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INVESTIGATION OF SOIL FREEZING IN ASSOCIATION WITH A BURIED CHILLED PIPELINE IN A LARGE SCALE TEST FACILITY - PHASE 2

GEOTECHNICAL SCIENCES LABS
Carleton University

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Résumé

Ce volume décrit la deuxième année du projet de recherche France-Canada à la station expérimentale de gel à Caen. Les caractéristiques des systèmes de mesure et les conditions de mise en oeuvre ont été décrites dans un premier rapport (dossier public 82-18). Durant cette dernière année la circulation de l'air réfrigéré dans le pipe a causé une pénétration d'un front de gel dans le sol, au préalable à température positive. Les changements de température, les mouvements d'eau, la croissance d'un front de gel annulaire, les changements morphologiques de la surface, les champs de contrainte et les déformations du pipe qui en sont résultés, ont tous été mesurés. Le front de gel a pénétré de 0.3 à 0.5 m sous l'axe du pipe, au cours des 250 journées depuis le début de la réfrigération. Le contraste dans la réfrigération et la croissance de glace dans les deux sols (de différente susceptibilité au gel) a entraîné un gonflement différentiel du pipeline de plus de 11 cm sur une distance horizontale de 16 m. Le gradient de déplacement vertical par rapport à la distance horizontale est aux environs de 1:100 dans la zone de transition entre les deux sols.

Abstract

The report describes the second year of activities under the Canada-France joint research program at the controlled environment facility in Caen. The initial report (Open File 82-18) described the initial instrumentation and preparation of the facility. In the past year chilled air was circulated through the pipe causing the previously unfrozen ground to freeze. The ensuing changes in temperature of the ground, the redistribution of water, the growth of a frost bulb, changes in surface morphology and the resulting stress on and deformation of the pipe, have all been monitored. Frost has penetrated to 0.3 to 0.5 m below in the centreline of the pipe in the 250 days since commencement of chilling. Differential freezing and ice aggradation in the two lithological units of very different frost susceptibility has led to a differential displacement of the pipe of 11 cm over a horizontal distance of 16 m. At the boundary between the two units the vertical to horizontal displacement gradient is approximately 1 in 100.

FINAL REPORT

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AND INTERIM REPORT

ANALYSES OF STRESSES DEVELOPED IN PIPELINE BURIED IN FREEZING GROUND[2]

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AND

(INTERIM REPORT)

ANALYSES OF STRESSES DEVELOPED IN PIPELINE BURIED IN FREEZING GROUND[2]

SUBMITTED
TO

ENERGY, MINES AND RESOURCES
EARTH PHYSICS BRANCH

BY

GEOTECHNICAL SCIENCE LABORATORIES
DEPARTMENT OF GEOGRAPHY
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AUGUST 1983

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FOREWORD

This report describes work carried out during the second year of the joint Canada - France project: "The Behaviour of Buried Pipelines under Negative Temperatures" and it constitutes the final report under contract OSU82-00294. "Investigation of Soil Freezing in Association with a Buried Chilled Pipeline in a Large-Scale Test Facility", Principal Investigator P.J. Williams, Co-Principal Investigator M.W. Smith. The report also includes the interim report for the contract: "Analysis of Stresses Developed in Pipeline Buried in Freezing Ground", Principal Investigator P.J. Williams, which terminates December 31, 1983.

Early in the year the experiment was brought into full operation. The freezing of the ground around the pipe caused significant deformations. Conditions in the pipe and ground were recorded in detail and analysis commenced. The project is continuing with a further period of freezing commencing in September, following a period of summer thaw.

Readers interested in the preliminary stages of the work are referred to earlier reports (Burgess et al 1982, Geotechnical Science Laboratories, 1982) on the project.

This report has been mainly prepared by David Halliwell and Scott Dallimore of the Geotechnical Science Laboratories Carleton University. Additional details of the Canadian personnel involved at the facility are given at the end of the report.

The France-Canada project as a whole is supervised by a scientific committee: Members affiliations indicate the contributing institutions which were involved in the Memorandum of Agreement for the Canada-France project:

Jaime Aguirre-Puente, Laboratoire d'Aerothermique, Centre National de la Recherche Scientifique;

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P.J. Williams

Principal Investigator

August, 1983

1. Introduction

1.1 General

This report presents an overview of results from an on-going Canada-France research project studying the interaction between a buried pipeline and the surrounding soil material during freezing and thawing conditions. The project is being undertaken in a large scale temperature-controlled facility in Caen, France. This facility was originally constructed by the French government for studying seasonal freeze-thaw problems relating to highway construction (Philippe et al, (1970). The facility has been refurbished and modified for its use in the present project. A report describing the experimental model, preparation of the test facilities and instrumentation, and related laboratory testing has already been submitted for Phase 1 of this project (Burgess et al, 1982).

Much of the work regarding pipe stress and soil mechanical properties in the experimental model is being carried out under an associated contract "Feasibility Study for Stresses in a Pipeline Buried in Freezing Soil". A report detailing instrumentation and analytical procedures for these aspects of the experiment has been submitted to Department of Energy, Mines and Resources, Earth Physics Branch (Geotechnical Science Laboratories, 1982).

This report describes the course of the experiment over the last year, from the beginning of the freeze cycle in September 1982 to the beginning of the thaw cycle in the summer of 1983. The collected data are summarised to describe the important features of the experiment.

Detailed analysis and interpretation is being carried out and will be presented in subsequent publications. Detailed descriptions of the experimental model and facilities are available in the earlier reports.

1.2 Background to the Experiment

This project is a response to the need for fundamental knowledge of freeze-thaw phenomena relating to chilled gas pipelines in arctic and sub-arctic environments. The facility in Caen, France provides a temperature-controlled room 8m X 18m which can be filled with soil to a depth of 2m. A 273 mm diameter pipeline is buried across a transition between a sandy soil (slightly frost susceptible) and a silt soil (highly frost susceptible). This indoor environment has two advantages over an outdoor field site:

1) natural variations in hydrologic, thermal, and physical soil conditions can be largely eliminated, and initial conditions can be selected to suit the experiment;
2) the protected indoor environment allows a much more detailed and complex instrumentation set-up, which is required to provide the necessary fundamental knowledge for predictive models.

The experimental conditions were selected to simulate the autumn start-up of a chilled gas pipeline in an unfrozen area (discontinuous permafrost), with simultaneous cooling of soil at the surface and around the buried pipe. (Air temperatures and pipe temperatures are controlled independently). As a result of the differential heave between the two soils, and the high uplift resistance of the frozen sand, stresses develop in the pipe.

2. Experimental Conditions (September 1982 to July, 1983)

2.1 Operating Conditions

The initial conditions for the experiment called for soil temperatures approaching 0°C at the surface, in order to minimize temperature gradients and heat fluxes once freezing had started. A period of cooling from the surface preceded initiation of freezing, but time constraints precluded establishment of isothermal conditions (see Burgess et al, 1982). At the start of freezing, the water table was located at the top of the buried pipe.

Freezing from the surface was initiated on September 21, 1982. The air temperature in the room was lowered to -5°C for about 6 hours, then raised to -0.75°C. The short, intense cooling at the start was intended to assure nucleation of ice crystals in the soil, thus avoiding problems of supercooling. Freezing around the pipe was initiated on September 23, 1982 by lowering the gas (air) temperature in the pipe to -5°C for about 16 hours, after which the temperature was raised to -2°C. These temperatures of -0.75°C (room air) and -2°C (pipe air) were maintained for the duration of the freezing cycle except for very short interruptions.

For both room and pipe temperatures, the temperature of the circulating air was controlled rather than the ground surface or pipe surface temperatures. Surface temperatures were measured, but were not considered in adjusting the control systems. Room temperature was measured near the centre of the room using a thermocouple and a thermometer placed in a beaker of anti-freeze (which damped the temperature fluctuations). A thermocouple exposed directly to the air at the same location supplemented the damped value, giving an indication of the short-term variability. The exposed thermocouple fluctuated by up to $\pm$ 2^{o}C (higher during defrost cycles); while the damped measurement showed that temperatures averaged over a period of a few hours were stable to $\pm$ 0.5^{o}C. Some variation in room temperature could be seen due to large changes in outside air temperature. Pipe air temperature was measured at the two extremities, and the two values averaged. These two values were found to differ by up to 2^{o}C, due to the flux of heat into the pipe. Generally this difference was less than 1^{o}C. This difference would reverse each time the direction of air flow through the pipe was reversed (every 4 hours). The average pipe temperature was generally controlled to $\pm$ 0.5^{o}C. Variations in pipe temprature for periods of more than an hour were negligible (except during defrost cycles, when no air circulated).

During the first 2-3 weeks of operation, mechanical and frosting problems with the cooling systems caused several interruptions and irregularities in room and pipe temperatures. Occasional problems with the pipe refrigeration system persisted on a minor scale throughout the freeze cycle.

The water table was maintained at the top of the pipe by adding water at the base of the soil, through the hydraulic system. This was continued until the end of November (about 70 days after initiation of freezing) at which point it was decided to lower the water table to a depth of approximately 30cm below the base of the pipe (approximately 90 cm below the surface, or 60 cm below the original water table.) This was necessitated by the rapid rate of frost heave which was causing concern, as was the small rate of frost penetration to that time due to high water content. This was interpreted as being due to the continuing growth of a single ice lens adjacent to the pipe which, it was felt, was not the situation desired for the initial freezing cycle. Addition of water was halted, and for several weeks the water table was allowed to drop slowly, this being intended to halt the growth of the lens. In late December, pumping commenced in order to accelerate the drop of the water table. The new level was reached in late January 1983, and the addition of water was started again in mid-February to maintain this position. This level remained the same to the end of the freezing cycle. Throughout the experiment, occasional abrupt changes in water level were noted, possibly due to infiltration of water from outside the building during or after rainy periods, but generally the water levels were regulated to $\pm$ 3 cm.

On June 8, 1983 the room temperature was raised to $\pm$ 1°C for 24 hours, then to + 4°C to end the freeze cycle and commence to thaw the soil from the surface downward. Pipe temperature was left at -2°C in order to maintain an annulus of frozen soil around the pipe. These conditions are expected to be continued until September, 1983, when a new freezing cycle is planned to commence. During the first week of thaw, problems were encountered maintaining the pipe temperature at -2°C. The increased relative humidity in the warmer room led to rapid frosting in the pipe refrigeration system, inadequate refrigeration and poor circulation of the air in the pipe. This problem was rectified by modifying the defrost cycle. Further problems with pipe temperatures were encountered in July, when a period of 30-35°C outside temperatures caused repeated overloads of the pipe refrigeration system. The system underwent numerous automatic shutdowns which required manual resetting. On several occasions, this occurred during the night, and the system would be off for several hours.

2.2 Instrumentation and Readings

During the course of the experiment, a large number of readings were taken on a regular schedule. These readings were then supplemented by occasional measurements using additional instruments or procedures. Measurements taken on a regular basis are summarized in Table 1. Most thermal measurements were taken and recorded automatically, but all other measurements were performed manually. A number of microcomputer programs were written - mostly by French staff members in Caen - to stock a compilation of all data on floppy discs. The data will be transferred to magnetic tape for transmission to Canada.

After 10 months of continuous operation, nearly all sensors were still operating normally. Twelve thermistors (eleven in the silt) had been lost due to leads breaking as the soil heaved, and several markers for surface levelling had been disturbed. The capacitance probes for water content measurement mentioned in Burgess et al (1982) functioned only for a short period, and problems were encountered with one frost tube.

The most serious problem during the course of the experiment arose with the temperature data acquisition system (Solartron Orion) used for thermocouple readouts. The system was arranged to provide cold junction

Regime	Type of Sensor or Measurement	Number	Frequency of Readings	Comments
Thermal	Thermocouples (Iron/Constantan)	Approx. 160	every 4 hours	Read automatically by Solartron Orion data-logging system.
	Heat Flux Plates	5	every 4 hours	Read by same system as thermocouples.
	Thermistors	25	3 times per week	
	Frost Tubes	5	3 times per week	Indicate frost depth by colour change of organic dye.
Hydrologic	Piezometers	12	every day	Periodically supplemented by readings in 6 control wells.
	Tensiometers	20	3 times per week	
	Addition/removal of water		every day	Collected and measured defrost water from each of the three room ventilators and the pipe. Also recorded volume of water added at or pumped from base of pit.
	Time Domain Reflectometry (TDR)	28 horizontal 6 vertical	once per week	Electromagnetic measurement of volumetric unfrozen water content.
Pipe Deformation	Levelling (rods on pipe)	29 rods	once per week	Optical surveying.
	Rotation (rods on pipe)	29 rods	once per week	Angle measurement
	Curvature (rods on pipe)	24 points (3 rods each)	once per week	"curvature gauge" using finite difference approximation
	Strain guages	22 pairs (half-bridge) 2 rosettes (3 guages each)	2 times per week	Half bridge measures flexional strain only. Rosettes measure all strain components.

TABLE 1 INSTRUMENTATION SCHEME

Regime	Type of Sensor or Measurement	Number	Frequency of Readings	Comments
Physical Soil Parameters	Levelling (points on surface)	226 points	Axis and 2 cross-sections once per week. All points once per month.	All points referenced to fixed outside datum.
	Telescoping Tubes (Soil Heave)	38 in 4 sets	Once per week.	Nested tubes of various length, indicate relative movement of soil layers.
	Glotzl Earth Pressure Cells	15	3 times per week	
	Gamma Ray Probes	8 profiles in 2 cross-sections	Approx. every 4 months	Only 3 sets of measurements done to date. Gives profiles of total soil density. Buried PVC discs provide markers for soil heave estimation.

N.B. For a detailed description of sensor placement and measurement devices, see Burgess et al (1982) and Dallimore et al (1982).
The frequency of reading given here is typical over most of the duration of the experiment. Readings were taken more frequently during the first few weeks of freezing in September and October, 1982, and during the first few weeks of thaw in June, 1983.

TABLE 1 INSTRUMENTATION SCHEME (CONT'D)

compensation on the connectors at the rear of the instrument. During a period of particularly cold weather in Caen in February, it became evident that temperature readouts in the pit were showing diurnal variations which could not be real. Testing indicated that the problem originated in the data acquisition system, due to rapid changes in temperature in the instrumentation room. Improved temperature regulation in the room greatly reduced the problem of variations, but continued testing indicated that the method of cold junction compensation was inadequate. Efforts continued until June to ameliorate the temperature conditions around the connectors of the data system, but it was eventually concluded that all cold junctions would have to be transferred to an external reference point. The series of tests carried out indicated that overall accuracy of the thermocouple readouts during the period described in this report was likely no better than several tenths of a degree.

Supplemental readings not presented in Table 1 include; temperature soundings in small-diameter plastic tubes embedded in the soil, temperature measurements in plastic cups filled with antifreeze placed at various positions on the surface (to monitor areal variations in air temperature), measurement of the growth of fissures at the surface due to differential settlement during thaw, gravimetric determinations of water content versus depth prior to thaw, and thaw depths determined by probing with a small diameter rod. The results of some measurements indicated possibilities for other, future measurements: for example, problems encountered during gamma ray measurements around the pipe, as a result of horizontal deformation of the access tubes, suggested a possible means of measuring horizontal heave components.

Several examples of data collected during this period, along with a qualitative discussion of some of the more salient features, is given in the following section.

3. Data Presentation

3.1 General

The data presented in this section has been chosen to illustrate some of the more important results of the experiment between the start of the freeze cycle in the fall of 1982 and the end of the contract period on June 30, 1983. Since eight of the nine months during the period were occupied by the freeze cycle, primary emphasis has been given to the period between the start of the freezing on September 22, 1982 and the beginning of the thaw on June 8, 1983. A complete analysis of the results of the thaw period of the experiment will be discussed in later reports. A location plan of the experiment arrangement is shown in fig. 3.1, showing instrumentation and location of cross-section with particular instrumentation.

3.2 Thermal Regime

The analysis of the thermal regime during the course of the experiment was complicated by the unreliability of some of the temperature measurements as recorded by the data acquisition system. (See Section 2.2). The figures relating to the thermal regime represent the best estimate from all of the available thermal data. The accuracy

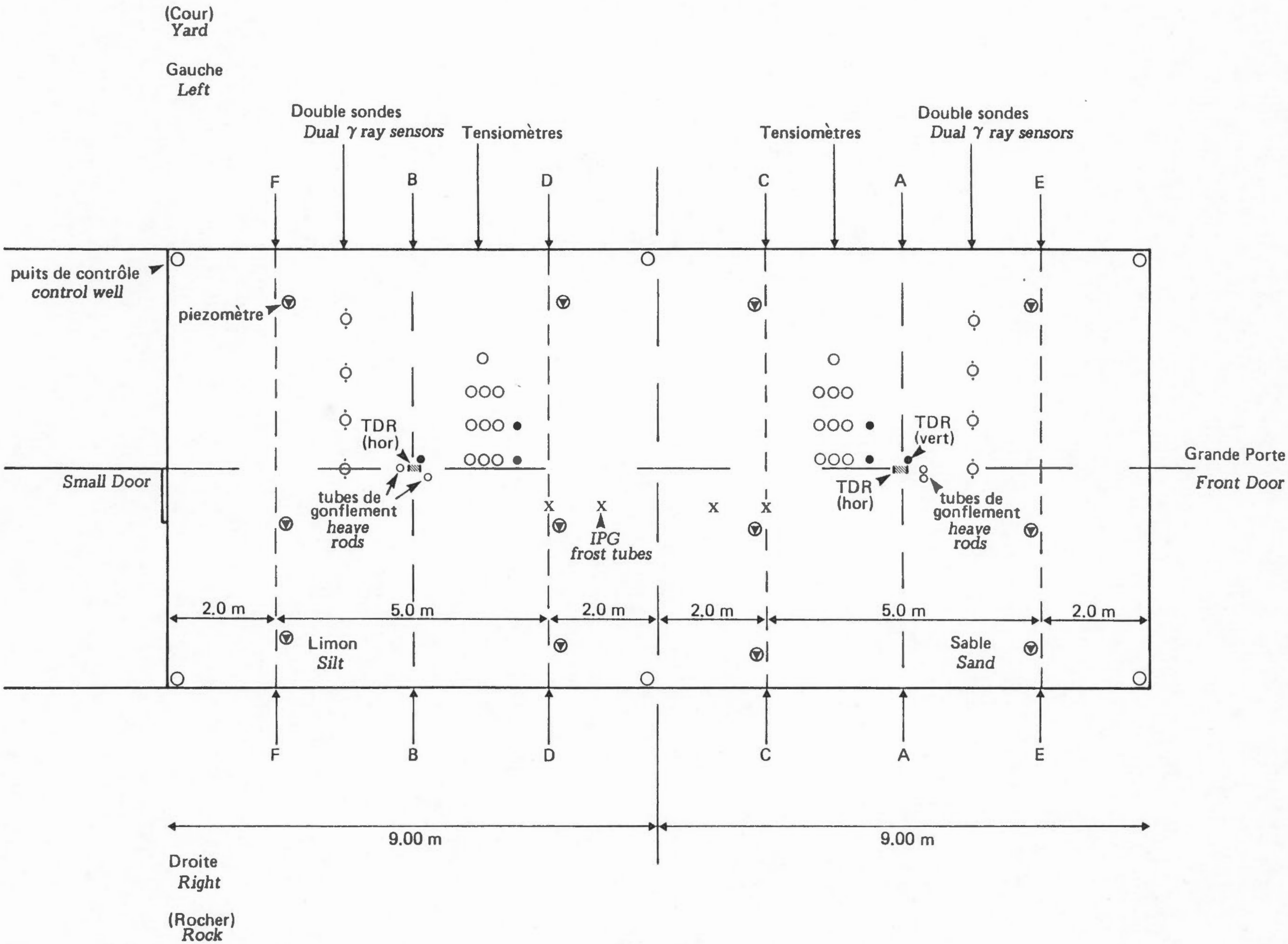

Figure 3.1 Plan view of experimental facility.

of individual temperature measurements was found to be only about $\pm$ 0.2^{o}C.

Figures 3.2 and 3.3 present the changes in the thermal gradients beneath the centre line of the pipe during the freeze cycle. Although isothermal conditions near 0^{o}C were desired at the start of the freeze cycle, time constraints limited the cooling of the two soils. As shown on the figures for September 22, 1982, the temperatures in the two soils were slightly warmer than desired, with the silt being warmer than the sand.

The progression of the 0^{o}C isotherm beneath the centre line of the pipe in the sand and the silt is shown as Figure 3.4. This figure shows the relatively slow progression in the silt and the more rapid progression in the sand.

3.3 Hydrologic Regime

Water content profiles beneath the centre line of the pipe have been determined from Time Domain Reflectometry (T.D.R.) probes installed in the two soils. Figures 3.5 and 3.6 show the distribution of the unfrozen water during the freeze cycle of the experiment. These profiles show a significant drop in the water content in a zone 100 - 200 mm beneath the position of the 0^{o}C isotherm. This phenomenon appears to be a result of dessication of the soils beneath the frost line as water migrates under cryosuction forces towards the zone of ice formation.

Water content profiles as determined by the T.D.R. probes were found to be relatively unaffected by the lowering of the water table

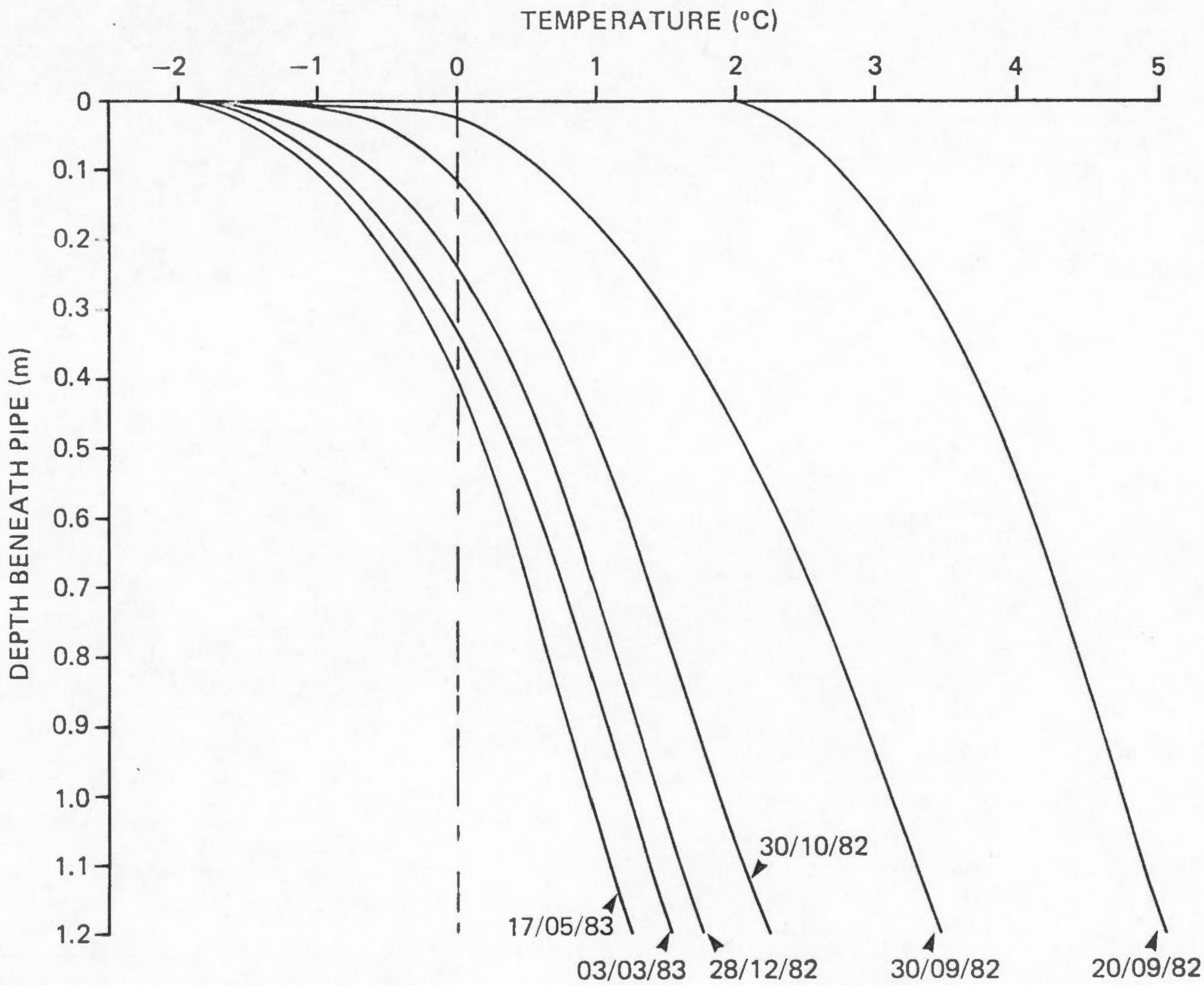

Figure 3.2 Generalized temperature profiles beneath centreline of pipe. Sand section AA. (Best fit profiles derived from thermistor and corrected thermocouple observations).

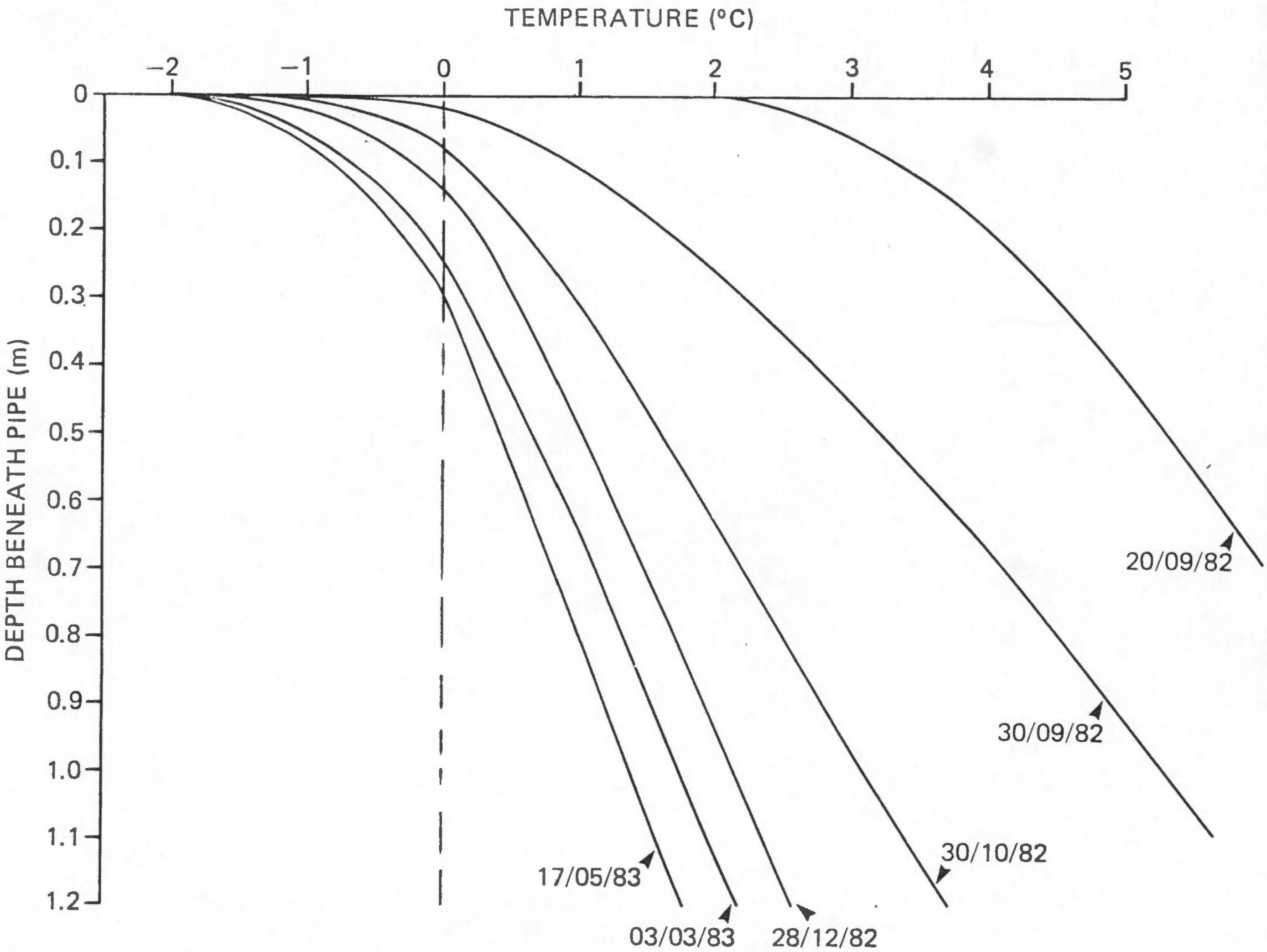

Figure 3.3 Generalized temperature profiles beneath centreline of pipe. Silt section BB. (Best fit profiles derived from thermistor and corrected thermocouple observations).

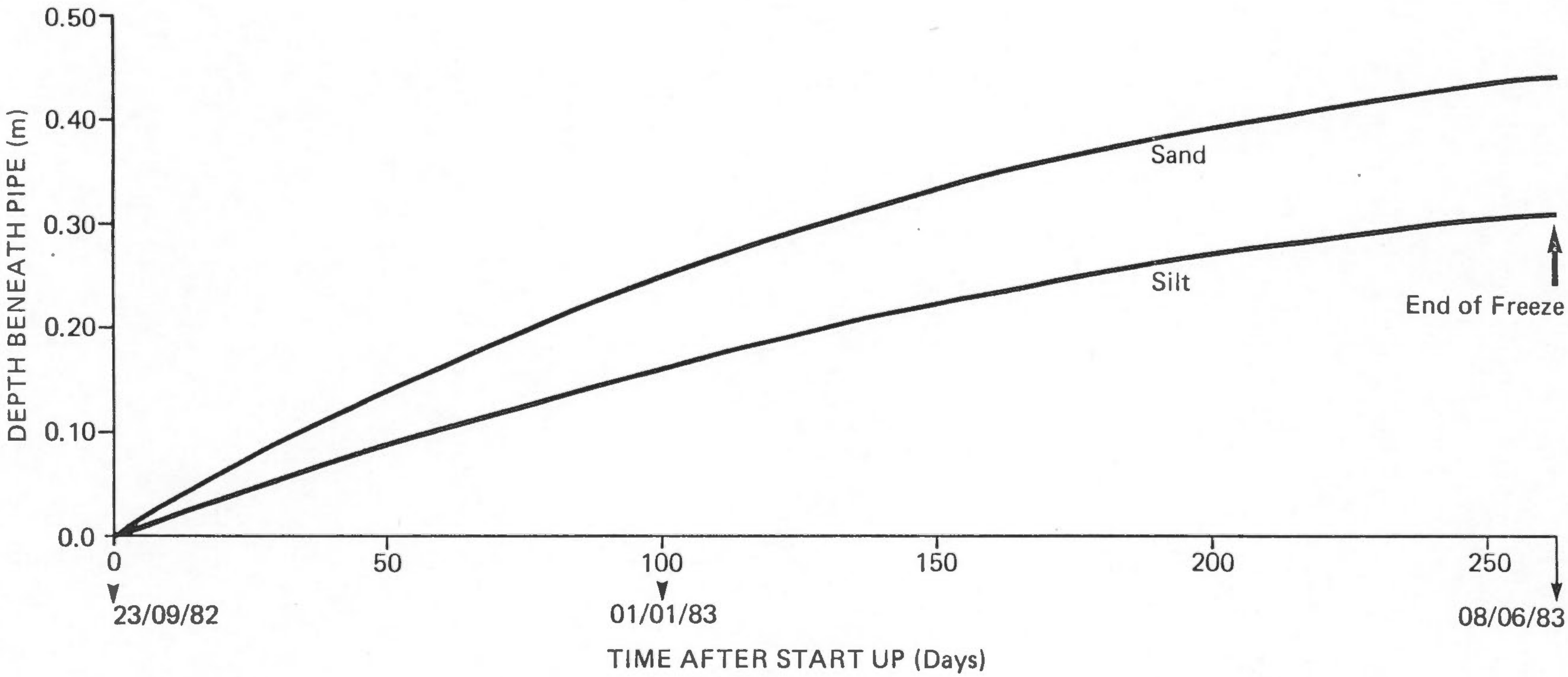

Figure 3.4 Evolution of frost front beneath centreline of pipe.

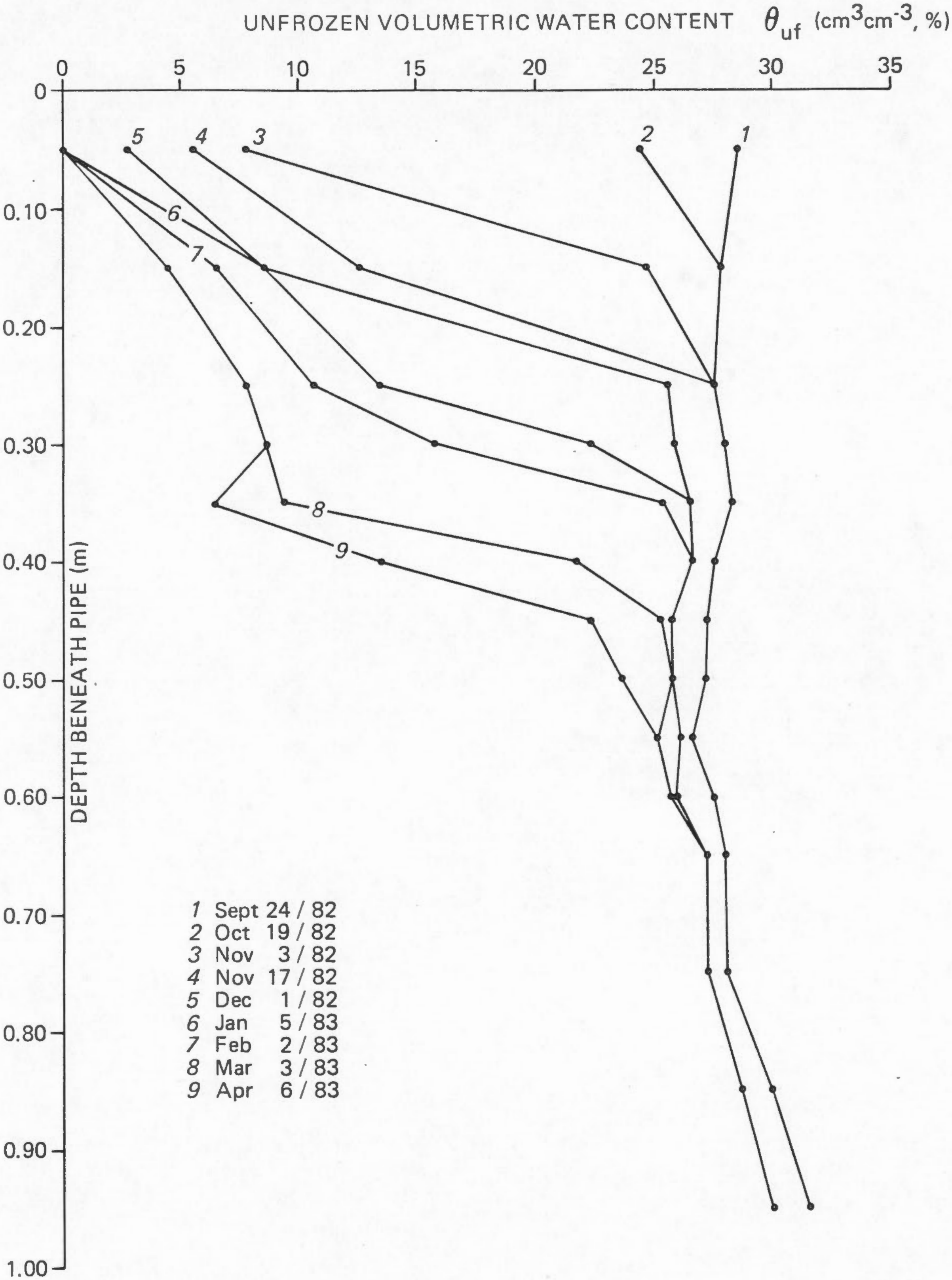

Figure 3.5 Unfrozen water content of sand beneath centreline of pipe.

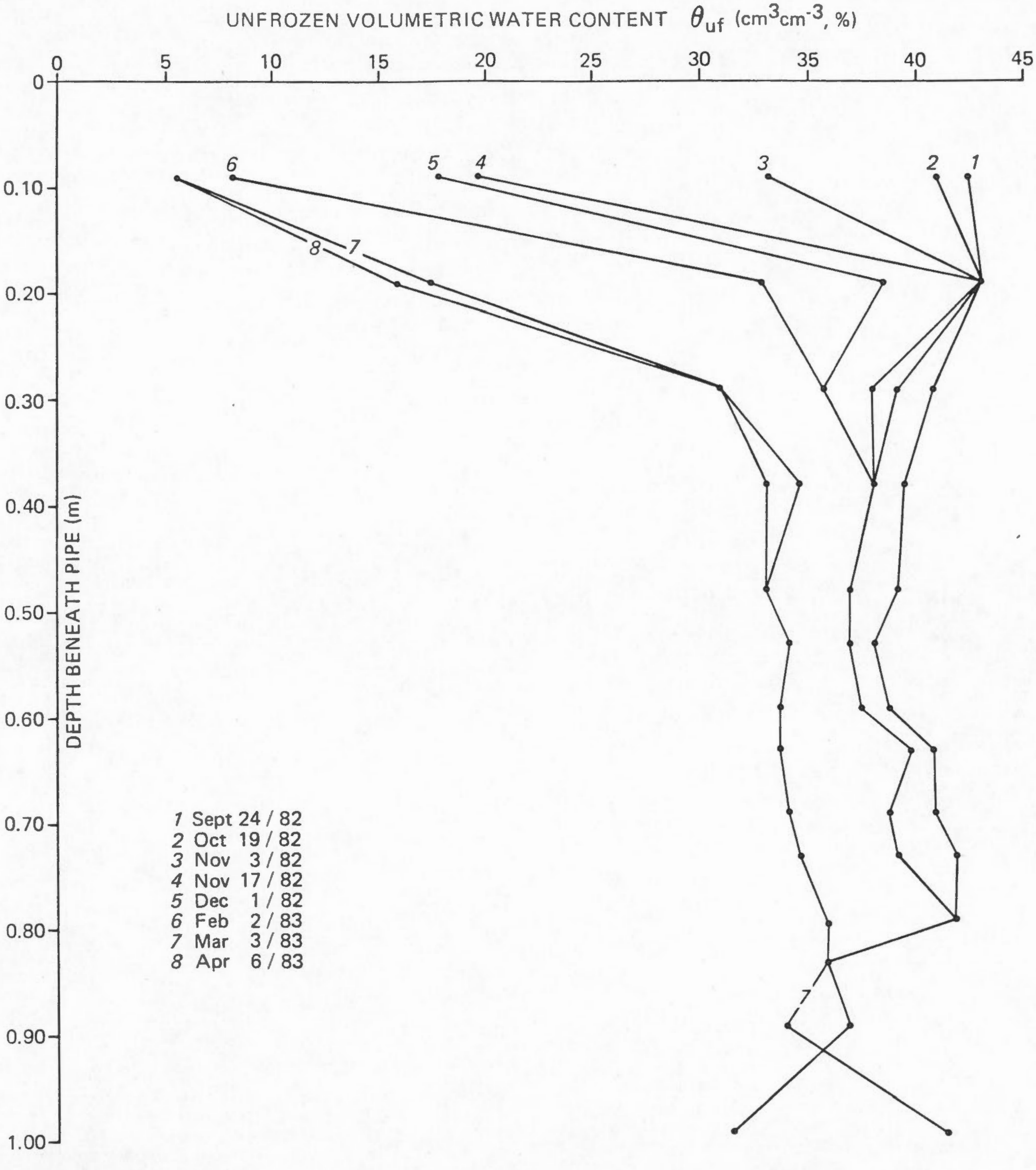

Figure 3.6 Unfrozen water content of silt beneath centreline of pipe.

carried out near the beginning of January. This is likely the result of the high capillary rise in the silt, maintaining approximately saturated conditions and the deeper depth of frost penetration in the sand which almost reached to the water table.

3.4 Pipe Deformation

Deformation of the pipeline began during the first few weeks of the freeze cycle when differential heave between the silt and the sand began to occur. As shown on Figure 3.7 this caused an upward displacement of the pipe in both soils with pipe deformation occurring in the transition zone between the two soils.

Determination of the state of stress within the pipe has been carried out according to the procedure outlined in the report, Geotechnical Sciences Laboratories, 1982. Build up of stress within the pipe is shown at four periods during the freeze cycle on Figures 3.8, 3.9, 3.10 and 3.11. Figure 3.11 indicates that a maximum stress of about 115 MPa or about 50% of the yield stress was present near the end of the freeze cycle.

A comparison of the various methods of measuring pipe stress has been shown on Figures 3.9 and 3.11. A qualitative appraisal of these results indicate that the strain gauges are the most reliable method of measuring stress. The curvature device and the angle plates which directly monitor movement of rods fixed to the pipe, seem to be functioning as expected, however significant scatter is present in some of the results. This is likely a result of disturbance to the vertical rods and in the case of the angle plates, movement of individual plates.

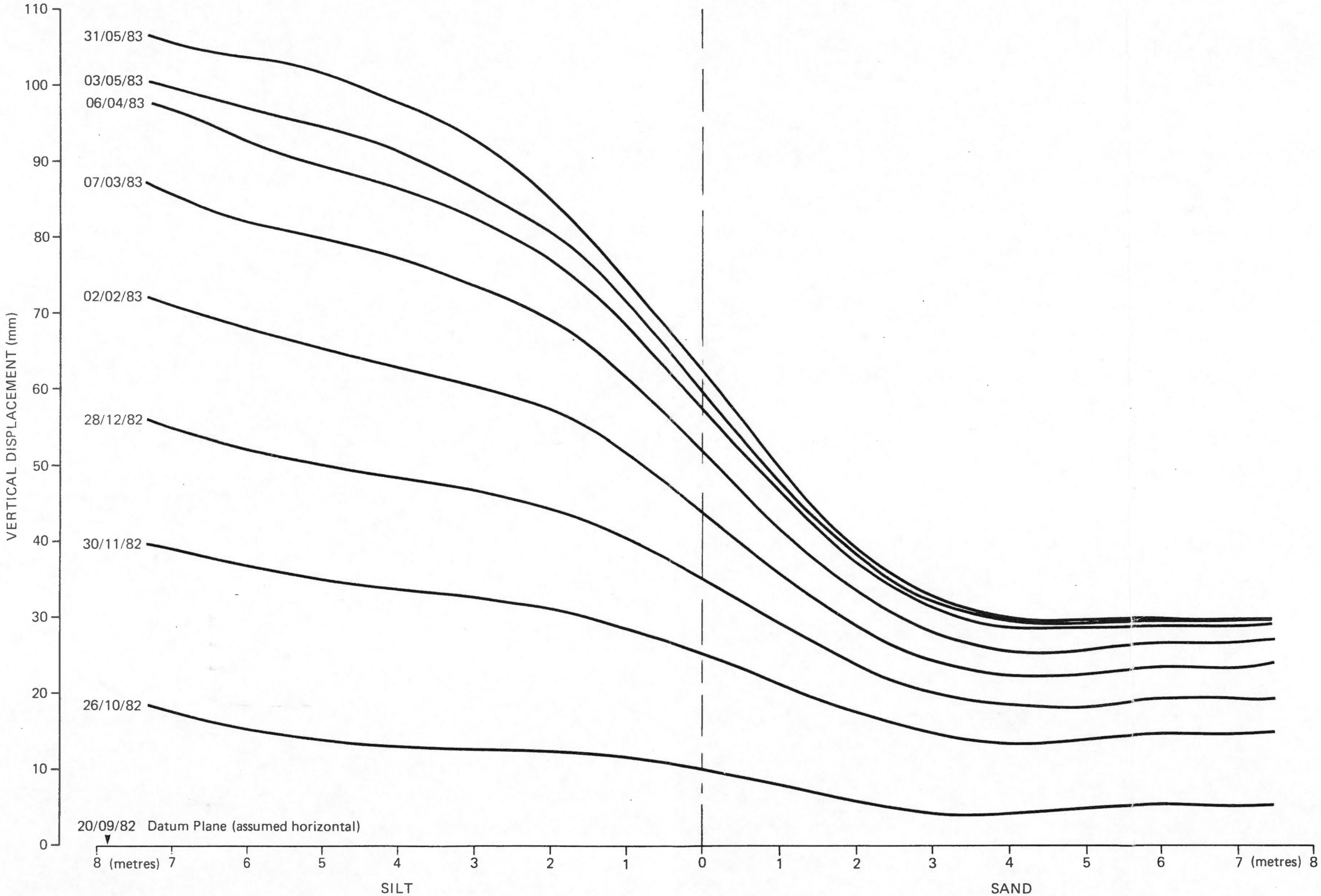

Figure 3.7 Deformation of pipe as measured by displacement of rods fixed on axis of pipeline from 20/09/82 to 07/06/83.

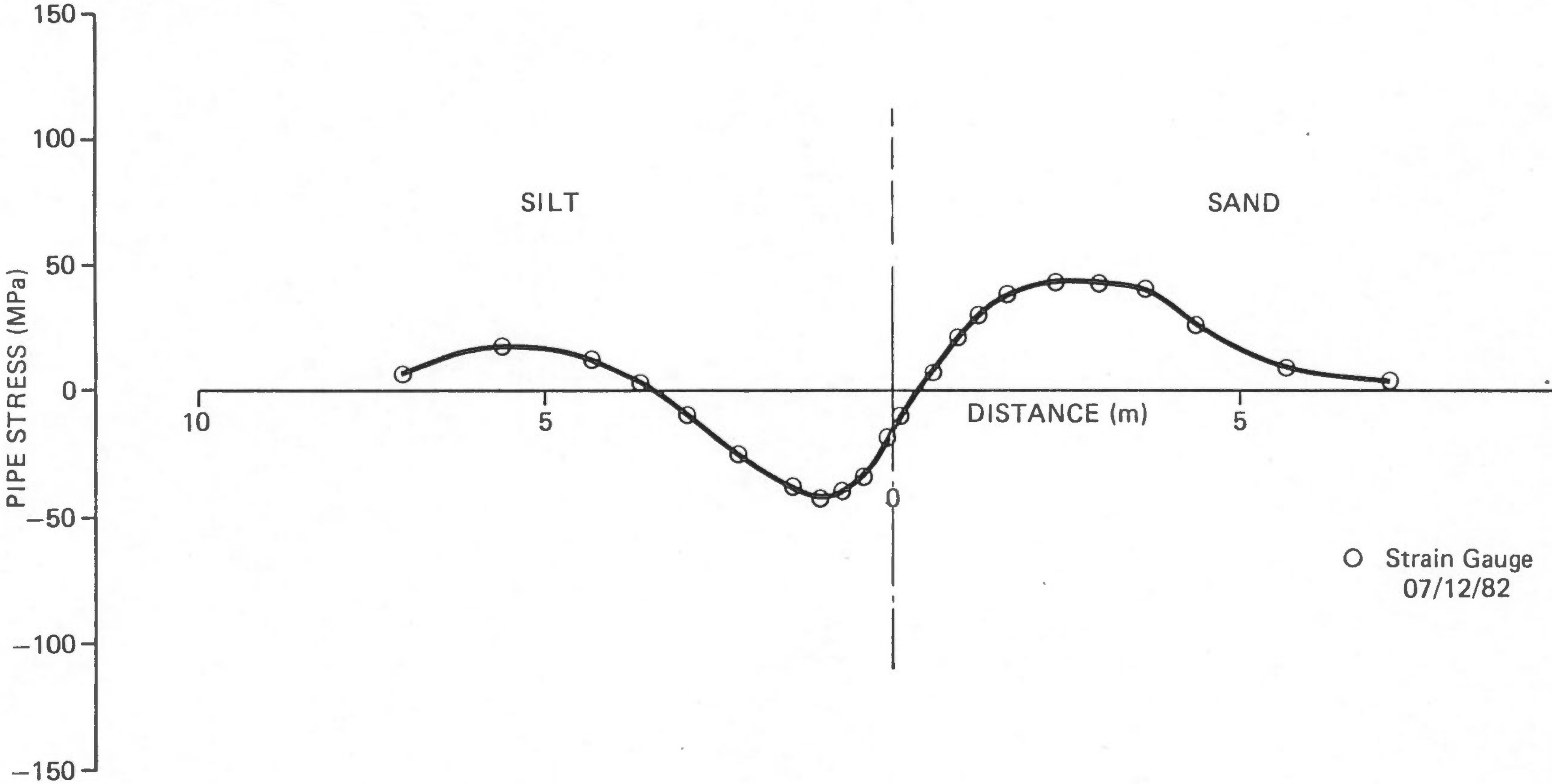

Figure 3.8 Distribution of pipe stress along axis of pipe.

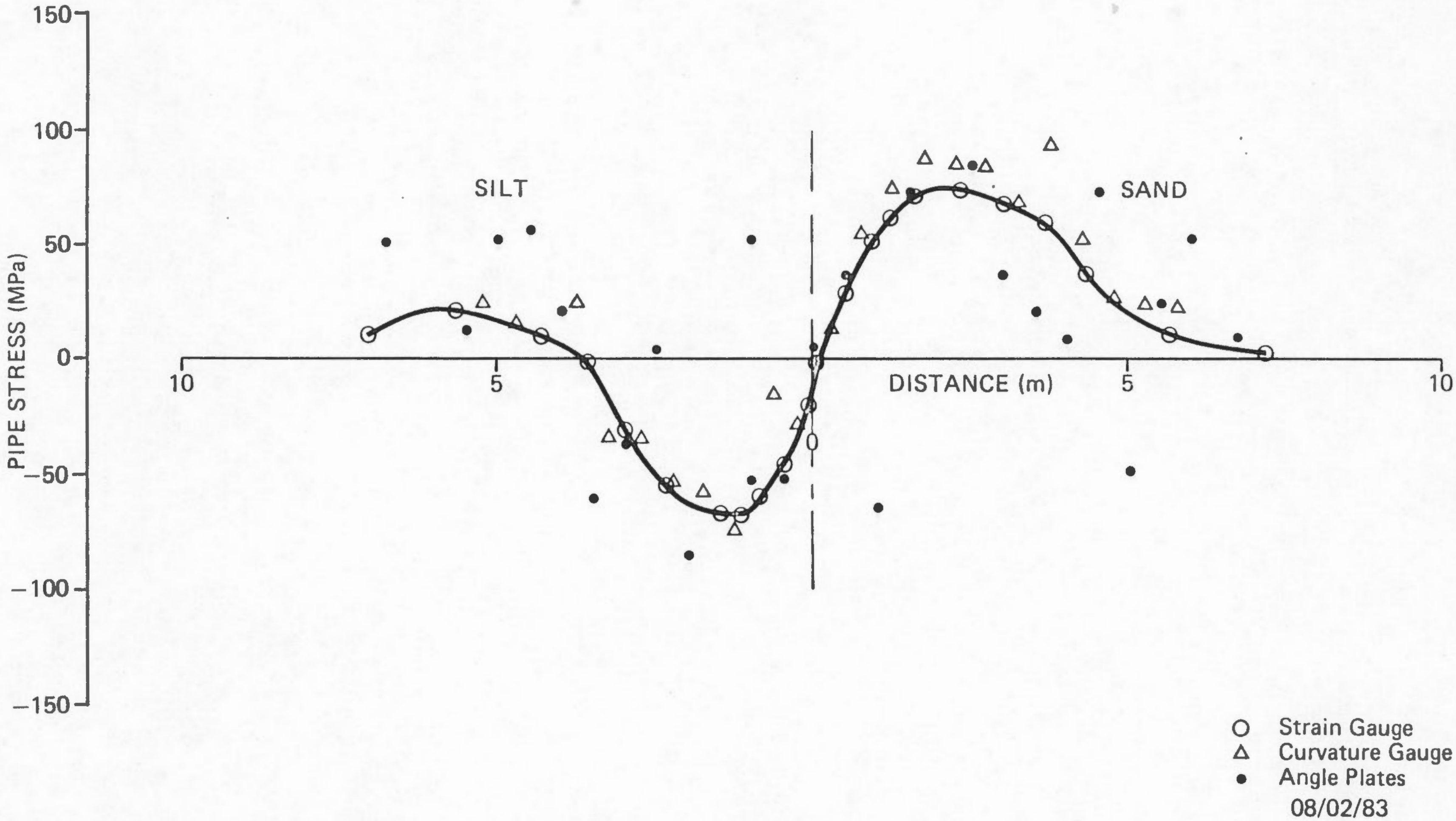

Figure 3.9 Distribution of pipe stress along axis of pipe as measured by different methods.

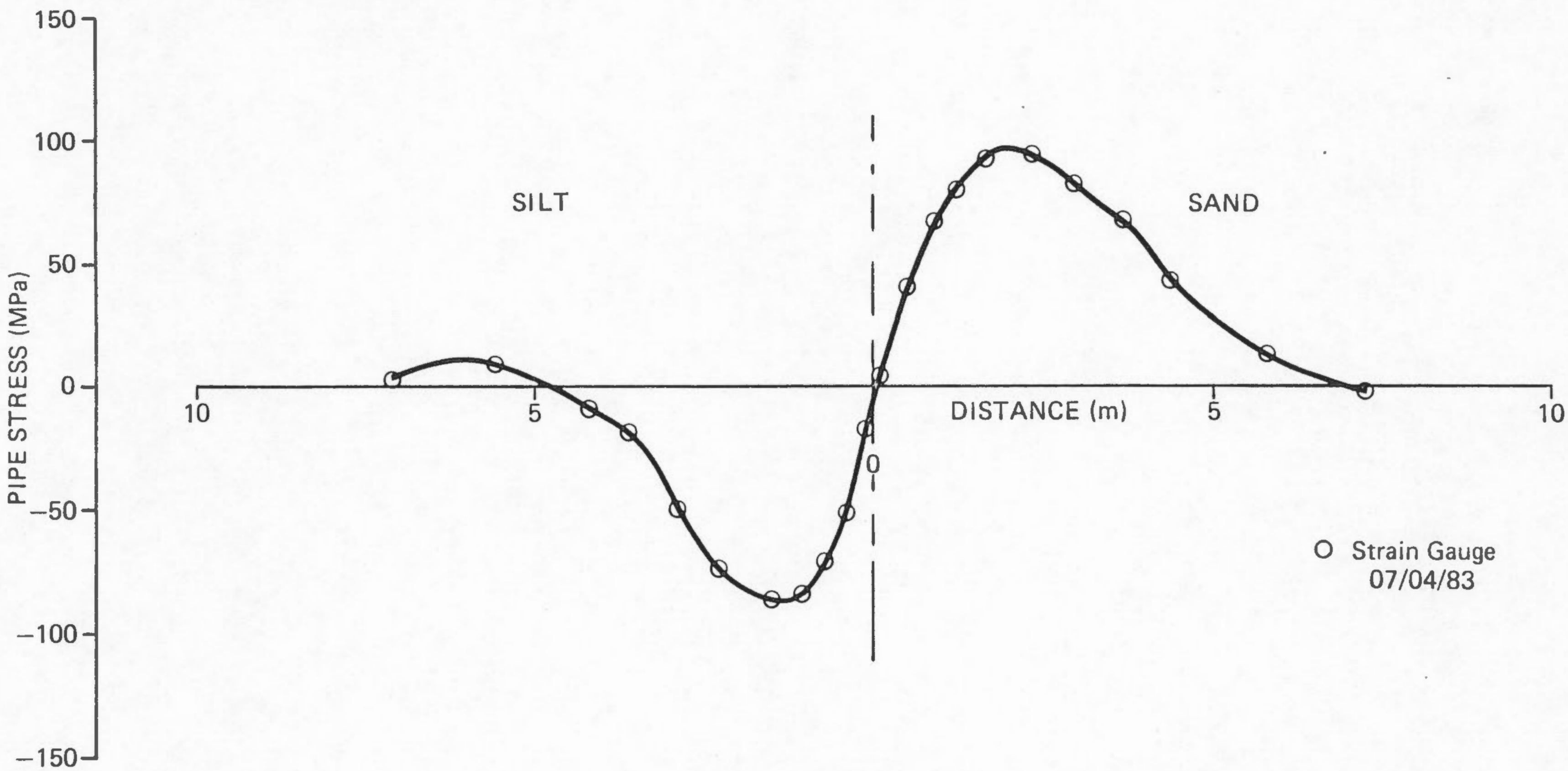

Figure 3.10 Distribution of pipe stress along axis of pipe.

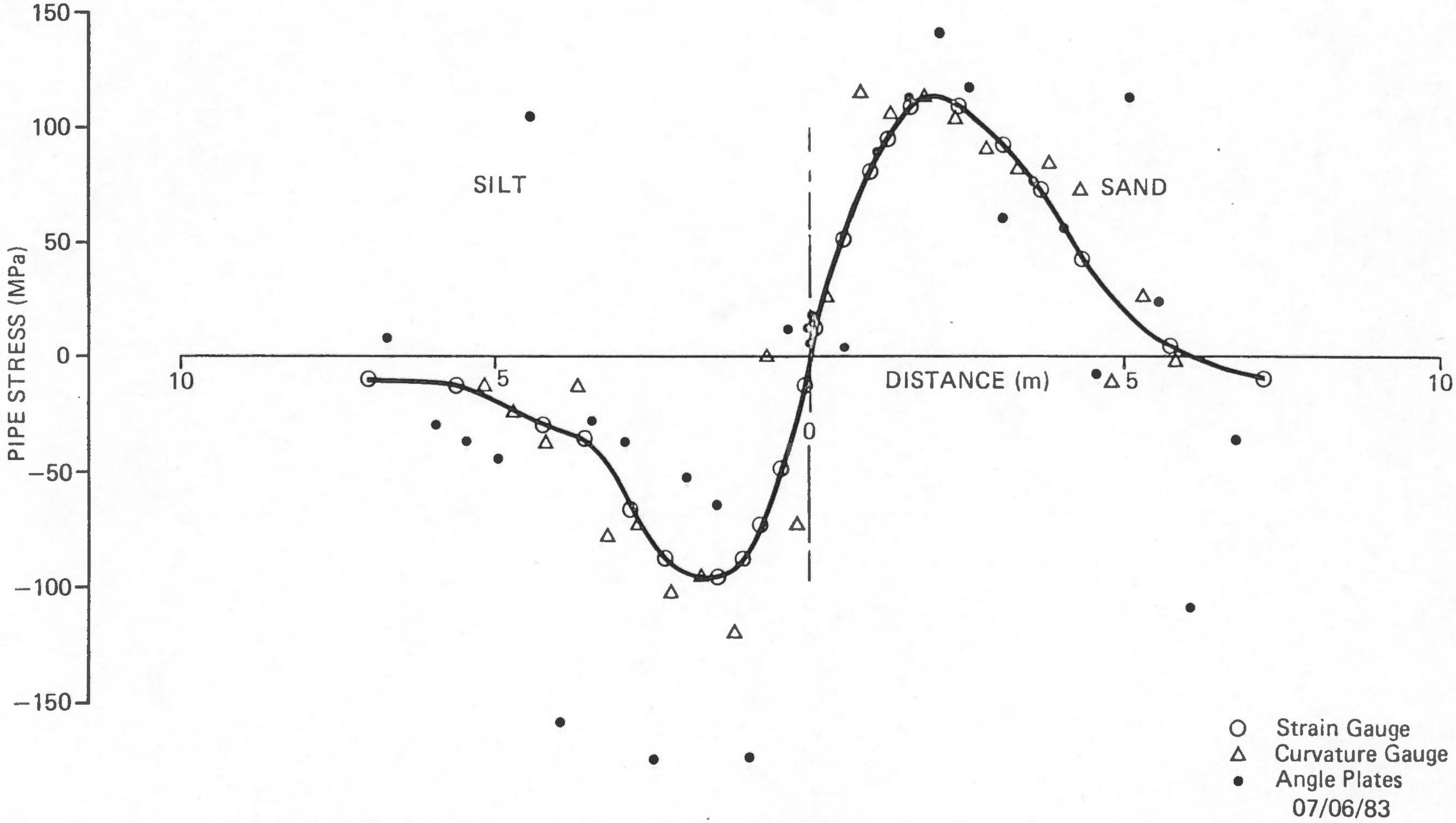

Figure 3.11 Distribution of pipe stress along axis of pipe as measured by different methods.

3.5 Physical Soil Parameters

The relative movement of the surface of the two soils has been shown on Figure 3.12 - 3.18 which are a series of surface contour maps indicating net heave. These plots illustrate the undulating nature of much of the surface of both soils and the roughly symmetrical heave over the pipeline axis.

Observations with the telescopic heave tubes show these to be working satisfactorily and the observed heaves are in accordance with frost penetrations depths. Because total frost penetration in the silt is only 30 cm, relatively few of the observations can be used to interpret possible strain of already frozen ground. As yet these readings give no indication of such strain, but the renewed frost penetration in September and subsequently, will allow further study of this.

The limited frost penetration also means that only two of the installed Glotzl cells show any significant effect due to frost heave generated pressures.

The programme of observations for these and other parameters being observed at Caen is summarised in Table 1.

Work on the determination of the creep parameters of the frozen ground, which is particularly important for analysis of pipe stresses, has been initiated at Ecole Polytechnique. These observations must be extended to include a range of temperatures, and these studies are continuing.

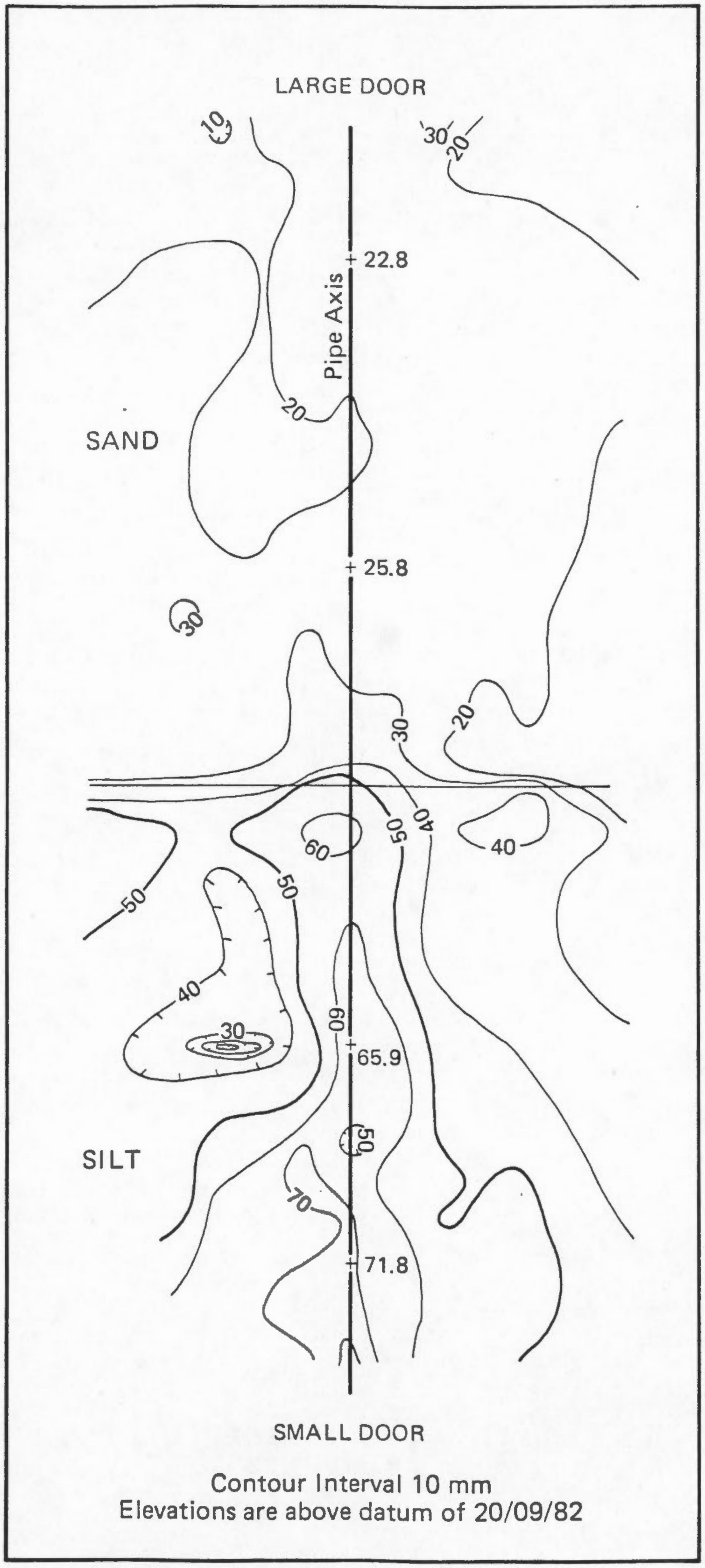

Figure 3.12 Elevation of soil surface, 05/12/82.

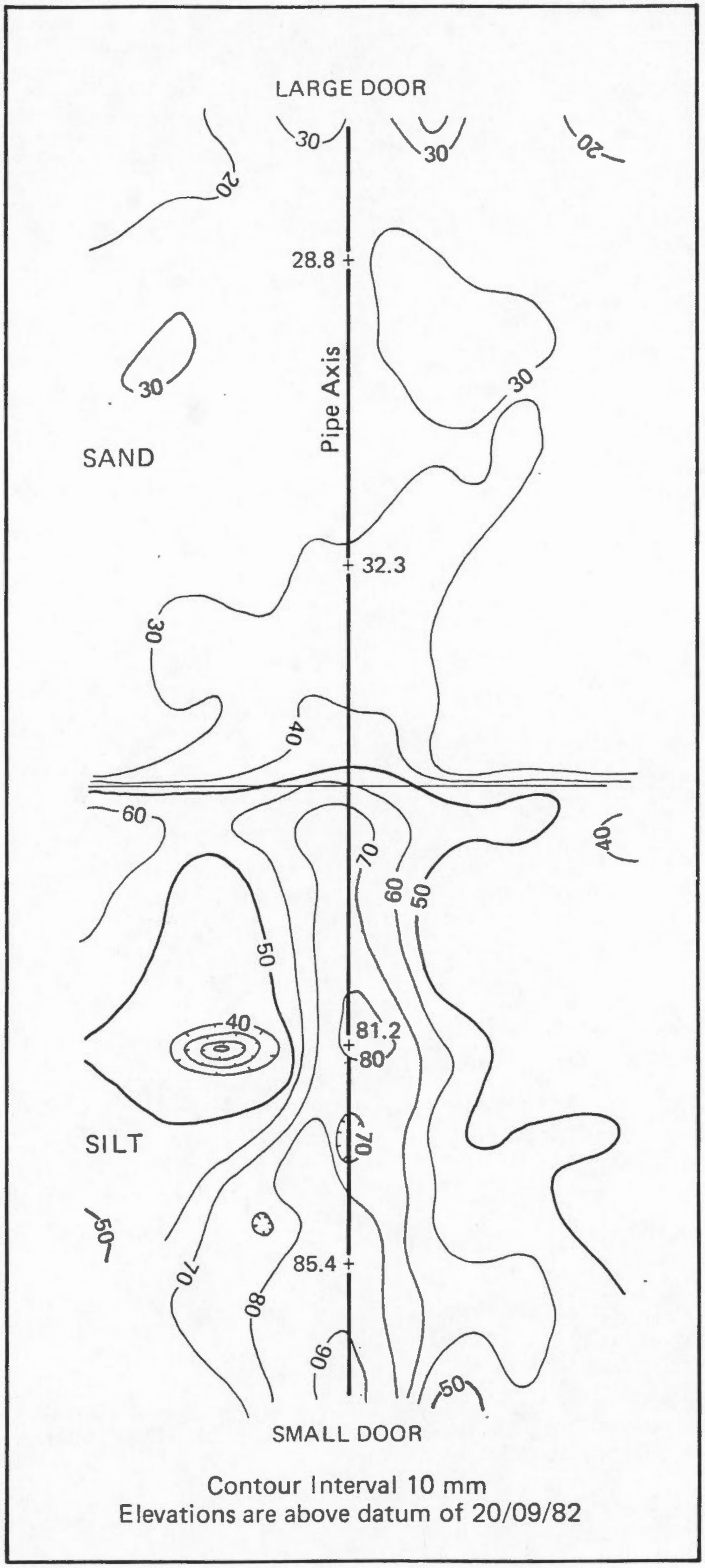

Figure 3.13 Elevation of soil surface, 05/01/83.

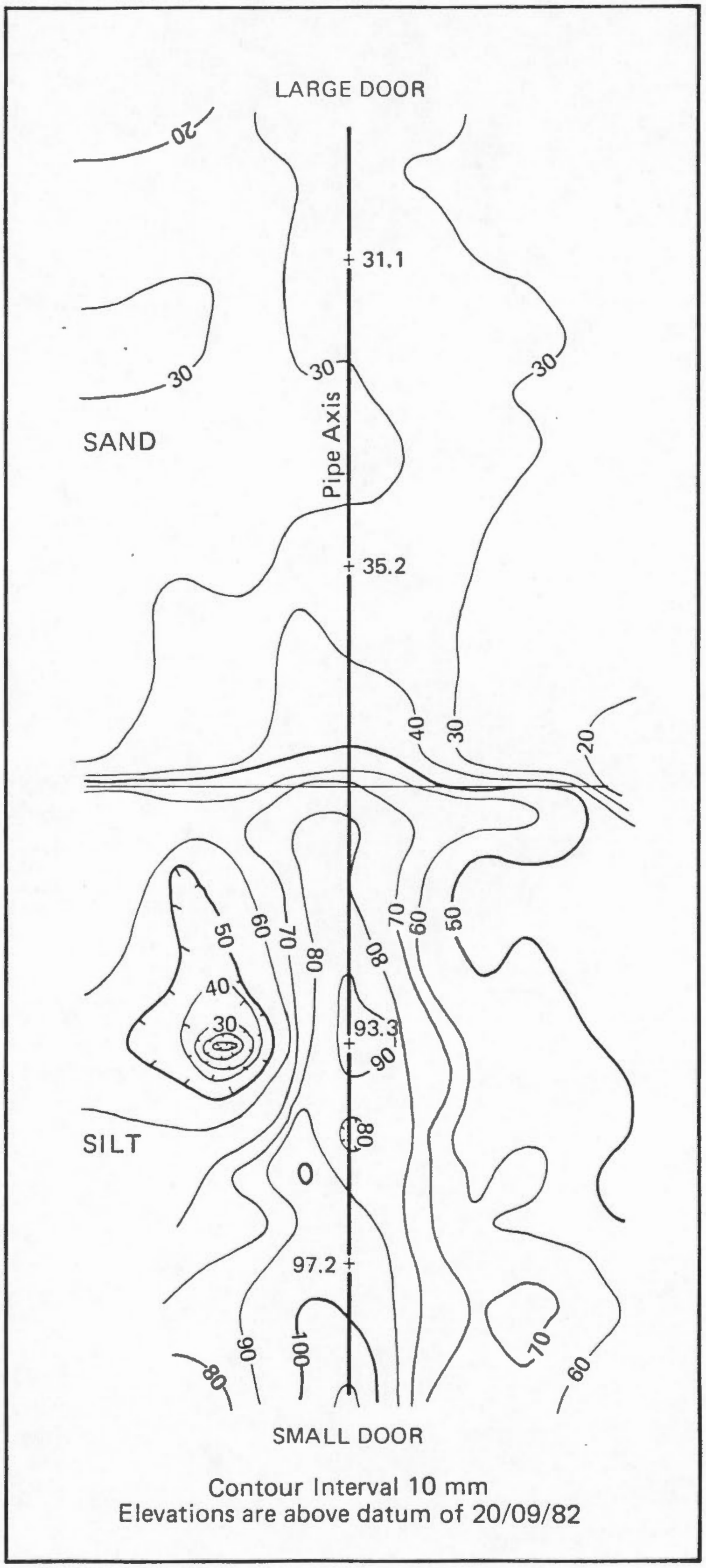

Figure 3.14 Elevation of soil surface, 08/02/83.

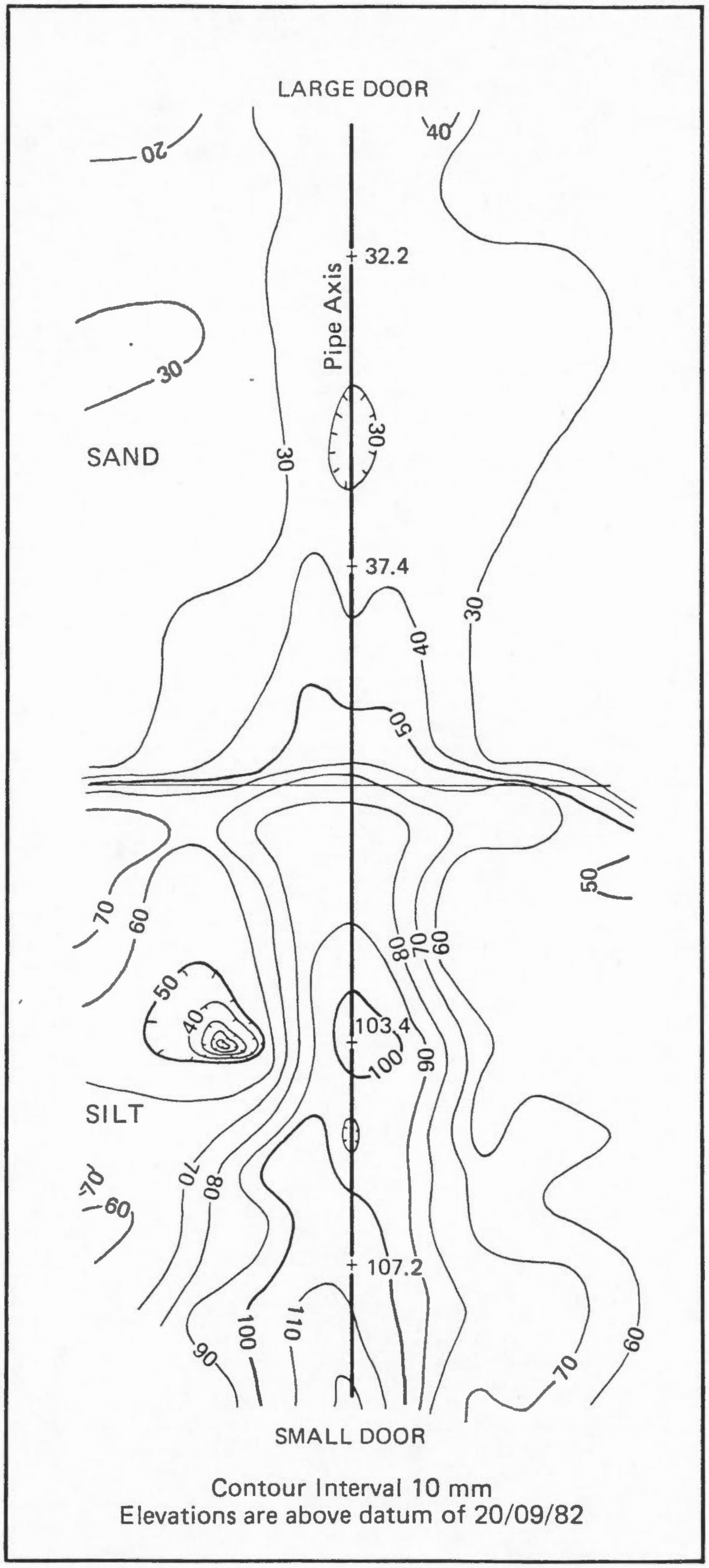

Figure 3.15 Elevation of soil surface, 08/03/83.

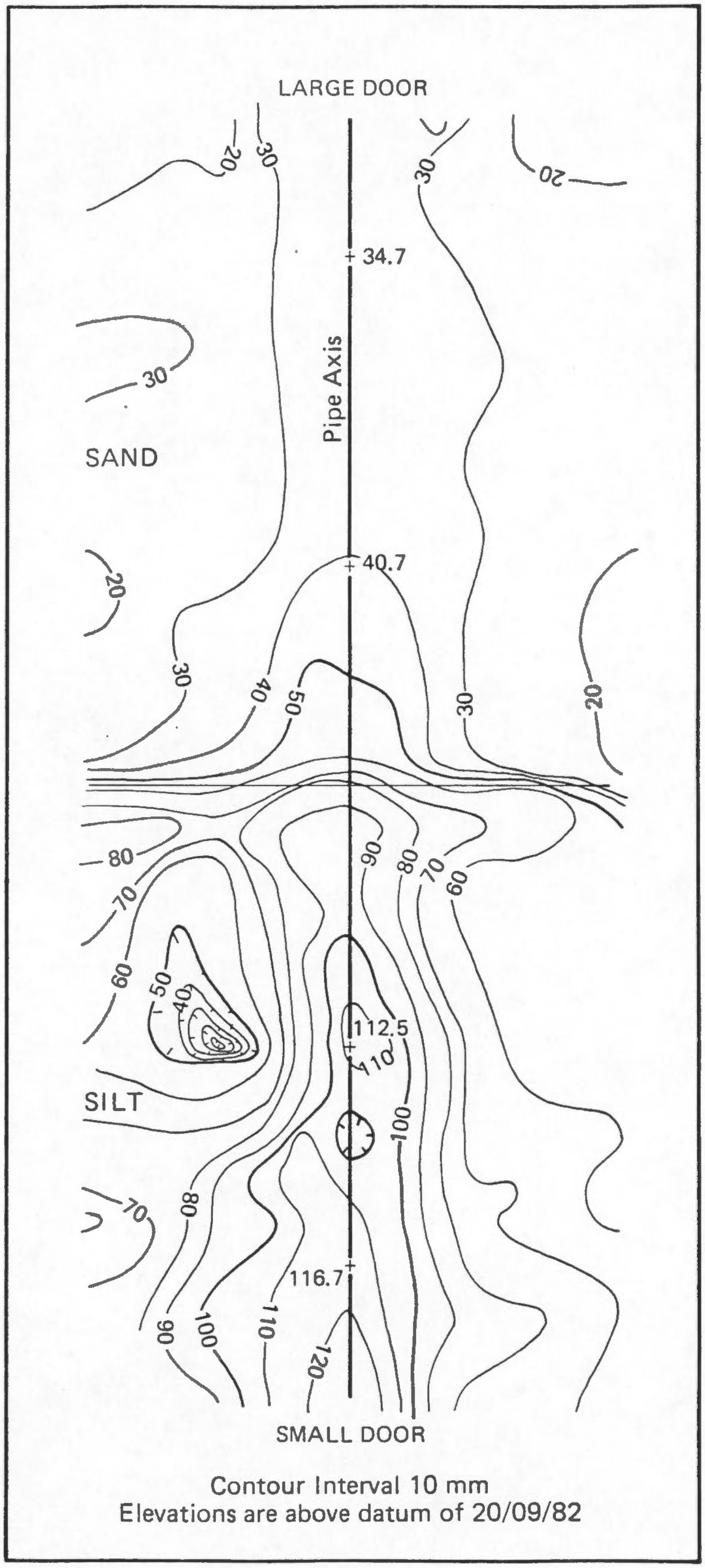

Figure 3.16 Elevation of soil surface, 05/04/83.

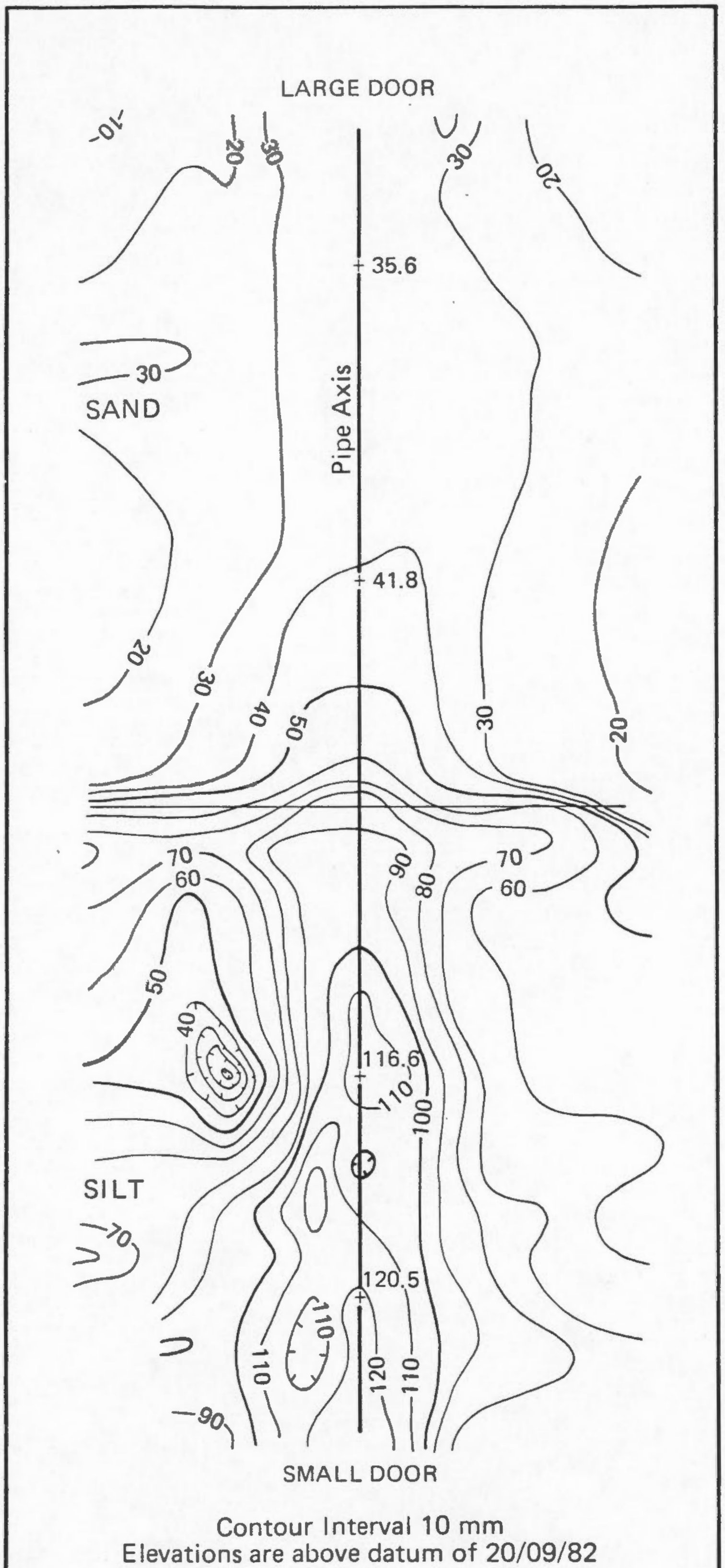

Figure 3.17 Elevation of soil surface, 04/05/83.

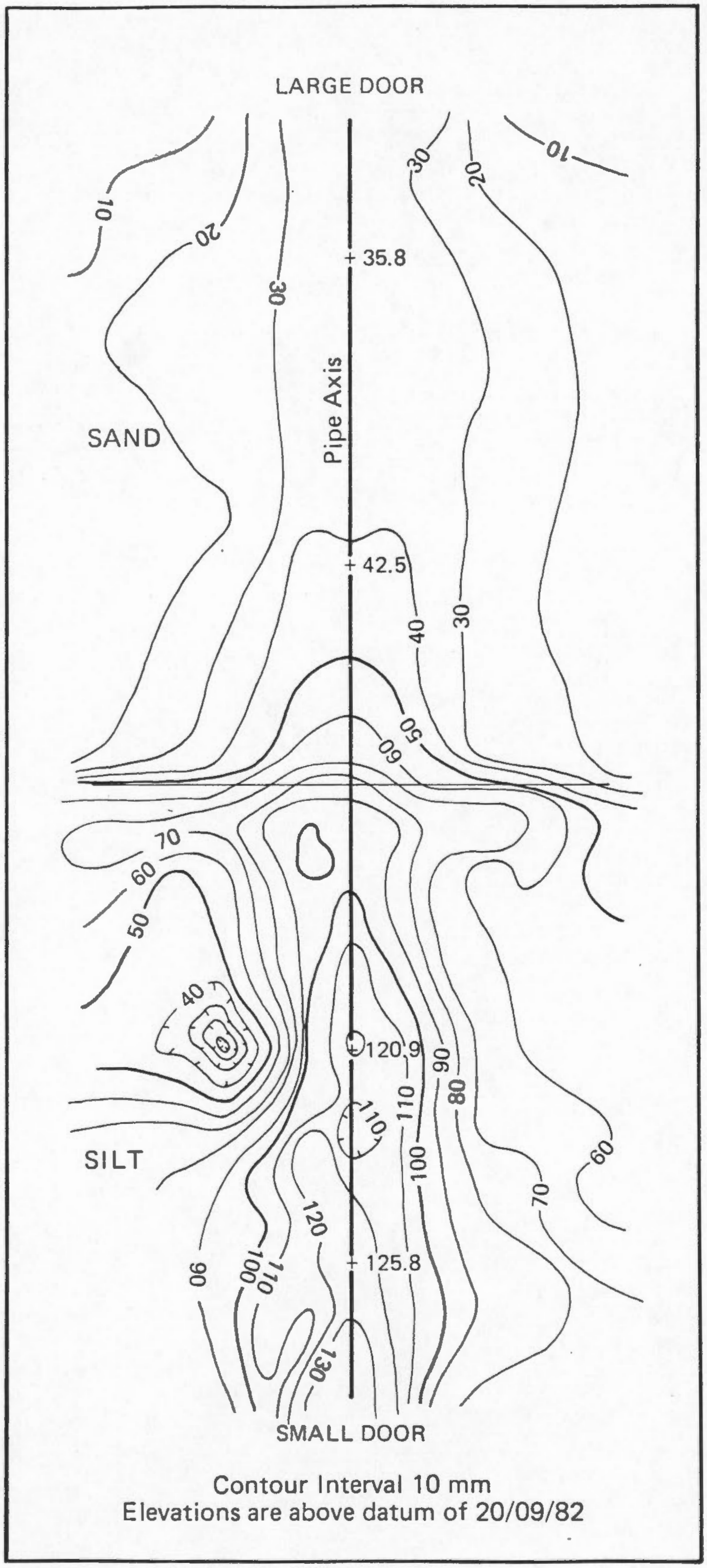

Figure 3.18 Elevation of soil surface, 07/06/83.

4. Continuation of the Experiment

4.1 Experimental Conditions

Current planning calls for continuation of the thaw cycle until early September, 1983: the room temperature is being maintained at +4^{o}C and the pipe temperature at -2^{o}C. In September, a second freeze cycle will commence with room temperatures slightly below freezing and a significantly colder pipe temperature.

During the course of the thaw period, extensive fissures up to 3-4mm wide developed along the axis as a result of settlement of soil on either side of the pipe. In addition, foot traffic during readings tended to compact the soil along frequently travelled paths. Sheets of porous geotextile were placed on the soil surface to reduce the disturbance, but variations in soil density near the surface are likely important. Some form of compaction will probably be necessary prior to starting a second freeze cycle.

4.2 Equipment Modifications

As a result of the first year of operation, several modifications to equipment and instrumentation are planned. The primary concern is an improvement of the thermocouple readout system (Solartron Orion data-logger) mentioned in Section 2.2. Tests to determine the best way to provide adequate cold junction compensation were carried out in June and July, 1983, and a method has been selected using an external 0^{o}C reference. Tests using all recoverable thermocouples suggested that the selected method would provide an overall accuracy of better than

0.1°C. Conversion of all thermocouples to this new configuration had been started in July, for completion prior to September. Conversion could be carried out without removing the thermocouples from their locations in the pit.

To supplement existing temperature sensors, personnel at Laboratoire Centrale des Ponts et Chaussees (Paris) are working on a semi-automated system to provide temperature profiles in the small diameter plastic "wells". A major advantage of this form of sounding is the ability to alter the sampling increment with depth, to provide a more detailed and more precise determination of the 0°C isotherm.

Consideration was being given in Paris to obtaining a more precise angle level for measurement of the slope (rotation) of the rods attached to the pipe. The current device is not sufficiently accurate to calculate curvature (and thus stress) in the pipe. It is likely that this system would require a fixed plate on each rod, instead of the current use of a moveable plate, in order to provide consistent results.

An overhaul of the pipe refrigeration system, with particular reference to defrosting procedures, is intended prior to September. Ice accumulation problems encountered at the beginning of both the freeze and thaw periods were never completely solved, and this problem would likely be accentuated if a colder pipe temperature is used in September. The ventilation system in the cold room will also likely be slightly modified, in order to improve temperature uniformity.

ADMINISTRATIVE NOTE

During the year covered by this report July 1, 1982 to July 1, 1983 the success of the France - Canada cooperative project has become evident, with the obtaining of a full set of observations of pipe and ground behaviour during a ten-month freezing period.

On the Canadian side, Margo Burgess and Gilles Lemaire were involved in an intense period of work prior to commencement of cooling of the pipe. After their departure Scott Dallimore remained at Caen for a period of four months as field project manager and was succeeded by David Halliwell for a six month period. The work of both resident Canadians was praised by the French. During the year the Principal Investigator (P.J. Williams) made five visits from his temporary position in Cambridge, England. Several visits were also made by M.W. Smith, and by several scientists not directly involved in the work but interested in the Canadian involvement. The French student resident at Caen, Bernard Cotte, terminated during June and a replacement is expected for September.

Work continued on the creep properties of the two soils with samples shipped from Caen, to Centre d'Ingénierie Nordique, Ecole Polytechnique. Gilles Lemaire, who has been responsible for the initial creep tests, has also prepared a thesis relating to pipe-ground interaction. Dr. B. Ladanyi has been a consultant for the project in these aspects. Dr. W.H. Bowes has been a consultant for analysis of pipe behaviour.

Several formal visits were made to the facility by senior French personnel from the contributing French organizations. The project has been the subject of several favourable articles in French newspapers.

There was no cost overrun with the contract in spite of a number of unforeseen requirements and a continuing high level of inflation throughout the period, in France. Increases in cost of certain budget items were fortunately balanced by savings on other items - especially living costs which were reduced by the obtaining of a small apartment for the resident Canadian personnel.

The project has already provided a substantial and unique experience for five Canadian graduate students. The value of the Canadian expertise so gained, will become more evident in the future. In addition to this educational role the project has now supplied valuable data for elucidating important problems relating to frost heave of pipelines in cold regions.

REFERENCES

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