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PRE-SHUTDOWN STUDIES AT THE CALGARY FROST HEAVE TEST FACILITY

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ABSTRACT

The Calgary Frost Heave Test Facility, operational since 1974, is currently being run jointly by Foothills Pipeline and Energy, Mines and Resources Canada. The scientific and engineering purposes have largely been met in terms of the frost behaviour. In this report a science programme is outlined for conduct prior to and during the closure of the facility. The projects include geophysical surveys, drilling for core samples, excavation of the frost bulb and natural thawback of a frost bulb.

RESUME

La station expérimentale sur le soulèvement dû au gel, en fonctionnement depuis 1974 à Calgary, est couramment dirigee conjointement par Foothills Pipeline et le Ministère d'Energie, mines et ressources. Les objectifs scientifiques et techniques de l'étude du comportement au gel ont été atteints en grande partie. Le présent rapport decrit un programme d'études scientifiques qui pourraient être mener lors de la fermeture de l'installation. Ces études comprennent des levés géophysiques, des forages pour obtenir des carottes de sol gelé, l'excavation de l'anneau de gel autour un des tuyaux enterrés et le dégel naturel d'un de ces anneaux.

PRE-SHUTDOWN STUDIES
AT THE
CALGARY FROST HEAVE
TEST FACILITY

FINAL REPORT

by

L.E.C. ENGINEERING

Work on this project was conducted under the auspices of the Earth Physics Branch, Energy, Mines and Resources Canada

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SCIENTIFIC AUTHORIITY: Dr. A. JUDGE

PRE-SHUTDOWN STUDIES AT THE CALGARY FROST HEAVE TEST FACILITY

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1. SUMMARY

The Calgary Frost Heave Test facility has been operational since 1974. It is currently being operated by Foothills Pipe Lines and the Department of Energy Mines and Resources.

The operating history of the Test Facility was reported in Carlson [1984]. An updating of the field data is presented in chapter 2 of this report.

It has been decided to shut down the test facility next year, before September 30, 1986.

Five potential studies, which are of interest to the Scientific and Engineering Permafrost community, are outlined in this report. These studies should be undertaken before the Test facility is shut down. The study objectives, procedures and time requirements are discussed in chapter 3, the cost estimate in chapter 4, and the project schedule in chapter 5.

The five studies described in the report are:

1. Geophysical survey of the Insulated Silt and Insulated Gravel sections.

2. Drilling for core samples at each of the five test sections.

3. Excavation of frost bulbs.

4. Pipe leak detection through a frost bulb.

5. Natural thawback of a frost bulb.

The most important study , and also the most expensive, is #3, the excavation of the Frost Bulbs.

The above program was developed at a meeting held on 29 September 1985 of Foothills Pipe Lines, EMR and L.E.C. Engineering personal. The input of many other interested parties has been included in setting up the current program.

A list of parties contacted for input into the program is given in Appendix 1.

2. CURRENT STATUS OF THE TEST FACILITY

2.1) OPERATING HISTORY

The test facility operation has had no significant problems in the past year. This shows up in the 1984-85 increase of the pipe frost heave of the Deep Burial section, seen in Figure 2.1.

Defrosting of the refrigeration equipment has been carried out twice a day throughout the summer in an attempt to maintain a cool air temperature.

2.2) HEAVE UPDATE

Pipe frost heave time histories, updated to 1985, are seen in Figures 2.1 to 2.5 for the Deep Burial, Gravel, Restrained, Insulated Silt and Insulated Gravel sections respectively. The heave has generally increased since the fall of 1983.

2.3) FROST BULB SIZE UPDATE

The frost front depth curves of Figures 2.6-2.10 for the five pipe sections show that all frost bulbs have continued to grow through 1985.

2.4) WATER TABLE HISTORY UPDATE

The water table depth curve (Figure 2.11) shows that the water table dropped to it's lowest level since 1974, of 10 feet below ground level. At this depth the water table is well above the bases of the frost bulbs for the non-insulated sections and one to two feet above the base of the frost bulb for the insulated sections. There will therefore be water seepage problems during the frost bulb excavation study, and a water pump will probably be required to pump water out of the ditches.

2.5) AMBIENT AIR TEMPERATURE HISTORY

It is important for the ice lens mapping study that the ambient air temperature does not climb much above zero degrees centigrade and cause melting of the cut face of the frost bulb.

Figures 2.12 & 2.13 show the average and maximum mean monthly ambient air temperatures for Calgary, respectively, over the operating period of the test

The average mean monthly temperature (Figure 2.12) for February is seen to vary between -16 Deg. C & +2 Deg. C, for March between -7 Deg. C & +3 Deg. C and for April between 0 Deg. C & +7 Deg. C.The above freezing air temperatures in April are not acceptable for the ice lens mapping and so this study must be undertaken before April, so that the opened frost bulbs do not thaw out before the ice mapping can be completed.

Moreover, the ice mapping will be done during the working day, mornings and afternoons, when the air temperatures are above the daily average. The maximum monthly air temperatures (Figure 2.13) are seen to be between -11 Deg. C & +7 Deg. C for February and -2 Deg. C & +8 Deg. C for March.

The timing of the frost bulb excavation studies has been chosen to fall in late February and early March to avoid the cold winter temperatures and the warm April temperatures.

3. POTENTIAL STUDIES

The procedures outlined in this section are recommended, based on planning to date. Once the budget and individual projects have been defined, the individual study procedures will have to be refined and detailed for the preparation of scope of work statements for the geotechnical consultant and contractor.

3.1) GEOPHYSICS ON THE INSULATED SECTIONS

PURPOSE OF THE STUDY

The purpose is to see how well the ground surface geophysics does at determining the size and shape of the frost bulb around the buried pipe, during winter when the ground surface is frozen.

PROCEDURE FOR THE STUDY

The surface air ducting for these two sections must be removed before the measurements can be taken. This is required, because the presence of metal close to the survey region affects the readings of the ground radar device.

The large number of steel ground heave rods at the Deep Burial, Gravel and Restrained sections, was seen in past geophysical surveys, to greatly influence the detector, making the measurements at these sections un-interpretable. No geophysical measurements are planned at these section because of these problems.

TIME ESTIMATE FOR THE STUDY

It is estimated that it will take about 3 days to remove the air ducts, and 2 days to carry out the surface measurements on the two insulated pipe sections.

3.2) DRILLING FOR CORE SAMPLES

PURPOSE OF THE STUDY

It is common practice, in Permafrost Engineering to obtain core samples for laboratory determination of ice content and thaw settlement parameters. The shutdown of this Frost Heave Test Facility provides a good test case for the comparison of the results of core sample analysis against results obtained from the laboratory analysis of "large" bulk frozen soil samples. Verification of the similarity of the analysis results from the two sample collection procedures will be welcome in the Permafrost Engineering field.

PROCEDURE FOR THE STUDY

As seen in the project schedule of Figure 5.1, the drilling is planned to take place before the pipe sections are dug out of the frozen ground. Also, since the Gravel and Restrained sections will NOT be dug up at this time it is stressed that the Gravel and Restrained sections are to undergo minimal disturbance to their berms.

DEEP BURIAL, INSULATED SILT & INSULATED GRAVEL SECTIONS

Firstly, the berms should be taken off the areas to be drilled so that a truck mounted drill can easily be positioned as required. This means that the large berm over the Deep Burial section should be removed along with the much smaller berms over the Insulated Silt and Insulated Gravel sections.

At least two holes should be drilled at each of the three sections. The two holes should be taken as close together as possible so that the similarity of the ice lens content can be assessed. These drillholes should be near the middle of the pipe for all sections. Vertical holes will be drilled at the side of the pipe, with continuous sampling, via a CRREL barrel, through the frost bulb. Bulk soil samples will later be collected at the same location, i.e. the bulk sample will contain the drill hole. All samples will be placed in insulated boxes, if required, and stored in cold rooms until they are analysed in a laboratory.

RESTRAINED & GRAVEL SECTIONS

Because these sections are to undergo minimal disturbance, drilling at these sections may have to be carried out via slanted drill holes using the truck mounted drill planned for use at the other three sections. Care must be taken NOT to destroy any existing instrumentation. It may be worthwile to bring in a portable drill rig capable of drilling vertical holes from the top of the berms. This would allow for a more precise positioning of the drill holes, and therefore of the frozen core samples.

TIME ESTIMATE FOR THE STUDY

The core sampling program should last 5 days, about one day per section. The laboratory testing program may last a month or longer.

3.3) EXCAVATE FROST BULBS

PURPOSE OF THE STUDY

This phase of these studies has the most scientific importance. Large samples of the ice rich frozen soil composing the Frost Bulbs will be collected by direct excavation, and analysed in a laboratory for visible excess ice and total moisture content. A map of the excess ice content will be developed and compared to a similar one produced by direct in-situ observation of the excess ice content in the field. Photographs will be taken of the core samples during the laboratory analysis.

PROCEDURE FOR THE STUDY

DEEP BURIAL, INSULATED SILT & INSULATED GRAVEL SECTIONS

The procedure for the Deep Burial, Insulated Silt and Insulated Gravel sections follows:

a. Soil over the pipes may be thawed by burning coal and straw above the pipe area for about a week.

b. A dozer with a ripper may have to be used to breakup the frozen soil above the pipe so that a back hoe can dig down to the base of the pipe. The pipe will then be removed with a crane. It may prove expedient to circulate hot air through the pipe to weaken the pipe-soil adhesion, however this process should be minimized so as to not melt any ice adjacent to the pipe.

c. The frost bulb can be excavated from pipe level to the base of the frost bulb starting at one end of the pipe and working towards the other end.

d. To aid in the frost bulb excavation, an air drill will be used to drill two series of closely spaced holes across the frost bulb at each of the sample planes, if required. These drill holes will form two "fracture" planes, about one foot apart, which will define the soil sample planes. This procedure will facilitate the collection of the frozen soil samples. It is shown schematically in Figure 3-1.

e. It is recommended that, if possible, five (5) x-sections be studied at each of these section [see Figures 3-2 & 3-3].

f. Once the excavation reaches the depth of the water table, provision will have to be made to control the seeping water via sumps and a water pump.

g. The cut face of the frost bulb will be mapped by the soil technicians and bulk soil samples collected, at each of the five (5) x-sections. Some of the samples collected near the centre of the pipe section should contain the drill holes left from study 3.2.

TIME ESTIMATE FOR THE STUDY

DEEP BURIAL & INSULATED SECTIONS

It is estimated that it will take two (2) weeks per section or a total of six (6) weeks to complete the excavation, ice mapping and soil sample collection at these three sections.

The maximum cost to be expended for this phase is set at $50,000. Optimistically, this budget will allow the collection of samples from the five planes at all three test sections. However, it has also been speculated that, due to the difficulty of digging frozen soils, progress may be as low as 1/3 of the above value. In this case, the Insulated Gravel section will not be studied at all, and a smaller number of x-sections will be studied at the Deep Burial and Insulated Silt sections.

3.4) PIPE LEAK DETECTION

PURPOSE OF THE STUDY

This study has been proposed by the NEB. Its purpose is to see if a leak in a chilled pipeline can be detected at the ground surface, or if the frozen frost bulb around the pipe seals the leak off from the ground surface.

PROCEDURE FOR THE STUDY

a. A hole will be drilled in the Restrained section pipe to simulate a leak. A gas bottle filled with a detectably non explosive gas will be welded to the hole in the pipe.The end of the pipe where the air duct enters and exits must be checked for possible air leaks along the outside of the pipe. Such air leaks between the frost bulb and the pipe would render this test void. The testing should be carried out before mid December while the section is still being chilled, to simulate leak detection of an operating chilled pipelne.

TIME ESTIMATE FOR THE STUDY

It is estimated that two (2) days are required to remove the existing inner pipe [see Figure 2.2-9 of Carlson, 1984], drill a hole at the centre of the pipe and weld a gas bottle with an inlet pipe and valve,inside the pipe.

"Sniffing" for the non-explosive gas will carry on for several weeks.

3.5) NATURAL THAWBACK

PURPOSE OF THE STUDY

This study will observe the effects of natural melting of a frost bulb . It is a simulation of a possible shutdown mode for an operating chilled pipeline. Sections with pipes buried in both silt and gravel will be studied.

PROCEDURE FOR THE STUDY

This procedure would be carried out at the Restrained (silt backfill) and Gravel (gravel backfill) sections. Chilled air circulation will stop at the beginning of this series of studies. Monitoring of the ground temperature and settlement would continue, and the resulting data would be interpreted by a Permafrost consultant and compared to Geothermal simulations of the thawback.

TIME ESTIMATE FOR THE STUDY

This study starts when the chilled air circulation is stopped. Quasi static calculations indicate that it will take more than one summer for the frost bulb to thaw out. It will tend to become isothermal at the freezing point of the soil, after several weeks. It is recommended that a Geothermal computer simulation be carried out as soon as possible to further evaluate the Natural thawback time requirement. If the frost bulb around the Restrained section pipe and restraining system has not thawed out by August, it may be necessary to speed up the thawing by circulating warm air through the pipe.

3.6) PROJECT ENGINEER

The project engineer will be required to set up the various studies to be undertaken, let the contracts for the field and soil consulting work, and supervise the on-site work for the various studies. In addition, he must monitor the progress of the Geotechnical laboratory analysis program and data report writing, and also produce a summary report of all the work undertaken for the project.

4. COST ESTIMATES OF STUDIES

The cost for the five studies and for the project engineer required to direct the field work is summarised below:

4.1) GEOPHYSICS ON THE INSULATED SECTIONS

Field equipment & labour	$2,000
Consulting Fees	$2,000
Air fare for Consultant	$2,000
Analysis & report	$4,000

SUB TOTAL	$10,000
	======

4.2) DRILLING FOR CORE SAMPLES

Field equipment & labour	$5,000
Soil technician	$2,000
Lab analysis & report	$3,000

SUB TOTAL	$10,000
	======

4.3) EXCAVATE FROST BULBS

DEEP BURIAL, INSULATED SILT & INSULATED GRAVEL SECTIONS

	(2 wk/sect)
Field equipment & labour	$30,000
Soil technician	$15,000
Lab analysis & report	$ 5,000

SUB TOTAL	$50,000
	======

4.4) PIPE LEAK DETECTION

Field equipment & labour	$1,000
Sniffing for leaks	0

SUB TOTAL	$1,000
	=====

4.5) NATURAL THAWBACK (Gravel & Restrained sections)

Temp & settlement readings	0
Data interpretation, report & Geothermal simulations	$5,000

SUB TOTAL	$5,000
	=====

4.6) PROJECT ENGINEER

Professional fees (10 WEEKS)	$20,000
	======

==

TOTAL COST OF PROGRAMS	$96,000
	======

==

4.7 RESTORATION OF TEST SITE

Restore site to original condition in September	$34,000
	======

==

TOTAL BUDGET REQUIREMENT	$130,000
	=======

==

5. SCHEDULE FOR STUDIES

The project schedule is shown in Figure 5 - 1. Week 1 is the first week in February.

5.1 PIPE LEAK DETECTION

One week is scheduled for the setup work required for this study, followed by two weeks of periodic field measurements. This study should be undertaken in December while chilled air is being circulated.

5.2 GEOPHYSICS - INSULATED SECTIONS

This task is estimated to take 3 days for removal of the above ground air duct system for the insulated pipe sections and also the duct close to the other three sections. Once the air ducts are removed two days are scheduled for the actual geophysical data collection. Week one of the program is devoted to this task.

5.3 DRILLING FOR CORE SAMPLES

The drill rig is scheduled to be on site for one week or 5 working days. This study is scheduled for week 2 of the study.

5.4 EXCAVATE FROST BULBS

This study is the most important, longest, and most costly. It is expected to take from 1 week to 2 weeks per section, and is scheduled to start in week 3, with an early completion at the end of week 5 or a late completion at the end of week 8.

5.5 NATURAL THAWBACK.

This study will start when the chilled air circulation is stopped. It is shown on the schedule as starting in week 1, however, the chilled air circulation may stop a week or so before week 1, so that the soil adjacent to the pipe sections warms up a few degrees, and is therefore less difficult to dig out.

TABLE 4.1

TOTAL COST OF PROGRAMS

PROGRAM	PROGRAM COST ($1,000)
1. GEOPYSICS	10
2. CORE SAMPLES	10
3. EXCAVATE FROST BULBS DB, IS & IG sections	50
4. LEAK DETECTION	1
5. NATURAL THAWBACK	5
6. PROJECT ENGINEER	20
TOTAL COST OF PROGRAMS ($1,000)	96
7. SITE RESTORATION	34
PROGRAM BUDGET	130

DB = Deep Burial section
IS = Insulated Silt section
IG = Insulated Gravel section

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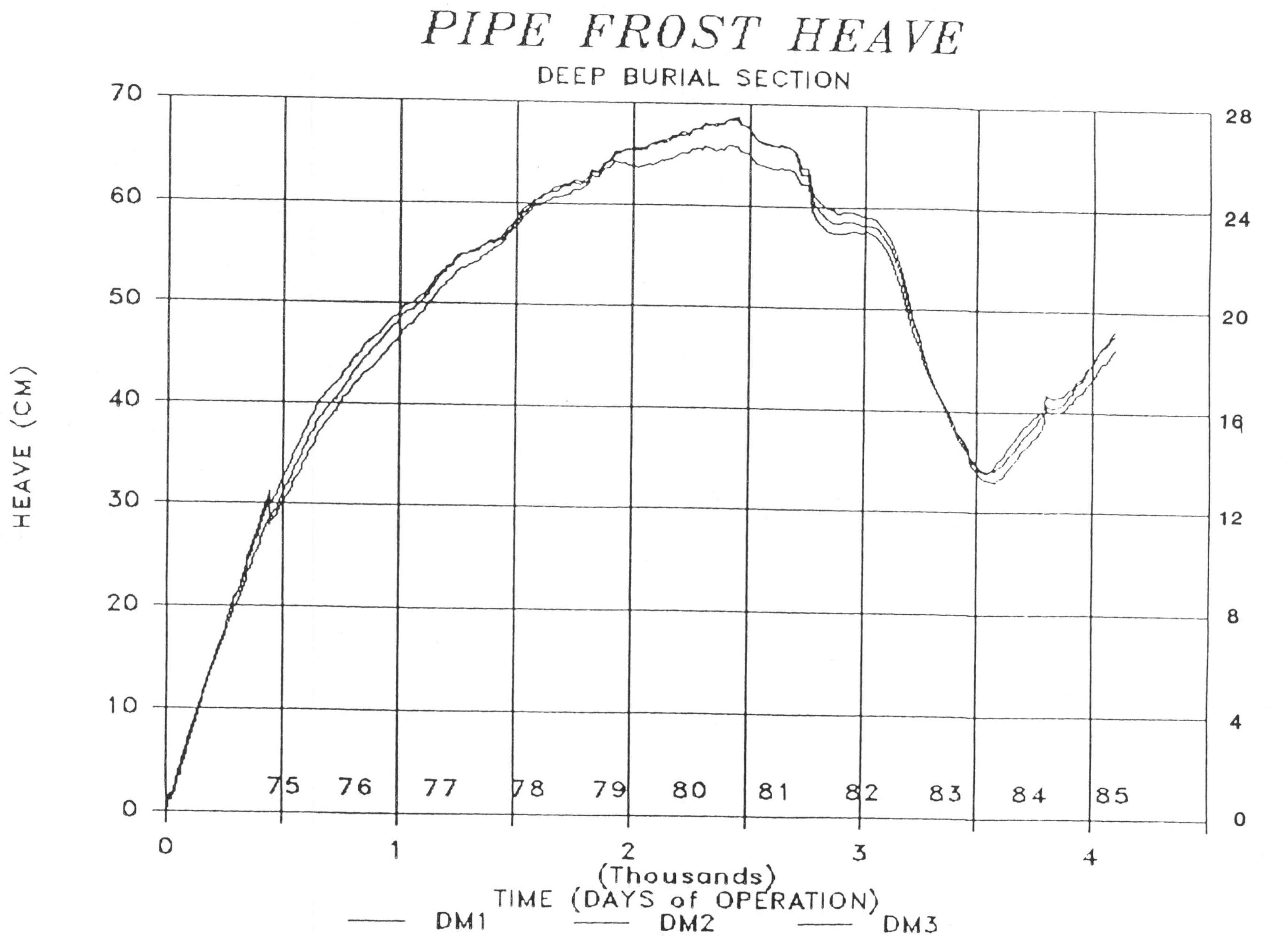

PIPE FROST HEAVE
DEEP BURIAL SECTION
HEAVE (CM)
(INCHES)
70
60
50
40
30
20
10
0
28
24
20
16
12
8
4
0
75
76
77
78
79
80
81
82
83
84
85
0
1
2
3
4
(Thousands)
TIME (DAYS of OPERATION)
DM1
DM2
DM3

FIGURE 2-1

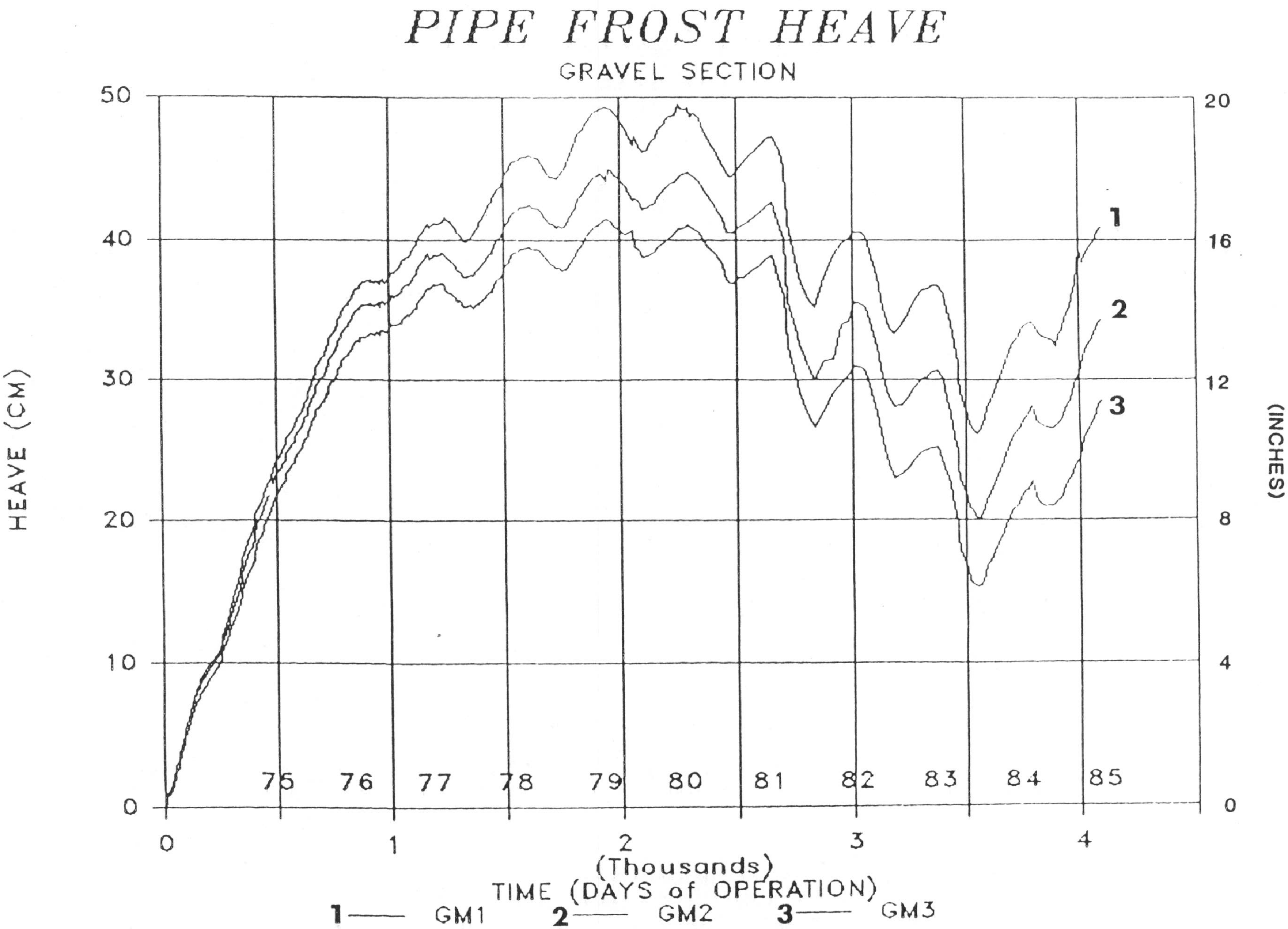

PIPE FROST HEAVE
GRAVEL SECTION
HEAVE (CM)
(INCHES)
50
40
30
20
10
0
20
16
12
8
4
0
75
76
77
78
79
80
81
82
83
84
85
1
2
3
0
1
2
3
4
(Thousands)
TIME (DAYS of OPERATION)
1 GM1
2 GM2
3 GM3

FIGURE 2-2

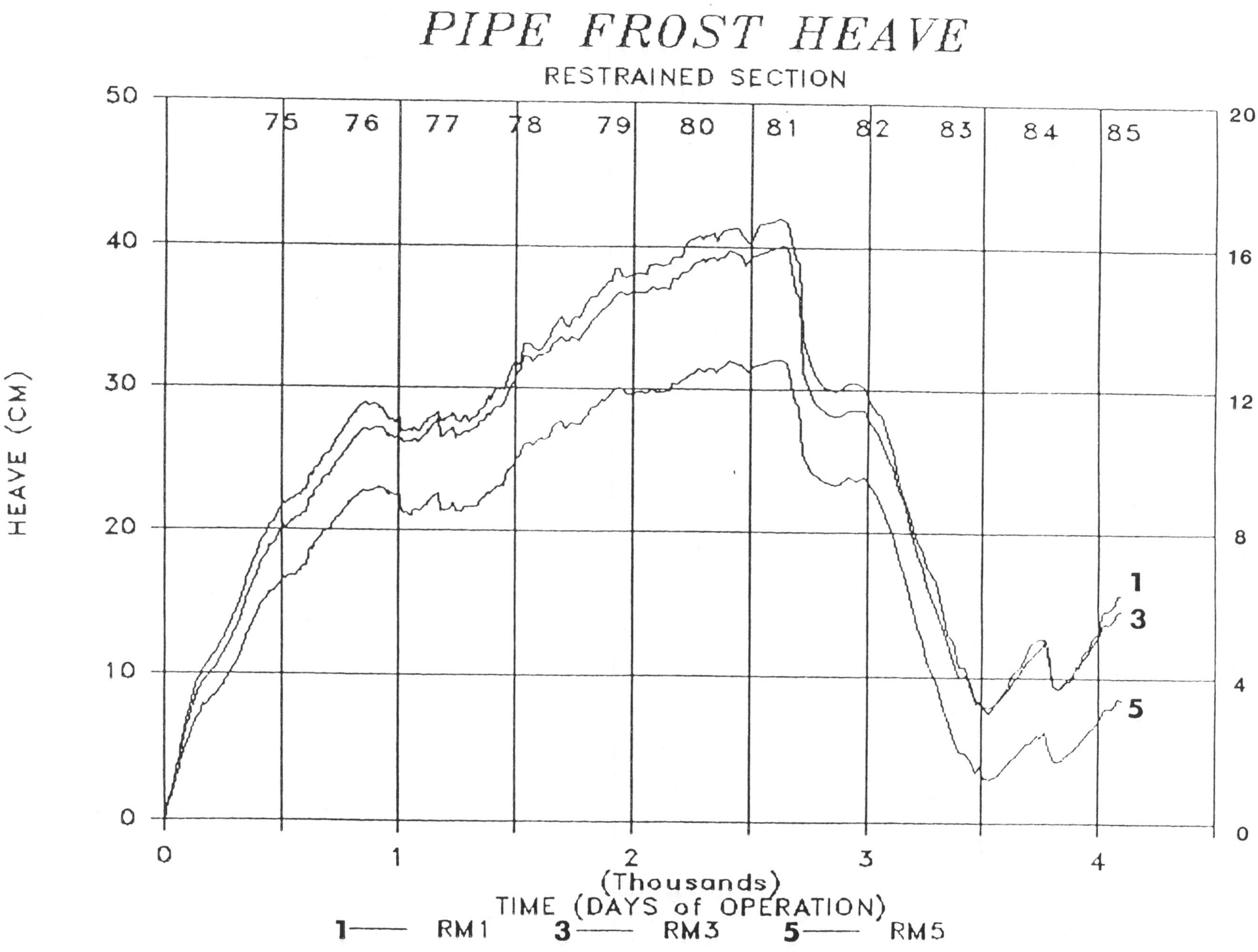

PIPE FROST HEAVE
RESTRAINED SECTION
HEAVE (CM)
(INCHES)
75
76
77
78
79
80
81
82
83
84
85
50
40
30
20
10
0
20
16
12
8
4
0
0
1
2
3
4
(Thousands)
TIME (DAYS of OPERATION)
1
3
5
1—— RM1
3—— RM3
5—— RM5

FIGURE 2-3

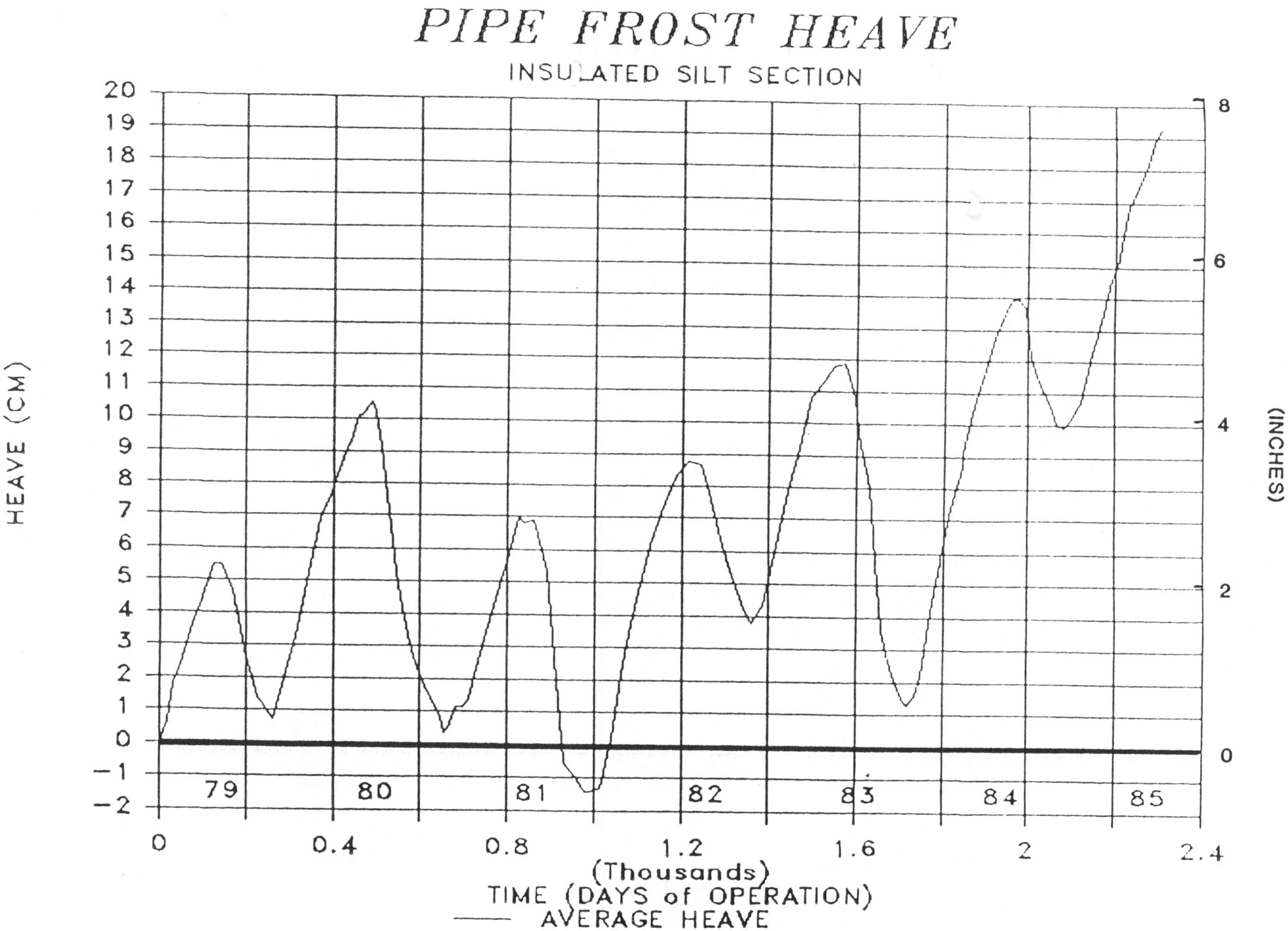

PIPE FROST HEAVE
INSULATED SILT SECTION
HEAVE (CM)
(INCHES)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
−1
−2
8
6
4
2
0
79
80
81
82
83
84
85
0
0.4
0.8
1.2
1.6
2
2.4
(Thousands)
TIME (DAYS of OPERATION)
AVERAGE HEAVE

FIGURE 2-4

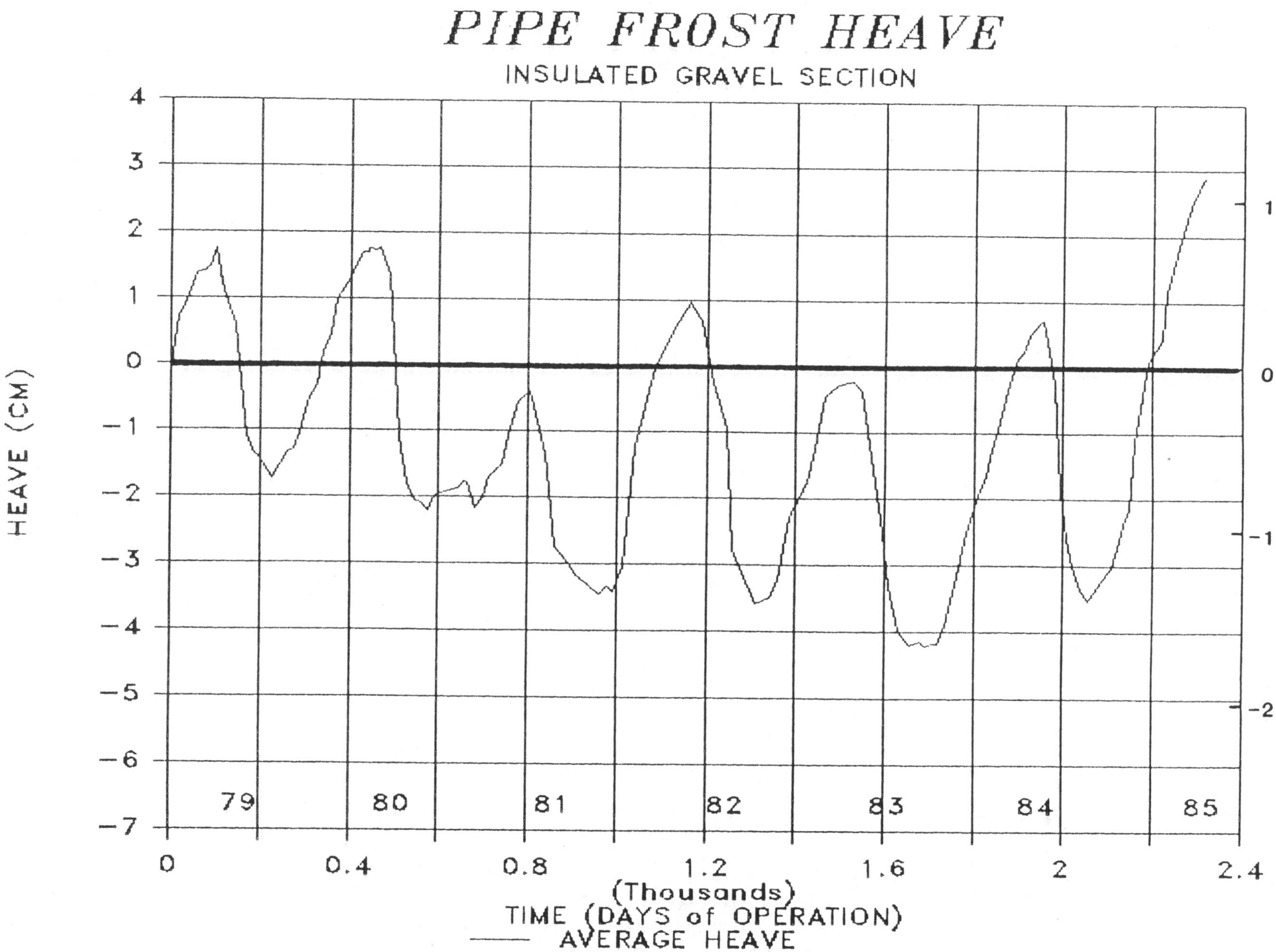

PIPE FROST HEAVE
INSULATED GRAVEL SECTION
HEAVE (CM)
(INCHES)
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
1
0
-1
-2
79
80
81
82
83
84
85
0
0.4
0.8
1.2
1.6
2
2.4
(Thousands)
TIME (DAYS of OPERATION)
AVERAGE HEAVE

FIGURE 2-5

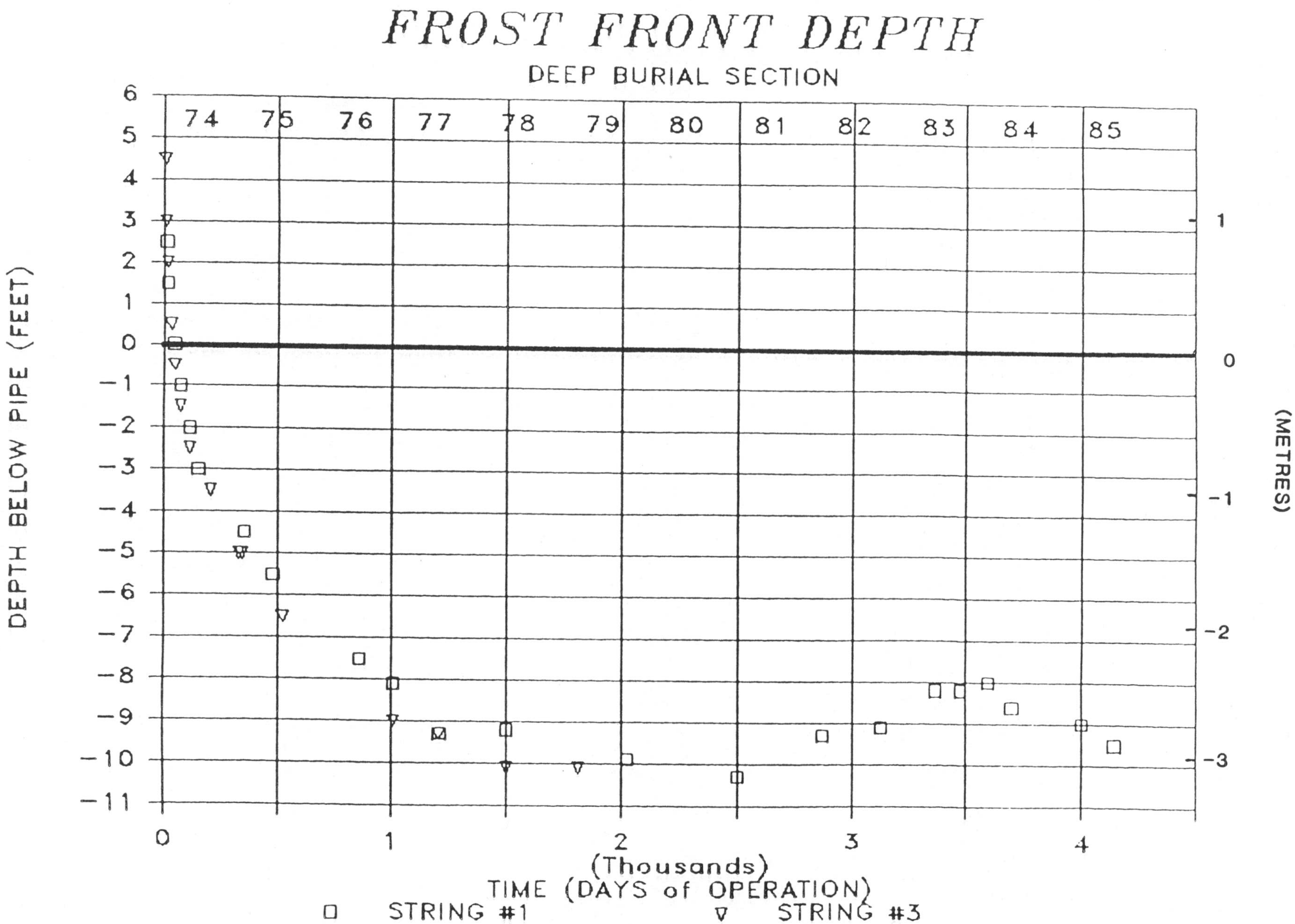

FROST FRONT DEPTH
DEEP BURIAL SECTION
74
75
76
77
78
79
80
81
82
83
84
85
DEPTH BELOW PIPE (FEET)
(METRES)
6
5
4
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
−10
−11
1
0
−1
−2
−3
0
1
2
3
4
(Thousands)
TIME (DAYS of OPERATION)
STRING #1
STRING #3

FIGURE 2-6

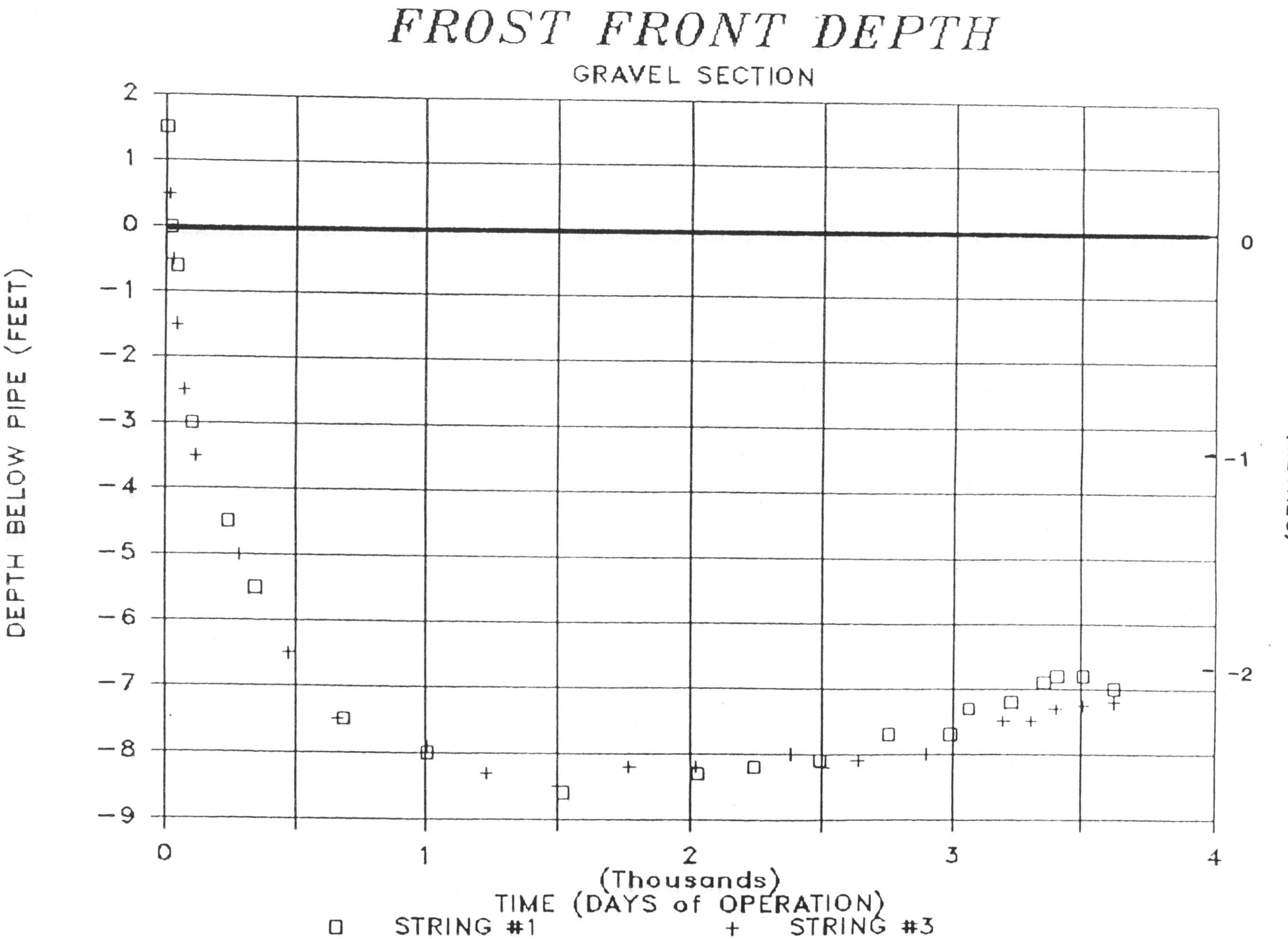

FROST FRONT DEPTH
GRAVEL SECTION
DEPTH BELOW PIPE (FEET)
(METRES)
2
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
−1
−2
0
1
2
3
4
(Thousands)
TIME (DAYS of OPERATION)
□ STRING #1
+ STRING #3

FIGURE 2-7

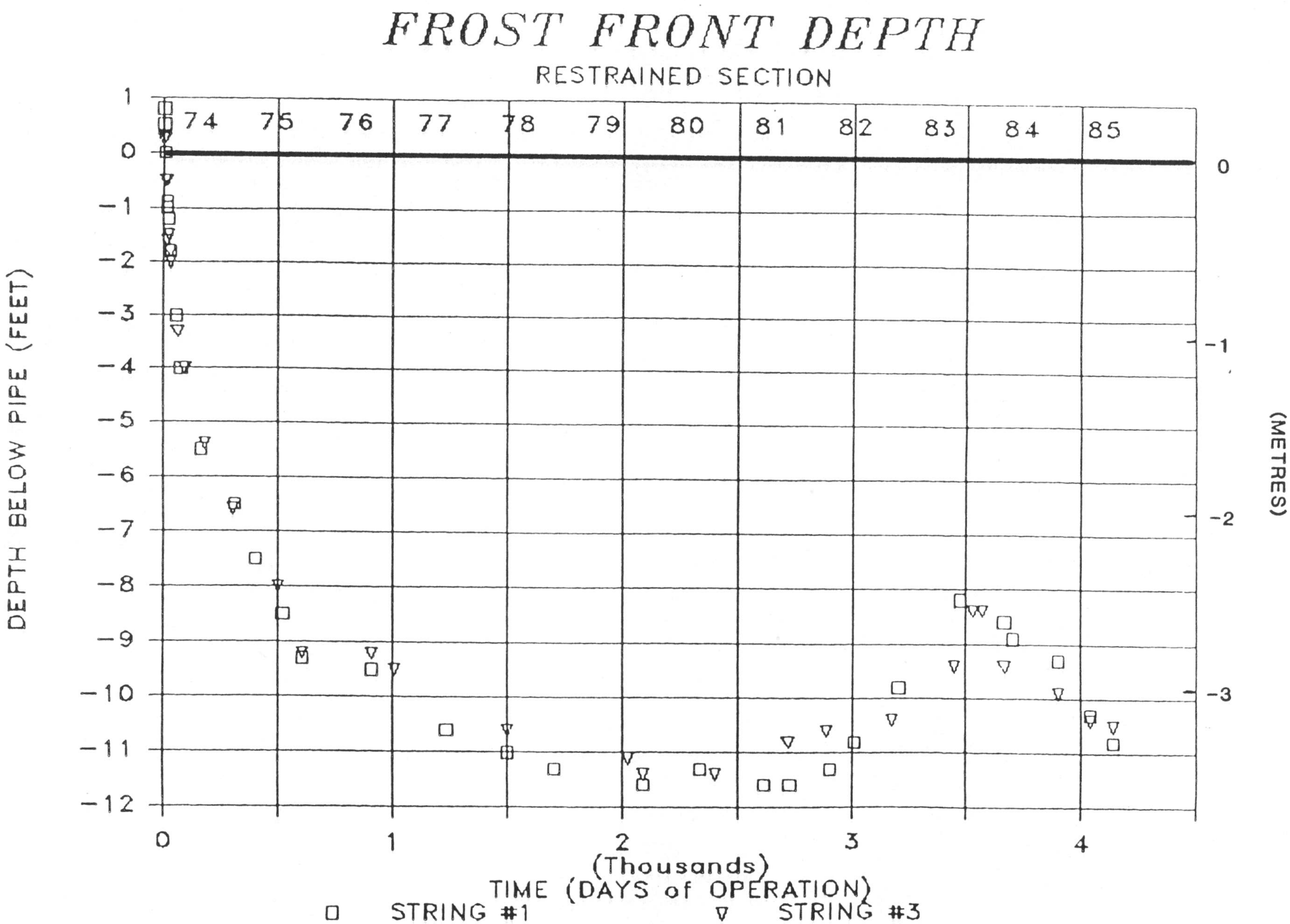
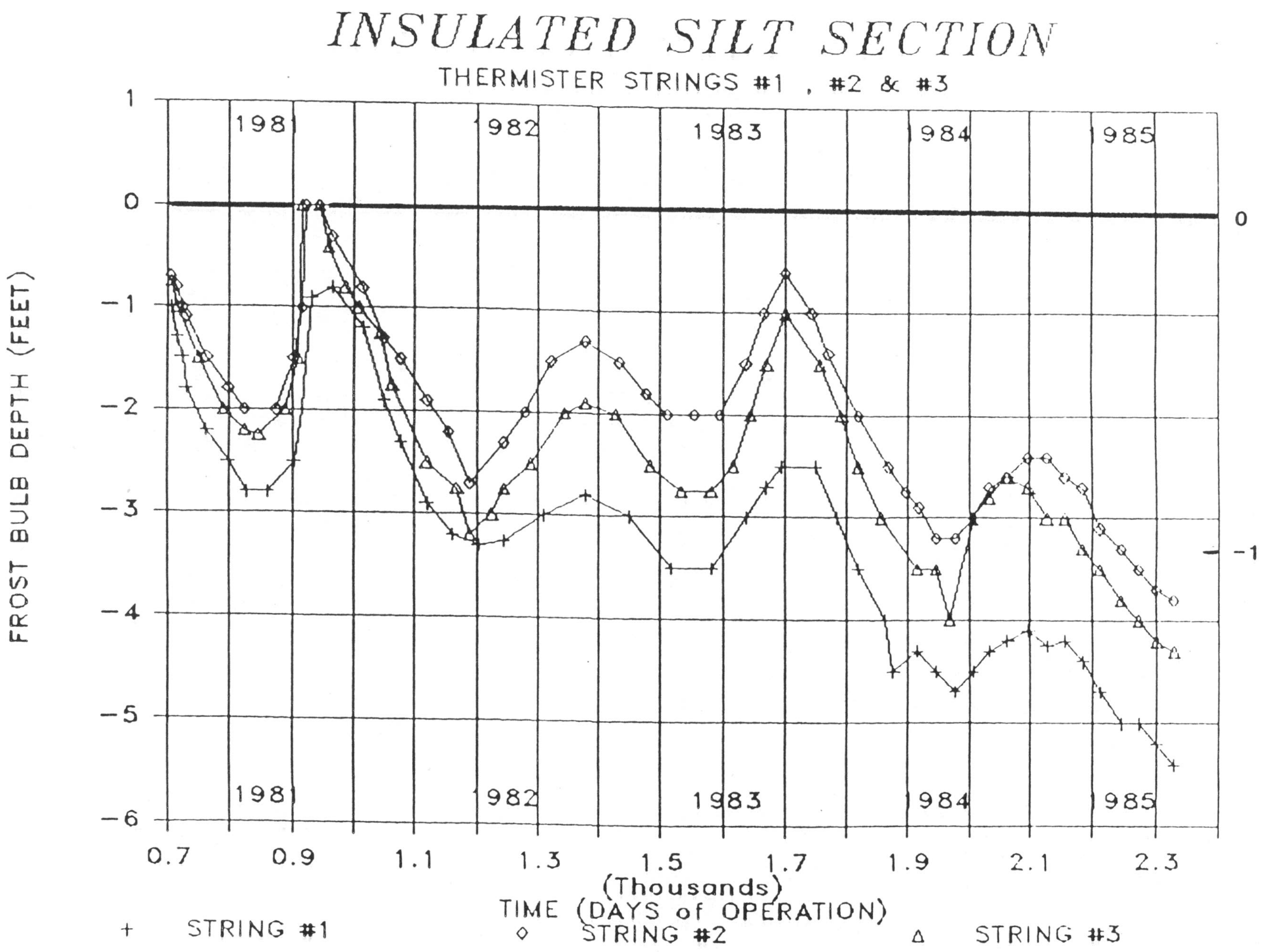
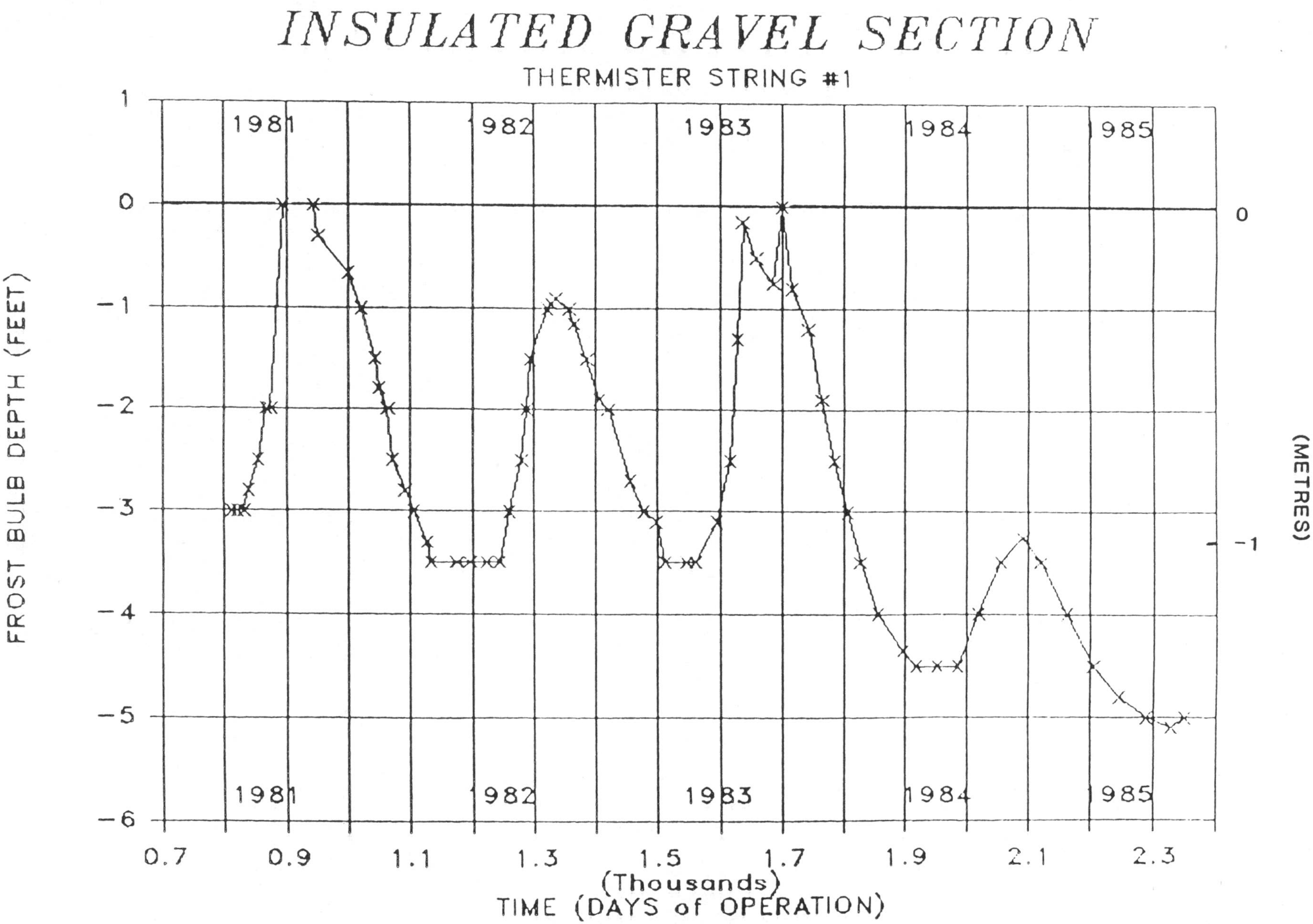

FROST FRONT DEPTH
RESTRAINED SECTION
DEPTH BELOW PIPE (FEET)
(METRES)
74
75
76
77
78
79
80
81
82
83
84
85
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
−10
−11
−12
0
−1
−2
−3
0
1
2
3
4
(Thousands)
TIME (DAYS of OPERATION)
□ STRING #1
▽ STRING #3

FIGURE 2-8



INSULATED SILT SECTION
THERMISTER STRINGS #1 , #2 & #3
FROST BULB DEPTH (FEET)
(METRES)
1981
1982
1983
1984
1985
1
0
−1
−2
−3
−4
−5
−6
0
−1
0.7
0.9
1.1
1.3
1.5
1.7
1.9
2.1
2.3
(Thousands)
TIME (DAYS of OPERATION)
+ STRING #1
◇ STRING #2
△ STRING #3

FIGURE 2-9



INSULATED GRAVEL SECTION
THERMISTER STRING #1
1981
1982
1983
1984
1985
FROST BULB DEPTH (FEET)
(METRES)
1
0
-1
-2
-3
-4
-5
-6
0
-1
0.7
0.9
1.1
1.3
1.5
1.7
1.9
2.1
2.3
(Thousands)
TIME (DAYS of OPERATION)

FIGURE 2-10

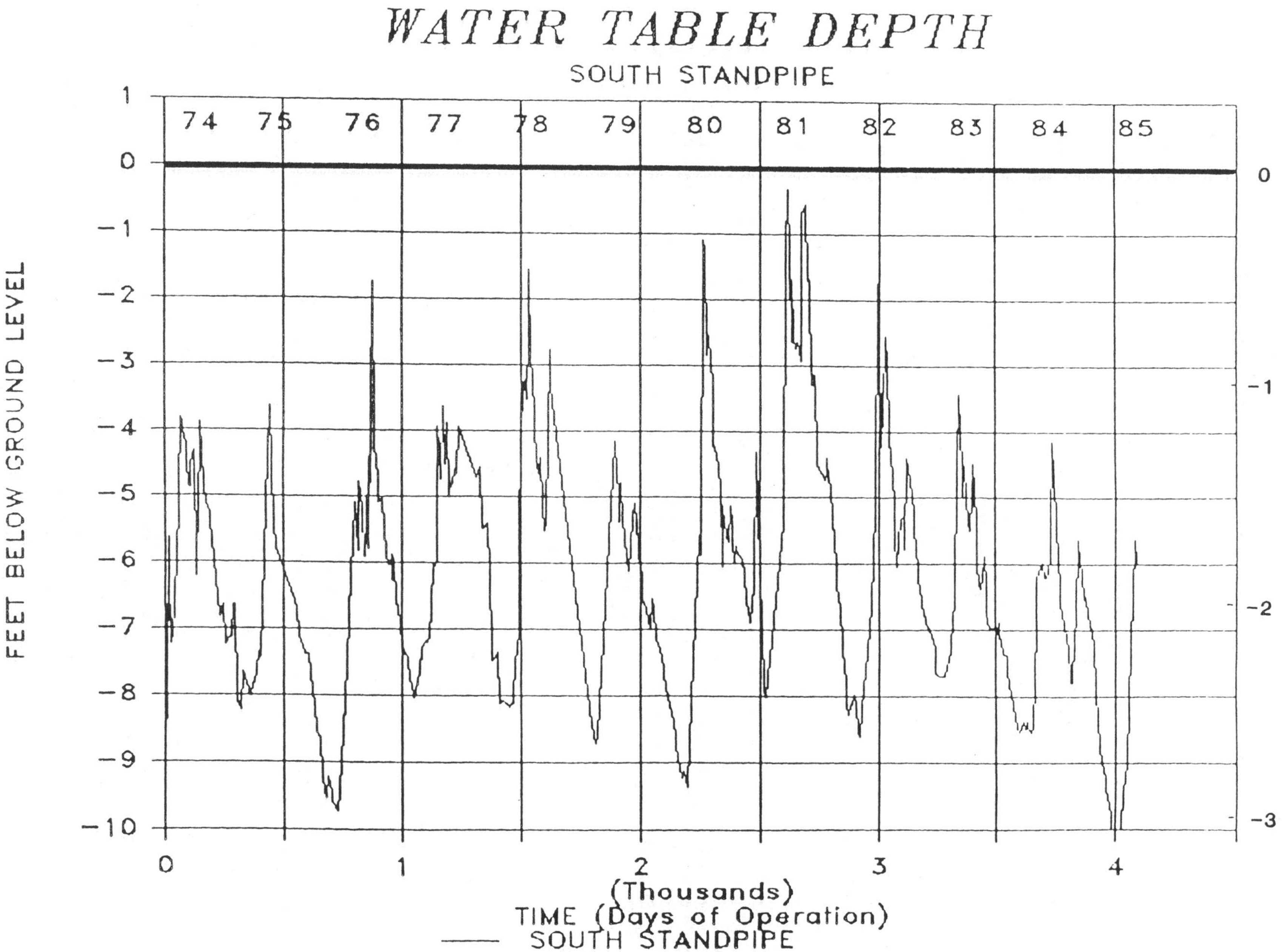

WATER TABLE DEPTH
SOUTH STANDPIPE
74 75 76 77 78 79 80 81 82 83 84 85
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
−10
FEET BELOW GROUND LEVEL
0
−1
−2
−3
(METRES)
0
1
2
3
4
(Thousands)
TIME (Days of Operation)
SOUTH STANDPIPE

FIGURE 2-11

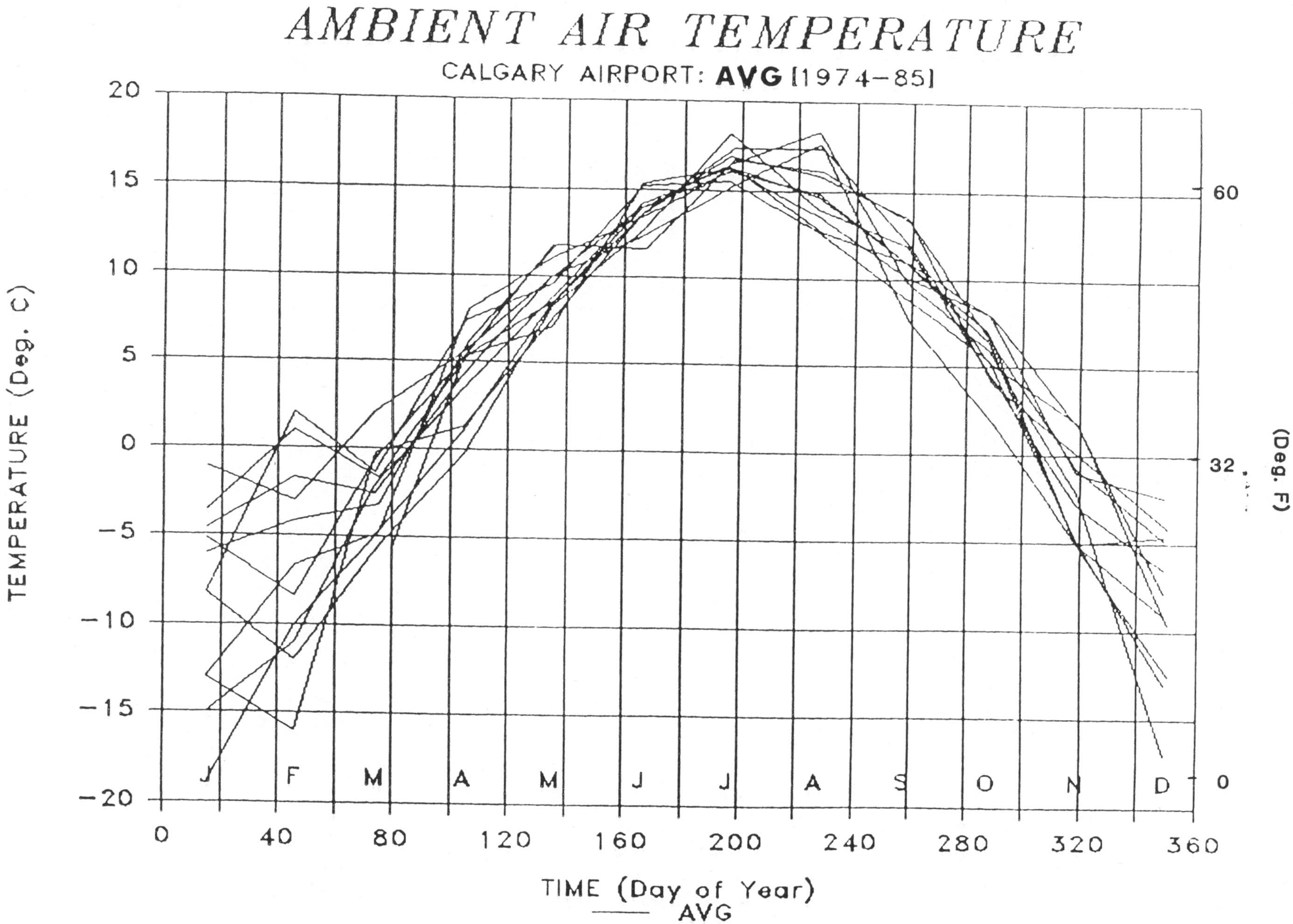

AMBIENT AIR TEMPERATURE
CALGARY AIRPORT: AVG [1974-85]
TEMPERATURE (Deg. C)
20
15
10
5
0
-5
-10
-15
-20
(Deg. F)
60
32
0
J
F
M
A
M
J
J
A
S
O
N
D
0
40
80
120
160
200
240
280
320
360
TIME (Day of Year)
AVG

FIGURE 2-12

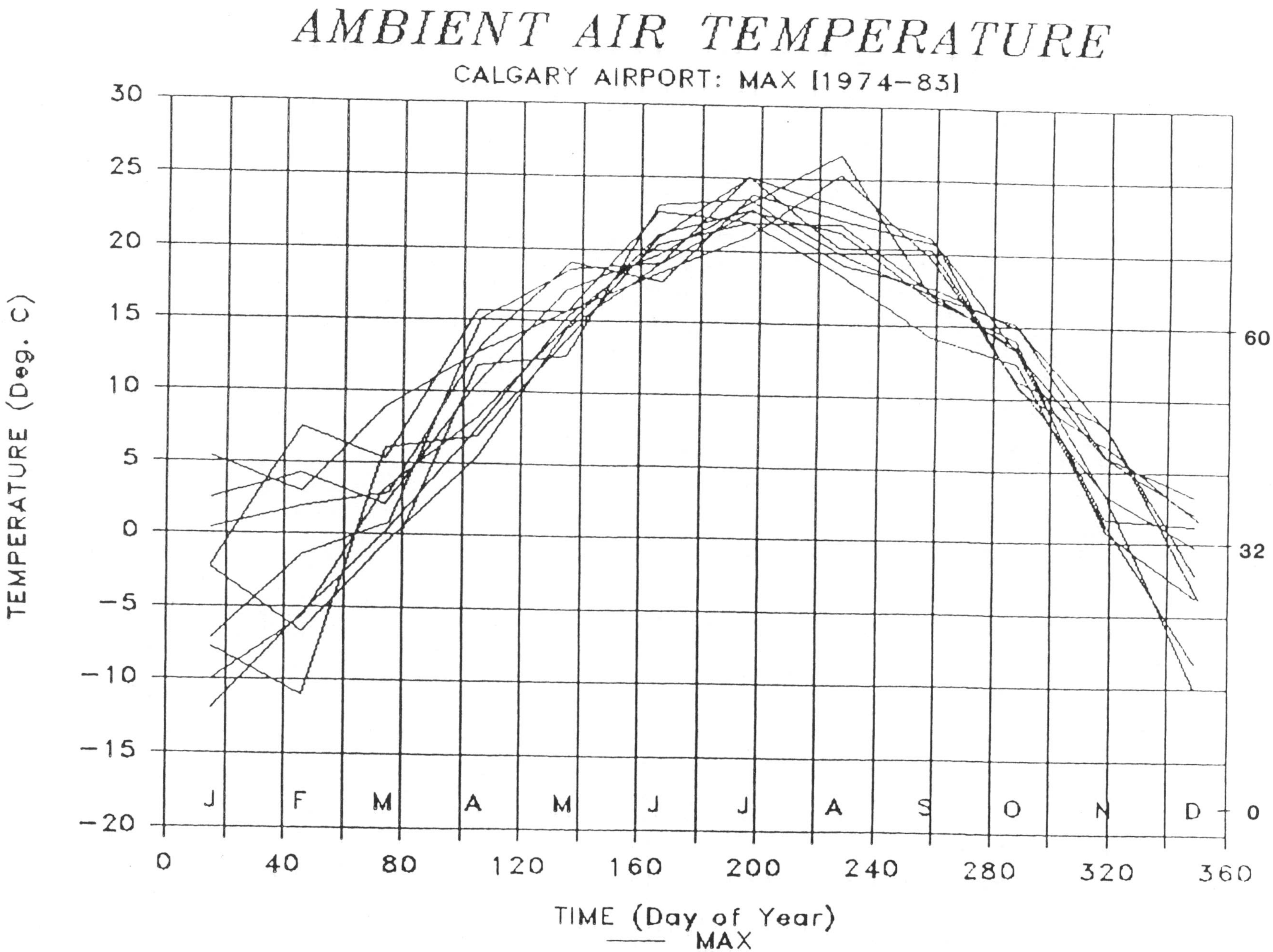

AMBIENT AIR TEMPERATURE
CALGARY AIRPORT: MAX [1974-83]
TEMPERATURE (Deg. C)
30
25
20
15
10
5
0
-5
-10
-15
-20
(Deg.F)
60
32
0
J
F
M
A
M
J
J
A
S
O
N
D
0
40
80
120
160
200
240
280
320
360
TIME (Day of Year)
MAX

FIGURE 2-13

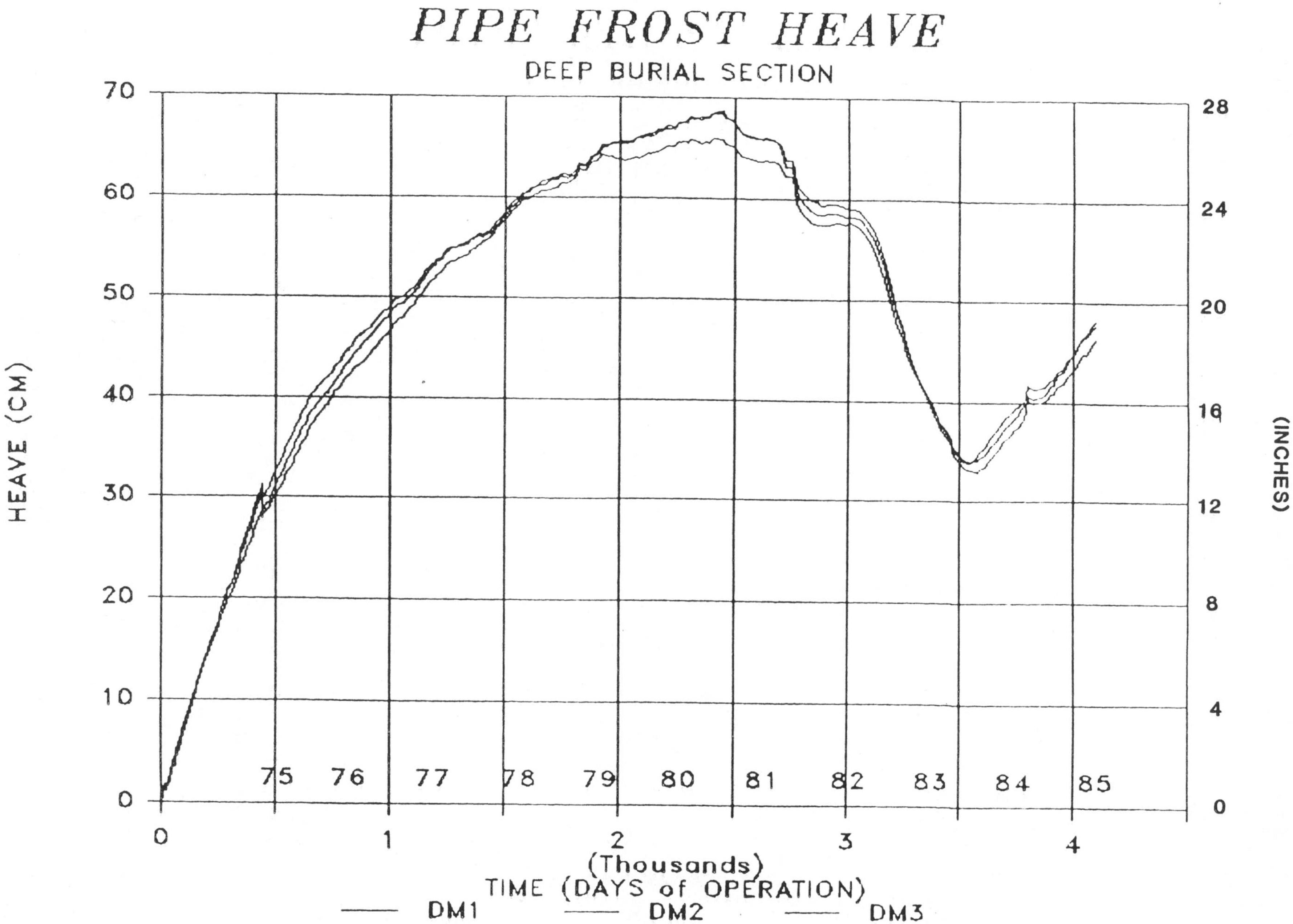

PIPE FROST HEAVE
DEEP BURIAL SECTION
HEAVE (CM)
(INCHES)
0
10
20
30
40
50
60
70
0
4
8
12
16
20
24
28
75
76
77
78
79
80
81
82
83
84
85
0
1
2
3
4
(Thousands)
TIME (DAYS of OPERATION)
DM1
DM2
DM3

FIGURE 2-1

PIPE FROST HEAVE

GRAVEL SECTION

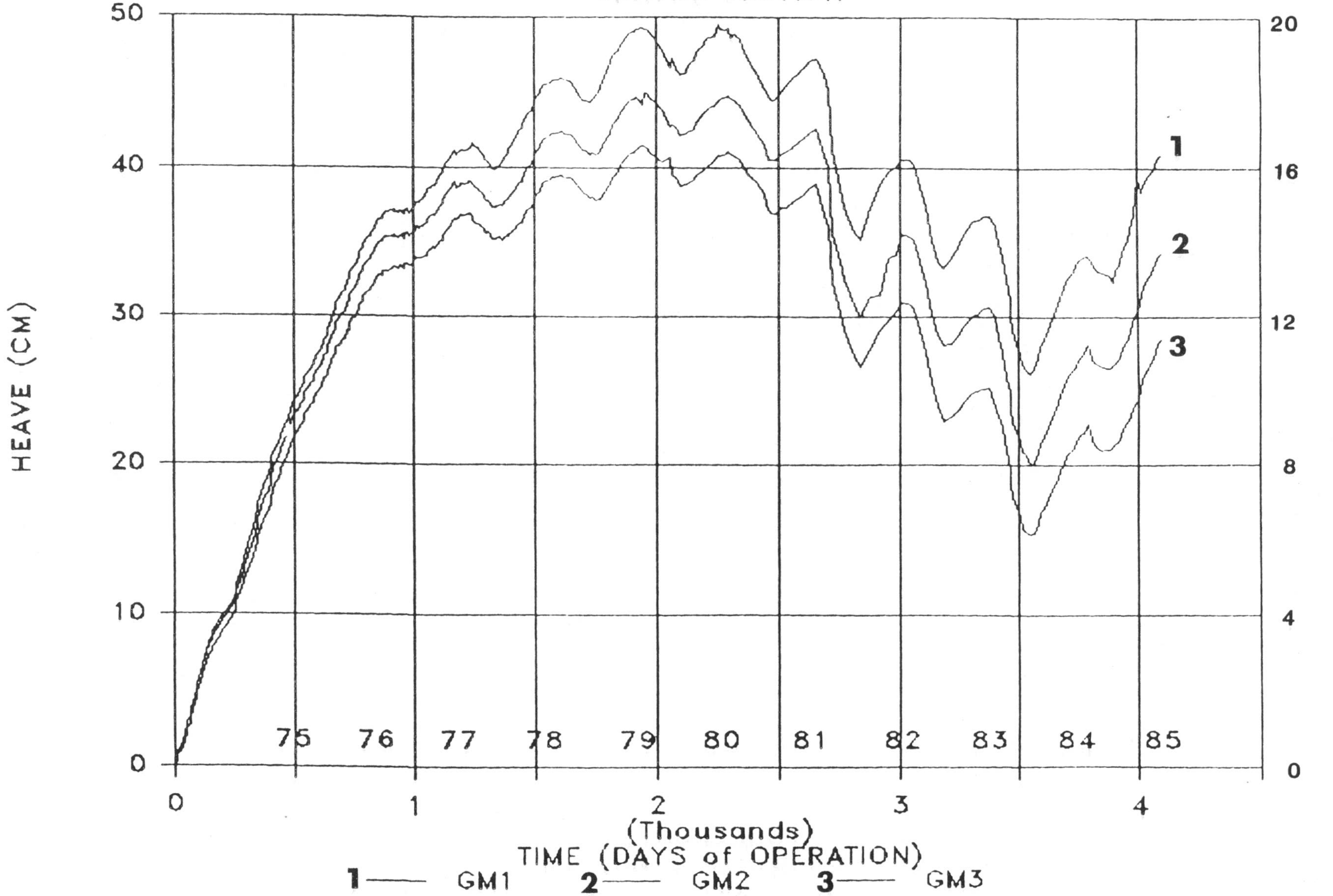


FIGURE 2-2

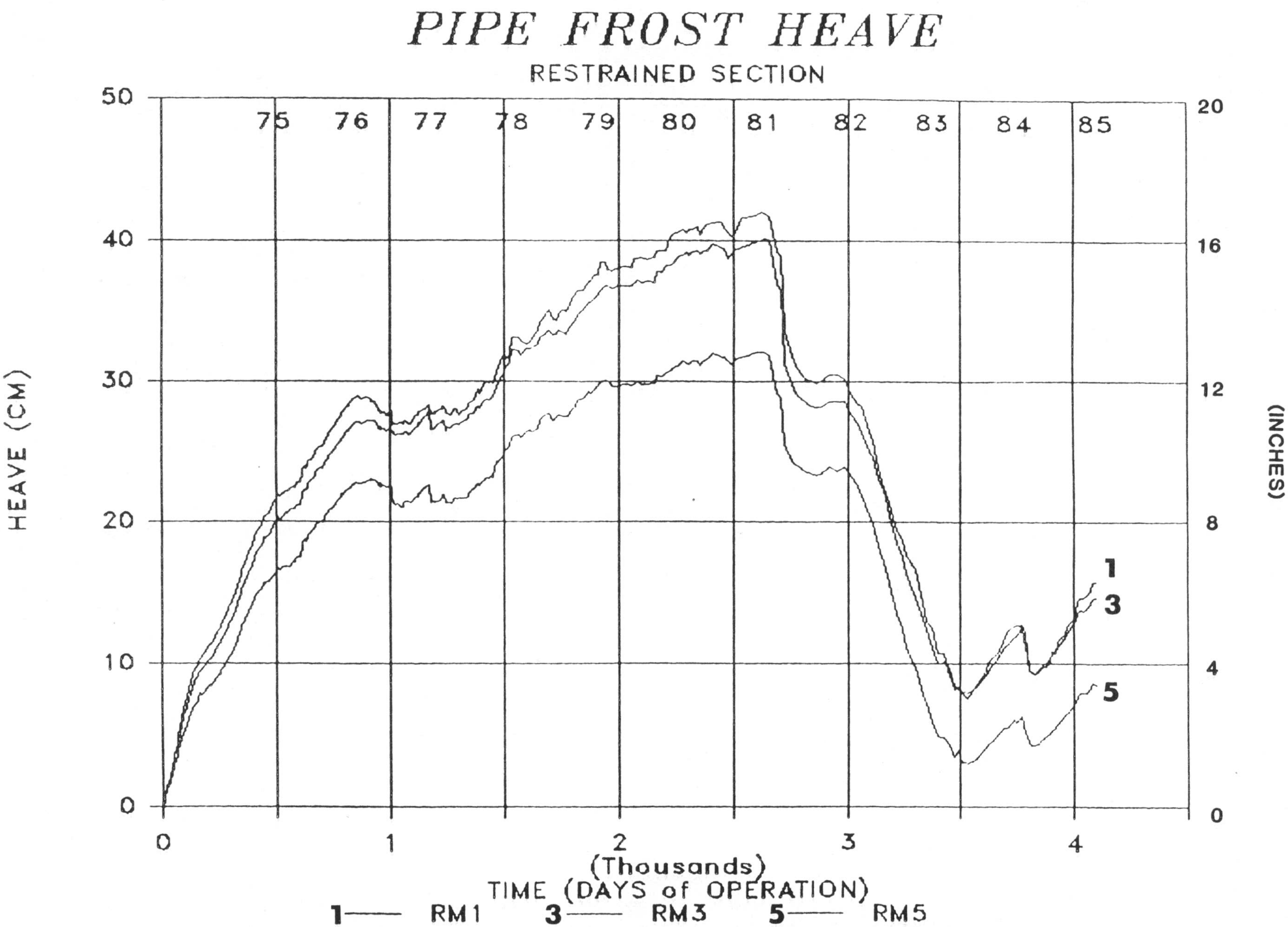

PIPE FROST HEAVE
RESTRAINED SECTION
HEAVE (CM)
(INCHES)
0
10
20
30
40
50
0
4
8
12
16
20
75
76
77
78
79
80
81
82
83
84
85
0
1
2
3
4
(Thousands)
TIME (DAYS of OPERATION)
1
3
5
1—— RM1 3—— RM3 5—— RM5

FIGURE 2-3

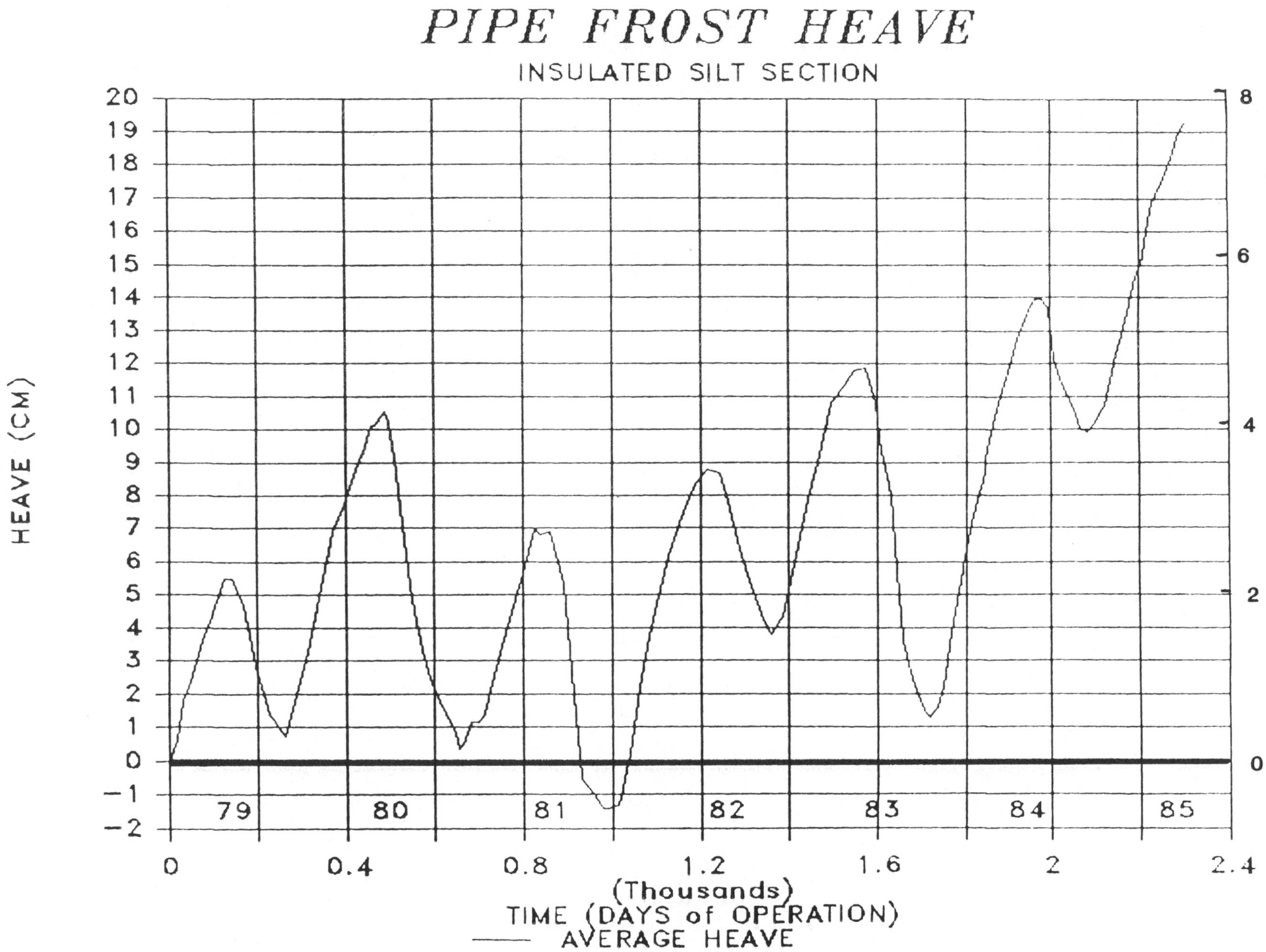

PIPE FROST HEAVE
INSULATED SILT SECTION
HEAVE (CM)
(INCHES)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
−1
−2
8
6
4
2
0
79
80
81
82
83
84
85
0
0.4
0.8
1.2
1.6
2
2.4
(Thousands)
TIME (DAYS of OPERATION)
AVERAGE HEAVE

FIGURE 2-4

PIPE FROST HEAVE

INSULATED GRAVEL SECTION

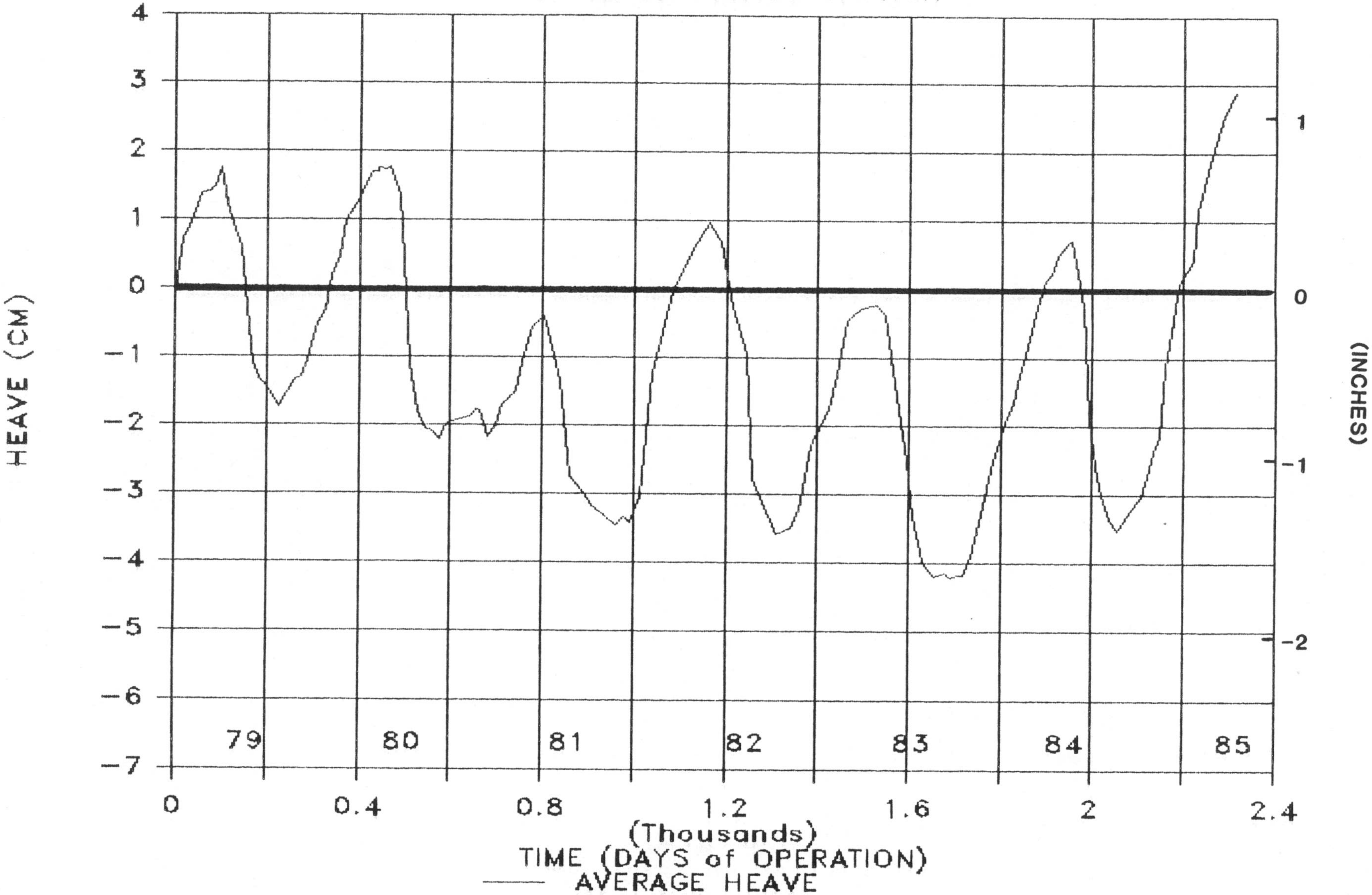


FIGURE 2-5

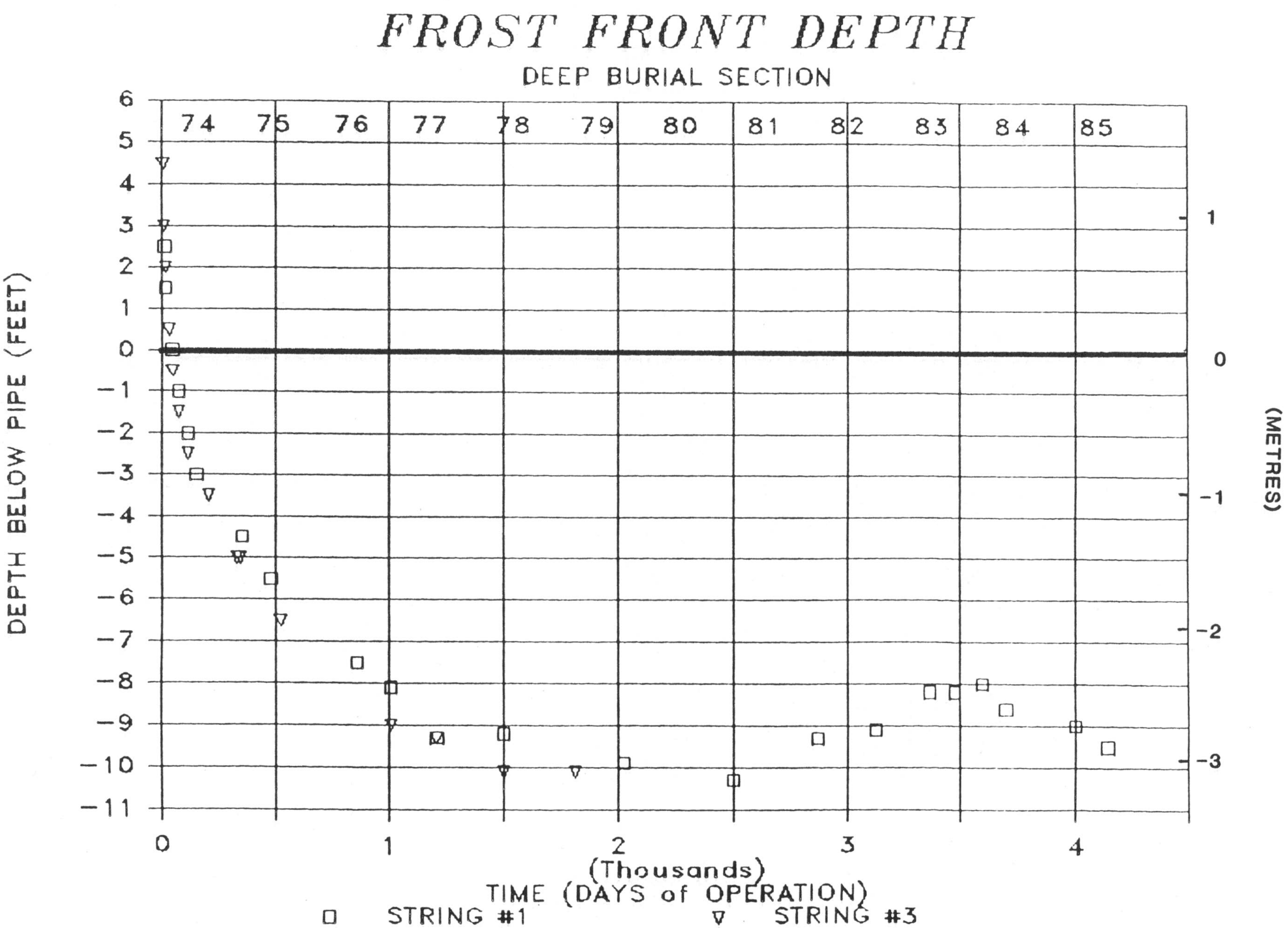

FROST FRONT DEPTH
DEEP BURIAL SECTION
74
75
76
77
78
79
80
81
82
83
84
85
DEPTH BELOW PIPE (FEET)
6
5
4
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
−10
−11
(METRES)
1
0
−1
−2
−3
0
1
2
3
4
(Thousands)
TIME (DAYS of OPERATION)
STRING #1
STRING #3

FIGURE 2-6

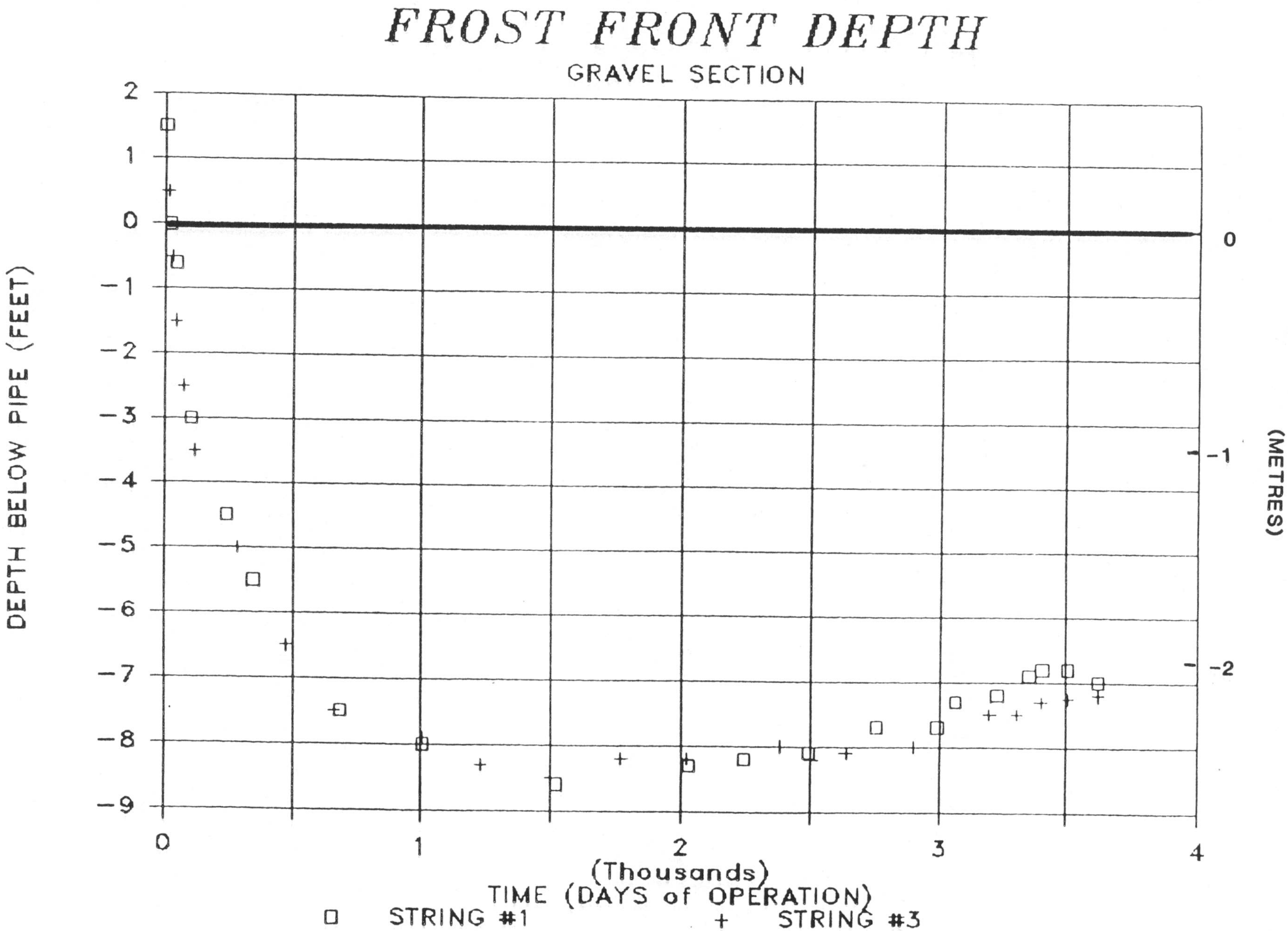
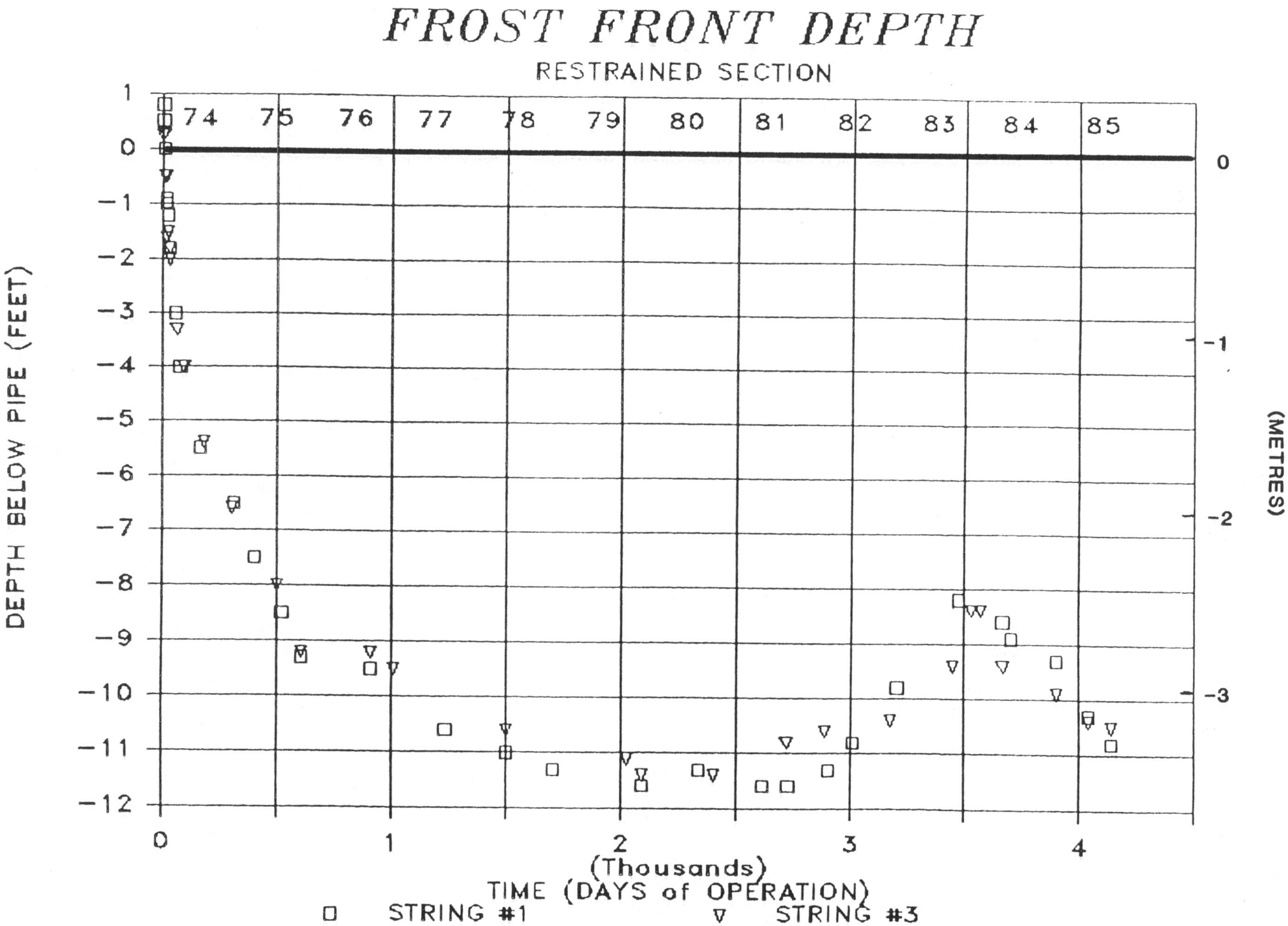

FROST FRONT DEPTH
GRAVEL SECTION
DEPTH BELOW PIPE (FEET)
(METRES)
2
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
−1
−2
0
1
2
3
4
(Thousands)
TIME (DAYS of OPERATION)
STRING #1
STRING #3

FIGURE 2-7



FROST FRONT DEPTH
RESTRAINED SECTION
74
75
76
77
78
79
80
81
82
83
84
85
DEPTH BELOW PIPE (FEET)
(METRES)
(Thousands)
TIME (DAYS of OPERATION)
STRING #1
STRING #3

FIGURE 2-8

INSULATED SILT SECTION

THERMISTER STRINGS #1 , #2 & #3

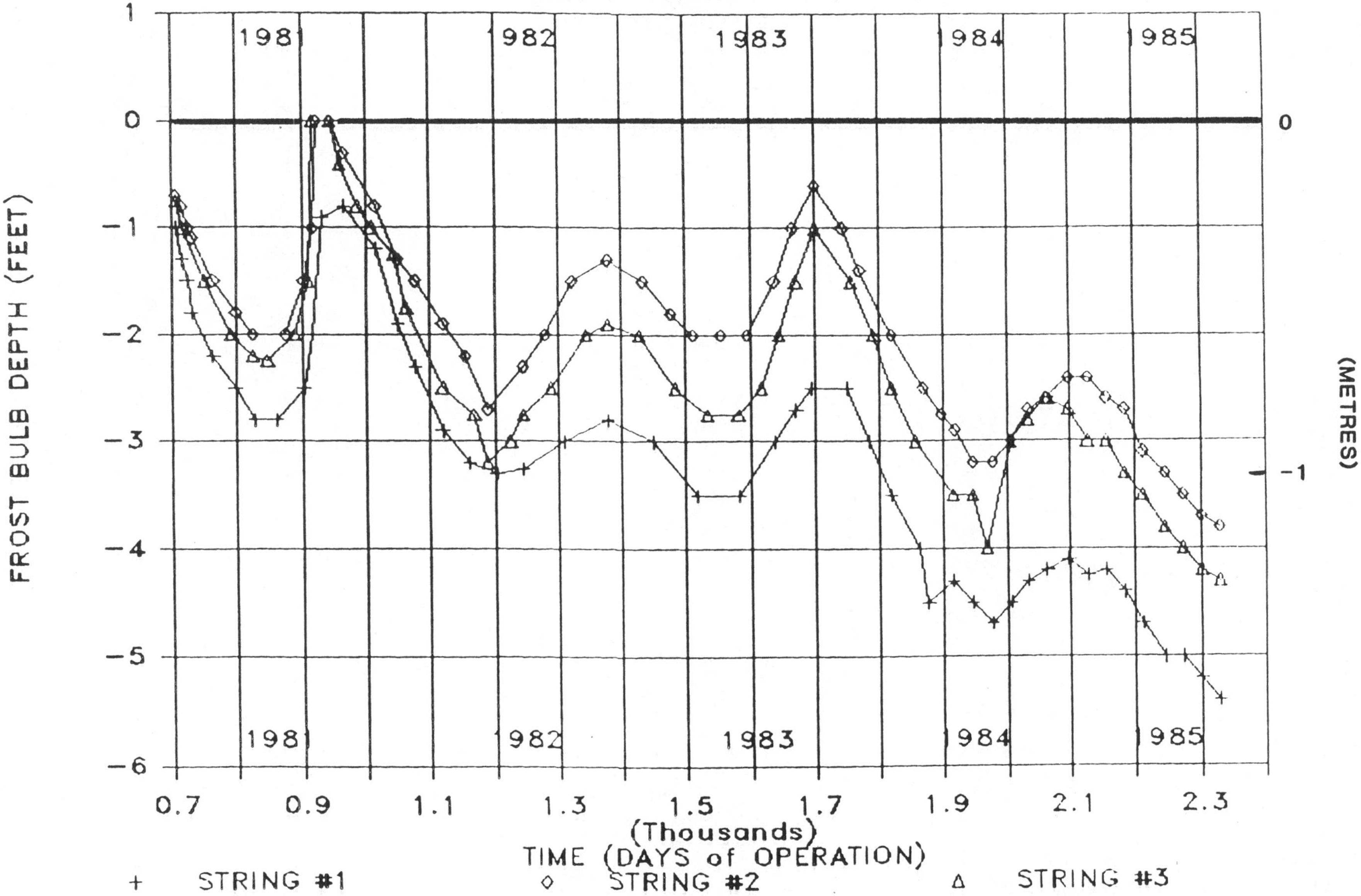


FIGURE 2-9

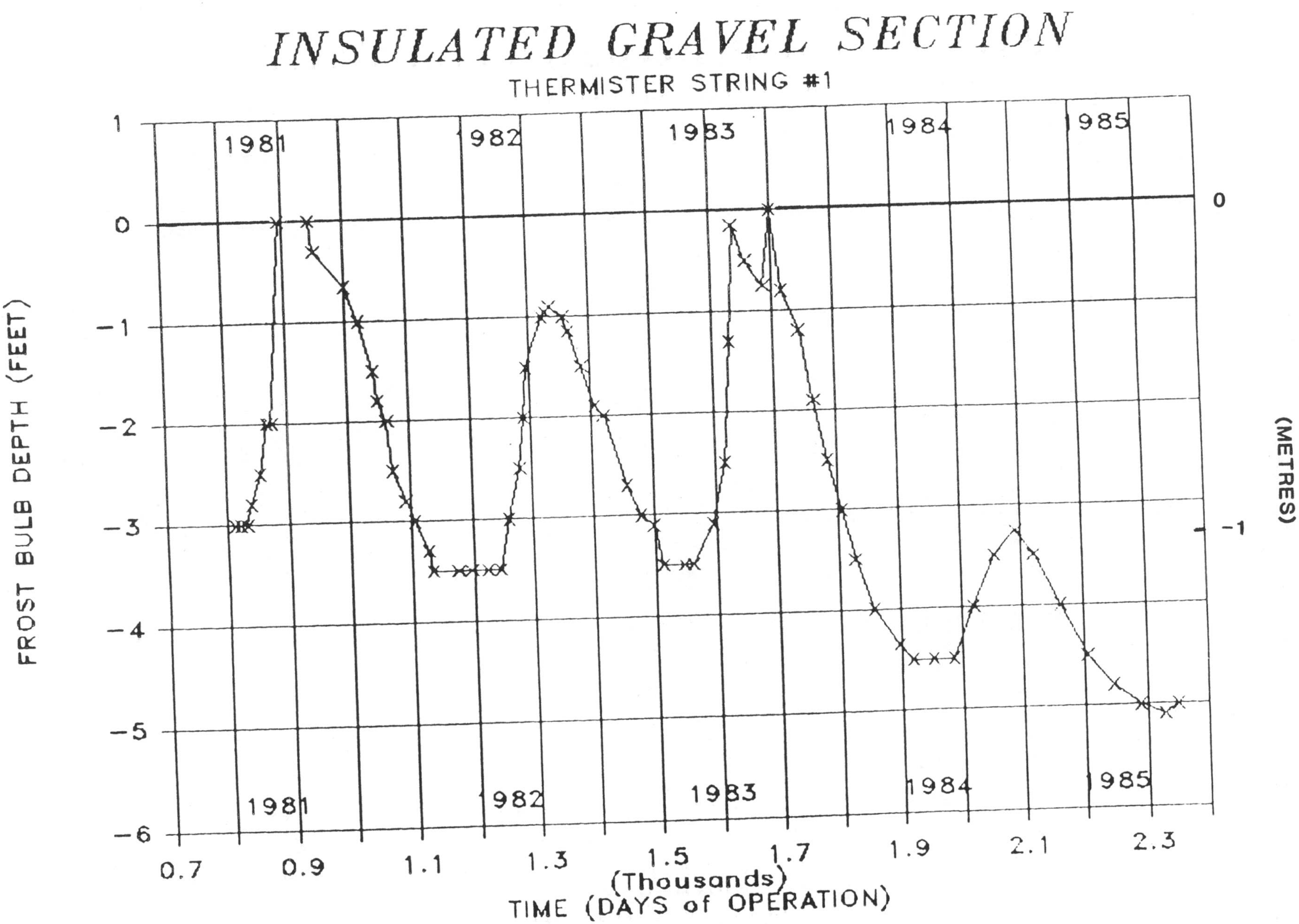

INSULATED GRAVEL SECTION
THERMISTER STRING #1
FROST BULB DEPTH (FEET)
(METRES)
1
0
-1
-2
-3
-4
-5
-6
0
-1
1981
1982
1983
1984
1985
0.7
0.9
1.1
1.3
1.5
1.7
1.9
2.1
2.3
(Thousands)
TIME (DAYS of OPERATION)

FIGURE 2-10

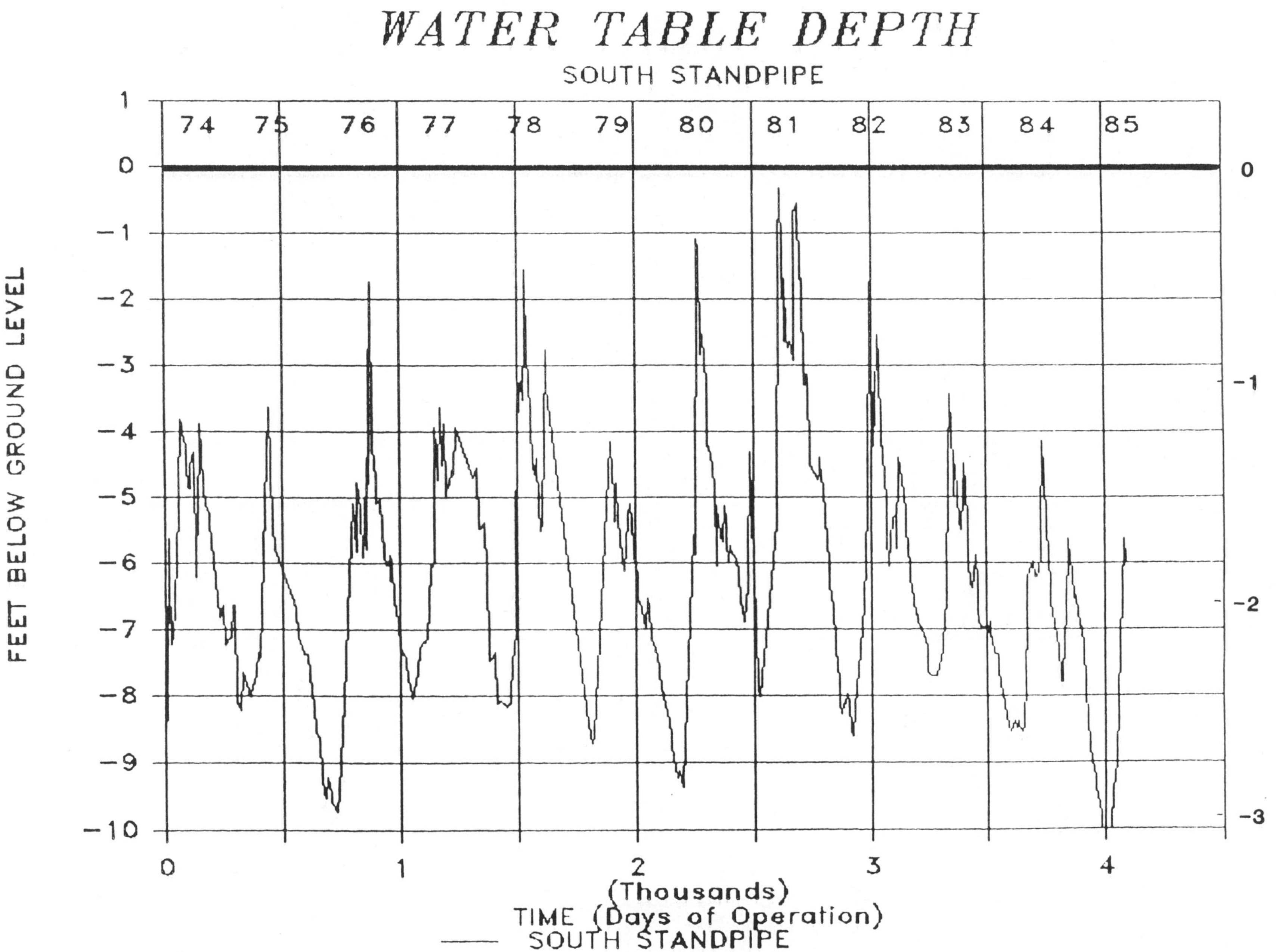

WATER TABLE DEPTH
SOUTH STANDPIPE
74
75
76
77
78
79
80
81
82
83
84
85
FEET BELOW GROUND LEVEL
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
−10
(METRES)
0
−1
−2
−3
0
1
2
3
4
(Thousands)
TIME (Days of Operation)
SOUTH STANDPIPE

FIGURE 2-11

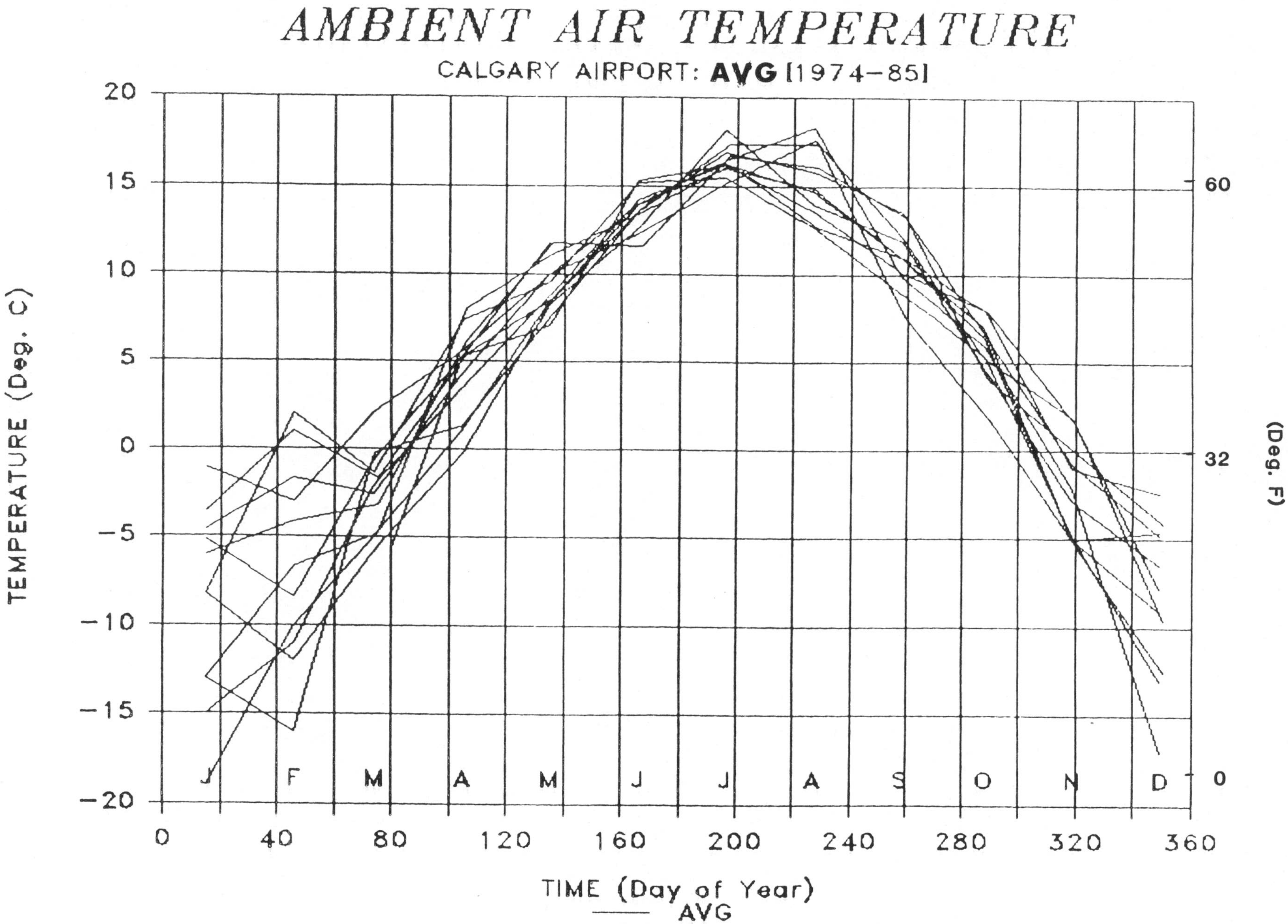

AMBIENT AIR TEMPERATURE
CALGARY AIRPORT: AVG [1974-85]
TEMPERATURE (Deg. C)
(Deg. F)
20
15
10
5
0
-5
-10
-15
-20
60
32
0
J
F
M
A
M
J
J
A
S
O
N
D
0
40
80
120
160
200
240
280
320
360
TIME (Day of Year)
AVG

FIGURE 2-12

AMBIENT AIR TEMPERATURE

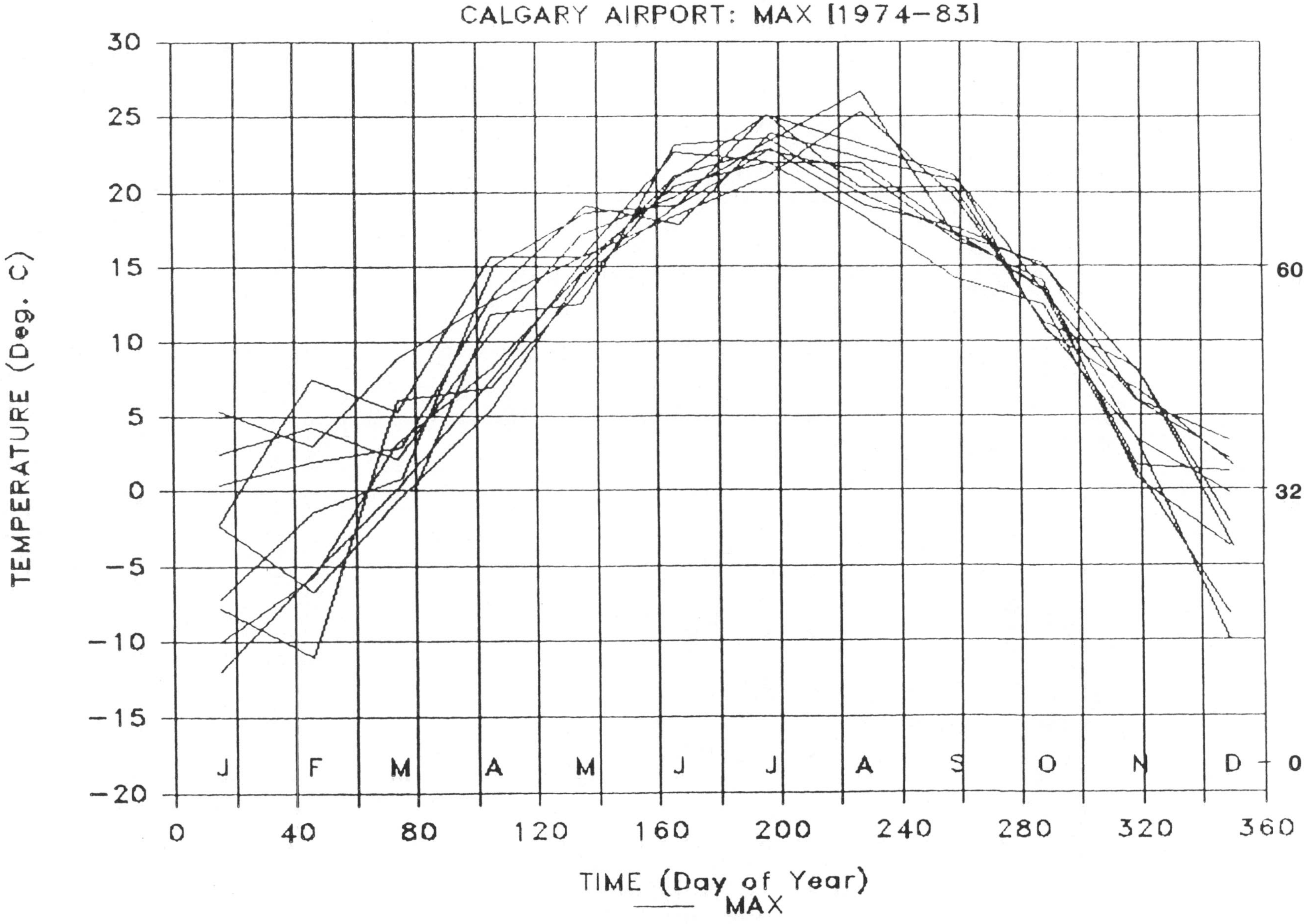


FIGURE 2-13

SAMPLE PLANE # 5
DEEP BURIAL SECTION

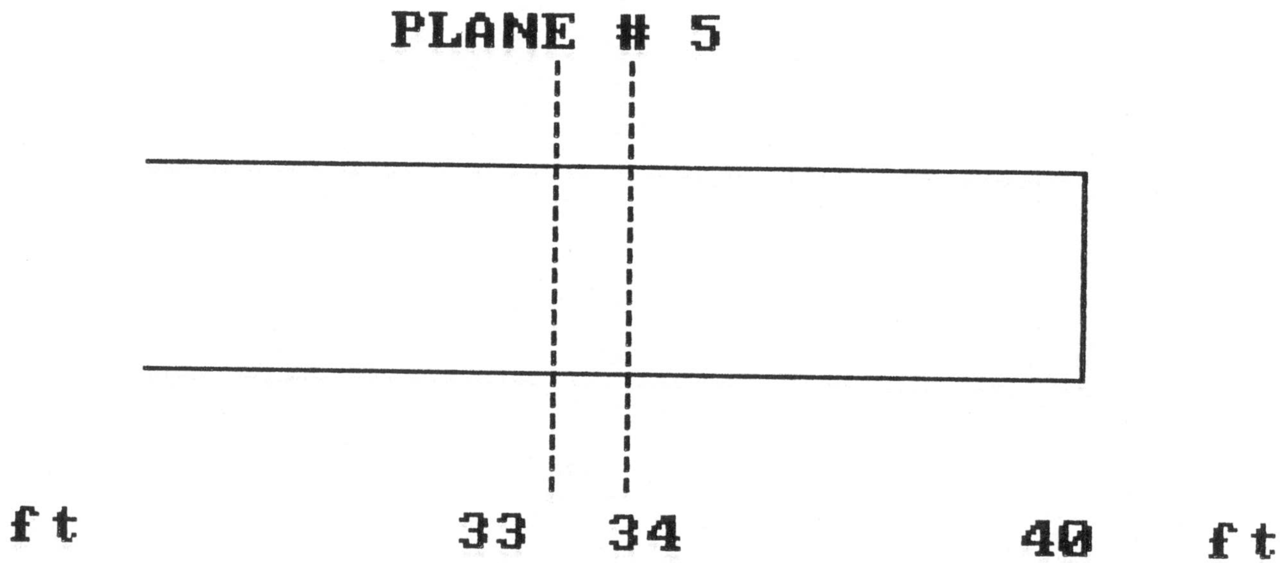


FIGURE 3-1

FIGURE 3-1

SAMPLE PLANES

DEEP BURIAL SECTION

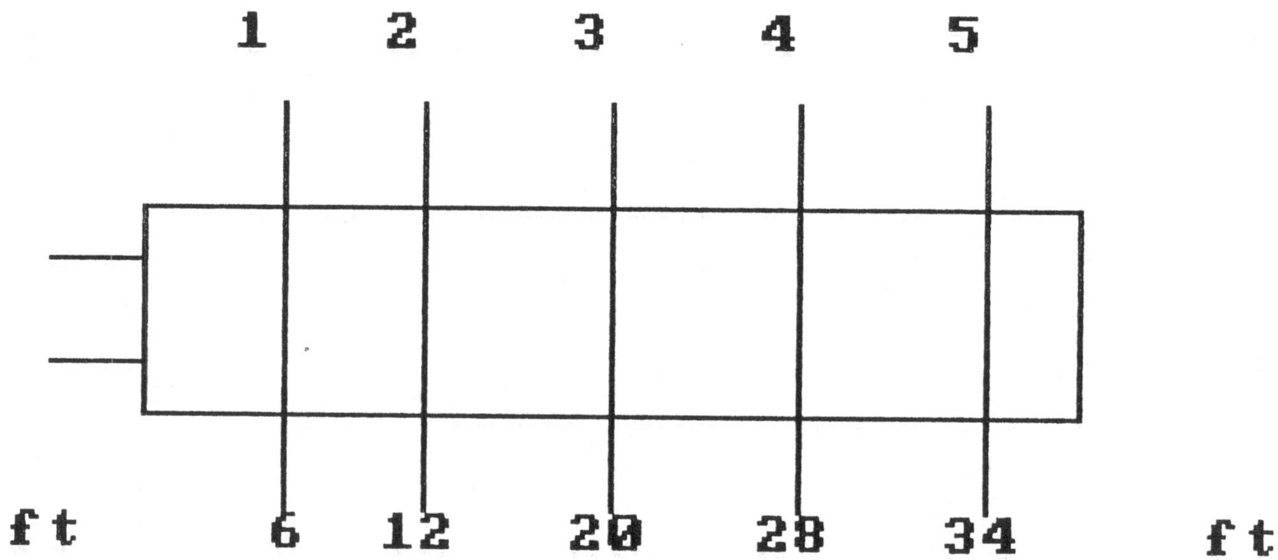


FIGURE 3-2

FIGURE 3-2

SAMPLE PLANES

INSULATED SECTION

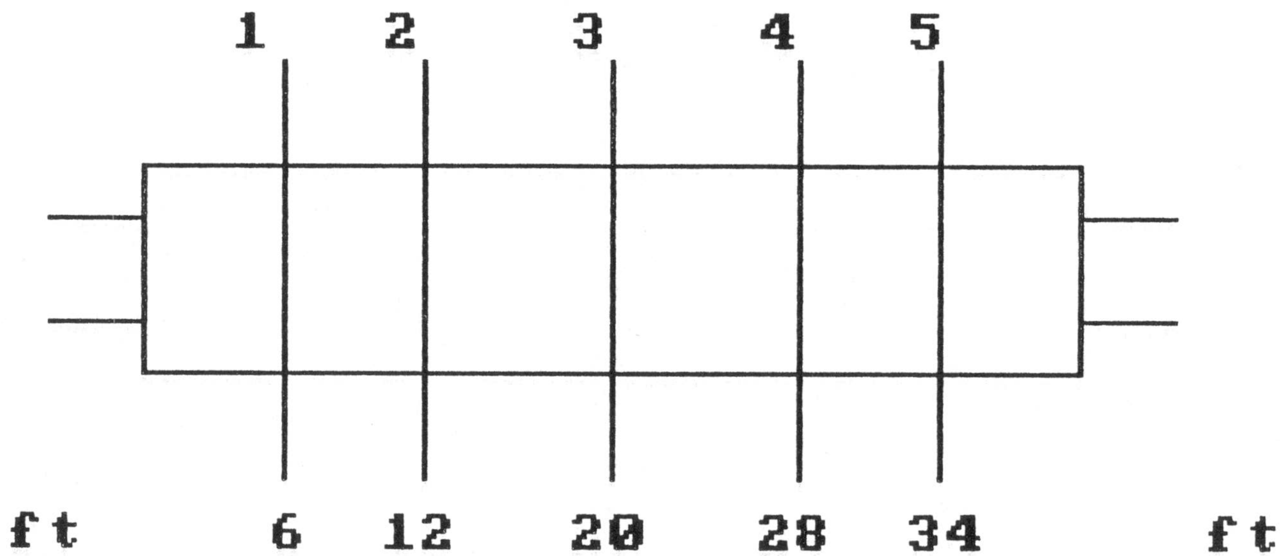


FIGURE 3-3

FIGURE 3–3

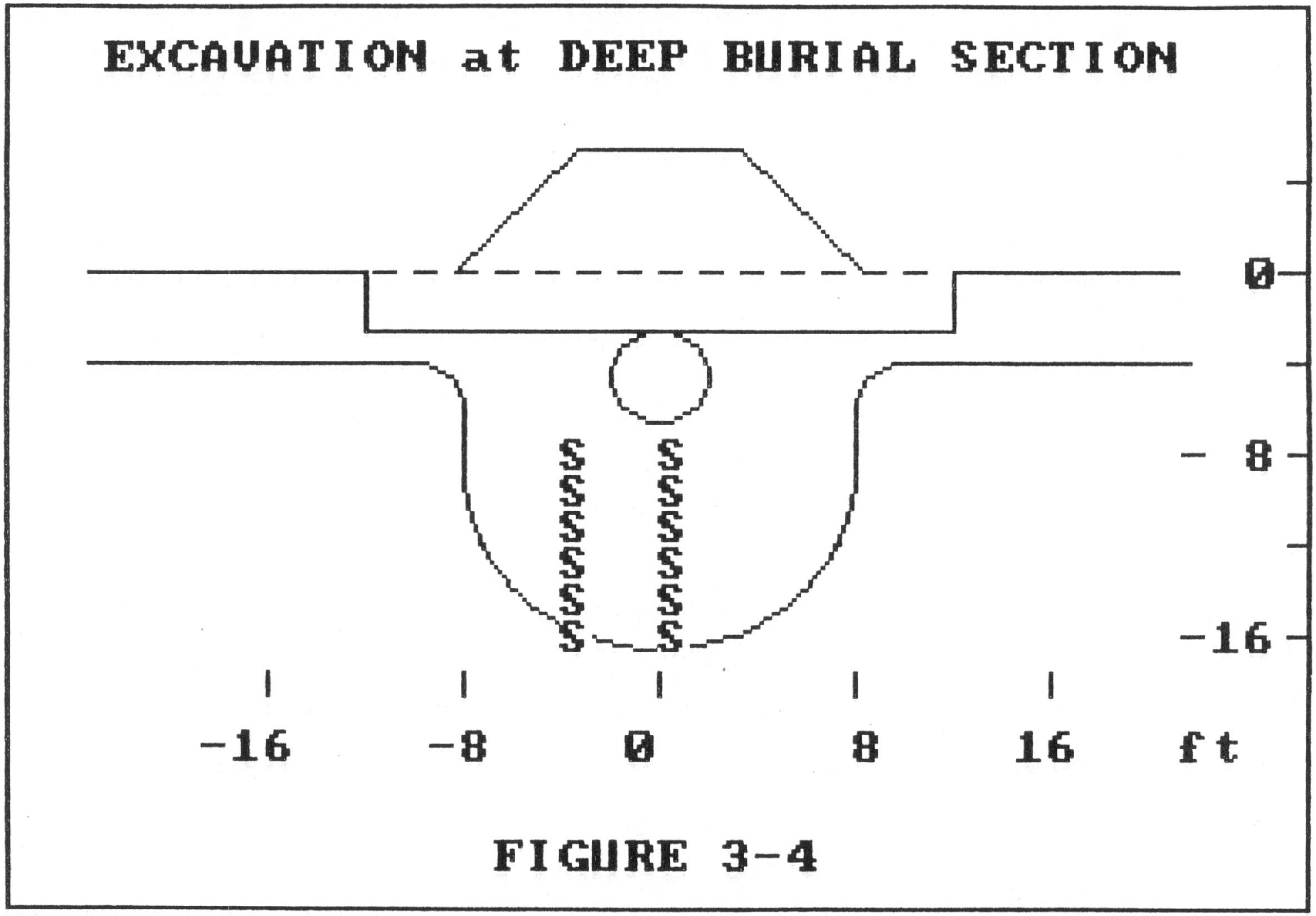


FIGURE 3-4

FIGURE 3-4

```
                 CALGARY FROST HEAVE TEST SITE STUDIES

                                              -- 1986 --
                                 1985!FEB!MAR!APR !MAY!JUN!JUL !AUG!SEP!
                                 ---------------------------------------
                                !    !   !   !    !   !   !    !   !   !!
A)  PIPE LEAK DETECTION        E! AA !   .   .    .   .   .    .   .   . !
                               L! aa !   .   .    .   .   .    .   .   . !
                                !    !   .   .    .   .   .    .   .   . !
B)  GEOPHYSICS                 E!    !B  .   .    .   .   .    .   .   . !
                               L!    !b  .   .    .   .   .    .   .   . !
                                !    !   .   .    .   .   .    .   .   . !
C)  DRILLING                   E!    ! C .   .    .   .   .    .   .   . !
                               L!    ! c .   .    .   .   .    .   .   . !
                                !    !   .   .    .   .   .    .   .   . !
D)  EXCAVATE FROST BULBS       E!    !  DDD  .    .   .   .    .   .   . !
                               L!    !  dddddd    .   .   .    .   .   . !
                                !    !   .   .    .   .   .    .   .   . !
E)  NATURAL THAWBACK           E!    !EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE  . !
                               L!    !eeeeeeeeeeeeeeeeeeeeeeeeeeeeeee  . !
                                !    !   .   .    .   .   .    .   .   . !
                                !    !   !   !   .!  .!  .!   .!  .!  .!!
                                 ---------------------------------------
                                      E=EARLY START    L=LATE START
```

FIGURE 5-1

APPENDIX 1

APPENDIX 1

This appendix contains a list of the people and agencies who were contacted, by telephone, and contributed to the studies outlined in the report.

1. Foothills Pipe Lines - Mr. D. Fielder & Mr. R. Laithwaite

2. Geotechnical consultants

   EBA Engineering Consultants Ltd. - Dr. C.T. Hwang
   Hardy Associates (1978) Ltd. - Dr. J.F. Nixon &
   Dr. W. Slusarchuk

3. Government Departments

   Energy Mines & Resources - Dr. A. Judge
   NEB - Mr. K.W. Vollman
   NRC - Dr. T.H.W. Baker
   Terrain Science - Dr. A. Higgenbottom
   Indian Affairs - Mr. M. Barnette

4. Universities

   U of Alberta - Dr. N. Morgenstern
   Carleton - Dr. P.J. Williams
   Ecole Polytechnique - Dr. B. Ladanyi