Canada-France
Pipeline - Ground Freezing Experiment:
Frozen Transition Experiment

Experimental Design, Planning and Start-up Phase

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Report to

Permafrost Section,
Terrain Sciences Division,
Geological Survey of Canada,
Energy, Mines and Resources Canada

and to
ESSO RESOURCES CANADA LIMITED

FOOTHILLS PIPE LINES LTD.

GULF CANADA RESOURCES LIMITED

INTERPROVINCIAL PIPE LINE INC.

NOVA CORPORATION OF ALBERTA

TRANSCANADA PIPELINES LIMITED
on behalf of THE POLAR GAS PROJECT

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YUKON PACIFIC CORPORATION

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Foreword

The Canada-France pipeline ground freezing project is concerned with the behaviour of gas pipelines in permafrost. The project was formally commenced in 1982, with the construction of a test section of pipeline in freezing ground in the controlled environment facility at Caen, France. The project proceeded over the next seven years, funded by Energy Mines and Resources Canada and Laboratoire Central des Ponts et Chausssées with Centre National de la Recherche Scientifique in France. The findings, which concern the deformation and stresses to which pipelines may be subjected when constructed in permafrost, have attracted widespread interest. The more fundamental investigations of the thermodynamics of freezing soil have been of particular interest to specialists and have provided a basis for a rational analysis of the technical and design problems. By 1989 it was clear that the original aims of the project had been attained but that there remained many aspects on which additional research was necessary, to ensure optimum efficiency of design, operation and maintenance and minimal environmental disturbance.

This realisation coincided with a renewed interest in gas pipelines in the cold regions of northern North America. More recently the evolving situation in the Soviet Union with its vast reserves of oil and gas in its permafrost

regions, the difficulties experienced in the development of the pipeline network there, and the global geopolitical situation have given a further impetus to sophisticated research into Northern geotechnical and environmental problems. The possible effects of climatic instability in the Polar regions are an added factor in the need for a deeper understanding of the thermodynamic regime to which Northern pipelines are exposed.

In 1989, discussions were held with representatives of major oil and gas companies, pipeline companies and consultants, concerning a further joint programme of theoretical and experimental studies, again based on the controlled environment facility at Caen and with our French colleagues as partners. It was quickly evident that the two teams, French and Canadian, were keen to carry out the project and that they would have first priority in the future use of the controlled environment facility at Caen. A series of planning meetings ensued in Canada and in France, and it became evident that total restructuring of the experimental layout would be necessary with a new pipe section, replacement of the soil, and significant modifications to internal structures in the building. Together with the need for up-to-date instrumentation and progressively more sophisticated data analysis, this meant that there would be a significant increase in funding

required.

By the end of 1989 it was evident there was general agreement on the need for and requirements of the project, and planning and preparations were under way but at a low level of activity. Contracts were signed with Energy Mines and Resources Canada, and with eight companies acting in consortium, and with the French government institutions, at various times during 1990. Although some contracts signed during the year were made effective January 1, funding was not available for purchase of instrumentation or for on site work until early summer. Plans were developed that called for the reconstruction of the experiment (including placing of the pipe and backfilling) to be completed by year's end. In spite of strenuous efforts to regain the time lost this did not prove possible, not least because the freezing of the soil to give the planned initial body of permafrost proceeded only at the rate nature allowed. The experiment centres on the behaviour of a pipeline crossing an interface (or boundary) between a body of permafrost and unfrozen soil.

By early April 1991 it was possible to lay the new pipeline section which extends through the body of created permafrost and through an unfrozen section of ground which will freeze progressively as cooled air passes through the

pipe. The modelling of a naturally- occurring condition in this way, with the opportunity it presents of advanced studies of pipe reaction, is unique. Already much useful experience has been gained in the design and selection of the new instrumentation and in the process of design and calculation for the new experimental set-up.

The earlier project continues to attract widespread interest, not least in the Soviet Union where there is extensive, but mixed experience with operating pipelines in the permafrost regions.

Lecture presentations have been made by personnel associated with the project, in Canada, Alaska, the United Kingdom and in the USSR. Publications have appeared covering various aspects. A major seminar is planned for October (1991), in Paris. It is intended that this seminar will give an opportunity for the various sectors concerned with eventual pipeline development - consultants, regulators, those concerned with finance and investment - to meet with the engineers and scientists.

The detailed arrangements of the seminar are being undertaken by our French partners. As usual, it is important to note the indispensable role they have in making possible the project as a whole. We would particularly note the

contributions of M. Andre Dupas and M. René Dumoulin who have again applied their special abilities but this time in addition have responded nobly to the pressures for rapid progress. The assistance of the Director of the Centre de Geomorphologie where the Station de Gel is located and members of his staff is also appreciated as is the continuing smooth cooperation with the Laboratoire Central des Ponts et Chaussées and the Centre National de la Recherche Scientifique.

The field project managers for various times within the period covered by this report have been Karin Collins and Joan Watton for the Canadian team, and Olivier Jean and Marie-Christine Delhomme for the French team. During the laying of the pipe assistance was also provided by Moness Rizkalla of Nova and Dr. Colin Smith, University of Cambridge. Liaison with the eight sponsoring companies:

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has been maintained through John Ellwood of Foothills, with technical advice from Derrick Nixon (Esso Resources).Liaison with

Energy Mines and Resources Canada is through Dr. Alan Judge. The help of all these is appreciated. The project is supervised by a Scientific Committee whose members are listed below.

This report was prepared by D. W. Riseborough, Project Manager, Ottawa.

Peter J. Williams

Ottawa, 91-05-30

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Introduction

This report describes work carried out in the first 18 months of a three year ground freezing experiment being carried out in Caen, France.

The aim of the experiment is to examine the forces that would be exerted on a buried gas pipeline crossing a boundary between permafrost and unfrozen, frost-susceptible ground. Crossing a vertical thermal interface of this type is expected to be the worst case frost heave design scenario for gas pipelines buried at high latitudes. When such a pipeline is operated at freezing temperatures, soil freezing around the pipe on the initially unfrozen side of the transition will induce ice segregation and lead to frost heave. (On the permafrost side of the transition, ice segregation or continuing frost heave forces will be present, but will be significantly less.) Adhesion of frozen material to the pipe and cohesion of the frozen soil mass will anchor the pipe in the permafrost. This differential frost heave combined with the resistance to pipe uplift on the frozen side will result in bending stresses in the pipe. At the same time, the resistance of the pipe to bending will transfer stresses to the soil, which will alter the thermodynamic conditions governing the process of ice segregation. This experiment is concerned primarily with an examination of this interdependence of pipe and soil behaviour.

Conceptually, the present experiment is similar to the previous set of experiments undertaken at Caen (Geotechnical Science Laboratories 1982, 1983, 1984a, 1984b, 1985, 1986, 1988a, 1988b, 1989) : it allows examination of the problems of frost heave (and thaw settlement) for a buried gas pipeline crossing a transition in soil type. In the previous experiment this transition was from a non-frost-susceptible sand to a highly frost susceptible silt.

As an auxiliary experiment, a constant-rate pullout test on a short section of pipe is also being carried out: details of this experiment are not yet finalized. This experiment, being executed as a sub-contract by Dr. Branko Ladanyi, is described briefly in this report.

This report does not include data from the limited number of measurements which were taken during the start-up phase of the experiment: much of this data has not been analyzed, and is not yet in the form in which it will eventually be distributed. Such data will be available with the first quarterly summary of results from the experiment for the next contract period.

Experimental Design

Summary of experiment

The test facility (a cold room 8 m wide by 18 m long) was filled to a depth of 2.3 m with a frost susceptible soil. An insulating thermal wall (consisting of stacked blocks of polystyrene honeycomb material) was constructed to divide the facility and soil into two sections whose temperature could be separately controlled. The soil on one side of the wall was frozen as rapidly as possible, to a depth of at least 2 metres. A pipe trench was excavated as soon as the frost depth was sufficient to permit traffic on the trench floor. A 16 m long, 273 mm diameter steel pipe was placed in the trench at a depth to the top of the pipe of approximately one pipe diameter and backfilled.

Prior to the start of the experiment, the water table will be raised to a depth of 30 cm below the base of the pipe, ground temperatures will be stabilized near +4°C and -4°C at the surface for a period of time in order to establish less extreme ground thermal conditions for the start of the experiment.

At the start of the experiment, the thermal wall will be removed from the cold room, and air temperature in the cold room will be maintained at -0.75°C. Pipe circulation temperature will be maintained at -5°C. Surface and pipe temperatures will be maintained for a period of freezing expected to last for 8

months, during which soil and pipe behaviour will be monitored, using the suite of instrumentation described below.

Instrumentation

The measurement requirements of a frost heave experiment are to monitor thermal and hydrological regimes, internal soil pressures, and soil movement and expansion. In the current experiment, measurements of pipe movement, pipe deformation and pipe/soil interaction are also required. These requirements are met using a variety of instruments and techniques:

Thermal regime:	- thermistor strings in the soil - thermistors on pipe surface - thermistors to monitor air temperature
Hydrological regime:	- monitoring of water inputs - piezometer wells to monitor water table
Pressure measurements:	- EPC total earth pressure cells - Petur/RST total pressure cells - Glotzl total pressure cells
Soil movement/expansion:	- Optical surface surveying - Magnet heave measurement system - Bison soil strain gauges - Hydrostatic profiler (for soil movement beneath pipe)
Pipe movement:	- Optical survey of pipe survey rods
Pipe deformation:	- strain gauges
Pipe- soil interaction:	- "LVDT" longitudinal pipe-soil shear device - flexible steel strip soil shear device. - wooden disc vertical shear columns.

These devices and techniques are described in a separate

chapter. Instrument locations in the soil and on the pipe, as well as instrument specifications and calibration data, where appropriate, are included in the appendix.

Comparison with earlier experiments

As mentioned in the introduction, the current experiment is conceptually similar to the previous set of experiments undertaken at Caen (Geotechnical Science Laboratories 1982, 1983, 1984a, 1984b, 1985, 1986, 1988a, 1988b, 1989). To enhance the utility of both sets of experiments, several aspects of the current experiment have been designed to allow comparison with the results from the earlier experiment :

- The same silt has been used;
- Pipe diameter and wall thickness are the same;
- Depth of pipe burial is the same;
- The water table will be maintained at the same depth (30 cm below the base of the pipe).

In addition, two proposals for experimental operating temperatures were considered:

1. Thermal conditions as in previous experiments, with pipe circulation temperature at -5°C, ambient temperature at -0.75°C.
2. Pipe and ambient temperatures at -4, with an insulating mat on the surface on the unfrozen side, to limit frost penetration and to provide uniform temperatures on the (frozen) side of the experiment providing uplift resistance to the pipe. A variation of this proposal was to keep the thermal wall in place for the

duration of the freezing cycle, with surface temperatures held at +4°C and -4°C on the warm and cold sides of the wall.
The first of these alternatives allows easier comparison with earlier tests at Caen. The second alternative provides increased uplift resistance on the prefrozen side.

It has been agreed that the first alternative for surface temperature control is to be used for the initial freezing cycle of the experiment.

Experimental Conditions

Test facility

The experiment utilizes the "Station de Gel" at the Centre de Geomorphologie du CNRS in Caen, France. The Station de Gel facility consists of a refrigerated hall 18 m long by 8 m wide with adjacent rooms for instrumentation and refrigeration equipment. The hall was designed as a test basin lined with insulation with a capacity for soil to a depth of approximately 1.8 m. For the current experiment, modifications were made to allow soil to be placed to 63 cm above the top of the basin, by extending an impermeable membrane to this height and by the placement of cribbing around the entrances to the cold room. Below the soil, an irrigation system, an impermeable membrane, and insulation have been laid down in layers. From the bottom of the soil to the floor of the basin the layers are as follows:

- "BIDIM" permeable geotextile;
- 10 cm of sand, with embedded irrigation tubes;
- 5 cm of Styrofoam insulation;
- an impermeable PVC membrane;
- "BIDIM" permeable geotextile
- 1-2 cm of sand.

The floor of the basin is bedrock.

The irrigation tubes are connected to a metered faucet in the instrumentation room. The PVC membrane surrounds the soil.

The walls of the basin are insulated with 10 cm of Styrofoam; above the basin , the walls are insulated with 16 cm of Styrofoam.

Thermal preconditioning

Thermal wall

Establishment of the frozen soil interface was made possible by the construction of a temporary insulated wall across the midpoint of the cold room from the soil surface to the ceiling. This wall was constructed from honeycomb polystyrene blocks, originally developed as lightweight fill for embankments. A stack of 3 of these blocks is visible in Figure 1, supporting the pipe. The blocks are approximately 40 cm high by 50 cm thick, and 80 to 160 cm in length. They are self supporting when stacked to a moderate height, though a wooden frame was built to stabilize the thermal wall. After the wall was assembled, joints between blocks were filled with foam-in-place insulation, and plastic sheets were hung on the cold side of the wall to limit vapour loss. Access to the freezing side of the cold room was through a hole in the wall normally filled with blocks. The blocks are extremely light, allowing easy removal as needed for access or for passage of equipment.

Pre-freezing

Figure 2 shows frost line development to the time of pipe installation: after this period the frost line extends beyond the deepest sensors. Extrapolations from thermistor cables suggest

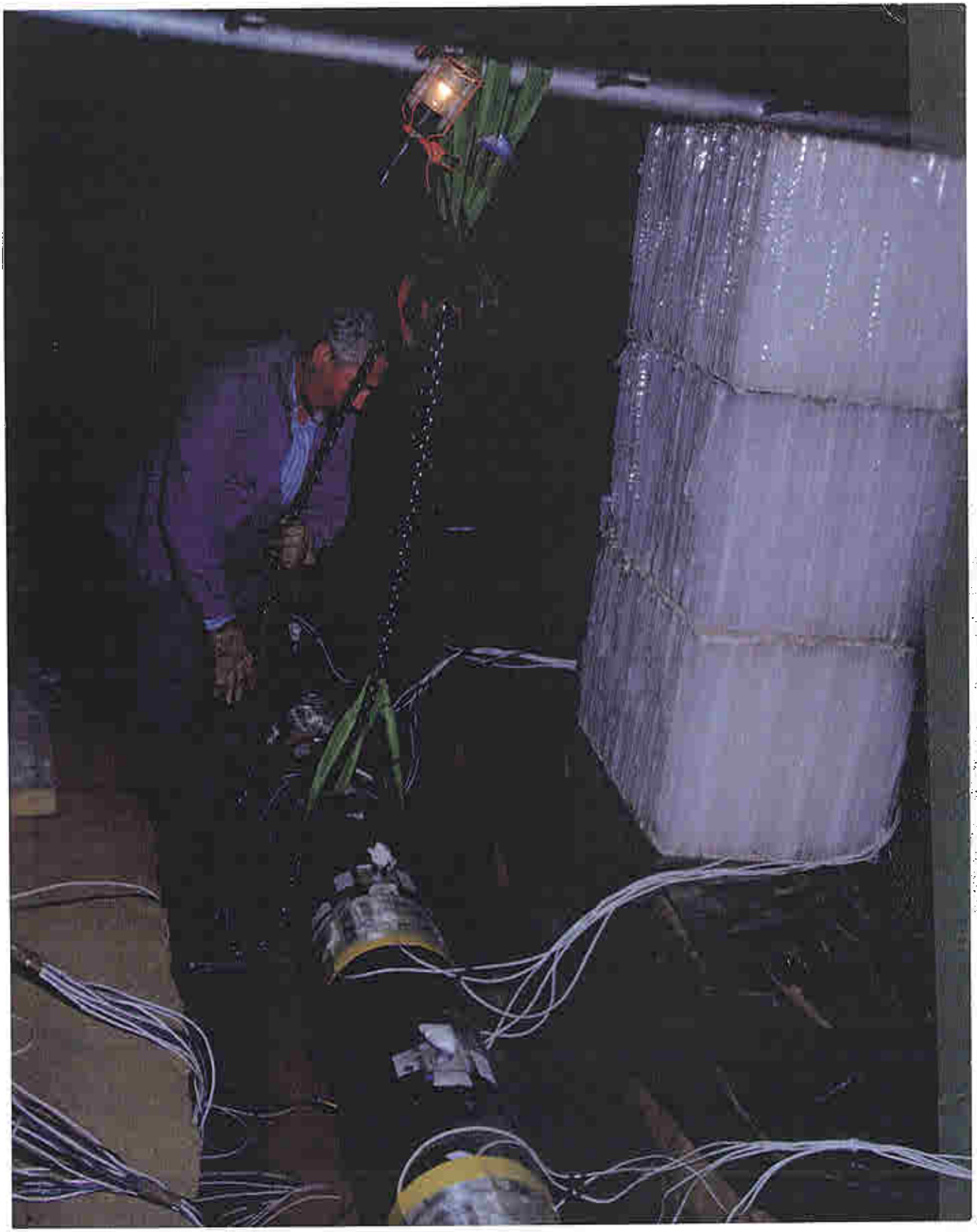

Figure 1

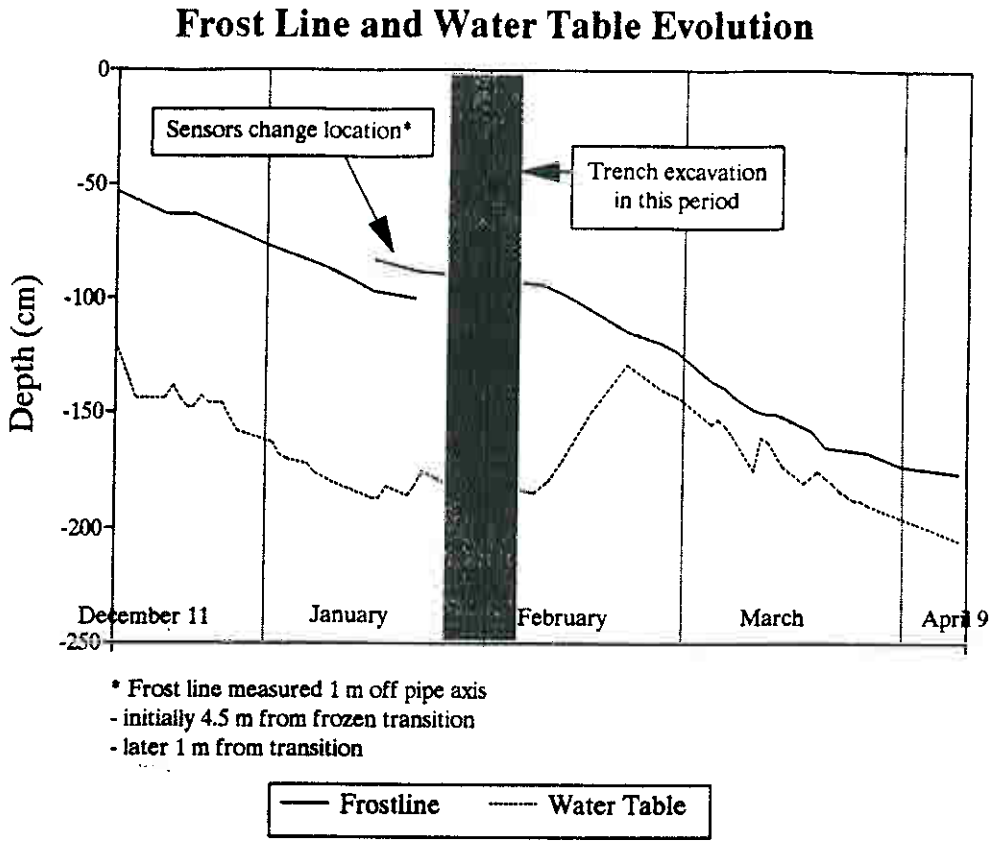

Figure 2

that the freezing extends to a depth of approximately 2 m on the side of the basin which was under the spoil from trench excavation as of May 30 1991 (Figure 3), and extends to the base of the soil on the opposite side of the trench (Figure 4).

During pre-freezing, the water table was maintained approximately 30 cm below the advancing freezing front, to allow the frost line to advance without excessive ice segregation.

Air temperatures in the cold room during pre-freezing were as follows:

November 1 - 12 : -3°C

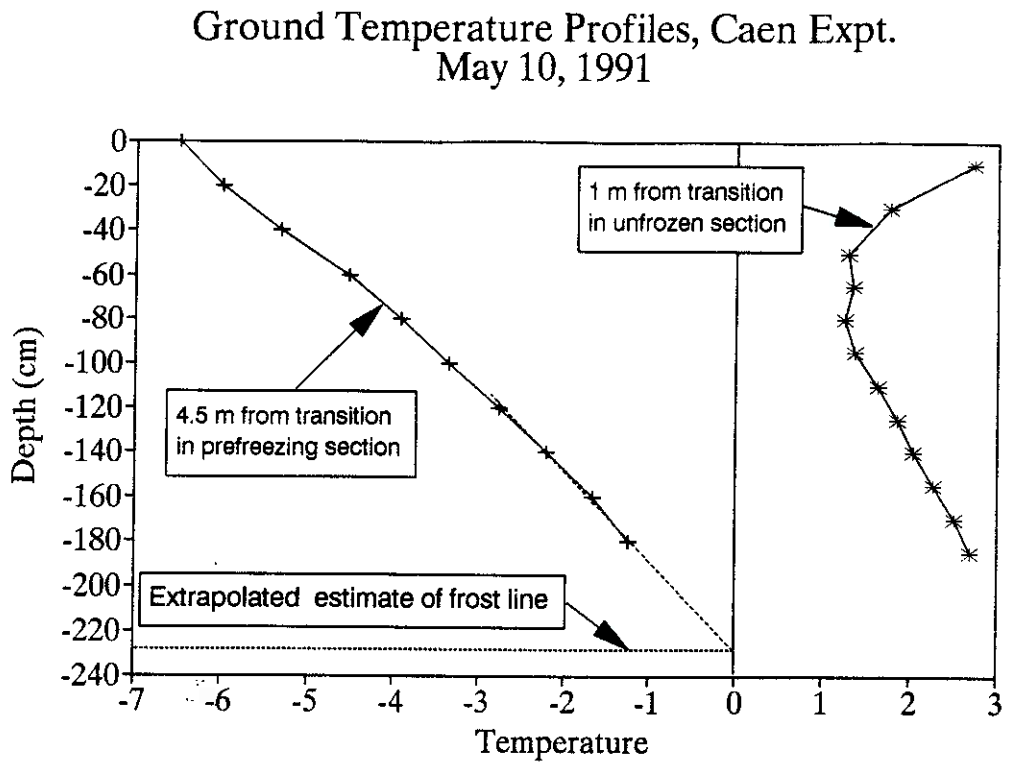

Figure 3

November 12 - December 3 : -8°C

December 8 - January 15 :-15°C

January 15 - April 26: -18°C

April 26 - June 12 : -8°C

June 12 - June 24 : -4°C

As mentioned above, air temperatures were maintained close to 0°C during removal of the thermal wall. Compressors were shut off and temperatures allowed to rise during trench excavation, pipe placement, and during excavation for instruments and access tubes.

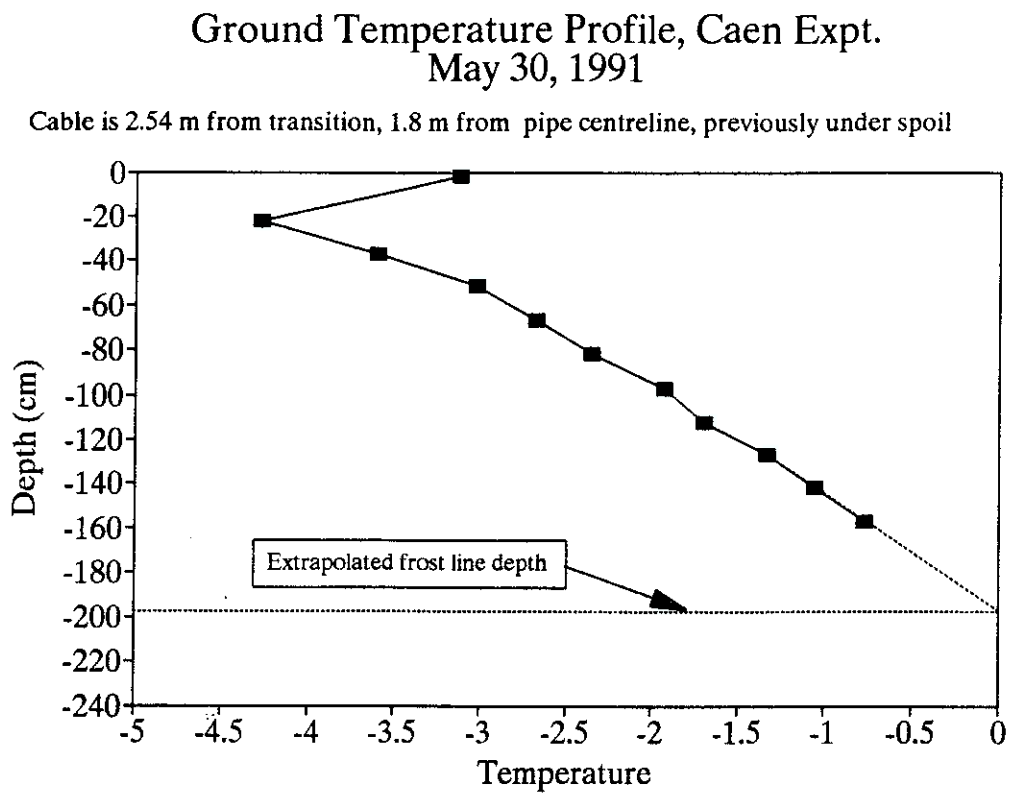

Figure 4

Realization

Schedule of events

Realization of the experimental design was accomplished as a series of related tasks:

- Removal of soil and instruments from the previous experiment. (April - May 1990)

- Placement of new soil (Placed to a depth of 148 cm by July 1990. All soil placed in the facility by September 28 1990). Some instruments placed concurrently: Petur cells, Glotzl cells.

- Placement of instruments (Bison cells, Magnet heave measurement system, piezometer wells) and access tubes (thermistor).(October 3- 17 1990)

- Installation of thermal wall. (October 18-24 1990)

- Prefreezing of cold side of experiment. (commenced November 1 1990)

- Instrumentation of pipe (strain gauges, pipe survey rods). (November 8 1990 - March 15 1991)

- Excavation of pipe trench. (February 4 - 6 1991)

- Placement of Hydrostatic profiler access tubes and bison cells in pipe trench. (February 6-7 1991).

- Placement of pipe in trench. (April 2 1991)

- Installation of instruments on and around pipe (Thermistors, Longitudinal shear devices, EPC cells, bison cells). (April 3 - 8)

- Backfilling cold side of pipe. (April 20 - 26 1991)

- Placement of remaining instrumentation (thermistor cables, vertical shear rods). (May 13 - 22)

- Backfilling warm side of pipe. (May 23 - 29 1991)

- Raising water table to final level. (May 23 - June 26)

- Backfill pipe for pullout test. (June 6 - 12)

- Establish initial thermal conditions (air temperatures maintained at +4°C and -4°C on the warm and cold sides of the wall). (June 12 - 24 1991)

- Removal of thermal wall. (June 24 - 25 1991)

- Connection of pipe to circulation system. (June 25 1991)

The freezing phase of the experiment began June 26 1991 at 9:30 a.m., when pipe circulation was started and air and pipe temperatures were established at -0.75°C and -5°C, respectively. Unlike the previous experiment, the start cannot be considered a discrete point in time, since the pipe is buried in already frozen ground with ongoing (albeit limited) continuing frost

heave, and because of the time required to remove the thermal wall from the cold room. While removing the wall, air temperatures in the cold room were maintained close to 0°C, to prevent thawing of the prefrozen soil while preventing surface freezing on the unfrozen side.

Trench excavation

On the unfrozen side, the pipe trench was excavated using a backhoe. On the frozen side, slit trenches approximately 15 cm wide were first cut along the edges of the trench, using a device described as "a chain saw on wheels". The soil between these cuts was then removed using a backhoe. The excavated material was placed on plastic sheets on the soil surface (on the un-instrumented side). The trench was excavated to 80 cm (20 cm below the base of the pipe), to allow for installation of access tubes for the hydrostatic profiler. Bison cells below the pipe were also placed at this time.

Pipe placement and in situ instrumentation

Prior to pipe placement, the trench was surveyed and made level to within 1 cm along its length. The pipe was placed on April 2, 1991. It was transported from Rouen on a flatbed truck, supported by 6 wooden cradles along its length. On arrival in Caen, a nylon strap was looped through two eyelets attached to cradles near the midpoint of the pipe. The pipe was lifted into place by a truck mounted crane.

The insulating wall within the cold room was partially disassembled to allow the pipe to pass through: the pipe was moved to within 2 m of its final position at the first attempt. The pipe was then temporarily supported over the trench on blocks from the insulating wall while the nylon strap was repositioned away from the pipe midpoint. The heavy end of the pipe was then supported by a group of 6 people while the crane moved it into its final position. The pipe was lowered into the trench with cradles still attached, allowing additional instrumentation (thermistors and EPC earth pressure cells) to be connected. The pipe was moved from the truck to the trench in about 1 hour.

Connection of thermistors and earth pressure cells took 2 days. It was necessary to excavate small depressions on the unfrozen side where the earth pressure cells were attached to the bottom of the pipe, since they protruded from the pipe by about 3 cm. The depressions were excavated to approximately the same depth as the cells, with a small amount of loose soil placed in them to allow good contact between the soil and the cells.

Thermistors were attached to the pipe using cold-curing epoxy cement. The plastic pipe coating had been cut away for thermistors in Rouen, allowing direct contact with the metal pipe surface. Seven sets of 3 thermistors (top, side, and bottom) were installed along the length of the pipe.

On April 5, the pipe was hoisted off the trench floor to allow removal of the cradles, and then lowered to the trench floor. Figure 1 shows the pipe being hoisted in the trench. Connection of longitudinal shear devices was done on April 8 and took less than 1 hour. Stringing the strain gauge cable to the measurements room took 3 days, and connection of the strain gauges to the data logger took another 4 days.

Backfilling

Backfilling of the prefrozen side was accomplished in the period April 23 - 26 by Joan Watton and Marie Delhomme with the assistance of Karin Collins and René DuMoulin. The procedure to backfill the pipe was as follows:

On the cold side:

- the trench base was wetted several times;
- frozen spoil material was processed to aggregates approximately 2-3 cm in diameter.

For each lift:

- 5 cm of water was placed in the trench;
- about 15 cm of frozen soil was added to complete the lift, ensuring that the water level was approximately level with the top of the lift;
- the backfill was prodded after 1-2 hours to remove air;
- room temperature was lowered overnight to well below freezing to create at least a frozen skin on the lift.

Four lifts were placed in four days.

On the warm side:

- the trench was wetted initially;
- the soil was mixed to 2-4% wetter than the proctor optimum water content;
- the soil was placed in 8 cm lifts;

For each lift:

- water was added to the point that the soil sweated at the surface when tapped;
- the soil was tamped to obtain a high degree of saturation.

The final water content in the trench material was about 18%.

The pipe

Figure 5 shows the pipe mounted on supports in the workshop in Rouen where strain gauges and bolts for attachment of pipe survey rods were installed. The pipe used in the current experiment is the same as that used in the previous experiment. The pipe was fabricated from two short sections, welded together at the midpoint (located at the frozen interface).

Specifications for the pipe are as follows:

- grade B steel;
- elastic limit 2.41 $x10^5$ KPa;
- rupture resistance 4.13 x 10^5 KPa;
- 7.3 mm wall thickness (tolerance of 12.3%);
- exterior protective coating 3.8 mm thick made from 3 layers of machine wrapped polyethylene (water resistant to 8600 KPa).

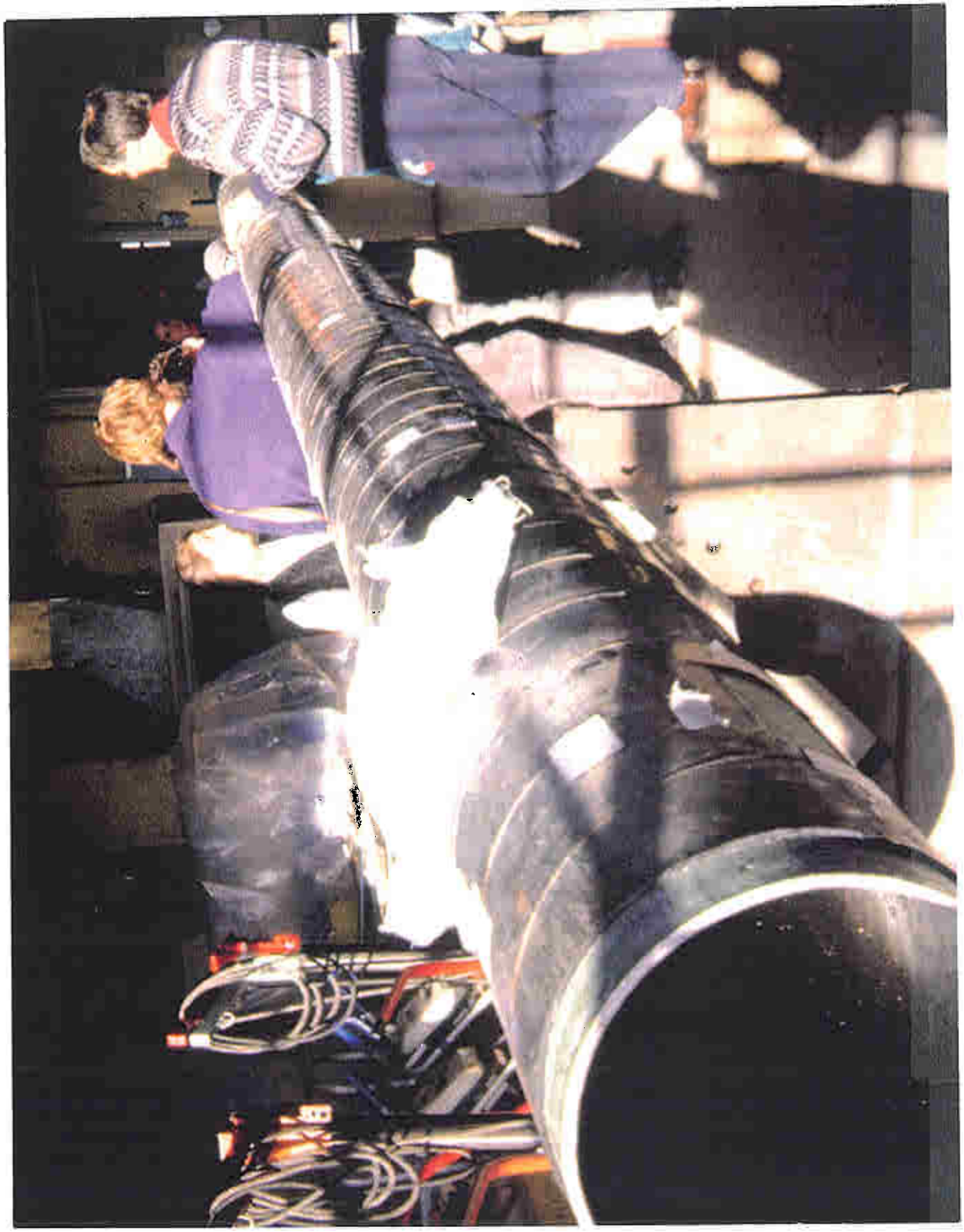

Figure 5 pipe in workshop

Pipe temperature and circulation are controlled by a fan and compressor system mounted inside the cold room on the ceiling. The system incorporates a mechanism to reverse the direction of flow in the pipe: the difference in temperature between air entering and leaving the pipe was as much as 2C° in the previous experiments. Reversal of pipe circulation every six hours as in the previous experiments a uniform average pipe temperature to be maintained.

Properties of Caen silt II

The silt used for the current experiment was obtained from the same pit and it similar to the silt from the previous experiment. Physical property tests (grain size distribution, freezing characteristic curve, thermal conductivity and diffusivity) will be carried out on specimens of this material in the coming year. Data for the Caen silt used in the first experiment (taken from Dallimore, 1985) on volumetric unfrozen moisture content, grain size distribution, and the range of values for segregation potential (SP) are given in the appendix.

Properties of the new silt:

- Particle Density : 2.665 g cm^{-3}
- Installed mean bulk density: 1.56 g cm^{-3}
- 95.7% passes a 0.08 mm sieve.
- Moisture content for placement: 11-13%

- Atterberg Limits:
    - Liquid Limit: 32%
    - Plastic Limit: 21%
    - Plasticity Index: 11
- Proctor Normal Optimum 14.5% moisture content gives maximum density of 1.86 g cm^{-3} (see Figure in the appendix)

The soil was placed and compacted in 8 layers:

Backfill layering

Layer	Loose Thickness (cm)	Compacted Thickness (cm)	Ratio compact: loose
1	40	32.73	0.818
2	40	33.07	0.827
3	38	27.91	0.734
4	36	26.60	0.739
5	36	27.50	0.764
6	37	29.12	0.787
7	36	27.95	0.776
8	36	28.59	0.794

giving a total depth of 2.33 m

Instrumentation

Figure 6 is a plan showing the layout of instruments placed in the soil, using the labelling scheme for sensor sites shown in Table I.

Temperature measurements

Thermistors

Four major thermal "cross sections" (i.e. multiple thermistor cables) have been installed transverse to the pipe axis: 1 and 4.5 m from the transition in both the prefrozen and unfrozen sections. Each cross section consists of:

- a 12 thermistor cable 25 cm from pipe centre line;
- a 10 thermistor cable 1 m from pipe c.l.
- a 10 thermistor cable 2 m from pipe c.l.
- an 8 thermistor cable 3 m from pipe c.l.

There are four additional 10 thermistor strings placed adjacent to the pipe (for a total of eight strings 25 cm off pipe axis).

In addition to these cables, 21 thermistors are attached to the pipe exterior (7 arrays of 3: top, side, and bottom); two thermistors monitor inflow and outflow temperatures inside the pipe, and each bison cell has one thermistor attached. (Two bison cell arrays 1 m from transition and 2 m off axis occupy positions for two cables above: the thermistors on these bison cells replace these two thermistor cables.)

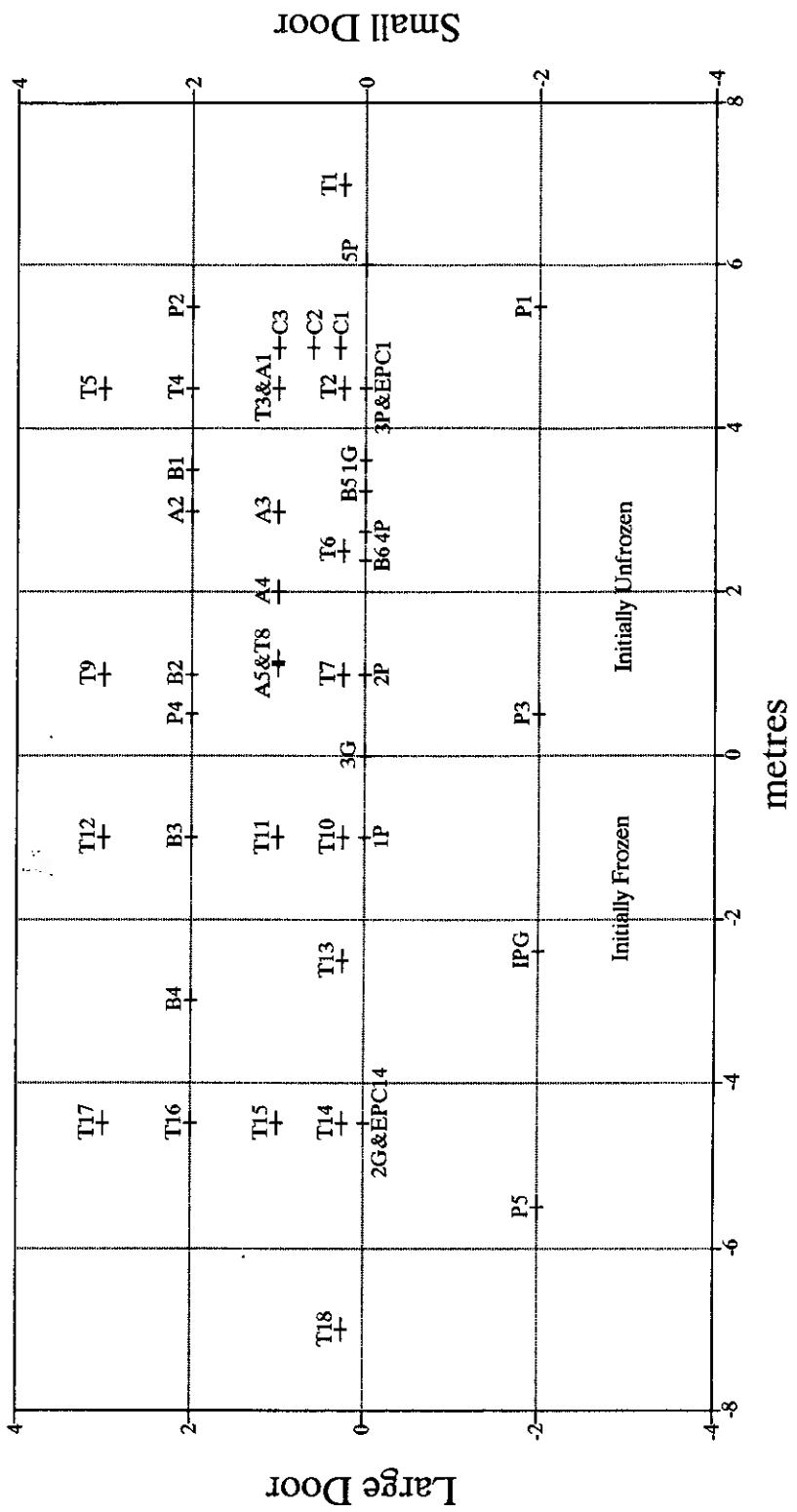

Figure 6 Sensor locations. See Table I for abbreviations.

Thermistor cables are in access tubes, with a rugged (Amphenol series 97) connector at the surface. This arrangement permits

- manual readings of logged cables;
- rapid recovery and replacement of damaged cables;
- moving cables to new locations;
- replacement of cables with new thermistor positions.

After assembly into cables, thermistor strings were calibrated at 0°C in a circulating ice-water bath. Calibration data for all cables are provided in the instrumentation appendix.

A total of 200 thermistors will be logged automatically. All thermistors attached to the datalogger are continuously charged by a 10 microampere current source.

Pressure measurements

All pressure sensors used in the experiment operate on the same principle: compression of an oil filled vessel forces displacement of a diaphragm within the sensor. Back-pressure is applied to the opposite side of the diaphragm to return it to its neutral position: measured back-pressure is thus equal to the pressure on the sensor.

The EPC and Glotzl cells are designed specifically for earth pressure measurements: both consist of flat steel plates welded

Table I: Surface location of sensors

Device	Site	Distance Off Axis (m)	Axial Distance (m)
Bison Cells	B1	2.00	-3.50
	B2	2.00	-1.00
	B3	2.00	1.00
	B4	2.00	3.00
	B5	0.00	-3.25
	B6	0.00	-2.40
Magnet Rings (Anneaux Magnetiques)	A1	1.00	-4.50
	A2	2.00	-3.00
	A3	1.00	-3.00
	A4	1.00	-2.00
	A5	1.00	-1.10
Petur total pressure cells	1P	0.00	1.00
	2P	0.00	-1.00
	3P	0.00	-4.50
	4P	0.00	-2.75
	5P	0.00	-6.00
Glotzl total pressure cells	1G	0.00	-3.63
	2G	0.00	4.50
	3G	0.00	0.00
EPC pressure cells	EPC1	0.00	-4.50
	EPC14	0.00	4.50
Thermistor cable sites (cables are interchangable between sites)	T1	0.25	-7.00
	T2	0.25	-4.50
	T3	1.00	-4.50
	T4	2.00	-4.50
	T5	3.00	-4.50
	T6	0.25	-2.50
	T7	0.25	-1.00
	T8	1.00	-1.00
	T9	3.00	-1.00
	T10	0.25	1.00
	T11	1.00	1.00
	T12	3.00	1.00
	T13	0.25	2.50
	T14	0.25	4.50
	T15	1.00	4.50
	T16	2.00	4.50
	T17	3.00	4.50
	T18	0.25	7.00
Wood columns (vertical shear)	C1	0.30	-5.00
	C2	0.60	-5.00
	C3	1.00	-5.00
Frost tube	IPG	-2.00	2.40
Piezomter wells	P1	-2.00	-5.50
	P2	2.00	-5.50
	P3	-2.00	0.50
	P4	2.00	0.50
	P5	-2.00	5.50

Table I

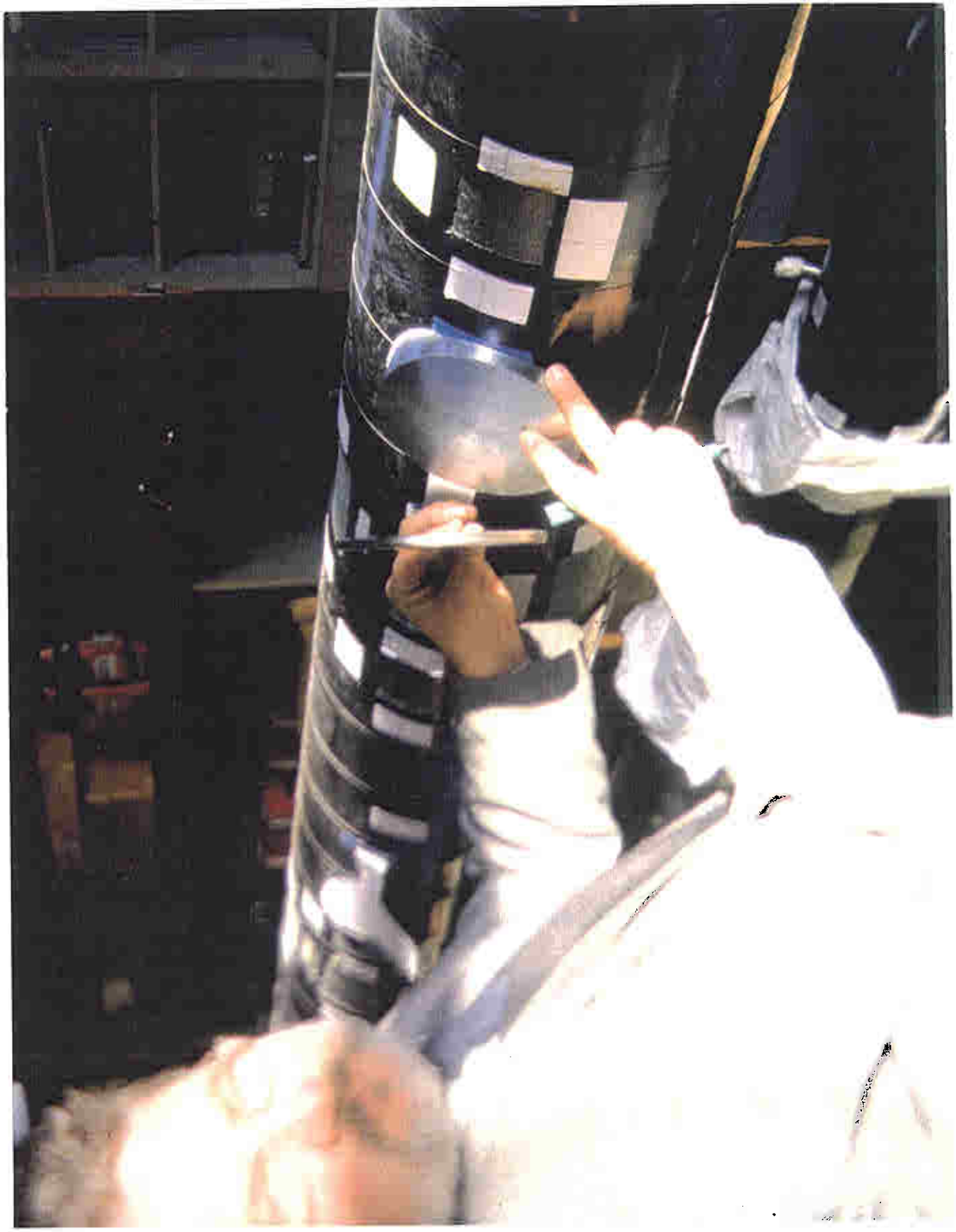

Figure 7 EPC (on edge toward camera) and seating plate (on pipe)

("SICADUR"). This compound fills the space between the cell and the bearing plate surface, since the EPCs are not perfectly flat. Seating plates are attached to the pipe using steel straps.

Petur cells

Petur (now RST Instruments) piezometers (model P-100) are originally designed to measure pore water pressure. As delivered they are small diameter cylindrical devices (1.6 cm O.D. x 6.3 cm long), with a non-metallic filter at one end and air lines to the readout device at the other. To modify the piezometer to measure total pressure, an oil filled latex rubber bulb is placed over the filtered end, and secured using a hose clamp (care is taken to exclude air from the bulb).

There are five arrays of five petur cells each, all installed below the pipe, along the axis. All arrays have the first sensor 10 cm below the pipe, with additional sensors at a spacing of 20 cm. The petur cells from the previous experiment which were intended to provide "directional" pressures have been modified to give total pressure.

Glotzl cells

As with the Petur cells, glotzl cell arrays are below the pipe, along the pipe axis, with the first sensor 10 cm below the pipe, then at a spacing of 20 cm. There are two arrays of five glotzl cells each, on either side of the transition. Two additional cells are placed at the transition, 10 and 30 cm below

the pipe.

Soil movement and expansion

Optical survey

The soil surface is surveyed optically using a level mounted in the frame of the small door to the cold room. The reference point for all level measurements is an iron bar embedded in the concrete of a retaining wall just outside the facility. Survey points are laid out in a grid of nails embedded in the soil surface. There are 11 survey lines axial to the pipe, each having 30 marker nails at 50 cm spacing. Locations of survey lines and individual nails are included in the instrumentation appendix.

Magnet heave system

The magnet heave measurement system (Figure 8) is described in Smith and Patterson (1989). To quote directly from their description, the system consists of:

> "...a system of ring magnets around an access tube. The magnets are used as floating markers in the ground and their positions can be determined by lowering a sensor down the tube. By repeating the measurements over time, one can determine strain by soil layer.
>
> "While the general principle of the magnet probe has been used in a variety of position-detecting devices for many years, Mackay and Leslie (1987) were the first to miniaturize it for measuring soil displacements in

frozen ground. As described by them (p.38), the probe consists of three parts..." "...:a vertical access tube inserted into a small borehole; a vertical array of ring magnets placed around the tube as the hole is backfilled, and a reed switch probe that is lowered down the access tube and that produces an audible signal when it encounters the field of the magnet. To measure magnet position accurately, the reed switch was mounted on a aluminum rod that runs through a rack and pinion assembly connected to an incremental encoder

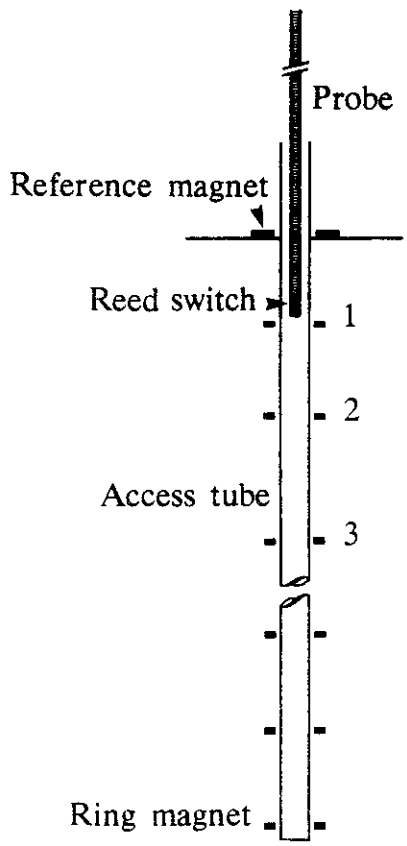

Figure 8 Magnet heave measurement system.

(ACCUCODER^{tm} Model #713330-600). With allowance for variation between operators and some minor backlash in the system, the readings are accurate to within +/- 0.3mm. The positions of magnet rings in the profile are determined with reference to a ring on the soil surface. Magnets should not be spaced closer than about 5 cm, otherwise the fields of successive magnets may overlap."

In total, five magnet arrays have been installed, all in the unfrozen section: four arrays are 1 m off axis, at 1,2,3, and 4.5 m from the transition. The fifth array is installed beside the bison array 2 m off pipe axis and 3 m from transition, to permit comparison of the two techniques.

Bison cells

Bison soil strain gauges (Bison "cells") consist of resin covered discs containing induction coils. The cells are buried co-axially, at spacings of 1 to 4 times their diameter. The measurement device sends a sinusoidal excitation voltage through one cell, which is received by a second cell. The ratio of emitted to received amplitudes is calibrated to cell spacing. A series of cells arranged in a single array permits monitoring of soil strain over several depths: cells are used alternately as emitters and receivers as measurements are taken down a column of soil.

Cells of 9.5 cm diameter were chosen for the experiment, having a hole about 5 mm in diameter in the centre. Calibration was evaluated over the range 10-25 cm. Repeatability for position was found to be within +/-1 mm: strain measurements will be much more precise. The Bison cells will compliment the magnetic heave device measurements, which are more precise for position but less precise for strain. One Bison cell array was placed away from the pipe and adjacent to a magnet array. This will allow direct comparison of the two systems.

Cells were installed in 12 cm diameter holes , using a small diameter metal rod through the centre hole for alignment. (The rod was removed after placement of the cells.) Six arrays were installed, with sensors at 20 cm spacing: four arrays are 2 m off of the pipe axis; the two remaining arrays are buried beneath the pipe. Special nylon seats were constructed for the attachment of two bison cells to the pipe, permitting monitoring of pipe movements above the cell arrays installed on the pipe axis. Exact locations of cells and arrays are given in the instrumentation appendix.

An individually calibrated thermistor is glued to each cell.

Hydrostatic profiler

This SINCO hydrostatic profiler is a new type of instrument to measure soil movements along a buried horizontal access tube.

As its name implies, it operates on the hydrostatic principle: a change in the elevation of a pressure sensor connected to a datum by liquid filled tubing is measured as a change in hydrostatic pressure. In the current experiment this device will be used to measure soil displacements immediately below the pipe. It is intended to measure the profile of frost heave along the length of the pipe independent of the pipe. Any differences between pipe uplift as determined from optical surveying and frost heave immediately below the pipe would indicate the development of a cavity between the pipe base and the soil, due to the bending resistance of the pipe. A horizontal slope indicator (from SINCO) initially specified for this task proved to be impractical for monitoring frost heave beneath the pipe due to the significant curvatures anticipated.

Two access tubes for the profiler sensor were buried 10 cm below the base of the pipe, and just outside the pipe diameter (Figure 9). Figure 10 shows the (red) access tubes as they exit at the end of the trench. The sensor (nicknamed the "fish") fits loosely in the access tube, to permit its easy passage: a centering system has been devised, consisting of three small test-tube cleaning brushes evenly spaced around the fish with a metal ring holding them in place at the nose and tape holding them at the tail.
a brush-like sleeve or spring steel runners are being investigated as methods of ensuring the precise location of the

sensor in the tube during measurements.

Pipe instrumentation

Survey rods

Vertical survey rods are attached to the pipe at 66 cm intervals along its full length, for a total of 24 rods. The survey rods are threaded to fit into steel nuts welded onto the pipe surface. A loose plastic sleeve was placed around each rod prior to backfilling, to permit their free movement as the pipe is deformed and lifted by the heaving soil. Survey rods can be seen in Figure 13. The bolts anchoring them to the pipe surface

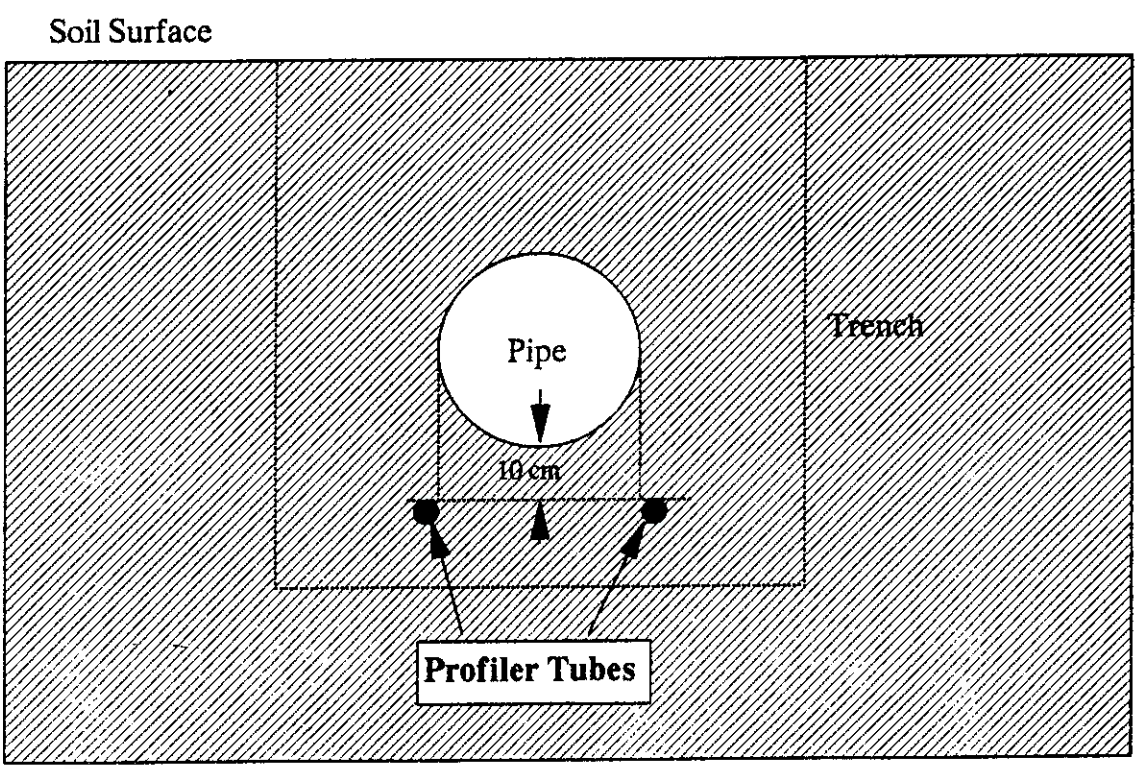

Figure 9 Position of profiler access tubes beneath the pipe.

Figure 10

can be seen in Figure 11.

Pipe strain gauges

The pipe is instrumented with 72 120 ohm strain gauges (Micro Measurements model CEA-06-250UW-120) in two configurations:

- ten radial arrays of six gauges each, individually wired for a quarter bridge measurement;
- six pairs of gauges, placed at the 12 o'clock and 6 o'clock positions on the pipe, wired for half bridge measurements.

Radial arrays are at 1 m intervals on either side of the frozen transition, staring 50 cm from the transition. Strain gauge pairs start 1 m beyond the last radial array on both sides of the transition, at 1 m intervals.

Preparation of the pipe surface for strain gauges was a lengthy process, involving:

- removal of the pvc coating (accomplished by heating with hot air, cutting a patch, and scraping);
- cleaning the surface with a solvent;
- grinding and polishing the steel surface.

Figure 11 shows the prepared pipe surface prior to strain gauge installation. The gauges were installed using the procedure specified by the manufacturer. Gauges were coated with silicon sealant and covered by aluminum tape.

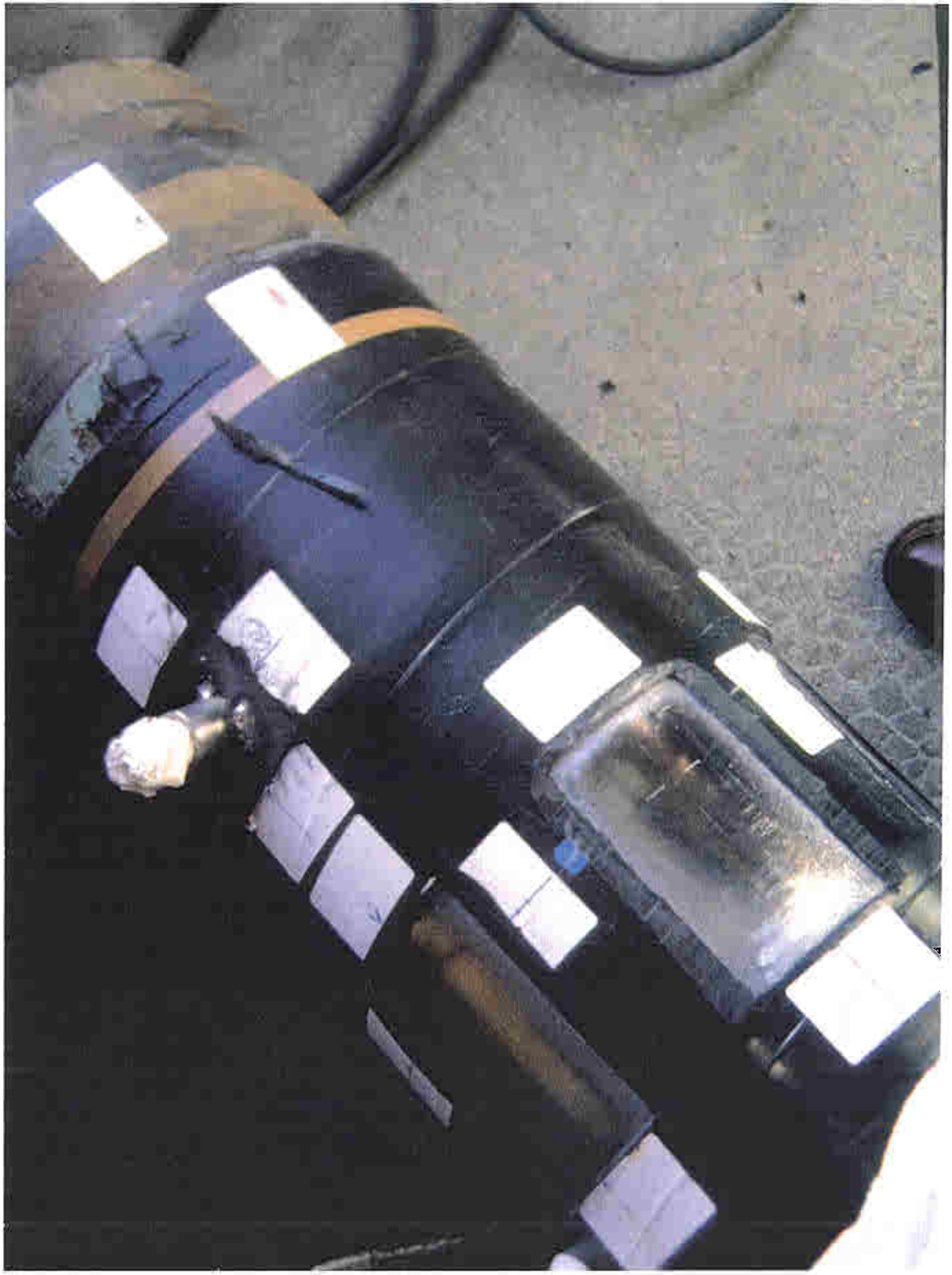

Figure 11

Pipe-soil interaction

Longitudinal shear stress

Two devices were installed to measure longitudinal shear between the pipe and the soil. The "LVDT" device is intended to measure the movement of the pipe relative to soil unaffected by the shearing forces. The steel strip device is intended to measure the shear within the soil immediately adjacent to the pipe. Both are installed approximately 2 m from the frozen interface, on the unfrozen side. Figures 12 and 13 shows both devices installed in the trench.

Both shear devices are attached to anchors at the end distant from the pipe. The anchors for both consist of a pair of crossed aluminum plates 20 cm square and 1 cm thick. This design allowed for easy transport of the plates, and provides a shape which will resist rotation in the ground. Ideally, the anchors should be placed in soil which will not move; in the present experiment, a fixed anchor would not permit the devices to rise with the heaving soil. The compromise solution has been to allow the devices to move upwards with the heaving soil, but to place the anchors at a distance from the pipe sufficient to ensure that they will not be influenced by longitudinal shear.

"LVDT" device

This device consists of a linear potentiometer (rather than an LVDT) attached to two "fixed" points : one on the pipe and the

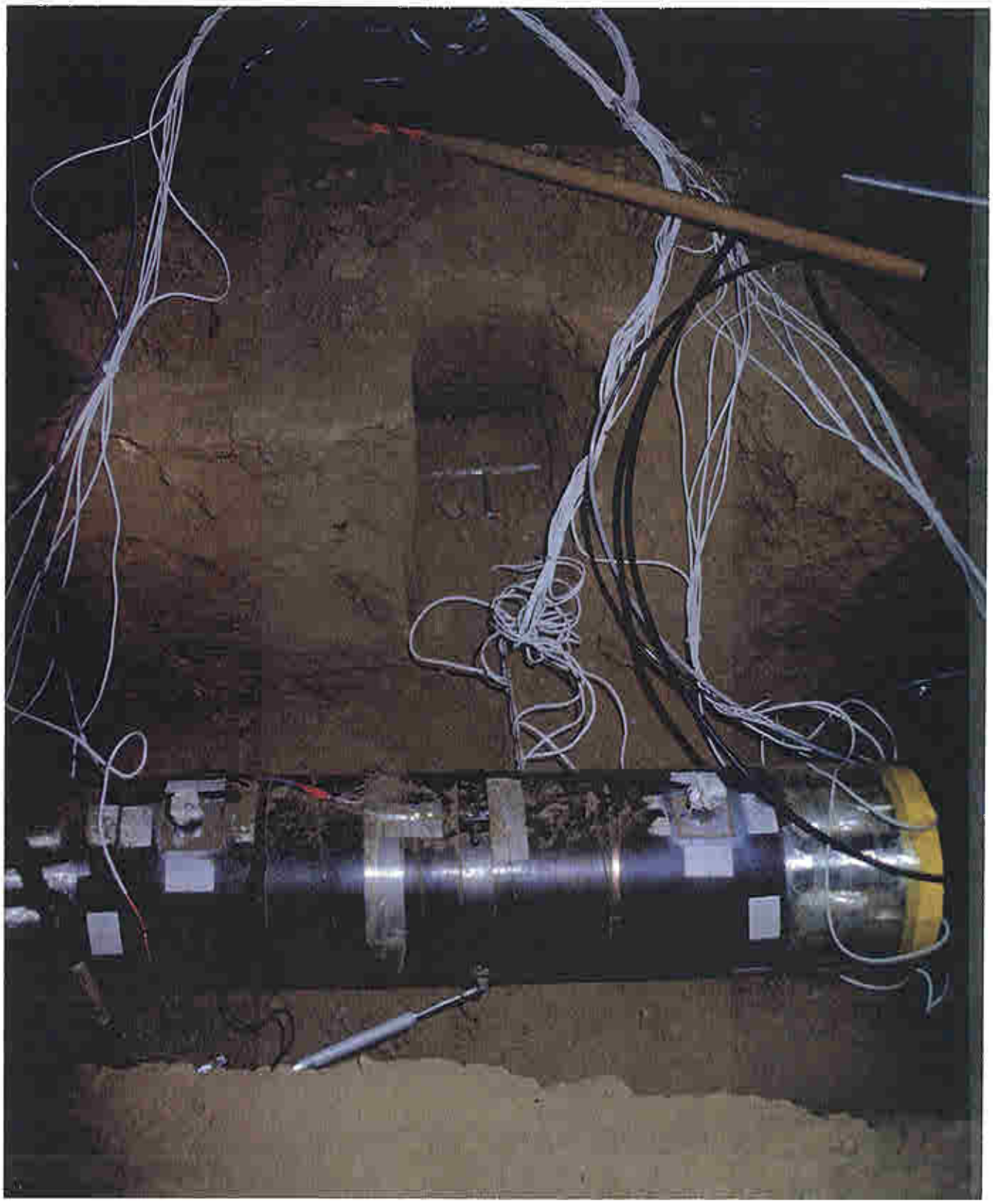

Figure 12 lvdt and strip

other in the soil some distance from the pipe. The linear potentiometer consists of a piston and sleeve with universal joints on both parts for attachment. At one end, the universal joint attaches to a steel strap connected rigidly to the pipe. At the other end the potentiometer attaches to a soil anchor as described above. A survey rod is attached to the anchor, to allow determination of the vertical heave component of the movements of the potentiometer. For a given excitation voltage, output voltage changes in proportion to displacement when the piston moves in the sleeve.

"Steel strip" device

This device, based on Williams (1957), consists of a steel strip instrumented with 350 ohm strain gauges (Micro-Measurements model CEA-06-125UW-350) in paired half bridge configuration, installed horizontally radial to the pipe (Figure 14). The strip bends when the adjacent frozen soil is deformed. Analysis of strain gauge measurements from the strip can be used to measure shear within the soil adjacent to the pipe. The end farthest from the pipe is attached to an anchor as described above. The end adjacent to the pipe is free, and is installed 1 to 2 mm from the pipe surface (that is, it does not touch the pipe).

The device requires calibration before strain measurements can be interpreted: a specimen of the steel used in the strip will be tested to determine its mechanical properties. In

Figure 13 lvdt and strip

addition, identical strain gauges will be installed on a sample steel strip to calibrate gauge response to strip curvature in the laboratory.

Vertical shear

Horizontal displacements of the soil around the pipe will be examined as in the previous experiment, using a simple system of stacked wooden discs installed in vertical columns adjacent to the pipe. Irreversible movements of soil will be evident as changes to the linear alignment of the discs in the columns.

Steel Strip Longitudinal Shear Device

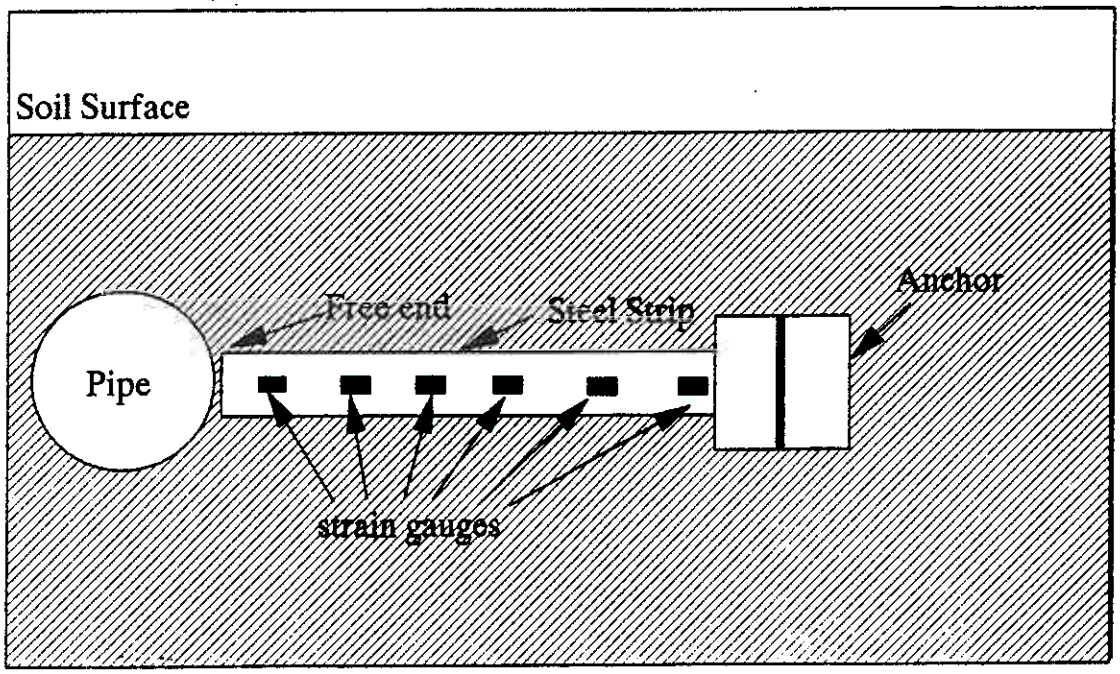

Figure 14

Three columns of discs will be monitored, all 5 metres from the transition in the unfrozen section. The three arrays, in the same location as previous experiment, will permit a two dimensional view of the zone of displacements around the pipe.

Other measurements

Monitoring water table and water inputs

The water table within the experimental basin is monitored via seven piezometer wells placed at regular intervals along the pipe and 2 m to either side of the pipe axis. Elevation of the water table relative to the surface is monitored using an electronic dip-stick: an LED indicates when the end of the stick makes contact with the water. The depth to the water table can be read directly from the side of the stick.

Water inputs to the soil are monitored with a dial gauge at the input valve: all water inputs are recorded.

In the previous experiments at the facility, it has been a standard practice to capture, measure and record the amount of water removed by the defrost cycles of the compressors in the cold room, to include in the total water balance for the experiment.

Data acquisition

Automatic data acquisition

Two separate systems are being used for data acquisition. The 200 channel system used in the previous experiment will be devoted to logging thermistors in the new experiment.

A data acquisition system from Sciemetric Instruments was chosen to monitor strain gauges. The system incorporates 80 individual bridge circuits, designed for strain gauge applications. The LVDT device and some additional instruments will also be logged on un-allocated channels. Channel allocations for the Sciemetric logger are included in the instrumentation appendix.

Schedule of measurements

During the early stage of the experiment, most manual measurements (pressure, strain, heave) will be taken 2 times per week, with optical levelling and hydrostatic profiling once per week. The data acquisition system being used for thermistors is logging temperatures every 6 hours. During this stage of the experiment, the datalogger for strain gauges will be activated for a period of an hour two times per week, during which measurements will be recorded once per minute. Once a computer is purchased to dedicate to this datalogger, recording frequency will be reduced and data logged continuously.

Pullout Test

As an auxiliary experiment, a constant-rate pullout test on a short section of pipe is being executed under a sub-contract by Dr. Branko Ladanyi. The pullout resistance of the pipe will be one of the governing considerations in gas pipeline design.

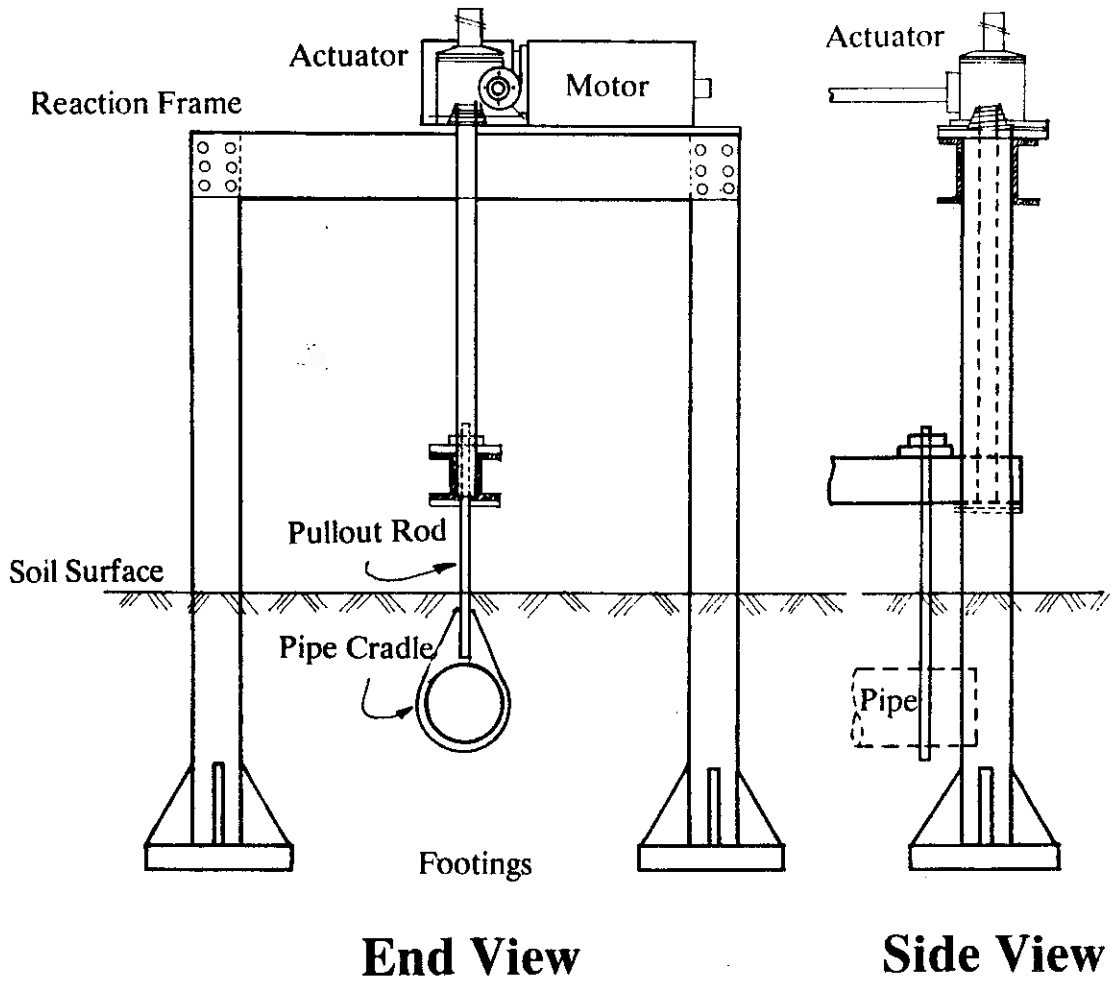

Figure 15 Pipe pullout test apparatus

Details of this experiment are not yet finalized. Figure 15 shows a schematic diagram of the pullout test apparatus. Sketch details for the pipe cradle and pullout apparatus reaction frame, as sent to Caen, are included in the Appendix.

The pipe will be pulled up through the soil at a constant rate of 1 mm per day for a period of approximately 30 days. The force required to achieve this will be provided by worm gear linear actuators (Duff-Morton Simplex Uni-Lift model 24837).

As an aid to the interpretation of data from the main experiment, the pullout test is being done on a section of pipe identical to the pipe used in the main experiment. It was backfilled in the same manner as the pipe in the main experiment, and is connected to the circulation system in series with the main pipe. Soil conditions should thus closely match those of the main experiment. The pipe section is 1.5 m in length, providing a ratio of length to diameter which reduces end effects to an acceptable level.

A steel plate has been buried adjacent to the short pipe section, and will also be subjected to a constant rate pullout test. This test will provide an indication of the degree to which pullout plate tests model the behaviour of tests on pipe, which are more realistic (but more difficult). The important differences between the plate and the pipe are:

- differences in geometry (curvature; length/width ratio);

- polyethylene coating on the pipe; the plate is uncoated steel.
- the pipe will have cold air circulation in series with the main experiment, while the pullout plate will be at ambient soil temperature.

The 1.5 metre pipe section is buried in a trench centred between the main pipe and the wall of the cold room (i.e., 2 metres form the wall and the main pipe centreline). This position affords little room for the placement of footings for the test reaction frame. Because the test details were not established in time to provide footings resting directly on floor of the basin, various options are now being explored that will provide secure footings for the frame, but will not interfere with instruments for the main experiment nor transfer stresses to the test pipe section or to the main pipe. Footings on the base of the chamber would pierce the membrane, while attachment to the walls of the chamber is not considered possible since they are constructed of low density insulating concrete blocks.

Due to concerns raised by members of the consortium regarding some details of the pullout test, the pipe section was reinforced with a 120° section of pipe added to the underside of the pipe (fitting between the test section and the pipe cradles), effectively doubling the thickness of the pipe where it bears on the pullout cradles.

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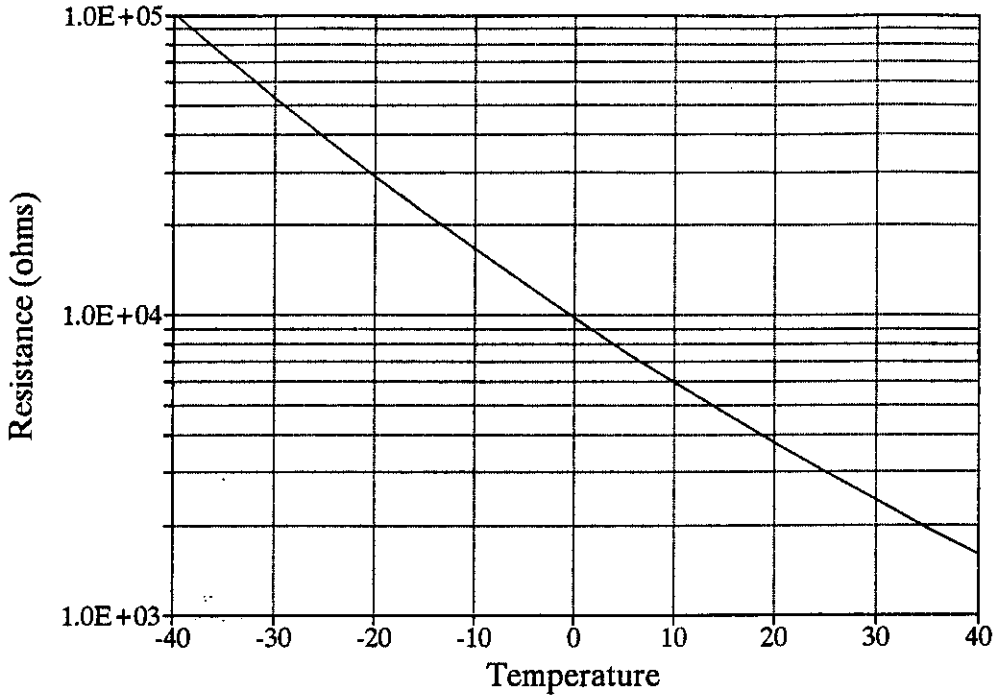
Appendix:

Instrument positions
Instrument specifications and calibration data
Caen silt data sheet.

R-Temperature for Fenwal Thermistors

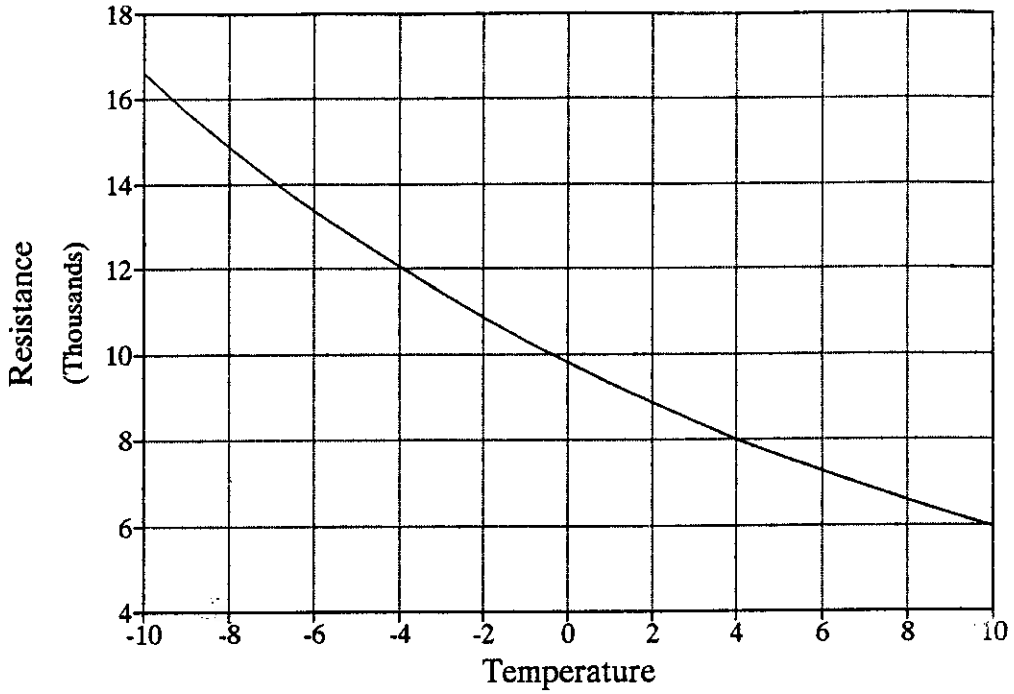
no. 192-302LZS-A01



Temperature	Resistance
-40	100950
-35	72810
-30	53100
-25	39120
-20	29120
-15	21885
-10	16599
-5	12699
0	9795
5	7617
10	5970
15	4713
20	3747
25	3000
30	2417
35	1959
40	1598

R-Temperature for Fenwal Thermistors

no. 192-302LZS-A01



Temperature	Resistance
-10	16599
-9	15720
-8	14895
-7	14118
-6	13386
-5	12699
-4	12048
-3	11433
-2	10857
-1	10311
0	9795
1	9309
2	8850
3	8415
4	8007
5	7617
6	7251
7	6903
8	6576
9	6264
10	5970

Thermistor String Wiring

- Each thermistor has its own ground.

- Thermistor wires are attached to the connectors as pairs, with the ground wire as the second in the pair (see following).

- They are soldered to the connectors with the topmost thermistor (closest to the connector) connected to pins A and B (B= ground), the next closest at C and D (D=ground), etc.

12 THERMISTOR CABLE

Pair #	Depth (cm)	Dist. from end	Pin #	Colour High	Colour Gnd
1	10	175	A B	White	Black
2	30	155	C D	Green	Black
3	50	135	E F	Red	Black
4	65	120	G H	Blue	Red
5	80	105	J K	Yellow	Red
6	95	90	L M	Green	Red
7	110	75	N P	Blue	Black
8	125	60	Q R	White	Red
9	140	45	S T	Brown	Red
10	155	30	U V	Yellow	Black
11	170	15	W X	Orange	Black
12	185	0	Y Z	Brown	Black

10 THERMISTOR CABLE

Pair #	Depth (cm)	Dist. from end	Pin #	Colour High	Colour Gnd
1	10	180	A B	White	Red
2	30	160	C D	Red	Black
3	50	140	E F	Blue	Red
4	70	120	G H	Green	Red
5	90	100	J K	Green	Black
6	110	80	L M	White	Black
7	130	60	N P	Brown	Black
8	150	40	Q R	Blue	Black
9	170	20	S T	Orange	Black
10	190	0	U V	Yellow	Black

8 THERMISTOR CABLE

Pair #	Depth (cm)	Dist from end	Pin #	Colour High	Colour Gnd
1	10	175	A B	Blue	Red
2	35	150	C D	Green	Red
3	60	125	E F	Green	Black
4	85	100	G H	White	Black
5	110	75	J K	Brown	Black
6	130	50	L M	Blue	Black
7	160	25	N P	Orange	Black
8	185	0	Q R	Yellow	Black

Thermistor calibration for 0 degrees Celsius
For Fenwal thermistors nominally 3000 ohms at 25 degrees

Cable	Sensor Number	Sensor Depth	Distance from end	0 C Calibration
10A	1	10	180	9737
	2	30	160	9720
	3	50	140	9747
	4	70	120	9803
	5	90	100	9797
	6	110	80	9797
	7	130	60	9747
	8	150	40	9742
	9	170	20	9777
	10	190	0	9790
10B	1	10	180	9781
	2	30	160	9777
	3	50	140	9736
	4	70	120	9732
	5	90	100	9774
	6	110	80	9744
	7	130	60	9760
	8	150	40	9749
	9	170	20	9784
	10	190	0	9823
10C	1	10	180	9719
	2	30	160	9752
	3	50	140	9812
	4	70	120	9730
	5	90	100	9803
	6	110	80	9749
	7	130	60	9820
	8	150	40	9777
	9	170	20	9722
	10	190	0	9726
10D	1	10	180	9753
	2	30	160	9741
	3	50	140	9804
	4	70	120	9751
	5	90	100	9741
	6	110	80	9763
	7	130	60	9752
	8	150	40	9750
	9	170	20	9741
	10	190	0	9782

Thermistor calibration for 0 degrees Celsius
For Fenwal thermistors nominally 3000 ohms at 25 degrees

Cable	Sensor Number	Sensor Depth	Distance from end	0 C Calibration
10E	1	10	180	9732
	2	30	160	9764
	3	50	140	9810
	4	70	120	9811
	5	90	100	9709
	6	110	80	9773
	7	130	60	9728
	8	150	40	9812
	9	170	20	9748
	10	190	0	9762
10F	1	10	180	9717
	2	30	160	9740
	3	50	140	9798
	4	70	120	9727
	5	90	100	9717
	6	110	80	9627
	7	130	60	9675
	8	150	40	9762
	9	170	20	9807
	10	190	0	9801
10G	1	10	180	9747
	2	30	160	9777
	3	50	140	9690
	4	70	120	9708
	5	90	100	9768
	6	110	80	9720
	7	130	60	9742
	8	150	40	9733
	9	170	20	9758
	10	190	0	9781
10H	1	10	180	9739
	2	30	160	9754
	3	50	140	9747
	4	70	120	9732
	5	90	100	9763
	6	110	80	9809
	7	130	60	9791
	8	150	40	9781
	9	170	20	9735
	10	190	0	9718

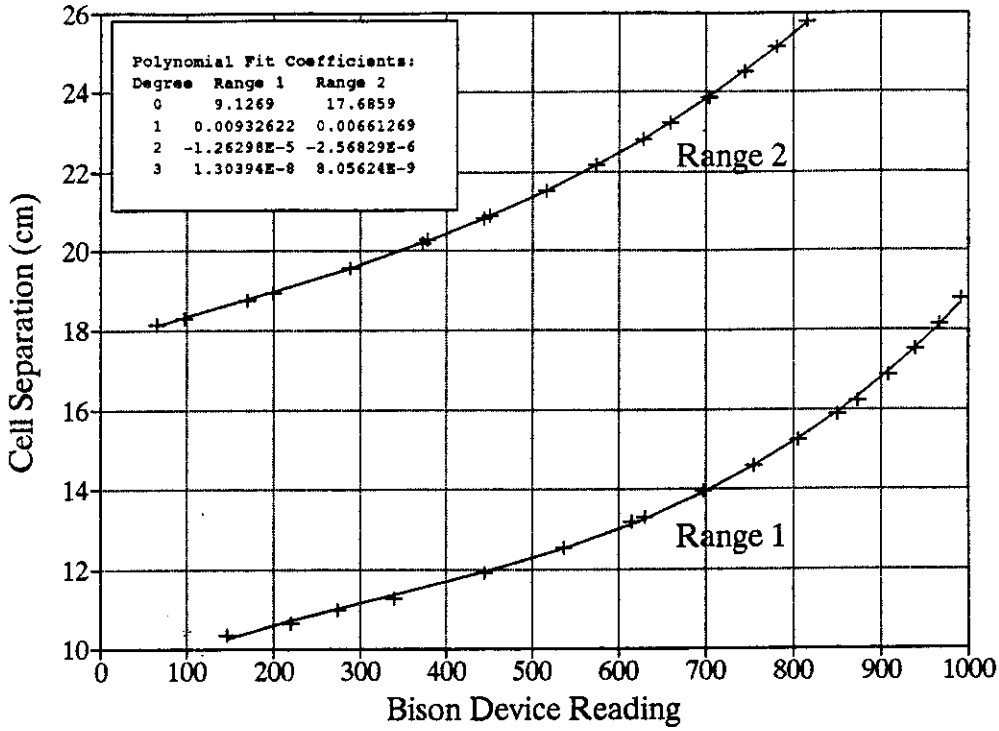
Thermistor calibration for 0 degrees Celsius
For Fenwal thermistors nominally 3000 ohms at 25 degrees celsius

Cable	Sensor Number	Sensor Depth	Distance from end	0 C Calibration
10J	1	10	180	9704
	2	30	160	9746
	3	50	140	9751
	4	70	120	9666
	5	90	100	9718
	6	110	80	9776
	7	130	60	9726
	8	150	40	9747
	9	170	20	9745
	10	190	0	9741
10K	1	10	180	9734
	2	30	160	9778
	3	50	140	9751
	4	70	120	9755
	5	90	100	9779
	6	110	80	9737
	7	130	60	9695
	8	150	40	9746
	9	170	20	9789
	10	190	0	9607
8A	1	10	175	9761
	2	35	150	9769
	3	60	125	9810
	4	85	100	9743
	5	110	75	9766
	6	135	50	9783
	7	160	25	9797
	8	185	0	9776
8B	1	10	175	9723
	2	35	150	9812
	3	60	125	9750
	4	85	100	9671
	5	110	75	9816
	6	135	50	9799
	7	160	25	9785
	8	185	0	9794
8C	1	10	175	9780
	2	35	150	9730
	3	60	125	9764
	4	85	100	9768
	5	110	75	9737
	6	135	50	9720
	7	160	25	9734
	8	185	0	9720
8D	1	10	175	9788
	2	35	150	9737
	3	60	125	9756
	4	85	100	9820
	5	110	75	9767
	6	135	50	9730
	7	160	25	9702
	8	185	0	9712

Thermistor calibration for 0 degrees Celsius
For Fenwal thermistors nominally 3000 ohms at 25 degrees celsius

Cable	Sensor Number	Sensor Depth	Distance from end	0 C Calibration
12A	1	10	175	9767
	2	30	155	9804
	3	50	135	9792
	4	65	120	9730
	5	80	105	9733
	6	95	90	9747
	7	110	75	9759
	8	125	60	9761
	9	140	45	9773
	10	155	30	9755
	11	170	15	9828
	12	185	0	9773
12B	1	10	175	9757
	2	30	155	9778
	3	50	135	9813
	4	65	120	9743
	5	80	105	9795
	6	95	90	9802
	7	110	75	9778
	8	125	60	9746
	9	140	45	9775
	10	155	30	9762
	11	170	15	9740
	12	185	0	9777
12C	1	10	175	9720
	2	30	155	9781
	3	50	135	9771
	4	65	120	9758
	5	80	105	9757
	6	95	90	9767
	7	110	75	9798
	8	125	60	9769
	9	140	45	9823
	10	155	30	9811
	11	170	15	9765
	12	185	0	9732
12D	1	10	175	9673
	2	30	155	9721
	3	50	135	9785
	4	65	120	9812
	5	80	105	9788
	6	95	90	9806
	7	110	75	9792
	8	125	60	9739
	9	140	45	9764
	10	155	30	9728
	11	170	15	9737
	12	185	0	9734

Bison Cell Calibration



Bison Cells

Site	Distance Off Axis (m)	Axial Distance (m)	Cell Position	Bison Cell number	Depth (cm)	Thermistor resistance at 0 C
1	2.00	-3.50	1	1	207	9765
			2	2	189	9790
			3	3	171	9786
			4	4	153	9747
			5	5	135	9772
			6	6	117	9725
			7	7	99	9736
			8	8	81	9739
			9	9	63	9750
			10	10	45	9806
			11	11	27	9815
2	2.00	-1.00	1	12	207	9744
			2	13	189	9778
			3	14	171	9813
			4	15	153	9799
			5	16	135	9739
			6	17	117	9820
			7	18	99	9760
			8	19	81	9764
			9	20	63	9795
			10	21	45	9772
			11	22	27	9808
3	2.00	1.00	1	23	207	9734
			2	24	189	9816
			3	25	171	9746
			4	26	153	9791
			5	27	134.5	9790
			6	28	117	9749
			7	29	98.7	9764
			8	30	81	9776
			9	31	63	9773
			10	32	45	9815
			11	33	27	9798

Bison Cells

Site	Distance Off Axis (m)	Axial Distance (m)	Cell Position	Bison Cell number	Depth (cm)	Thermistor resistance at 0 C
4	2.00	3.00	1	34	207	9773
			2	35	189	9756
			3	36	171	9735
			4	37	153	9781
			5	38	135	9726
			6	39	115	9778
			7	40	99	9810
			8	41	81	9792
			9	42	63	9737
5	0.00	-3.25	1	54	On Pipe	9796
			2	53	79.5	9771
			3	52	97.5	9734
			4	51	115.5	9790
			5	50	133.5	9797
			6	49	151	9802
			7	48	169.5	9767
			8	47	187.5	9804
			9	43	203.5	9811
6	0.00	-2.40	1	63	On Pipe	9774
			2	62	79.5	9759
			3	61	97.5	9749
			4	60	115.5	9781
			5	59	133.5	9736
			6	58	151	9766
			7	57	169.5	9760
			8	56	187.5	9729
			9	55	203.5	9735

Glotzl total pressure cells

Site	Off Axis (m)	Axial Distance (m)	Glotzl Number	(cm) (cm)	Initial Reading (exposed) mbar	Initial Reading (buried) mbar
1G	0.00	-3.63	1	163	680	735
			2	142	1140	1170
			3	124	1420	
			4	103	1260	
			5	83	750	870
2G	0.00	4.50	6	163	940	1000
			7	143	1085	1115
			8	123	1230	
			9	103	1170	1350
			10	83	1260	
3G	0.00	0.00	11	103	1260	
			12	83	760	830

EPC earth pressure cells

Site	Off Axis (m)	Axial Distance (m)	EPC Number	Depth (cm)	Initial Reading (exposed) mbar	Initial Reading (buried) mbar
EPC1	0.00	-4.50	1	17	140	140
EPC14	0.00	4.50	14	17	90	100

Petur total pressure cells

Site	Off Axis (m)	Axial Distance (m)	Petur Number	Depth (cm)
1P	0.00	1.00	1	162
			2	143
			3	123
			4	103
			5	83
2P	0.00	-1.00	6	163
			7	143
			8	123
			9	103
			10	83
3P	0.00	-4.50	16	163
			17	144
			18	123
			19	103
			20	83
4P	0.00	-2.75	11	163
			12	143
			13	123
			14	103
			15	83
5P	0.00	-6.00	21	163
			22	143
			23	123
			24	103
			25	83

Magnet Rings (Anneaux Magnetiques)

Site	Off Axis (m)	Axial Distance (m)	Ring Number	Depth (cm)
1	1.00	-4.50	1	155.5
			2	141
			3	132
			4	120
			5	108
			6	96.5
			7	83.5
			8	69
			9	60
			10	47.5
			11	34
			12	24
			13	13
			14	0.75
2	2.00	-3.00	1	156
			2	144
			3	132
			4	120.5
			5	108
			6	95.6
			7	84
			8	72
			9	60
			10	48
			11	36
			12	24
			13	12
			14	2
3	1.00	-3.00	1	156
			2	144
			3	132
			4	120
			5	108
			6	96
			7	83
			8	72
			9	60
			10	48
			11	36
			12	24
			13	12
			14	2

Magnet Rings (Anneaux Magnetiques)

Site	Off Axis (m)	Axial Distance (m)	Ring Number	Depth (cm)
4	1.00	-2.00	1	156
			2	144
			3	132
			4	120
			5	108
			6	95.5
			7	83
			8	71.5
			9	60
			10	48
			11	36
			12	23.5
			13	12
			14	2
5	1.00	-1.10	1	156
			2	143.5
			3	132
			4	120
			5	108
			6	96
			7	83.5
			8	72
			9	60
			10	48
			11	36
			12	24
			13	12
			14	2

Pipe Mounted Sensors

Symbol	Type	Distance (m) From Transition	Clockwise Position Facing PP
T24	Pipe Survey Rod	-7.595	12
T23	Pipe Survey Rod	-6.935	12
T22	Pipe Survey Rod	-6.275	12
T21	Pipe Survey Rod	-5.615	12
T20	Pipe Survey Rod	-4.955	12
T19	Pipe Survey Rod	-4.295	12
T18	Pipe Survey Rod	-3.630	12
T17	Pipe Survey Rod	-2.975	12
T16	Pipe Survey Rod	-2.315	12
T15	Pipe Survey Rod	-1.655	12
T14	Pipe Survey Rod	-0.998	12
T13	Pipe Survey Rod	-0.330	12
T12	Pipe Survey Rod	0.330	12
T11	Pipe Survey Rod	0.988	12
T10	Pipe Survey Rod	1.650	12
T9	Pipe Survey Rod	2.310	12
T8	Pipe Survey Rod	2.970	12
T7	Pipe Survey Rod	3.630	12
T6	Pipe Survey Rod	4.290	12
T5	Pipe Survey Rod	4.950	12
T4	Pipe Survey Rod	5.605	12
T3	Pipe Survey Rod	6.265	12
T2	Pipe Survey Rod	6.930	12
T1	Pipe Survey Rod	7.585	12
EPC2	Earth Pressure Cell	-3.77	12
EPC3	Earth Pressure Cell	-2.78	12
EPC4	Earth Pressure Cell	-1.75	12
EPC5	Earth Pressure Cell	-1.25	12
EPC6	Earth Pressure Cell	-0.75	12
EPC7	Earth Pressure Cell	0.00	12
EPC8	Earth Pressure Cell	0.00	6
EPC9	Earth Pressure Cell	0.78	6
EPC10	Earth Pressure Cell	1.77	6
EPC11	Earth Pressure Cell	2.84	6
EPC12	Earth Pressure Cell	3.86	6
EPC13	Earth Pressure Cell	4.77	6

Pipe Mounted Sensors

Symbol	Type	Distance (m) From Transition	Clockwise Position Facing PP
PT1-T	Thermistor	-6.00	12
PT1-S	Thermistor	-6.00	3
PT1-B	Thermistor	-6.00	6
PT2-T	Thermistor	-4.00	12
PT2-S	Thermistor	-4.00	3
PT2-B	Thermistor	-4.00	6
PT3-T	Thermistor	-2.00	12
PT3-S	Thermistor	-2.00	3
PT3-B	Thermistor	-2.00	6
PT4-T	Thermistor	0.00	12
PT4-S	Thermistor	0.00	3
PT4-B	Thermistor	0.00	6
PT5-T	Thermistor	2.00	12
PT5-S	Thermistor	2.00	3
PT5-B	Thermistor	2.00	6
PT6-T	Thermistor	4.00	12
PT6-S	Thermistor	4.00	3
PT6-B	Thermistor	4.00	6
PT7-T	Thermistor	6.00	12
PT7-S	Thermistor	6.00	3
PT7-B	Thermistor	6.00	6
LVDT	LVDT Longitudinal Shear	-1.95	9
SS	Steel Strip Long. Shear	-1.85	3
A11	Strain Gauge Quarter Bridge	0.50	12
A12	Strain Gauge Quarter Bridge	0.50	10
A13	Strain Gauge Quarter Bridge	0.50	8
A14	Strain Gauge Quarter Bridge	0.50	6
A15	Strain Gauge Quarter Bridge	0.50	4
A16	Strain Gauge Quarter Bridge	0.50	2
A21	Strain Gauge Quarter Bridge	1.50	12
A22	Strain Gauge Quarter Bridge	1.50	10
A23	Strain Gauge Quarter Bridge	1.50	8
A24	Strain Gauge Quarter Bridge	1.50	6
A25	Strain Gauge Quarter Bridge	1.50	4
A26	Strain Gauge Quarter Bridge	1.50	2

Pipe Mounted Sensors

Symbol	Type	Distance (m) From Transition	Clockwise Position Facing PP
A31	Strain Gauge Quarter Bridge	2.50	12
A32	Strain Gauge Quarter Bridge	2.50	10
A33	Strain Gauge Quarter Bridge	2.50	8
A34	Strain Gauge Quarter Bridge	2.50	6
A35	Strain Gauge Quarter Bridge	2.50	4
A36	Strain Gauge Quarter Bridge	2.50	2
A41	Strain Gauge Quarter Bridge	3.50	12
A42	Strain Gauge Quarter Bridge	3.50	10
A43	Strain Gauge Quarter Bridge	3.50	8
A44	Strain Gauge Quarter Bridge	3.50	6
A45	Strain Gauge Quarter Bridge	3.50	4
A46	Strain Gauge Quarter Bridge	3.50	2
A51	Strain Gauge Quarter Bridge	4.50	12
A52	Strain Gauge Quarter Bridge	4.50	10
A53	Strain Gauge Quarter Bridge	4.50	8
A54	Strain Gauge Quarter Bridge	4.50	6
A55	Strain Gauge Quarter Bridge	4.50	4
A56	Strain Gauge Quarter Bridge	4.50	2
A6	Strain Gauge Half Bridge	5.50	6 & 12
A7	Strain Gauge Half Bridge	6.50	6 & 12
A8	Strain Gauge Half Bridge	7.50	6 & 12
B11	Strain Gauge Quarter Bridge	-0.50	12
B12	Strain Gauge Quarter Bridge	-0.50	10
B13	Strain Gauge Quarter Bridge	-0.50	8
B14	Strain Gauge Quarter Bridge	-0.50	6
B15	Strain Gauge Quarter Bridge	-0.50	4
B16	Strain Gauge Quarter Bridge	-0.50	2
B21	Strain Gauge Quarter Bridge	-1.50	12
B22	Strain Gauge Quarter Bridge	-1.50	10
B23	Strain Gauge Quarter Bridge	-1.50	8
B24	Strain Gauge Quarter Bridge	-1.50	6
B25	Strain Gauge Quarter Bridge	-1.50	4
B26	Strain Gauge Quarter Bridge	-1.50	2
B31	Strain Gauge Quarter Bridge	-2.50	12
B32	Strain Gauge Quarter Bridge	-2.50	10
B33	Strain Gauge Quarter Bridge	-2.50	8
B34	Strain Gauge Quarter Bridge	-2.50	6
B35	Strain Gauge Quarter Bridge	-2.50	4
B36	Strain Gauge Quarter Bridge	-2.50	2

Pipe Mounted Sensors

Symbol	Type	Distance (m) From Transition	Clockwise Position Facing PP
B42	Strain Gauge Quarter Bridge	-3.50	10
B43	Strain Gauge Quarter Bridge	-3.50	8
B44	Strain Gauge Quarter Bridge	-3.50	6
B45	Strain Gauge Quarter Bridge	-3.50	4
B46	Strain Gauge Quarter Bridge	-3.50	2
B51	Strain Gauge Quarter Bridge	-4.50	12
B52	Strain Gauge Quarter Bridge	-4.50	10
B53	Strain Gauge Quarter Bridge	-4.50	8
B54	Strain Gauge Quarter Bridge	-4.50	6
B55	Strain Gauge Quarter Bridge	-4.50	4
B56	Strain Gauge Quarter Bridge	-4.50	2
B6	Strain Gauge Half Bridge	-5.50	6 & 12
B7	Strain Gauge Half Bridge	-6.50	6 & 12
B8	Strain Gauge Half Bridge	-7.50	6 & 12
BP-6	Bison Cell	-2.20	6
BP-5	Bison Cell	-3.20	6

Location of surface survey nails

Axial survey lines

Line	Distance off axis (m)
1	-3
2	-2
3	-1.5
4	-1
5	-0.5
6	0
7	0.5
8	1
9	1.5
10	2
11	3

Nails on axial survey lines

Nail	Axial Distance (m)
1	-7.0
2	-6.5
3	-6.0
4	-5.5
5	-5.0
6	-4.5
7	-4.0
8	-3.5
9	-3.0
10	-2.5
11	-2.0
12	-1.5
13	-1.0
14	-0.5
15	0.0
16	0.5
17	1.0
18	1.5
19	2.0
20	2.5
21	3.0
22	3.5
23	4.0
24	4.5
25	5.0
26	5.5
27	6.0
28	6.5
29	7.0
30	7.5

Sciemetric Datalogger Channel Configuration

Logger Channel	CARD Channel	Card	Channel Type	Sensor
0	0	A	350 ohm half	Steel strip 1 & 7
1	1	A	350 ohm half	Steel strip 2 & 8
2	2	A	350 ohm half	Steel strip 3 & 9
3	3	A	350 ohm half	Steel strip 4 & 10
4	4	A	350 ohm half	Steel strip 5 & 11
5	5	A	350 ohm half	Steel strip 6 & 12
6	6	A	350 ohm half	
7	7	A	350 ohm half	
8	8	A	120 ohm quarter	Gauge i.d. A11
9	9	A	120 ohm quarter	Gauge i.d. A12
10	10	A	120 ohm quarter	Gauge i.d. A13
11	11	A	120 ohm quarter	Gauge i.d. A14
12	12	A	Open bridge	LVDT
13	13	A	Open bridge	
14	14	A	Open bridge	
15	15	A	Open bridge	
16	16	A	120 ohm half	Gauge i.d. A6
17	17	A	120 ohm half	Gauge i.d. A7
18	18	A	120 ohm half	Gauge i.d. A8
19	19	A	120 ohm half	Gauge i.d. B6
20	20	A	120 ohm half	Gauge i.d. B7
21	21	A	120 ohm half	Gauge i.d. B8
22	22	A	120 ohm half	
23	23	A	120 ohm half	
24	24	A	120 ohm quarter	Gauge i.d. A15
25	25	A	120 ohm quarter	Gauge i.d. A16
26	26	A	120 ohm quarter	Gauge i.d. A21
27	27	A	120 ohm quarter	Gauge i.d. A22
28	28	A	120 ohm quarter	Gauge i.d. A23
29	29	A	120 ohm quarter	Gauge i.d. A24
30	30	A	120 ohm quarter	Gauge i.d. A25
31	31	A	120 ohm quarter	Gauge i.d. A26

Sciemetric Datalogger Channel Configuration

Logger Channel	CARD Channel	Card	Channel Type	Sensor
32	0	B	120 ohm quarter	Gauge i.d. A31
33	1	B	120 ohm quarter	Gauge i.d. A32
34	2	B	120 ohm quarter	Gauge i.d. A33
35	3	B	120 ohm quarter	Gauge i.d. A34
36	4	B	120 ohm quarter	Gauge i.d. A35
37	5	B	120 ohm quarter	Gauge i.d. A36
38	6	B	120 ohm quarter	Gauge i.d. A41
39	7	B	120 ohm quarter	Gauge i.d. A42
40	8	B	120 ohm quarter	Gauge i.d. A43
41	9	B	120 ohm quarter	Gauge i.d. A44
42	10	B	120 ohm quarter	Gauge i.d. A45
43	11	B	120 ohm quarter	Gauge i.d. A46
44	12	B	120 ohm quarter	Gauge i.d. A51
45	13	B	120 ohm quarter	Gauge i.d. A52
46	14	B	120 ohm quarter	Gauge i.d. A53
47	15	B	120 ohm quarter	Gauge i.d. A54
48	16	B	120 ohm quarter	Gauge i.d. A55
49	17	B	120 ohm quarter	Gauge i.d. A56
50	18	B	120 ohm quarter	Gauge i.d. B11
51	19	B	120 ohm quarter	Gauge i.d. B12
52	20	B	120 ohm quarter	Gauge i.d. B13
53	21	B	120 ohm quarter	Gauge i.d. B14
54	22	B	120 ohm quarter	Gauge i.d. B15
55	23	B	120 ohm quarter	Gauge i.d. B16
56	24	B	120 ohm quarter	Gauge i.d. B21
57	25	B	120 ohm quarter	Gauge i.d. B22
58	26	B	120 ohm quarter	Gauge i.d. B23
59	27	B	120 ohm quarter	Gauge i.d. B24
60	28	B	120 ohm quarter	Gauge i.d. B25
61	29	B	120 ohm quarter	Gauge i.d. B26
62	30	B	120 ohm quarter	Gauge i.d. B31
63	31	B	120 ohm quarter	Gauge i.d. B32

Sciemetric Datalogger Channel Configuration

Logger Channel	CARD Channel	Card	Channel Type	Sensor
64	0	C	120 ohm quarter	Gauge i.d. B33
65	1	C	120 ohm quarter	Gauge i.d. B34
66	2	C	120 ohm quarter	Gauge i.d. B35
67	3	C	120 ohm quarter	Gauge i.d. B36
68	4	C	120 ohm quarter	Gauge i.d. B41
69	5	C	120 ohm quarter	Gauge i.d. B42
70	6	C	120 ohm quarter	Gauge i.d. B43
71	7	C	120 ohm quarter	Gauge i.d. B44
72	8	C	120 ohm quarter	Gauge i.d. B45
73	9	C	120 ohm quarter	Gauge i.d. B46
74	10	C	120 ohm quarter	Gauge i.d. B51
75	11	C	120 ohm quarter	Gauge i.d. B52
76	12	C	120 ohm quarter	Gauge i.d. B53
77	13	C	120 ohm quarter	Gauge i.d. B54
78	14	C	120 ohm quarter	Gauge i.d. B55
79	15	C	120 ohm quarter	Gauge i.d. B56
80	16	C	normal	
81	17	C	normal	
82	18	C	normal	
83	19	C	normal	
84	20	C	normal	
85	21	C	normal	
86	22	C	normal	
87	23	C	normal	
88	24	C	normal	
89	25	C	normal	
90	26	C	normal	
91	27	C	normal	
92	28	C	normal	
93	29	C	normal	
94	30	C	normal	
95	31	C	normal	

SINCO HYDROSTATIC PROFILE GAUGE

OPERATING PRINCIPLE

The operating principle of the instrument is based upon the ability of a pneumatic piezometer transducer, operating under fixed nitrogen trickle-flow conditions, to accurately resolve the magnitude of pressure resulting from a water head to which it is subjected. In the case of the hydrostatic profile gauge this pressure is derived from a liquid filled header unit housed in the box of the cable drum assembly which acts through a continuous liquid column in the connecting tubing to the pneumatic transducer contained within the probe unit. Therefore, as the latter is drawn through the field access tube set under the structure to be monitored, the magnitude of pressure exerted upon the pneumatic transducer will vary dependant upon the relative elevation of probe and header unit (and thus in accordance with the elevation of the access tube) at each dwelling point along its length.

Since the magnitude of such liquid head pressures resulting from relative elevations between probe and header unit of only a few feet are quite small, the following provisions are essential to ensure adequate performance of the instrument;

1. Use of a sensitive digital pressure indicator to monitor the pneumatic piezometer. A 5 psi pressure transducer is employed for this purpose and accomodates a maximum elevation difference between probe and header unit of approximately 11.5 feet (3.5m).

2. In order to isolate the sensitive measuring system from transient barometric pressure changes caused by winds or approaching storm fronts, etc. (which might otherwise temporarily destabilise it whilst equilibrium is disturbed) a differential pressure transducer is used within an enclosed pneumatic system. Pressurizing this system to approximately 10 psi above ambient barametric pressure affords the following practical advantages;

   (a) The liquid portion of the measuring system from header unit to probe is now subjected to a positive pressure, which by preventing possible cavitation caused by elevation difference, minimizes the chance of a broken water column and the consequential loss of reading accuracy.

   (b) Since the 10 psi system surcharge is applied via a flexible rubber membrane to the liquid contained within the header unit, this elevates the effective liquid head from header unit to probe by a similar amount, ensuring that the pneumatic portion of the measuring system operates from a 10 psi datum pressure, and not zero, as would otherwise be the case. In consequence variations in probe level encountered

during the normal reading operation result in pressure variations that when added to the 10 psi surcharge, represent a small fraction of the total. Such an arrangement tends to equalize the rate at which the measuring system is able to restablise following probe elevation change, somewhat indepently of the magnitude of elevation difference that exists between the header unit and the probe.

Futhermore, since the outlet port of the pneumatic transducer in the probe unit in now venting nitrogen from a 10 psi datum pressure relative to mean atmospheric pressure, when the elevation difference between header unit and probe decreases as the result of moving the latter from one reading point to the next, surplus nitrogen pressure in the tubing linking cable drum and probe is more efficiently relieved by the improved venting thus provided.

The 10 psi surcharge pressure also provides an improved speed of response as the elevation of the probe is lowered (thus increasing the liquid head) whereupon it is necessary for the nitrogen line pressure to increase to a level at which the probe transducer achieves a renewed state of equilibrium as venting flow restores across it.

OPERATING PROCEDURE:

1. PREREQUISITES

a) Ensure at least 500 psi of nitrogen is available for use as indicated by the tank pressure gauge before a prolonged installation reading sequence is commenced. Recharge as necessary.
b) Ensure that at least 25 percent of the battery capacity remains in the Druck DPI 601 indicator before a reading sequence is commenced. Recharge as necessary.
c) On reaching the field installation location, position trolley assembly on concrete datum pad, engage trolley securing hook to the eye installed in the concrete and lock firmly in position by tightening the handwheel. This action will allow cable pull-off and retrieval operations to be conducted single-handed from a steady platform.

2. SETTING UP PROCEDURE

a) Unclip probe assembly from its storage position on the face of the control box, loosen cable drum brake handwheel, feed off a few turns of tubing sufficient to allow the probe to be placed flat upon the surface of the concrete datum pad.
b) Place probe on the control box, open Supply Shut-off Valve and if necessary adjust Supply Regulator handwheel to indicate 50 psi on the Regulated Pressure Gauge.
c) Note indicated pressure at the Back Pressure Gauge. Should this be less than 10 psi set the Read/Precharge Valve to 'Precharge' and wait until 10 psi is indicated at the Back pressure Gauge. Reset valve to the 'Read' position.

d) Wait at least 30 seconds after setting the Back Pressure before connecting the DPI 601 indicator via the Hansen quick connect couplings at the rear face of the Control Box. Observe polarity markings on Control Box and DPI input couplings.
e) Switch DPI 601 on, and select appropriate measuring range (feet or metres of water head). Wait for reading to stabilise.
f) Raise the probe unit and secure into the clips set on the front face of the control box (Datum level).
g) At the DPI 601 press range button previously selected and zero button simultaneously. Zero will be indicated on the DPI display.
h) Return probe to concrete pad, ensure it lies flat and await reading restabilization. Record.

3. READING PROCEDURE

a) Remove security cap from access tube, retrieve pull-chord and connect securely to the eyelet at the probe end. Insert probe into access tube.
b) Have assistant remove security cap at remote end of access tube and draw probe unit into tube by pulling steadily on pull-chord until the probe appears. Remove from access tube and place flat on datum concrete pad. Record reading.
c) Have assistant relocate probe into access tube. Draw probe back by rotating cable drum handle until the first numbered marking on the HPG tubing aligns with the daylighting edge of the installed access tube.

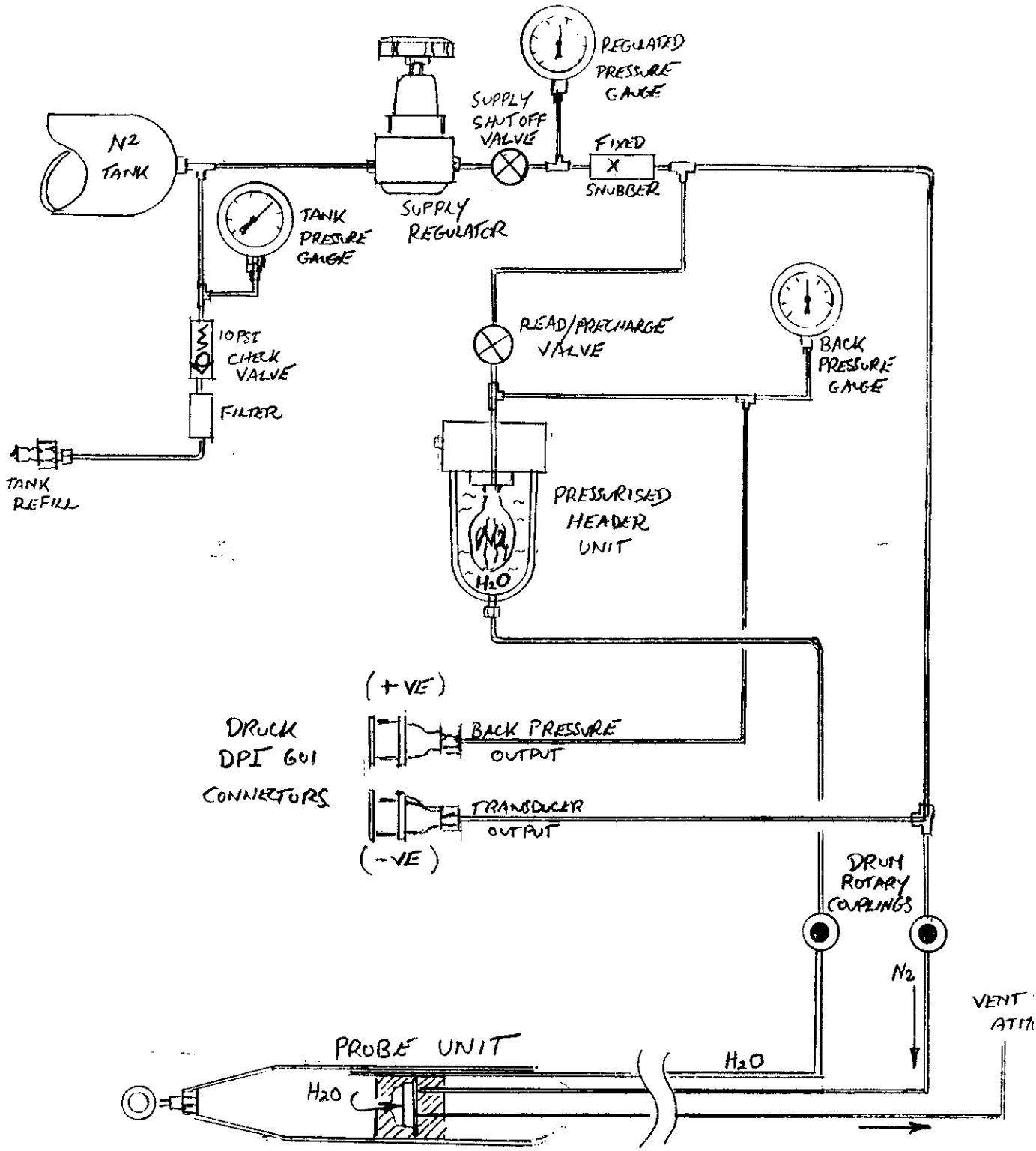
NOTE: Each distance mark is identified in metres (or feet) referenced to the centre of the probe unit, and each is preceeded by approximately 300 mm (1 ft) by a warning marker which emerges from the access tube before the related distance marker becomes visible. This facility is useful in preventing overrun from one reading point to the next.

d) Allow time for DPI 601 reading to stabilise. Record against distance as indicated by marker on HPG tubing.
e) Repeat the above procedure at each distance measuring increment throughout the installed tubing route length.
f) On completion of the above, withdraw probe unit from access tube and place flat on concrete datum pad as in 2(h) above. Record.
g) Disconnect draw cord, replace in access tube and resecure security caps at both ends of the installation.

4. PREPARING HPG FOR TRANSPORTATION AND STORAGE

a) Disconnect DPI 601 indicator at quick connect couplings. Switch off and store in hand carrying case.
b) On control box set Supply Shut-off Valve to OFF. Replace probe unit into clips provided on the front face of the control box. Rotate drum to take up excess tubing. Lock drum by rotating hand wheel brake located close to drum handle.
c) Loosen hand wheel clamp which is retaining trolley to concrete pad at the eyelet. Disengage trolley. The HPG may now be transported or stored until next used.

SINCO HYDROSTATIC PROFILE GAUGE - SYSTEM SCHEMATIC



Bison Specifications

BISON INSTRUMENTS, INC. / 5708 W. 36th St. / Minneapolis, MN. 55416 U.S.A. / (612) 926-1846 / Telex: 29-0208

BISON MODEL 4101A

PORTABLE SOIL STRAIN GAUGE

The Bison Model 4101A Soil Strain Gauge accurately measures soil strain over a given distance using only electrical inductive coupling. Since there is no mechanical linkage between the free-floating sensors, there is no built-in mechanical distortion. The gauge can be used to measure strain in settlement of embankments, seasonal variations in soil volume, changes during compaction, arching and differential settlement around buried structures, and pavement deflection under traffic.

Model 4101A Soil Strain Gauge measures soil strain remotely and continuously over periods as short as milliseconds or as long as years. The sensors are inexpensive (and thus expendable), but durable enough for use in the construction industry, where measurements often have to be made over the course of years. Changes as small as 0.0001 in. or as much as 12 in. can be observed.

The Model 4101A Soil Strain Gauge measures the electromagnetic coupling between two coaxial sensors embedded within a volume of soil or other materials. The coupling is extremely sensitive to axial distance between the sensors, while the effects of rotational or transverse movements are only second order. It is from this distinction that the strain measurements are obtained.

With an operating weight of only 10 pounds, the Model 4101A Soil Gauge is easily hand-portable to virtually any test location. it is completely self-contained with all necessary operating controls and rechargeable power supply built in. It is designed for both field and laboratory applications. It permits investigation of soil problems accurately, easily and inexpensively.

FEATURES AND OPERATION OF MODEL 4101A SOIL STRAIN GAUGE

PERIOD OF OPERATION

Strain variations can be measured over a very broad range of time scales. Strains with a fundamental period in milliseconds, seconds, minutes, hours, days or even longer can be measured directly on a calibrated panel meter, or can be recorded continuously or intermittently on a conventional recorder.

MULTIPLE MEASUREMENTS

An unlimited number of the inexpensive and expendable sensors can be used in conjunction with one 4101A Soil Strain Gauge. Each pair of sensors can be embedded in a fixed location, permanently, if desired, since the sensors can be regarded as expendables. After the measurement has been completed at the point, the Soil Strain Console can be easily disconnected for use at the next point of interest. The system permits rebalance to compare original strain readings with the new ones whenever it is reconnected at a point. In this way, strain measurements can be carried out at a large number of locations with only one Soil Strain Console.

ENVIRONMENTAL EFFECTS

The accuracy of the readings is not affected by changes in soil composition or moisture content. Also, methods of compensation have been developed for situations which affect the magnetic field around the sensors. . .large metal bodies or highly magnetic soil. Changes in temperature have negligible influence on readings.

SIMPLE OPERATION

1. Calibrate sensors, using micrometer fixture (if desired).
2. Embed sensors in the soil.
3. Determine initial spacing by balancing the instrument.
4. Adjust sensitivity (gain) to give desired output voltage or meter deflection for the range of strain anticipated. The internal calibration circuit can be used to apply a signal representing the desired amount of strain.
5. Read directly the soil strain or sensor spacing change.
6. For intermittent, long term application or where several gauges are to be monitored, disconnect sensors from the Console and move on to the next gauging point.

SENSOR SIZE SELECTION

A variety of sensors is available. The small sensors are recommended where the original distance between the points of measurement is small, or where the available volume is limited. The larger sensors are recommended where these limitations do not exist. In general, sensors should be selected so that separation lies within the range of 1 to 4 sensors diameters.

GAUGE ELEMENTS

The essential elements of the Soil Strain Gauge are:

1. A pair of rugged disk-shaped sensors embedded in the soil in near parallel and coaxial orientation separated by a distance over which the strain is to be averaged.
2. A lightweight portable instrument package to which the sensors are connected, including all necessary driving, amplification, balancing, recording and calibration controls and self-contained power supply.

SPECIFICATIONS:

SENSOR SIZE:
1" (2.5 cm.) Dia., 0.0625 cm. thickness.
2" (5.1 cm.) Dia., 0.125 cm. thickness.
4" (10.2 cm.) Dia., 0.250 cm. thickness.
Sensor bodies are machined linen phenolic base forms with molded plastic coverings for environmental stability. Other dimension sensors available on special order.

EXCITATION CHARACTERISTICS:
Frequency – 20 Khz
Amplitude – 15 Volts peak-to-peak.
Total Harmonic Distortion, 0.3%
Short term frequency stability of ±0.1% (1 hour period under any load.) Provision for external oscillator provided. Input impedance greater than 2 Kohm.

SENSITIVITY: 41 Volt/percent strain (Based on sensor separation of 1 Dia.) Applicable for strains as small as .01% or as large as 50%.

RESOLUTION: Infinite on recorder output. Limited on the meter only by static friction of bearings and readability.

OPERATING TEMPERATURE: 0°C to 70°C ambient.

STORAGE TEMPERATURE: -55°C to +85°C ambient.

SIGNAL TO NOISE RATIO: 50 to 1.

CABLE LENGTHS: 0 to 1000 feet. Longer if desired. Output and strain measurements are independent of changes in cable length and changes in cable characteristics due to temperature, time, pressure and moisture.

POWER SUPPLY: Self-contained rechargeable ±12 V 1.2 AH battery pack operation. Integral 110/220 V -50/60 hz charger (may be operated continuously with the charger cord plugged into bench supply.) Charging rate of 0.12 Amps.

READOUTS: Panel mounted meter -100 to 0 to +100 scale. Digital readouts 0 to 10,000.

CASE: Bison designed high impact ABS case, weatherproof and operable in any position.

DIMENSIONS: 10" x 6.5" x 12".

OPERATING WEIGHT: 10 lbs.

SHIPPING WEIGHT: (Air freight worldwide) 13 lbs.

Specifications subject to change without notice.

PETUR™ Pneumatic Piezometers

INTRODUCTION:

There is a recognized demand in the geotechnical field for instruments capable of measuring pore water pressures. In choosing such instruments one would normally consider the following parameters:

1. Range of pressures anticipated
2. Required sensitivity and accuracy
3. Dynamic response and time lag
4. Instrument stability
5. Long term reliability
6. Cost

PETUR pneumatic piezometers have been specifically designed to provide reliable, accurate, inexpensive, long term measurement of pore pressure with little or no movement of water throughout the soil formation.

ADVANTAGES:

1. The system utilizes a direct reading pneumatically operated diaphragm. The null balance operation is extremely simple ensuring long term stability, high accuracy, and proven reliability.
2. PETUR piezometers are available to cover ranges from negative pressures to 2000 psi.
3. PETUR piezometers employ almost negligible (0.002 cc) volume change characteristics hence there is no time lag problem. This low displacement allows critical measurements under essentially no volume change conditions.
4. Either 2 or 3 tube principle of operation available in all models. Three tubes are preferable in long leads and/or high pressures due to the 3rd tube negating the effects of friction loss in the pneumatic lines. The third tube has the additional benefit of field adjustment of lead lengths without affecting the piezometer calibration.
5. PETUR piezometers have a moderate dynamic response, and are capable of handling pore pressure changes that do not exceed 1 psi per second.
6. Remote readings via flexible direct burial tubing avoid construction obstacles.
7. High system accuracy and sensitivity. Standard ranges of either 0.25% or 0.1% accuracy.
8. PETUR systems are designed for cold weather operation. The Model T-102 tubing combines low temperature flexibility with extremely low permeability.
9. Recording may be on a continuous or intermittent basis.
10. All piezometer parts are corrosion resistant.
11. Low cost.
12. Assembled to client specified length. Tested, calibrated, and ready to install.
13. Shipping - 48 hours from receipt of order.

SPECIFICATIONS FOR PIEZOMETER - MODEL P-100

MAXIMUM OPERATING PRESSURE	DIMENSIONS	MATERIALS BODY	DIAPHRAGM	FILTER	LINEAR RANGE	SENSITIVITY	ACCURACY	DIAPHRAGM DISPLACE-MENT	MAX. TUBING LENGTH
2000 psi 13,800 kPa	0.625" O.D. x 2.48" 1.59 cm O.D. x 6.30 cm	Glass filled Nylon-12	Nitrile rubber (Buna-N)	Porous (50 u) 316 Stainless Steel	3-2000 psi 20-13,800 kPa at 28 SCCM	±0.1% at constant flow rate of 28 SCCM	Equal to readout gauge	002 cc	5000 ft. 1500 m

*The repeatability and sensitivity of the pneumatic piezometers is extremely high and will always exceed the readout gauge accuracy

P-100 GENERAL PURPOSE PIEZOMETER

The Model P-100 is a general purpose piezometer capable of monitoring pore pressure from 3-2000 psi (21-13,800 kPa). This instrument combines the features of high accuracy and reliability, small size, low cost, and extremely low displacement (0.002 cc), with the ability to be constantly monitored.

In applications where the measurement of small or rapid changes in pore pressure is critical, this constant output capability is a definite asset.

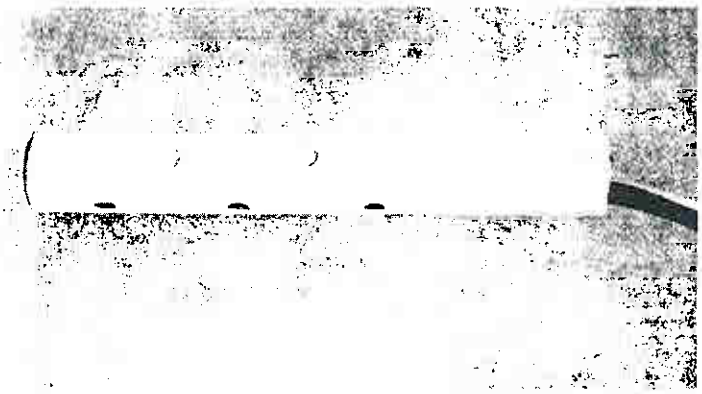
The key to the long term reliability and accuracy lies in the simplicity of the design. There is no critical mechanical valving assembly to stick, jam, or corrode thereby rendering the piezometer inoperable. The P-100 is nonmetallic and corrosion free, both internally and externally.

Because of the small size (0.625 in. O.D. x 2.45 in. long) (1.59 cm x 6.22 cm) multiple installations are possible in virtually any size borehole.

P-100 (Actual Size)

P-100-1 GENERAL PURPOSE PIEZOMETER

The Model P-100-1 consists of a P-100 transducer encapsulated in a sand filled, Casagrande type piezometer body. This body employs a protected 70 micron porous plastic filter and sand filter, in addition to the P-100's 50 micron stainless steel filter. The piezometer body will accept a ¾ in. PVC pipe, allowing a riser to be fitted for increased tubing protection and ease of installation. Filter area 21 in.^{2} (133 cm^2). 1.32 in. O.D. x 10.0 in. long (3.35 cm x 24.8 cm).



P-100-1

P-102 WELLPOINT PIEZOMETER

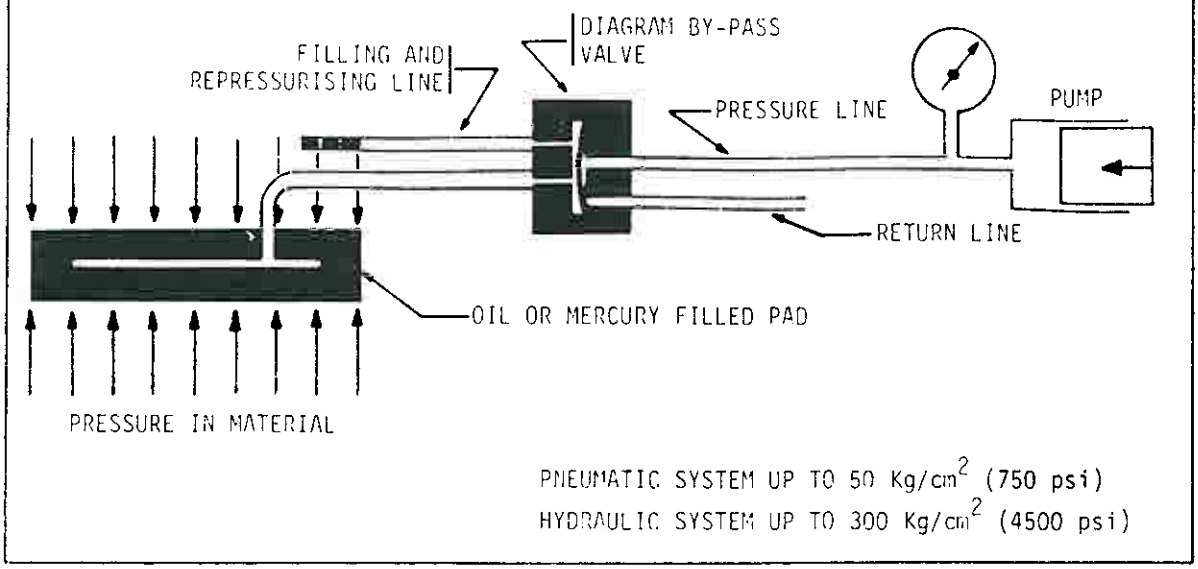
The Model P-102 Wellpoint piezometer has been specifically designed to withstand the forces of impact driving. This model utilizes our P-100-1 piezometer, epoxied into a perforated steel housing. There is no critical mechanical valving assembly in the P-100 and therefore no concern with installation shock and acceleration. If required this unit is capable of being constantly monitored during the installation process.

The Model P-102 is ideal for use in soft clays and cohesionless soils, as it eliminates the need to drill a hole in order to install the piezometer. They may either be driven by a non-rotating hammer or pushed directly into the soil.

The standard model utilizes a 37.69 sq. in. (245 sq. cm) porous plastic filter, having a 70 micron pore diameter The threaded connection is 1¼" male NPT Length 17 5 in (44 45 cm) x 1 69 in (4.29 cm) O D

P-102

GLOETZL PRESSURE CELLS



DESCRIPTION

The Gloetzl total pressure cells are designed to measure the total stress field exerted inside a material (e.g. soil, rock, concrete) or against a plane or curved surface (e.g. retaining wall, pipeline). It consists of a thin steel pad filled with either oil or mercury and a diaphragm by-pass valve which is activated pneumatically or hydraulically by means of a remote control unit.

There are more than 50 different standard configurations with pad sizes varying from 1 to 100 sq. in.

The standard pad thicknesses vary from 0.1 to 0.4 in. (0.25 to 1 cm).

Several combinations of pad coatings, reinforcements and attachments are available to suit every application. The pad filling is mercury when the modulus of elasticity of the material surrounding the cell is greater than 150,000 psi (10,000 kg/cm²). Otherwise it is oil.

RANGE, ACCURACY AND ACTIVATION

STANDARD RANGES	CORRESPONDING ACCURACY	ACTIVATION
0-300 psi (0-20 kg/cm²)	± 0.15 psi (0.01 kg/cm²)	Air
0-750 psi (0-50 kg/cm²)	± 0.15 psi (0.01 kg/cm²)	Oil
0-3000 psi (0-200 kg/cm²)	± 0.8 psi (0.05 kg/cm²)	Oil
0-4500 psi (0-300 kg/cm²)	± 1.5 psi (0.1 kg/cm²)	Oil

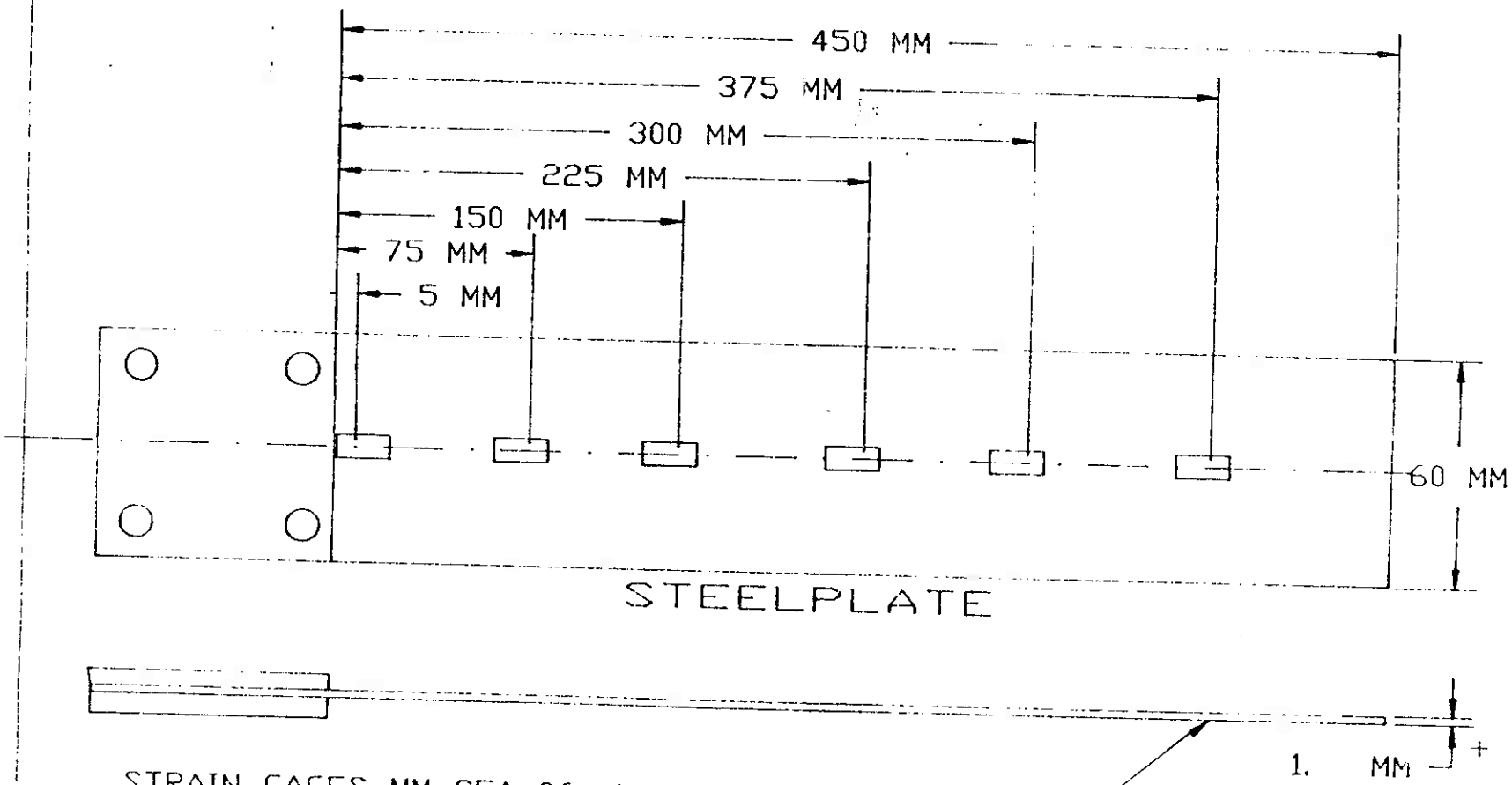
READOUT

The pressure cells are read with manually operated or completely automatic pneumatic or hydraulic compensating measuring systems with recording facilities.

Pore pressure cells and load cells are also available. They are read with the same systems.

ROCTEST

ROCTEST LTÉE LTD.
665 PINE, ST-LAMBERT (MONTREAL), CANADA J4P 2P4
TEL.: (514) 465-1113 · TELEX: 055-61134 · CABLE: TESTROC



MT&T

MT&T TESTING LTD
CALGARY ALBERTA
CANADA

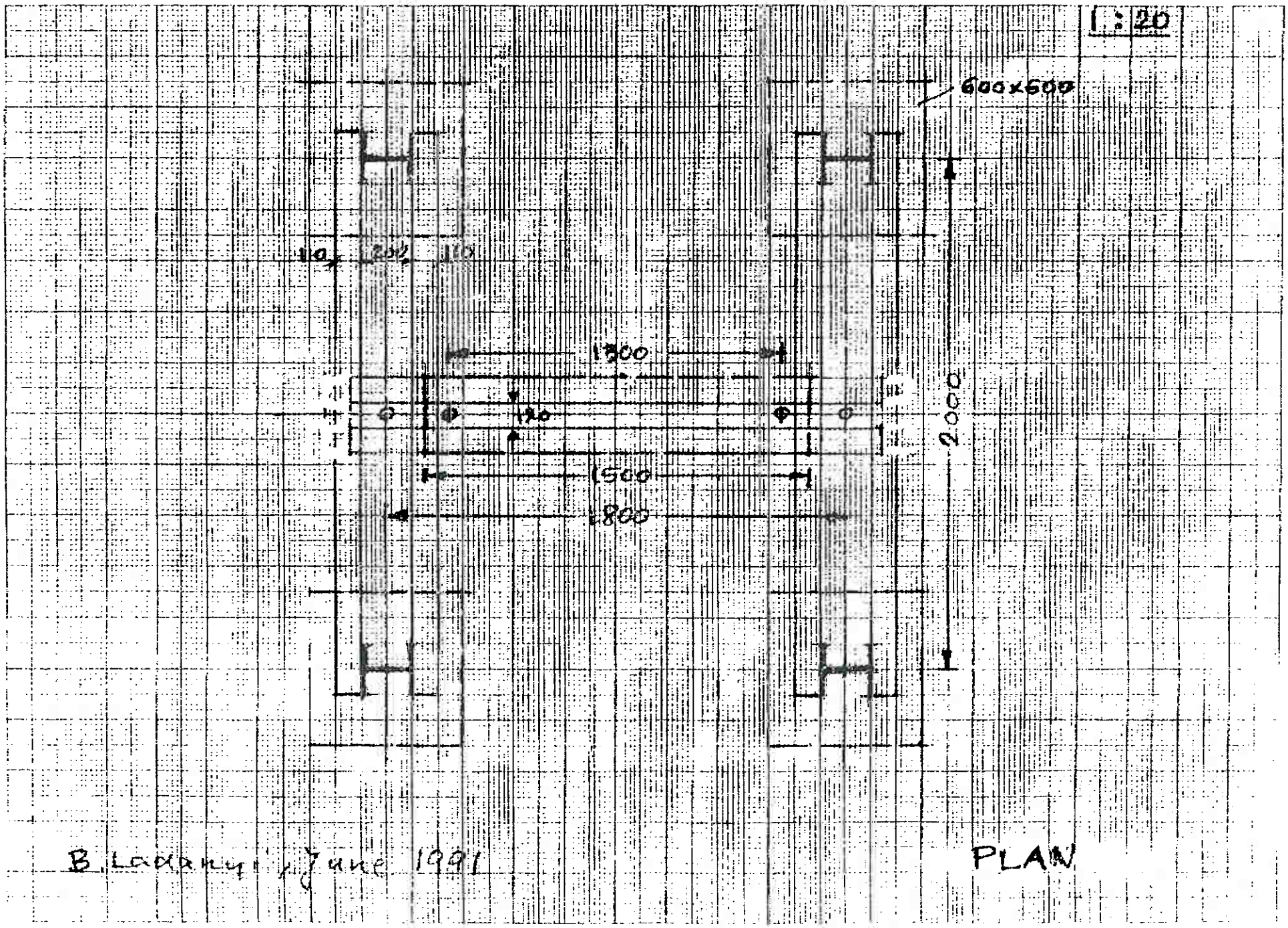
CANTILEVER BEAM

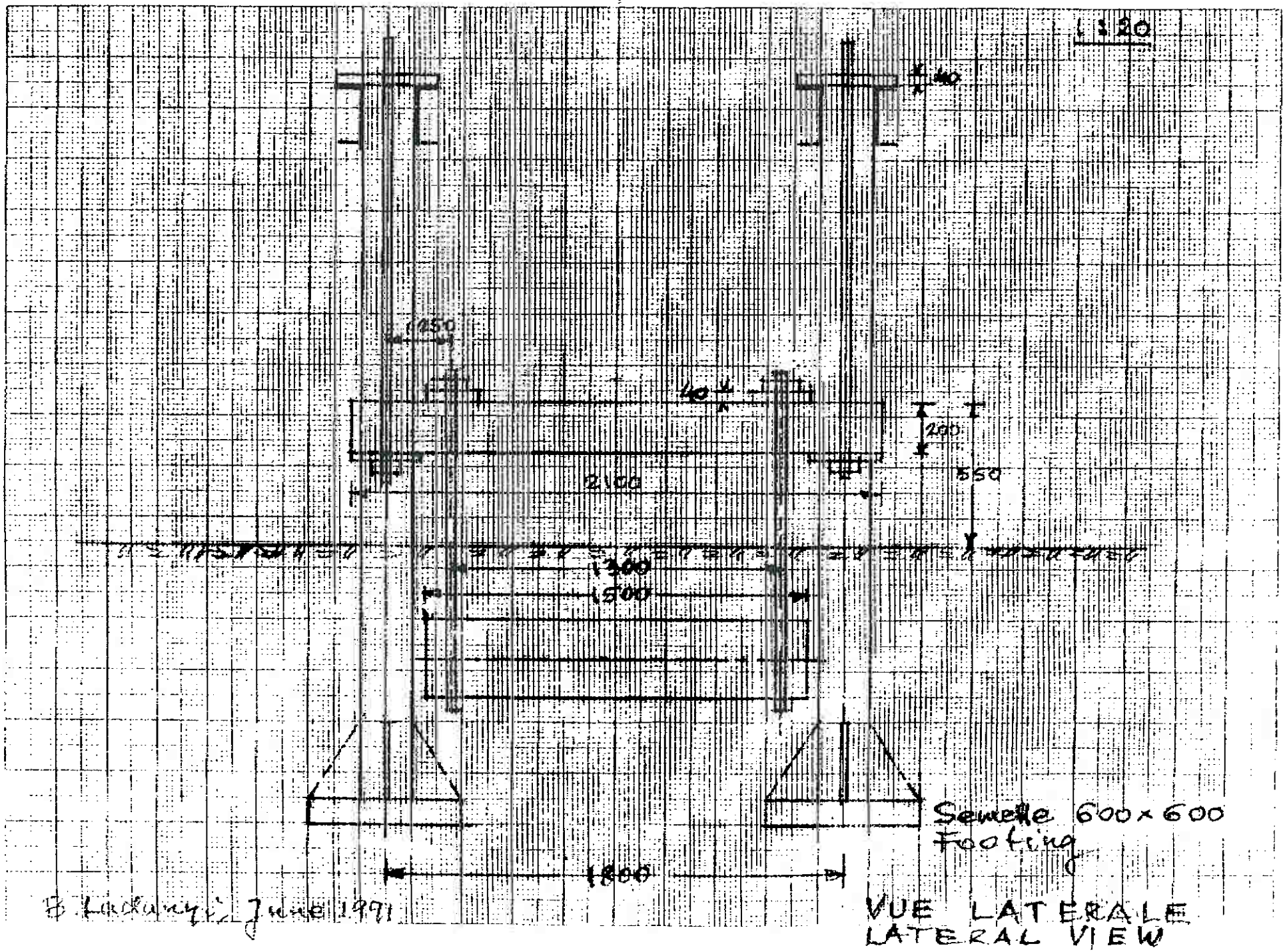
P.O. #

DATE	DESIGN	DRAWN	APPROVED	REV	REV DATE	SHEET OF

Design drawings for pullout test reaction frame

KEUFFEL & ESSER CO. MADE IN U.S.A.
46-1517

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Semelle 600×600
Footing
1800
B. Lackanyi, June 1991
VUE LATERALE
LATERAL VIEW

K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1517

June 6 1977

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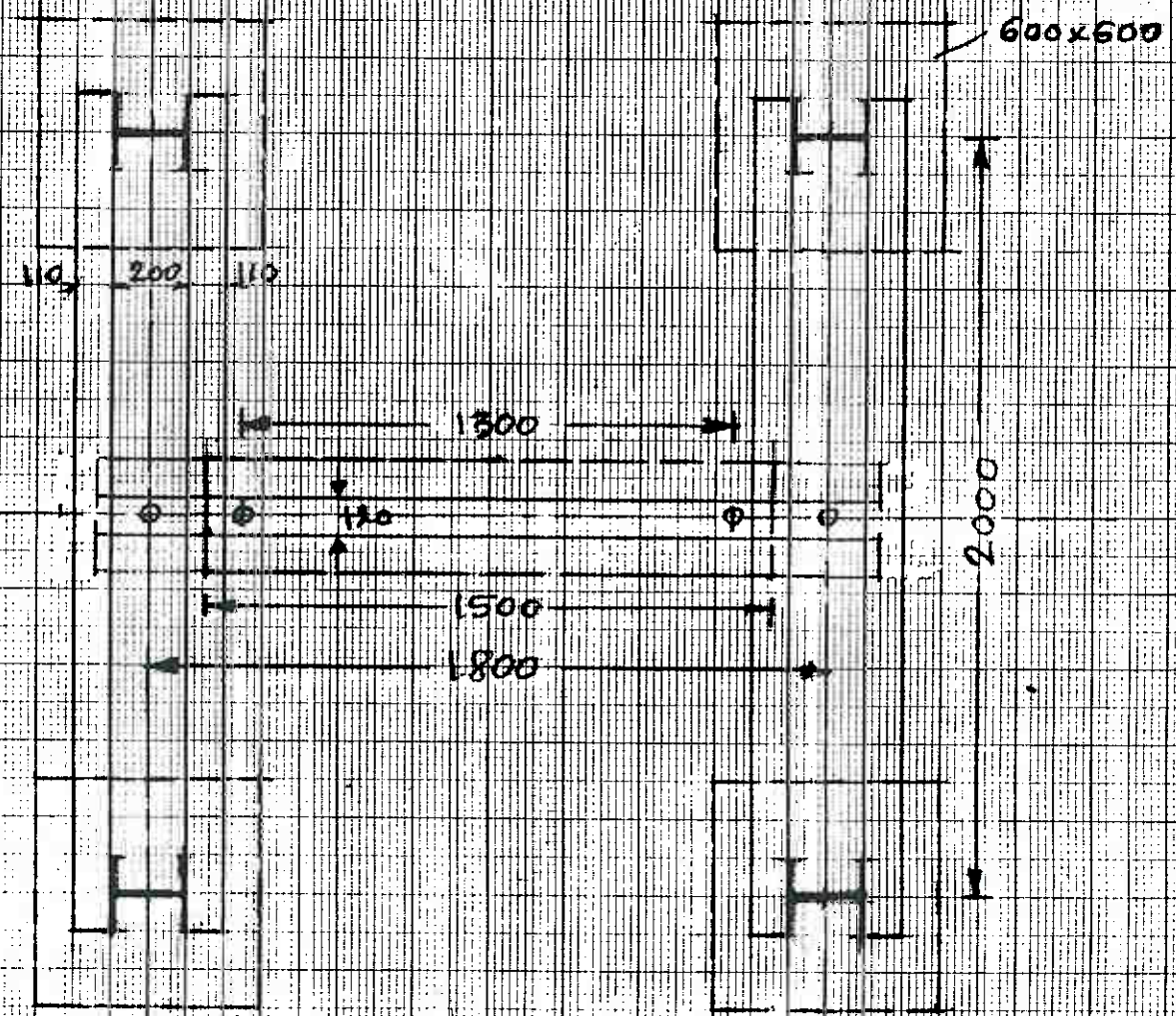


PLAN

Reaction Frame Plan

Properties of Caen Silt

(SP, grain size, and unfrozen water content for silt from previous experiment)

PROJET : A-E-R - [illegible]

DOSSIER N° A.E.R. [illegible]

EMPLACEMENT : ROUGEMONTIER

PROCTOR N° _____

PRELEVEMENT N° _____ DATE DU PRELEVEMENT _____.

EFFECTUE PAR _____ LIEU DU PRELEVEMENT _____.

NATURE DU MATERIAU LIMON.

CARACTERISTIQUES DU COMPACTAGE

Moule : CBR. Nombre de couches : 3. Nombre de coups par couches : 55.

IDENTIFICATION DU MATERIAU

Teneur en eau naturelle Wn : 17,5 %

Limites d'Atterberg Wl : 32 %
Wp : 21 %
Ip : 11.
Ic : 1,32.

Analyse granulométrique
Tamisat à 0,08 mm : 95,7 %
2 mm : _____ %
5 mm : _____ %
20 mm : _____ %
Dmax : _____ mm

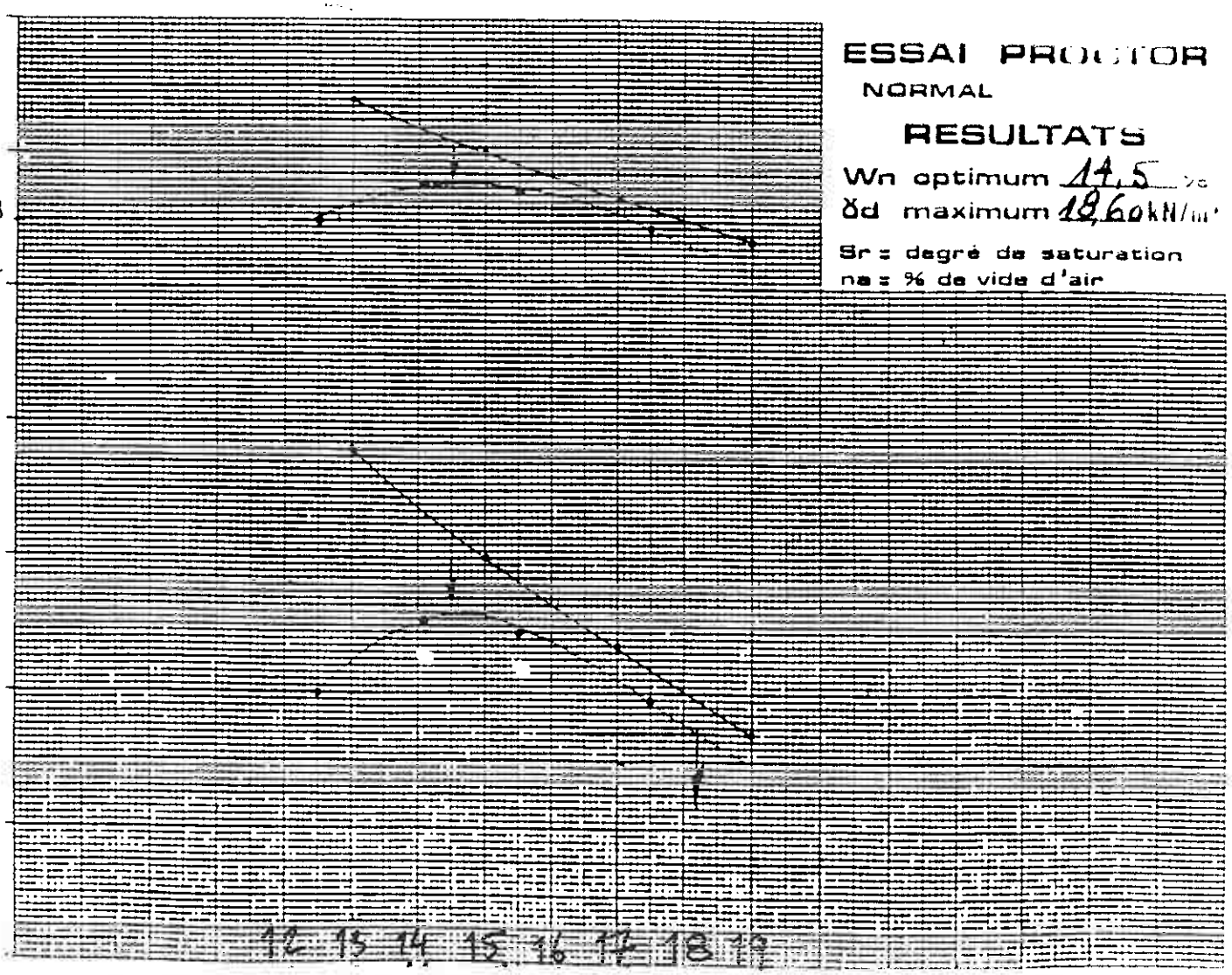
E.S. V _____. P _____. Co_3Ca : _____ %

γs : 26,65 kN/m³

CLASSIFICATION RTR

A2

Couche n° : _____.



ESSAI PROCTOR NORMAL

RESULTATS

Wn optimum 14,5 %

γd maximum 18,60 kN/m³

Sr = degré de saturation
na = % de vide d'air

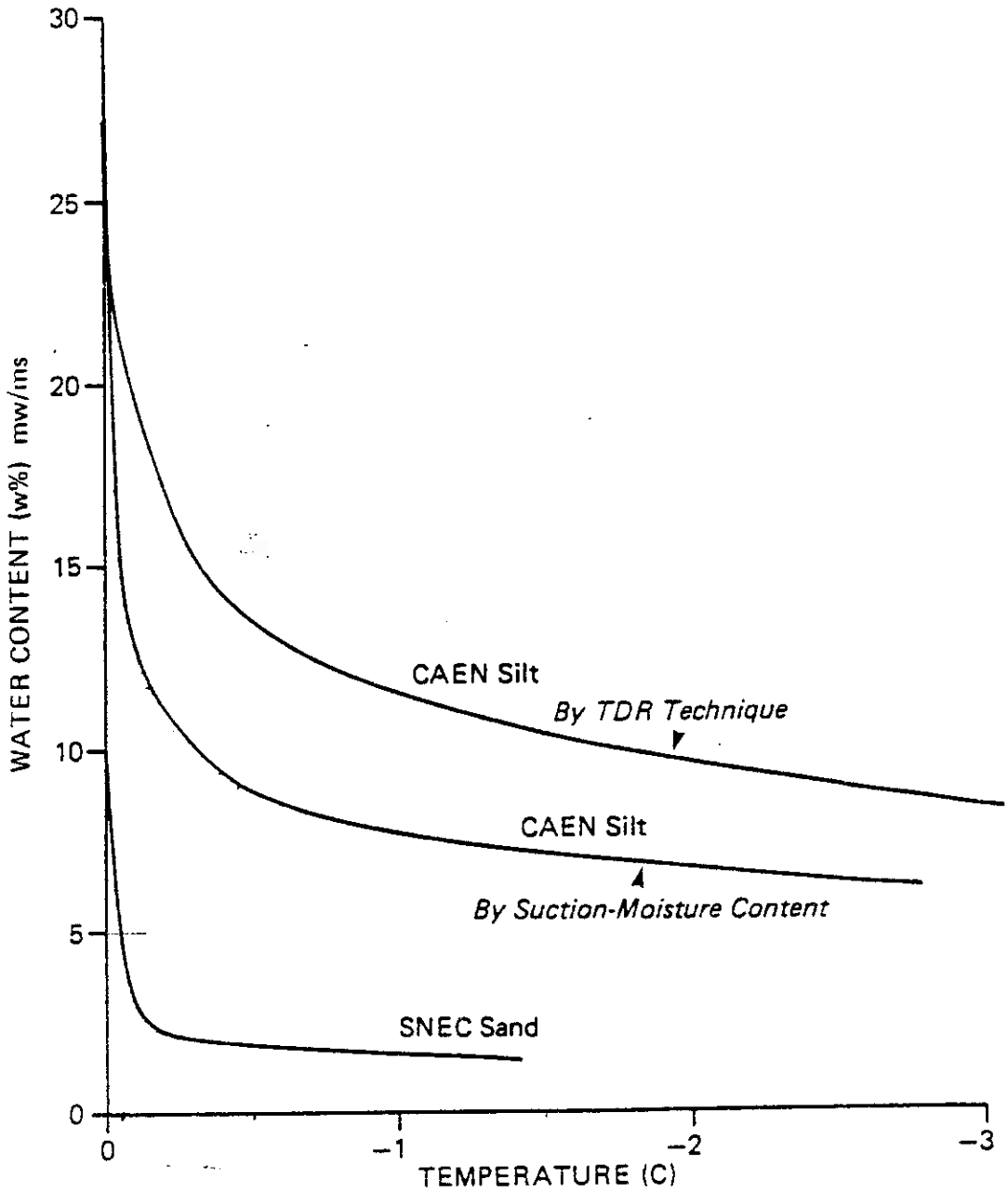


Figure 3.7: Unfrozen water content vs temperature for Caen silt and SNEC sand

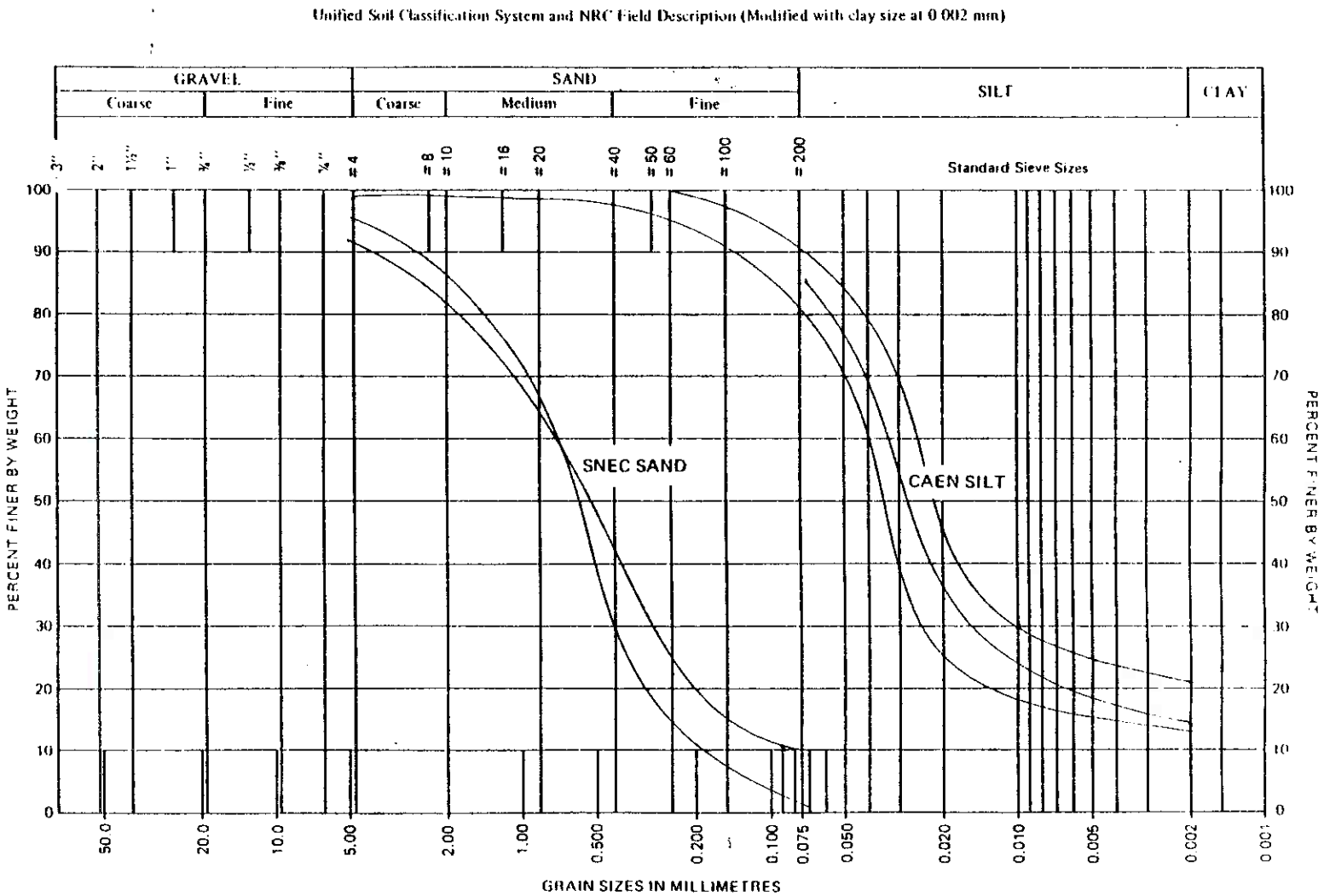


Figure 3.6: Grain size analyses of Caen silt and SNEC sand

Table 1 Summary of Frost Heave Testing of Caen Silt

TEST	Compaction Method	ρ_d (kg m^{-3})	Sample Length (mm)	Sample Diam (mm)	Cold/Warm Temp	Applied Pressure kPa	Dur. hr.	Total heave mm 30hr	Total heave mm 60hr	Total heave mm EOT	FINAL ICE LENS Init. hr.	FINAL ICE LENS Grad T °C mm^{-1}	FINAL ICE LENS $\dot{H}$ mms^{-1}	SP mm^{2}s^{-1}°C^{-1}
Carleton														
SRD 5	PR.	1.76x10^3	115	102	-5°C, 1.5°C	0	71	4.7	6.2	6.6	32	0.048	2.98x10^{-5}	57x10^{-5}
SRD 6	PR.	1.76x10	115	102	-5°C, 1.5°C	0	73	4.9	6.8	7.3	41	0.046	2.3x10^{-5}	45x10^{-5}
SRD 7	CONS	1.72x10^3	90	102	-5°C, 1.5°C	0	93	7.2	10.1	10.9	46	0.043	3.5x10^{-5}	75x10^{-5}
SRD 8	CONS	1.76x10^3	110	102	-5°C, 1.75°C	0	68	13	17.5	17.8	62	0.046	3.3x10^{-5}	67x10^{-5}
SRD 9	CONS.	1.76x10^3	110	102	-5°C, 1.8°C	0	100	6.6	7.6	10.0	31	0.048	3.1x10^{-5}	60x10^{-5}
SRD 10a	CONS.	1.76x10^3	110	102	-3.0°C, 1.0°C	0	67.5	6.7	9.8	10.42	40	0.031	3.2x10^{-5}	95x10^{-5}
SRD 10b	TR-C.	1.73x10^3	108	102	-3.0°C, 1.0°C	0	65.5	15.8	23.4	24.4	49	0.028	5.8x10^{-5}	190x10^{-5}
SRD 10c	TR-C.	1.76x10^3	110	102	-3.0°C, 1.0°C	0	53	15.2		21.1	48	0.026	5.1x10^{-5}	180x10^{-5}
SRD 10d	TR-C.	1.76x10^3	110	102	-3.0°C, 1.0°C	20 KPa	61	9.6	15.2	16.37	47	0.028	5.1x10^{-5}	167x10^{-5}
SRD 10e	TR-C.	1.76x10^3	110	102	-3.0°C, 1.0°C	30 KPa	62.5	6.4	10.3	10.5	40	0.028	3.8x10^{-5}	125x10^{-5}
SRD 11	CONS.	1.65-1.7 x 10^3	105	102	-1°C, 1.0°C	0	47	4.7		6.0	40	0.021	2.0x10^{-5}	87x10^{-5}
SRD 12	CONS.	1.73x10^3	112	102	-4.9°C, 0.9°C	0	49	9.5		13.3	26	0.043	7.1x10^{-5}	151x10^{-5}
SRD 12b	TR-C.	1.73x10^3	112	102	-4.9°C, 0.9°C	0	65.5	9.9	13.2	1.6	30	0.037	8.55x10^{-5}	212x10^{-5}
SRD 12c	TR-C.	1.73x10^3	112	102	-7.4°C, 0.95°C	0	44	11.1		14.8	18	0.058	9.5x10^{-5}	150x10^{-5}
SRD 13a	CONS.	1.73x10^3	110	102	-1.1°C, 0.8°C	0	61	4.0	6.5	6.6	42	-0.019	2.4x10^{-5}	116x10^{-5}
SRD 13b	TR-C.	1.73x10^3	110	102	-1.2°C, 0.9°C	0	50	2.4		3.3	25	-0.024	1.74x10^{-5}	67x10^{-5}
SRD 13c	TR-C.	1.73x10^3	110	102	-3.0°C, 0.9°C	0	48	7.4		9.7	45	—	—	—
SRD 13d	TR-C.	1.73x10^3	110	102	-5.0°C, 0.9°C	0	52	10.1		13.6	24	0.045	7.5x10^{-5}	153x10^{-5}
SRD 13f	TR-C.	1.73x10^3	110	102	-5.0°C, 0.9°C	0	64	14.7	21.8	22.4	28	0.046	1.0x10^{-4}	199x10^{-5}
SRD 13g	TR-C.	1.73x10^3	110	102	-7.5°C, 0.8°C	0	30	13.7		13.7	13.5	0.071	1.0x10^{-4}	123x10^{-5}
SRD 13h	TR-C.	1.73x10^3	110	102	-7.4°C, 0.4°C	0	32	23.0		23.9	23	0.060	1.7x10^{-4}	260x10^{-5}
SRD 13i	TR-C.	1.73x10^3	110	102	-5.0°C, 0.9°C	0	51	14.8		20.7	25.5	0.055	8.6x10^{-5}	143x10^{-5}
SRD 13j	TR-C.	1.73x10^3	110	102	-5.0°C, 0.9°C	20	52	5.9		7.8	38	0.054	2.6x10^{-5}	44x10^{-5}
Hardy														
FR-1a	CONS.	1.8x10^3	110	102	-5°C, 1.5°C	29.6	42	7.8		9.0	22	0.06	3.5x10^{-5}	57x10^{-5}
FR-1b	TR-C.	1.8x10^3	110	102	-1.0°C, 0.5°C	29.6	47.5	6.4		6.9	36	0.014	1.8x10^{-5}	126x10^{-5}
FR-1c	TR-C.	1.8x10^3	110	102	-1.0°C, 0.5°C	100	60	1.3	2.1	2.2	48	0.014	5.7x10^{-6}	41x10^{-5}
FR-1d	TR-C.	1.8x10^3	110	102	-1.0°C, 0.5°C	200	47.5	0.45		0.66	40	0.014	3.5x10^{-6}	25x10^{-5}
FR-2a	PROC.	1.83x10^3	110	102	-5.9°C, 1.0°C	20.7	25			3.5	21	0.06	2.1x10^{-5}	33x10^{-5}
FR-2b	TR-C.	1.83x10^3	110	102	-0.9°C, 0.1°C	20.7	52.5	2.85		3.8	42	0.013	9.8x10^{-6}	77x10^{-5}
FR-2c	TR-C.	1.83x10^3	110	102	-1.05, 0.5°C	69	80	1.1	1.75	2.1	58	0.013	3.7x10^{-6}	28x10^{-5}
FR-2d	TR-C.	1.83x10^3	110	102	-1.08, 0.5°C	200	72	0.17	0.41	0.5	55	0.013	1.34x10^{-6}	15.2x10^{-5}
FR-2e	TR-C	1.73x10^3	112	102	-1.08, 0.5°C	20.7	69	3.45	5.1	5.4	65	—	—	—
LRPC														
82/000 #1	PR.	1.73x10^3	260	70	-5.7°C, +1°C	0	157	0.5	1.7	4.2	120	0.011	6.46x10^{-6}	54x10^{-5}
82/000 #2	PR.	1.73x10^3	260	70	-5.7°C, +1°C	0	142	0.2	2.2		100	0.01	6,94x10^{-6}	64x10^{-5}
82/000 #3	PR.	1.73x10^3	260	70	-5.7°C, +1°C	0	214	0.5	1.6	5.0	90	0.012	8.4x10^{-6}	64x10^{-5}
906/81 #3	PR.	1.73x10^3	260	70	-5.7°C, +1°C	0	267	0.2	5.5		115	0.016	9.0x10^{-6}	52x10^{-5}
906/81 #4	PR.	1.73x10^3	260	70	-5.7°C, +1°C	0	230	0.5	1.6	10.8	160	0.016	1.2x10^{-6}	65x10^{-5}
906/81 #5	PR.	1.73x10^3	260	70	-5.7°C, +1°C	0	267	0.2	5.5		150	0.017	8.0x10^{-6}	43x10^{-5}
906/81 #6	PR.	1.73x10^3	260	70	-5.7°C, +1°C	0	235	0.2	9.0		150	0.016	1.2x10^{-6}	75x10^{-5}
U. of Aston														
1	PR.	1.73x10^3	110	102	-4.8, 0.5°C	0	170	15.8	21.5	33	70	0.039	4.1x10^{-5}	105x10^{-5}
2	PR.	1.73x10^3	152	102	-7.0, 4.0°C	0	250	8.0	14.0	38	—	—	—	—

PR — Proctor Compaction
CONS. — Consolidated from slurry
TR-C. — Thawed Re-Consolidated
DUR. — Duraton
INIT. — Initiation
EOT — End of test

NOTES: Hardy Associates testing — freezing from below, sample incorporated in a greased membrane to reduce side wall friction. Test results after Nixon, 1983.

Laboratoire Regional des Ponts et Chaussees de Nancy testing — freezing from above, sample incorporated in a greased foam rubber tube to reduce friction. Test results after Laboratoire Regional des Ponts et Chaussees de Nancy, 1982 and 1983.

University of Aston testing — freezing from above, sample placed in a series of tufnol rings to reduce side wall friction. Test results after McCabe, 1983.