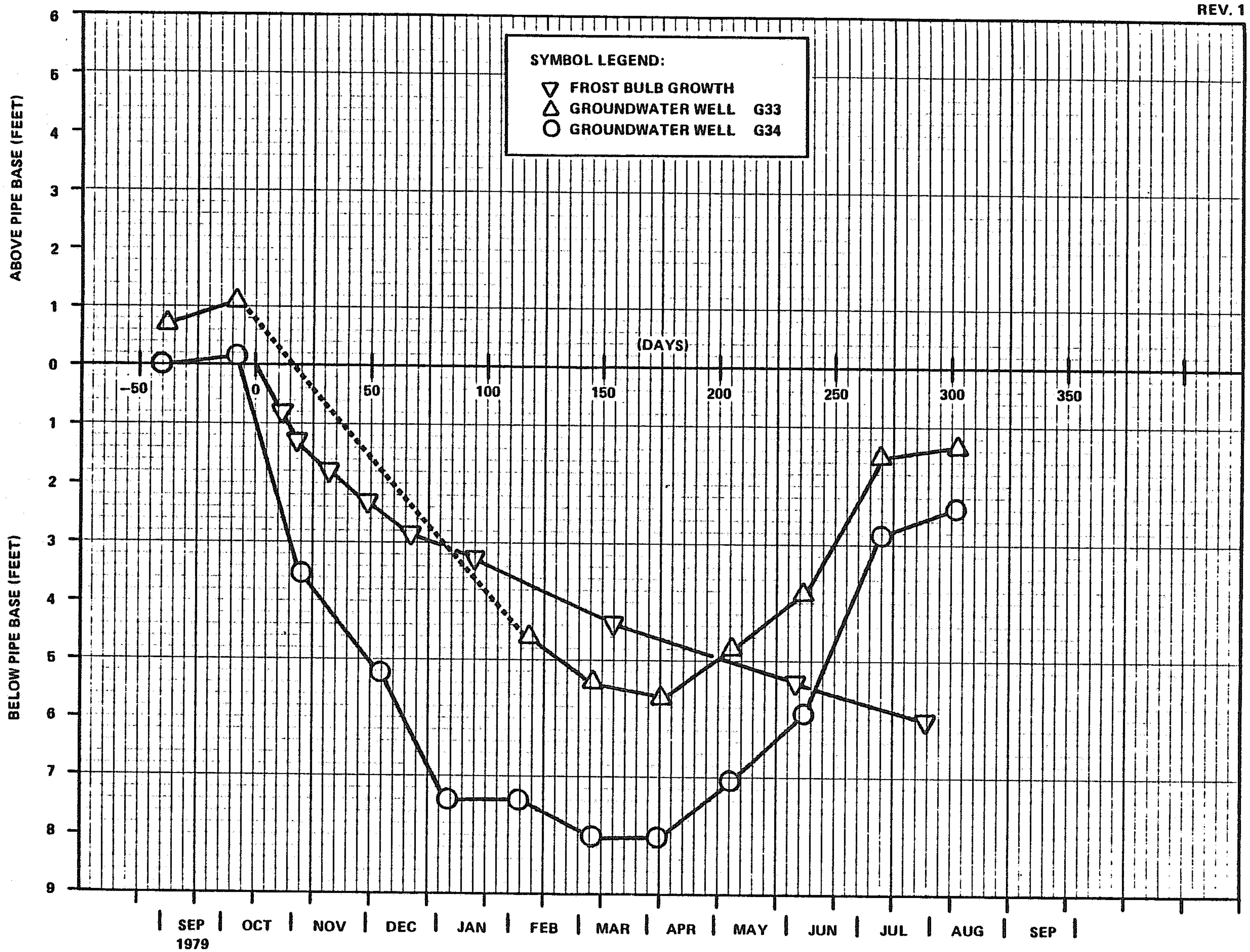


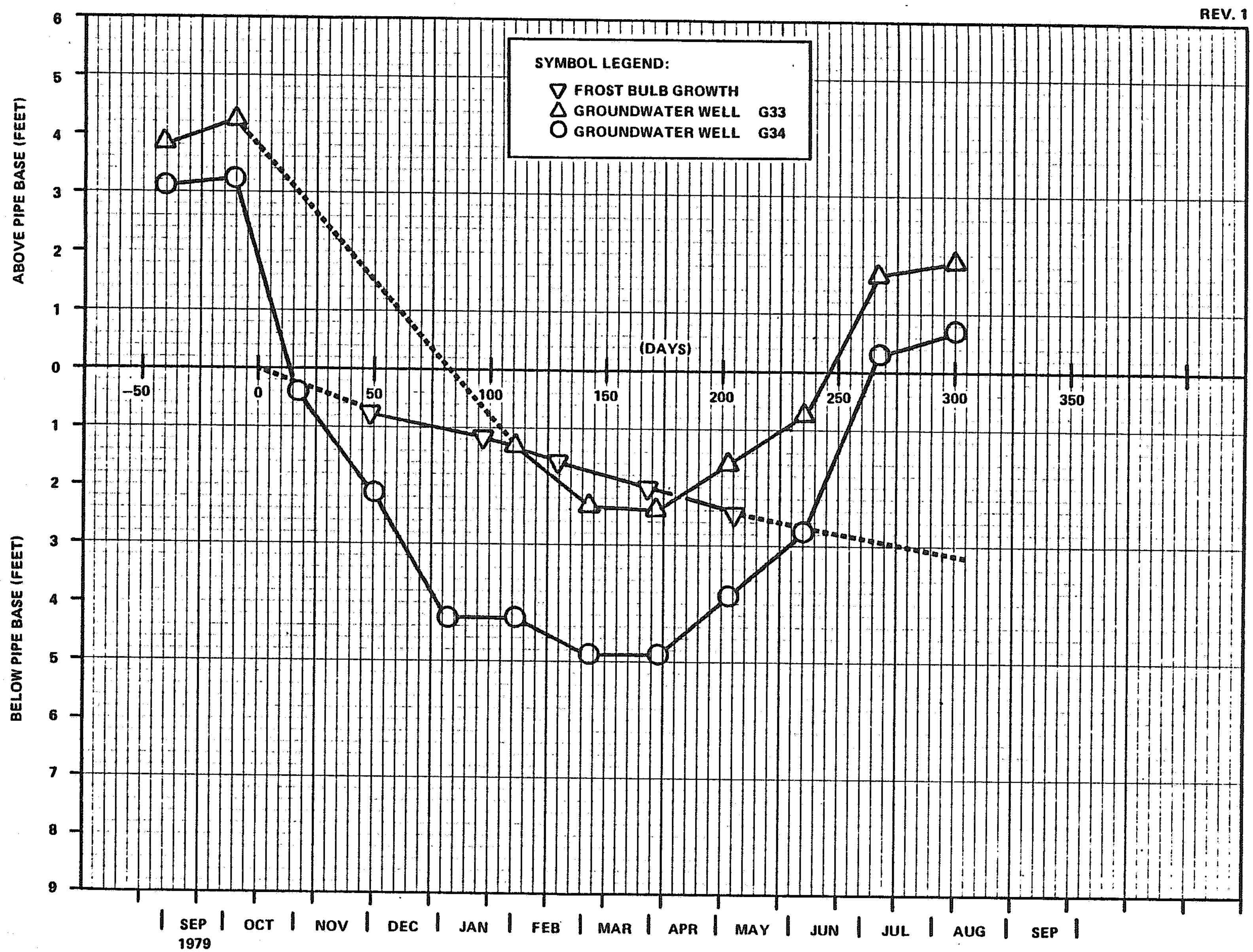
FIGURE 6.7-1 FAIRBANKS FROST HEAVE TEST FACILITY, LOCATION OF GROUNDWATER WELLS.

FIGURE 6.7–2, FROST BULB GROWTH AND GROUNDWATER WELL HYDROGRAPHS V.S. TIME, TEST SECTION 1



NOTE: DAY ZERO IS OCTOBER 13, 1979

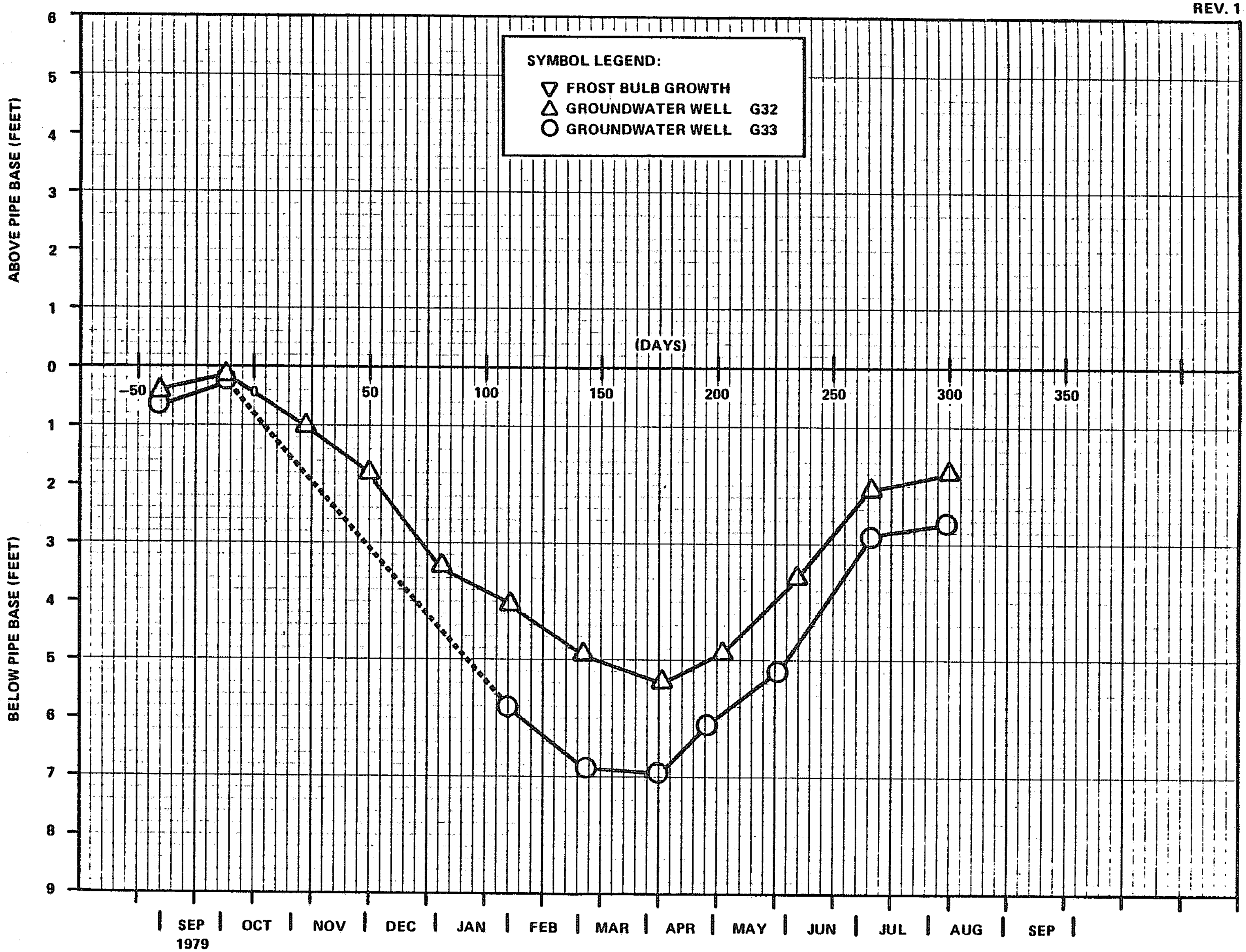
FIGURE 6.7–3, FROST BULB GROWTH AND GROUNDWATER WELL HYDROGRAPHS V.S. TIME, TEST SECTION 2



NOTE: DAY ZERO IS OCTOBER 13, 1979

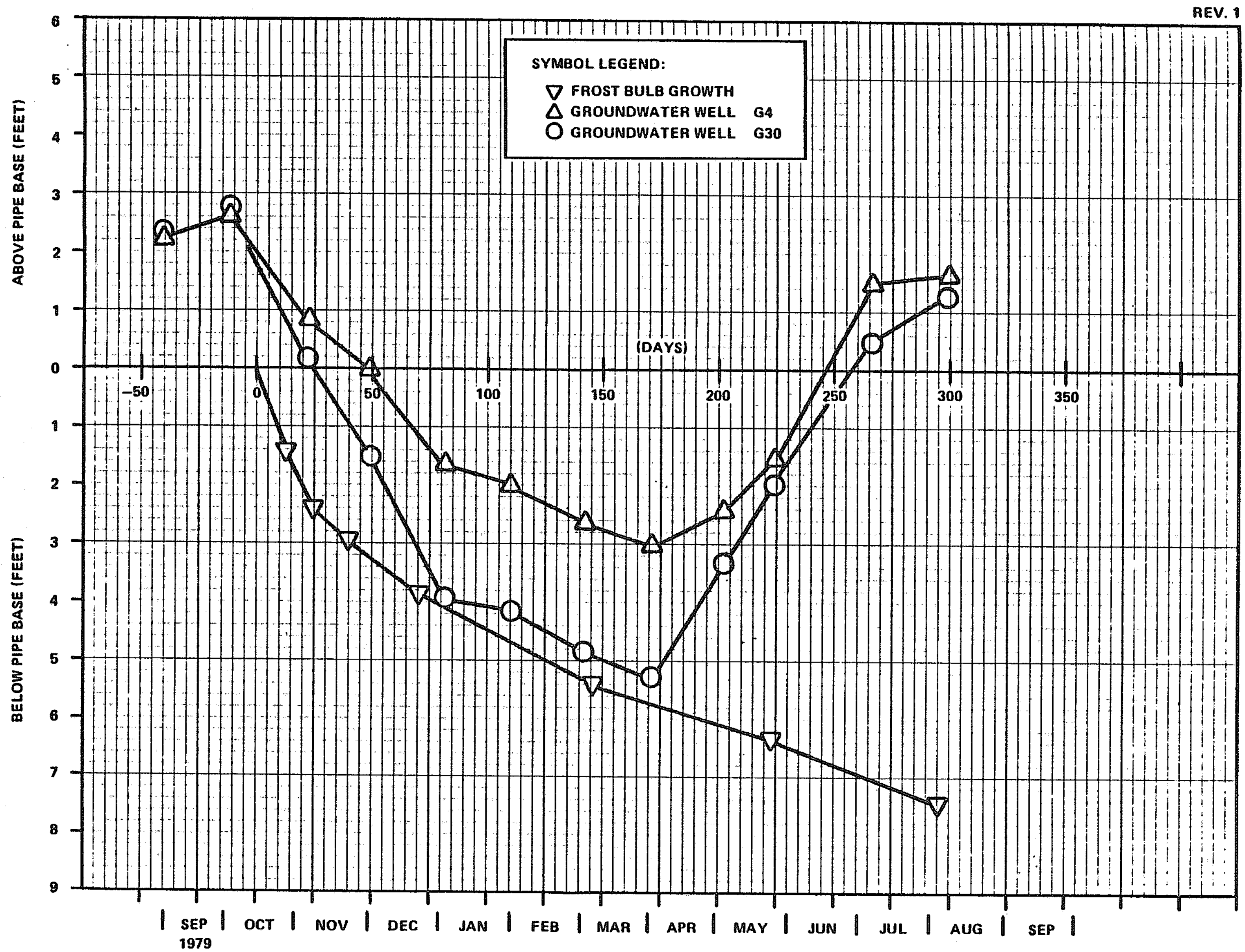
FIGURE 6.7–4, FROST BULB GROWTH AND GROUNDWATER WELL HYDROGRAPHS V.S. TIME, TEST SECTION 3

REV. 1



NOTE: DAY ZERO IS OCTOBER 13, 1979

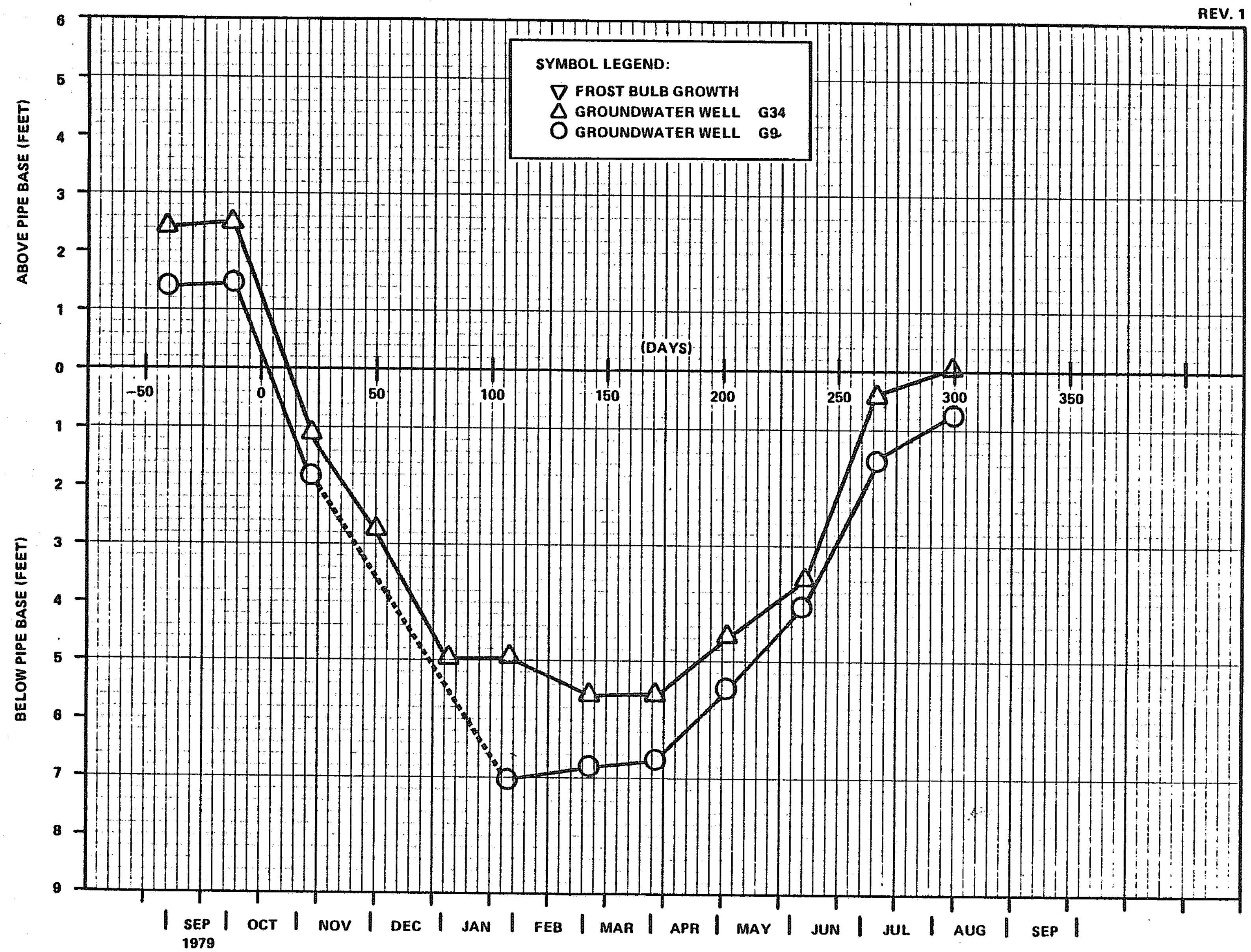
FIGURE 6.7–5, FROST BULB GROWTH AND GROUNDWATER WELL HYDROGRAPHS V.S. TIME, TEST SECTION 4



NOTE: DAY ZERO IS OCTOBER 13, 1979

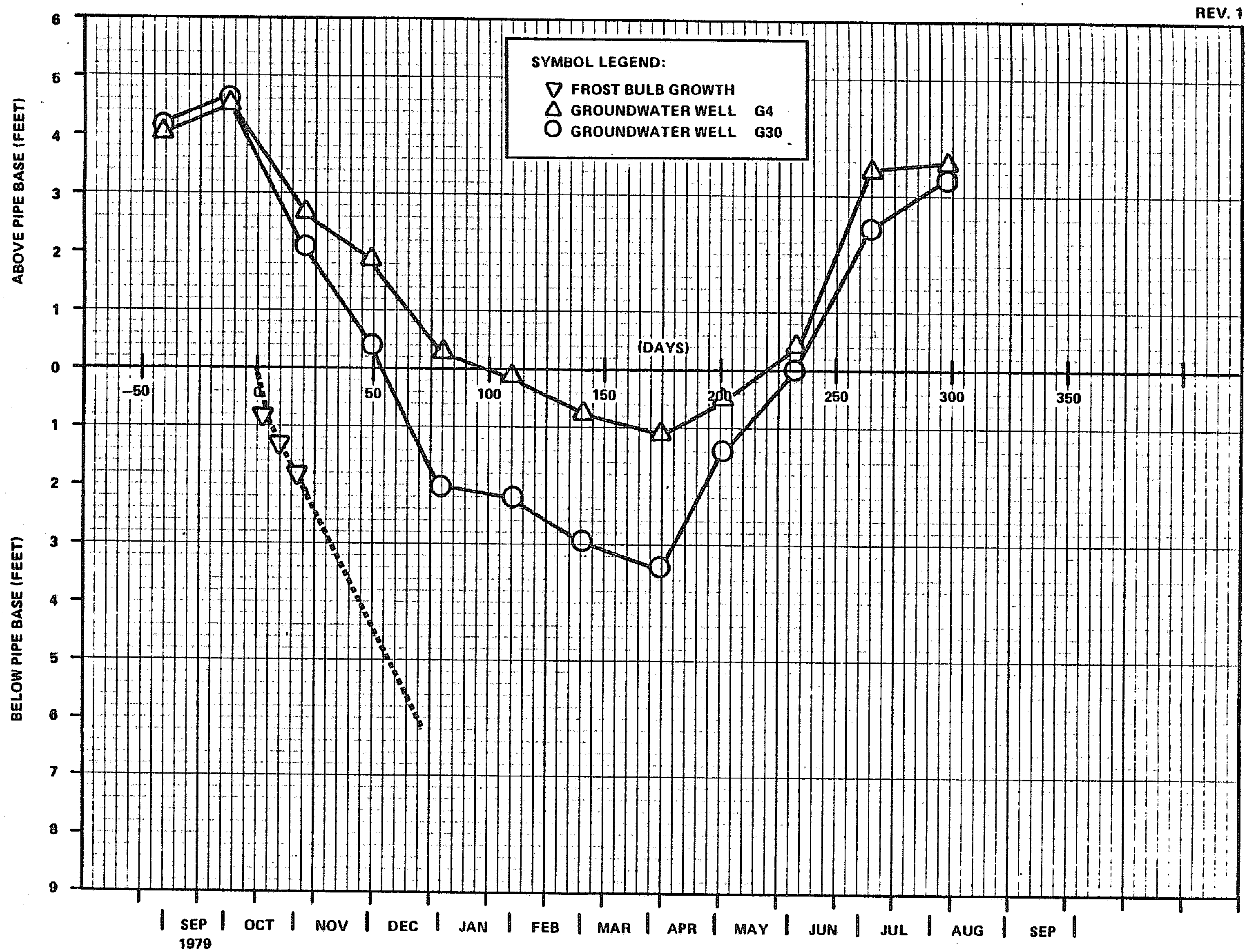
FIGURE 6.7–6, FROST BULB GROWTH AND GROUNDWATER WELL HYDROGRAPHS V.S. TIME, TEST SECTION 5

REV. 1



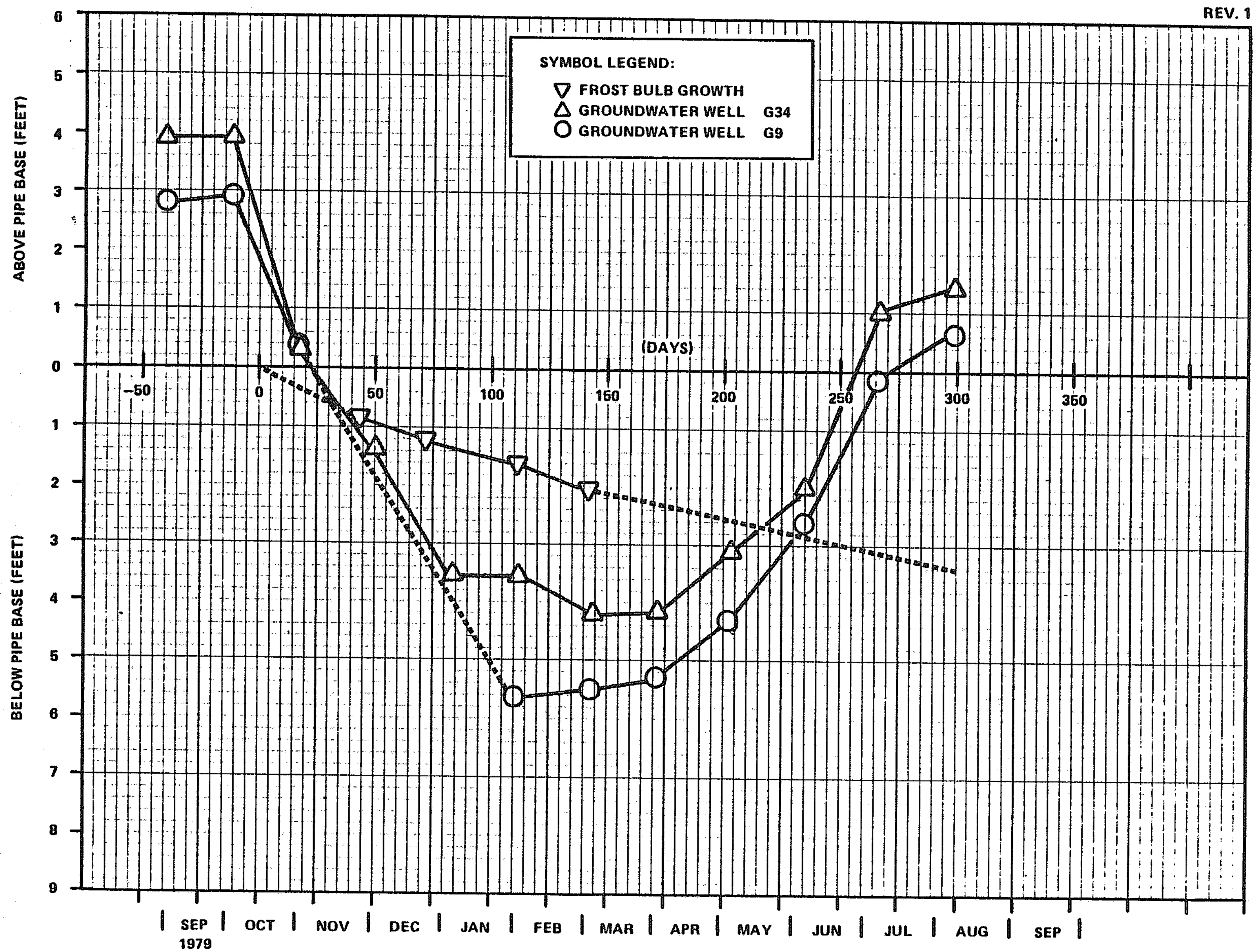
NOTE: DAY ZERO IS OCTOBER 13, 1979

FIGURE 6.7–7, FROST BULB GROWTH AND GROUNDWATER WELL HYDROGRAPHS V.S. TIME, TEST SECTION 6



NOTE: DAY ZERO IS OCTOBER 13, 1979

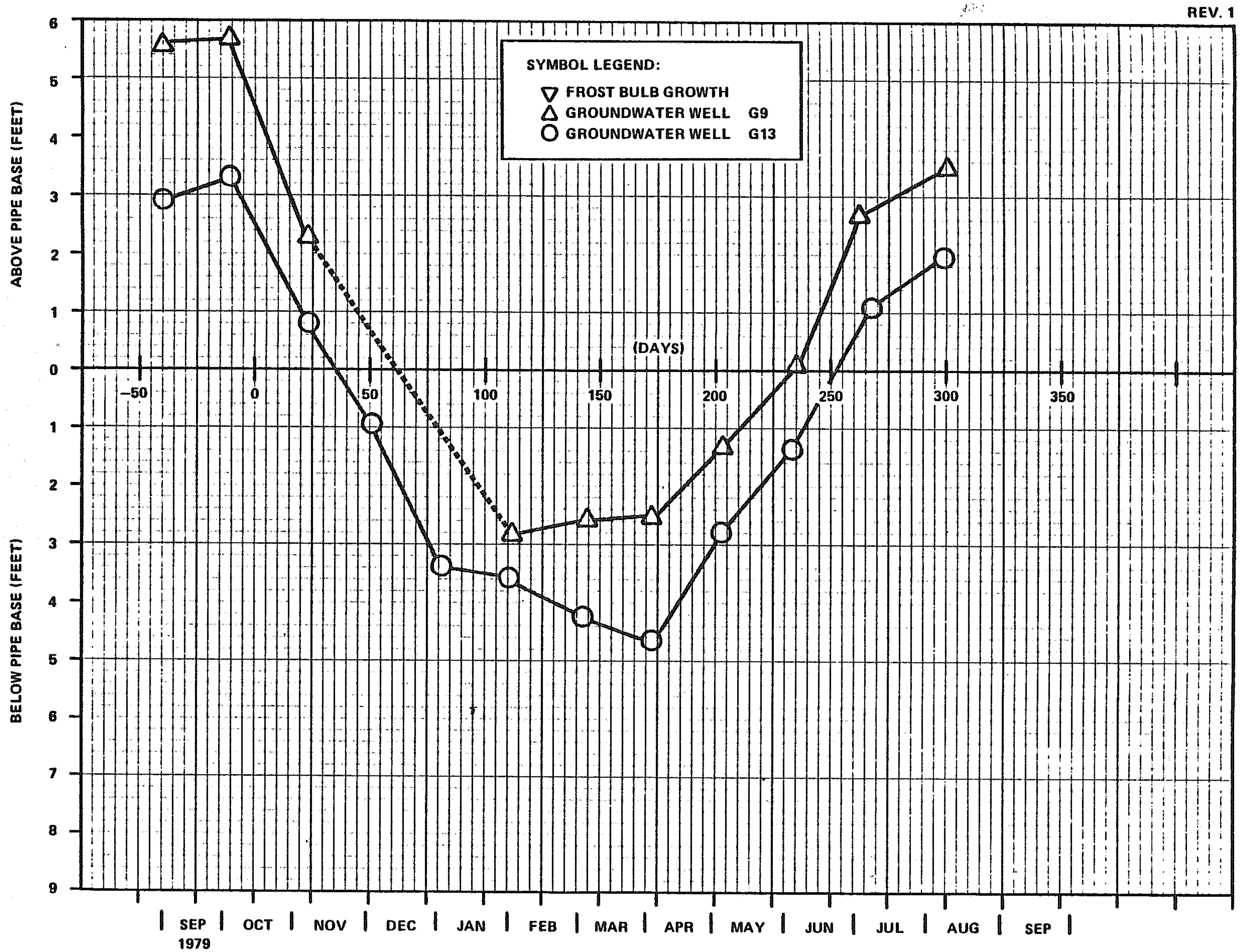
FIGURE 6.7–8, FROST BULB GROWTH AND GROUNDWATER WELL HYDROGRAPHS V.S. TIME, TEST SECTION 7



NOTE: DAY ZERO IS OCTOBER 13, 1979

FIGURE 6.7–9, FROST BULB GROWTH AND GROUNDWATER WELL HYDROGRAPHS V.S. TIME, TEST SECTION 8

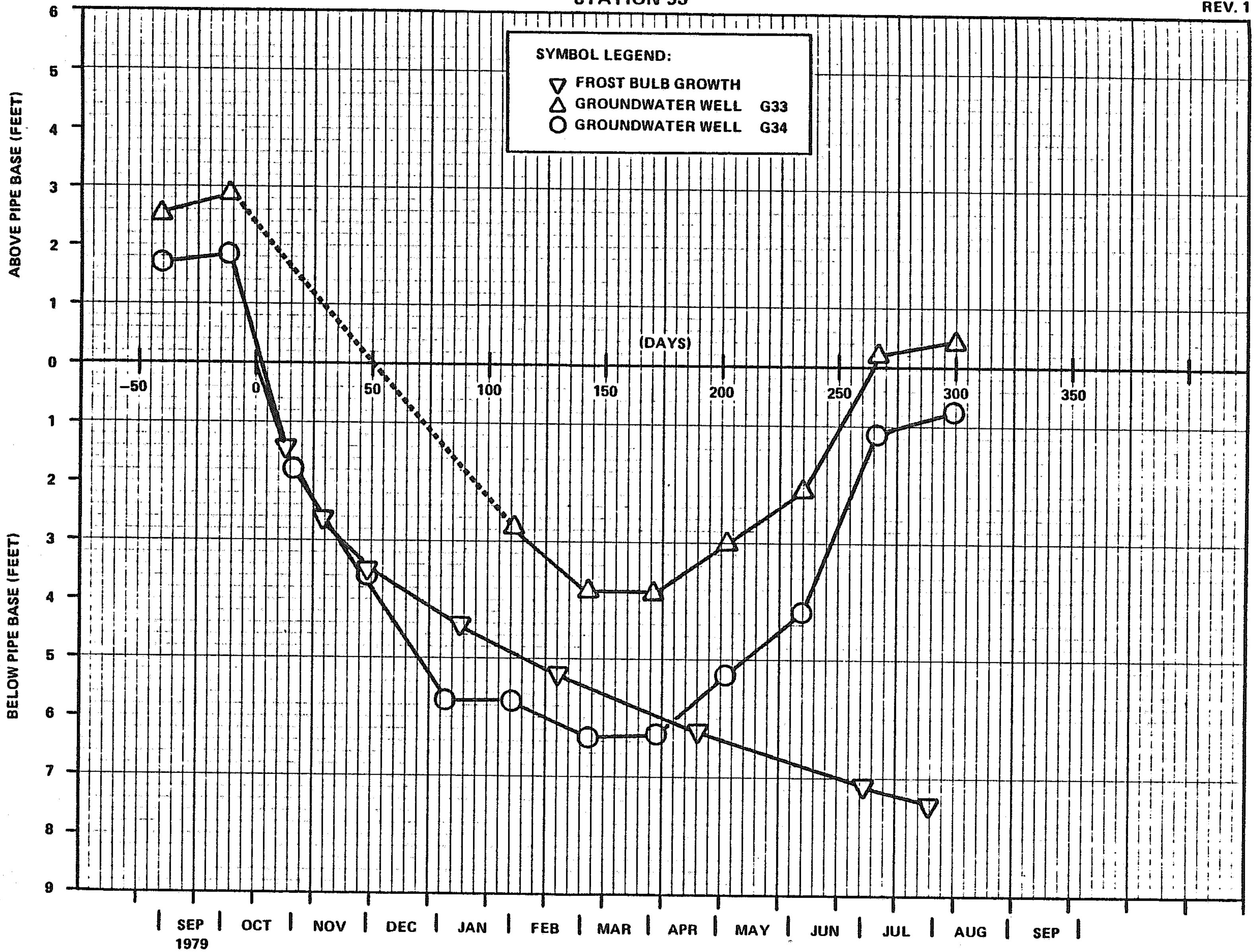
REV. 1



NOTE: DAY ZERO IS OCTOBER 13, 1979

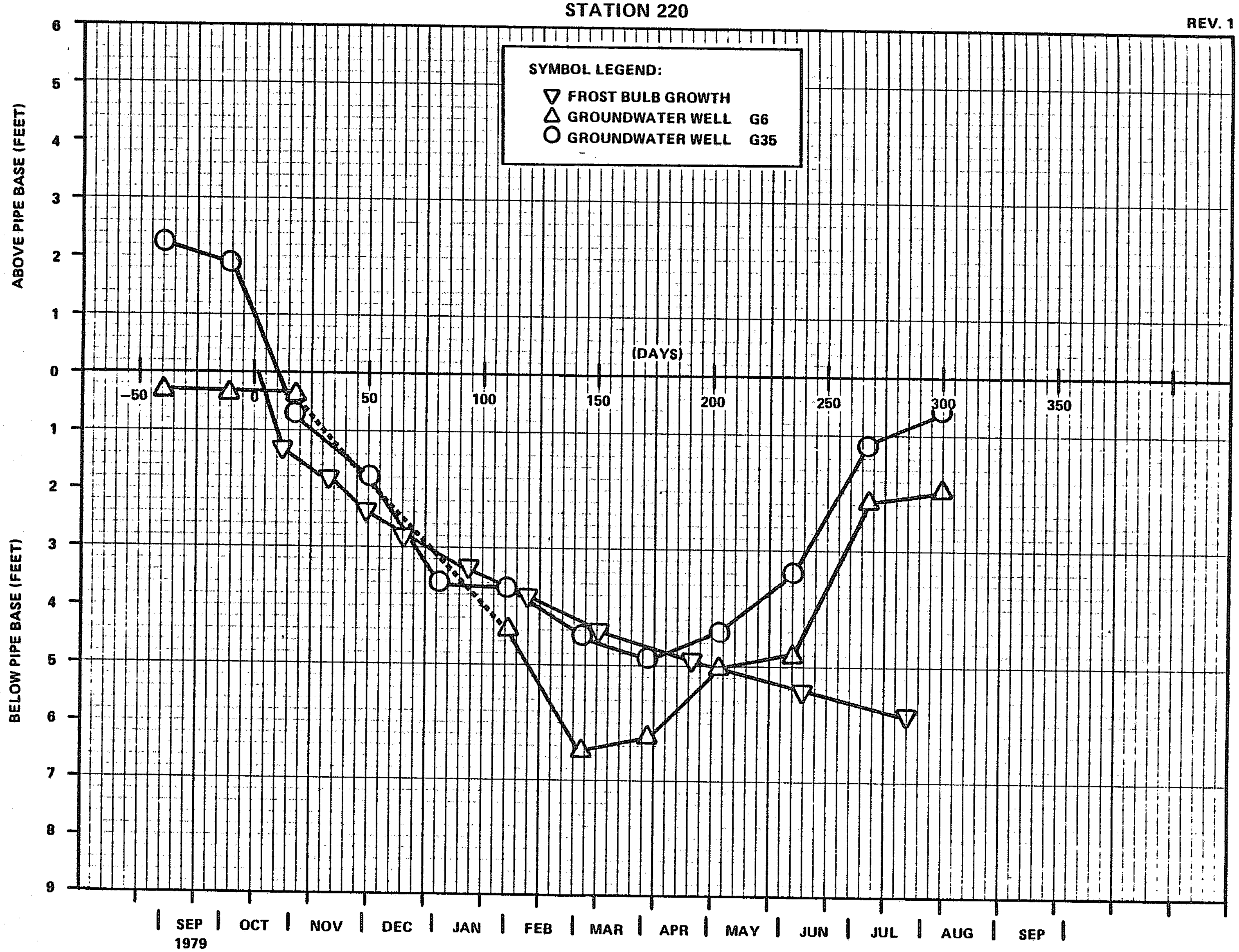
FIGURE 6.7–10, FROST BULB GROWTH AND GROUNDWATER WELL HYDROGRAPHS V.S. TIME, TEST SECTION 9 STATION 95

REV. 1



NOTE: DAY ZERO IS OCTOBER 13, 1979

FIGURE 6.7–11, FROST BULB GROWTH AND GROUNDWATER WELL HYDROGRAPHS V.S. TIME, TEST SECTION 9 STATION 220



NOTE: DAY ZERO IS OCTOBER 13, 1979

7.0 PLANNED PROGRAMS

7.1 Data Acquisition System

A program is underway to improve the reliability of the Data Acquisition System and to reduce electronic maintenance costs. The 22 small buildings that presently house the field electronics will be replaced by 11 larger buildings. During cold weather, electronic maintenance personnel were previously constrained to extracting the integrated-circuit multiplexer cards from their field locations in order to isolate suspected component failures. Consolidation of the field electronics will facilitate field electronic testing and will provide better environment control for these electronics.

7.2 Vertical Distance Data

Presently, the site operators record vertical distance data from the Hewlett-Packard Electronic Total Station during their prescribed reading sequence. By computer prompt, these data are entered into the database.

A program is underway to reduce the labor intensity of the recording process by providing a computer interface by either manual entry at the surveying station or via direct-link between the surveying instrument and the computer.

7.3 Short-span Differential Test Sections 11 and 12

Two new test sections at the Fairbanks site will be constructed early in 1981. Both test sections will be restrained at both ends via artificial permafrost. The purposes of these "guillotine" test sections are to characterize further the relationships between pressure, heave, and structural response of the short-span-length pipes during frost bulb growth.

As presented in the FERC filing and in NWA's Frost Heave Report, February 1980, parametric studies using the PIPLIN computer program show that the length of heaving span will have a considerable impact on the design allowable heave. When the heaving span is short, less than 25 feet, the pipe is relatively stiff with respect to the soil. When the heaving span is long, greater than 100 feet, the soil is relatively stiff with respect to the pipe; therefore, the pipe tends to exhibit the flexibility to accommodate or "ride" the imposed, frost-heave induced, displacement profile. Attendantly, the focus of structured interest shifts from a discussion of span length to a discussion of transition length.

Test Section 11 will be 120 feet in length. It will span 25 feet of frost-susceptible soils and both of its 47.5-foot ends will be restrained by the artificial permafrost. This test section will represent a short heaving span. Test Section 12 will be 160 feet in length. It will span 60 feet of frost-susceptible soils and both of its 50-foot ends will be restrained by the artificial permafrost. This test section will represent an intermediate length heaving span. Existing Test Section 9 represents differential heave for a long span length pipe.

Chilling to achieve and maintain the vertical faces of the artificial permafrost will be accomplished by a supplemental ethylene-glycol/water circulating system to be interfaced with the existing refrigeration equipment. These new test sections will be tied into the existing chilled air circulation system. Chilled air circulation will not commence until the artificial permafrost has joined with the natural permafrost (approximately 25 feet below the natural ground surface).

To control inhibition or aggravation of the frost bulb growth in the thawed soil medium between the vertical face of the artificial permafrost, an "insulation sandwich" will be constructed with an electrical heat tracing network within. The heat tracing will be controlled to provide an adiabatic surface at the interface between the thawed soil and the insulation sandwich.

Both test sections use 48 inch diameter coated pipe installed upon and backfilled with native soil. Typical of the majority of the existing test sections, the pipe's crown will be installed at an elevation of 2.5 feet below the natural ground surface and the ditch walls will be constructed at a 1-to-1 sideslope.

Four inches of urethane insulation, 20-feet long, will be applied over one segment of both Test Sections 11 and 12. Fifteen feet of the insulated pipe will be located within the artificially frozen soil zone and the remaining five feet will extend into the thawed zone. The insulation is being placed on these test sections to demonstrate the behavior of the insulation and its jacket under forced structural-distress conditions at and near the frost-susceptible soil and frozen soil interface.

The test sections will be heavily instrumented with both strain gauges and heave rods. Temperature sensors will be located on the inside wall of the pipe and in string arrangements, closely spaced adjacent to and beneath the test sections. Heave plates will also be used to monitor the vertical displacement of the soil adjacent to the test sections.

7.4 Field Uplift Resistance Tests

A program is underway to bury eight short pipe sections at the Fairbanks site for uplift resistance testing. Four 48 inch diameter by 8-foot long and four 18 inch diameter by 8-foot long concrete-filled steel pipes will be buried at a shallow permafrost area of the Fairbanks site. The purposes of these tests, together with on-going small-scale model uplift tests, are to provide force-deformation data for structural modeling.

Each of these test sections will be constructed with three lifting rods extending from beneath the test section to approximately 1 foot above the natural ground surface. These rods will be in-turn connected to rods extending from the jacking super-structure when it is moved in place. Each test will be accomplished using a prescribed constant strain-rate.

Off both ends of each test section, vertical slide panels will be buried to provide for plane-strain conditions. Concrete reaction pads will be placed adjacent to the test sections to support the jacking apparatus.

Two of the 18 inch, and two of the 48 inch section will be tested under conditions simulating the winter state of a bare chilled-gas pipeline. The remaining 18 inch and 48 inch diameter sections will be tested so as to simulate summer conditions of a bare chilled-gas pipeline.

The test sections will be equipped with a chilled ethylene glycol/water circulating system to ensure that their thermal environment simulates that of a chilled-gas pipeline under winter or summer conditions. A chilled ethylene glycol/water solution will also be circulated in "bayonets" located adjacent to the concrete reaction pads to ensure a credible frozen foundation for the pads.

Instrumentation for these tests will consist of: (1) temperature sensor arrays to define the thermal environment adjacent to and above each test section; (2) pressure sensors to measure the stress applied to the jacking apparatus; and, (3) heave rods on the test sections and reference points on the jacking apparatus and reaction pads from which to compute vertical displacement.

7.5 Small-Diameter Test Sections 13 and 14

Two new small-diameter test sections will be constructed at the Fairbanks site early in 1981. The coated test sections will be 12 inch diameter by 25-feet long and will be chilled with a circulating ethylene glycol/water solution.

Test Section 13 will operate at approximately zero degrees Fahrenheit. Test Section 14, like existing 48 inch diameter Test Section 1, will operate at approximately 14 degrees Fahrenheit.

Test Section 14 will serve to define frost bulb growth and frost heave relationships between its 12 inch diameter and that of existing 48 inch diameter Test Section 1. Together, Test Sections 13 and 14 will serve to define relationships between operating temperature, frost bulb growth, and frost heave.

8.0 SUMMARY AND OBSERVATIONS

8.1 Overview

Recognizing the need to understand and quantify the effects of frost heave upon an operating chilled-gas pipeline, Northwest Alaskan Pipeline Company and Foothills Pipeline (Yukon) Limited constructed the Fairbanks Frost Heave Test Facility.

The Fairbanks facility's location, some six miles from Fairbanks, Alaska, was choosen because it satisfied the requisite experimental and geotechnical criteria necessary to accommodate long-term frost bulb growth. The test site possesses high-silt content soils (Fairbanks silt) together with a high-water table.

The ten full-scale test sections at the facility were designed to investigate the heave relationships between the sections, to test proposed mitigative solutions, and to advance the predictive capabilities of structural and empirical frost heave models.

This report, intended to be the first of bi-annual reports, describes the equipment, operational procedures, and presents the performance of the Fairbanks Frost Heave Test Facility during its first ten months of operation. Subsequent reports will concentrate upon presentation of ongoing analytical programs, correlations, and predictions.

8.2 Operating History

No problems have been experienced with the air supply, circulating, or refrigeration equipment at the facility. Since commissioning of the facility on October 13, 1979, its operation has been virtually un-interrupted. No substantial problems have been experienced with either heave or benchmark readings at the facility.

Environmentally-aggravated component failures of field (satellite) electronics has incurred near-regular electronic maintenance efforts. A program underway to consolidate the field electronics from 22 small buildings to 11 large and better environmentally controlled buildings will serve to increase the reliability of the electronics and provide better maintenance conditions.

8.3 Frost Bulb Growth

In the fall of 1979, Northwest Alaskan commissioned EBA Engineering Consultants, Limited, to prepare a performance prediction for the Fairbanks Frost Heave Test Facility (reference 4). EBA's empirical frost heave model couples laboratory-derived Ice Segregation Ratio (ISR) values for the soils beneath the chilled pipes with a two-dimensional geothermal model to predict frost heave as a function of frost bulb growth. These Ice Segregation Ratio (ISR) values were derived using NWA's standard frost heave test cell with remolded Fairbanks silt. Because the predictions were intentionally made before operating data were available from the facility, the predictions represent colder (8 to 10°F) circulating air temperatures than the historical temperatures of approximately 12 to 14°F. Additionally, EBA correctly utilized typical (historical/statistically average) climatological data for their long-term predictions.

The facts that Fairbanks experienced a milder winter than a "typical" winter, and that the circulating air temperatures have been warmer than those used in the simulations will both serve to lessen the frost bulb growth and thereby strengthen the correlations between predicted and actual frost bulb growth and thereby frost heave. EBA is in the process of remodeling the test sections using historical operating conditions coupled with the results of the new laboratory testing techniques. These results will be presented in a later report.

In July and August of 1980, Northwest Alaskan conducted a drilling and trenching program at the test site. The purposes of these investigations were: (1) to verify the extent of the frost bulb and location of the permafrost table; (2) to recover and document continuous core samples of the frost bulb attendant to each test section for use in laboratory testing; (3) to identify the soil beneath the frost bulb (i.e., the soil that the frost bulb would eventually encounter); and, (4) to conduct in-situ permeability tests at the site for ongoing groundwater analyses.

Although analyses of below-ground temperature sensor data have been generally difficult, analytical techniques employed to identify the location of the frost bulb and permafrost table exhibit good agreement with the physical results obtained from the 1980 drilling program. Subsection 6.3 provides an explanation of frost bulb geometry relating to interpretation of the results obtained during the 1980 drilling program.

A new temperature sensor string will be placed in each of the 20 PVC pipes emplaced during the 1980 drilling program to define further the thermal environment around the test sections and to substantiate existing analyses.

8.4 Observations of Test Section Performance

Since early in 1980, the test sections have ordered themselves into two general groups (see Figure 6.6-1): those that have demonstrated a decaying heave rate, and those that have maintained a relatively constant heave rate.

In the decaying heave-rate group are bare Test Sections 1, 4, 6, and 9, and insulated Test Section 5, which is configured with two inches of urethane insulation and is buried beneath a gravel berm. In decreasing order of heave, Test Sections 1 and 9 (at 9's most rapidly heaving station) are closely paralleling each other. Next is Test Section 4 with, since early in 1980, a heave rate of approximately 72 percent of Test Section 1. Next is Test Section 5 with, since early in 1980, a heave rate of approximately 49 percent of Test Section 1. Last in the decaying heave-rate group is Test Section 6 which is now nearly frozen-in under the influence of its chill pipes and has virtually ceased heaving.

In the relatively constant heave rate group are insulated Test Sections 2, 7, 8, and 3 in order of heave response. During July, 1980, Test Section 2's heave rate was approximately twice that of Test Section 1, the facility's bare reference section. Although many influences will serve to modify the relative performance of these test sections, if their present trends persist, Test Section 2 will overtake Test Section 1 early in 1981.

Test Section 9 continues to demonstrate differential frost heave of a long pipeline structure. Where this test section was buried in initially thawed soils (approximately 270 feet), its heave has closely paralleled that of Test Section 1 -- the bare reference section. Where Test Section 9 was buried in permafrost soils (approximately 130 feet), its heave has closely paralleled that of Test Section 10 -- the test section wholly installed in permafrost. These comparisons are presented on Figure 6.6-5.

The following comparisons between the performance predictions report and the actual heave performance of the test sections are presented without adjustment to circulating air temperature or climatological inputs. It should be noted that these adjustments will serve to strengthen the correlations between predicted and actual performance. All of the percentages are referenced to August 5, 1980:

1. Test Section 1 was approximately 49 percent of the predicted value (0.35 feet actual, 0.72 feet predicted).

2. Test Section 2 was approximately 96 percent of the predicted value (0.25 feet actual, 0.26 feet predicted).

3. Test Section 3 was approximately 38 percent of the predicted value (0.05 feet actual, 0.13 feet predicted).

4. Test Section 4 was approximately 36 percent of the predicted value (0.17 feet actual, 0.47 feet predicted).

5. Test Section 5 was approximately 50 percent of the predicted value (0.14 feet actual, 0.28 feet predicted).

Test Section 8 has heaved sooner than predicted (0.04 feet actual, zero feet predicted). Test Sections 6, 7, and 9 were not simulated. Test Section 6 was not simulated because it is configured with chill-pipes. Test Sections 7 and 9 are similar in configuration to Test Sections 2 and 1, respectively.

8.5 Planned Programs

Two up-grade and three new testing programs are planned for the test site. The first up-grade program is designed to improve the reliability of the Data Acquisition System by providing better environmental control for the field (satellite) electronics.

In the second up-grade program, two options are being developed to reduce the labor intensity of the vertical distance data (heave rods and benchmarks) entry into the master computer at the Fairbanks site. These options consist of either providing a remote computer port/ terminal at the surveying station or providing a direct-link between the surveying instrument and the master computer.

In the first testing program, two new 48 inch diameter Test Sections, 11 and 12, will be constructed beginning early in 1981. Both test sections will be restrained at both ends via artificial permafrost. The purposes of these "guillotine" test sections are to characterize further the relationships between pressure, heave, and structural response of the short-span-length pipes during frost bulb growth.

In the second testing program, four 8-foot long, 48 inch diameter, and four 8-foot long, 18 inch diameter concrete-filled pipes will be pulled out of the soil. Two of the 18 inch and two of the 48 inch pipes will be pulled during the late winter and early spring of 1981, and the remaining 18 inch and 48 inch pipes will be pulled during the spring of 1981. The purposes of these tests, together with ongoing small-scale model uplift tests, are to provide force-deformation data for structural modeling.

In the third testing program, two new Small-Diameter Test Sections, 13 and 14, will be constructed beginning early in 1981. Together with existing test sections, these test sections will serve to define relationships between operating temperature, frost bulb growth, and frost heave.

8.6 Ongoing Frost Heave Programs

Northwest Alaskan has utilized the heave relationships defined by the existing Fairbanks test sections to configure the 80 foot long, 48 inch diameter mitigative test section to be constructed at each of the new Chilled-Pipe Test Sites. Designs for the new sites, and for the additions to the Fairbanks test site, have incorporated the operations, instrumentation, and data acquisition experience gained at the existing Fairbanks facility. The data handling, security, and analytical procedures established for the database from the existing Fairbanks facility were designed to accommodate data from the new sources.

In ongoing programs, Northwest Alaskan is proceeding to strengthen the correlations between laboratory frost heave tests, empirical frost heave prediction models, and field heave performance; between laboratory and field pipe/soil interaction tests; and between structural-pipe responses and structural models.

9.0 REFERENCES CITED

References

1. "Survey for Frost Heave Test Site," for Northwest Alaskan Pipeline Company by R. M. Hardy and Associates, Ltd., and R. A. Kreig and Associates, March, 1978.

2. "Frost Heave Test Site Search in Alaska," for Northwest Alaskan Pipeline Company by Dr. Arvind Phukan, April, 1978.

3. "Subsurface Investigations, Potential Frost Heave Test Sites, Fairbanks, Alaska," for Northwest Alaskan Pipeline Company by Shannon and Wilson, Inc., February, 1978.

4. "Performance Predictions for Fairbanks Frost Heave Test Facility," for Northwest Alaskan Pipeline Company by EBA Engineering Consultants, Ltd., February, 1980.

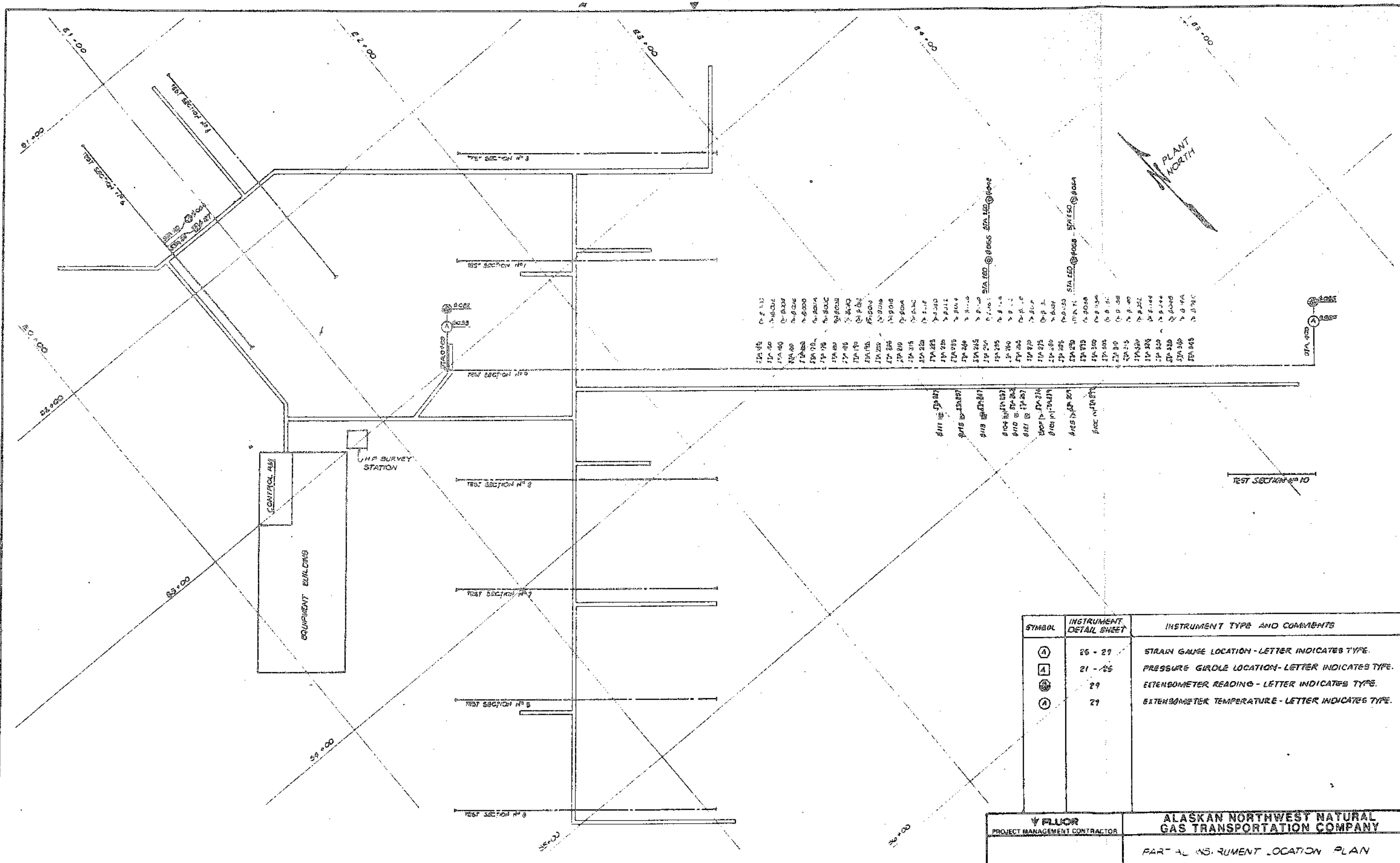
10.0 APPENDICES

Appendix 1: Isometric drawings presenting instrumentation locations for Test Sections 1 through 9.

Appendix 2: Plan view of the test facility presenting the locations of boreholes, trenches, and permeability wells accomplished during the 1980 Field Verification Program.

Appendix 3: Preliminary analysis of the structural response of Test Section 9.

APPENDIX 1



SYMBOL	INSTRUMENT DETAIL SHEET	INSTRUMENT TYPE AND COMMENTS
(A)	26 - 29	STRAIN GAUGE LOCATION - LETTER INDICATES TYPE.
[A]	21 - 25	PRESSURE GIRDLE LOCATION - LETTER INDICATES TYPE.
(A)	29	EXTENSOMETER READING - LETTER INDICATES TYPE.
(A)	29	EXTENSOMETER TEMPERATURE - LETTER INDICATES TYPE.

FLUOR
PROJECT MANAGEMENT CONTRACTOR

NOTICE

ALASKAN NORTHWEST NATURAL GAS TRANSPORTATION COMPANY

PARTIAL INSTRUMENT LOCATION PLAN

FROST HEAVE TEST FACILITY

ALASKA SEGMENT OF THE ALASKA NATURAL GAS TRANSPORTATION SYSTEM

SCALE IN FEET	DRAWING NUMBER	REV
1" = 10'-0"		

NOTES	No.	DATE	REVISION		APP	DWG NO	REFERENCE DRAWING

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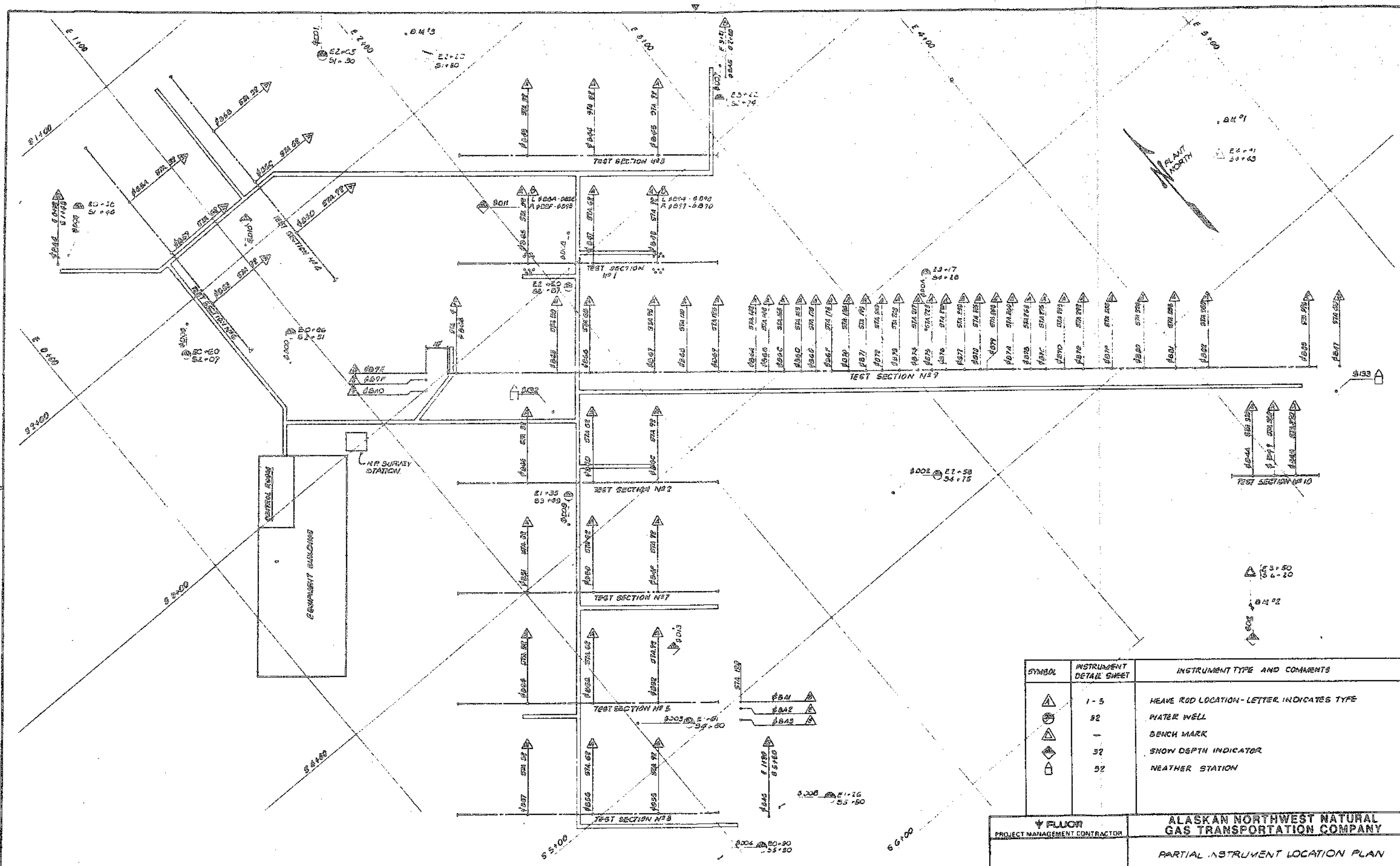

SYMBOL	INSTRUMENT DETAIL SHEET	INSTRUMENT TYPE AND COMMENTS
△ (A)	1 - 5	HEAVE ROD LOCATION - LETTER INDICATES TYPE
◎	32	WATER WELL
△	—	BENCH MARK
◇	32	SNOW DEPTH INDICATOR
⌂	32	WEATHER STATION

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NOTICE

ALASKAN NORTHWEST NATURAL GAS TRANSPORTATION COMPANY

PARTIAL INSTRUMENT LOCATION PLAN
FROST HEAVE TEST FACILITY

ALASKA SEGMENT OF THE ALASKA NATURAL GAS TRANSPORTATION SYSTEM

SCALE IN FEET: =20'-0"

DRAWING NUMBER | REV

DISTRIBUTION CODE

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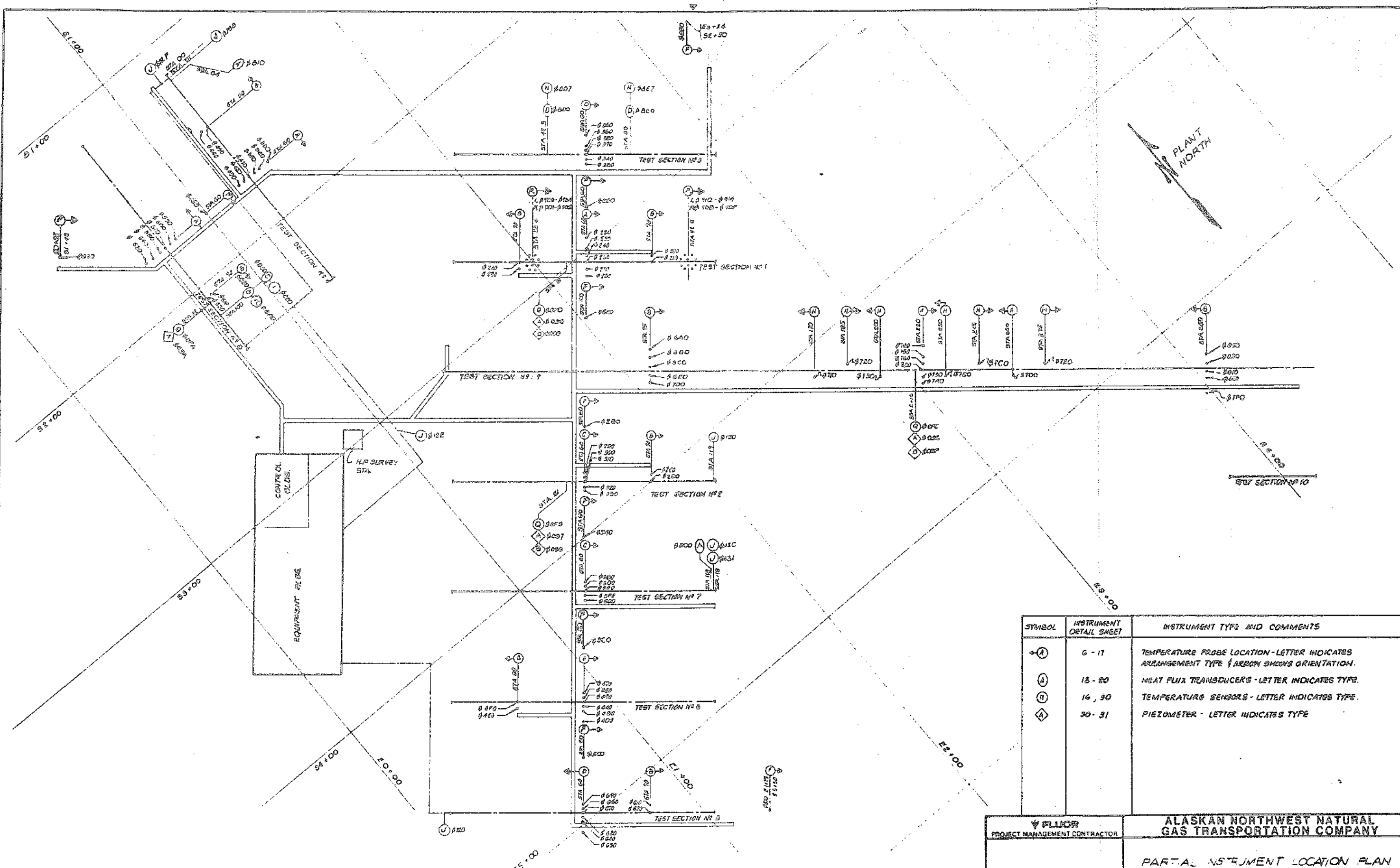

SYMBOL	INSTRUMENT DETAIL SHEET	INSTRUMENT TYPE AND COMMENTS
→(A)	6 - 17	TEMPERATURE PROBE LOCATION - LETTER INDICATES ARRANGEMENT TYPE & ARROW SHOWS ORIENTATION.
(A)	18 - 20	HEAT FLUX TRANSDUCERS - LETTER INDICATES TYPE.
(N)	16 , 30	TEMPERATURE SENSORS - LETTER INDICATES TYPE.
◇A	30 - 31	PIEZOMETER - LETTER INDICATES TYPE

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ALASKAN NORTHWEST NATURAL GAS TRANSPORTATION COMPANY

PARTIAL INSTRUMENT LOCATION PLAN
FROST HEAVE TEST FACILITY

ALASKA SEGMENT OF THE ALASKA NATURAL GAS TRANSPORTATION SYSTEM

SCALE IN FEET	DRAWING NUMBER	REV
1"=20'-0"		

NOTES

REVISION

REFERENCE DRAWINGS

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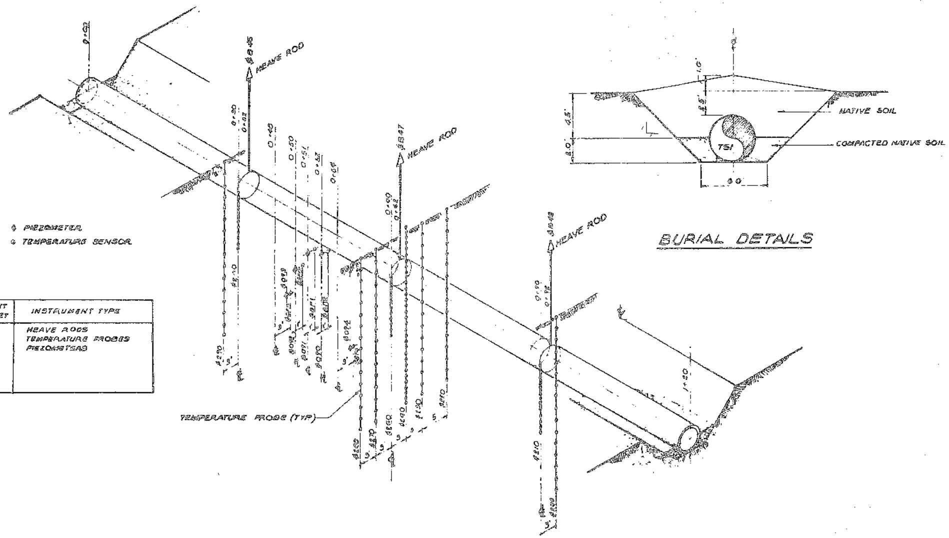


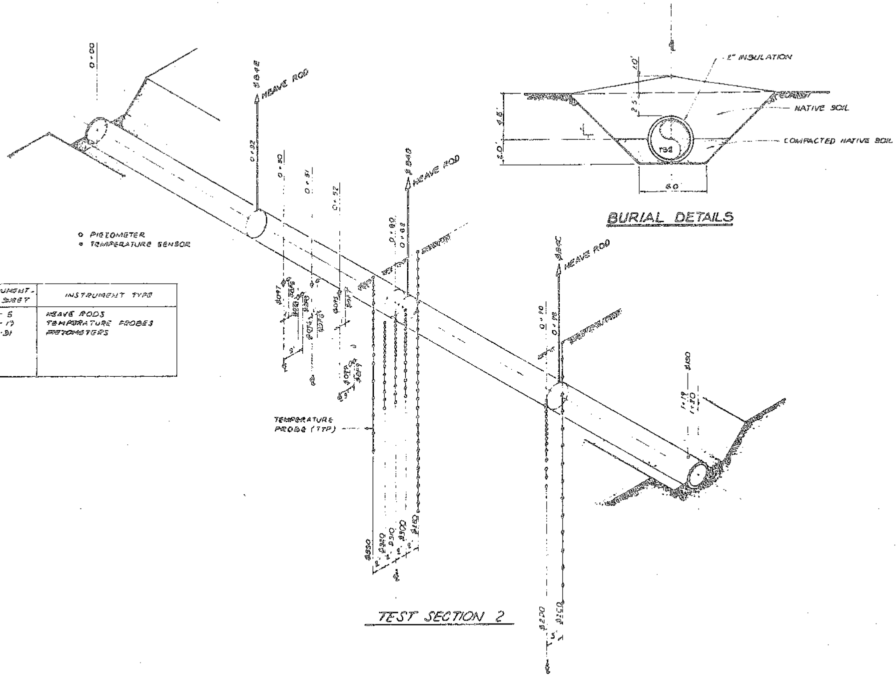
BURIAL DETAILS

◊ PIEZOMETER

○ TEMPERATURE SENSOR

INSTRUMENT DETAIL SHEET	INSTRUMENT TYPE
1-6	HEAVE RODS
6-17	TEMPERATURE PROBES
20-31	PIEZOMETERS

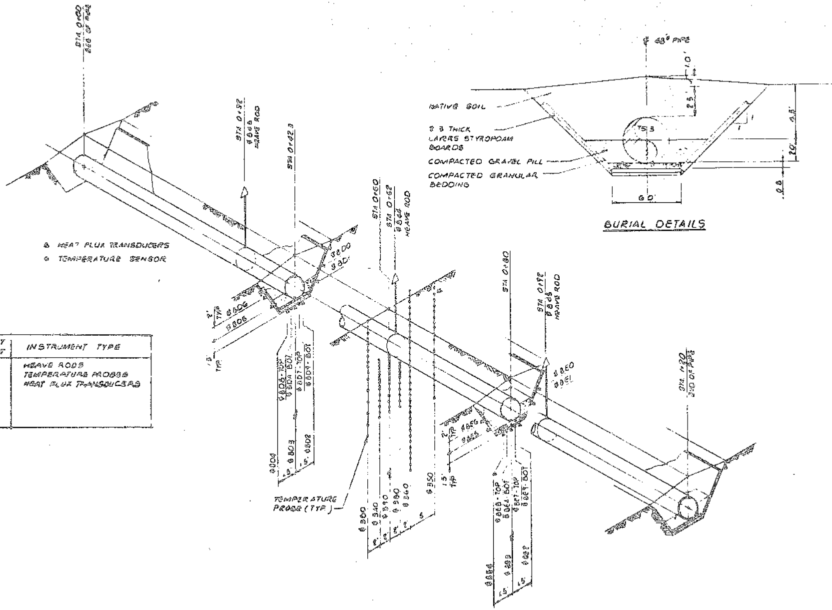
TEST SECTION 1



INSTRUMENT-DETAIL SHEET	INSTRUMENT TYPE
1 - 5	HEAVE RODS
6 - 17	TEMPERATURE PROBES
20 - 31	PIEZOMETERS

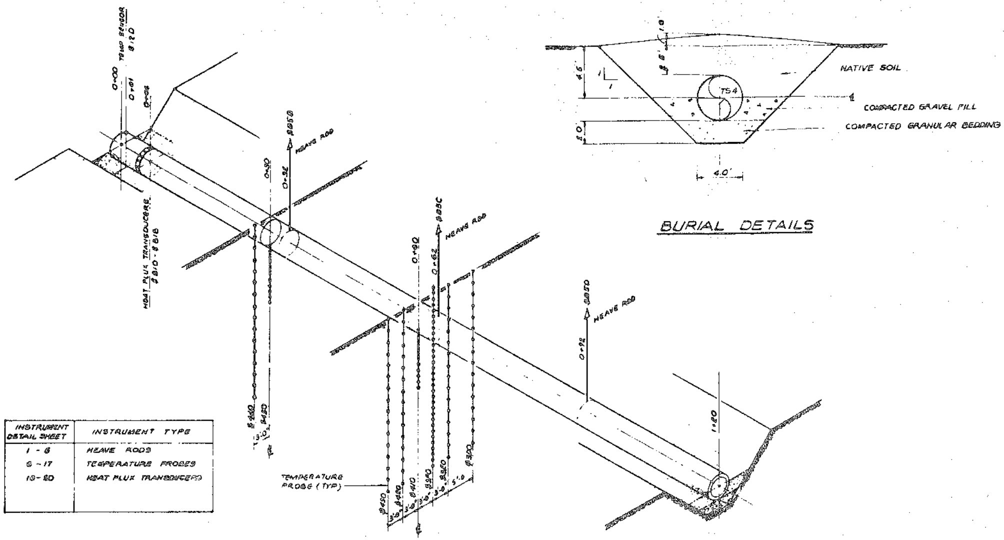
TEST SECTION 2

REDUCED PRINT SCALES



INSTRUMENT DETAIL SHEET	INSTRUMENT TYPE
1-5	HEAVE RODS
6-17	TEMPERATURE PROBES
18-20	HEAT FLUX TRANSDUCERS

TEST SECTION 3

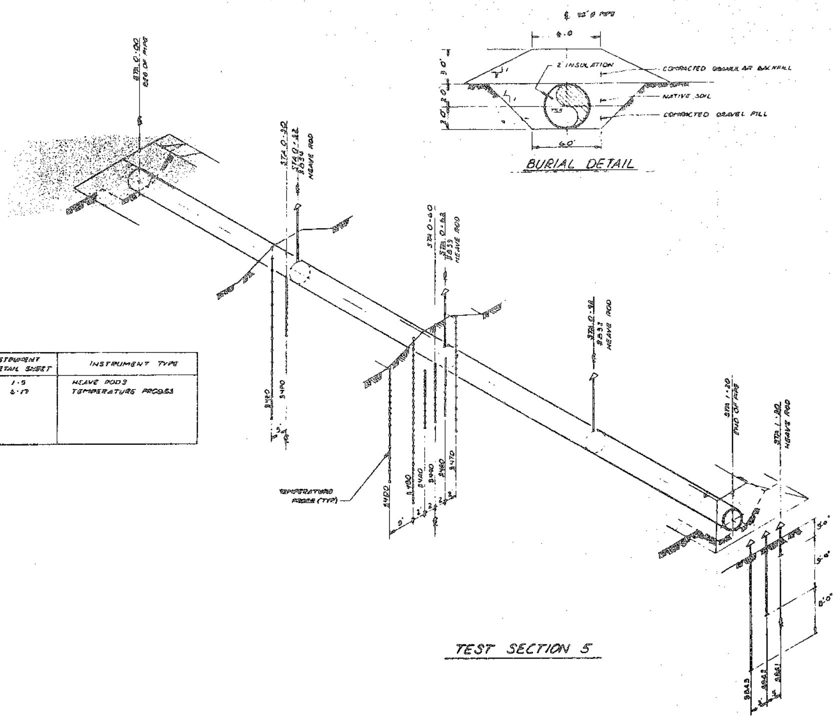


BURIAL DETAILS

INSTRUMENT DETAIL SHEET	INSTRUMENT TYPE
1 - 6	HEAVE RODS
6 - 17	TEMPERATURE PROBES
18 - 20	HEAT FLUX TRANSDUCERS

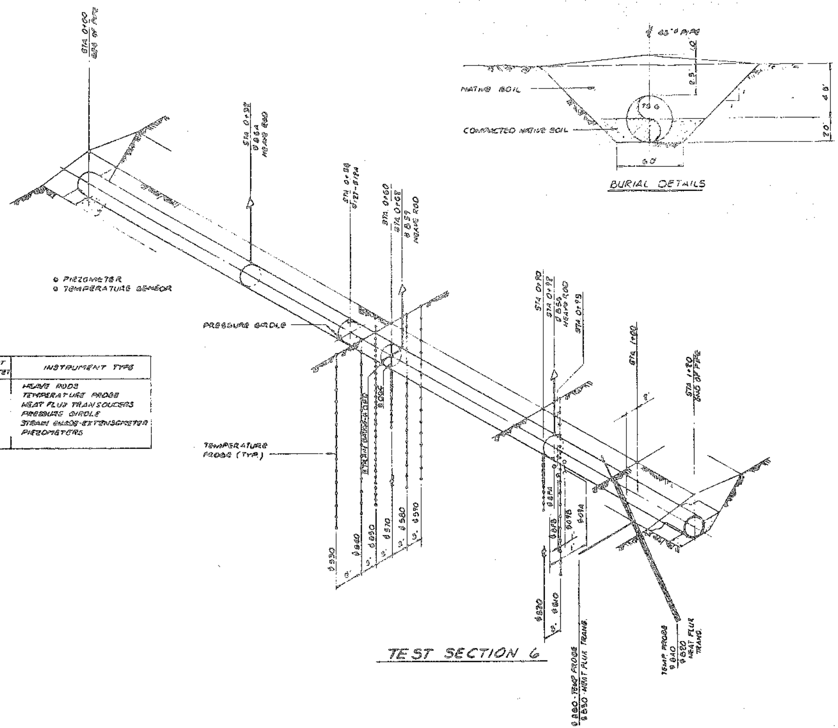
TEST SECTION 4

REDUCED PRINT SCALES



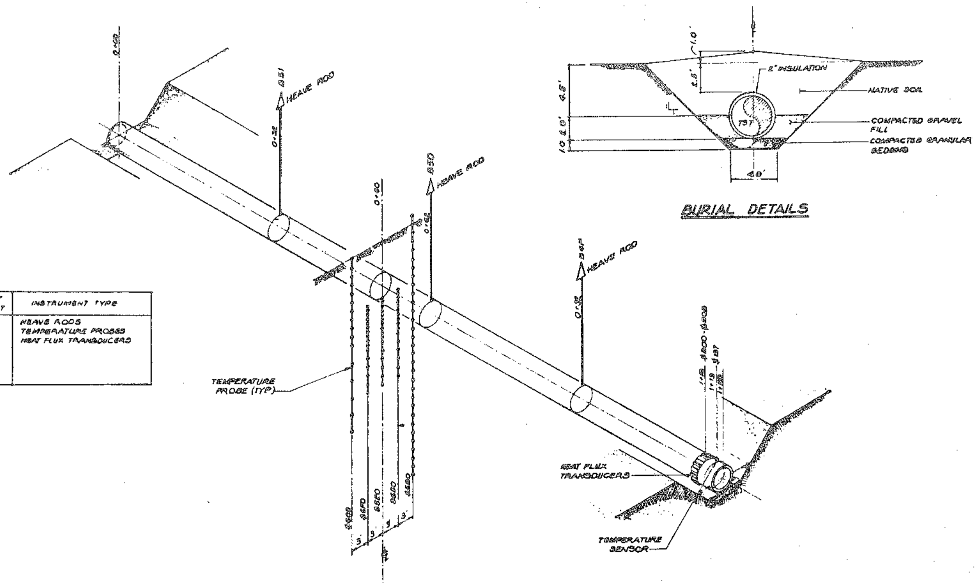
INSTRUMENT DETAIL SHEET	INSTRUMENT TYPE
1-5	HEAVE RODS
6-17	TEMPERATURE PROBES

TEST SECTION 5



INSTRUMENT DETAIL SHEET	INSTRUMENT TYPE
1 - 5	HEAVE RODS
6 - 17	TEMPERATURE PROBE
18 - 20	HEAT FLUX TRANSDUCERS
21 - 24	PRESSURE GIRDLE
25 - 29	STRAIN GAGES-EXTENSOMETER
30 - 31	PIEZOMETERS

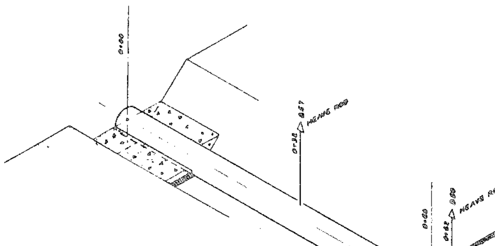
TEST SECTION 6

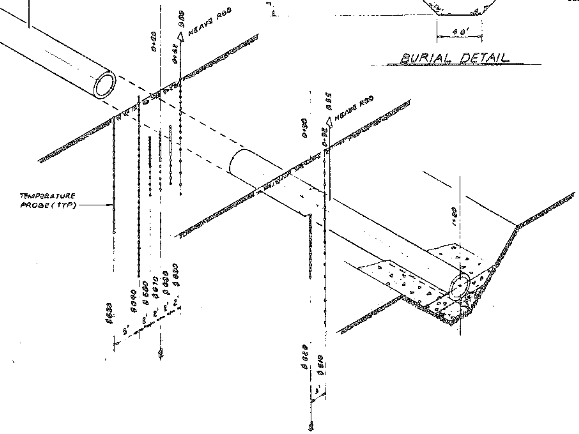


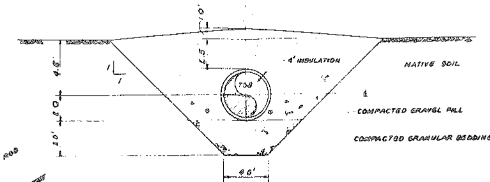
BURIAL DETAILS

TEST SECTION 7

INSTRUMENT DETAIL SHEET	INSTRUMENT TYPE
1-5	HEAVE RODS
6-17	TEMPERATURE PROBES
18-20	HEAT FLUX TRANSDUCERS



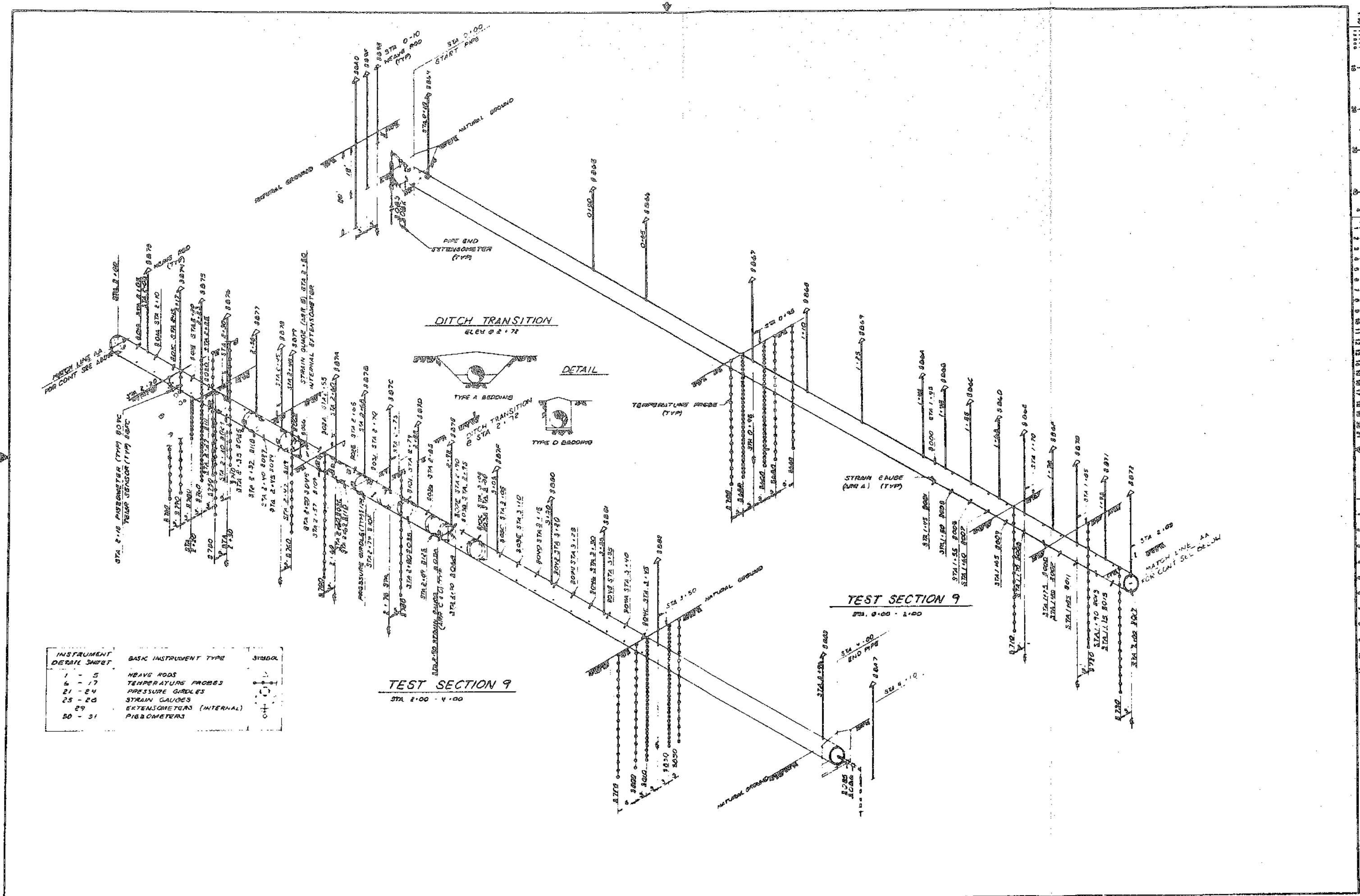




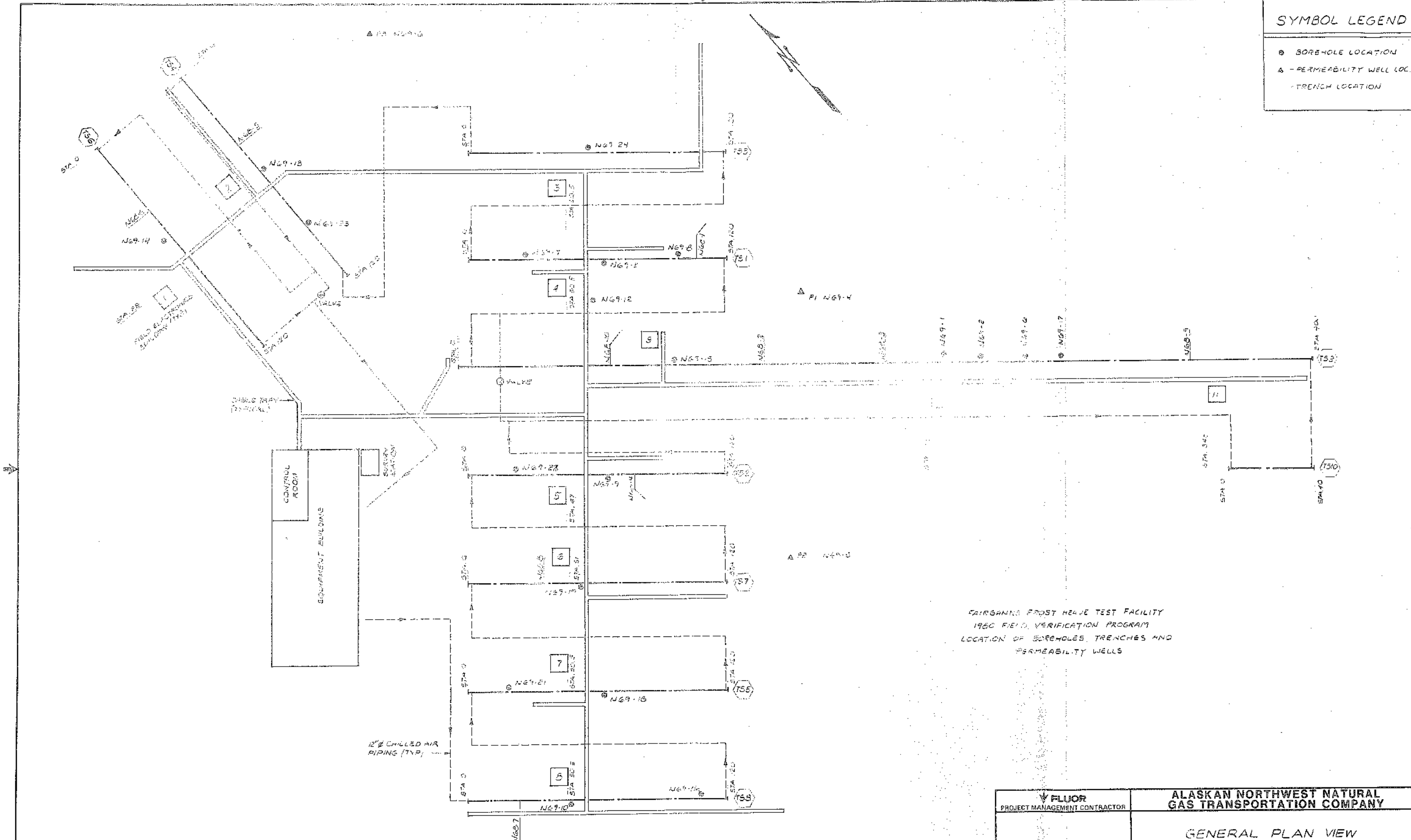
BURIAL DETAIL

INSTRUMENT DETAIL SHEET	INSTRUMENT TYPE
1-5	HEAVE RODS
6-17	TEMPERATURE PROBE

TEST SECTION B


DITCH TRANSITION
ELEV @ 2+72
TYPE A BEDDING
DETAIL
TYPE D BEDDING
DITCH TRANSITION @ STA 2+72
PIPE END EXTENSOMETER (TYP)
NATURAL GROUND
STA 0+00 START PIPE
TEMPERATURE PROBE (TYP)
STRAIN GAUGE (TYP)
MATCH LINE AA FOR CONT SEE BELOW
MATCH LINE AA FOR CONT SEE ABOVE
TEST SECTION 9
STA. 0+00 - 2+00
TEST SECTION 9
STA 2+00 - 4+00
STA 4+00 END PIPE
STA 3+50
STRAIN GAUGE INTERNAL EXTENSOMETER
PRESSURE GIRDLE (TYP)
INSTRUMENT DETAIL SHEET
BASIC INSTRUMENT TYPE
SYMBOL
1 - 5 HEAVE RODS
6 - 17 TEMPERATURE PROBES
21 - 24 PRESSURE GIRDLES
25 - 28 STRAIN GAUGES
29 EXTENSOMETERS (INTERNAL)
30 - 31 PIEZOMETERS
REDUCED PRINT SCALES

APPENDIX 2



ALASKAN NORTHWEST NATURAL GAS TRANSPORTATION COMPANY

FLUOR PROJECT MANAGEMENT CONTRACTOR

GENERAL PLAN VIEW

FAIRBANKS FROST HEAVE TEST FACILITY

ALASKA SEGMENT OF THE ALASKA NATURAL GAS TRANSPORTATION SYSTEM

MONTECILLO, T	DATE Feb 1980	FLUOR	DATE
C. DALLAIRILLE		NW ALASKAN DEEZ HAZEN	DATE

SCALE IN FEET	DRAWING NUMBER	REV.
1" = 20 FT		1

DISTRIBUTION CODE NO.

FORM E-727 2/80

NOTES	REV. NO.	DATE	REVISION	DRAWN CHECK	APP	DWG NO.	REFERENCE DRAWING
						MICROFILM NO.	

APPENDIX 3

PRELIMINARY STRUCTURAL ANALYSIS

FAIRBANKS FROST HEAVE TEST FACILITY

PRELIMINARY STRUCTURAL ANALYSIS OF TEST SITE NO. 9

1.0 OBJECTIVES

On July 10, 1980, NWA directed Fluor to study the effects of pipe/soil interaction at the Fairbanks test site. Fluor was asked to fulfill the following work requirements:

1.1 Determine the proper instrumentation for pipe/soil interaction, including pipe stresses and strains, and soil pressures.

1.2 Recommend modifications to existing instrumentation, if required, to ensure that we are collecting the necessary data for design analysis.

1.3 Analyze TS-9 to determine if stresses and strains being recorded will correlate with analytical predictions derived from measurements of heave.

1.4 Develop a pipe/soil instrumentation plan for the proposed Haines test site incorporating the lessons learned from Fairbanks.

Since that time, it has been decided that two new test sections will be located at the Fairbanks test facility. These test sections, designated TS11 and TS12, will be used to replace the proposed Haines test site.

Section 2.0 presents a description of the TS-9 site and its instrumentation. The analysis of the data and instrumentation of TS-9 which partly fulfills the first work requirements, is contained in section 3.0.

Analytical correlation of the data from TS-9, which fulfills the third work requirement, is contained in section 4.0.

The development of the instrumentation plan for the proposed test sites, which fulfills the first and fourth work requirement, is contained in section 5.0.

The recommended modifications for the existing instrumentation, as well as recommendations for data correlation studies, fulfilling the second work requirement, is contained in section 6.0.

The design and analysis of a pipeline for frost heave is still in the development stages. Thus, it is not possible to regard the present study as conclusive or exhaustive. Continuing effort is needed to effectively utilize the developed data. This is especially true in view of the new test sites and their data correlation requirements. Section 7.0 presents the conclusions and recommendations for future extensions of this work.

2.0 TEST SECTION 9 - DESCRIPTION

Test Section Number 9 consists of a 48-inch OD section of pipe approximately 400 feet long (Figure 3.1). Approximately 130 feet of the length is embedded in permanently frozen ground while the remainder of length is in frost susceptible soil. The permanently frozen ground serves as an anchor against upward movement. As the frost susceptible soil heaves, the pipe experiences differential heave between the two soil types. The two lengths of soil sections are long enough so that the end effects can be ignored. The region where the transition from the nondisplacing (perma-frost) to displacing (frost susceptible) soil occurs, is of greatest interest to pipe stress analysis since flexural stresses are induced in the pipe because of the curvature in this region.

2.1 Instrumentation

A summary of the instrumentation that is of greatest interest to pipe stress analysis is shown below:

2.1.1 32 Heave Rods - the locations of the heave rods along the pipe length are noted on the top of Figure 3.1. Their computer addresses run from B64 to B83.

2.1.2 Strain Gauges

a. 78 type "A" gauges - there are 39 locations for type "A" gauges, each location having two groups. The one gauge is on the top, the other on the bottom. Each set is spaced about 5 feet apart in the transition region, the location noted on Figure 3.1. Their computer addresses run from 000 to 04D. These gauges measure axial strain.

b. 8 type "C" gauges - there are 2 locations for type "C"gauges, each location having four gauges. The gauges are located 90° apart around the periphery of the pipe. They are located at station 250 and 290. Their computer addresses are 06E and 075. These gauges measure hoop strain.

2.1 Instrumentation (Continued)

c. 24 type "D" gauges - there are 2 locations for type "D"gauges, each location having twelve gauges. The gauges are located in groups of three located 90° apart around the periphery of the pipe. Each group of three form a three element rectangular rosette with the axes of the gauges corresponding to axial, hoop, and a 45° axis, respectively. The groups are located at stations 249 and 280. Their computer addresses range from 04E to 065.

d. 6 Internal Extensiometers - There are three locations for these instruments, each location having a vertical and horizontal extensiometer to measure changes in internal pipe diameter. They are located at stations 60, 250 and 290.

e. 2 End Extensiometers - These instruments are located at the extreme ends of the pipe to measure changes in pipe length.

f. 46 Pressure Girdles These instruments are located around the pipe periphery in the transition region. The locations of girdles mounted on the top and bottom of the pipe are noted on fig. #3.1.

3.0 TEST SECTION 9 - RESPONSE OF INSTRUMENTATION

The first part of the study was to check data consistency and instrumentation error and/or malfunction for test section 9. For this preliminary study the pipe stress group used data generated by a Fluor computer program. Since that time, Battelle has introduced a computer system, that can be accessed interactively, to produce graphical displays of data. It is expected that the system will be used for all future data presentation, including that needed for the planned test sites.

3.1 Frost Heave Rods

The frost heave rods are the most direct, foolproof and practical means of obtaining the pipe displacement profile. The height of the instrument is taken as the average of the heights computed according to three benchmarks. The instrument itself is capable of resolution to 0.001 feet.

The displacement profile for 4-25-80 is plotted on Figure 3.1.a. This may be compared with the profile of 6-20-80, (Figure 3.1.b) and 8-26-80 (Figure 3.1.c).

There is a clearly defined transition region extending over a 60-foot length. The permanently frozen ground seems to be adequate in restraining the movement of the pipe since displacements are small in that region. Displacements in the heaving region remain fairly constant.

There are several points of concern about the profile.

3.1.1 The high point of the heaving region at station 95 (heave rod B67). There is a local increase of heave at this point. It was suggested that this reading may be due to instrument error either on the day it was plotted (4-25-80) or on the day the readings were "zeroed" (10-13-79). To check this, another day was taken as the zero date (9-13-79) and another plot day was used (4-29-80). Part of the results are reported in Figure 3.2. Note that instrument B67 still shows a relatively high point in the heaving profile. It must be concluded that more heaving has actually occurred at that point, possibly due to soil inhomogeneity.

3.1.2 The high point of the heaving region at station 210 (heave rod B73) and the relative low point at station 290 (heave rod B7E). These points mark the approximate limits of the transition region of the pipe. The readings at B73 may then be explained as due to the pipe flexural actions. The abrupt change at B7E is more difficult to comprehend since pipe flexure should smooth the profile more than is indicated. It is also difficult to imagine an actual kink in the pipe at the pressure and observed strain values. A visual inspection of this region is indicated.

3.2 Axial Gauges

Before analyzing the data in detail, the strain gauge readings were scanned to find anomalies that would indicate malfunction. There were two basic anomalies found:

3.2.1 Those gauges which did not move from a zero reading after 10/13:

These include:

00D	041
015	043
023	048
03B	058
03D	065

3.2.2 Strain gauges which show large, unexplained jumps in strain:

These include: 003 (Jumped between 2/8 and 2/12)
04A (Jumped between 12/11 and 12/14)

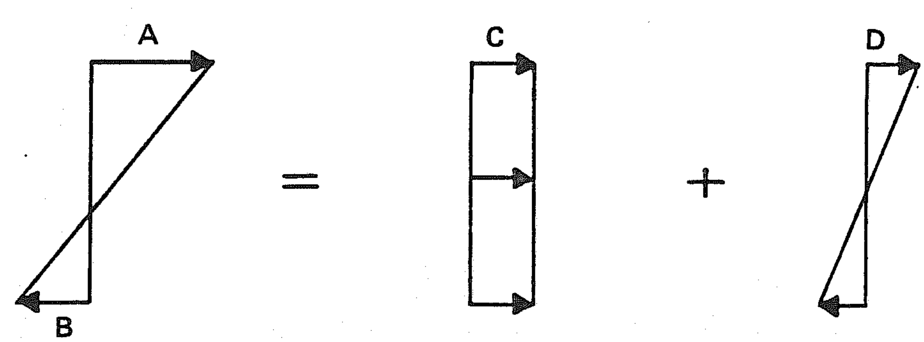
These gauges were excluded from later analysis. It is important to note that one of the most important pieces of information for stress analysis for the problem is the flexural strain. As will be explained later, the flexural strain can only be derived from a relationship involving two axial gauges at a single location. Thus, if one gauge malfunctions, the value of the other axial gauge at that location is greatly diminished.

The pairs of axial gauges can be used to find the strain due to flexure from the following derivation.

Let A = strain measured in top of pipe

B = strain measured in bottom of pipe

Then, as is usual, assume a linear relationship in strain across the pipe section:



3.2.2 (Continued)

Measured strain = direct axial strain + flexural strain

or A = C + D

B = C - D

so C = (A + B)/2

D = (A - B)/2

A sample calculation is performed in Figure 3.3.

At this point, the pipe stress group attempted to see if there was a correlation between the measured strains and the strains theoretically associated with the displacement profile indicated by the heave rods. A series of computer analyses were performed to verify this correlation.

The test model was analyzed by using the PIPLIN III computer program. The nodes in the finite element mesh were made to correspond to points of interest along the pipe (heave rod locations or strain gauge locations). Additional nodes were placed as necessary in accordance with good modeling practice. A linear spring stiffness was assigned to the nodes. Then a displacement corresponding to the observed heave rod displacement was imposed on the pipe. The attached springs would tend to smooth the observed profile. The criteria for this smoothing process was that the output profile would differ by less than 0.1 inch at any point from the observed profile. The output profile was then used by the PIPLIN III program to calculate stresses along the profile (which can be easily converted to strains). A plot of the strain distribution predicted by PIPLIN III is shown on the Figure 3.4.b. Note the similarity in shape and magnitude with the observed profile on 3.4.a. Notable points:

a. The point of inflection near station 170. This is around the area of one of the observed high points on the heave profile.

b. The point of inflection near station 270. Between approximately stations 210 and 290 is the transition region.

3.2.2 (Continued)

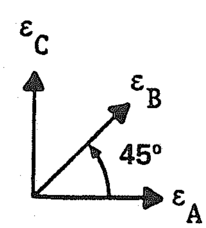
c. The high strain magnitudes observed in the transition region, especially near the permafrost sector. This is to be expected since a stiff soil sector will allow less redistribution of strain.

d. The relative magnitude of the gauges 030 and 031. There appears to be no discernible reason for the behavior observed at this location. On the other hand, a scan of the strain data at these points does not indicate gauge malfunction. It is noted that the information becomes much more believable if 030 is taken as a bottom gauge and 031 as a top gauge. It would be necessary to check this possible error in installation in the field inspection.

   It is also noted that the direct axial strain along the pipeline is about 200 microstrain, although considerable fluctuation exists in the value. At this point, there appears no theoretical reason why such a direct strain should exist. The possibility of gauge drift should not be overlooked.

3.3 Triaxial Rosettes (Type "D" Gauges)

In this test section, the principal strain directions should correspond with the principal axes of the pipe (hoop and axial). The triaxial rosettes should be used to verify this assumption. For the three element rectangular rosette used in TS-9 the following relationships hold:



Gage Positions

Principal strains =

$$\tfrac{1}{2}(\varepsilon_A + \varepsilon_C) \pm \tfrac{1}{2}\sqrt{(\varepsilon_A + \varepsilon_C)^2 + (2\varepsilon_B - \varepsilon_A - \varepsilon_A - \varepsilon_C)^2}$$

3.3 (Continued)

and the principal angle is given by

$$\tan \quad 2\phi = (2\varepsilon_B - \varepsilon_A - \varepsilon_C) / (\varepsilon_A - \varepsilon_C)$$

These relationships are worked out for the strain gauge rosettes and are shown in Figure 3.5. Note that the calculations generally confirm the assumption of principal strain directions except for configuration 060-061-062. When examined more closely, it appears that gauge 061 may be malfunctioning so as to give a consistently low reading. It is also to be noted that an analyst can use the rosettes to give another flexural data point. Thus the two rosettes locations are marked on the strain gauge plots on figure #3.4 (noted as pairs 057-051 and 063-05D). Also information from the rosettes can be used to derive hoop strain distribution. For this purpose, however, the rosettes of TS9 were incorrectly placed 6-inches away from a set of hoop gauges. Thus, this valuable information was being duplicated by a set of identical gauges.

3.4 Hoop Gauges

The hoop gauge readings are shown in Figure 3.6. The strain distribution is asymmetrical, indicating some ovalling of the pipe has occurred. The pattern revealed by the readings show that the bottom reading is less than the top and both are less than the side readings. Such a distribution can be partially explained by a cos2Ø distribution of pressure superimposed on a constant pressure distribution. However, a survey of the temporal variation in strain indicates that this strain distribution existed on 10/15/79 and remained relatively constant to 4/25/80. The strain distribution of 10/13/79 was similar in pattern but approximately half the amplitude of 10/15/79.

The following conclusions can be made:

3.4.1 The strain distributions really exists, as opposed to being caused by malfunction or noise. This conclusion is based on the duplication of the pattern at all four locations.

3.4.2 The pattern is not being caused by forces exerted by the frost heave action. The strain pattern and amplitudes are set by 10/15/79. The small amount of time needed to develop the amplitude rules out the possibility of frost heave action.

3.4.3 The pattern is not caused by local material variation since the sets of readings are taken in locations composed of different pipe materials.

3.4 Hoop Gauges (Continued)

It becomes apparent that the pattern was caused by the pipe springing from its initial configuration to the pressurized configuration. The initial configuration was caused by the pipe laying operations and the overburden pressure. Very little ovalling of the pipe is evident after this effect.

3.5 Pressure Cells

Response of the pressure cells showed large variations with time. Plots of various cells with time are shown in Figure 3.7. Moreover, little correlation could be found between the readings of different cells.

Some cells at some times did show correlation with the expected range of values, although it was not felt that any conclusive evidence could be derived. Further study will be necessary to find reasons for the variations. At this time, it is not recommended that these cells be used in the new sites.

4.0 TEST SECTION 9 - ANALYTICAL CORRELLATION

The main analytical tool used in the analysis of frost heave on the pipeline is a computer program, PIPLIN. The PIPLIN program is uniquely designed to consider the parameters that are considered essential in the analysis.

4.1 Input to the PIPLIN program

The active, or driving, function in the frost heave analysis is the imposed displacement profile. The amplitude of this displacement profile is increased in a load stepping process to simulate the expected growth of the heave with time.

The amplitude of the profile is found by a consideration of the geothermal regime and the ice segregation ratio (ISR). The ISR is a meaure of the amount of growth of a soil length per unit penetration of the freezing isotherm. For example, suppose a geothermal analysis predicts a 1-foot depth penetration of the frost bulb for some period of time. If the ISR is 10 percent, then the expected heave displacement is 0.1-foot. This growth is imposed as the heave displacement profile on the soil pipe. The flexural stiffness of the pipe will develop resistance to this heave, increasing the pressure and relieving the ISR function. (Figure 4.1.a)

Actual values input to PIPLIN were found from an evaluation of the heave behavior of section 1 (fig. 4.1.b). The thermal and soil

4.1 Input to the PIPLIN Program (Continued)

characteristics of TS1 and TS9 are assumed to be identical. Figure 4.1.b shows the measured heave of this pipe. TS1, being considerably shorter than TS9, should show little structural influence on frost bulb growth. This means that TS1 results form a good data base to develop the input to the structural analysis of TS 9. The actual ISR for TS1 for any given time can be found simply by dividing the observed heave by the observed frost bulb depth.

4.1.1 Soil Characteristics

Soil values used to describe uplift resistance for test section #9 was "nominal silt" values obtained from Figure 4.2 and Figure 4.3 based on heave displacement of 6 inches at the end of one year.

The maximum uplift resistance value obtained from Figure 4.2 for frozen soil is 100 K/FT. and from Figure 4.3 for unfrozen soil is 10 K/FT.

Soil stiffness for a force displacement value was obtained based on data from the geotechnical group. Figure 4.4 describes soil stiffness corresponding to frozen and thawed soil failures values obtained from Figure 4.2 and Figure 4.3 with a maximum of 2-inch soil deflection for frozen soil and 0.2 inch for thawed soil.

4.1.2 Seasonal Variations of Uplift Resistance

Seasonal changes in maximum uplift resistance for the heaving section of TS9 were obtained from Figure 4.5. The stiffness of the soil was assumed to be constant for all displacements less than the yield displacement for this study. The stiffness was taken at 50 K/in/ft.

4.1.3 Analytical Model

The geometric description of model points used as input to the PIPLIN computer program corresponded to heave rod locations. Seasonal variations in strength were modelled using the option in the PIPLIN program described in section 3.3 of the Users Guides. Four load cases were used to simulate the strength seasonal behavior depected in Figure 4.5.

4.1.4 Effects of Heave Displacement Profile

The heave displacement profile was specified to be zero for the non-heaving section. The displacement would then linearly rise to the maximum value of heave for the heaving section. The length over which this rise was specified to occur was varied. The results of a rise over 0 feet, 30 feet, and 60 feet are reported in Figure 4.6. The stiffness of the pipe and stiffness functions of the soil for these runs were identical.

4.1.5 Soil Properties Variation

A series of runs were made which varied the given soil properties to find the relative impact on the final pipe displacement. All of these runs used identical geometric configurations, ie, a 50 foot heaving span with 50 feet of adjacent non-heaving sections. The heave was modelled to rise over a very small length (the "guillotine" profile). Representative results an plotted in Figure 4.7. It is noted that most of the difference occurred when the stiffness was varied.

4.2 Comparison Between Transition Lengths and Test Site #9

Using the recommended soil values, the PIPLIN studies indicate the best comparison between the analytical results and observed phenomenon occurred when the heave displacement profile was linearly varied over 60 feet. This resulted in a pipe transition length (the length between the flat section in the heaving region and the flat section in the non-heaving region) of approximately 90 feet. The study also indicated that if the soil properties are varied, the observed phenomenon can be analytically duplicated by other variations in the heave displacement profile. There does not seem to be a unique correspondence between the observed phenonmenon and the analytical procedures. However, the range of soil stiffness characteristics recommended for this study appears to be justified based on overall results.

A further study using PIPLIN modelling a 60-foot soil transition for a second year frost heave growth (assumed to be 50 percent of the first year growth) was performed. Results of the study indicate no appreciable change in the pipe transition length of 90 feet.

5.0 PROPOSED DIFFERENTIAL TEST SITES

Two additional test sites for the observation of the effects of differential frost heave action are planned for the Fairbanks test site. Test sections 11 and 12 will be prepared from 48-inch diameter, 0.6-inch

5.0 PROPOSED DIFFERENTIAL TEST SITES (Continued)

thick pipe and will have the same pressure and temperature characteristics as test section 9. The distinguishing characteristics of the three sites will be their respective heave spans.

5.1 The Effect of Span

The heave span is defined as the length of the frost heave susceptible soil region. The adjacent frozen soil regions do not experience the heaving directly and so tend to restrain the upward movement of the heaving span.

When the heaving span is small, less than 25 feet, the pipe is relatively stiff with respect to the soil. An imposed heave displacement will be heavily influenced by the pipe response, causing large resisting pressures in the soil. The high pressures cause the pipe to push into the soil so that the pipe displacement will be less than the heave of an unrestrained pipe. It then becomes apparent why the pipe will only produce a few inches of displacement for short spans.

When the heaving span is large, greater than 100 feet, the soil is relatively stiff with respect to the pipe. The amplitude of the imposed heave is equal to the pipe displacement near the center of the heaving span since the pipe now has the flexibility to "ride" the imposed displacement profile. The focus of structural interest shifts from a discussion of span to a discussion of transition length. Transition length may be described as the region between the relatively flat section of a nonheaving soil to the relatively flat section of the heaving soil.

The above discussion is based on parametric studies using the PIPLIN program. Figure 5.1 shows the results of a study performed in preparation for the FERC filing. The response was activated by a uniform heave load. Figure 5.2 shows the results of the present study. Note the same general shape of the load versus span curves, i.e., high gradients for small spans and very low gradients for large spans.

This type of study shows that the length of the heaving span will have considerable impact on the design allowable heave. However, even the extensive drilling program of NWA cannot hope to characterize the soil in sufficient detail to allow prediction of span lengths which will be meaningful in our analysis. It is evident that all plausible span lengths must be considered.

5.1 The Effect of Span (Continued)

Based on the above discussion, it was decided that the additional tests would have heaving spans of 25 feet and 60 feet respectively. This will allow observation of heave in short and intermediate span lengths. Test section 9 is adequate to describe differential conditions for the long span lengths.

It is noted that the design objectives of these spans are different. For the short span it is felt that the large resistance forces which will be mobilized will reduce the effective ISR (ice segregation ratio). Thus, it is expected that the tendency, or driving force, of heave will be reduced so that the maximum expected heave displacement will be small.

Long spans will not mobilize these resisting pressures as quickly; however, the pipe will be able to withstand considerable displacement. So the expected heave displacements, though relatively large, can be tolerated. The 60-foot span will find the relative influence of these conflicting events on an intermediate span length.

5.2 Anchor Lengths

As the center span of the test section develops heave pressures, the pipe will vertically displace. Since the frozen adjacent (end) sections do not mobilize the heave pressures, they will tend to restrain the center span movements. This restraint is caused by the uplift soil resistance in these end sections.

This is not to imply that the end soil sections will not displace; a portion of their length will be dragged up with the center section. Since the test is trying to simulate the pipe behavior in an actual line, it becomes important to make the end spans long enough so that the end conditions do not affect the center span conditions.

A series of analyses were performed to derive a sufficiently long end length. The first part of this study involved the theory of a beam on an elastic foundation. The governing equation for this problem is $EI \frac{d^4w}{dx^4} + Kw = p$, where:

- w is displacement
- K is modulus of subgrade reaction
- p is distributed load

5.2 Anchor Lengths (Continued)

The solution to this equation is governed by the value:

$$\lambda = \sqrt[4]{\frac{K}{4EI}}$$

which is used as a parameter in the four basic solution functions. These functions, which are tabulated in Hetenyi, Beams on Elastic Foundations, show a rapid decrease in amplitude with distance. A scan of these functions shows the values to be small when $X = \pi/\lambda$. This means that the manner in which the beam is supported at a distance of $X = \pi/\lambda$ from the application of the load will have only a small effect on the moments and shears developed in the loaded region.

Using $K = 50$ K/in/ft

$I = 25100 \text{ in}^4$

$E = 29 \times 10^6$ psi

then $\Pi/\lambda = 42.6'$

To investigate further the end anchor situation, a computer program was written to solve the governing differential equation. The program was used to analyze a 60-foot center span subjected to a uniform load with 50-foot end lengths. The uniform load amplitude was chosen to produce about a 1-inch displacement.

The first analysis, reported in Figure 5.3, solved the equation assuming infinite beam conditions (which would be the conditions of an actual pipeline). The second analysis (Figure 5.4) solved the equation with the end conditions of the test site. A comparison of the results show essentially identical results except near the ends of the spans. The comparison was also performed on the PIPLIN computer program with similar results. It may thus be concluded that 50 feet is an adequate anchor length for this section. The analysis was also performed for the 25-foot heaving span with 47.5-foot end lengths. The conclusion was the same. (Note that this result is expected since the dissipation of the solution functions is completely independent of the center span length and the center span load).

5.3 Physical Description

Based on the above studies, it is recommended that TS11 should consist of a 25-foot heaving span with 47.5-foot end lengths, 5.3 Physical Description (Continued)

making the total length 120 feet. TS12 will consist of a 60-foot heaving span with 50-foot end lengths, making the total length 160-foot.

The end lengths should be permanently frozen by means of freeze pipes, in addition to the pipe chilling effect. This should have the effect of "quick chilling" the end regions, thus preventing heave. The transfer of heat from the center to end span should be prevented by an insulation barrier supplemented by heating elements to control the heat flow. The temperature on both the end and center spans should be continually monitored to ensure the independence of the thermal regimes.

Insulation around the pipe is being added at one barrier, extending into both the center and end spans. The maximum bending moments are expected in this area so the effect on the insulation will be maximum also. The insulation cannot be extended far into the center span since that would decrease the amplitude of the heave displacements.

The pressure and temperature of the pipe will be achieved by simply extending the existing loop at Fairbanks so as to include the two new sections.

5.4 Instrumentation

Sheets 5.5 and 5.6 show the instrumentation for the two new test sites, based on recommendations of instrumentation consultants.

6.0 RECOMMENDATIONS

Based on the study, a number of recommendations will be implemented for both the existing test section 9 and the proposed test sections 11 and 12.

As was mentioned, test sections 11 and 12 will be connected with the rest of the Fairbanks test section loop. Since it will be necessary to interrupt temporarily operations of test section 9, a physical inspection of the section will be performed at that time to include the following items:

6.1 Check the strain gauge condition at the places which are now considered inoperable in an attempt to discern the failure mechanism. Repair or replace defective gauges.

6.2 Check the leads coming from the axial strain gauge pair 030-031. This can be done by placing a resistance across the respective loads. By detecting the channel on which movement is discerned, it can be concluded which gauges are actually being read on the respective channels.

6.3 Report on the physical condition of the inside of the pipe. Check the amount of scaling and corrosion to estimate the remaining effective thickness.

6.4 Report on the water or ice evident in the pipe.

6.5 Check the condition of the end extensiometers.

It is recommended that the geothermal computer programs that are being used for the project be correlated with the Fairbanks test site.

a. Try to duplicate the Fairbanks conditions as closely as possible. This would mean using actual weather conditions recorded at the Fairbanks region and using actual snow cover and soil geothermal properties (as closely as can be estimated from existing data). The results of the run would be directly correlated against the measured vertical growth at Fairbanks. The object of the run would be to substantiate this ability of the program to simulate real conditions.

b. Run the model using current design assumptions that would be appropriate for the soil and general location of the test facility. This run would not use the measured weather conditions but instead the "design climatic condition" that is currently being postulated as the coldest non-permafrost per-startup equilibrium condition i.e., approximately 32.1° on the average). The object of this would be to substantiate the safety factor existent in the design assumptions.

Laboratory tests are being performed on the (ISR) ice segregation ratio of the Fairbanks material. Several tests will be done to describe the variation in the soil and/or the laboratory procedure. This will also be correlated against observed heave. The tests will describe the variation in ISR with pressure so that this could be used in the design algorithm.

7.0 CONCLUSIONS AND FUTURE WORK

The study showed several areas in which the existing instrumentation was faulty. Recommendations were made to repair such equipment on the inside of the pipe when access is available during construction of the new sites. The pressure cells were also found faulty, though no repair is possible without critically disrupting the test.

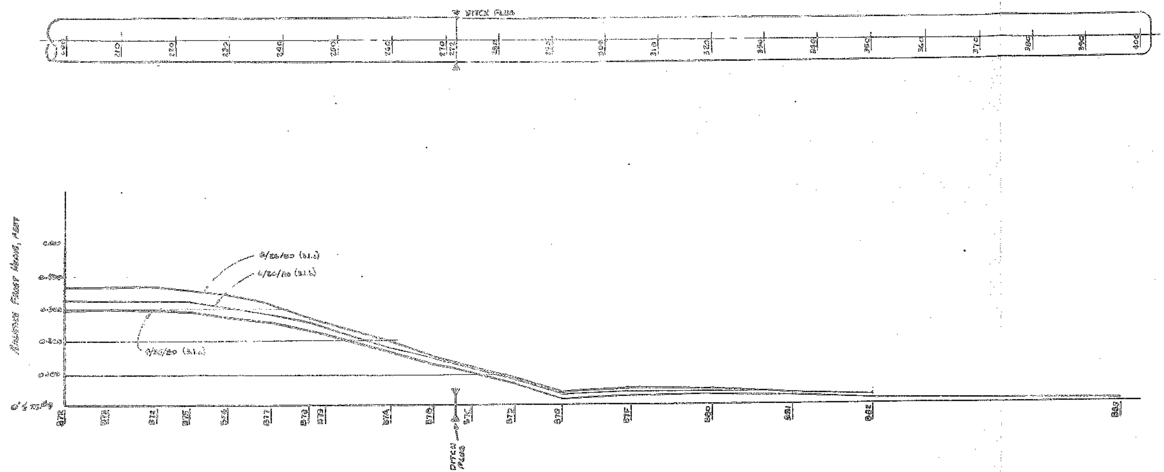
7.0 CONCLUSIONS AND FUTURE WORK (Continued)

The analytical correlation study showed that the analytical tools could duplicate the observed displacement profile. However, the input set required to perform this task is not unique. For example, the transition profile is influenced strongly by both the imposed heave profile and the soil stiffness function. Differing sets of heave profiles and stiffness functions would lead to the same pipe displacement.

It is noted that the creep analysis option of PIPLIN was not used, although preliminary results show that this may be an influential device in the analysis.

The new test sections reflect the concern of the stress analysis group concerning the length of the heaving region. Since it does not appear possible to predict through geotechnical means the length of heaving spans to be encountered, it becomes necessary to investigate the full spectrum of influential heave lengths. To predict analytically response of short spans, it will be necessary to understand the relation of heave to pressure. It will be necessary to modify the present analytical tools to reflect this criterion.

The interdependence of the various discipline groups has also been underscored in this study. A definitive study of the frost heave test sites can only be achieved through multi-discipline interaction. A task group will be designated to review regularly all data from the test facilities.



NOTES	NO.	DATE	REVISION	DRAWN / CHECK	APP.	DWG. NO.	REFERENCE DRAWING
						MICROFILM NO.	

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ALASKAN NORTHWEST NATURAL GAS TRANSPORTATION COMPANY

DISPLACEMENT PROFILE FROST HEAVE

ALASKA SEGMENT OF THE ALASKA NATURAL GAS TRANSPORTATION SYSTEM

	DATE	FLUOR	DATE
		N.W. ALASKAN	DATE

SCALE IN FEET	DRAWING NUMBER	REV.
	FIG # 3.1 (a, b, and c)	

DISTRIBUTION CODE NO.

FORM 8-737 2/80

Figure 3.2

Displacement Profile Using A Different Base Date

Find heave using 9/13/79 as base
4/29/80 as case

$$SUM_o = 2.900 + 0.613 + (-7.105) + 2.899 + 0.617 + (-7.101) = 7.177$$

$$SUM_t = 2.716 + 0.465 + (-7.253) + 2.717 + 0.467 + (-7.249) = 8.137$$

$$AIM = (SUM_o - SUM_t)/6 = 0.16$$

B64	=	-	3.754	+	0.16	+	3.872	=	0.278
B65	=		3.086	+	0.16	-	2.948	=	0.298
B66	=	-	3.728	+	0.16	+	3.878	=	0.310
B67	=	-	3.689	+	0.16	+	3.855	=	0.326
B68	=		4.270	+	0.16	-	4.127	=	0.303
B69	=	-	3.628	+	0.16	+	3.757	=	0.289
B6A	=	-	3.678	+	0.16	+	3.785	=	0.267
B6B	=	-	3.661	+	0.16	+	3.771	=	0.270
B6C	=	-	3.676	+	0.16	+	3.789	=	0.273
B6D	=	-	3.691	+	0.16	+	3.814	=	0.283
B6E	=	-	3.662	+	0.16	+	3.785	=	0.283
B6F	=	-	3.676	+	0.16	+	3.816	=	0.300
B70	=	-	3.677	+	0.16	+	3.814	=	0.297
B71	=	-	3.739	+	0.16	+	3.909	=	0.330
B72	=	-	3.449	+	0.16	+	3.611	=	0.322
B73	=	-	3.759	+	0.16	+	3.933	=	0.334
B74	=	-	3.820	+	0.16	+	3.981	=	0.321
B75	=		0.183	+	0.16	-	0.021	=	0.322
B76	=	-	.190	+	0.16	+	.322	=	0.292
B77	=		.061	+	0.16	+	.053	=	0.274
B78	=		.027	+	0.16	+	.053	=	0.240
B79	=	-	.006	+	0.16	+	.087	=	0.241
B7A	=		3.918	+	0.16	-	3.918	=	0.160
B7B	=		3.749	+	0.16	-	3.789	=	0.120
B7C	=		3.790	+	0.16		-		NA
B7D	=		3.703	+	0.16	-	3.823	=	0.040
B7E	=	-	.577	+	0.16	+	.435	=	0.018
B7F	=	-	.469	+	0.16	+	.299	=	0.010

Figure 3.3

Sample Calculation for Axial Strain Gauges

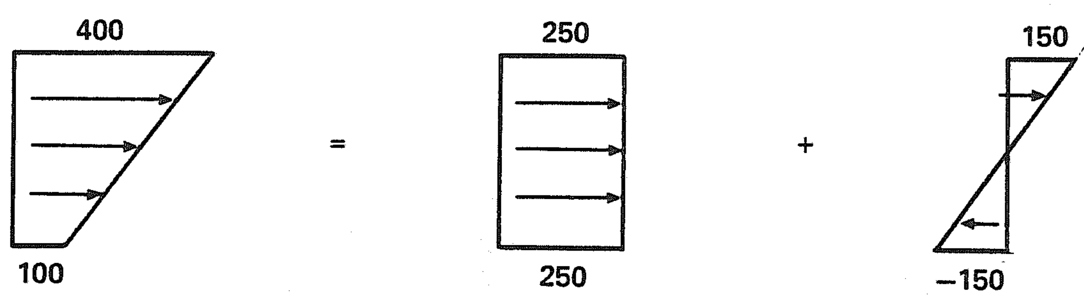
Observed strain at top of pipe = 400 ($\mu\epsilon$)

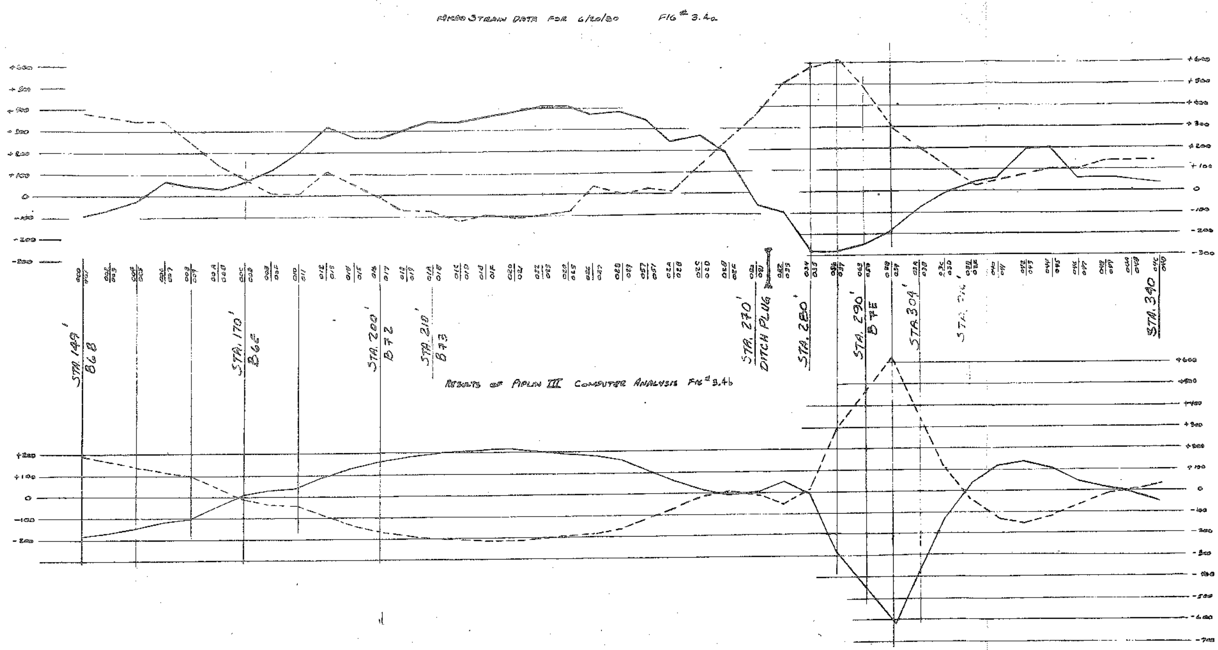
Observed strain at bottom of pipe = 100 ($\mu\epsilon$)

Then, direct axial strain = (400 + 100) / 2 = 250 ($\mu\epsilon$)

flexural strain = (400 − 100) / 2 = 150 ($\mu\epsilon$)

Graphically:





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ALASKAN NORTHWEST NATURAL GAS TRANSPORTATION COMPANY

AXIAL STRAIN - OBSERVED VS. ANALYZED

ALASKA SEGMENT OF THE ALASKA NATURAL GAS TRANSPORTATION SYSTEM

NOTES	REV.	DATE	REVISION	DRAWN / CHECK	APP	DWG. NO.	REFERENCE DRAWINGS

SCALE IN FEET | DRAWING NUMBER: FIG #3.4 (a and b) | REV.

Figure 3.5

Observed data for Strain Gauge Rosettes for 4/25/80

Station	Gauge Adress	Observed Value ($\mu\epsilon$)	Principal Strains ($\mu\epsilon$) & Direction
249	04E - Axial	190	ϵ_1 = 1070
	04F - 45°	630	ϵ_2 = 190
	050 - Circ	1070	ϕ = 90°
	051 - Axial	40	ϵ_1 = 522
	052 - 45°	250	ϵ_2 = 38
	053 - Circ	520	ϕ = 93.6°
	054 - Axial	210	ϵ_1 = 996
	055 - 45°	670	ϵ_2 = 204
	056 - Circ	990	ϕ = 84.91°
	057 - Axial	—	—
	058 - 45°	Omit	Omit
	059 - Circ	—	—

Calculation

$$\epsilon_{1,2} = 1/2(\epsilon_A + \epsilon_C) \pm [(\epsilon_A - \epsilon_C)^2 + (2\epsilon_{45°} - \epsilon_A - \epsilon_C)^2]^{1/2}$$

$$\tan 2\phi = \frac{2\epsilon_{45°} - \epsilon_A - \epsilon_C}{\epsilon_A - \epsilon_C}$$

Station	Gauge Adress	Observed Value ($\mu\epsilon$)	Principal Strains ($\mu\epsilon$) & Direction
289	05A - Axial	90	ϵ_1 = 1252
	05B - 45°	620	ϵ_2 = 88
	05C - Circ	1250	ϕ = 92.5°
	05D - Axial	510	ϵ_1 = 510
	05E - 45°	500	ϵ_2 = 510
	05F - Circ	510	ϕ = 90°
	060 - Axial	20	ϵ_1 = 1093
	061 - 45°	170	ϵ_2 = 77
	062 - Circ	1150	ϕ = 71.9°
	063 - Axial	—	—
	064 - 45°	Omit	Omit
	065 - Circ	—	—

Figure 3.6

Observed data for Hoop Gauges for 10/30/79 & 4/25/80

Station	Gauge Adress	Value 10/30/79 ($\mu\epsilon$)	Value 4/25/80 ($\mu\epsilon$)
249	059 - Up	590	600
	056 - Rt.	1030	990
	053 - Down	440	520
	050 - Lt.	1070	1070
250	06E - Up	560	570
	06F - Rt.	980	970
	070 - Down	430	520
	071 - Lt.	1050	1060
289	065 - Up	—	—
	062 - Rt.	1140	1150
	05F - Down	400	510
	05C - Lt.	1250	1250
290	072 - Up	550	600
	073 - Rt.	1100	1110
	074 - Down	310	330
	075 - Lt.	—	—

Figure 3.7 Soil Pressure vs. Time
Nov. 4-80

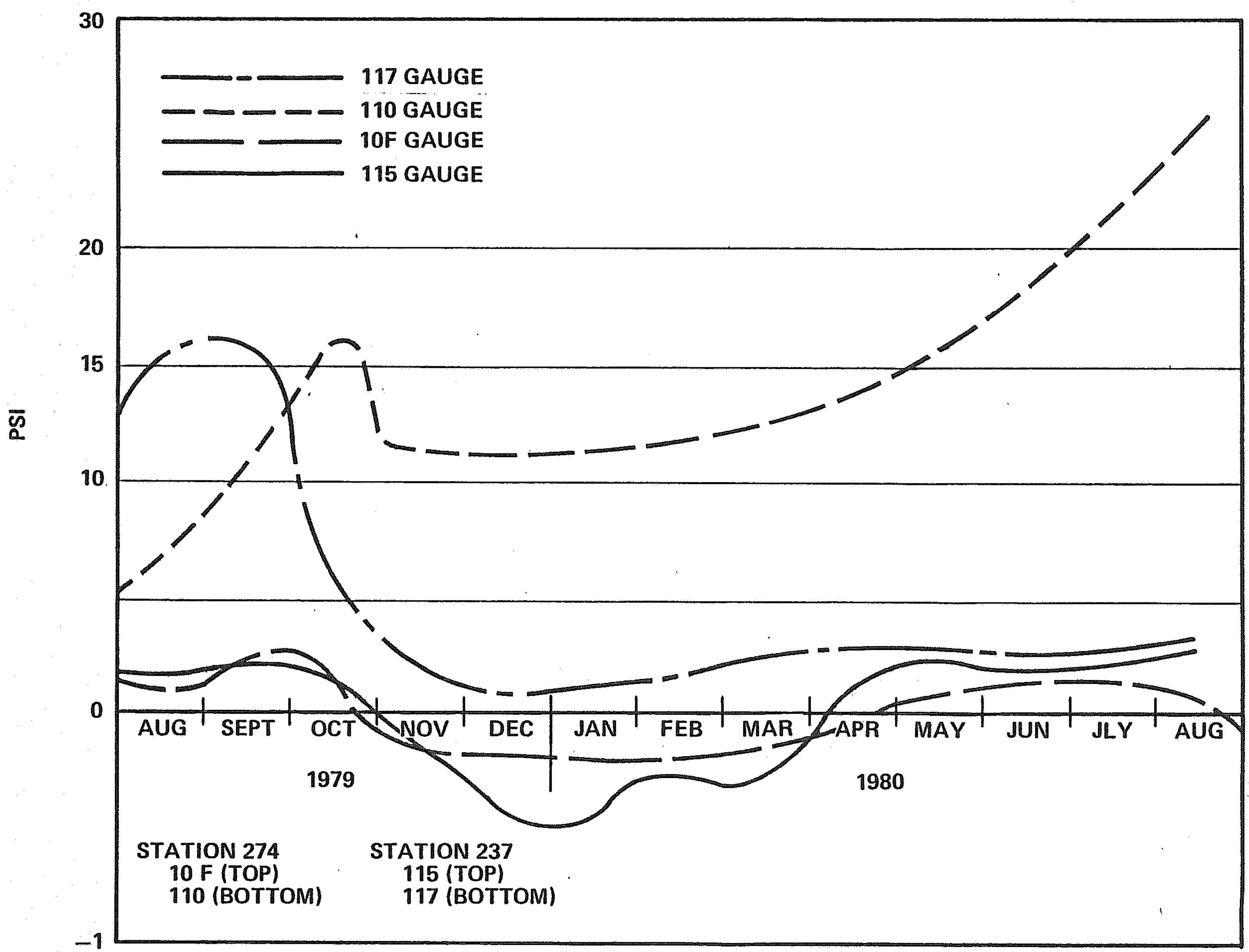
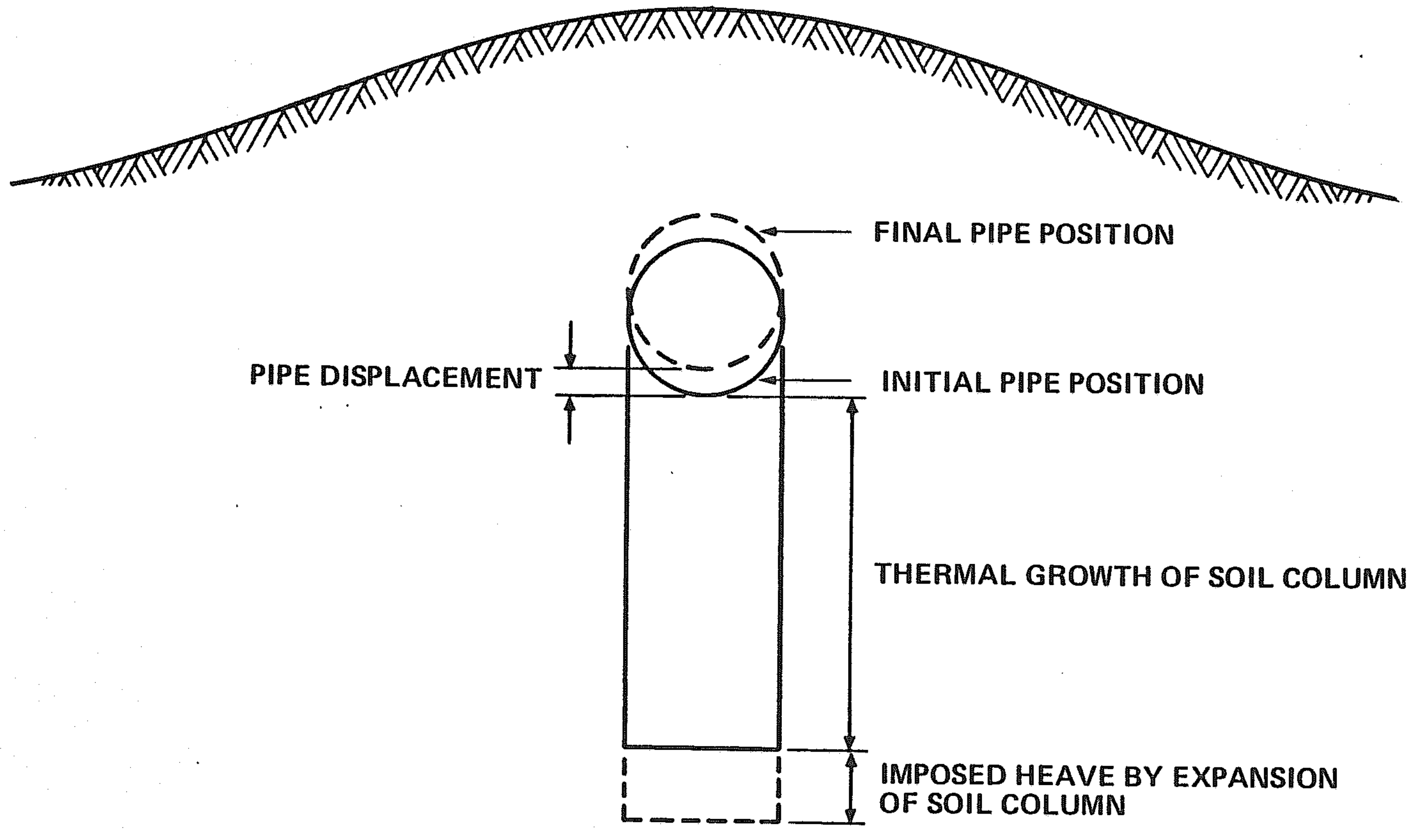


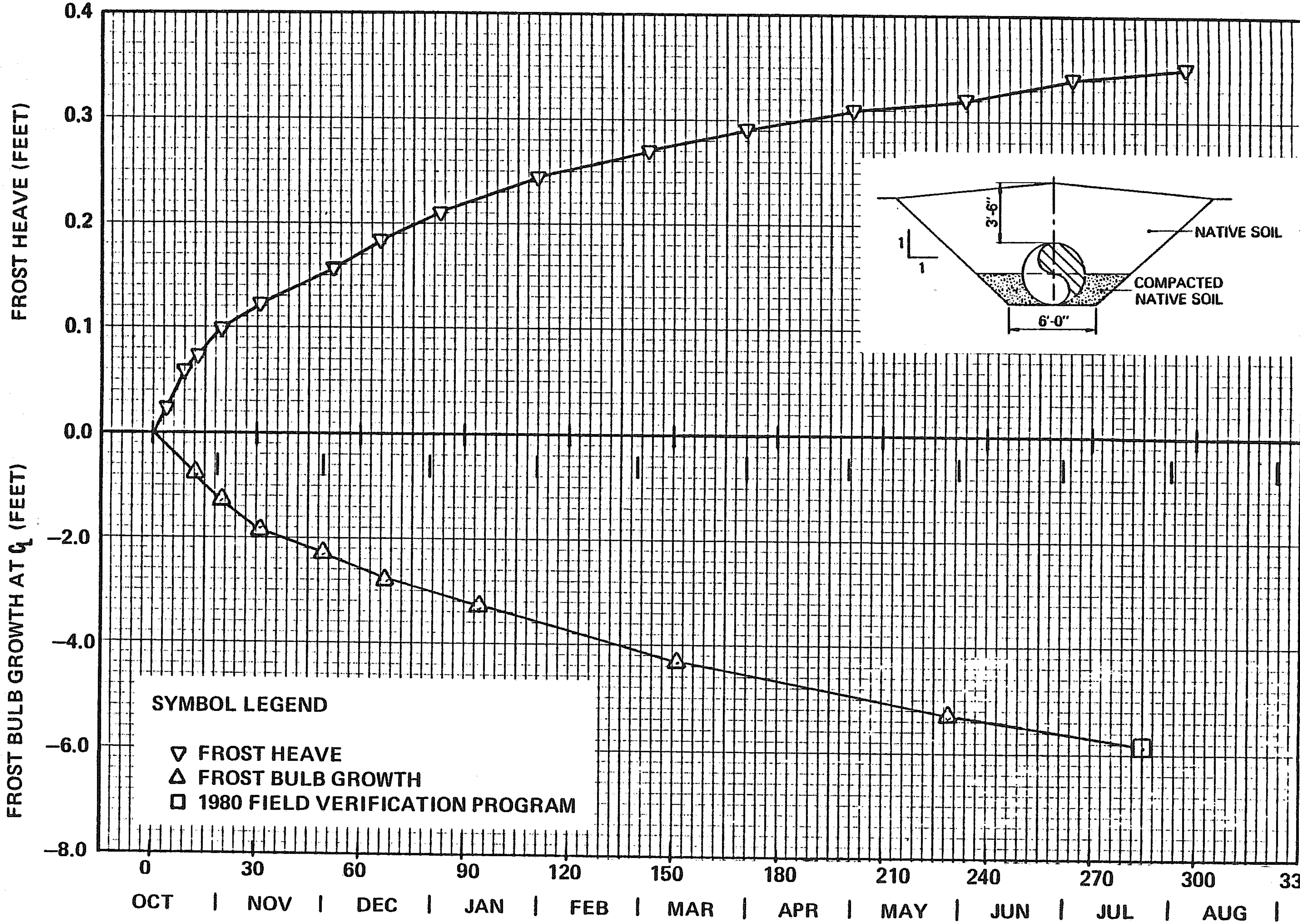
Figure 4.1a



I.S.R. = IMPOSED HEAVE / THERMAL GROWTH

PIPE DISPLACEMENT $\leq$ IMPOSED HEAVE

FIGURE 4.1b
FROST HEAVE & FROST BULB GROWTH VS. TIME
TEST SECTION 1



NOTE: DAY ZERO IS OCTOBER 13, 1979

Figure 4.2

Uplift Resistance, Frozen Season 5 mo. ± 1 mo.

(Parametric Study Only – Not For Final Design)

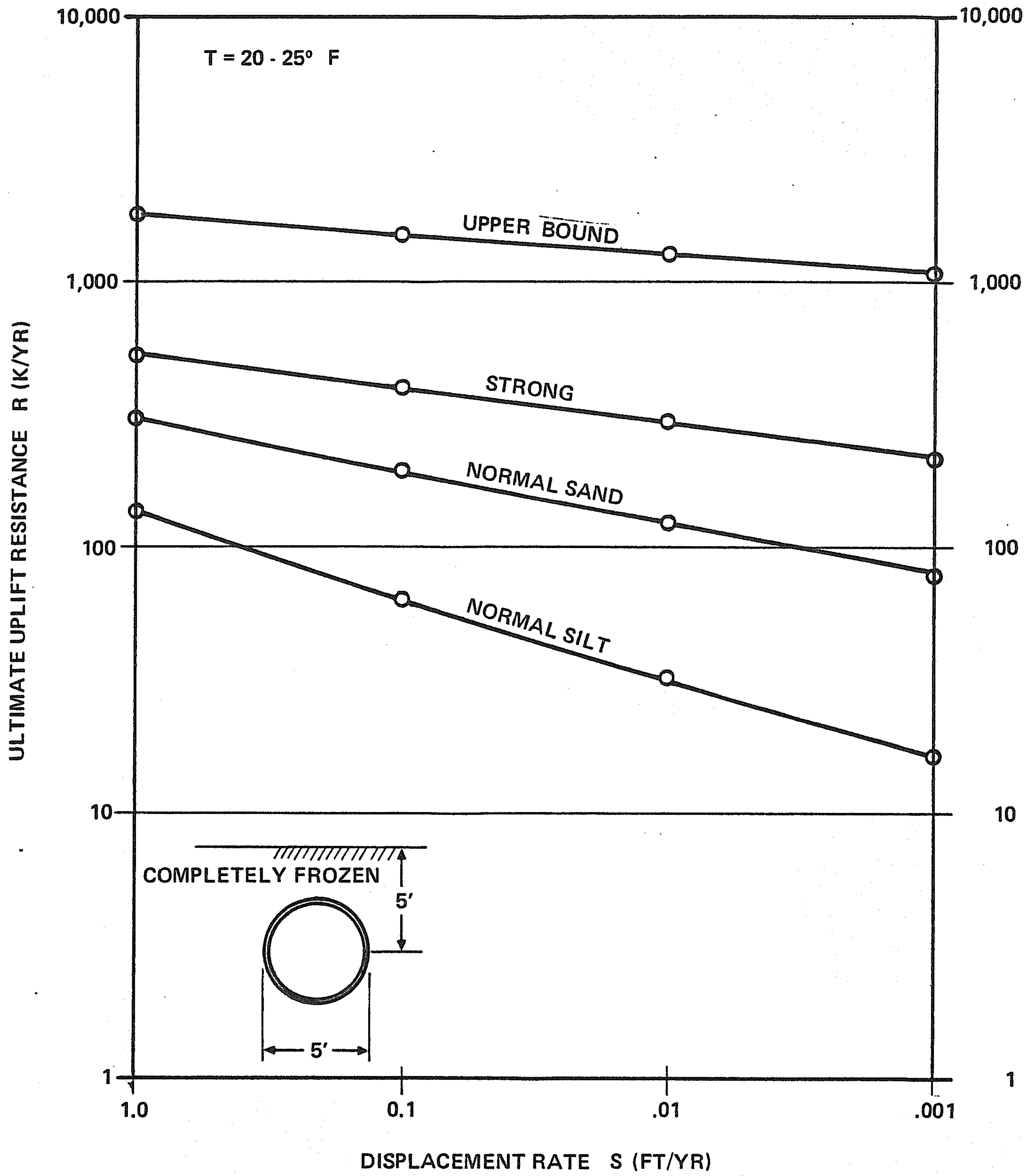
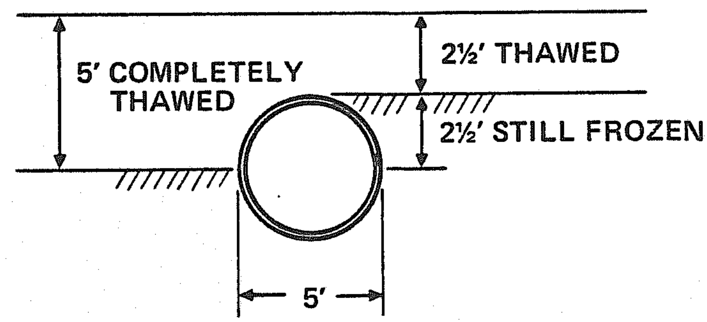


Figure 4.3

Uplift Resistance, Thawed Season 2 mo. ± 1 mo.

(For Parametric Study Only – Not For Final Design)

T = 30 - 31° F



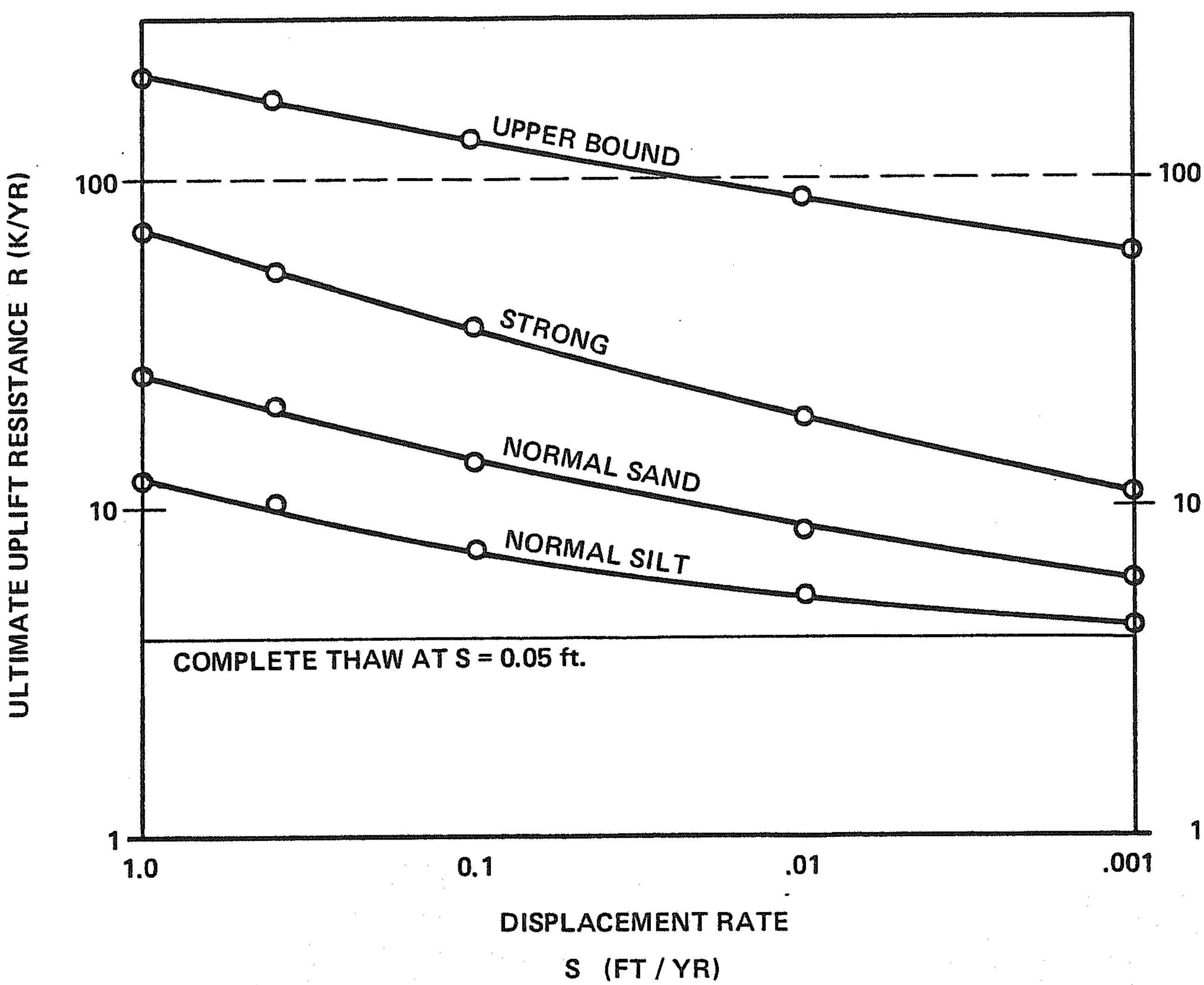
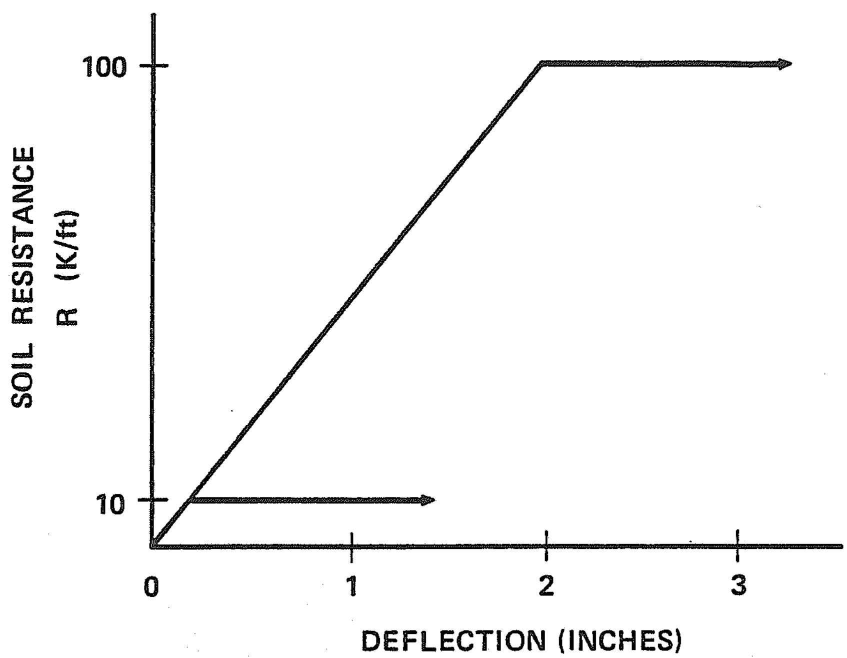


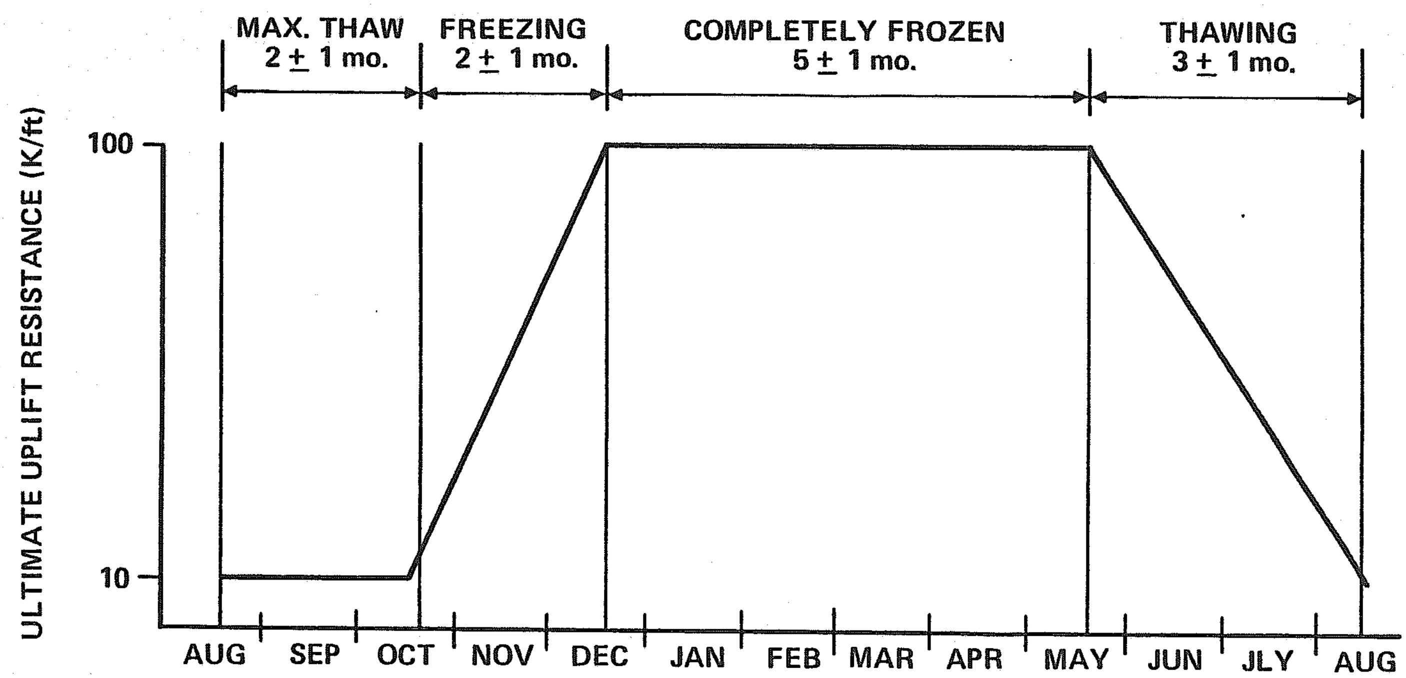
Figure 4.4

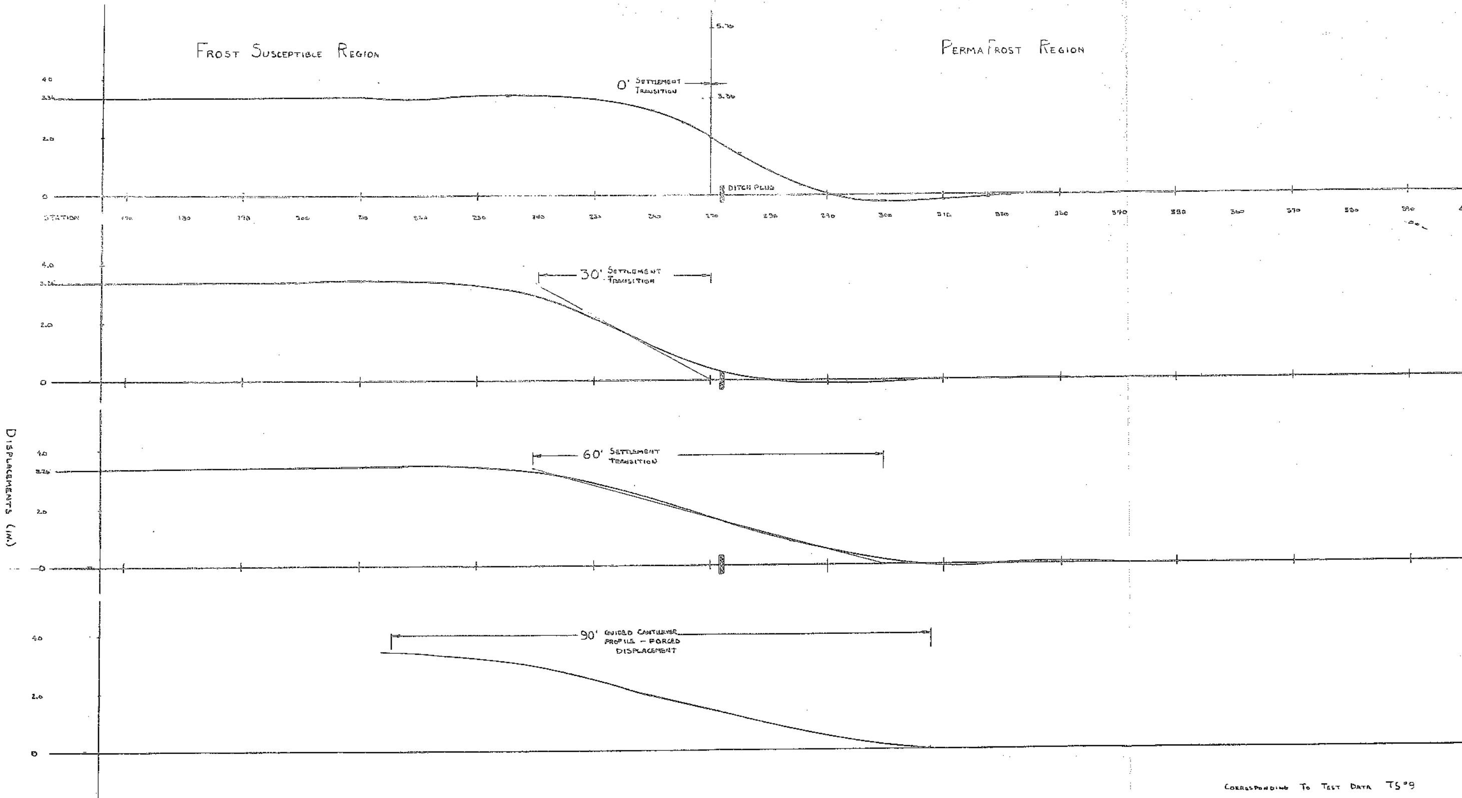
Soil Stiffness (Force-Displacement Relationship)



Soil Stiffness: $K = (R/\text{Deflection})_{\text{yield}} = 100\ \text{K/ft} / 2\text{in} = \underline{\underline{50\ \text{K/ in / ft}}}$

Figure 4.5 Uplift Resistance, Yearly Variation





Corresponding To Test Data TS#9

Data Date 4-25-80

FLUOR
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ALASKAN NORTHWEST NATURAL GAS TRANSPORTATION COMPANY

Analytical Models
Pipe Profile

ALASKA SEGMENT OF THE ALASKA NATURAL GAS TRANSPORTATION SYSTEM

NOTES	REV	DATE	REVISION	DRAWN / CHECK	APP.	DWG NO	REFERENCE DRAWING
						MICROFILM NO.	

DATE	FLUOR	DATE
Nov. 3 - 1980		

SCALE IN FEET	DRAWING NUMBER	REV.
	Figure 4.6	

REDUCED PRINT SCALES

Figure 4.7 Piplin III Parameter Comparison

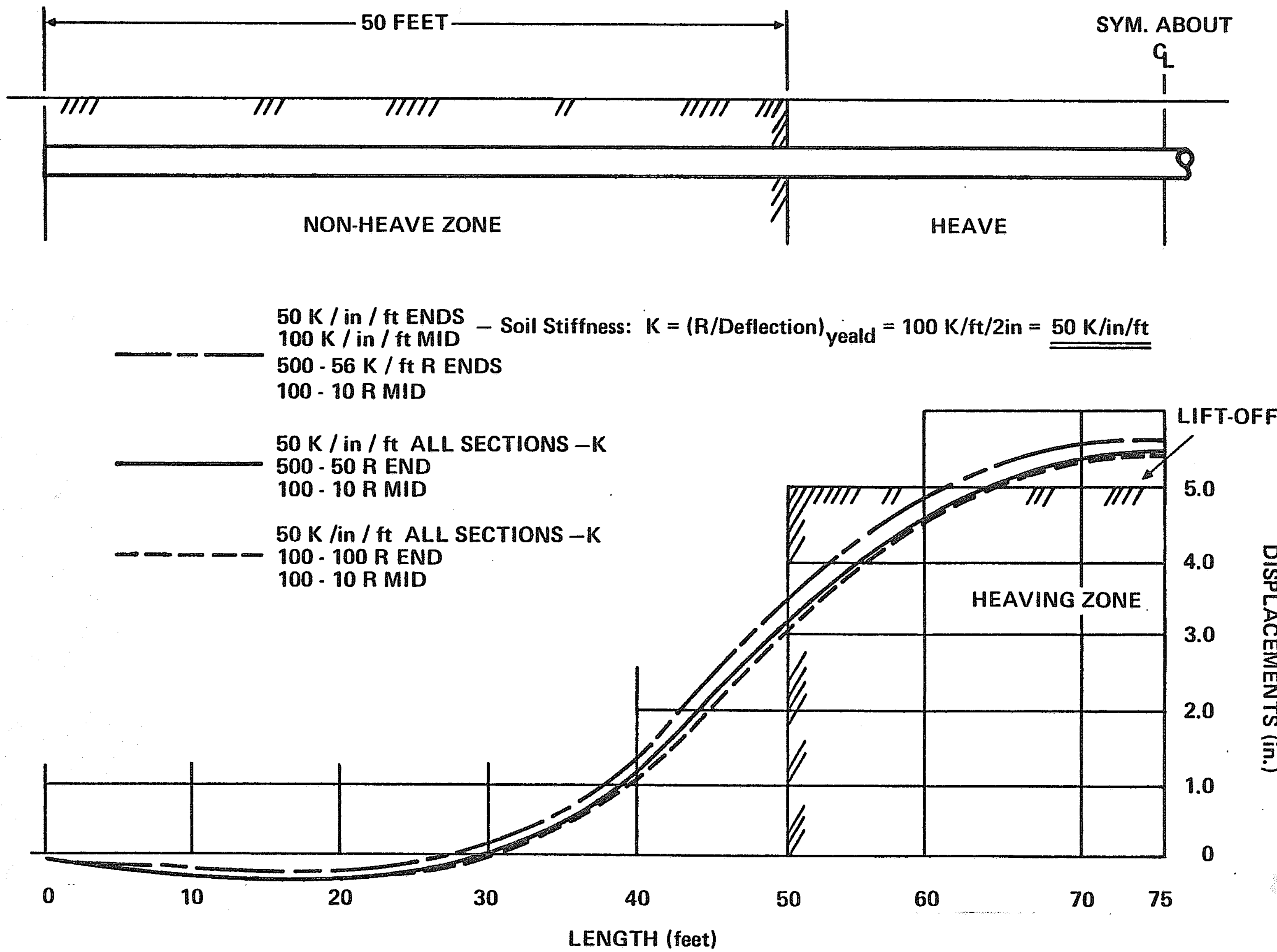


Figure 5.1

UNIFORM DISTRIBUTED HEAVE LOAD Vs.
SPAN AT MAX. MID–SPAN DISPLACEMENT

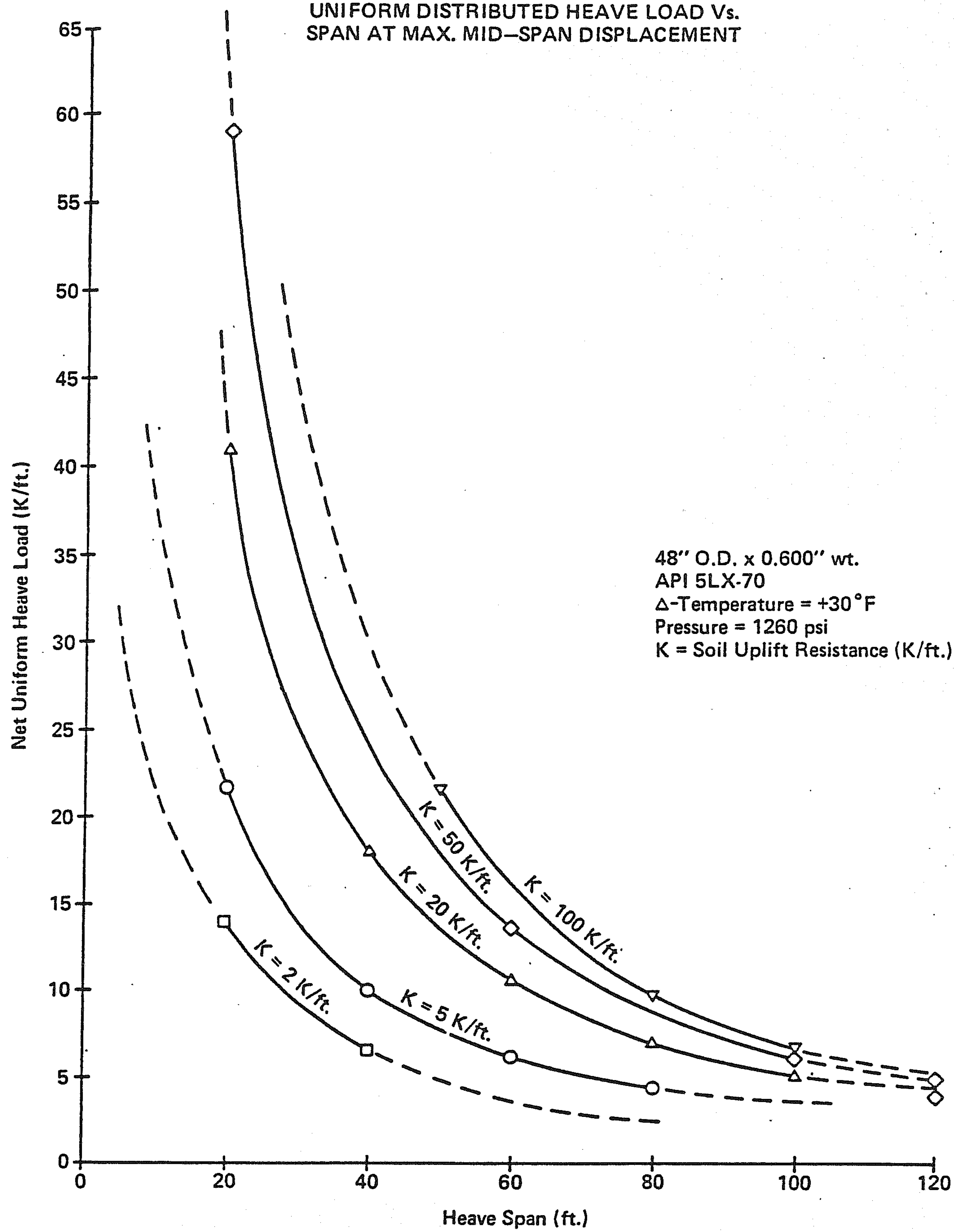


Figure 5.2

Transverse Pressure at Mid Span vs. Span of Heaving Section

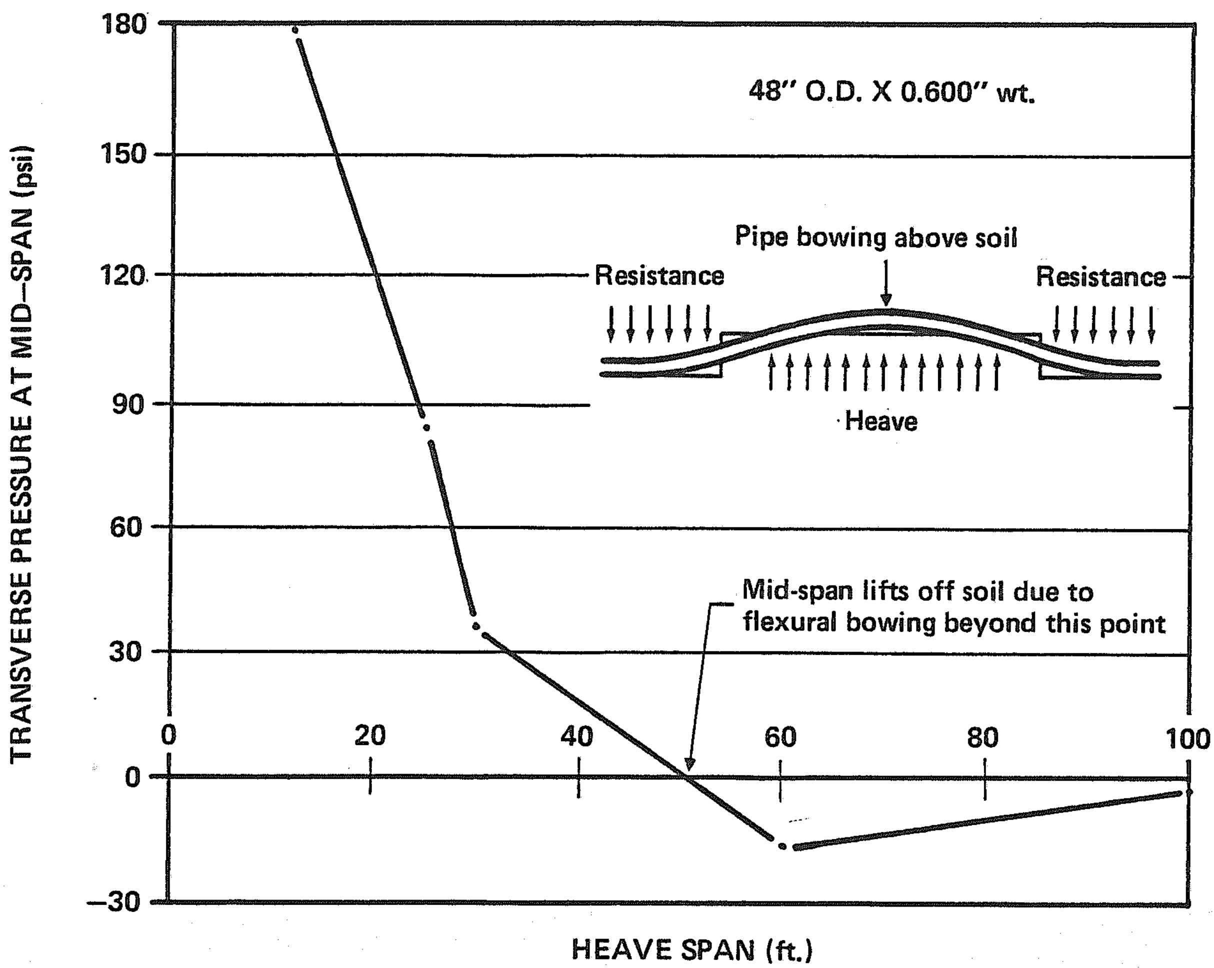


Figure 5.3

ANALYSIS OF A BEAM ON AN ELASTIC FOUNDATION

INPUT PARAMETERS

CENTER SPAN LENGTH	=	.600E+02 FEET
END SPAN LENGTH	=	.500E+02 FEET
SOIL SUBGRADE MODULUS	=	.500E+05 LBS/FT/IN
DISTRIBUTED LOAD	=	.500E+05 LBS/FT

BEAM ON ELASTIC FOUNDATION

RESULTS FOR INFINITE BEAM (LAMBDA = .615E-02)

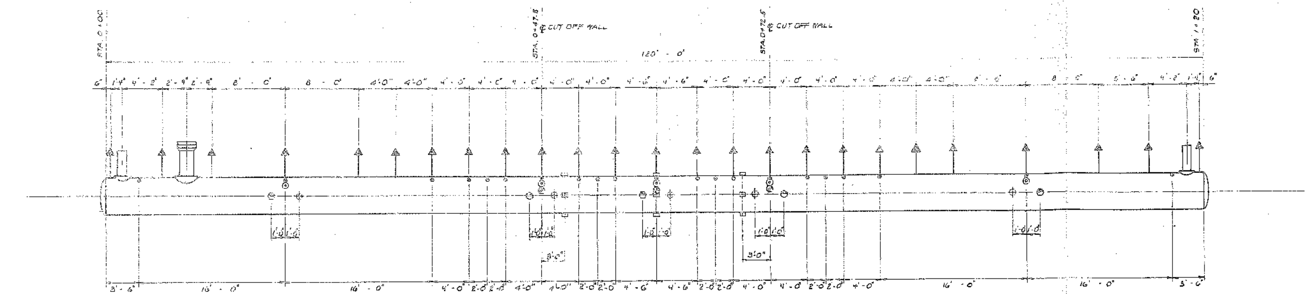
POINT	STATION	DEFL	ROTA	MOMT	SHEAR
1	0.0	-.106E-01	-.106E-03	.366E+06	-.134E+04
2	5.0	-.178E-01	-.131E-03	.190E+06	-.486E+04
3	10.0	-.258E-01	-.130E-03	-.255E+06	-.103E+05
4	15.0	-.324E-01	-.779E-04	-.109E+07	-.176E+05
5	20.0	-.334E-01	.620E-04	-.239E+07	-.260E+05
6	25.0	-.223E-01	.330E-03	-.419E+07	-.333E+05
7	30.0	.953E-02	.761E-03	-.629E+07	-.355E+05
8	35.0	.725E-01	.136E-02	-.821E+07	-.260E+05
9	40.0	.176E+00	.208E-02	-.900E+07	.412E+04
10	45.0	.322E+00	.277E-02	-.709E+07	.655E+05
11	50.0	.502E+00	.312E-02	-.315E+06	.168E+06
12	55.0	.683E+00	.282E-02	.649E+07	.664E+05
13	60.0	.834E+00	.218E-02	.850E+07	.682E+04
14	65.0	.944E+00	.149E-02	.796E+07	-.201E+05
15	70.0	.101E+01	.894E-03	.653E+07	-.245E+05
16	75.0	.105E+01	.410E-03	.529E+07	-.154E+05
17	80.0	.107E+01	0.	.481E+07	0.
18	85.0	.105E+01	-.410E-03	.529E+07	.154E+05
19	90.0	.101E+01	-.894E-03	.653E+07	.245E+05
20	95.0	.944E+00	-.149E-02	.796E+07	.201E+05
21	100.0	.834E+00	-.218E-02	.850E+07	-.682E+04
22	105.0	.683E+00	-.282E-02	.649E+07	-.664E+05
23	110.0	.502E+00	-.312E-02	-.315E+06	-.168E+06
24	115.0	.322E+00	-.277E-02	-.709E+07	-.655E+05
25	120.0	.176E+00	-.208E-02	-.900E+07	-.412E+04
26	125.0	.725E-01	-.136E-02	-.821E+07	.260E+05
27	130.0	.953E-02	-.761E-03	-.629E+07	.355E+05
28	135.0	-.223E-01	-.330E-03	-.419E+07	.333E+05
29	140.0	-.334E-01	-.620E-04	-.239E+07	.260E+05
30	145.0	-.324E-01	.779E-04	-.109E+07	.176E+05
31	150.0	-.258E-01	.130E-03	-.255E+06	.103E+05
32	155.0	-.178E-01	.131E-03	.190E+06	.486E+04
33	160.0	-.106E-01	.106E-03	.366E+06	.134E+04

Figure 5.4

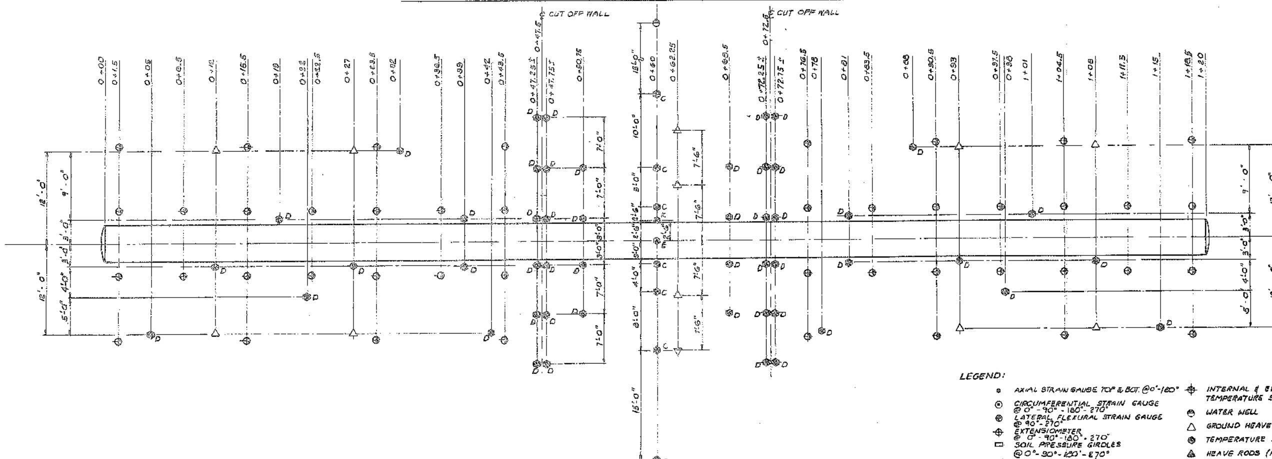
BEAM ON ELASTIC FOUNDATION

RESULTS FOR FINITE BEAM (LAMBDA = .615E-02)

POINT	STATION	DEFL	ROTA	MOMT	SHEAR
1	0.0	-.791E-02	-.164E-03	0.	0.
2	5.0	-.177E-01	-.162E-03	-.838E+05	-.320E+04
3	10.0	-.270E-01	-.143E-03	-.433E+06	-.881E+04
4	15.0	-.339E-01	-.792E-04	-.118E+07	-.165E+05
5	20.0	-.348E-01	.663E-04	-.244E+07	-.253E+05
6	25.0	-.235E-01	.336E-03	-.419E+07	-.329E+05
7	30.0	.877E-02	.767E-03	-.628E+07	-.353E+05
8	35.0	.720E-01	.137E-02	-.820E+07	-.259E+05
9	40.0	.175E+00	.209E-02	-.898E+07	.408E+04
10	45.0	.322E+00	.278E-02	-.708E+07	.654E+05
11	50.0	.502E+00	.312E-02	-.306E+06	.168E+06
12	55.0	.683E+00	.282E-02	.650E+07	.664E+05
13	60.0	.834E+00	.218E-02	.850E+07	.677E+04
14	65.0	.944E+00	.149E-02	.796E+07	-.201E+05
15	70.0	.101E+01	.893E-03	.653E+07	-.245E+05
16	75.0	.105E+01	.410E-03	.529E+07	-.154E+05
17	80.0	.107E+01	.266E-14	.481E+07	-.261E-07
18	85.0	.105E+01	-.410E-03	.529E+07	.154E+05
19	90.0	.101E+01	-.893E-03	.653E+07	.245E+05
20	95.0	.944E+00	-.149E-02	.796E+07	.201E+05
21	100.0	.834E+00	-.218E-02	.850E+07	-.677E+04
22	105.0	.683E+00	-.282E-02	.650E+07	-.664E+05
23	110.0	.502E+00	-.312E-02	-.306E+06	-.168E+06
24	115.0	.322E+00	-.278E-02	-.708E+07	-.654E+05
25	120.0	.175E+00	-.209E-02	-.898E+07	-.408E+04
26	125.0	.720E-01	-.137E-02	-.820E+07	.259E+05
27	130.0	.877E-02	-.767E-03	-.628E+07	.353E+05
28	135.0	-.235E-01	-.336E-03	-.419E+07	.329E+05
29	140.0	-.348E-01	-.663E-04	-.244E+07	.253E+05
30	145.0	-.339E-01	.792E-04	-.118E+07	.165E+05
31	150.0	-.270E-01	.143E-03	-.433E+06	.881E+04
32	155.0	-.177E-01	.162E-03	-.838E+05	.320E+04
33	160.0	-.791E-02	.164E-03	0.	-0.



PIPE MOUNTED INSTRUMENTATION LOCATION ELEV.



LEGEND:

- AXIAL STRAIN GAUGE TOP & BOT. @0°-180°
- CIRCUMFERENTIAL STRAIN GAUGE @ 0° - 90° - 180° - 270°
- LATERAL FLEXURAL STRAIN GAUGE @ 90° - 270°
- EXTENSIOMETER @ 0° - 90° - 180° - 270°
- SOIL PRESSURE GIRDLES @ 0° - 90° - 180° - 270°
- BAYONET FREEZE PROBES
- INTERNAL & EXTERNAL PIPE MOUNTED TEMPERATURE SENSORS @0°-90°-180°-270°
- WATER WELL
- GROUND HEAVE PLATES
- TEMPERATURE PROBES (LETTER DENOTES TYPE)
- HEAVE RODS (PIPE MOUNTED)

NOTES:
FINAL LOCATIONS OF TEMPERATURE PROBES @ STA. 0+47.25 ±, 0+47.75 ±, 0+71.25 ± AND 0+71.75 TO BE FIELD VERIFIED. THEY ARE TO BE LOCATED FLUSH WITH EXTERIOR OF THE CUT OFF WALL.

OFF PIPE INSTRUMENTATION LOCATION PLAN

70817 | 001 | 01 | 01 | TEST SECT NO. 11 INSTR LOC PLAN | 4 6 8 0

NOTES	NO.	DATE	REVISION	DRAWN / CHKD.	APP.	DWG. NO.	REFERENCE DRAWING
	1	3/6/80	RELEASED FOR CONSTRUCTION	PJ / CO		MICROFILM NO.	

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ALASKAN NORTHWEST NATURAL GAS TRANSPORTATION COMPANY

DIFFERENTIAL FROST HEAVE TEST
TEST SECTION NO. 11
INSTRUMENTATION LOCATION PLAN

ALASKA SEGMENT OF THE ALASKA NATURAL GAS TRANSPORTATION SYSTEM

AT/PW	DATE DEC.	FLUOR	DATE
C. DALLAVALLE			DATE

SCALE IN FEET	DRAWING NUMBER	REV.
1" = 5' - 0"	4680-70-81-7-001-01	1

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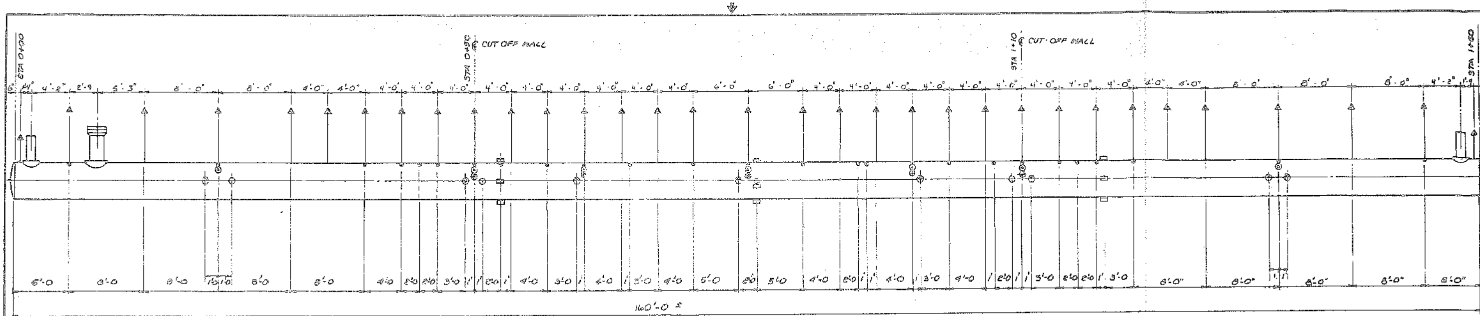
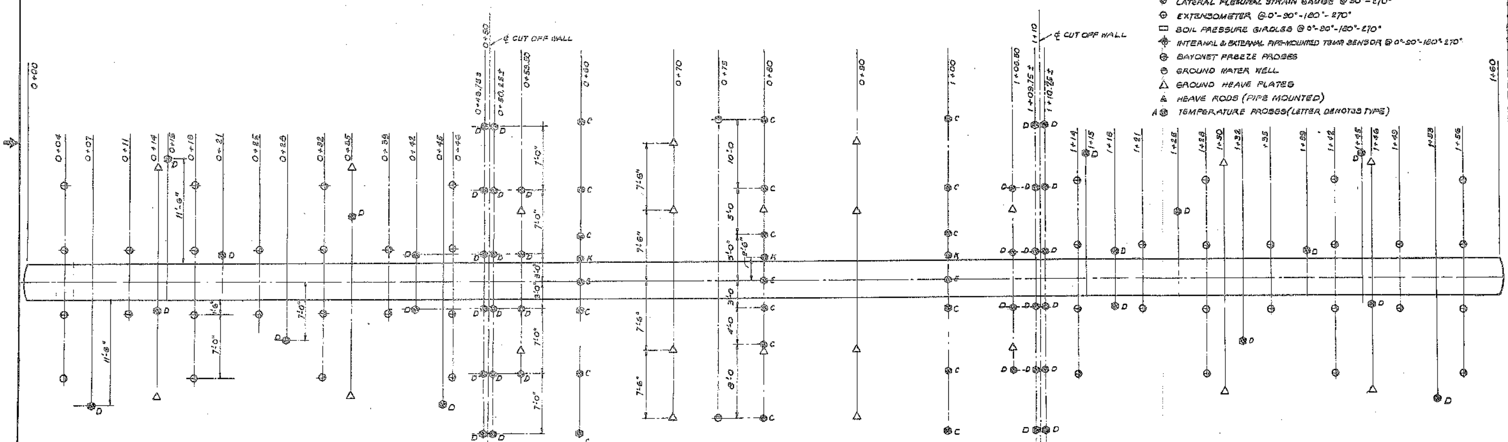


PIPE MOUNTED INSTRUMENTATION LOCATION ELEV.

LEGEND

- AXIAL STRAIN GAUGE TOP & BOT. @ 0°-180°
- CIRCUMFERENTIAL STRAIN GAUGE @ 0°-90°-180°-270°
- LATERAL FLEXURAL STRAIN GAUGE @ 90°-270°
- EXTENSOMETER @ 0°-90°-180°-270°
- SOIL PRESSURE GIRDLES @ 0°-90°-180°-270°
- INTERNAL & EXTERNAL PIPE-MOUNTED TEMP SENSOR @ 0°-90°-180°-270°
- BAYONET FREEZE PROBES
- GROUND WATER WELL
- GROUND HEAVE PLATES
- HEAVE RODS (PIPE MOUNTED)
- A TEMPERATURE PROBES (LETTER DENOTES TYPE)



NOTES:

FINAL LOCATIONS OF TEMPERATURE PROBES @ STA. 0+49.75 ±, 0+50.25 ± 1+09.75 ±, AND 1+10.75 ± TO BE FIELD VERIFIED. THEY ARE TO BE LOCATED FLUSH WITH EXTERIOR OF THE CUT OFF WALL.

OFF PIPE INSTRUMENTATION LOCATION PLAN

70817 002 01 01 TEST SECT NO. 12 INSTR LOC PLAN 4680

NOTES	REV.	DATE	REVISION	DRAWN / CHECK	APP	DWG. NO	REFERENCE DRAWING
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ALASKAN NORTHWEST NATURAL GAS TRANSPORTATION COMPANY

DIFFERENTIAL FROST HEAVE TEST

TEST SECTION NO. 12
INSTRUMENTATION LOCATION PLAN

ALASKA SEGMENT OF THE ALASKA NATURAL GAS TRANSPORTATION SYSTEM

KT/RVETROVEC	DATE	FLUOR	DATE 1 Dec 1980
DALLAVALLE, C			DATE 12-23-80

SCALE IN FEET	DRAWING NUMBER	REV.
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