PIPE HEAVE AND BENDING STRAIN DATA

FOR THE

CAEN FROST HEAVE

TEST FACILITY

by

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FOREWORD

The Geotechnical Science Laboratories (GSL) of Carleton University, funded by Energy, Mines and Resources Canada, has been operating and collecting data at the joint Canada-France chilled buried pipeline test facility since 1982. This ground freezing experiment is being carried out at the "station de gel" at the Centre de Geomorphologie, Caen, France.

Substantial analyses of the thermodynamics of the freezing soils and of their creep properties, have been carried out and reported by the Geotechnical Science Laboratories. Large volumes of data have been presented in the form of GSL internal reports and conference papers (see Bibliography).

Test data can be catagorized into two groups:

1) Data on the elevation changes (heave or settlement) of the pipe and its corresponding bending strains.

2) Data on the soil temperature, heave and pressure buildup around the pipe.

The current report presents and describes databases for the group 1 data. The database HEAVE.WK1 presents the relative pipe elevation changes for the four freeze-thaw periods up to July 1988. The corresponding pipe bending strain data is presented in the database STRAIN.WK1. The databases which are Lotus 1-2-3 worksheets are described in chapter 2.

Sample plots of

Pipe heave time history of selected measuring stations,

Pipe bending strain time history of selected measuring stations,

Pipe profile at selected times during the 3rd freeze period,

Pipe bending strain along the pipe at selected times during the 3rd freeze period,

are presented to give an overview of the data.

The data bases reported here have been prepared with the assistance of Geotechnical Science Laboratories staff.

1.0 INTRODUCTION

The Geotechnical Science Laboratory of Carleton University has been funded by Energy, Mines and Resources Canada to participate in a joint Canada-France investigation of the effects of frost heave around a cold pipeline.

This ground freezing experiment is being carried out at the "station de gel" at the Centre de Geomorphologie, Caen, France. A detailed description of the test facility and initial set-up of the experiment is given in the Carleton Geotechnical Science Laboratory internal report number IR-29 (Burgess et al (1982)).

The project is a multi-disciplinary study involving many aspects of soil freezing/thawing as well as the particular effects unique to soil freezing associated with a buried pipe. The investigation of stresses developed in a pipeline, and of the complex soil-structure interactions which occur when a chilled pipeline traverses two soils of different frost susceptibility, is an integral part of the study.

The main focus of the Caen project was to undertake a full scale experiment with precise control of the physical, thermal and hydrological conditions. The experiment does not attempt to model any particular field situation or pipeline foundation design.

The Caen project started in early 1982, with the first freeze period commencing on 21 September 1982. Resulting data from this and the subsequent freeze/thaw periods has been presented in several Carleton Geotechnical Science Laboratory internal reports (IR-29, IR-33, IR-36, IR-43, IR-50, IR-51, IR-54) and in Dallimore et. al. (1984).

Databases of both the pipe elevation data and the pipe strain data are presented in the form of Lotus 1-2-3 spreadsheets for use on personal computers. Details of the databases will be presented in section 2.

1.1 TEST FACILITY

The facility consists of a refrigerated hall 18 m long, 8 m wide and 5 m high with adjacent rooms to accommodate instrumentation and mechanical equipment. The base or trough of the hall, shown in Figures 1.1 and 1.2, is 1.75 m deep and has been specially prepared for the experiment in order to isolate the thermal and hydraulic regime from natural conditions. This isolation allows control of experimental air and ground temperatures and water table level conditions. Different soil types have been placed in each half of the trough. An 18 m long, 273 mm diameter buried steel pipeline with an independent refrigeration system was used to freeze the ground.

1.2 CHARACTERISTICS OF SOIL MATERIALS

The pipeline is buried with 33 cm of cover in a frost susceptible silt and a non-frost susceptible sand. The Caen silt is eolian in origin and is composed of about 3 to 10 percent sand (2-0.076 mm), 75 to 85 percent silt (0.076-0.002 mm). and 10 to 20 percent clay (<0.002 mm). It has a low plasticity and can be designated as ML by the Unified Soil Classification System.

The S.N.E.C. sand is fluvial in origin and is composed of about 10 to 20 percent gravel (10-2 mm), 70 to 85 percent sand (2- 0.076 mm) and trace amounts of silt. It is poorly graded and can be classified as SP by the Unified Soil Classification system.

The two soils were placed in the trough in 300 mm lifts compacted to an approximate dry density of 1,700 kg/m*m*m for the Caen silt and 1,850 kg/m*m*m for the SNEC sand. A large number of laboratory tests have been carried out on the soils to determine heaving character, thermal properties, salt content, frozen soil strength, creep behavior and mineralogy (see Burgess et a 1982 and Geotechnical Science Laboratories 1983, IR-36)

The unfrozen water content characteristics of the two soils has been determined by time-domain reflectometry and by the suction-moisture content relationship. A summary of the results showing unfrozen water content vs. temperature is presented in Dallimore & Williams (in Pipelines and Frost Heave, 1984).

1.3 INSTRUMENTATION

The experiment is heavily instrumented and a large number of readings are taken on a regular schedule. Burgess et al (1982) outline the main types of instruments and present a summary of the frequency of readings. Included are thermocouples and heat flux meters which are monitored automatically with a data acquisition unit. Regular measurements are also taken manually of thermistors, water levels, surface levelling, tensiometers, pressure cells, telescopic heave tubes, magnetic heave detectors, frost depth tubes, TDR moisture content probes, pipe deflection, pipe curvature and pipe strain. Periodic measurements include temperature soundings, soil density profiling and gravimetric water content determinations. Where possible, all data is entered into a micro-computer on site. It is then transferred onto a magnetic tape which is sent to Canada and Paris for analysis.

1.4 OPERATING CONDITIONS

A timetable summarizing the operating conditions of the freeze and thawback cycles is seen in Table 1.1.

The first freeze period began on September 21, 1982 after preparation

of the facility, installation of the instrumentation, stabilization of ground water levels and cooling of the two soils. The operating conditions during the freeze period called for an ambient air temperature in the hall of -0.75 and an average pipe temperature of -2 C. The water table was regulated at an approximate depth of 90 cm. below the original ground surface (initially the water table had been maintained at 30 cm. depth but due to excessive heave of the pipe and only limited frost penetration, after 3 months it was lowered to 90 cm depth.) The first freeze period continued for 8 months until June 8, 1983.

A period of thawing of the ground surface followed the first freeze period. It continued for 4 months until October 1983. During this phase, the ambient air temperature in the hall was raised to +4 C, while the pipe temperature was held at -2 C. At the end of the thaw period a thin frozen soil zone remained below the pipe.

Following several modifications to instrumentation, a second freeze period was begun on October 17, 1983. The operating conditions were similar to the first freeze period except that the average temperature of the pipe was reduced to -5 C to increase the depth of frost penetration. The air temperature of the hall was set at -0.75 C and the ground water table was maintained at 90 cm below the ground surface. The second freeze period continued for 23 months until September 18, 1985.

The second thaw cycle lasted 5 month. During this thawback phase the pipe was not chilled therefore the ambient air temperature in the hall of +4 C completely thawed out the soil around the pipe.

Significant changes in instrumentation were made for the third freeze cycle in order to provide additional information on the soil freezing and frost heave process. They are outlined in IR-54 (1986). This third freeze period lasted 12 months from March 3, 1986 to February 25, 1987. Pipe temperature was maintained at -5.25 C with an ambient air temperature of -0.75 C.

A third thaw period, having identical thermal conditions to the second one, lasted three months. It was followed by a seven month shutdown of the facility.

A fourth freeze period, which commenced January 4 1988 is currently in its 12 th month. Thermal conditions of -5.25 C for the pipe air temperature and -0.75 C for the ambient air are identical to those for the previous freeze period. Some newly-constructed measuring equipment (see IR-55 (1988)) was installed for examination of ground stress conditions.

2.0 PIPE ELEVATION AND BENDING STRAIN DATA

2.1 PIPE ELEVATION DATABASE (HEAVE AND SETTLEMENT)

Pipe heave/settlement over the four cycles is seen in Figure 2.1, for selected stations along the pipe. A list of the heave rod locations is seen in Table 2.1.

Typical pipe profile data are shown in Figure 2.2. These plots are for selected dates of the 3rd freeze period.

The database HEAVE.WK1 presents the relative pipe elevation changes for the four freeze-thaw periods up to July 1988. The database is a Lotus 1-2-3 worksheet. A schematic layout of the spreadsheet is given in Figure 2.3.

2.2 PIPE BENDING STRAIN DATABASE.

Bending strain readings for gauge pairs JA06 and JA17 are seen in Figure 2.4 for the four cycles. These locations showed the maximum bending strains. Strain gauge pair locations are presented in Table 2.1.

Typical pipe bending strain values along the pipe are seen in Figure 2.5. This plot is also for selected dates of the 3rd freeze period.

The database STRAIN.WK1 presents the pipe bending strain data for the four freeze-thaw periods up to July 1988. This database is also a Lotus 1-2-3 worksheet. A schematic layout of the spreadsheet is given in Figure 2.6.

3.0 BIBLIOGRAPHY

Dallimore,S.R., and Williams, P.J., editors, 1984. Pipelines and Frost Heave. Proceedings of a Seminar at Caen, France April 25-27, 1984.

IR-29, 1982. Burgess et. al. Investigation of Soil Freezing in association with a Buried Chilled Pipeline in a Large-Scale Test Facility - Phase I, and Feasibility Study for Stress in a Pipeline Buried in a Freezing Soil.

IR-33, 1983. Investigation of Soil Freezing in Association with a Buried Chilled Pipeline in a Large-Scale test Facility. A report by Geotechnical Science Laboratory, Carleton University, for dept. of Energy Mines and Resources, Earth Physics Branch.

IR-36, 1984. Analysis of Stresses Developed in Pipelines Buried in Freezing Ground. A report by Geotechnical Science Laboratory, Carleton University, for dept. of Energy Mines and Resources, Earth Physics Branch.

IR-43, 1985. Analysis of Stresses Developed in Pipelines Buried in Freezing Ground. A report by Geotechnical Science Laboratory, Carleton University, for dept. of Energy Mines and Resources, Earth Physics Branch.

IR-50, 1986A. Investigations of Frost Heave as a Cause of Pipeline Deformation. A report by Geotechnical Science Laboratory, Carleton University, for dept. of Energy Mines and Resources, Earth Physics Branch.

IR-51, 1986B. Thermodynamics and Mechanics of Freezing Soil Around a Pipeline. A report by Geotechnical Science Laboratory, Carleton University, for dept. of Energy Mines and Resources, Earth Physics Branch.

IR-54, 1988. The Third Freeze cycle of the Canada-France Ground Freezing Experiment. A report by Geotechnical Science Laboratory, Carleton University, for Permafrost Research Section, Terrain Sciences division, Geological Survey of Canada.

TABLE 1.1 TIMETABLE OF EVENTS

EVENT	DATE FROM	DATE TO	OPERATING CONDITIONS AIR/GROUND TEMP.(C)	OPERATING CONDITIONS PIPE TEMP.(C)
FIRST FREEZE	21 SEP 82	8 JUN 83	-0.75	-2.0
FIRST THAW	8 JUN 83	17 OCT 83	4.0	-2.0
SECOND FREEZE	17 OCT 83	18 SEP 85	-0.75	-5.0
SECOND THAW	18 SEP 85	1 FEB 86	4.0	AMBIENT
THIRD FREEZE	3 MAR 86	25 FEB 87	-0.75	-5.25
THIRD THAW	25 FEB 87	21 MAY 87	4.0	AMBIENT
FOURTH FREEZE	6 JAN 88	---------	-0.75	-5.25

TABLE 2.1 LOCATION OF DISPLACEMENT RODS AND STRAIN GAUGE PAIRS

	DISPLACEMENT RODS	STRAIN GAUGE PAIRS	LOCATION ALONG PIPE [METRES]
SILT END	NP01		-7.37
		JA01	-7.05
	NP02		-6.20
	NP03		-5.70
		JA02	-5.62
	NP04		-5.20
	NP05		-4.70
		JA03	-4.33
	NP06		-4.20
	NP07		-3.70
		JA04	-3.59
	NP08		-3.20
		JA05	-3.00
	NP09		-2.70
		JA06	-2.33
	NP10		-2.20
	NP11		-1.70
		JA07	-1.49
	NP12		-1.20
		JA08	-1.09
		JA09	-0.79
	NP13		-0.70
		JA10	-0.48
	NP14		-0.20
		JA11	-0.09
	NP15		0.00
		JA12	0.14
	NP16		0.30
		JA13	0.54
	NP17		0.80
		JA14	0.90
		JA15	1.24
	NP18		1.30
		JA16	1.60
	NP19		1.80
	NP20		2.30
		JA17	2.35
	NP21		2.80
		JA18	3.05
	NP22		3.30
		JA19	3.64
	NP23		3.80
	NP24		4.30
		JA20	4.40
	NP25		4.80
	NP26		5.30
		JA21	5.68
	NP27		5.80
	NP28		6.30
SAND END		JA22	7.13
	NP29		7.36

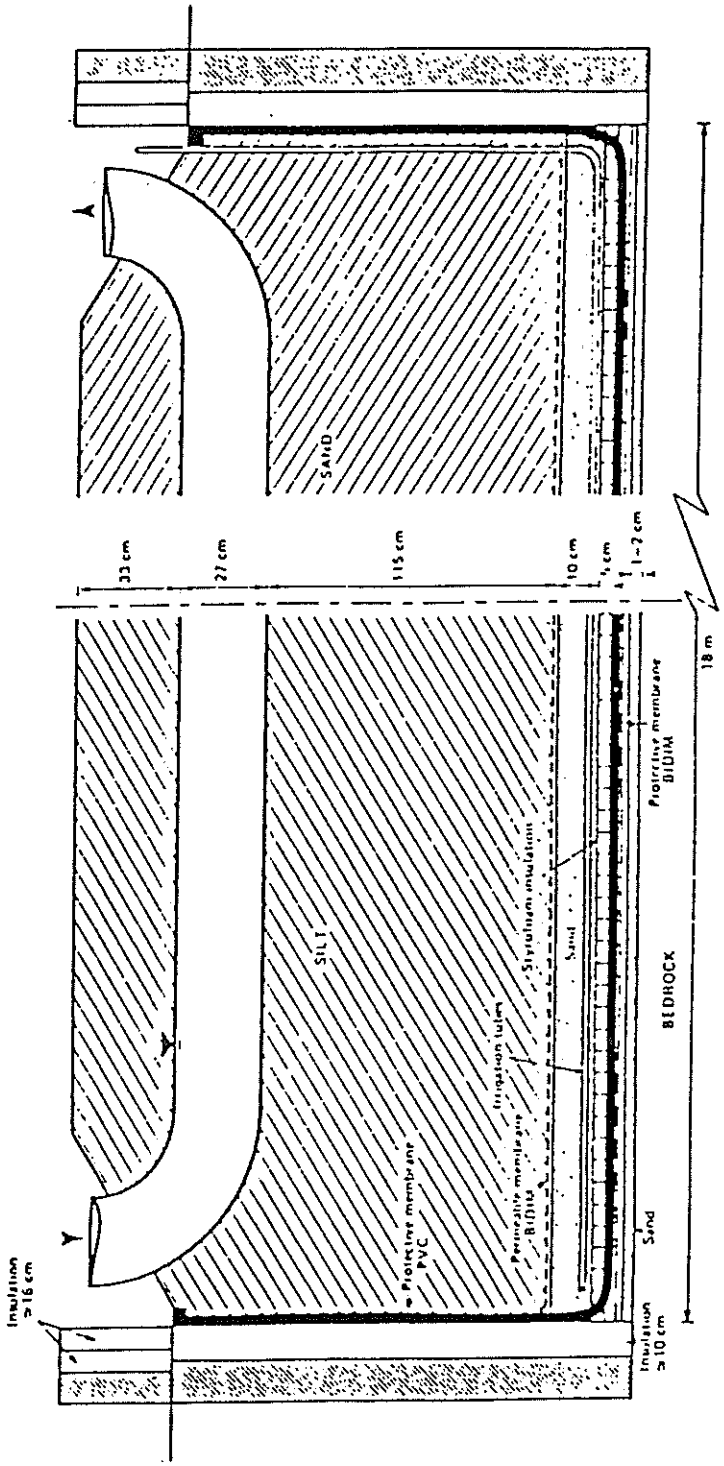

FIGURE 1.1 LONGITUDINAL SECTION OF TROUGH

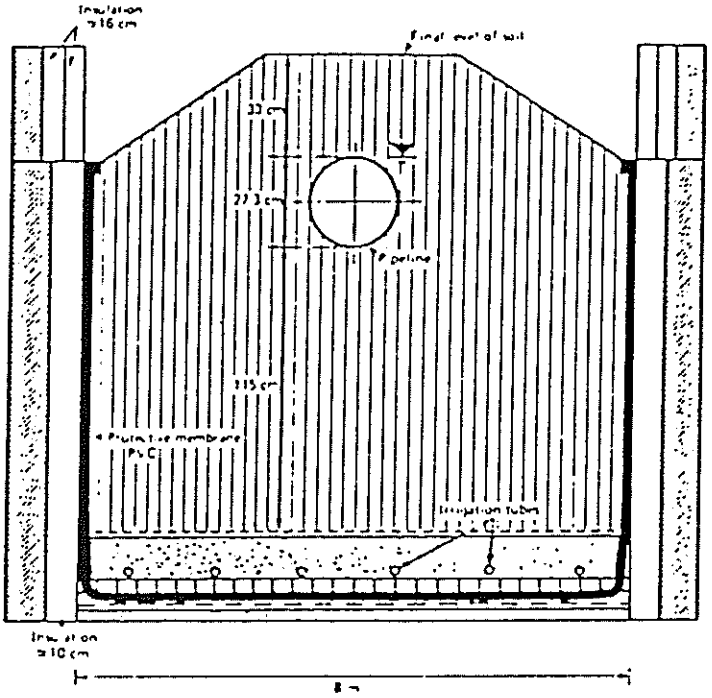

FIGURE 1.2 CROSS SECTION OF TROUGH

PIPE ELEVATION TIME HISTORY
NP04,NP08,NP12 & NP15

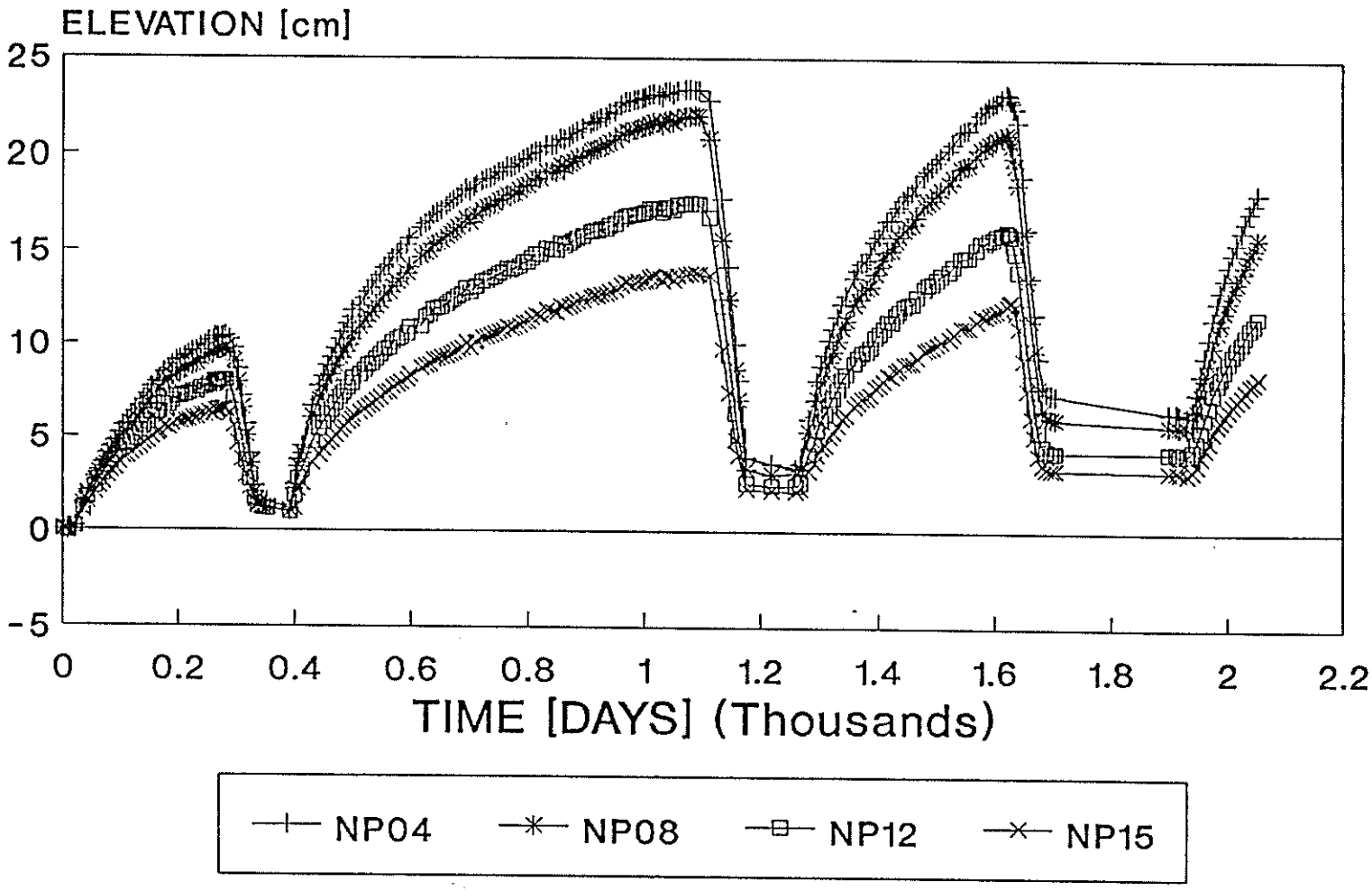

FIGURE 2.1

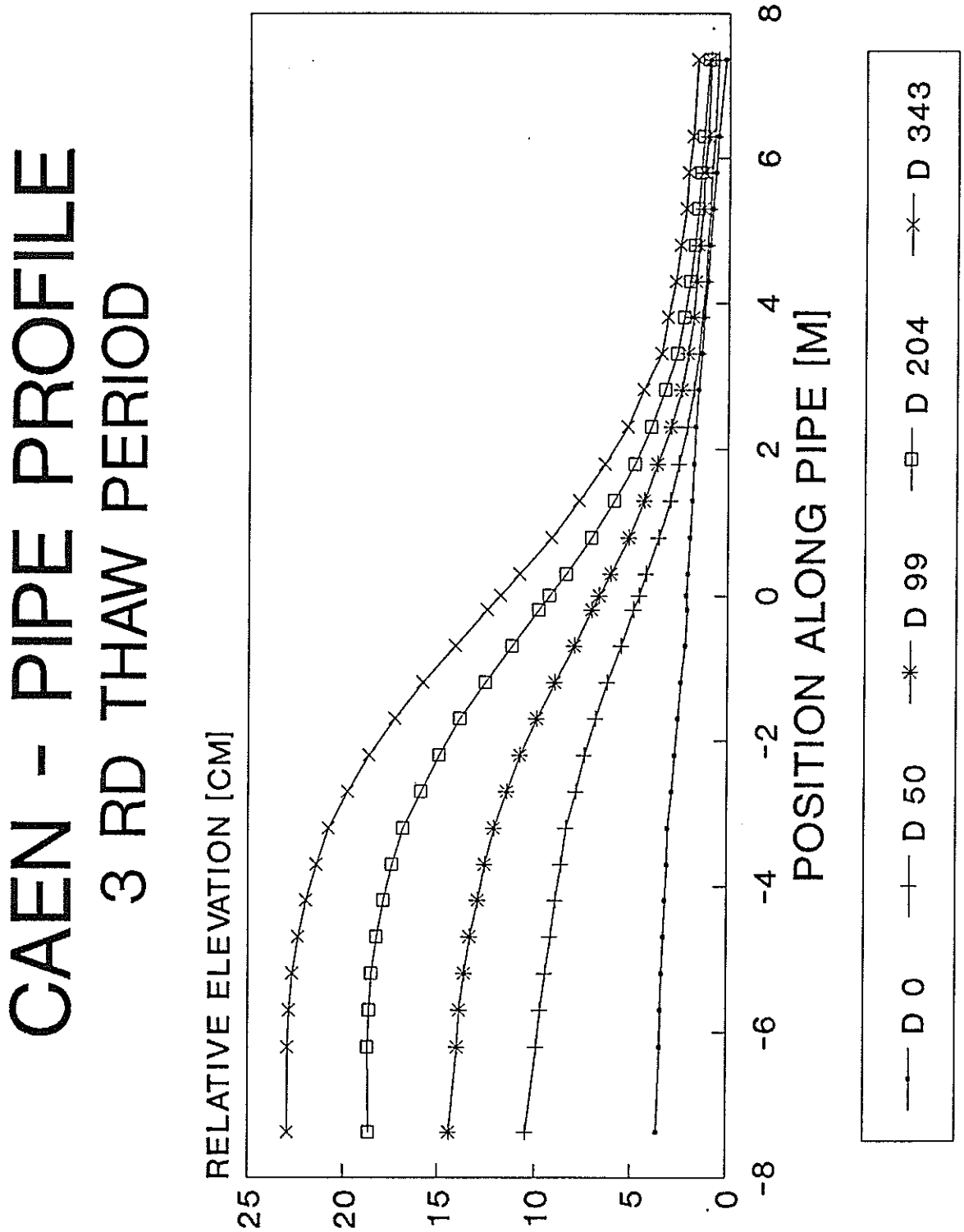
CAEN - PIPE PROFILE
3 RD THAW PERIOD
RELATIVE ELEVATION [CM]
25
20
15
10
5
0
-8
-6
-4
-2
0
2
4
6
8
POSITION ALONG PIPE [M]
D 0
D 50
D 99
D 204
D 343

FIGURE 2.2

FIGURE 2.3 LOTUS 1-2-3 SPREADSHEET FILE HEAVE.WK1

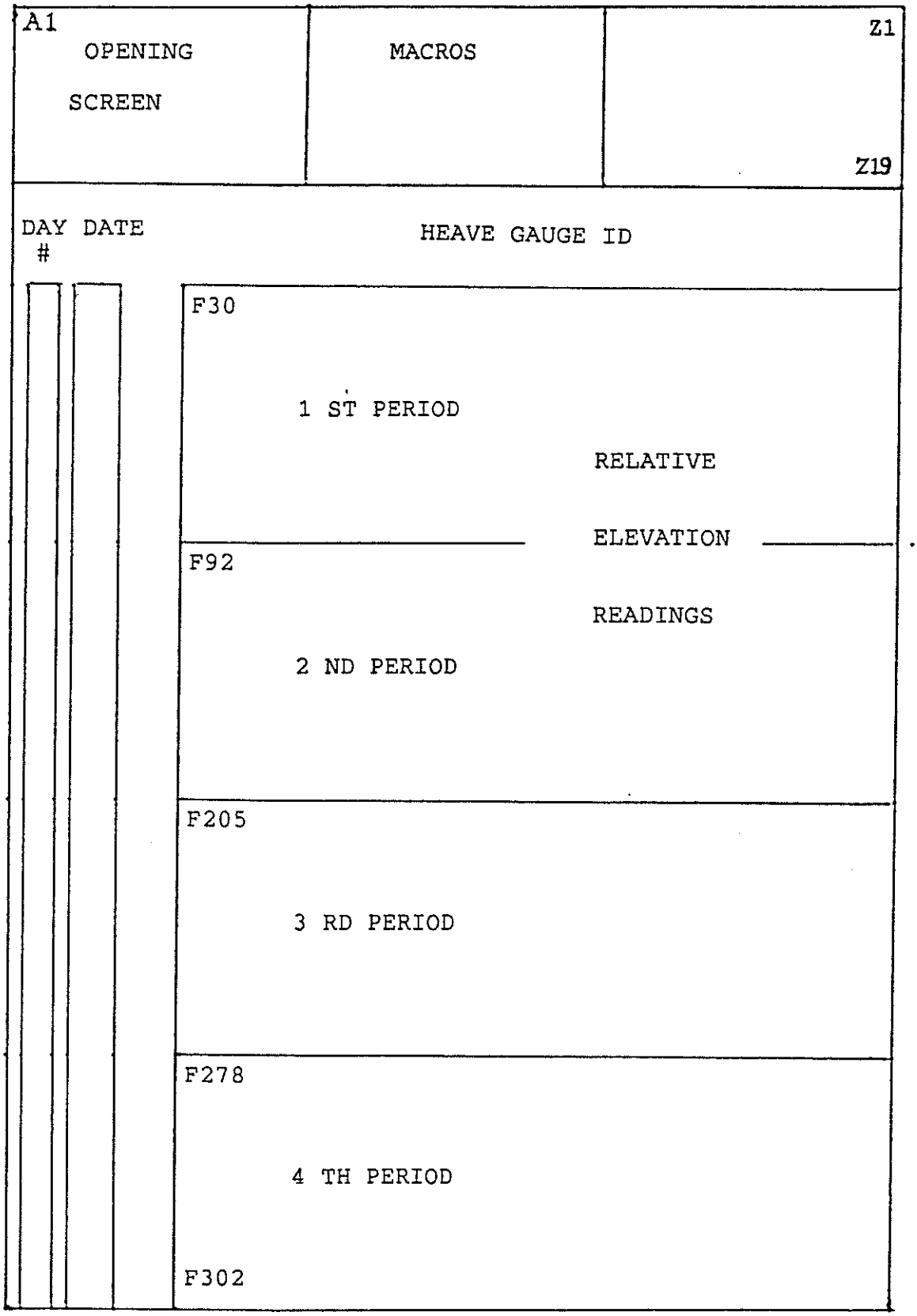

FIGURE 2.3B

FILE: HEAVE.WK1

OPTICALLY SURVEYED PIPE DEFORMATIONS FROM CAEN EXPERIMENT
RELATIVE PIPE ELEVATIONS ABOVE INITIAL ELEVATION (IN CM)

DATABASE COVERS 4 FREEZE-THAW CYCLES

DATA IS IN RANGES A23..AH302

CODE ==>			NP01	NP02	NP03	NP04	NP05	NP06
DISTANCE ==>			-7.37	-6.20	-5.70	-5.20	-4.70	-4.20
DAY								
1ST FREEZE COMMENCED 21 SEPT 1982								
0	0	21-Sep-82	0.00	0.00	0.00	0.00	0.00	0.00
2	2	23-Sep-82	-0.01	-0.02	-0.03	0.01	-0.01	-0.02
9	9	30-Sep-82	0.23	0.10	0.03	0.02	-0.04	-0.07
21	21	12-Oct-82	0.53	0.31	0.27	0.23	0.13	0.14
28	28	19-Oct-82	0.95	0.71	0.63	0.61	0.52	0.54
35	35	26-Oct-82	1.84	1.57	1.47	1.46	1.38	1.34
43	43	03-Nov-82	2.46	2.19	2.09	2.06	1.98	1.9
49	49	09-Nov-82	2.78	2.49	2.39	2.30	2.28	2.21
56	56	16-Nov-82	3.24	2.96	2.80	2.81	2.73	2.66
63	63	23-Nov-82	3.69	3.41	3.26	3.19	3.16	3.08
70	70	30-Nov-82	3.98	3.71	3.64	3.59	3.49	3.41
78	78	08-Dec-82	4.57	4.29	4.17	4.08	3.99	3.88
84	84	14-Dec-82	4.90	4.58	4.48	4.42	4.31	4.22
91	91	21-Dec-82	5.26	4.93	4.81	4.73	4.62	4.51
98	98	28-Dec-82	5.66	5.35	5.23	5.15	5.03	4.92
105	105	04-Jan-83	6.05	5.76	5.65	5.58	5.44	5.33
112	112	11-Jan-83	6.26	5.94	5.81	5.69	5.62	5.52
119	119	18-Jan-83	6.54	6.21	6.08	6.00	5.87	5.76
126	126	25-Jan-83	6.88	6.51	6.39	6.31	6.18	6.06
134	134	02-Feb-83	7.24	6.86	6.71	6.62	6.47	6.35
140	140	08-Feb-83	7.56	7.16	7.02	6.91	6.77	6.65

PIPE STRAIN TIME HISTORY
BENDING STRAIN, GAUGE PAIRS JA06 & JA17

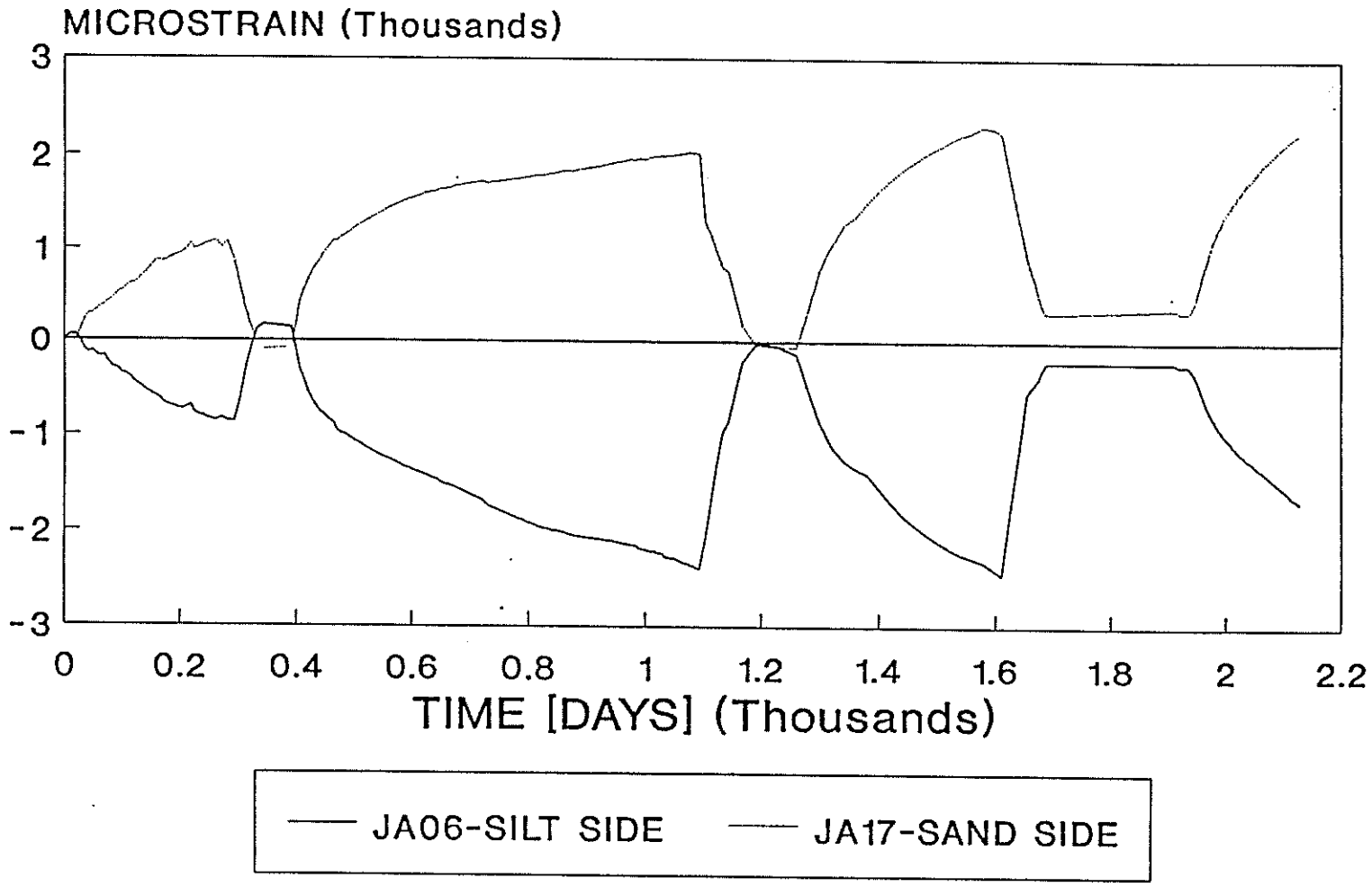

FIGURE 2.4

CAEN - STRAIN DATA
3RD FREEZE CYCLE

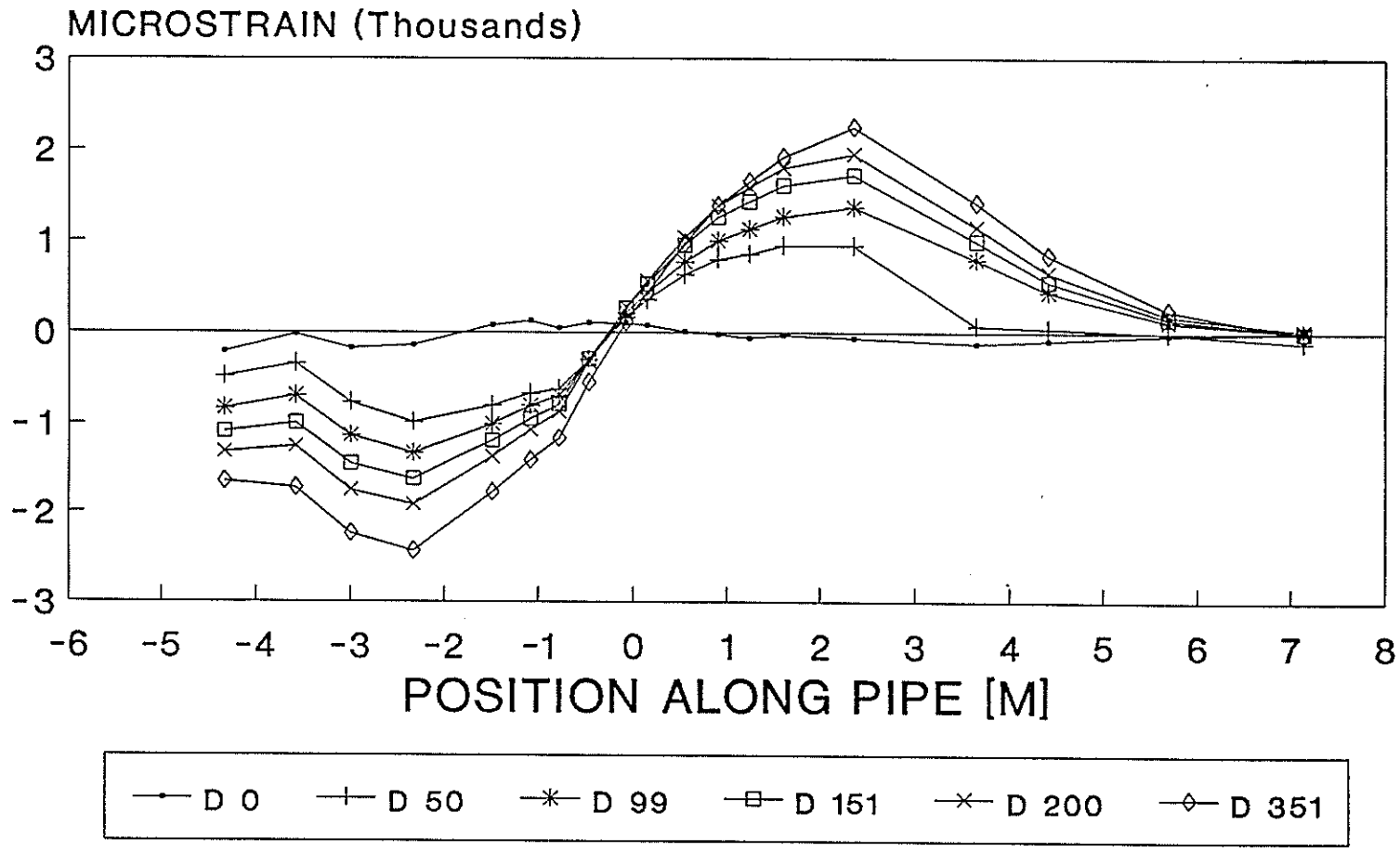

FIGURE 2.5

FIGURE 2.6 LOTUS 1-2-3 SPREADSHEET FILE STRAIN.WK1

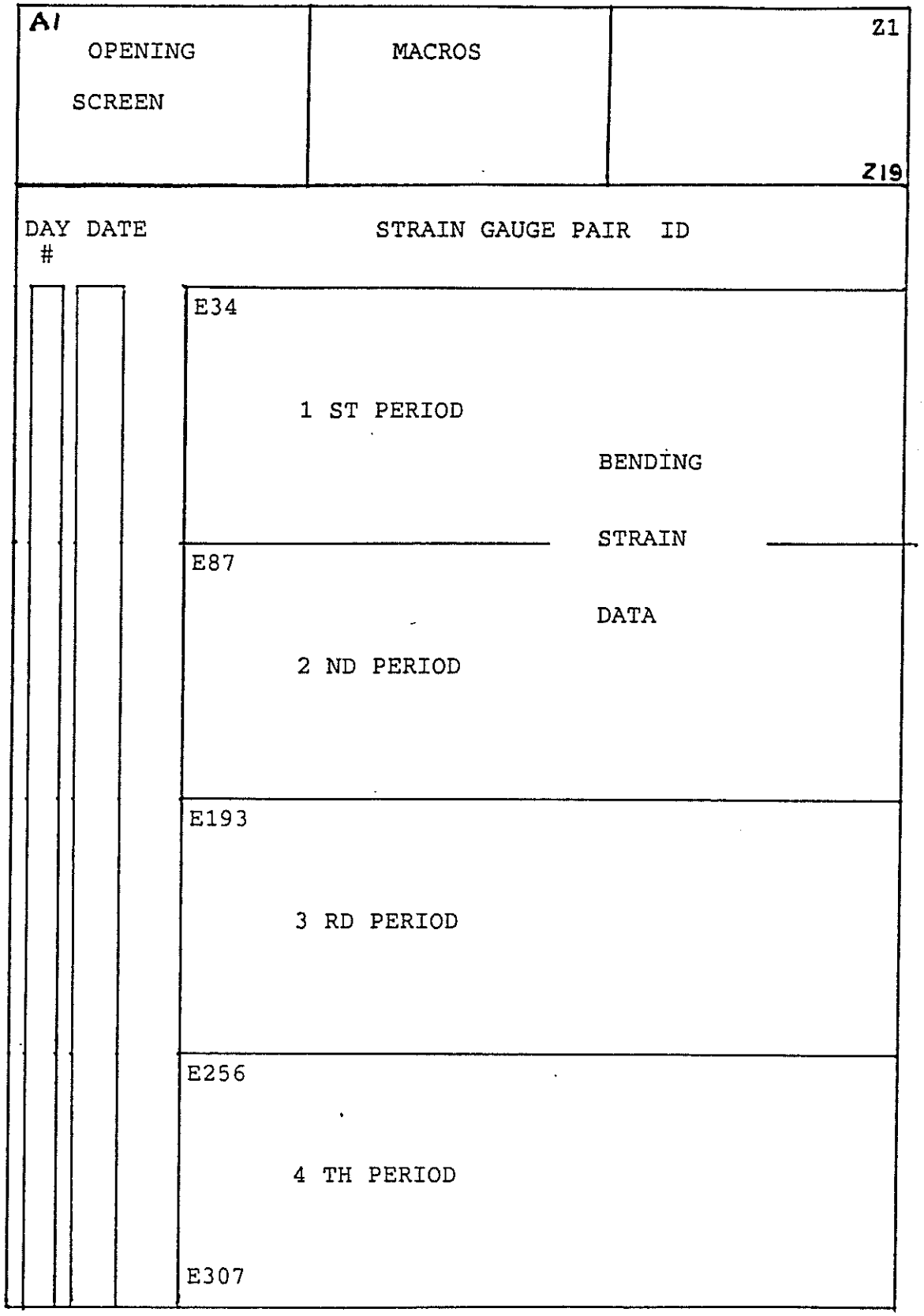

FIGURE 2.6B

FILE:STRAIN.WK1

CAEN EXPT. PIPE STRAINS

STRAIN VALUES ARE DIMENSIONLESS X 10E-6 (MICROSTRAIN)
YOUNGS MODULUS [E] = 200000 TO 210000 MPA
TO CONVERT TO STRESS : SIGMA = E * EPSILON / 2
(CONVERT MICROSTRAIN VALUES IN TABLE TO BENDING STRAIN (MPA)
..... BY MULTIPLYING VALUE BY 0.1 .....)

STRAIN DATA IS IN RANGE A26 to Y310

NEGATIVE DISTANCE IS IN SILT

	DISTANCE IN METRES FROM SAND-SILT TRANSITION		GUAGE I.D. JA01 -7.05	JA02 -5.62	JA03 -4.33	JA04 -3.59
1ST FREEZE	DAY	DATE				
	0	21-Sep-82	0	0	0	0
	6	27-Sep-82	40	80	106	58
	13	04-Oct-82	36	72	68	52
	20	11-Oct-82	80	155	156	81
	27	18-Oct-82	107	185	160	85
	35	26-Oct-82	98	199	169	76
	42	02-Nov-82	106	208	150	42
	49	09-Nov-82	122	222	144	28
	56	16-Nov-82	105	214	137	25
	63	23-Nov-82	83	198	130	16
	70	30-Nov-82	74	174	116	16
	77	07-Dec-82	70	166	112	16
	84	14-Dec-82	77	183	126	19
	93	23-Dec-82	82	192	130	23
	101	31-Dec-82	60	180	121	19
	108	07-Jan-83	74	192	120	12
	115	14-Jan-83	75	138	122	41