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CONCEPTUAL DESIGN FOR A CONTROLLED ENVIRONMENT TEST FACILITY

Hardy Associates (1978) Ltd., Calgary, Alberta

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Abstract

The report describes critically, similar facilities in other parts of the world and proposes an initial conceptual design of a Canadian facility for Cold Regions research.

Résumé

Ce rapport présente une critique détaillée de stations expérimentales sur le gel situées à travers le monde et élabore un plan initial d'une station canadienne pour la recherche sur les environnements froids.

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REPORT ON

CONCEPTUAL DESIGN

FOR A CONTROLLED ENVIRONMENT

TEST FACILITY

FOR COLD REGIONS SOILS RESEARCH

Prepared For
DEPARTMENT OF ENERGY, MINES & RESOURCES
OTTAWA, ONTARIO, CANADA

Prepared By
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1.0 EXECUTIVE SUMMARY

Hardy Associates were retained by the Department of Energy, Mines and Resources to undertake a review and conceptual design for a controlled environment test facility for cold regions soil research in Canada. The initial phase of work comprised an extensive review of existing cold region test facilities around the world. This review lead to a conceptual engineering design and specifications for a Canadian facility to be constructed at a yet-to-be determined location.

Facilities visited were:

(a) The CNRS facility at Caen, France;

(b) the Federal Ecole Polytechnique at Lausanne, Switzerland;

(c) the U.S. Army Cold Regions Research and Engineering Laboratories Facility at Hanover, New Hampshire;

(d) the Institute of Low Temperature Studies Facility near Sapporo, Japan;

(e) the Geomorphological Research Laboratories at the University of Washington in Seattle.

In addition, some other information on a similar facility constructed by the Swedish roads authority in Sweden was also obtained. Based on this review of the various facilities around the world, the conceptual design for a Canadian facility has been proposed. The services of a Calgary structural engineering firm were employed in order to assist in areas of building and refrigeration design.

A structure approximately 20 m x 35 m x 6 m high has been proposed, to contain the five soil test areas within the major facility. Based on discussions with the scientific authority in Ottawa, the following soil test areas are envisaged.

(a) a rectangular pipe/roadbed facility,

(b) two cylindrical areas for testing piles or footings or other foundations,

(c) two tilt tables used for studying slopes or geomorphological processes.

The structure will also house a data acquisition area and refrigeration and compression equipment. Ramp areas to access the larger pipe roadbed areas will be incorporated, and large access doors at both ends of the structure will permit entry and exit of construction and soil placement equipment. These soil test areas are basically reinforced concrete containers embedded within the ground, and instrumentation will be placed as compaction of the soil proceeds towards the surface of the test bed. Instrumentation cables and leads will be brought to the surface via vertical conduits.

Refrigeration equipment will be designed with 100% redundancy. That is, two compressor devices are envisaged, either one of which could provide the necessary cooling capacity for the facility for short time periods in emergencies. Control systems for water table, soil temperatures, soil surface temperatures, and any embedded structures such as pipes or piles will be incorporated. All systems derive their cooling capacity from the same large refrigeration plant. Individual heat exchangers are used to transmit cold air to each of the covered soil areas. The five soil test beds can therefore be controlled at different temperatures within the same large facility.

Instrumentation will incorporate such items as thermistors for measuring temperatures, strain gauges, tensiometers or pressure transducers, embedded soil plates for measuring soil strains, and other devices not yet foreseen. These sensors will be read automatically using a data acquisition system controlled by a mini computer. Storage of data will be on floppy discs, which are then used to drive a small plotter on site.

Staffing of the facility will require one senior person such as an institute director at least part time. One other relatively senior engineer or scientist will be required as project individual full time. Two technicians will be required for soil placement removal, data retrieval, data massage, and day-to-day maintenance of the facility. From time to time it will be necessary to hire a contractor for heavy construction related activities such as soil placement or removal. An overhead crane will be an important part of the facility to assist in soil placement and removal. In addition, it is foreseen that other personnel such as staff and graduate students from Canadian universities required for specialized experiments will be in attendance from time to time.

The initial capital cost of this facility, assuming it is constructed in isolation of any major facility, is approximately $2,000,000. The annual operating costs are anticipated to be in excess of $160,000. These costs assume that land is available for the project, and all additional costs such as structure, heavy equipment, instrumentation, staff costs, have been incorporated. Based on a review of existing facilities, it is strongly recommended that this Canadian facility be located adjacent to an existing research or university type facility. This is to facilitate support and maintenance personnel, assistance in the area of standard soil classification tests or chemical analyses tests, and also the availability of a secure power supply. The conceptual design and costing contained in this report are designed to act as a basis for appropriation of funding and further detail design work. It is assumed that a second phase of detailed engineering, complete with detailed costs and drawings, sufficient for contract and bid estimates will be carried out following approval of this phase of the study.

2.0 INTRODUCTION

2.1 Background

Hardy Associates (1978) Ltd. received a request for proposal for the design of a controlled environmental test facility for cold regions soil research in Canada dated November 25, 1981. In a proposal dated December 4, 1981, Hardy Associates responded to the Department of Supply and Service File #15SQ.23235-1-1254. On May 3, 1982, a signed copy of the contract having the above file number was returned to the Science Procurement Manager of the Department of Supply and Services.

2.2 Scope of Work

Initially it was agreed that meetings should be held with Dr. Alan Judge of the Earth Physics Branch, Department of Energy, Mines and Resources, (the scientific authority) to discuss the extent and nature of the studies. The list of overseas facilities that would be visited was to be finalized, in order to obtain the benefit of their experience in the design, construction and operation of a large controlled environment test facility. Basic concepts were to be reviewed and some possible layouts agreed with the scientific authority. In visiting each of the test facilities, careful notes were made on the following:

1. size and shape of facility
2. methods of temperature control
3. methods of moisture and other climatic control
4. data acquisition techniques
5. facility management, staffing and control
6. operating costs of facility
7. operating or experimental difficulties experienced
8. applications studied at the facility

9. backup power, refrigeration or other operating equipment
10. methods of excavation soil stock piling replacement, difficulties with consolidation or compaction of soils following replacement.

Special note would be taken of pipelines or other structures buried in soil, and methods of controlling the behaviour of these structures. The request for proposal outlined a rather extensive range of different experiments that might take place in such a Canadian facility, including solifluction on slopes, frost heave interaction with pipelines, behaviour of foundations in permafrost, etc. The major drawback or difficulty to a single facility designed to carry out many different experiments is the ability to locally monitor different parts of the facility at different desired controlled temperatures. In other words one experiment in one part of the facility might run for several months or even years, whereas other areas or test beds of soil might be controlled at different temperatures for shorter periods of time. This important capability would allow people of different disciplines access to the facility, and the continuation of experiments designed to study different phenomenon or engineering effects. As outlined in the Hardy Associates proposal of December 4, 1981, the recommendations arising out of the preliminary conceptual design would include:

1. drawings of a planned layout
2. cross sections detailing typical excavations and soil test pits
3. drawings of specialized equipment such as tilting soil containers for studying slope processes

4. temperature measurement, data acquisition, storage, reduction and retrieval system

5. methods of maintaining soil moisture profiles

6. outline of compression refrigeration and/or heating equipment requirements.

The work described in this report was carried out under the direction of Dr. J.F. Nixon, P.Eng. Mr. D. Halliwell and Mr. J. Lobach are experienced in the area of cold regions research and assisted in the design of the equipment and data acquisition system. The firm of T. Lamb-McManus Associates of Calgary was subcontracted to assist in the area of structural design in refrigeration requirements. Dr. Ed McRoberts of the Hardy Associates Edmonton office assisted in reviewing and reporting on the University of Washington facilities on slopes and geomorphological processes.

3.0 TYPES OF EXPERIMENTS AND DESIGN BASIS

In early discussions with Dr. Alan Judge of the Department of Energy, Mines and Resources, concurrence was obtained on the broad nature or extent of experiments that would be carried out on the facility. This was necessary to broadly define the shape and size of the facility and the type of instrumentation and staffing requirements. Broadly, it was decided that one major pipe/road bed facility would be incorporated in the facility. This would be approximately 5 m wide, 2.5 m deep and 20 m long, and would be used for testing pipeline or roadway sections. Two cylindrical test beds, approximately 5 m in diameter and 5 m deep, would be used for testing foundations of different types, likely under controlled subzero temperatures. These facilities would be controlled at different temperatures from the pipe/road bed section. In addition, two tilt tables of the type used by the University of Washington would be used to study geomorphological processes, such as slope movements in active layers, solifluction and other periglacial effects.

The pipeline/road bed facility would be used in researching a linear structure such as a pipeline for long term controlled temperature experiments. For example, the frost heaving from frozen to unfrozen ground, or from non-frost susceptible to frost susceptible soil types could be studied. Alternatively, the soil bed could be prefrozen and used for a warm pipeline in permafrost experiment, where the pipeline is operated in a warm mode and thaws the ground beneath the pipe section. Thermistors would be used to monitor the advance of thaw or frost front, and rods fixed to the pipe would keep track of the heave or settlement of the pipe, and its curvature. Strain gauges could be fixed to the pipe to monitor curvatures and strains in the pipe itself, and earth pressure cells of various kinds could be used to monitor uplift or downward loading on the pipe. A separate temperature controlled device would be needed to maintain the temperature of the pipe at desired level. This could be accomplished by either (a) maintaining a small separate refrigeration and heating unit with an independent chilling/

heating capacity, or alternatively could derive its refrigeration or heating capacity from the primary facility refrigeration unit, incorporating a local heat exchanger to circulate air or fluid through the pipe. For the purposes of further discussion, the latter alternative has been proposed, although either alternative is quite feasible. It will be necessary to insulate the exterior of the walls and base of the test pit where the soil is placed and in addition, it may also be necessary to control temperature at these locations. Consequently, temperature circulation pipes would be necessary within the concrete walls of the test beds themselves. It would also be necessary to carefully control the water table and amount of water added or subtracted to the soil test beds.

In order that side friction does not cause mechanical restraint on the edge of the soil section, slip joints would be incorporated at the vertical walls of the soil structure contact. In order to maintain the temperature of the pipe/road test facility at some different temperature from the remaining soils tests, some form of cell or removable soil cover must be incorporated for the different soil test beds. The concept of a removable soil cover has been introduced to allow this to take place. It has been successfully used on one of the facilities visited in connection with this project, and allows soil placement and removal, and subsequent temperature control within a certain confined area. Efforts will be made in the ensuing report to maintain the size and construction of the removable soil cover segments to a standard size. The size and shaping of the covers will be such as to span the width of soil test beds selected, allow easy stacking when not in use, and finally to allow access to the soil test beds during cold temperature test operation.

The dimensions of the cylindrical test beds were selected to allow the testing of foundations such as deep pile foundations. Ideally, the perimeter and base should be insulated and possibly equipped with independent temperature control, and would allow the placement and testing of a cylindrical deep pile foundation. In addition, these test beds could be used for the surface testing of shallow foundations such as footings or piers. The interior core of the pile or footing itself could be used as a heat exchange structure to assist in controlling the temperature of the adjacent soil. Instrumentation would include temperatures, vertical settlement, tilting of the these foundation and monitoring of the applied load. It will be important to incorporate a method of applying reaction to an applied force in these particular soil beds. This reaction will be applied through the walls of the concrete test bed itself. The use of slip joints at the vertical walls of the structure and independent water table control will also be incorporated in these test beds.

The tilt tables would typically be 3 m square, and would involve approximately a 1 m depth of soil. There would have the capability to tilt the soil layer following consolidation and thermal conditioning, to some angle of interest to the researchers. The thermal disturbance such as a summer warming cycle would be imposed on the soil surface to cause the desired thawing or temperature change effect. Some maximum tilt angle in the range of 40° would be incorporated.

4.0 REVIEW OF EXISTING FACILITIES

The detailed questionnaire and reply form for each facility visited are enclosed in Appendicies A, B, C, D, and E at the end of this report.

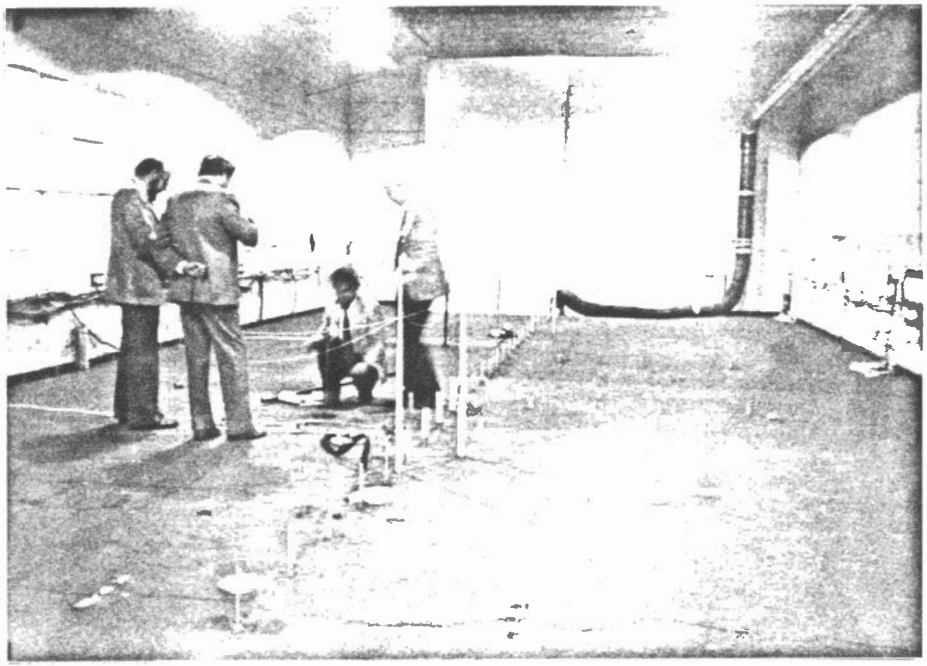
4.1 Caen, France

The detailed questionnaire/reply form for the visit to this facility is contained in Appendix "A" of this report. The facility is operated by the Centre de Geomorphologie, which is a division of the Centre National de la Recherche Scientifique. The scientific direction for the present project is obtained jointly from Dr. Peter Williams of Carlton University and Prof. Michel Fremond of the Department de Ponts et Chausees in Paris, France. The Department of Energy, Mines and Resources in Ottawa funds the effort by the Carlton University, Geotechnical Science Laboratories and the background research in support of the project. At the present, the soil bed is being prepared for an important experiment in soil pipeline interaction. A 30 cm diameter pipe has been buried in the 2 m soil bed at this facility, and data generated by the CNRS and the Dept. of Energy, Mines and Resources through Carlton University will be oriented towards research applications. Experiments are scheduled to start sometime in September and continue for a period of at least two years.

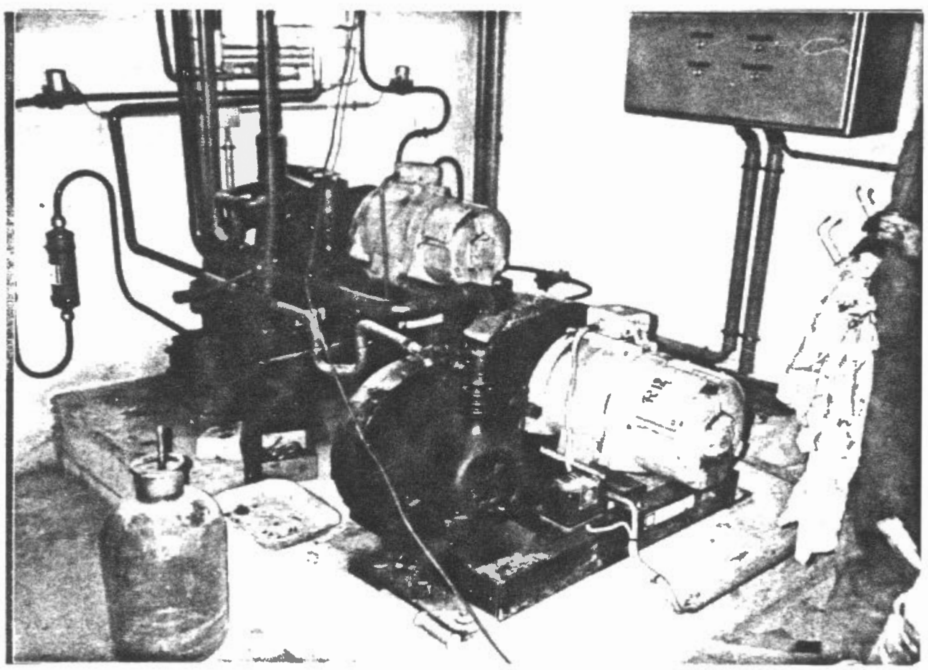
A front end loader is used to place and remove the soil in the facility, and soil is subsequently compacted using a hand operated vibratory compactor. The installation and compaction of the soil for the first experiment took several months, and the thermal and hydrological conditioning of the soil is apparently involving at least two further months duration. Two compressors provide 20,000 calories per hour through three ducts mounted near the ceiling of the facility, and 16 cm of beadboard insulation in the walls together with 5 cm of styrofoam in the base of the facility provide a partial barrier to heat loss within the facility. A problem with icing on refrigeration coils was acknowledged and it is reported that electrically heated coils were used for 20 minutes approximately per day to defrost the coils. A separate 2 horsepower compressor provides 3,000 calories per hour to an air temperature control duct to the buried pipe. An interesting feature of this facility is the reversal of air flow depending on the temperature difference across the ends of the pipe. The exact quantity of water added to the soil is monitored manually, and the water is added through a large diameter vertical standpipe to a base drainage system.

The main temperature instrumentation is achieved using thermocouples. Some additional thermistors are installed with TDR (Time-domain reflectrometry) devices only. An automatic data acquisition system together with a mini computer and floppy disc storage system comprised the basis of data acquisition storage and retrieval. Tensiometers are used in conjunction with standpipes to monitor the position of the water table and hydrological conditions in the soil. Telescoping heave gauges of the type used by Prof. MacKay in the Arctic are installed in this facility, and are read manually using a scale or gauge. Several Gloetzl earth pressure cells are used to monitor the total pressure in the ground at different points. No cells are installed in the backfill above the pipe to monitor uplift resistance in the non-heaving pipe section at this time. The soil conditions are designed to model a sudden transition from a relatively clean sandy gravel to a loess silt soil. Soil strains are also measured to an accuracy of a few millimeters using a Caesium source lowered down a pair of boreholes. This method is known as "double-sond" and is used to locate buried plastic plates, and thereby estimate soil movements from the motion of these low density buried plates. (See Figure 4.1)

The overall operation reliability and performance of the facility cannot as yet be determined as operation has not yet commenced. The installation of soil and instrumentation has been well documented and Hardy Associates were given a report containing a pictorial record showing early installation of the soil and the pipe. It is also



a) INTERIOR OF FACILITY. NOTE TELESCOPING DIFFERENTIAL HEAVE GAUGES IN MID-FOREGROUND, HEAVE GUAGES ALONG PIPE C.L. AND INSTRUMENT CABLES ALONG LEFT WALL.



b) COMPRESSOR EQUIPMENT; 2 MACHINES, RATED AT 10 AND 8 H.P.

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PHOTOS OF PIPE TEST FACILITY AT CAEN, FRANCE

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FIGURE 4.1

understood that a video movie is currently being prepared for documentation purposes. The initial capital costs for this facility would not be appropriate as the facility was constructed many years ago. Costs for operating the facility in 1982 will be approximately $500,000.00, with additional logistical and materials support from the local institute not included in the above figure. Currently, costs are derived $50,000 per annum from EMR in Canada and the remainder from the French CNRS. The staffing apparently involves two technicians full time, one senior scientist on a part time basis, one institute director on an occasional basis, and the scientific input of two remote directors from time to time as required.

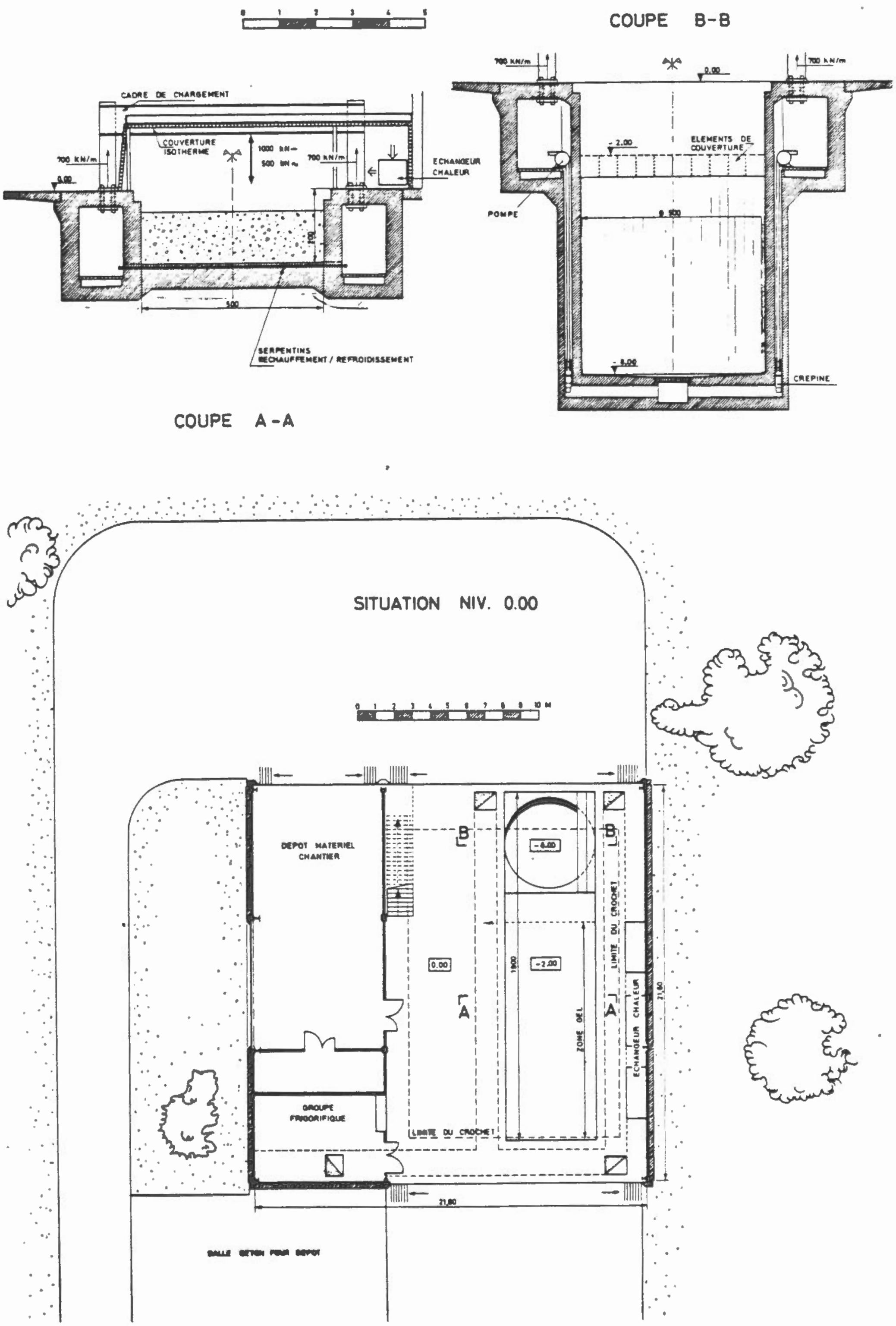
4.2 Lausanne, Switzerland

This facility in Lausanne has been operating for about three years, and in that time has carried out two major experiments. Each experiment involves about seven freeze-thaw cycles of a roadway section, and each series of freeze-thaw cycles on the same soil section requires about two years duration. The facility operation and administration is particularly impressive, and the quality of data output was generally extremely good. Much thought has gone into the design of the facility and instrumentation, and this facility would appear at this stage to be closest to the requirements of a Canadian facility. It is operated in conjunction with the existing Ecole Federale de Lausanne, and receives its funding and support from the University and from the Swiss road fund. The primary application is in the area of road testing and the effects of freeze-thaw cycling. (See Figure 4.2)

In addition to the rectangular 20 m x 5 m pit, a 5 m diameter cylindrical pit is available for tests involving heat flow around cylindrical wells, etc. An important feature of this facility is the removable insulated cover that can be placed and removed from the rectangular pit depending on the mode of operation of the facility. Vertical rods and horizontal I-beams provide the structural strength of the cover, and styrofoam board insulation is slid in between the I-beams forming the horizontal support. A tarpaulin is draped on the sides of the covered area, and chilled air at the desired temperature is ducted into the covered area. A temperature of -20^{o}C is achieveable in the rectangular pit area, and refrigeration requirements are in the order of 80,000 calories per hour. This is rather high value for such a pit, but undoubtedly reflects the poorly insulated and sealed nature of the removable cover. A very impressive control system and control board was present to alert the operators to any malfunction or changes in operating conditions. Defrosting is achieved using warm water circulated through the coils for five minutes in each hour. Base temperature control is available for the rectangular pit to maintain constant temperature at this area. To achieve this, a separate glycol circulation system is used to exchange heat with the master refrigeration system. Base water level control is obtained using a grid of about 10 pipes on 4 m centres. The water table is usually maintained about 1.5 m below the soil surface.

ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE

Département de génie civil



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SECTIONS AND PLAN LAYOUT FOR RECTANGULAR AND CYLINDRICAL PITS AT LAUSANNE, CH.

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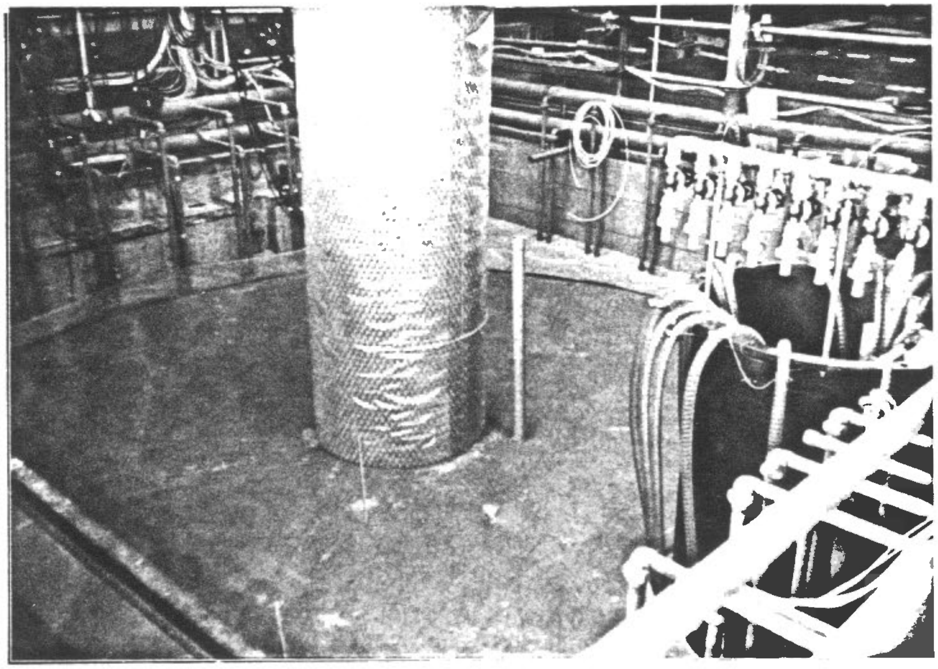
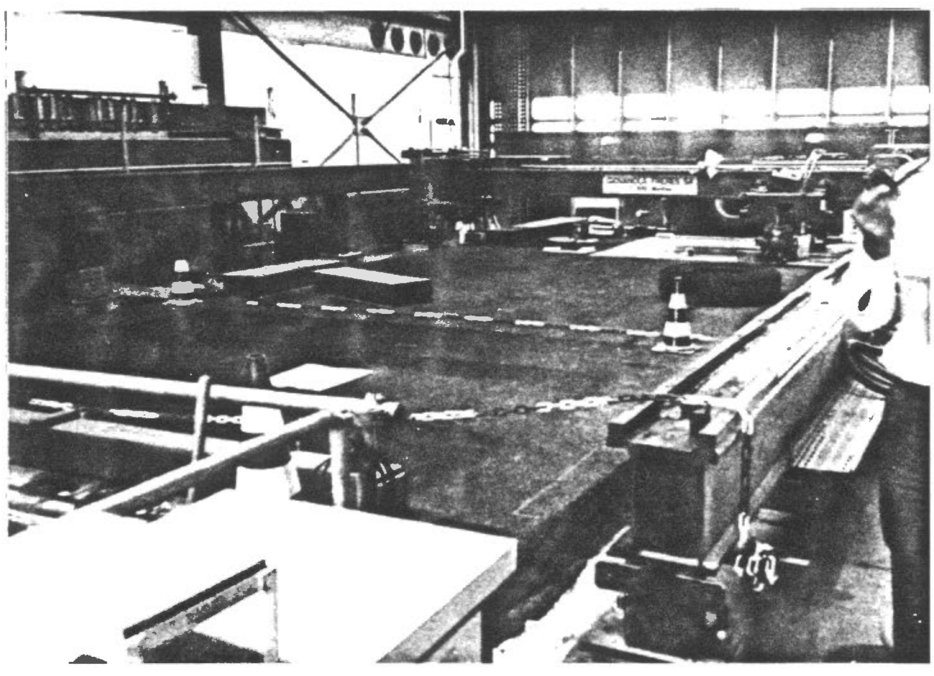
FIGURE 4.2

Temperature instrumentation is not extensive and about forty PT-100 thermistors are used. The name is derived from the resistance of the device which is 100 ohms at 0°C. This is a very low resistance compared to those in North America, and the problem of line losses is allegedly solved by having a 4 wire readout system, as distinct from the 2 wire readout system common in North America. Cables exit into a vertical plastic conduit which in turn pass into a trench or access gallery at the side of the rectangular pit. These reinforced concrete access tunnels on either side of the pit are an important feature of this facility, and at first sight would seem to greatly facilitate instrumentation and access to instrumentation cabling. However, in discussion with the director of the institute, it was revealed that the original purpose of the access terminals was to allow a reaction to be applied to the roadway surface. That is, vertical reaction beams and associated bolts and plates were passed through the floor of the reinforced concrete pit surface, and allowed bolts and plates to be placed and removed to the overlying reaction system. As cabling for a facility can also be passed into plastic conduit and run to the surface, it is not clear that these trenches or access tunnel will be necessary in a test bed where no surface reaction need be applied. In any case, surface reactions can be applied through bushings or metal fittings embedded in the concrete of the surrounding area of the test bed. An automatic data acquisition system is also present in the main building area, and is covered by polythene sheeting to keep out dust, etc. (See photos on Figures B.3 and B.4).



a) CYLINDRICAL PIT, CURRENTLY USED FOR STUDYING HEAT FLOW AROUND WARM WELLS IN UNFROZEN SOIL



b) RECTANGULAR PIT IN UNCOVERED, NON-FREEZING SITUATION. NOTE PAVED SECTION, AND RIG FOR TRAFFIC SIMULATION IN BACKGROUND.

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PHOTOS OF HIGHWAY FACILITY AT LAUSANNE, CH.

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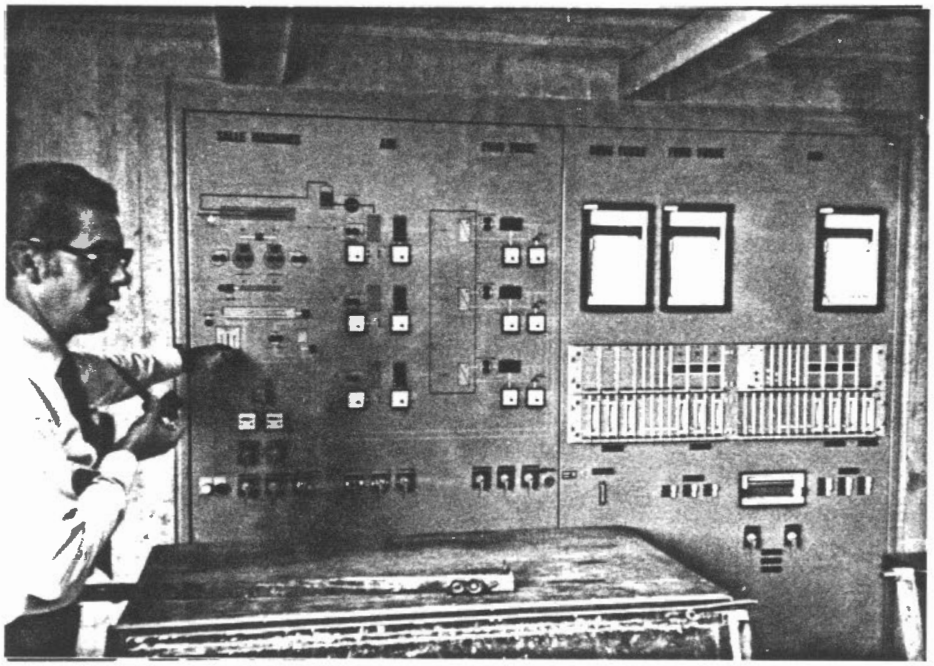
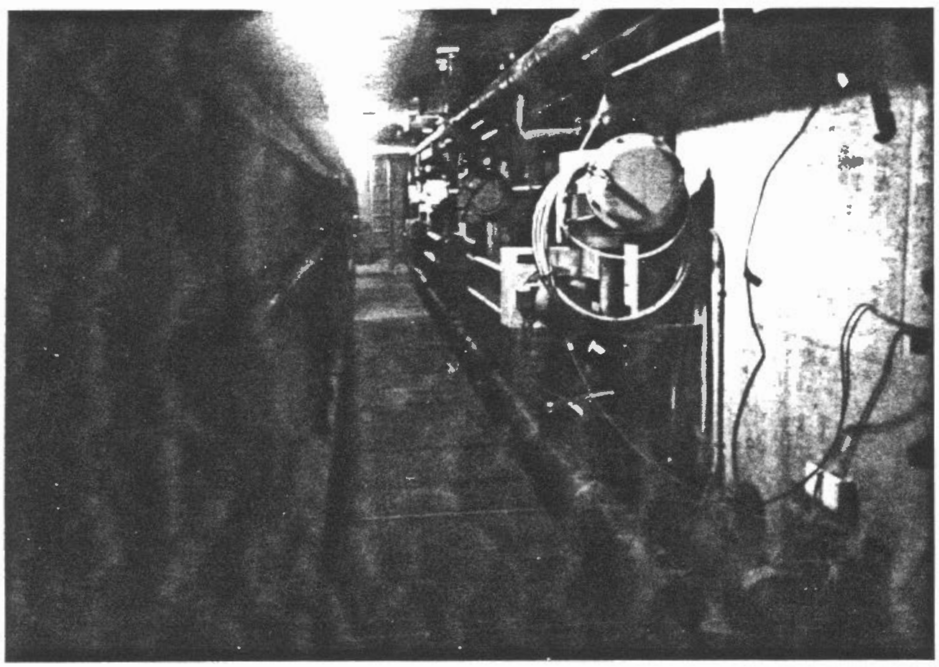
FIGURE 4.3



a) MASTER CONTROL PANEL FOR TEMPERATURE CONTROL COMPONENTS



b) ACCESS TUNNELS AT SIDES OF RECTANGULAR PIT. NOTE PROTRUDING BOLTS FROM ROOF, USED TO OBTAIN REACTION FROM TRAFFIC SIMULATOR

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PHOTOS OF CONTROL BOARD AND ACCESS TUNNEL AT LAUSANNE HIGHWAY FACILITY

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FIGURE 4.4

To date the cylindrical pit has not been used to its full capability, and has been used primarily for tests on unfrozen soils. Currently it is being used to investigate warm heat transfer around a cylindrical buried heat source such as a well. Two compressors operating in parallel provide the necessary refrigeration capacity. Consequently, another important feature of backup and redundancy exists, as each compressor can operate independently of the other.

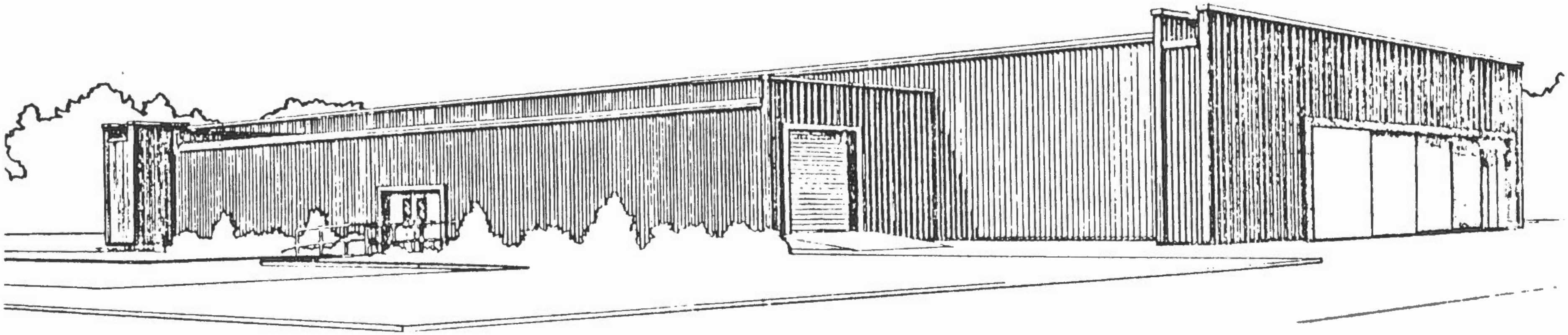
The director of the institute devotes approximately 20% of his time to overall policy matters regarding the test facilities. One senior engineer and two technicians are necessary to operate the facility. A contractor supplies additional help during soil placement or other major construction activities. In addition, secretarial, drafting and computing support are required part time. The initial capital cost of this facility, (which is very similar to that necessary for the Canadian facility in our opinion), was about two million ($2,000,000.00) dollars some three years ago. The cost of the first seven freeze thaw cycles cost approximately 0.5 million dollars over a two year period. The facility is self contained and scientifically administrated and technically through the adjacent Ecole Polytechnique. Financially, it relies on outside support from a Swiss road fund, and outside industry support.

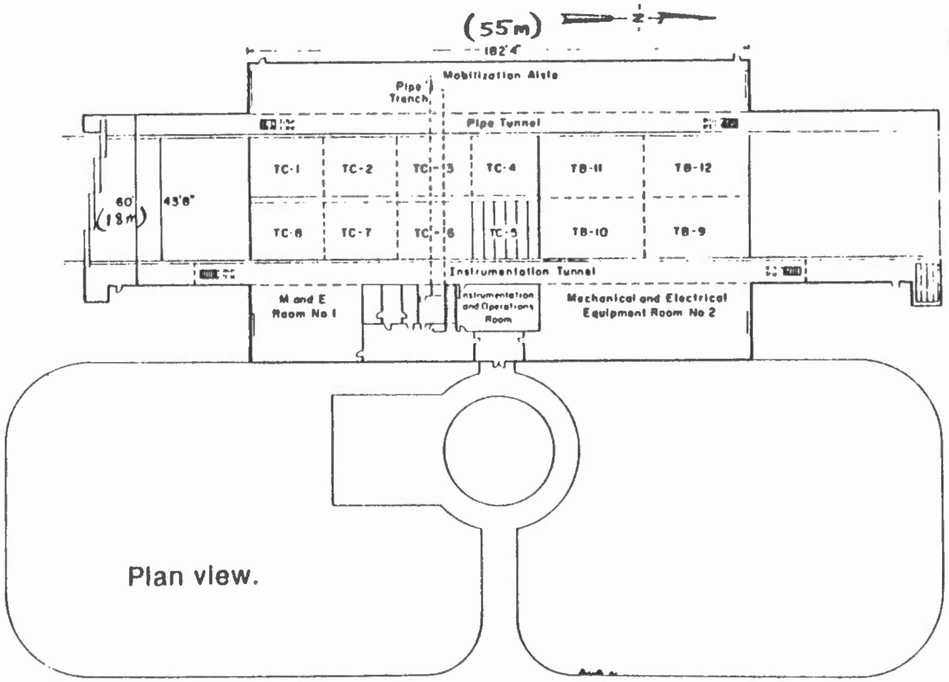
4.3 U.S. Army CRREL

The U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL) is presently constructing a large-scale Frost Effects Research Facility (FERF) on their site in Hanover, New Hampshire. Construction began in October, 1981 and should be completed in the spring of 1983. At present, the excavation has been completed, and footings and some of the basin walls have been poured.

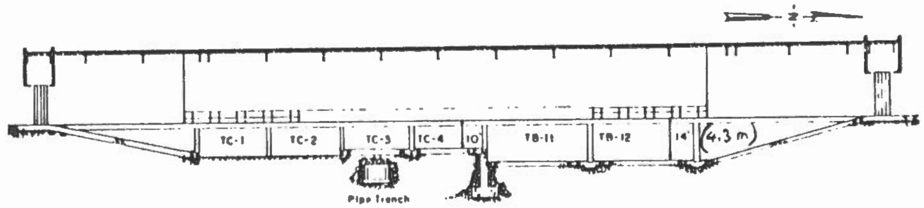
The CRREL FERF was visited on June 24, 1982 by David Halliwell of Hardy Associates. The Facility Review form had been completed in advance by Pete Smallidge of CRREL, and discussions were carried out with R.L. Berg and R. Eaton. This form is included in Appendix "C". A visit to the construction site was included, under the supervision of the site engineer.

The CRREL facility is a composite structure, providing test sections for several uses (see Figure 4.5). All test cells share a single room with soil temperature control achieved by means of surface heat exchange panels with a separate control for each cell. Air temperature, however, is uniform throughout the facility. Since the surface panels would usually be removed for testing (they are used to condition the soil to the desired temperature before testing), it appears likely that conflicts or difficulties could arise in selecting the air temperature while more than one test is in progress.





Plan view.



Section (through test cells).

US Army Corps of Engineers

Cold Regions Research & Engineering Laboratory

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U.S. ARMY CRREL

FROST EFFECTS RESEARCH FACILITY

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FIGURE 4.5

The facility is mainly oriented towards pavement testing. One section (2 small test cells) are modified for use as a utilities test section (see facility report, Appendix "C"). Only the utilities test section has capabilities of temperature control on the sides and bottom. At present, no pipeline experiments are planned, and equipment for control of pipe temperatures is not included in the design. (The "Pipe Tunnel" mentioned in the facility report contains pipes and wiring for the heat transfer panel system and instrumentation.)

Working clearance in the test area was determined by the height required for a standard-lift dump truck. All soil placement and compaction, and roadbed construction requires use of standard road construction equipment. The only specialized transport mechanism is a rail system extending the length of the facility on which a cart can be mounted for transport and storage of heat transfer panels. This same rail system is capable of carrying a load cart for applying loads to the surface of the test pits during experiments. Unfortunately, budget restrictions have eliminated both the load cart and the heat transfer panel cart from the current plans. It is anticipated that the heat transfer panels will be moved by fork-lift.

In conversation with the site engineer, two problems were mentioned regarding the design. First, the detail involved in the poured-concrete walls - consisting of numerous notches, ledges, etc. for test cell bulkhead support, drains, etc. - represent a departure from standard construction practice, and complicate tendering, bidding, and construction of the facility. Second, the "Pipe Tunnel", running underneath the test pits at right angles to the instrumentation tunnels, contains copper piping installed during construction. If problems occur in this system, then access at the end of the tunnel is extremely limited: removal of a pipe would have to be done in six-foot sections. Extra pipes have been installed so that failed pipes can be by-passed with a minimum of effort.

The original design of the mechanical system has proved to be inadequate, and is undergoing extensive revision. As such, few details can be specified. Instrumentation systems are also still undergoing design, and information is not available.

4.4 Sapporo, Japan

The facility operated by the Insitute of Low Temperature Science within Hokkaido University in Sapporo is located nearby in the Tomokamai Experimental Forest. The Director or head of this institute is Prof. Kinosita. However, Dr. M. Fukuda and other staff members provide the necessary technical operation and support. The primary purpose of this facility is research into frost heave and other geomorphological processes. A total of four square concrete pits are embedded in the ground and are exposed to subfreezing ambient temperature conditions throughout the winter. Soil is placed and compacted within the pits by hand, and remains in the test pits for a period of five years. The first two years are used simply to consolidate and settle the soil and provide some natural structure, and density within the seasonal frost zone. The final three years of data are used as the important observation period. A base or water level control is available within the soil pit, but no insulation or slip joints are provided at the vertical or horizontal concrete surfaces. Bi-metallic/strain gauge type temperature sensors are used to measure temperatures at 24 locations, and readings are recorded via a data logger onto a floppy disc. These discs are transported to Sapporo for data reduction every week. Soil water content is measured using a neutron scattering device, and is claimed to be accurate to 25% of dry weight. Buried heave plates of the telescoping variety are used to measure heave every 5 cm within the soil. These are anchored to the base of the pit and thereby providing a fixed data for the readings. Approximately 12 experiments have been completed in the four pits within 15 years. As mentioned above, the duration of the experiment is quite long, and there is a significant conditioning period for the soil, because of the low densities and subsequent settlements obtained following soil placement. The personnel at the site indicated that recalibration of temperature was a major problem every few years. The typical operating cost for the facility itself is approximately $75,000.00 per annum. However, it is difficult to assign a precise cost to this portion of the facility as very extensive support is obtained from the Institute of Low Temperature Science at Hokkaido University.

Funding is obtained through normal university funding, and also from the Ministry of Education. The facility is used as an educational device in making students aware of the facility operation, instrumentation, logging and other scientific activities there. Basically the staffing of this facility is one senior scientist part time and one part time graduate student. Two men are required for three weeks for filling or removal operations at the test pit, once every year or so.

4.5 Seattle, Washington

The Quaternary Research Center is an operating sub-unit under the control of the University of Washington, Faculty of Graduate Studies. The center itself does not grant degrees. There is at present, a staff of four professionals funded through the QRC and in addition, up to ten to fifteen adjunct staff from other faculties.

Initial and present funding for the facility was obtained from grants from the US National Science foundation and the US Army Research office. Copies of the original grant requests are provided in Appendix "E". University of Washington provides additional support. The facility itself was constructed as part of an addition to the physics building as a combined Quaternary Research - Geophysics Building. Drawing 224-A-39 in Appendix "E" gives an overview of this extension. The cold rooms built as part of this extension were also shared, part intended for glaciology studies and the remainder for periglacial studies. There is a total of 115 m^2 of cold rooms of which 75 m^2 are for the QRC Periglacial Laboratory and 40 m^2 for the geophysics/glaciology group which is not part of the QRC. The tilting table (slab) is the primary experimental feature of interest, and is 9 m^2 in plan area, with a soil depth of 1 m. It can be tilted hydraulically to an angle of 40°, after surface freezing with access to a basal water supply. An array of infra red lamps provide the "summer" temperature fluctuations, which are controlled in a sinusoidal fashion.

The periglacial lab is essentially research orientated and no work has ever been undertaken for a commercial user. However, the indication received by the reporter is that they would be prepared to do contract research. The facility has been used by other groups within the University of Washington.

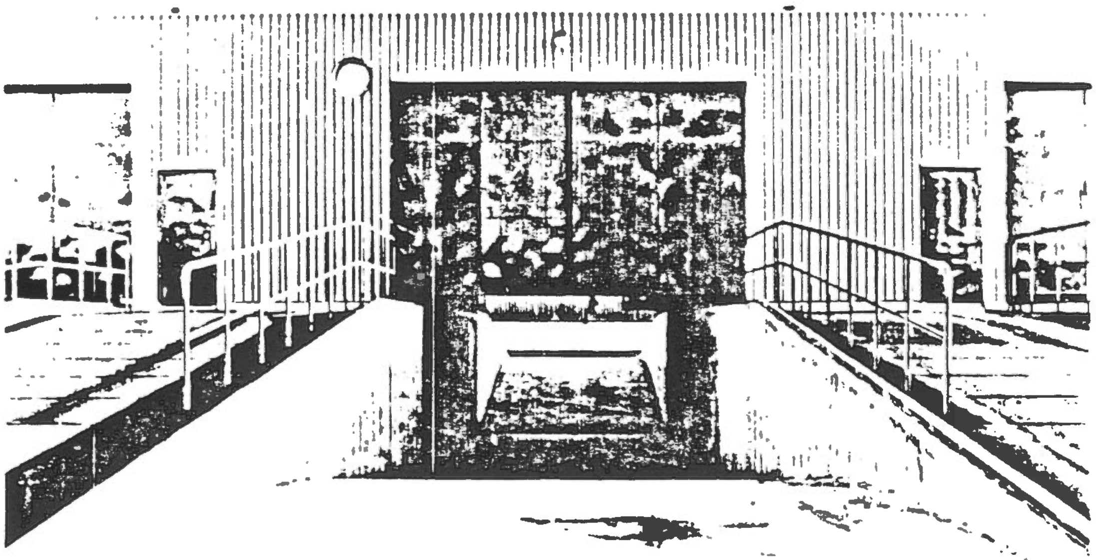
The QRC currently is engaged in field studies of periglacial phenomenon at Cornwallis Island in the Canadian Arctic and Dr. Hallet has a proposal in to the National Science Foundation for work in the Spitzbergen.

A complete description and report on this facility is found in Appendix "E".

4.6 Linköping, Sweden

While visiting Mr. Disli of the Lausanne facility and also in meetings with Dr. R. Gandahl in Switzerland, it was learned that the National Swedish Road and Traffic Research Institute has recently constructed a roadway test facility at their facility at Linkoping, Sweden. This facility is directed by Dr. Gandahl, and is modelled very much along the lines of the Lausanne facility. Dr. Gandahl toured this facility two or three years ago, prior to construction of the Swedish facility. Some improvements or enlargements were incorporated in the Swedish facility (namely a ramp into the pit allowing easier access for construction equipment). Mr. Disli agreed to send the Hardy Associates reporter a copy of some material on this facility, and some limited information was later obtained. Efforts are being made to obtain further information from Dr. Gandahl also. (See Figure 4.6)

Unfortunately, it appears that construction of the Swedish facility depleted funds that might have been available for testing, and subsequently no tests have been run in the facility since construction. This facility was not visited due to its lack of experience on soil placement, instrumentation, facility operation and maintenance or hard data on soil freezing. However, it might be visited during a second detailed engineering phase, as the construction details and/or problems will be clearly visible to the observer due to the absence of soil within the test pit. (Ref: Dr. R. Gandahl. Statens Vag-och trafikinstitut, Fack, S-581 01 Linköping, Sweden, Tel. 013-11 5200.)



Test pit in test road building.

Test road buildings and climate building

Each of the three buildings contains a test pit of the following dimensions: length 15 m, width 5 m and depth 3 m. Road pavements can be constructed in these pits. Water can be supplied to the material through nozzles in the bottom of the pits. Various mechanical or electronic measuring devices can be inserted into the fill at the desired levels, either form resesses at the sides or from tunnels underneath the pits.

There are rails along the sides of the pits for a loading frame. When the frame is locked to the rails it acts as a counterweight for loading equipment used for dynamic loads up to 200 kN and static loads up to 500 kN.

The test road buildings are insulated, which permits test temperatures above +15°C during the winter.

The climate building, which is primarily intended for frost research, has specially insulated walls and is connected to the cooling machinery of the road simulator. The temperature can thus be varied form –20°C to +30°C, irrespective of the time of year.

The road surfacing building

The road surfacing building, measuring 42×9 m, is intended for full-scale laboratory tests on surfacings over a floorspace of 42×6 m. The building can be heated to about +18°C and can thus be used all the year round for studies under summer conditions.

VTI

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FIGURE 4.6

5.0 CONCEPTUAL DESIGN OF CANADIAN FACILITY

5.1 General Design Philosophy

The design of the Canadian facility has been based on the assumption that up to 5 experiments may be run simultaneously within an overall facility. As outlined in earlier sections, these test beds would include one long rectangular road or pipeline test facility, two cylindrical facilities for testing foundations, and two tilt tables for observing slope movements or geomorphological processes in periglacial regions. It is assumed that soil will have to be loaded and unloaded into each of these test beds, and sufficient access must be allowed for soil handling equipment. Further, it would be necessary to have an overhead crane and other soil handling facilities to enable the operators to load and unload the test beds of soil. Large access doors will be necessary to allow entry of a front end loader/dumper and other personnel and equipment as necessary. It has been assumed that the facility will be self-contained to a large extent. That is, some requirement for office, washroom facilities and communication has been acknowledged in the design.

An important constraint is that each test bed must be capable of independent temperature control at different temperature levels. This will require the provision of some multi-cell structure with covers over each test bed, in order to separate the different tests and allow independent temperature control. The nature and shape of some of the test pits, in particular the long rectangular pit, suggested that some form of segmental type construction had to be considered. That is, the test bed cover or cell would have to be constructed in small units, as its size prohibited the use of single cover. The construction or provision of removable cover units was also considered desirable in that it allowed access to construction equipment and personnel during soil loading and unloading phases. Some standard interchangeable unit would be preferred, such that when joined together could form a cover for any of the test beds considered in the facility. The cover units should also be relatively light, simple to manoeuver, and easy to store and stack.

It has been assumed that each test pit embedded in the ground would require some form of basal temperature control. This is necessary in the event that the operator would require the formation of a permanently frozen ground deposit, or alternatively would require some sub-zero temperature conditioning at the base of an unfrozen soil deposit. In order to reduce heat flow into the soil, it would be necessary to heavily insulate the base and sides of each embedded soil test pit. In the event that the soil mass would be maintained at sub-zero temperatures for a lengthy time period, the danger of frost action beneath the foundation of the embedded test pit becomes apparent. The same is true in the chilled area surrounding a tilting slope test table. In order to offset this problem, an array of soil heating pipes would be required beneath the base of each insulated test pit. Around the perimeter of each test pit, two alternatives are possible. Two of the facilities reviewed employed test tunnels running around the perimeter of their test beds, in order to allow access to the sides of the test pit and to simplify the application of a vertical reaction loading. In addition, it is believed that these lateral access tunnels provide protection against frost action around the perimeter of each test bed, provided the access tunnels are suitably ventilated to the outside building. The other alternative is to construct a single wall around each test pit, with no access tunnels. This would limit access to the base heating system which is necessary for frost protection, and would also necessitate the use of a grid of heating pipes along the vertical walls of each test pit to prevent lateral frost action. On balance therefore, it is considered desirable to introduce the concept of lateral access tunnel along each side of the embedded test pits. This concept is not, of course, necessary in the case of the slope tilt tables, as they are completely above grade and are accessible from the interior of the controlled temperature enclosure.

A further assumption concerning the floor plan of the test facility involves the data acquisition area. In order to prevent dust and contaminants from affecting delicate electronic data gathering equipment during soil placement or unloading, it is assumed that the data acquisition area will require a separate room.

5.2 Structural

(a) Building

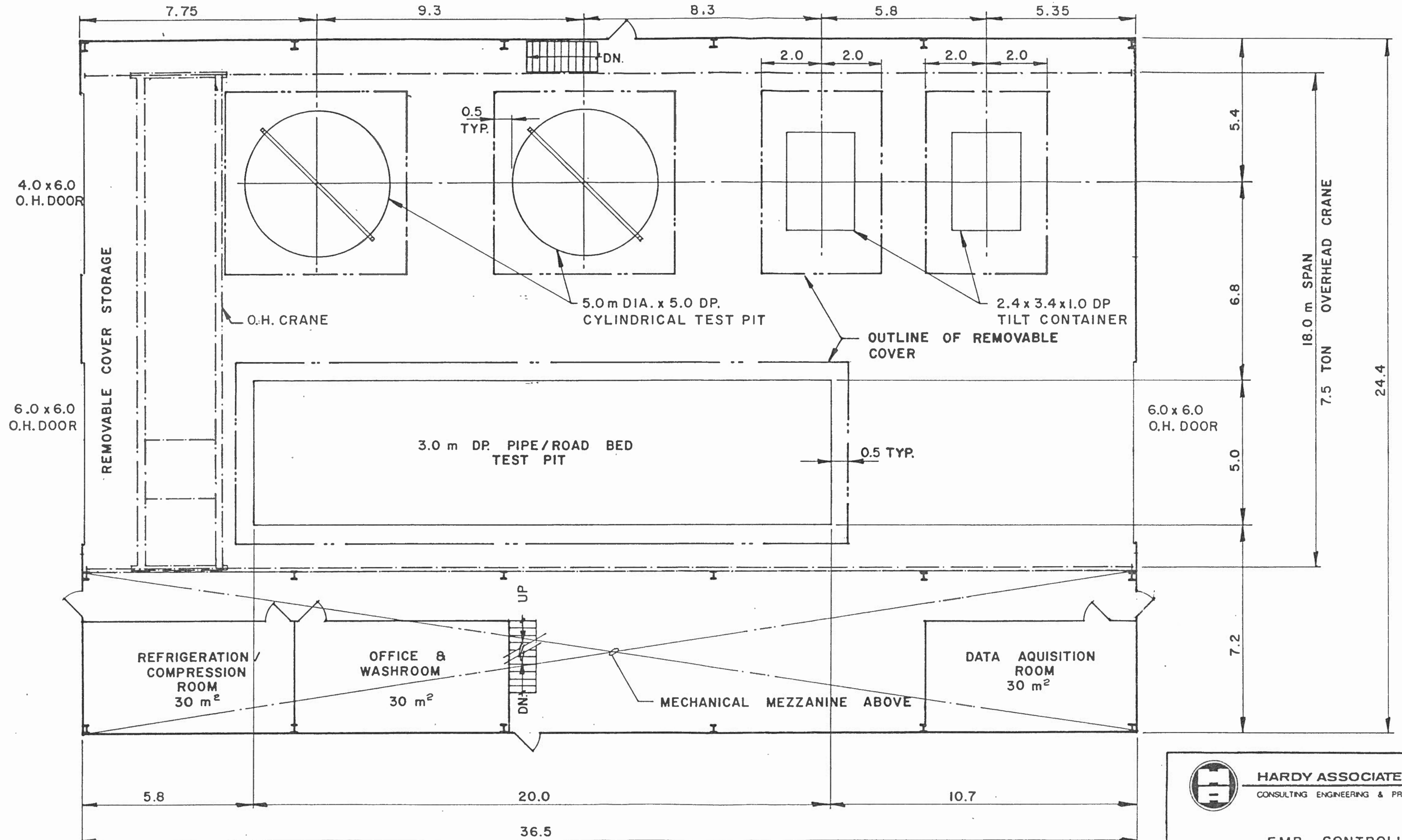
The building will be a prefabricated steel rigid frame structure set on reinforced concrete perimeter walls and column footings. The exterior walls will be made from prefinished precoloured gauge metal panelling, R-15 fibreglass insulation and galvanized gauge metal interior vapour barrier. The exterior of the building will have a total of 3-manually operated overhead sectional doors, and 4-exterior man doors.

Crane columns, beams and rails and also a mezzanine floor structure running the full length of the building in the side bay, will be provided inside the building.

Offices, and two washroom facilities, including windows and doors will be provided along the side bay of the building under the mezzanine floor. These facilities are shown on the main floor plan on Figure 5.1.

(b) Test Pits and Tunnels

These shall be constructed of reinforced concrete, with the test pits and piping access tunnels insulated from each other with rigid



FLOOR PLAN

0 .5 1 2 5

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FIGURE 5.1

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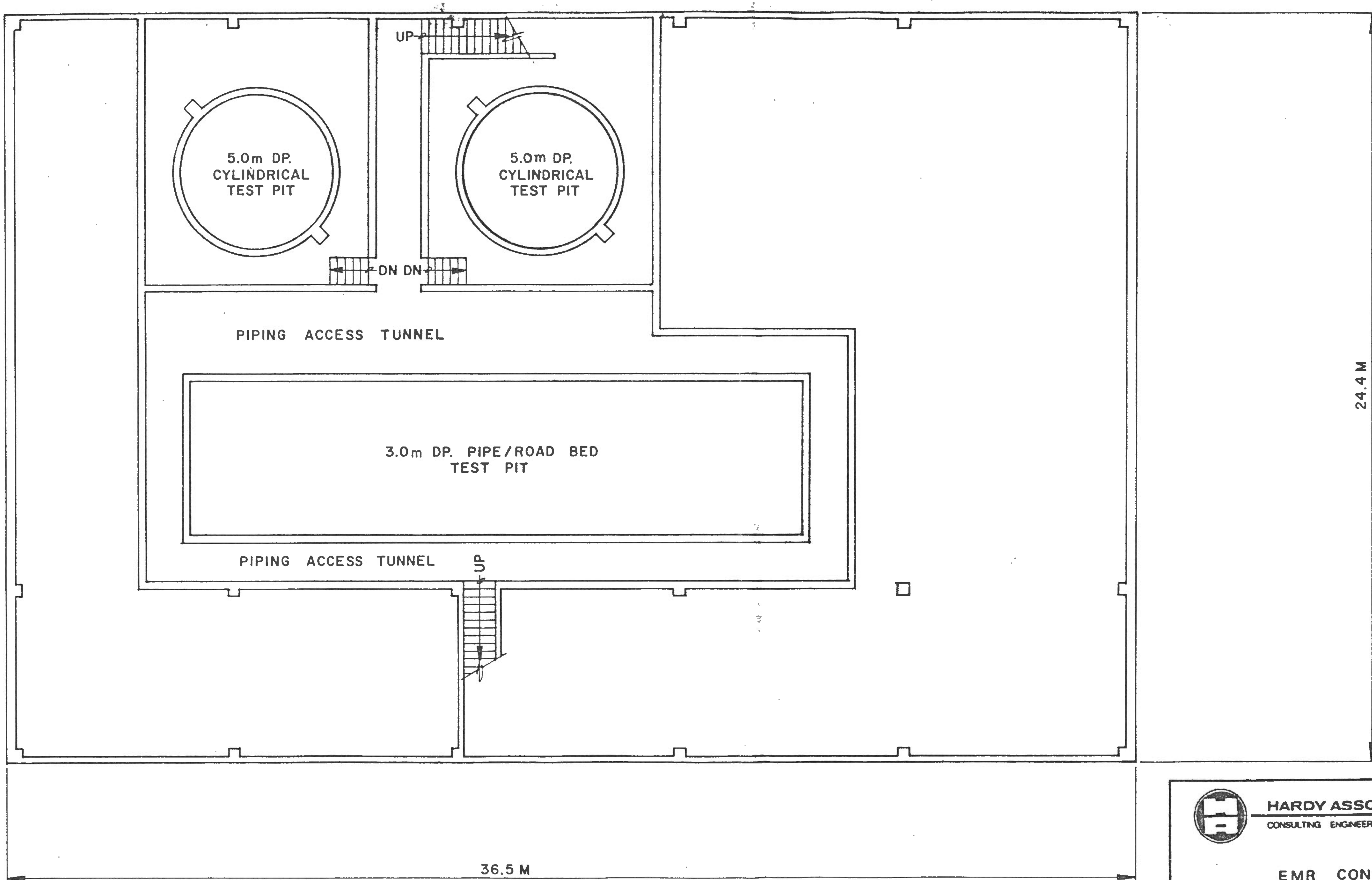
polystyrene insulation. Each test pit is equipped with a 15 cm basal insulation layer overlying heating coils. These would be embedded in a 15 cm sand layer, and are designed to prevent frost heaving of the foundation soils following a lengthy exposure to freezing conditions. A foundation plan is shown on Figure 5.2, giving the layout in plan of the access tunnels. These are considered necessary to access instrumentation and basal heating ducts, and also to prevent the requirement for lateral soil heating coils embedded in the walls of each test pit. A transverse cross-section is given on Figure 5.3, showing the relative positions of the soil test beds, access tunnels, wall and basal insulation and the removable soil covers. A double or triple layer of greased polythene can be applied to the inner walls of the test pits, if it is deemed necessary to reduce or prevent vertical side friction between freezing soil and the walls of the container.

(c) Crane

An overhead travelling crane will be provided to run the full length of the building. This crane will be complete with all controls and electrical pick-ups running the length of the building. It will have a capacity of 7.5 tonnes, and will be equipped with a bucket having a 1.0 m^3 capacity.



FOUNDATION PLAN

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FIGURE 5.2

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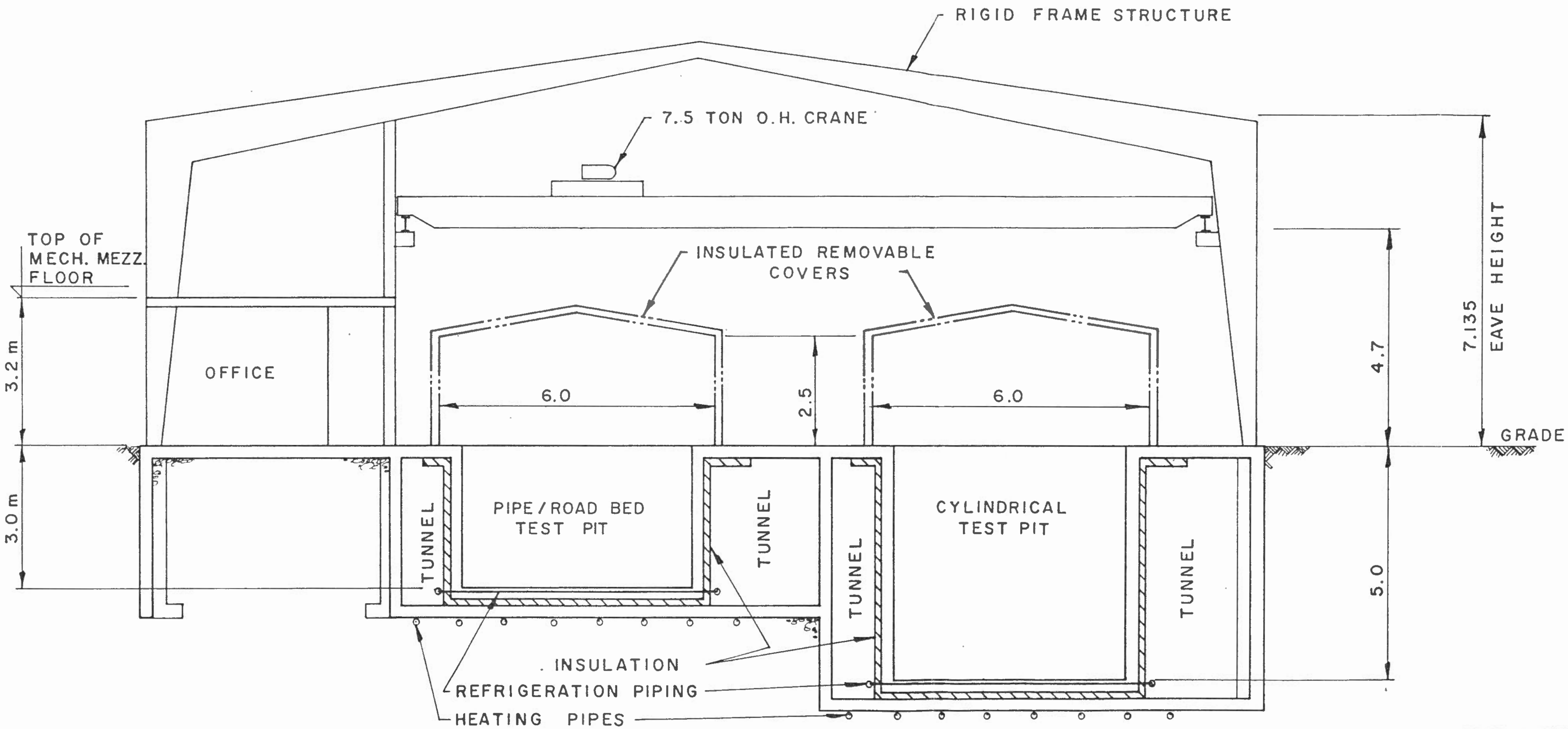

TRANSVERSE CROSS SECTION

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FIGURE 5.3

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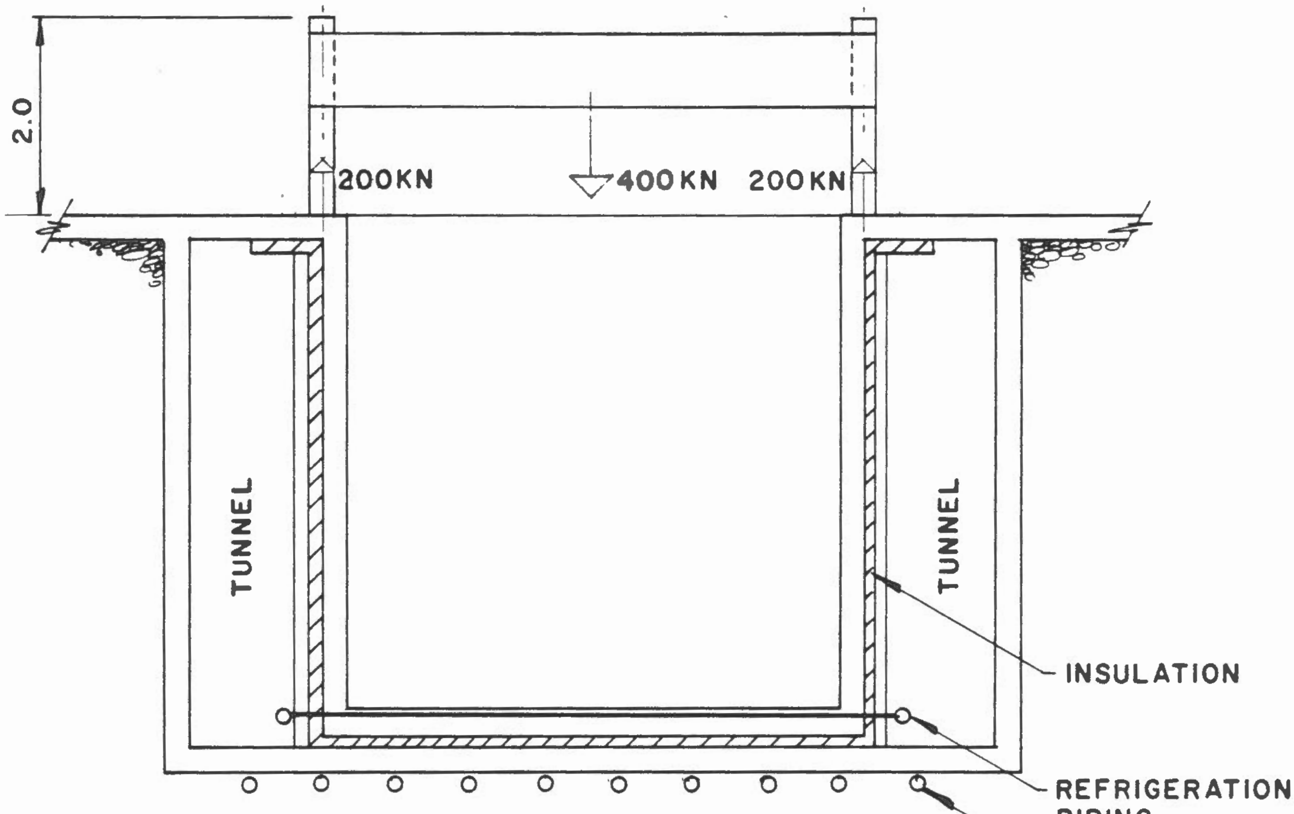
(d) Test Equipment

Each of the two cylindrical test pits shall be equipped with two hydraulic rams, a connecting cross beam member, and a hydraulic pump with necessary controls. A section through the cylindrical pit including a schematic detail of a loading frame required for pile or footing load tests is shown on Figure 5.4. The cross beam and reactions could be designed, if desired, to accommodate some other design load than that shown.

Each of the two tilt test areas shall be equipped with a 9 cu metre steel box hinged at one end with a hydraulic lift cylinder at the other end and shall include a hydraulic pump with necessary controls and an adjustable safety support beam. A section outlining the schematic details of a tilt table is given on Figure 5.5.

(e) Test Pit Covers

Insulated, fold-up steel construction covers and end panels complete with man doors will be provided over the test pits and tilt-up boxes. The walls and roof are galvanized gauge metal panelling with R-30 fibreglass insulation. Details of the assembly or removal of the cover sections are given on Figure 5.6.



SECTION THRU CYLINDRICAL PIT

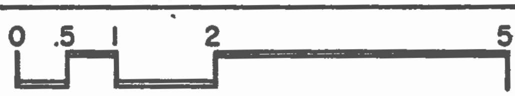


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FIGURE 5.4

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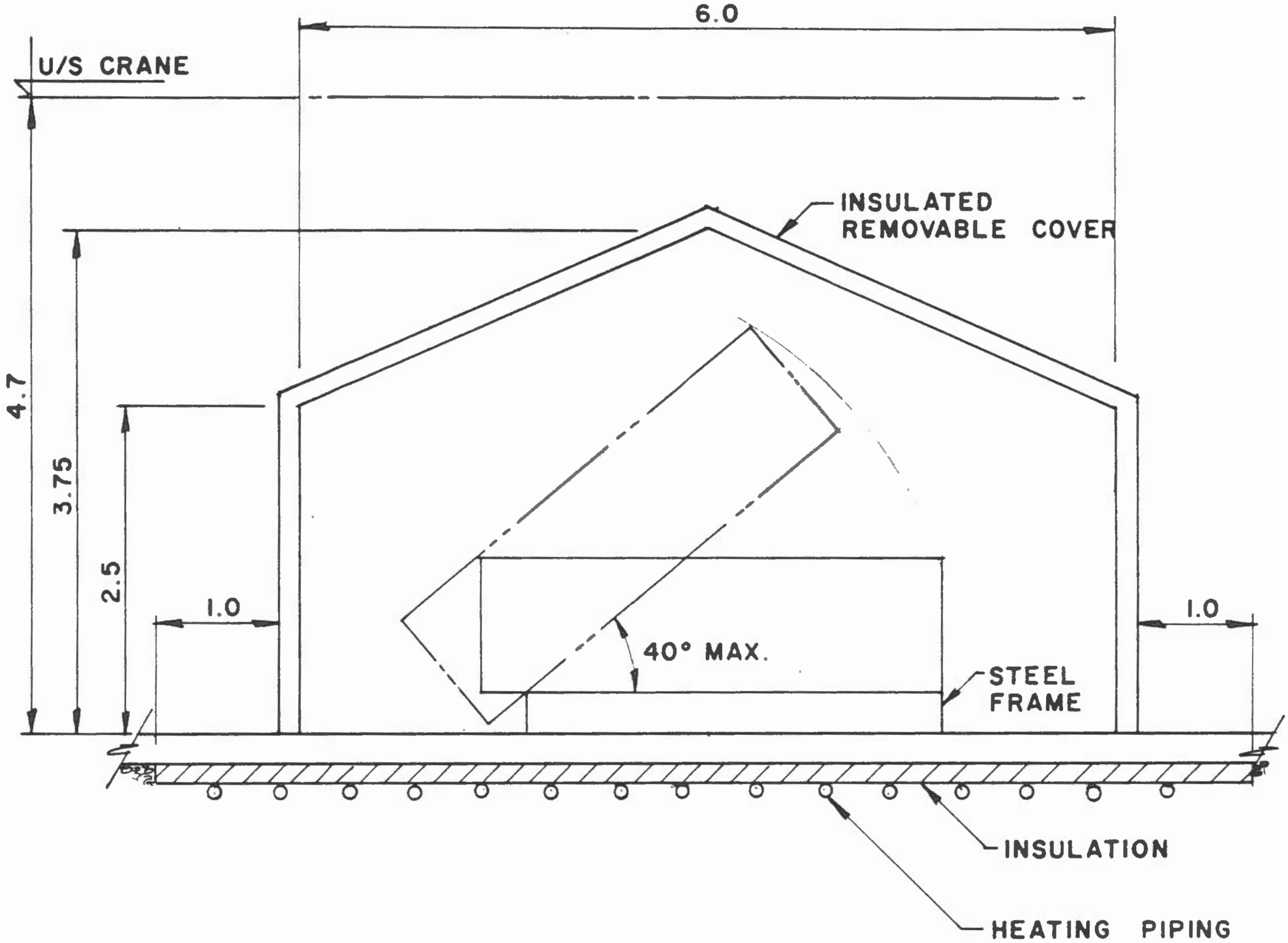

LONGITUDINAL SECTION THRU TILT CONTAINER

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FIGURE 5.5

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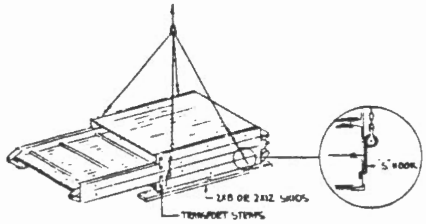
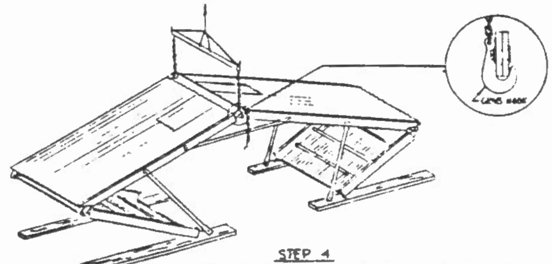


STEP 1

(a) UNLOAD WITH SLING "S" HOOKS ENGAGED IN HOLES IN LOWER WALL.

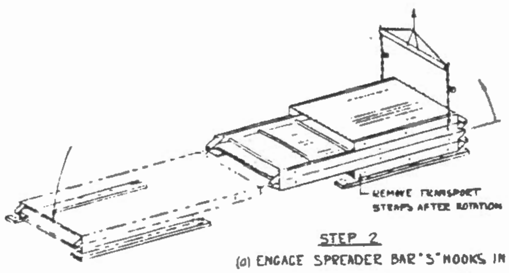
(b) LOWER ONTO TIMBER SKIDS



STEP 4

(a) ENGAGE SPREADER BAR GRAB HOOKS UNDER PEAK HINGES INSERT HOOKS FROM INSIDE FOR EASE OF WITHDRAWL WHEN ADJACENT TO MATING SECTIONS.

(b) LIFT & SECURE EAVE STRUTS TO ROOF WITH WASHERS & COTTER PINS

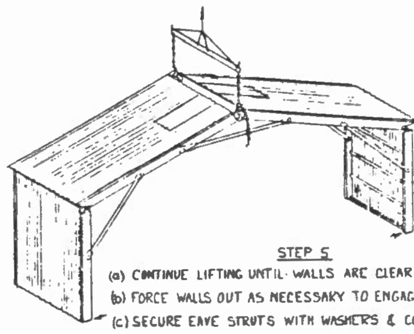


STEP 2

(a) ENGAGE SPREADER BAR "S" HOOKS IN UPPER ROOF PANEL NEAR EAVE HINGE

(b) ROTATE UPPER ROOF/WALL ASS'Y 180°

(c) REMOVE TRANSPORT STRAPS

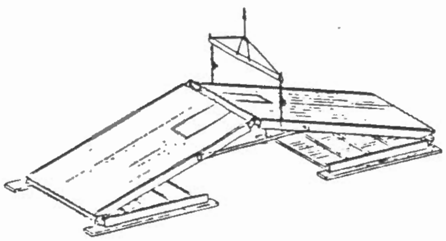


STEP 5

(a) CONTINUE LIFTING UNTIL WALLS ARE CLEAR OF GROUND

(b) FORCE WALLS OUT AS NECESSARY TO ENGAGE LOWER END OF EAVE STRUT

(c) SECURE EAVE STRUTS WITH WASHERS & COTTER PINS



STEP 3

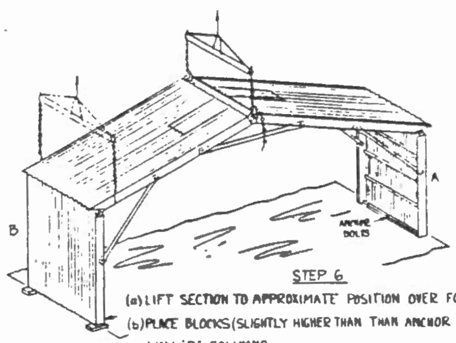
(a) ENGAGE "S" HOOKS IN ROOF PANEL HOLES NEAR PEAK.

(b) LIFT UNIT UNTIL PEAK STRUTS CAN BE ENGAGED.

CAUTION → DO NOT LIFT WITH GRAB HOOKS UNDER PEAK HINGES (SCISSOR ACTION OF ROOF CLOSING CAN DAMAGE HINGES OR PINS)

(c) SECURE PEAK STRUTS WITH WASHERS & COTTER PINS SUPPLIED.

(d) DISENGAGE "S" HOOKS FROM ROOF



STEP 6

(a) LIFT SECTION TO APPROXIMATE POSITION OVER FOUNDATION

(b) PLACE BLOCKS (SLIGHTLY HIGHER THAN THAN ANCHOR BOLTS) UNDER WALL "B" COLUMNS.

(c) LOWER SECTION INDEXING WALL "A" WITH ANCHOR BOLTS

(d) INSTALL ANCHOR BOLT NUTS "FINGER TIGHT"

(e) MOVE SPREADER BAR TO EAVE END OF WALL "B". LIFT SLIGHTLY, REMOVE BLOCKS, FORCE WALL OUT AS NECESSARY TO ENGAGE ANCHOR BOLTS & LOWER

REMOVABLE COVER ASSEMBLY DIAGRAM

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FIGURE 5.6

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(f) General Equipment

A four-wheel drive diesel powered front end loader with a bucket capacity of 1.3 m^3 shall be required for general soil handling around and within the test facility.

An electrically operated, portable inclined trough belt conveyor approximately 12 m long, complete with loading hopper and weighing not more than 5 tonnes shall be required for test pit soil removal.

A steel clam shell type bucket, capable of being suspended and operated from the overhead crane and having a bucket capacity of 1 cubic metre shall be required for cylindrical pit soil removal.

5.3 Electrical

(a) Site Services

Power would be supplied to the building underground from a utility company owned pad mounted transformer located outside the building. Transformer capacity is estimated at 112.5 KVA.

Telephone service would be by underground cable in an owner-supplied duct from the property line.

(b) Power Distribution

Actual supply voltage would depend upon:

1. The final connected load in the building.

2. The utility company supplying the power (voltage available varies from company to company depending on the anticipated load and company policy).

It is estimated at this time that the service would be 400 amps at 120/208 volts 3 phase 4 wire. This would be an economical voltage for the building assuming there are no large individual motors. Motors 3/4 HP and over will be supplied at 208 volts, 3 phase; smaller motors at 120 volts single phase. Convenience outlets and all lighting would be supplied at 120 volts. Isolated ground receptacles would be supplied for the data acquisition area.

Power would be supplied for all refrigeration, ventilation, mechanical and test equipment and the cranes; also the overhead doors if these are to be power-operated.

Power would be supplied for car parking plugs. It is estimated that 5 stalls would be required.

(c) Lighting

The main test area would be illuminated by H.I.D. high bay luminaires mounted above the crane area. Thirty dekalux would be provided at test floor level.

Permanent lighting would be provided at a lower level for the tunnel area by either incandescent or fluorescent luminaires. Demountable lighting would be provided for the covered test areas. Lighting in machine rooms and office space would be fluorescent at appropriate levels of luminance.

H.I.D. lighting, photocell and timer controlled would be provided for yard lighting. Exit lighting and emergency light would be provided as required.

(d) Communications

An empty conduit system would be provided for telephones.

Special communications systems can be provided if required, but no allowance has been made for these in the estimate.

There is no requirement for a fire alarm system.

Estimated costs for this electrical system are included in Table 6.2 in the next section.

5.4 Mechanical and Refrigeration

(a) Site Services

Natural gas, water, sanitary and storm services and services connections will be provided to mains located adjacent to the proposed building. It has been assumed that the building will be sited adjacent to existing services at a distance of 60 m away.

(b) Plumbing

A basic plumbing system consisting of domestic cold water, domestic hot water and sanitary drainage will be provided for the anticipated plumbing fixture requirements of the building. A storm drainage system will be provided for roof services and paved areas on the site.

(c) Fire Protection

A fire protection system in accordance with the National Building Code and local code requirements will be provided for the building and the site.

(d) Heating

A low temperature hot water heating system will provide the heating requirements for the building. A hot water to glycol heat exchanger will also be utilized to provide a glycol heating system for the test bed enclosures and the subsoil below the tests beds.

(e) Ventilation

Washroom areas will be provided with exhaust systems capable of removing odors from these areas. The proposed building work areas will also be provided with a ventilation system in accordance with code requirements.

(f) Refrigeration

A two stage refrigeration system consisting of two 5 ton refrigeration packages will provide the cooling necessary for the proposed soils test facility. The packages will be piped and controlled so that in the event of equipment failure or during reduced load conditions, one package can operate independently. Individually piped and controlled circuits to the base of each test facility will be provided, to simulate permafrost conditions. A ducted air cooling system will be provided to each test facility. Individually controlled air handling units (supply fan, cooling coil, heating coil and filters) on the mezzanine level will supply cooled air to each test facility to simulate the required cold environmental conditions. A glycol heating system will be incorporated in each air supply unit to simulate thaw conditions. Cooling coils in air handling units will be provided with automatic defrost systems for the removal of accumulated frozen moisture on the coils. The long pipeline/roadbed facility will require at least 3 inlet/outlet ducts, spaced along the length of the enclosure to obtain better temperature equalization throughout the area.

Waste heat from the refrigeration systems will be piped, utilizing a glycol loop below each test bed for the purpose of preventing frost penetration in the soil below the test beds.

(g) Automatic Controls

Automatic control systems will be utilized to control the heating, ventilating and refrigeration systems for the building. These control systems will be completely adjustable in order to simulate a range of desirable conditions. The control systems will also include control panels which will provide monitoring capabilities for all relevant system operating conditions.

5.5 Removable Covers

An important feature of the internal layout of the facility is the use of removable covers to maintain independent temperature control over each test bed. As shown in Figure 5.6, it has been proposed that a unique folding section can be constructed by a Canadian fabricator, specially designed for this project. The cover features insulated metal covered panels, with bracing and sufficient structural rigidity to span a width of 6 metres. It is proposed at the present time that each section could be of the order of 2 m long, and therefore the pipeline/roadbed facility would required 11 of these panels, and two special end panels. Each cylindrical test pit would required three of these panels and two end sections, and each tilt table would require two folding sections with two end sections. This requires a total of 21 folding cover sections, and a total of 10 end sections.

Each group of removable covers will require the provision of inlet/outlet cooling ducts, electrical connections for lighting in the interior of the removable cover, and each end section will require a door for access. Each test enclosure will require the provision of some alarm and safety features to protect the operator from becoming locked in the interior of the enclosure. The floor plan of the facility has been designed so that sufficient floor space has been set aside to accommodate the folded stacked covers, assuming that several of the test beds are out of service at the same time.

5.6 Soil Placement and Removal

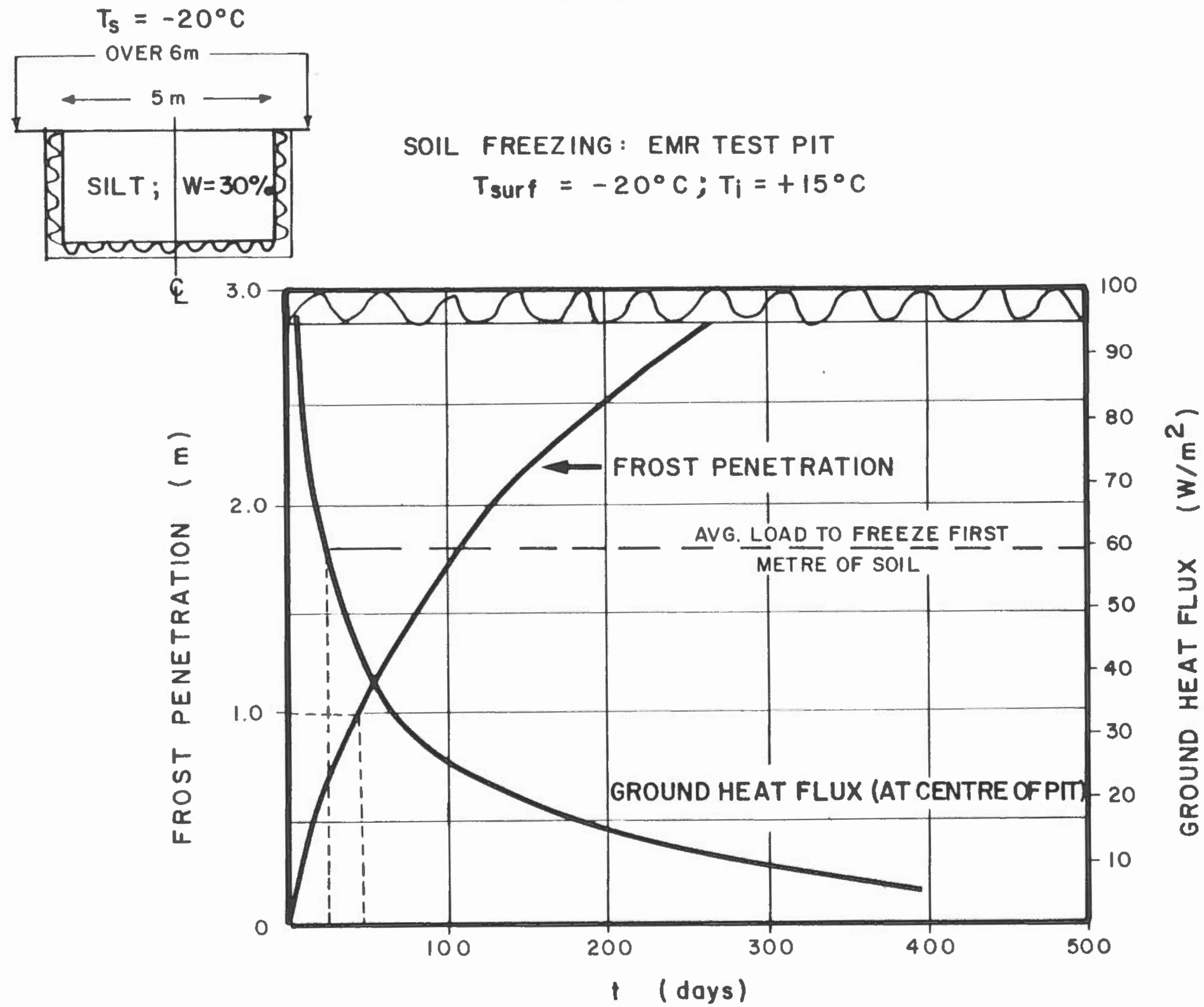
Soil placement and removal will be achieved using a combination of (a) the overhead crane equipped with a 1 cubic metre bucket, (b) the front end loader/dumper mentioned previously under the design of the facility, (c) hand labour within the pit itself, (d) hand held vibratory compaction equipment, and (e) a semi-portable conveyor belt. A soil stockpile area will be maintained in the parking area outside the facility, and the provision of large access doors allows the dumper/loader to enter and leave the structure during periods of soil placement or removal. Instrumentation will be embedded in the soil layers as backfilling proceeds and on completion of back-filling of the test pit, the soil covers can be erected to create the controlled environment enclosure over the test bed. In addition, a small conveyor will be used during soil unloading to transport the soil from the test bed to the overhead crane bucket or the front end loader.

5.7 Soil Control Systems

There are three important control systems which can be used in conditioning the soil test bed. These are the water table, the soil temperatures, and the pipe temperatures. The water table will be controlled by placing a 15-20 cm layer of coarse sand or fine gravel at the base of each soil test bed. Within this layer of granular material, there will be embedded a relatively widely spaced grid of water distribution pipes. These will be connected in turn to manifolds at either end of the test pit which are connected to vertical standpipes protruding above the surface of the test pit. The basal layer of sand is then separated from the test soil by the use of a pervious geotextile, in order to prevent washing of the fine soil particles into the coarse sand fraction. As the soil backfilling proceeds, the level of water in the soil test pit can be controlled by addition or removal of water from the vertical stand pipe risers. This same system is used later during the test to maintain control on the water table within the soil test bed.

Soil temperature conditioning can be achieved once backfilling of the soil is completed. Similar or differing soil temperatures can be applied at the surface or the base of the soil deposit by circulating glycol at the basal soil cooling pipes, and by control of the air temperature in the surface controlled environment enclosure. The walls of each test pit would be heavily insulated in order to maintain essentially one-dimensional heat flow in a vertical direction during this soil conditioning period. Many weeks or months may be required for this thermal conditioning phase as the thickness, (i.e. 2.5 to 3 m), and the thermal properties of soil are such as to require relatively long time periods for temperature equalization. In the event that a frozen soil deposit will be required, it is strongly recommended that sequential backfilling and freezing of each backfill lift should be considered as a method for creating a frozen soil bed. For example, each 0.3 m of soil which is backfilled could then be frozen by the application of cold temperatures from below and above. In this way, the heat flow path to freeze a 2.5 or 3 m thick deposit of soil is greatly reduced. It has been calculated if a 3 m thick deposit of soil is frozen monotonically from the surface of the soil, a time of approximately 260 days would be required to freeze the entire deposit. This calculation is shown in Figure 5.7, which presents the results of a geothermal simulation using the Hardy Associates thermal simulation program. It was assumed for the purposes of illustration that the soil surface was maintained at $-20^{o}C$, and the initial soil temperature was $+15^{o}C$. It addition, this calculation yielded the variation in the ground heat flux with time. In the first few days of frost penetration, the ground heat flux is extremely high in the range of 50 to 100 W/m^2. However, after the frost has penetrated of the order of 1 to 1.5 m, the ground heat flux is in the range of 30 to 50 W/m^2. Once the soil is completely frozen, the ground heat flux has fallen to a level of around 10 W/m^2. These calculations, in conjunctions with the predicted heat losses through the removable insulated covers, provided the background for sizing of refrigeration equipment described earlier.

Further geothermal simulations showed that an insulation thickness in the range of 15-20 cm around the base and sides would allow a high degree of temperature equalization and uniformity in the steady state, for the boundary temperatures envisaged for these experiments.



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PREDICTED FROST PENETRATION AND GROUND HEAT FLUX IN COVERED PIT AREA

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FIGURE 5.7

The overall circulating brine system can be used in conjunction with a heat exchanger and pump to maintain a separate temperature control for an embedded pipe or pile or footing as the case may be. These structures may be required to examine, for example, frost heaving around a buried pipe, heat flow around a vertical well, or alternatively to assist in temperature control around a pile foundation, for example. The heat load for this type of facility is not anticipated to be large, and the overall refrigeration system will be capable of supplying this demand.

5.8 Instrumentation

Several different types of instrumentation will be necessary to monitor soil temperatures, frost heave, settlement, strains in buried structures, surface displacements of soil, earth pressures, water level indicators, and other types of soil strain or vertical heave measurement. In general, these sensors will be embedded in the soil test bed as backfilling proceeds, and cables or wires run horizontally out to one or both walls of the test bed. Vertical metal or plastic conduits will be present to collect the cables from the various sensors. Holes will be drilled in the vertical conduit, the cable run through to the interior of the conduit, and the hole sealed to prevent access of water from soil. These cables will then be passed through the vertical conduit into the access tunnels at either side of the soil test bed, and run in cable trays or conduits to the data acquisition room. Most of these sensors employ the measurement or resistance or voltage, and require some form of calibration prior to installation or following installation in the soil mass.

The water table in the vertical risers can be monitored by installing a water pressure transducer in the place of the vertical stand pipe, at a location where it is always immersed in water. This functions essentially the same way as an electrical piezometer, and the readout will be read automatically using a data acquisition system. When monitoring the advance of a frost or thaw bulb around a buried pipe, for example, several strings or cables of thermistors will be required for this purpose. Each cable or string might involve 8 to 12 thermistors, and 5 or 6 thermistor cables would be required to form an instrument plane at right angles to the pipeline or roadway structure. Up to 4 or 5 of these instrument planes would be necessary to observe the variation of frost advance around the buried structure along the length of the test bed. Typically, this might involve the use of 250 thermistors to obtain the variation of frost advance along the length of 25 m soil test beds. In addition, several other thermistors would be required to monitor pipe temperature, inlet/outlet flowing air temperature, temperature at isolated instrumentation installations, and temperatures at the surface and base of the soil itself. The two cylindrical test pits and the tilting slope table test areas will require at least the same number of thermistors again, giving a total of 500 - 600 thermistors required for temperature measurement. It is considered that approximately 500 further channels will be required for monitoring earth pressures, vertical soil strains, water pressures, strains on buried structures on pipelines using strain gauges, and other forms of data such as TDR or other soil instrumentation not yet envisaged. Therefore the data acquisition system was sized to accommodate 1,000 channels of data, and this is covered in more detail in the next section.

It is considered that the soil strain gauges of the "Bison" type are much superior in accuracy and ability to be automated than the vertical telescoping gauges currently in use in some field locations in the Canadian Arctic, and therefore should be considered for use at this facility.

5.9 Data Acquisition, Manipulation and Control

The cold room facility will consist of five experiments housed within an area of about 20 m x 25 m. The experiments will be monitored an estimated 500 thermistors, 50 strain gauges, 50 pressure transducers, 50 linear voltage distance transducers, and 50 other miscellaneous types of instruments. A further 200 channels are required for further expansion or instrumentation requirements.

A data logger will be required to monitor the state of these sensors, store the logged parameters on a storage media, and allow access by a desktop computer to both recent and archive data. A desktop will be required to access portions of the data collected, process the data, and present it in graphical form on a small flatbed plotter. A generalized description of how the system could be configured is shown in Figure 5.1.

5.9.1 Basic Logger Requirements

The off-the-shelf data logger market offers a broad range of features, some optional and expensive and other standard equipment. Only two off-the-shelf vendors offer the ability to monitor one thousand channels - Acurex and Hewlett Packard.

The conceptual design outlined here calls initially for 1000 sensors. It should be noted in advance that extra channels could only be added at the additional expense of doubling part of the data logger hardware.

Datek Industries of Edmonton offers a open-ended design with regards to the number of ports available. However they do not offer a completely packaged off-the-shelf system. The components used by them are functional and have been used extensively on custom designed loggers. The advantage of this approach is that a logger can be packaged to exact specifications and design requirements, eliminating the compromises inherent in other systems.

On this basis it is recommended that Datek Industries be commissioned to supply the data logger. The logger as constructed by Datek would have the following features:

- The system design would consist of all the desired specifications, rather than compromising to obtain a standard data logger package.

- The system hardware will be split into a master/slave configuration, which reduces noise pickup on the sensor lead wires, and the cost of wiring.

- The slaves units will be semi-intelligent in that their cyclic pattern of logging the transducers will be virtually interrupt free.

- The more complex cyclic pattern of the master unit as determined by the alarms, log intervals, last channel logged, etc. will also be interrupt free. These parameters will be stored in non-volatile memory (i.e. cannot be lost in the event of a power failure) and will be reloaded into the program after an interrupt.

- Once the logger is operational these channel parameters can be easily changed without interrupting the logging process.

- The master unit will control the floppy disc storage device which would allow immediate access to recent data via the interface link to the desktop computer.

- A second floppy disc unit will allow access to archive data.

5.9.2 Data Processing

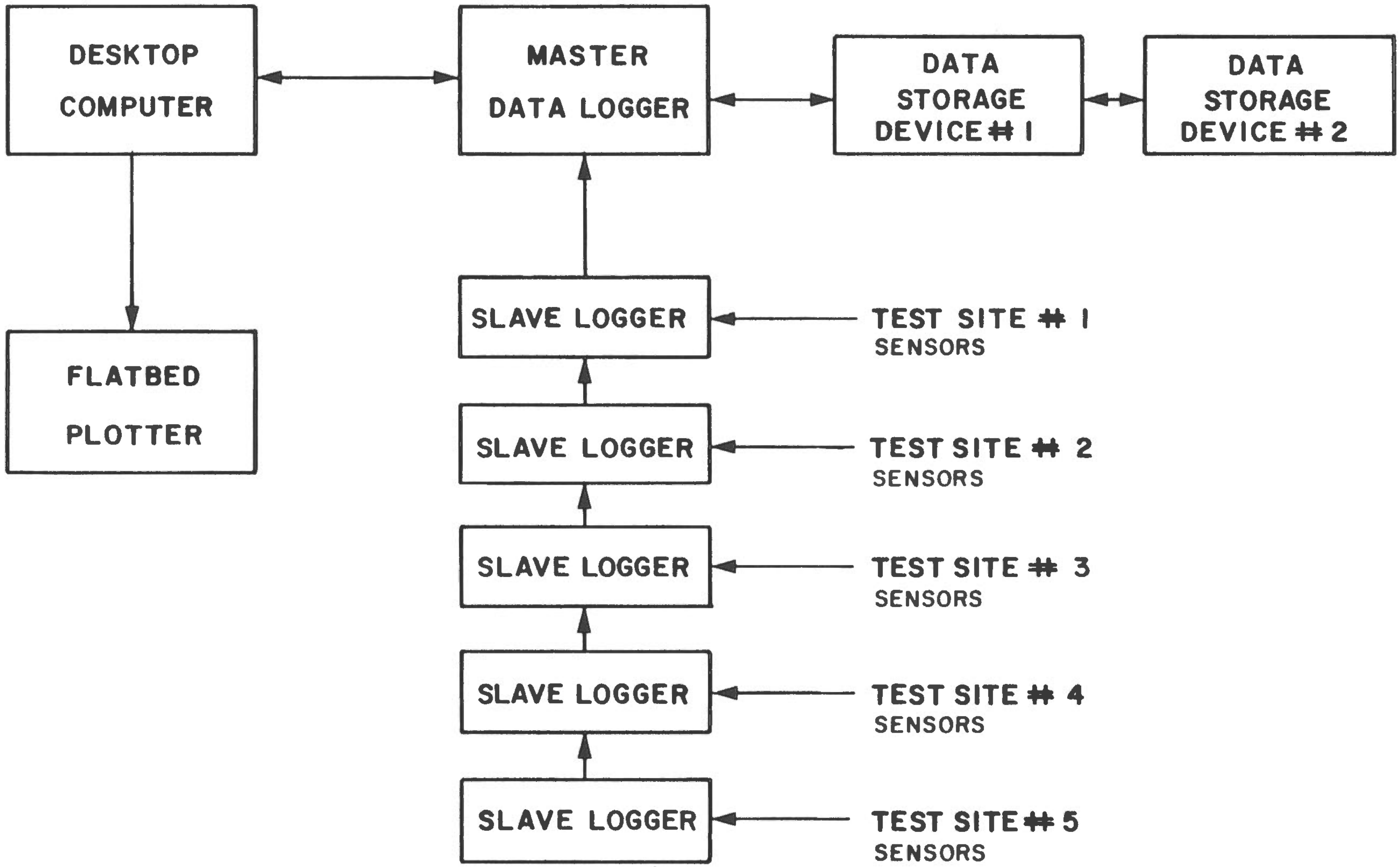
As shown in Figure 5.8, there will be a requirement for a desktop computer and plotter. Hewlett Packard offers quick and easy installation of peripheral devices such as plotters and storage devices and is therefore probably one of the better choices on the market. The HP Basic programming language is also a close facsimile of Fortran, which is an advantage for many programmers.

The Hewlett Packard models recommended for this application are a HP9826A for the desktop mini-computer and a HP9872A for the plotter. The plotter size is A3 (297 mm x 420 mm).

5.9.3 Cost Estimate

There are three components to the Data acquisition system:

1) Data logger
2) Storage
3) Computer and plotter for data processing.



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DATA ACQUISITION

CGI4027

FIG 5.8

The individual costs for these components are given below for the three vendors surveyed in connection with this project.

Item/Supplier	Acurex	Datek	Hewlett Packard
1. Data Logger	$110,000 (TEN/50)	$110,000	$70,000 (HP3497A)
Software	Included	Included	$25,000*
2. Storage	$12,000 (HP9895A)	Included	$12,000 (HP9895A)
3. Computer (HP9826A)	$13,000	$13,000	$13,000
Plotter (HP9872A)	$7,300	$7,300	$7,300
TOTAL	$142,300	$130,300	$127,300

* estimated

Based on this, a cost of $140,000 has been allocated for data acquisition purposes in a later table summarizing costs for a Canadian facility.

6.0 ORGANIZATION, BUDGET AND ADMINISTRATION

6.1 Relationship to Adjacent or Existing Facilities

During the review of foreign facilities, a very important fact emerged. Each facility designed to observe cold regions engineering or geomorphological effects was associated with a major academic institute. The facility at Caen, France, for example, was associated with a national center for geomorphological studies, whereas the facilities at Lausanne, Sapporo, and Seattle are associated with universities. The U.S. Army Cold Regions Institute is, of course, associated with the major cold regions research laboratory in New Hampshire. The advantages of association with a major facility are obvious. Manpower and graduate students support can be obtained from a university. Existing geotechnical or soil science laboratories can be used for soil testing support. In addition, an existing infrastructure or hierarchy of management and organization may exist at the present in such an institute. Land costs may well be minimized or obviated because of available space on a government or university facility. This reduces the costs of services and site development to the Canadian government.

Table 6.1 summarizes some of the observations at the facilities reviewed earlier in this report. All of the facilities are associated with a major institute or university, and in addition, this table reviews the annual costs and staffing associated with each facility visited. These costs provide some background for the cost estimates for a Canadian facility to follow in the next subsection. Initial capital costs would seem to vary between 0.5 and 2 million dollars, with annual operating costs somewhere between 75,000 and 500,000 dollars depending on the magnitude and the extent of the studies being carried out. The costs for the Lauzanne, Switzerland facility would seem to be closest

TABLE 6.1 SUMMARY OF EXPERIENCE AT OTHER FACILITIES

	Adjacent Facility	Initial Capital Cost	Annual Operating Costs	Staffing
CAEN, France	Major Centre for Geomorphological Studies	Not relevant, out of date	$500,000	Director (occasional) Sr. Scientist (part time) 2 Tech. (full time)
LAUSANNE, Switzerland	Ecole Polytechnique	$2,000,000	$250,000	Director (occasional) Sr. Engineer (part time) 2 Tech. (full time)
U.S. ARMY CRREL	Army Cold Regions Institute	Unknown	$200,000 (estimate)	Several Engineers involved (part time) 2-3 Tech. (full time)
SAPPORO, Japan	University at Sapporo nearby	Out of date	$75,000 (approx.)	Director (occasional) Sr. Engineer (part time) Grad Student (part time)
SEATTLE, Washington	University at Seattle	$470,000 (1972)	$30,000 + power (ie. could be $50,000)	4 Prof. Staff Secretary (part time) Maintenance from University
LINKÖPING, Sweden	Swedish Road and Traffic Res. Institute	$1,250,000 in 1976	$140,000 (estimated)	Director (part time) Remainder unknown

and most appropriate for the present study, and these suggest figures in the range of 2 million dollars for initial capital costs, and 250,000 dollars per annum for operating costs.

Also in Table 6.1, the staffing level for the reviewed facilities are summarized. Typically, it appears that each facility requires a part time director in addition to a senior project engineer full time. At least two full time technicians will be required for day-to-day soil handling, data acquisition, data manipulation, maintainenance of facility, etc. In addition, it is considered that several graduate students would provide support for specialized projects from time to time, at the discretion of the facility and depending on the needs of government and industry. In addition, some part time clerical and drafting support may be needed for routine preparation of progress reports or reports of construction and maintenance activities at the facility.

6.2 Capital Costs

The costs for a Canadian facility have been broken down into two categories, (a) initial capital costs, and (b) annual operating costs. The initial capital costs are based on the conceptual design outlined in the previous Section 5 of this report. These costs have been prepared in a preliminary fashion by Hardy Associates and T. Lamb-McManual Associates Ltd. during the preparation of conceptual design.

The potential expenditures have been broken down into 16 major cost items as shown on the accompanying Table 6.2. The major costs are the building structure itself, its delivery and assembly, the foundations and concrete work, the refrigeration equipment and controls, and the removable covers. Electrical work also forms a major cost of the facility. During routine operation, the major expenditures will be staffing costs to maintain a staff level of 2 full time technicians, one senior project engineer, and one director occupied occasionally to part time. Electricity and equipment operation costs will also be a significant capital outlay. It appears that initial capital cost in today's dollars will be approximately $2,000,000. An annual operating cost budget of $160,000 will be required simply to operate the facility. This does not account for major purchases of specialized structures to be tested, highway testing equipment, or other peripheral equipment that might be required for specialized tests.

6.3 Operating Budget, Staffing and Administration

The annual budget outlined above is in the order of $160,000 per annum. This may not include additional expenditures for special structures such as piping, piles, construction of footings, special heating or cooling equipment associated with these structures, or other unforseen expenses. Therefore, it would be advisable to increase the budget allowance to an amount substantially greater than this for annual operating expenses.

The staffing would consist of one full time senior project engineer, whose long range policy and direction is established by a part time director. This director would be a senior person in government or university who would likely be responsible to a committee of directors or scientific advisors, who would meet from time to time to discuss the overall policy of the test facility. This group of scientific advisors might be selected from across the country and would represent senior high profile personnel in industry, government and university. As the funding of the facility would be obtained from government sources, the government objectives for the long term scientific and research needs would form an important input to the policies and priorities of the facility. Should the facility be located within a university or provincial or federal government research institute, then the administration of the cold room test facility would be guided to some extent by the administration of the adjacent facility. However, a large amount of autonomy would be required for the controlled temperature facility to operate in a scientific manner, and meet the priorities and research needs of the government.

6.4 Closure

This report should serve as a base for discussion and conceptual design for a Canadian controlled environmental facility. It is understood that upon acceptance of the concepts outlined here, a Phase II detailed engineering effort would be undertaken. This would

TABLE 6.2 ESTIMATED COSTS FOR CANADIAN FACILITY

Costs are based on the assumption that the facility is located on an undeveloped lot, adjacent to a large facility in an urban area with services and utilities nearby.

(a) Initial Capital Costs

- Building Structure, delivered and erected	532,000
- Site Development, services, excavation (Depends on adjacent facility)	unknown
- Foundations, concrete work, slabs	378,000
- Fittings, cranes, loading beams	54,000
- Tilt Tables (2) + hydraulic gear	20,000
- Refrigeration equipment and controls, Heat exchangers, blowers, ducting	367,000
- Removable covers + end sections	240,000
- Instrumentation, cabling and spec. readout*	50,000
- Soil placement equipment, dumper, crane bucket	78,000
- Data acquisition equipment and computer	150,000
- Soil storage, parking area	10,000
- Washroom, plumbing, office equipment	10,000
- Sign posting, fencing, security, alarms	2,500
- Senior Supervisor, technician for 6 month construction period	45,000
- Camera/video equipment	3,000
- Electrical	56,000
Sub Total	1,996,000

* Includes such items as readout for earth pressure cells and Bison soil strain gauge devices.

(b) Operating Costs (Annual)

Director (occasional/part time)	10,000
Senior Project Engineer (full time)	50,000
2 Technicians (full time)	60,000
Secretary (part time)	5,000
Maintenance Contracts (routine and emergency)	10,000
Instrumentation and other equipment consumables**	5,000
Electricity and Gas	10,000
Equipment operation, contractors for soil placement	10,000
Sub Total per annum	$ 160,000

** Based on 10% of capital cost per annum.

prepare final detailed drawings, and the design effort to a stage where contract drawings were prepared and bids were obtained. Following completion of the Phase II effort, construction would proceed with the facility. It is estimated at this time that a period of six to nine months would be required to complete the basic installation, and clearly several subsequent months would be required for initial filling and thermal stabilization of the soil test beds.

Respectfully Submitted,

HARDY ASSOCIATES (1978) LTD.

Per:

J.F. (Derick) Nixon, Ph.D., P.Eng.
Associate

JFN:mm
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APPENDIX "A"

REPORT ON VISIT TO FACILITY

LOCATION: CAEN, FRANCE

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1.0 FACILITY IDENTIFICATION

Name of Facility:	Centre de Geomorphologie, ("Cryotron") Division of Centre National de la Recherche Scientifique
Location:	Caen, France
Full Address:	as above, Rue des Tilleues, 14000 Caen, France
Director or Head:	Mon. Faugere (overall) MOn. J.P. Lautridou (specific to the cold room)
Phone No./Telex:	Phone 864-4800
Hardy Associates Reporter:	J. Nixon
Date Visited:	June 29, 1982
Personnel Interviewed:	Messrs. Faugere, Lautridou from Caen; Drs. Williams, Bowes from Carlton Univ. Ottawa.

2.0 GENERAL FUNCTION OF FACILITY

- Operating organization	Centre National de la Recherche Scientifique also Dr. Michel Fremond of Dept. of POnts et chausees, Paris, France. and Dr. P.J. Williams, Carlton University, Ottawa.
- Affiliated agencies (eg. government department, universities, research organizations) (groups that are involved in scientific aspects of work done at the facility)	
- External support organizations (eg. government, industry, universities) (groups which provide logistical or administrative support, or monetary support)	CNRS in France, and Dept. Energy Mines and Resources (through a contract with Carlton University, Geotechnical Science Laboratories).
- Research interests of groups involved (major and minor) eg. foundations, pipelines, road beds/ pavements, geomorphologic processes, other	Specifically pipelines at present, but roads and geo-mophological processes in the past.
- Is facility research-oriented or application-oriented? eg. A facility for development of new road bed materials would be application-oriented; a facility for analysis of periglacial slope formation would be research-oriented. (This would be important with regard to the range of experiments carried out.)	Generally research oriented, although with definite practical overtones.
- To what extent is facility operated in conjunction with laboratory research facilities? Are there laboratories on site? separate?	Other basic physical, chemical and pedological labs on site. No geotechnical or frost heave lab facilities as such.
- Are experiments also carried out in an open air environment? (eg. micro-meterological stations, etc.)	Some experiments on frost shattering of exposed rock faces are carried out.

3.0 GENERAL SIZE & SHAPE OF FACILITY & SUPPORT FUNCTIONS

- Total size of site (controlled environment building, offices, support structures for power supplies, cooling facilities, material storage, equipment storage, soil stockpiles, access and maneuvering areas)	Approx. 25 m x 9 m with large parking, storage and clearing area at each end.
- Note whether any of these are located off-site (eg. administrative offices) or in separate buildings on-site	Large Institute for Geomorphological Research on site.
- Note general site plan: relative locations of buildings, stockpiles, etc.	Representative bags of soil from each soil layer storage inside main institute control systems located in approximately 4 m x 4 m office at one end of 18 m x 8 m facility.
- Note proportions of space allocated to experiments, stockpiles, administration, control systems, etc.	
- Number and size of controlled environment buildings	One.
- Total building size? construction methods/style?	25 x 9 m approx. x 6 m high. Construction is vertical steel beams with concrete wall.
- Are control systems entirely contained in the building or housed separately?	Same building.
- Location and size of soil/material stockpiles	Small area for bagged storage
- Are large quantities of soil or construction materials (eg. pipes, road materials) stored on site?	NO
- If so, are they inside or outside? (Degree of protection from elements?)	NO
- Can a large variety of materials be stored/handled?	YES
- Auxillary facilities - offices? labs? washrooms?	Yes, in adjacent Institute.

4.0 <u>DETAILS OF TESTING FACILITIES</u>	One main pit 18 m x 8 m x 2 m.
4.1 Size and layout of test pits, environmental controls, data aquisition systems	
- Number and size of test pits (note pits with special functions), size of rooms containing pits.	
- If more than one test pit, do test pits share control/data systems, or is each a stand-alone system?	n/a
- How are test pits separated from each other? (separate rooms, partitions in one large room, in same room?) Can sizes be adjusted if necessary?	n/a
- Where are control and data aquisition systems located in relation to test pits? How much room is required for them?	Separate 4 m x 4 m (approx) room.
4.2 Materials Handling Systems	
- How are soils, road beds, pipelines or whatever installed in pits? Note whether mobile equipment is required (and where is it stored), whether fixed equipment is present (eg. overhead crane in testing area).	With front end loader, access thru large hinged doors. No overhead crane in this facility. Large 3000 kg capacity overhead crane in adjacent facility.
- Is special handling of soils in test pits required due to pit lining materials (eg. insulation) control systems, or data sensors?	
- How are materials removed from test pits? How are they disposed of?	Materials placed and removed with front end loader.
- Note size and location of access doors, approach ramps, etc.	Doors are approx 3 m wide x 4 m high (two), and open outwards.
- How is soil compacted? What controls are maintained on bulk density, soil uniformity, etc? Can soil be layered?	Two passes of small static roller per 30 cm lift, followed by 4 passes of small, hand operated vibratory compactor. Density read subsequently by nuclear densometer.

4.2 Materials Handling Systems (Continued)... - What time is involved in installing, compacting, and removing soil and other materials?	Installation and compaction of soil for first experiment took at least 2 months.

4.3 Environmental Control Systems
 	
- Air Temperature Control
  - Range of possible air temperatures, accuracy of control (note if this differs from pit to pit).
  - Refrigeration requirements (capacity for each pit, or total if all on one system).
  - Refrigeration hardware description.
  - Method of temperature control (eg. continuous cooling with heat added to control temperature; or cycling between heating and cooling).
  - Type and placement of building or room insulation.
  - Backup systems? Number of failures? Reliability?
  - Humidity or any other variable controlled?
	Air - thermostat switches compressors and blowers on/off with about $\pm$ 1°C accuracy. Has been controlled as low as -20°C in past, but present experiment will be 0°C. Two compressors (one 10 HP and one 8 HP) provide 20,000 cal/hour through 3 ducts. Velocity of air thru ducts in 9 m/sec from a 0.5 HP fan.
	
	Approx. 16 cm of beadboard insulation in walls and ceiling and 5 cm of styrofoam in base.
	
	Partial backup thru 2 compressors acting in parallel. Reliability as yet untested for present tests. Previous problems with defrosting coils. Coils heated electrically for 20 min. or so per day to defrost. No humidity control.

- Pipe Temperature Control
  - Is separate control provided for such things as pipes?
  - If so, describe as for Air Temperature.
	2 HP compressor separate from above provide 3000 cal/hour to an air temp control duct to pipe. Air flow is reversed regularly depending on temperature difference across ends of pipe.

4.3 Environmental Control Systems Continued ...

- Soil Temperature Control - Is additional temperature control available in soil (especially at the base)? If so, describe methods, reliability, degree of control, system capacity, range of temperatures possible, location, etc. - Is base of soil pit insulated? (type and thickness)	Base insulation, 5 cm styrofoam. NO other control.
- Local Heating/Cooling - Are methods available to heat or cool small local areas of soil? If so, describe size, method, degree and range of control, heating/cooling capacity, placement, etc.	Not at this facility. In the main Institute lab, two soil basins 5 m x 5 m have been controlled independently by a removable metal cover with a separate cooling system.
- Soil Moisture - Are systems available to control soil moisture during a test? (eg. base drainage, base or surface infiltration) Note degree of control, whether or not changes can be made during test, whether different areas can be provided with water, uniformity at application, etc.	Base drainage, sand and standpipe system is used to raise water table at base of silt/sand layers. Exact quantity of water added is metered, and other observation pipes and tensio meters record water table location.
- Slope - What methods are available for controlling slope? Note angles of slope possible, whether slope can be changed during test, etc. (If pit slope cannot be adjusted, perhaps, pit is deep enough to allow construction of slopes?) Describe system, ie. total weight elevated, lifting system.	NOne in main cold room facility. HOwever localized soil basins 5 m x 5 m are present in adjacent facility, and slopes were sedimented at a 7 degree slope to investigate slope movements due to cryo-processes.

4.4 Data Aquisition Systems

- Temperatures (soil) - Number and type of sensors (eg. thermistors, platinum resistance sensors, thermocouples) - Manual or automatic readout - Method or reduction and storage - Placement of sensors, grouping, etc. - Time involved in getting reduced data - Calibration methods for sensors - Accuracy and precision of sensors, readout system, calibration system.	150 thermocouples, no RTD. Some additional thermistors associated with TDR devices only. Automatic acquisition using Schlumberger 3530 Orion data logging system. Control, manipulation and storage by SMT* Goupil 2 mini-computer and floppy discs. Sensors placed in several planes and on pipe. Thermistors associated with several TDR devices. Turnaround for data is fast, and can be programmed by mini-computer. Calibration for thermocouples completed using German "DIN" method, appears to give about 0.1°C accuracy. Overall accuracy of system not yet known.
- "Meteorological" Data - Method and placement of air temperature readout. (Describe as for soil temperature, unless identical to or part of soil temperature readout.) - Are any other meteorological variables monitored (eg. humidity)? If so, describe system used.	Identical to, and part of soil temperature readout. Humidity is not monitored.
- Soil Moisture - Describe any systems used to monitor soil moisture (eg. pore pressure transducers, suction gauges, electrical methods); method of readout and data reduction, etc. - Can water movement be measured to any degree?	12 Tensiometers read using water filled liner, and mercury manometer. Tips are (approx) 2 cm x 8 cm long. Several open standpipes are present in silt and sand layers. Water input monitored during addition to base acquifer system. Density can be monitored using radio-active source method.

* SMT=Societé Micro-Informatique Telecommunications, a French National Company.

4.4 Data Aquisition Systems Continued ...

- Soil Movement - Describe systems for monitoring heave, settlement of soil, road beds, pipes, etc. and method of reducing data. - Can both vertical and horizontal movement be measured? - What is used as a reference mark (bench mark) for movement? (If variable, or different for horizontal/vertical movement, describe each.)	Threaded nuts were fixed to the pipe and protected by plastic inserts. These were later exposed by augering, and a threaded rod and plastic sleeve were attached. Tilt of the pipe may also be checked by attaching a shoe to the top of the heave rod, and using a sensitive tilt meter to monitor changes in slope of the pipe. Reference mark is a bench at the entrance of the room on which a survey instrument is placed. No horizontal motion is monitored. Soil surface movement is observed by surveying a grid of pins driven flush with the soil surface on a grid system.
- Other - Are any other variables monitored (eg. pipe strains, earth pressures, heat fluxes)? If so, describe how data is recorded, stored, etc.	30 electrical strain gauges are bonded to the pipe, and are read by the data acquisition system. Several vertical and horizontal TDR devices have been installed by Carlton personnel to observe changes in liquid water content. These are read manually using the usual device for recording changes in dielectric constant. Four sets of soil strain gauges (such as those used by Prof. Mackay for measuring frozen soil strains in the Canadian Arctic) are installed. These use a set of 10 telescoping rods. These are currently read using a mm scale, however, some more accurate method of observing the relative movement of gauge pairs may be introducted. Earth pressures are measured at 14 locations using Gloetzl cells. None, however, are present above the pipe to record frozen soil uplift resistance. These are read by a valved manifold to the usual Gloetzl cell readout. Soil strains are also measured using a Caesuim source ("double-sond") to locate buried plastic plates. The absolute accuracy of locating each buried plate is hoped to be better than 5 mm.

5.0 OPERATIONAL HISTORY

5.1 Length - How long has facility been operating? Have any major changes occured in this time? (eg. Who uses or runs the facility, major construction changes?)	Operated several years ago as a road test bed facility. Currently, the facility has been occupied for about 6 months, in preparation for the first test, projected to start in September.

5.2 Applications
 	
- Describe a number of experiments that have taken place over the past few years. Include:
  - Duration of experiment (include preparation time)
  - Type of experiment (eg. road, foundation, slope, etc.)
  - Purpose of experiment
  - Which part of facilities were used
  - Type of data recorded
  - Result of study (eg. papers published on work, that can be looked at, etc.)
  - Suitability of various control and data systems
  - Problems with systems used
  - Would any additional control systems or data systems have been beneficial (made things easier, or provided helpful data)
	Present test under preparation, and no published results are available yet. Hardy Associates were given a report containing a pictorial record of early installation of the soil and pipe, entitlted "Compartment des conduites enterres soumises a des temperatures negatives", a report by Carlton University (under contract to the Depart. of Energy, Mines and Resources) and the Centre National de la recherche scientifique.
	
	Additional instrumention such as (a) a more complete array of thermistors, (b) earth pressure cells above the pipe would have added considerably to the quality of data acquisition.

5.3 Facility Demand - Which portions of facility are most often used?	The associated tanks for sloping soil conditions have not been in use for some time. The primary facility where the pipeline is now located, lay empty for several years until the present Franco-Canadian contract.

5.3 Facility Demand Continued ...	
- For a multi-pit facility, which pits are in use the most?	n/a
- For individual pits, which control systems, data aquisition capabilities, etc. are used most often?	unknown as yet
- If any portions are under-used, is this problem due to lack of demand, or reliability problems, or unsuitability of control or data systems?	n/a
- For fully utilized facilities, is there demand for additional capacity (more or large pits, another building, more features)?	likely not.
5.4 Maintenance	
- Schedules. What maintenance is carried out on fixed schedules (eg. monthly, semi-annually, at the end of each test, etc.)? What maintenance is carried out on an "as-required" basis (ie. if it breaks, fix it)? Describe for each system (environmental control, data aquisition, etc.). What is the down-time involved?	unknown
- Which systems require the most maintenance? Which systems are better than expected? Worse than expected?	Main freezers for room require regular defrosting of coils due to high humidity environment.
- Have maintenance requirements ever interfer ed with tests in progress? To what extent were the tests jeopardized?	n/a
- To what extent does maintenance or repair of one test pit or system affect the operation of other pits or systems? Can each system be repaired while keeping other systems running?	n/a
- What back-up systems are present (eg. refrigeration systems, power supplies for building, data aquisition system, etc.)? In retrospect, would any additional back-up systems be desirable?	There is some backup within the refrigeration system involving the two small (10 and 8 HP) compressors used to chill the room.

6.0 OPERATIONAL MANAGEMENT

6.1 Staffing. Number of full and part-time staff in the following categories (specify which are off-site): (a) scientific (b) technical support (eg. electrical, data aquisition, computer, construction, maintenance) (c) administrative support - Management hierarchy. Who controls what? Who decides which experiments are run, or who runs them? Are administrative and scientific authorities separate?	Two part-time directors (Williams and Fremond). Part-time administration by Messrs Faugere and Lautradou. Two full time technicians from French centre. Part-time support from Carlton on an as-required basis by up to 2 staff members or researchers. Presumably , the directors mentioned above set the long-range policies in consultation with their respective funding agencies.
6.2 Budget - What are typical operating costs for the facility? - Where does the money come from? - Is there basically one budgeting system, or do different aspects of the facility follow different budgeting schemes (eg. one group provides budget and support for overall facility, while individual groups or scientists provide budget for experiments)?	Costs for 1982 are approx. $500,000, with additional logistical and material support from the local French Institute. The money is derived $50,000 from EMR in Canada, and the remainder from the French CNRS.
6.3 Outside Support - Is facility basically self-contained (scientific, technical, administrative, and financial requirements)? - Do outside organizations provide support? Is providing support to this facility a major or minor role for them? - To what extent are the test facilities used by outside agencies (ie. is the facility operated for use by a number of "outside" agencies)?	see above see above see above

APPENDIX "B"

REPORT ON VISIT TO FACILITY

LOCATION: LAUSANNE, SWITZERLAND

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES
CGI4027

1.0 FACILITY IDENTIFICATION

Name of Facility:	Ecole Polytechnique Federale de Lausanne Dept. de Genie Civil, Laboratoire de Geotechnique
Location:	University of Dorigny, Lausanne, Switzerland
Full Address:	Ecole Polytechnique Federale de Lausanne CH.-1015, Lausanne, Switzerland
Director or Head:	Mr. Disli
Phone No./Telex:	41-21-472325
Hardy Associates Reporter:	J.F. Nixon
Date Visited:	July 1, 1982
Personnel Interviewed:	Mr. Disli

2.0 GENERAL FUNCTION OF FACILITY

- Operating organization	Laboratoire de Mechnique des Sols/Ecole Polytechnique Federale Lausanne
- Affiliated agencies (eg. government department, universities, research organizations) (groups that are involved in scientific aspects of work done at the facility)	Funding from Swiss Federal road fund
- External support organizations (eg. government, industry, universities) (groups which provide logistical or administrative support, or monetary support)	Institute has three functions, i.e. teaching, research and tests for industry. Research is funded by government and industry (i.e. through a road fund for research).
- Research interests of groups involved (major and minor) eg. foundations, pipelines, road beds/ pavements, geomorphologic processes, other	Main interest is roads, but pits can be used for other tests involving unfrozen soils.
- Is facility research-oriented or application-oriented? eg. A facility for development of new road bed materials would be application-oriented; a facility for analysis of periglacial slope formation would be research-oriented. (This would be important with regard to the range of experiments carried out.)	Research and application.
- To what extent is facility operated in conjunction with laboratory research facilities? Are there laboratories on site? separate?	Major geotechnical labs on site.
- Are experiments also carried out in an open air environment? (eg. micro-meterological stations, etc.)	In-situ experiments have gone on for 40 years on road construction materials, heave, etc.

3.0 GENERAL SIZE & SHAPE OF FACILITY & SUPPORT FUNCTIONS

- Total size of site (controlled environment building, offices, support structures for power supplies, cooling facilities, material storage, equipment storage, soil stockpiles, access and maneuvering areas)	Building 21 x 21.6 m^2, with extensive area around main structure for equipment, parking, stockpiles, etc.
- Note whether any of these are located off-site (eg. administrative offices) or in separate buildings on-site	Administrative building in adjacent institute.
- Note general site plan: relative locations of buildings, stockpiles, etc.	Stockpiles situated adjacent to main doors at one end of structure.
- Note proportions of space allocated to experiments, stockpiles, administration, control systems, etc.	Majority of space (approx. 70%) devoted to experiments. This was a problem, in fact, that more space was not available around experiments.
- Number and size of controlled environment buildings	One
- Total building size? construction methods/style?	Vertical steel I - beam with concrete/masonry walls
- Are control systems entirely contained in the building or housed separately?	In same building, but outside of control temperature area.
- Location and size of soil/material stockpiles - Are large quantities of soil or construction materials (eg. pipes, road materials) stored on site?	Several cubic metres of sandy gravel and a local silt are stored outside structure in open bins constructed from vertical steel beams and wood sleepers.
- If so, are they inside or outside? (Degree of protection from elements?)	Outside, no protection from elements.
- Can a large variety of materials be stored/handled?	Yes.
- Auxillary facilities - offices? labs? washrooms?	Two offices and one washroom within same building. Laboratory in adjacent institute.

4.0 DETAILS OF TESTING FACILITIES

4.1 Size and layout of test pits, environmental controls, data aquisition systems	21 x 21.6 m
- Number and size of test pits (note pits with special functions), size of rooms containing pits.	1. Rectangular Pit - 2 m x 20 m x 5 m wide 2. Cylindrical Pit - 5 m Ø x 8 m deep
- If more than one test pit, do test pits share control/data systems, or is each a stand-alone system?	
- How are test pits separated from each other? (separate rooms, partitions in one large room, in same room?) Can sizes be adjusted if necessary?	The rectangular pit is covered with an insulated 2 m cover. The freezing pit can be subdivided with steel walls slotted into sides in concrete walls.
- Where are control and data aquisition systems located in relation to test pits? How much room is required for them?	The control and data acquisition system is located in a polythene covered shack in main test area.
4.2 Materials Handling Systems	
- How are soils, road beds, pipelines or whatever installed in pits? Note whether mobile equipment is required (and where is it stored), whether fixed equipment is present (eg. overhead crane in testing area).	Soils are dumped at edge of pit, and moved around using small bucket, suspended from an overhead crane (capacity = 800 litre).
- Is special handling of soils in test pits required due to pit lining materials (eg. insulation) control systems, or data sensors?	Geotextile to separate gravel from silt. Small dynamic compacter densifies soils which are raised in 20 cm lifts.
- How are materials removed from test pits? How are they disposed of?	A loader and the overhead bucket are used to remove the materials.
- Note size and location of access doors, approach ramps, etc.	Access doors are 7 m high and 10 m wide (approx), and are present at both ends of the structure.
- How is soil compacted? What controls are maintained on bulk density, soil uniformity, etc? Can soil be layered?	

4.2 Materials Handling Systems (Continued)...	
- What time is involved in installing, compacting, and removing soil and other materials?	Several weeks required for placement and set-up. Each freeze thaw cycle subsequently takes 60 - 90 days.
4.3 Environmental Control Systems	
- Air Temperature Control	$-20^{o}C$ to $+30^{o}C$ in rectangular pit, and remainder of room is at $+20^{o}C$.
- Range of possible air temperatures, accuracy of control (note if this differs from pit to pit).	80,000 cal/hour maximum.
- Refrigeration requirements (capacity for each pit, or total if all on one system).	Two compressors, 100 kW for both.
- Refrigeration hardware description.	
- Method of temperature control (eg. continuous cooling with heat added to control temperature; or cycling between heating and cooling).	Three thermometers sense temperature. Photo cells $\pm$ $1^{o}C$. Heating circuit to warm air in cabinet.
- Type and placement of building or room insulation.	Cam follows a programmed pattern of termperature control. 8 cm styrofoam in walls and ceiling.
- Backup systems? Number of failures? Reliability?	De-icing of refrigeration coils with warm water for 5 min each hour.
- Humidity or any other variable controlled?	NO
- Pipe Temperature Control	
- Is separate control provided for such things as pipes?	No pipes
- If so, describe as for Air Temperature.	

4.3 Environmental Control Systems Continued ...

- Soil Temperature Control - Is additional temperature control available in soil (especially at the base)? If so, describe methods, reliability, degree of control, system capacity, range of temperatures possible, location, etc. - Is base of soil pit insulated? (type and thickness)	Base temperature control is available for the rectangular pit to maintain constant temperature over a range $-10^{\circ}C$ to $+20^{\circ}C$. Same system using Freon for air temperatures, and Gylcol system for soil base. 8 cm styrofoam
- Local Heating/Cooling - Are methods available to heat or cool small local areas of soil? If so, describe size, method, degree and range of control, heating/cooling capacity, placement, etc.	Yes, see above.
- Soil Moisture - Are systems available to control soil moisture during a test? (eg. base drainage, base or surface infiltration) Note degree of control, whether or not changes can be made during test, whether different areas can be provided with water, uniformity at application, etc.	8 cm of gravel, with about 10 pipes, 4 m spacing. Water is maintained 1.5 m below road surface.
- Slope - What methods are available for controlling slope? Note angles of slope possible, whether slope can be changed during test, etc. (If pit slope cannot be adjusted, perhaps, pit is deep enough to allow construction of slopes?) Describe system, ie. total weight elevated, lifting system.	NO.

4.4 Data Aquisition Systems

- Temperatures (soil) - Number and type of sensors (eg. thermistors, platinum resistance sensors, thermocouples) - Manual or automatic readout - Method or reduction and storage - Placement of sensors, grouping, etc. - Time involved in getting reduced data - Calibration methods for sensors - Accuracy and precision of sensors, readout system, calibration system.	Approx. 40 thermistors, and removeable probe also. Thermistors are PT-100 (common in Switzerland) whose resist = 100 Ω at 0°C. 1 m.A is passed thru bead, and it is read with a voltmeter. Accuracy is rated at ± 0.3°C, and a four wire readout is necessary. Grouping as shown in report. Sensor cables exit in plastic conduit, and are sealed on entry to conduit. Automatic data acquisition, all measurements plotted in near real time (1-day lag time). Temperature profiles are plotted by computer. Profile is tracked on same plot, as desired selected times. Data stored on hard disk. Data logged on Schumberger (300 channels), and a tape is transferred to computer (PDP/1134) Thermistors rated at ± 0.3°C.
- "Meteorological" Data - Method and placement of air temperature readout. (Describe as for soil temperature, unless identical to or part of soil temperature readout.) - Are any other meteorological variables monitored (eg. humidity)? If so, describe system used.	As above. Measured at 4 points with insulated cover over freezing section. Humidity using a gauge.
- Soil Moisture - Describe any systems used to monitor soil moisture (eg. pore pressure transducers, suction gauges, electrical methods); method of readout and data reduction, etc. - Can water movement be measured to any degree?	10 soil tensiometers to measure the distance in the phreatic surface. Two Gloet piezometers are used in addition to tensiometers to monitor phreatic surface. Use nuclear method to monitor water content in two holes. Troxxler measurement using "double-sand." Also recover samples for oven drying.

4.4 Data Aquisition Systems Continued ...

- Soil Movement - Describe systems for monitoring heave, settlement of soil, road beds, pipes, etc. and method of reducing data. - Can both vertical and horizontal movement be measured? - What is used as a reference mark (bench mark) for movement? (If variable, or different for horizontal/vertical movement, describe each.)	Surface of bituminous section is monitored on a grid system using a level. No horizontal motion is monitored.
- Other - Are any other variables monitored (eg. pipe strains, earth pressures, heat fluxes)? If so, describe how data is recorded, stored, etc.	15 Gloetzl cells measure earth pressures, and about 3 "Cambridge" pressure cells to measure normal and shear stresses in the ground. Magnetic "Bison" cells made in Minneapolis, (readout costs about $5,000) are used in sets of 6, spaced at 30 cm, to accuracy of 0.1 mm (Mr. Dysli) British TRRL soil strain gauges are used in bitumen layers. Four boreholes taken with samples. Can do TRRL type freezing tests in separate laboratory. (See Figures B.1, B.2 & B.3 for details on instrumentation lay-outs, etc.)

5.0 OPERATIONAL HISTORY	
5.1 Length	
- How long has facility been operating? Have any major changes occured in this time? (eg. Who uses or runs the facility, major construction changes?)	3 years.
5.2 Applications	
- Describe a number of experiments that have taken place over the past few years. Include:	Two major experiments in 3 years. In first series, 7 freeze-thaw cycles were completed. The second series is just beginning. About 3 months per cycle is required. The top is maintianed at 20°C before the start of the test.
- Duration of experiment (include preparation time)	
- Type of experiment (eg. road, foundation, slope, etc.)	
- Purpose of experiment	Repeated loading, traffic simulator effects.
- Which part of facilities were used	
- Type of data recorded	
- Result of study (eg. papers published on work, that can be looked at, etc.)	See report from Institute given to Hardy Associates
- Suitability of various control and data systems	The soil selected was difficult to work with. Water content measurements, and lateral soil insulation. Lateral insulation should be increased. Tensiometers when frozen would break. Solved this by saturating with a 50% glycol mixture.
- Problems with systems used	
- Would any additional control systems or data systems have been beneficial (made things easier, or provided helpful data)	
5.3 Facility Demand	The rectangular frost bed has been most often used.
- Which portions of facility are most often used?	

5.3 Facility Demand Continued ...

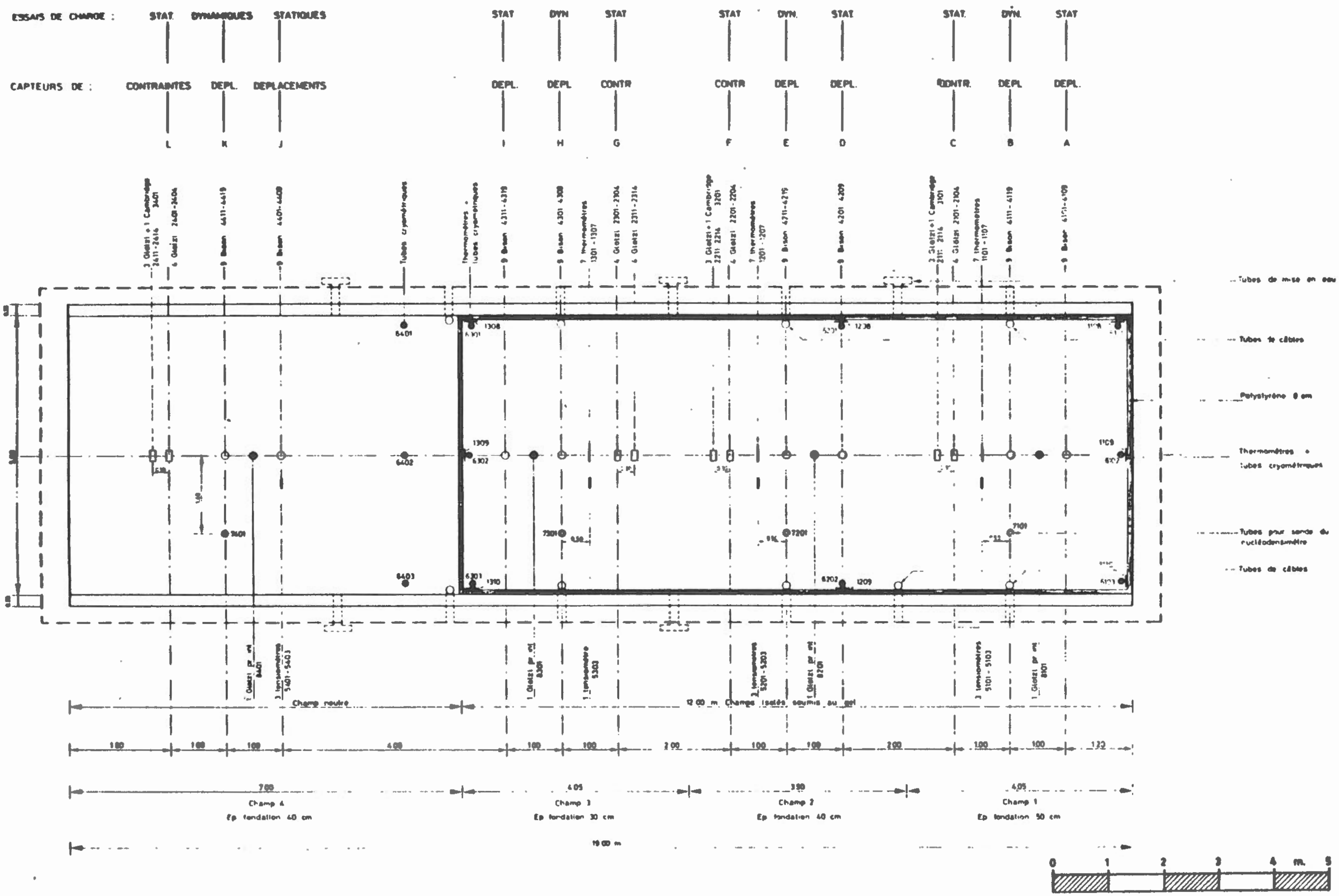
- For a multi-pit facility, which pits are in use the most?	Rectangular road test pit.
- For individual pits, which control systems, data aquisition capabilities, etc. are used most often?	-
- If any portions are under-used, is this problem due to lack of demand, or reliability problems, or unsuitability of control or data systems?	Cylindrical pit is used only for tests in unfrozen soil to the present.
- For fully utilized facilities, is there demand for additional capacity (more or large pits, another building, more features)?	Possibly, additional size or sc ope in 5 years or so.

5.4 Maintenance

- Schedules. What maintenance is carried out on fixed schedules (eg. monthly, semi-annually, at the end of each test, etc.)? What maintenance is carried out on an "as-required" basis (ie. if it breaks, fix it)? Describe for each system (environmental control, data aquisition, etc.). What is the down-time involved?	Building is under general maintenance of the Ecole. Contractor retained to respond at irregular intervals as required. Computer and instruments are maintained regularly by the personnel at the facility.
- Which systems require the most maintenance? Which systems are better than expected? Worse than expected?	Two compressors operating in parallel provide the refrigeration capacity. Some back-up and redundancy exist therefore, as each compressor can operate independently of the other.
- Have maintenance requirements ever interfer ed with tests in progress? To what extent were the tests jeopardized?	
- To what extent does maintenance or repair of one test pit or system affect the operation of other pits or systems? Can each system be repaired while keeping other systems running?	
- What back-up systems are present (eg. refrigeration systems, power supplies for building, data aquisition system, etc.)? In retrospect, would any additional back-up systems be desirable?	

6.0 OPERATIONAL MANAGEMENT

6.1 Staffing. Number of full and part-time staff in the following categories (specify which are off-site): (a) scientific (b) technical support (eg. electrical, data aquisition, computer, construction, maintenance) (c) administrative support	1 senior engineer, 2 technicians and Mr. Disli (20% of the time) as director. Also extra help during soil placement (i.e. contractor). Secretary is required part-time together with drafting and computing support.
- Management hierarchy. Who controls what? Who decides which experiments are run, or who runs them? Are administrative and scientific authorities separate?	The civil engineering department presents a proposal to the Swiss Road Fund, and they agree or disagree.
6.2 Budget	
- What are typical operating costs for the facility?	Initial captial cost was about 2 m $. The cost of the first 7 freeze thaw cycles cost 0.5 m$ over 2 years.
- Where does the money come from?	
- Is there basically one budgeting system, or do different aspects of the facility follow different budgeting schemes (eg. one group provides budget and support for overall facility, while individual groups or scientists provide budget for experiments)?	
6.3 Outside Support	
- Is facility basically self-contained (scientific, technical, administrative, and financial requirements)?	Facility is self-contained scientifically, administratively and technically, through the adjacent Ecole Polytechnique. Financially, it relies on outside support.
- Do outside organizations provide support? Is providing support to this facility a major or minor role for them?	Through industry using a Federal road fund.
- To what extent are the test facilities used by outside agencies (ie. is the facility operated for use by a number of "outside" agencies)?	NO.



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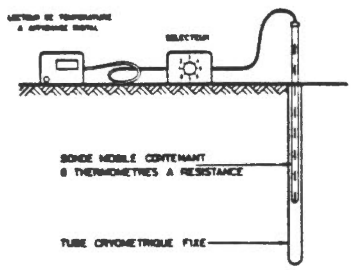
PLAN LAYOUT OF INSTRUMENTATION IN RECTANGULAR PIT-LAUSANNE, CH.

CG14027

FIGURE B.1

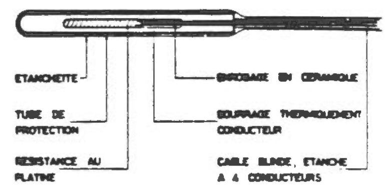
CRYOMETRE WYBO

MESURE DES TEMPERATURES DU SOL A L'AIDE D'UNE SONDE MOBILE

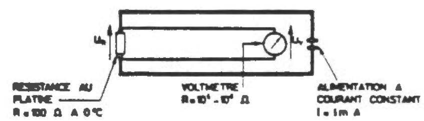


LA SONDE CRYOMETRIQUE MOBILE PERMET D'OBSERVER IMMEDIATEMENT LE PROFIL THERMIQUE DU TERRAIN A CHAQUE EMPLACEMENT DE TUBE

THERMOMETRE A RESISTANCE



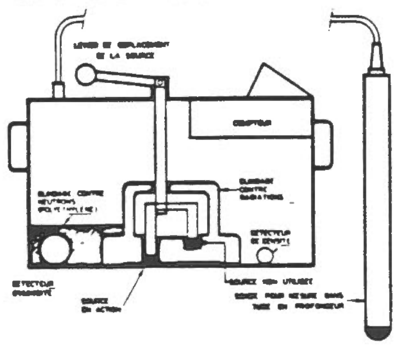
SCHEMA ELECTRIQUE -



$U_R = U_V$ CAR LA RESISTANCE ET LE VOLTMETRE SONT MONTES EN PARALLELE
LA RESISTANCE, DONC LA TENSION, VARIE AVEC LA TEMPERATURE
PRECISION A 0°C : ± 0,1 Ω ⟶ ± 0,3 °C

NUCLEO - DENSIMETRE

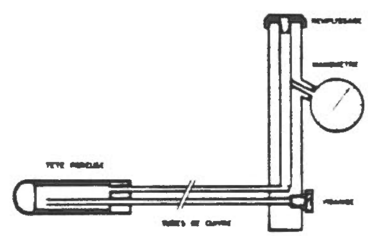
MESURES DE DENSITE ET D'HUMIDITE PAR RADIATIONS



LA SOURCE RADIOACTIVE AU RADIUM - BERYLLIUM EMET DES RAYONS γ ET DES NEUTRONS CEUX-CI SONT REFLECHIS PAR LE SOL HUMIDE.

LA MESURE DES RAYONS γ REEMIS DONNE LA DENSITE DU SOL. LA MESURE DES NEUTRONS DONNE LA TENEUR EN EAU.

TENSIOMETRE



PRINCIPE DE FONCTIONNEMENT

LA TETE POREUSE ET LES CONDUITES SONT SATUREES D'EAU ET PURGEES DE TOUTES BULLES D'AIR. LA TETE EST ALORS PLACEE DANS LE SOL.

SI LE SOL EST SATURE, L'EQUILIBRE N'EST PAS MODIFIE SI PAR CONTRE LE SOL N'EST PLUS SATURE, LA DEPRESSION CAPILLAIRE AUTOUR DE LA TETE POREUSE PROVOQUE UNE DEPRESSION MESUREE AU MANOMETRE

ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE

Département de génie civil

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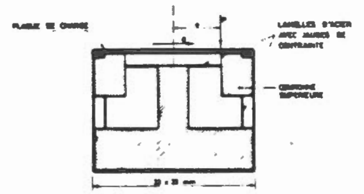
SOIL INSTRUMENTATION IN RECTANGULAR PIT - LAUSANNE, CH.

CG14027

FIGURE B.2

CAPTEUR DE CONTRAINTES CAMBRIDGE

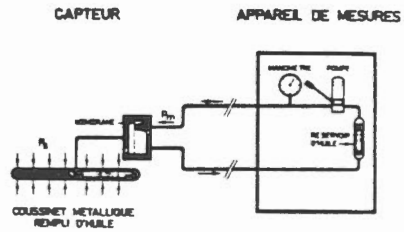


PRINCIPE DE FONCTIONNEMENT :

LA CHARGE APPLIQUEE SUR LA PLAQUE DE CHARGE PRODUIT UNE DEFORMATION DES JAUGES DE CONTRAINTES COLLEES SUR LES LAMELLES D'ACIER ET EN CONSEQUENCE MODIFIE LEUR RESISTANCE. AVEC UNE ALIMENTATION A COURANT CONSTANT LA MESURE DES VARIATIONS DE TENSION DONNE, PAR L'INTERMEDIAIRE DE COEFFICIENTS D'ETALONNAGE, LES EFFORTS APPLIQUES.

L'ENSEMBLE DU CAPTEUR EST TAILLE DANS UN BLOC D'ACIER.

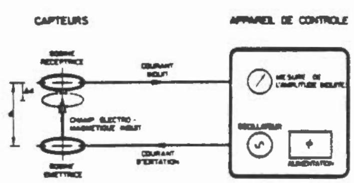
CAPTEUR DE PRESSION GLÖTZL



PRINCIPE DE FONCTIONNEMENT

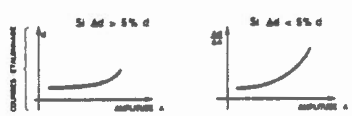
LA PRESSION EXERCEE PAR LE SOL SUR LE CAPTEUR FERME LE CIRCUIT D'HUILE EN POUSSANT LA MEMBRANE JUSQU'A CE QUE $P_m = P_s$. L'AIGUILLE DU MANOMETRE S'ARRETE ALORS SUR LA VALEUR $P_m = P_{sol}$.

CAPTEURS MAGNETIQUES DE DEPLACEMENTS



PRINCIPE LA VARIATION DE DISTANCE DES BOBINES PROVOQUE UNE VARIATION DU COURANT INDUIT

. ON UTILISE LE CHANGEMENT D'AMPLITUDE DU COURANT INDUIT POUR DETERMINER LE DEPLACEMENT DES BOBINES A L'AIDE DE COURBES D'ETALONNAGE PREALABLEMENT ETABLIES



NOTE : THESE ARE "BISON" GAUGES AVAILABLE FROM McPHAR, WILLOWDALE, ONT.

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SOIL INSTRUMENTATION IN RECTANGULAR PIT — LAUSANNE, CH.

CG14027

FIGURE B.3

APPENDIX "C"

REPORT ON
VISIT TO FACILITY

LOCATION: USA CRREL Hanover, N.H.

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES
CG14027

1.0 FACILITY IDENTIFICATION

Name of Facility:	USA CRREL Frost Effects Research Facility (FERF)
Location:	Hanover, N.H.
Full Address:	U.S. Army Cold Regions Research and Engineering Laboratory Hanover, N.H. 03755
Director or Head:	Richard Berg
Phone No./Telex:	603-643-3200
Hardy Associates Reporter:	D. Halliwell
Date Visited:	June 24, 1982
Personnel Interviewed:	R. Berg Pete Smallidge 603-643-3200 Ext. 414

2.0 GENERAL FUNCTION OF FACILITY

- Operating organization	U.S. Army Corps of Engineering (facility under construction)
- Affiliated agencies (eg. government department, universities, research organizations) (groups that are involved in scientific aspects of work done at the facility)	
- External support organizations (eg. government, industry, universities) (groups which provide logistical or administrative support, or monetary support)	Most money from Defence budget. Small projects sometime done for industry.
- Research interests of groups involved (major and minor) eg. foundations, pipelines, road beds/pavements, geomorphologic processes, other	Originally for pavements, added separate utilities, foundations, dynamics, too expensive, went to single main building.
- Is facility research-oriented or application-oriented? eg. A facility for development of new road bed materials would be application-oriented; a facility for analysis of periglacial slope formation would be research-oriented. (This would be important with regard to the range of experiments carried out.)	
- To what extent is facility operated in conjunction with laboratory research facilities? Are there laboratories on site? separate?	On CRREL site. Backed up by total CRREL facilities (extensive).
- Are experiments also carried out in an open air environment? (eg. micro-meterological stations, etc.)	

3.0 GENERAL SIZE & SHAPE OF FACILITY & SUPPORT FUNCTIONS

- Total size of site (controlled environment building offices, support structures for power supplies, cooling facilities, material storage, equipment storage, soil stockpiles, access and maneuvering areas)	See attached summary description.
- Note whether any of these are located off-site (eg. administrative offices) or in separate buildings on-site	
- Note general site plan: relative locations of buildings, stockpiles, etc.	
- Note proportions of space allocated to experiments, stockpiles, administration, control systems, etc.	
- Number and size of controlled environment buildings	One, see attached description summary.
- Total building size? construction methods/style?	Sheet metal siding (insulated).
- Are control systems entirely contained in the building or housed separately?	Contained in building.
- Location and size of soil/material stockpiles	There will be limited stockpiling capability on pads at either end of the building. The ATCO building may eventually be relocated to the FERF site for storage/ protection of materials. (No plans to do so at present.) ATCO building has been used mainly for pavement design.
- Are large quantities of soil or construction materials (eg. pipes, road materials) stored on site?	
- If so, are they inside or outside? (Degree of protection from elements?)	
- Can a large variety of materials be stored/handled?	
- Auxillary facilities - offices? labs? washrooms?	Washrooms and locker rooms.

4.0 DETAILS OF TESTING FACILITIES

4.1 Size and layout of test pits, environmental controls, data aquisition systems

- Number and size of test pits (note pits with special functions), size of rooms containing pits.	See attached description summary.
- If more than one test pit, do test pits share control/ data systems, or is each a stand-alone system?	Individual control from central console. Test instrumentation may be separate.
- How are test pits separated from each other? (separate rooms, partitions in one large room, in same room?) Can sizes be adjusted if necessary?	Separation by wooden bulkheads. Construction of partitions possible in future. Sizes limited to incremental cell sizes.
- Where are control and data aquisition systems located in relation to test pits? How much room is rquired for them?	Bulkheads not impermeable. Will line cell with polyethylene if water table control is desired. Add riser pipes and maybe layer of second to distribute water. Each section has manually controlled drains. See drawings.

4.2 Materials Handling Systems

- How are soils, road beds, pipelines or whatever installed in pits? Not whether mobile equipment is required (and where is it stored), whether fixed equipment is present (eg. overhead crane in testing area).	Normal construction techniques will be used. Installation will probably be contracted to local construction firms. There will be some equipment storage space in the Vehicle Storage Building underway to the east of FERF. No crane is present in contract.
- Is special handling of soils in test pits required due to pit lining materials (eg. insulation) control systems, or data sensors?	No.
- How are materials removed from test pits? How are they disposed of?	Normal construction techniques. Materials disposed of by contractor offsite.
- Note size and location of access doors, approach ramps, etc.	See attached description summary.

- How is soil compacted? What controls are maintained on bulk density, soil uniformity, etc? Can soil be layered?	Normal construction techniques and testing. Rails on sides extending past ends of building. Will be able to carry load cart and equipment to move panels. (If and when money is available.) Pads on sides for load cart and panel removal equipment. For now, move panels by front end loader or other means (unsure).
- What time is involved in installing, compacting, and removing soil and other materials?	Estimate up to two weeks including time to place and remove instrumentation for a single cell. Additional cells done at same time would take much less time (month to 6 weeks to freeze soil (estimated).

4.3 Environmental Control Systems

- Air Temperature Control	See experimental capabilitues description.
- Range of possible air temperatures, accuracy of control (note if this differs from pit to pit).	Generally maintained slightly above 0°C. Soil surface temp. maintained by panels (below). Panels removed prior to running tests. Panels give much higher heat transfer, simple control for different test pits.
- Refrigeration requirements (capacity for each pit, or total if all on one system).	Pit to pit control only if partitions are constructed in the future. See drawings. Similar panels (smaller) used in ATCO building in past.
- Refrigeration hardware description.	See attached description summary.
- Method of temperature control (eg. continuous cooling with heat added to control temperature; or cycling between heating and cooling).	Cycle between hot and cold.
- Type and placement of building or room insulation.	Footings are insulated. Test cells to be insulated by user as required.
- Backup systems? Number of failures? Reliability?	There are back-up chillers and heat pumps. No operating experience.
- Humidity or any other variable controlled?	Basically only temp. Humidity will be limited in summer by HVAC system.

- Pipe Temperature Control

Soil surface Temp Control:

  - Is separate control provided for such things as pipes?

A heat transfer panel control system is provided. Panels are placed on soil surface to freeze soil. Separate control of each test cells is provided, see capabilities description and drawings.

  - If so, describe as for Air Temperature.

Three systems at -35, 10, 90°F. Desired temp will be maintained by adding sufficient coolant from one system to required panel circulation loop.

No definite plans at present to do pipeline experiments.

- Soil Temperature Control

  - Is additional temperature control available in soil (especially at the base)? If so, describe methods reliability, degree of control, system capacity, range of temperatures possible, location, etc.

See experimental capabilities description. Note special "permafrost" capabilities of Utilities Test Section.

  - Is base of soil pit insulated? (type and thickness)

Yes, in some areas. (Utilities section, walls between cells and instrumentation/pipe tunnels) (4-6" styrofoam).

- Local Heating/Cooling

  - Are methods available to heat or cool small local areas of soil? If so, describe size, method, degree and range of control, heating/cooling capacity, placement, etc.

May be possible, but heat transfer panel controls will have to be modified.

- Soil Moisture

  - Are systems available to control soil moisture during a test? (eg. base drainage, base or surface infiltration) Note degree of control, whether or not changes can be made during test, whether different areas can be provided with water, uniformity at application, etc.

Yes, see drawings. Water spigots (frost proof) and under-drains connected to water monitoring pits are available. Cell walls are waterproof but wood bulkheads between cells will have to be sealed by user.

- Slope

  - What methods are available for controlling slope? Note angles of slope possible, whether slope can be changed during test, etc. (If pit slope cannot be adjusted, perhaps, pit is deep enough to allow construction of slopes?) Describe system, ie. total weight elevated, lifting system.

    Should be possible within limitations of construction equipment. The larger Test Basins (37' x 21' x 12' deep) would be adaptable for this. The floor angle is not adjustable.

4.4 Data Aquisition Systems

- Temperatures (soil)

  - Number and type of sensors (eg. thermistors, platinum resistance sensors, thermocouples)

    Not really firmed up at this time. See experimental capabilities.

  - Manual or automatic readout

    Mainly automatic anticipated, one central room for acquisition, cables from cells led via tunnels on sides.

  - Method or reduction and storage

  - Placement of sensors, grouping, etc.

  - Time involved in getting reduced data

  - Calibration methods for sensors

  - Accuracy and precision of sensors, readout system, calibration system.

- "Meteorological" Data

  - Method and placement of air temperature readout. (Describe as for soil temperature, unless identical to or part of soil temperature readout.)

    See above.

  - Are any other meteorological variables monitored (eg. humidity)? If so, describe system used.

- Soil Moisture

  - Describe any systems used to monitor soil moisture (eg. pore pressure transducers, suction gauges, electrical methods); method of readout and data reduction, etc.

    See above.

  - Can water movement be measured to any degree?

    Water flow from floor drains can be measured in water monitoring pits. (Total drainage.) Some cells with side ports may be modified for drainage at sides.

- Soil Movement

  - Describe systems for monitoring heave, settlement of soil, road beds, pipes, etc. and method of reducing data.

    See above.

  - Can both vertical and horizontal movement be measured?

  - What is used as a reference mark (bench mark) for movement? (If variable, or different for horizontal/vertical movement, describe each.)

- Other

  - Are any other variables monitored (eg. pipe strains, earth pressures, heat fluxes)? If so, describe how data is recorded, stored, etc.

    See above.

5.0 OPERATIONAL HISTORY

5.1 Length

- How long has facility been operating? Have any major changes occured in this time? (eg. Who uses or runs the facility, major construction changes?)	Presently under construction.

5.2 Applications

- Describe a number of experiments that have taken place over the past few years. Include:	Step plan for equipment scheduled to be ready by October.

- Duration of experiment (include preparation time)
- Type of experiment (eg. road, foundation, slope, etc.)
- Purpose of experiment
- Which part of facilities were used
- Type of data recorded
- Result of study (eg. papers published on work, that can be looked at, etc.)
- Suitability of various control and data systems
- Problems with systems used
- Would any additional control systems or data systems have been beneficial (made things easier, or provided helpful data)

5.3 **Facility Demand**

- Which portions of facility are most often used?

  - For a multi-pit facility, which pits are in use the most?

  - For individual pits, which control systems, data aquisition capabilities, etc. are used most often?

  - If any portions are under-used, is this problem due to lack of demand, or reliability problems, or unsuitability of control or data systems?

- For fully utilized facilities, is there demand for additional capacity (more or large pits, another building, more features)?

5.4 **Maintenance**

- Schedules. What maintenance is carried out on fixed schedules (eg. monthly, semi-annually, at the end of each test, etc.)? What maintenance is carried out on an "as-required" basis (ie. if it breaks, fix it)? Describe for each system (environmental control, data aquisition, etc.). What is the down-time involved?

  Maintenance schedules will be per Corps of Engineers general guidance, plus manufacturer's recommendations and operators' experience once facility is operational.

- Which systems require the most maintenance? Which systems are better than expected? Worse than expected?

- Have maintenance requirements ever interferred with tests in progress? To what extent were the tests jeopardized?

- To what extent does maintenance or repair of one test pit or system affect the operation of other pits or systems? Can each system be repaired while keeping other systems running?

  The test cell temp control and piping systems can be isolated from main distribution systems for maintenance.

- What back-up systems are present (eg. refrigeration systems, power supplies for building, data aquisition system, etc.)? In retrospect, would any additional back-up systems be desirable?

  Main refrigeration components and some critical pumps have backups. No operational experience.

Frost Effects Research Facility

Experimental Capabilities

I Physical Plant

A. Size

1.	Pavements/Mobility Test Area (66 ft x 175 ft)	11,550
2.	Ramps	7,795
3.	Instrumentation Tunnel (8 ft x 218 ft)	1,745
4.	Pipe Tunnel (7 ft x 175 ft)	1,225
5.	Instrumentation/Operations Room (16 ft x 30 ft)	480
6.	Mechanical Equipment Rooms & Misc.	6,455
		29,250 SF Gross

B. Pavements/Mobility Test Area (P/M Area)

1. General

   a. A large open test area with a 24 foot wide mobilization aisle on its west side and enclosed ramps on the north and south ends for construction equipment access. A working clearance of 22 feet is provided throughout the P/M Area.

2. Test Basins

   a. Soil freeze/thaw from top surface only.

   b. Size: 37 ft x 21 ft x 11 ft deep.

   c. Quantity: 4

   d. Floor drains: one per basin.

3. Test Cells

   a. Soil freeze/thaw from top surface only, except in Utilities Section.

   b. Size: 25 ft x 21 ft x 8 ft deep.

   c. Quantity: 8

d. Floor drains: one per cell except Utilities Area which has two per cell.

e. Cells TC-1 and TC-2 are constructed without concrete floors.

f. Cells TC-7 and TC-8 serve as a Utilities Test Section.

4. Utilities Test Section

a. Soil freeze/thaw from top, sides, and bottom. Top surface has separate temperature control from the sides and bottom. This section will be able to simulate permafrost-type conditions.

b. Size: Cells TC-7 and TC-8 are divided into eight sub-sections, 12 1/2 ft x 10 ft x 8 ft deep each. A temporary wall is provided to separate the east and west halves of the test section.

c. Floor drains: One per pair of subsections.

5. Bulkheads

a. Stacked timbers used to separate Test Basins and Test Cells. Sealed water tight by user as necessary.

b. Size: Nominal 8 inch x 12 inch x 21 foot long timbers to construct 8 ft high bulkhead and nominal 8 inch x 12 inch x 43 foot long timers to construct 12 foot high bulkhead.

c. Quantity provided by construction contractor: Timbers for 3 - 8 foot high x 21 foot long bulkheads.

d. Additional requirement: Timbers for 7 - 8 foot high x 21 foot long bulkheads and 3 - 12 foot high x 43 foot long bulkheads.

6. Test Panels

a. Brine filled panels are used to freeze or thaw the soil in the test basins and cells. Surface panels for freezing soil are generally sized 4 feet by 10 feet with 18 panels required for each test basin and 12 panels required for each test cell. Special surface and vertical panels are provided for the Utilities Test Section. Panels are connected to the brine piping system with flexible hoses and quick disconnects.

b. Quantity provided by construction contractor:

Regular Surface Panels	-	12
Utilities Surface Panels	-	24
Utilities Vertical Panels	-	48

c. Additional requirement: Up to 132 regular surface panels.

C. Instrumentation Tunnel

1. Provides access for instrumentation and observation of test cells located on east side of P/M Area.

2. Instrumentation sleeves (6 inch diameter) are provided for each test basin or cell.

3. Monitoring pits are provided for measuring water flow from each test cell or basin.

4. Portholes for water level monitoring and general observation are provided on the wall of one test basin and one test cell in monitoring pits.

5. Unheated except for ventilation air brought in from ME Room.

D. Pipe Tunnel

1. Provides instrumentation access to west test cells and basins. Unheated.

E. Instrumentation/Operations Room

1. Provides general space for researchers and operators to monitor and control tests and general plant functions. All plant functions including test cell and P/M room air temperature control will be operated from a automatic control processor located in this room. The Instrumentation Room will be heated and air conditioned to 70°F with 50% rh. A computer room type floor is provided with cable chases leading to the Instrumentation Trench.

II. Mechanical Plant Capabilities

A. General

1. A central refrigeration and heating plant will provide all heating and cooling required by the FERF. The plant will supply 65% glycol and water brine at three temperatures, -35°F, +10°F, and +90°F as necessary to meet test requirements and building heating and cooling needs. The -35°F and +10°F temperature brine will be produced by low and medium temperature chillers using well water for heat rejection. The +90°F temperature brine will be produced by heat pumps using the waste well water as a heat source. The system will be interconnected through three storage tanks, piping, pumps, and controls to provide brine to the test panels for freezing or thawing soil and to the P/M Area air handlers for maintaining test room air temperatures.

B. Test Panel System

1. The Test Panels will be used to freeze or thaw soils in the test basins and cells. The panels are placed on the soil and connected to the brine system. A test temperature is selected at the operator's console and the refrigeration system will automatically provide that temperature to the test panels.

2. Brine Temperatures: Three temperatures are available, -35°F, +10°F, and +90°F. The automatic control system will select the appropriate brine loop to achieve the required temperature.

3. Panel Temperature Tolerance: ±2°F over the entire test cell for temperature from -35°F to +90°F.

4. Soil Freeze/Thaw Rates (Estimated)

   See Table 1.

5. Total Soil Freeze/Thaw Capacity: The refrigeration equipment is sized so that one half of the P/M Area surface (i.e.: 2 test basins and 4 test cells) can be frozen or thawed at one time. An exception to this is that if the whole Utilities Test Section is being operated, this section requires the full plant capacity for freezing or thawing as appropriate. Also, up to six tests with different temperature requirements can be conducted at a given time.

C. Heating, Ventilating and Air Conditioning System, P/M Area

1. Temperature control: +25°F to +75°F +5°±.

2. Humidity control: Summer, 50% rh; Winter, no additional control.

3. Pull down capability: +75°F to +25°F in 24 hours.

4. Vehicle Exhaust System: An exhaust system is provided for operation of one vehicle when P/M Area is being cooled and doors are closed. Connection from the vehicles exhaust to the floor intake port is required.

III. Instrumentation

A. General

Instrumentation for the FERF will be furnished based on the detailed requirements of the research programs utilizing the facility. Minimum instrumentation anticipated includes automatic data logging over long time periods and ability to make some test change decisions based on data received through the use of small computers or controllers. Printing and graphing capability is also anticipated.

APPENDIX "D"

REPORT ON VISIT TO FACILITY

LOCATION: Tomomakai, Hokkaido, Japan

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CG14027

1.0 FACILITY IDENTIFICATION

Name of Facility:	Tomokamai Frost heave facility
Location:	Tomokamai experimental forest, Hokkaido, Japan
Full Address:	C/O Prof. Kinosita, Institute of Low Temp. Science, Hokkaido Univ., Sapporo, Japan
Director or Head:	Prof. S. Kinosita
Phone No./Telex:	81-011-711-2111 (Hokkaido Univ.)
Hardy Associates Reporter:	J.F. Nixon
Date Visited:	July 22, 1982
Personnel Interviewed:	Prof. Kinosita, Dr. M. Fukuda, Dr. Suzuki, Dr. Horiguchi and others

2.0 GENERAL FUNCTION OF FACILITY

- Operating organization	Hokkaido University, and graduate students
- Affiliated agencies (eg. government department, universities, research organizations) (groups that are involved in scientific aspects of work done at the facility)	
- External support organizations (eg. government, industry, universities) (groups which provide logistical or administrative support, or monetary support)	Government Ministry of Education
- Research interests of groups involved (major and minor) eg. foundations, pipelines, road beds/ pavements, geomorphologic processes, other	Frost heave and geomorphologic processes
- Is facility research-oriented or application-oriented? eg. A facility for development of new road bed materials would be application-oriented; a facility for analysis of periglacial slope formation would be research-oriented. (This would be important with regard to the range of experiments carried out.)	Research oriented
- To what extent is facility operated in conjunction with laboratory research facilities? Are there laboratories on site? separate?	Closely; adjacent laboratory at test site does classification tests, and specialized cold rooms in Sapporo provide more extensive testing support. The adjacent university Forest research centre provides micro-met data.
- Are experiments also carried out in an open air environment? (eg. micro-meterological stations, etc.)	

3.0 GENERAL SIZE & SHAPE OF FACILITY & SUPPORT FUNCTIONS

- Total size of site (controlled environment building, offices, support structures for power supplies, cooling facilities, material storage, equipment storage, soil stockpiles, access and maneuvering areas) - Note whether any of these are located off-site (eg. administrative offices) or in separate buildings on-site - Note general site plan: relative locations of buildings, stockpiles, etc. - Note proportions of space allocated to experiments, stockpiles, administration, control systems, etc.	Building and support structures for data acquisition, office, 4 beds, washroom and small lab is about $100m^2$, facilities themselves are outdoors. Four test beds are surrounded by stockpiles for soil
- Number and size of controlled environment buildings - Total building size? construction methods/style? - Are control systems entirely contained in the building or housed separately?	None. The support building is standard simple one-storey construction. Control systems are housed in the support building.
- Location and size of soil/material stockpiles - Are large quantities of soil or construction materials (eg. pipes, road materials) stored on site? - If so, are they inside or outside? (Degree of protection from elements?) - Can a large variety of materials be stored/handled?	Soil stockpiles are extensive. The soil is a local volcanic clast deposit, reworked by wind. It is a relative well graded material with a high silt content, that is very frost susceptible.
- Auxillary facilities - offices? labs? washrooms?	Yes, in support building described above.

4.0 DETAILS OF TESTING FACILITIES

4.1 Size and layout of test pits, environmental controls, data aquisition systems

- Number and size of test pits (note pits with special functions), size of rooms containing pits.
- If more than one test pit, do test pits share control/data systems, or is each a stand-alone system?
- How are test pits separated from each other? (separate rooms, partitions in one large room, in same room?) Can sizes be adjusted if necessary?
- Where are control and data aquisition systems located in relation to test pits? How much room is required for them?

Two 5X5mX2m deep square concrete pits. Two 3mX3mX1.8m pits. Separated by several m . Pits are filled by hand and conveyor equipment and compacted in 10-15 cm lifts by a small vibration compactor to a density of 1500 kg/m^3. The first two freezing reasons are generally ignored as the soil settles to a reasonable density. The last 3 years data provide the results for each 5 year cycle. All data acquisition located in a separate building 20-30 m away.

4.2 Materials Handling Systems

- How are soils, road beds, pipelines or whatever installed in pits? Note whether mobile equipment is required (and where is it stored), whether fixed equipment is present (eg. overhead crane in testing area).

A small conveyor is used to transport the material from stockpile to pit. There it is spread and compacted by hand methods. A 20 cm basal sand layer distributes water; there is no side insulation liners or in the base. Material is dug out by hand and loaded on the conveyor.

- Is special handling of soils in test pits required due to pit lining materials (eg. insulation) control systems, or data sensors?
- How are materials removed from test pits? How are they disposed of?
- Note size and location of access doors, approach ramps, etc.
- How is soil compacted? What controls are maintained on bulk density, soil uniformity, etc? Can soil be layered?

By hand vibratory compactor. Fairly low densities are attained, and the first 2 freezing seasons are used to densify the surface soils.

4.2 Materials Handling Systems (Continued)...	
- What time is involved in installing, compacting, and removing soil and other materials?	Several days per pit for 3-4 men
4.3 Environmental Control Systems	
- Air Temperature Control	
- Range of possible air temperatures, accuracy of control (note if this differs from pit to pit).	Ambient, Fr. Index = 600-700 ^{o}C-days.
- Refrigeration requirements (capacity for each pit, or total if all on one system).	None.
- Refrigeration hardware description.	----
- Method of temperature control (eg. continuous cooling with heat added to control temperature; or cycling between heating and cooling).	Ambient.
- Type and placement of building or room insulation.	----
- Backup systems? Number of failures? Reliability?	----
- Humidity or any other variable controlled?	----
- Pipe Temperature Control	
- Is separate control provided for such things as pipes?	----
- If so, describe as for Air Temperature.	----

4.3 Environmental Control Systems Continued ...

- Soil Temperature Control - Is additional temperature control available in soil (especially at the base)? If so, describe methods, reliability, degree of control, system capacity, range of temperatures possible, location, etc.	No base temperature control or insulation.
- Is base of soil pit insulated? (type and thickness)	----
- Local Heating/Cooling - Are methods available to heat or cool small local areas of soil? If so, describe size, method, degree and range of control, heating/cooling capacity, placement, etc.	No.
- Soil Moisture - Are systems available to control soil moisture during a test? (eg. base drainage, base or surface infiltration) Note degree of control, whether or not changes can be made during test, whether different areas can be provided with water, uniformity at application, etc.	20 cm base sand/gravel layer is connected to 15 cm riser to above soil surface. This is used to control water level in soil.
- Slope - What methods are available for controlling slope? Note angles of slope possible, whether slope can be changed during test, etc. (If pit slope cannot be adjusted, perhaps, pit is deep enough to allow construction of slopes?) Describe system, ie. total weight elevated, lifting system.	None.

4.4 Data Aquisition Systems

- Temperatures (soil) - Number and type of sensors (eg. thermistors, platinum resistance sensors, thermocouples) - Manual or automatic readout - Method or reduction and storage - Placement of sensors, grouping, etc. - Time involved in getting reduced data - Calibration methods for sensors - Accuracy and precision of sensors, readout system, calibration system.	24 bimetallic/strain gauge type temperature sensors. Heave is measured by dial gauges and automatically by heave sensor. Accuracy is claimed to be 0.5 ^{o}C. Readings are stored on a floppy disc, and transported to Sapporo every week for data reduction. Sensors are recalibrated each year in ice-water to counteract drift. Logger is Kyowa UCAM-5A with 64 channels.
- "Meteorological" Data - Method and placement of air temperature readout. (Describe as for soil temperature, unless identical to or part of soil temperature readout.) - Are any other meteorological variables monitored (eg. humidity)? If so, describe system used.	Standard met box with automated readout, using 12 channels of the acquisition system. Wind velocity, snow cover etc. are monitored by adjacent facility.
- Soil Moisture - Describe any systems used to monitor soil moisture (eg. pore pressure transducers, suction gauges, electrical methods); method of readout and data reduction, etc. - Can water movement be measured to any degree?	Soil water profile measured using neutron scattering device described later. Water suctions are measured using 12 tensiometers in mid-December of each year only. Water level is monitored using a water pressure transducer mounted in the base of the riser.

4.4 Data Aquisition Systems Continued ...

- Soil Movement	
- Describe systems for monitoring heave, settlement of soil, road beds, pipes, etc. and method of reducing data.	Buried heave plates measure heave every 5 cm interval to the base of the pit.
- Can both vertical and horizontal movement be measured?	No horizontal motion
- What is used as a reference mark (bench mark) for movement? (If variable, or different for horizontal/vertical movement, describe each.)	Gauges are referenced to a base gauge, which is anchored to the pit base.
- Other	
- Are any other variables monitored (eg. pipe strains, earth pressures, heat fluxes)? If so, describe how data is recorded, stored, etc.	Soil water content profile are measured using a neutron scattering probe. The source is Californium, 100 micro-curie intensity. The probe is lowered and raised automatically, controlled by the computer which records the reading, and the depth of the probe. Earth pressures (4 Kyowa cells per pit) are recorded electrically. Heat fluxes are measured at 20 cm intervals. (See Figure D.1 for instrumentation layout).

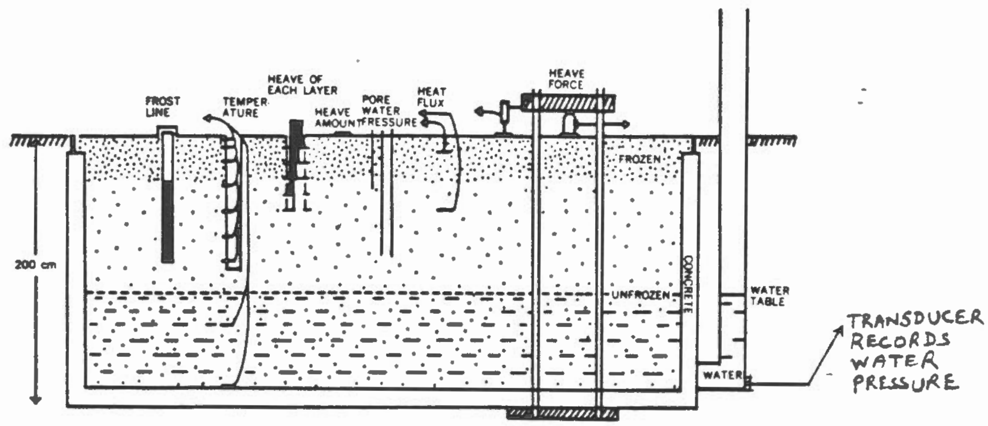
5.0 OPERATIONAL HISTORY

5.1 Length	
- How long has facility been operating? Have any major changes occured in this time? (eg. Who uses or runs the facility, major construction changes?)	15 years.
5.2 Applications	
- Describe a number of experiments that have taken place over the past few years. Include:	- about 12 experiments in 15 years.
- Duration of experiment (include preparation time)	- 5 years.
- Type of experiment (eg. road, foundation, slope, etc.)	- road/natural freezing.
- Purpose of experiment	- frost heave under natural conditions.
- Which part of facilities were used	- all.
- Type of data recorded	- temperatures, earth pressures, heave, water level.
- Result of study (eg. papers published on work, that can be looked at, etc.)	- several by Fukuda, see 3 rd Int'l. permafrost conf., for example.
- Suitability of various control and data systems	----
- Problems with systems used	- various recalibration of bimetallic/strain gauge temperature sensors is a major annual effort.
- Would any additional control systems or data systems have been beneficial (made things easier, or provided helpful data)	----
5.3 Facility Demand	
- Which portions of facility are most often used?	Same for 4 pits.

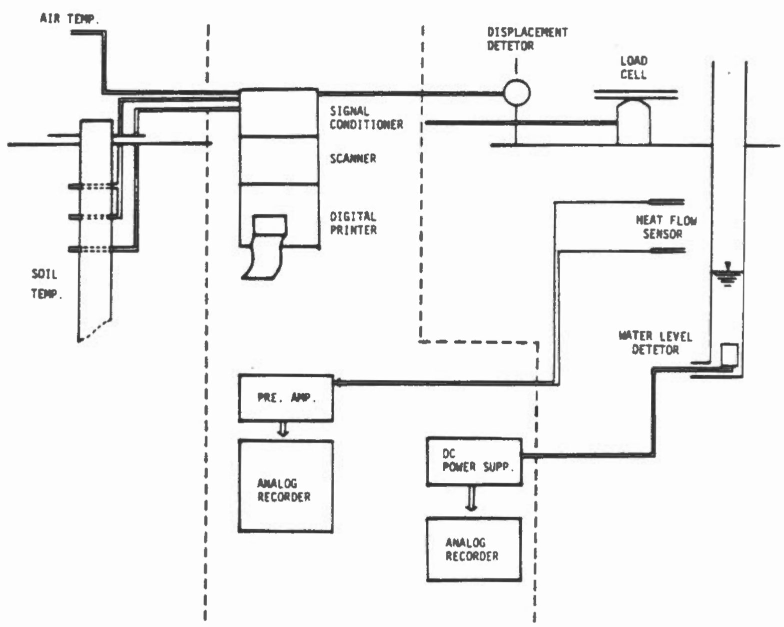
5.3 Facility Demand Continued ...	
- For a multi-pit facility, which pits are in use the most?	4 pits - same usage
- For individual pits, which control systems, data aquisition capabilities, etc. are used most often?	
- If any portions are under-used, is this problem due to lack of demand, or reliability problems, or unsuitability of control or data systems?	----
- For fully utilized facilities, is there demand for additional capacity (more or large pits, another building, more features)?	----
5.4 Maintenance	
- Schedules. What maintenance is carried out on fixed schedules (eg. monthly, semi-annually, at the end of each test, etc.)? What maintenance is carried out on an "as-required" basis (ie. if it breaks, fix it)? Describe for each system (environmental control, data aquisition, etc.). What is the down-time involved?	As required by Senior person
- Which systems require the most maintenance? Which systems are better than expected? Worse than expected?	Data logger, and temperature calibration data logging prodedure.
- Have maintenance requirements ever interfer ed with tests in progress? To what extent were the tests jeopardized?	Cables are expensive and are replaced every 3 years
- To what extent does maintenance or repair of one test pit or system affect the operation of other pits or systems? Can each system be repaired while keeping other systems running?	yes.
- What back-up systems are present (eg. refrigeration systems, power supplies for building, data aquisition system, etc.)? In retrospect, would any additional back-up systems be desirable?	Redundancy from older, outdated equipment.

6.0 OPERATIONAL MANAGEMENT

6.1 Staffing. Number of full and part-time staff in the following categories (specify which are off-site):	
(a) scientific	1 senior part-time.
(b) technical support (eg. electrical, data aquisition, computer, construction, maintenance)	1 part-time grad student.
(c) administrative support	2 extra men for 3 weeks for filling in every few years.
- Management hierarchy. Who controls what? Who decides which experiments are run, or who runs them? Are administrative and scientific authorities separate?	Inst. of Low Temp Science.
6.2 Budget	
- What are typical operating costs for the facility?	$75,000 p.a.
- Where does the money come from?	University funding and grant from Ministry of Education.
- Is there basically one budgeting system, or do different aspects of the facility follow different budgeting schemes (eg. one group provides budget and support for overall facility, while individual groups or scientists provide budget for experiments)?	
6.3 Outside Support	
- Is facility basically self-contained (scientific, technical, administrative, and financial requirements)?	Yes
- Do outside organizations provide support? Is providing support to this facility a major or minor role for them?	No
- To what extent are the test facilities used by outside agencies (ie. is the facility operated for use by a number of "outside" agencies)?	N/A



第1図　苫小牧凍上観測室測定要素の設置状況



第2図　測定及び記録装置の構成

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LAYOUT OF TEST PIT INSTRUMENTATION AND SCHEMATIC OF DATA ACQUISITION SYSTEM

CG14027

FIGURE D.1

APPENDIX "E"

REPORT ON VISIT TO FACILITY

LOCATION: QUATERNARY RESEARCH CENTER, SEATTLE

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1.0 FACILITY IDENTIFICATION

Name of Facility:	Quaternary Research Center University of Washington
Location:	Seattle, Washington
Full Address:	P.O. Box AK60 University of Washington Seattle, Washington, USA 98195
Director or Head:	Dr. Stephen C. Porter, Director Quaternary Research Center Dr. Bernard Hallet, Technical Director Laboratory
Phone No./Telex:	206 543 8140
Hardy Associates Reporter:	E.C. McRoberts
Date Visited:	July 22, 1981
Personnel Interviewed:	Dr. L. Washburn (Former Director) Dr. B. Hallet

2.0 GENERAL FUNCTION OF FACILITY

The Quaternary Research Center is an operating sub-unit under the control of the University of Washington, Facility of Graduate Studies. The center itself does not grant degrees. There is at present, a staff of four professionals funded through the QRC and in addition, up to ten to fifteen adjunct staff from other faculties.

Initial and present funding for the facility was obtained from grants from the US National Science foundation and the US Army Research office. Copies of the original grant requests are provided in Appendix "E". ??Where are they?? University of Washington provides additional support. The facility itself was constructed as part of an addition to the physics building as a combined Quaternary Research - Geophysics Building. Drawing 224-A-39 (Figure E.1) gives an overview of this extension. The cold rooms built as part of this extension were also shared, part intended for glaciology studies and the remainder for periglacial studies. There is a total of 115 m^2 of cold rooms of which 75 m^2 are for the QRC Periglacial Laboratory and 40 m^2 for the geophysics/glaciology group which is not part of the QRC. The tilting table (slab) is the primary experimental feature of interest, and is 9 m^2 in plan area, with a soil depth of 1 m. It can be tilted hydraulically to an angle of 40^o, after surface freezing with access to a basal water supply. An array of infra red lamps provide the "summer" temperature fluctuations, which are controlled in a sinusoidal fashion.

The QRC currently is engaged in field studies of periglacial phenomenon at Cornwallis Island in the Canadian Arctic and Dr. Hallet has a proposal in to the National Science Foundation for work in the Spitzbergen.

3.0 GENERAL SIZE AND SHAPE OF FACILITY AND SUPPORT FUNCTIONS

The cold rooms in the Periglacial laboratory consist of a 47 m^2 room for the tilting slab and has a 4 m ceiling. Two additional labs provide 28 m^2. The lab has about 80 m^2 of unfrozen preparation areas and storage and control rooms. There is approximately 160 m^2 of office and library space for the QRC. Facilities for washrooms, etc. are shared with the geophysics group, see Figure E.1.

General details of the floor plan are given in Figure E.1. The refrigeration system is housed in a separate level beneath the cold rooms.

The soil stockpiles are in two areas. Two large garbage containers of the type used by front end loading trucks are kept at the loading dock area. Smaller bins are located in the laboratory area designated dry soil storage in Figure E.1. QRC staff observed that storage space for soil and equipment was exceedingly limited due to budget restrictions when the facility was constructed.

4.0 DETAILS OF TESTING FACILITIES

4.1 Layout and Tilting Slab

The major test area is Lab E containing the tilting slab, see Figure E.1. Lab D is used for cold storage for cutting and Lab F is a working area for cutting and preparing cold samples and general storage or testing. Note the double doors providing access (doors with about 1.4 m clearance).

There is a main control room located adjacent to Lab E which houses the refrigeration controls. A duplicate set of refrigeration controls is located underneath the cold rooms in the refrigeration equipment area. Access ports are also available between the cold labs and the three offices which abut the cold room walls. This allows additional monitoring of individual experiments as required. There is a sump in the floor of all cold rooms which can act as a drain in the event of thawing or leaks.

The tilting slab consists of a 2.5 m by 3.6 m long by 1 m deep slab of soil that can be tilted up to 40° from the horizontal (see Figure E.2). This slab including the weight of the empty apparatus is in the order of 20,500 kg. The room, Lab E, can be refrigerated to -50°C and the base of the slab can be independently temperature controlled above or below 0°C. The sides of the box are heavily insulated and are equipped with a feed-back system using heat tape to control temperature gradients at the side and end boundaries. A bank of sixteen infra-red heaters (1 kW each) can be adjusted to any height above the soil surface in order to aid in soil thawing (see Figure E.3). In the original design specifications, consideration was given to simulating wind effects by blowing air across the slab but this boundary condition has never been tested.

Water can be introduced at the base of the slab to provide easily accessible water during open system freezing tests. Water is introduced in a system of pipes which are surrounded by a thin layer of clean sand and overlain by a layer of muslin to keep the overlying soil out. A water control setup in the unfrozen soil area is used to provide water at a constant head or constant flux. Water head can be controlled to ±1 cm. Problems have been experienced getting uniform water distribution. There are no techniques used to measure variations in water content during an experiment other than direct sampling (see Figure E.3).

Details of the tilting slab are given in Figure E.2.

4.2 Materials Handling

All materials handling for soil placement is done by hand. Soil is mixed in a concrete mixer at the loading dock and pushed by hand to the slab where it is dumped in.

Up to now, soils have always been placed in a wet slurry-like condition at water contents greater than the liquid limit. About 30 loads are required to fully fill the slab. Sometimes the slurry is stirred manually to get mixing as lifts are placed or the tilting mechanism is used. Apparently concrete vibrators have been used in some cases to densify the soil. The soil is then left to drain and settle before an experiment begins. Typically, it takes two days to fill up the slab and typically from six to eight days to consolidate the soil. Clearly this depends on soil type. A detailed description of procedures used is given as Appendix "F". Generally, it appears that the individual investigator develops his own procedures for soil placement.

From the information provided, it appears that soils tests are in the silt to clayey silt range and soils with a high collodial clay content have not been tested. Apparently, no placement involving compaction (in the geotechnical sense) has been used.

4.3 Environmental Control Systems

The cold rooms are chilled by a combination of brine (trichl-oroethylene) or freon systems. Apparently the rooms were designed to use brine coolant to finned coils over which air is circulated to a pressurized plenum chamber in the roof of the cold lab. However, it appears that the freon system which was for backup and now used for primary chilling as the freon system requires less maintenance. Details on this point were, however, not completely clear.

The chilled brine is also available for direct circulation into the base of the slab and cold brine outlet points are also available in the laboratories for other experiments. Warm brine is also available for ambient thaw in the rooms, beneath the slab, and at other access points. The cold brine is always delivered at an invarient temperature approximately (-50°C) and must be heated to get warmer chilled temperatures. Alternatively, the amount of cold brine may be reduced (throttled).

It was observed that considerable attention had been directed to ensuring that the chilled air in the rooms was circulated uniformly in order to get uniform cooling (or heating) and to minimize discomfort to personnel. This was accomplished by circulating air into a false ceiling with many small access holes.

Control on room temperatures could be cycled daily along a programmed cycle by using plexiglass templates on the temperature recorders. The only variable controlled in the rooms was temperature.

There are several safety features. All labs have a push button telephone for emergency calls. When the rooms are chilled, a buddy system is used to make sure people are safe. There is a crowbar inside each door and a brine fume detection system.

4.4 Data Acquisition System

The primary data acquisition system allows for the collection of 360 thermocouple points. This data is collected on paper and/or magnetic tape. The magnetic tape apparatus, however, was bought used and difficulties have been experienced. Moreover, the software programmed for data handling and processing was not well documented and is apparently not currently in use. Thermocouples are calibrated at three points, one being 0°C and are believed accurate to ±0.2°C. Some thermistors are used with accuracy to ±0.01°C.

Soil heave is measured by LVDT units bearing on soil surface. In some experiments, the LDVT is directly attached to an individual pebble.

No "meteorological" data other than room and soil surface temperature is recorded. Some experiments have been conducted using a pressure transducer in the soil to measure pore pressure, however no results are available. Some attempts were made to measure downslope tilt using a tiltmeter from Carleton (PJ Williams design) but apparently it never worked. Methods used to measure downslope movement are rudimentary involving columns of soil or circular segmented tubes places vertically and then exhumed after the event. In some experiments "glitter" is placed between lifts of soil to get an idea of the general deformation patterns.

5.0 OPERATIONAL HISTORY

5.1 Length

The facility was constructed in the early 1970's and became fully operational in 1975.

5.2 Applications

The major experiments have been directed towards several broad areas which are:

1. The upheaving of objects caused by freeze-thaw cycles.
2. The nature of discontinuities, cracks and fissures caused by freeze-thaw cycles.
3. The contrasting textures and sorting caused by freeze-thaws.
4. Vertical and downslope movements caused by freeze-thaw.

This report contains a reference list by C.M. Burrous which summarizes the published work undertaken up to 1979. An additional series of about 13 informal unpublished reports are also contained in the QRC Periglacial Lab records and would be available to interested research workers.

It was noted by Dr. Hallet that while the tilting slab provided a unique opportunity to model periglacial effects on a life-size scale, it is difficult to fully instrument and completely define the system being tested. The more complex one becomes, the greater the danger of being swamped with data. The QRC needs to get better facilities for computerized collection, processing and display data. It is also necessary to be very careful about defining the problem to be studied to ensure that the necessary but sufficient data is being collected.

In respect to the tilting slab, it was observed that end effect (i.e. active/passive in geotechnical sense) could have noticeable influence on the experiments.

The major maintenance problem noted was the compressors which required new valves every 5000 hours. Prof. Washburn noted they were of foreign (Japanese) manufacture and were the best they could afford when the facility was constructed.

The brine (trichloroethylene) used for chilling is highly toxic to humans and they have had one bad leak up to date.

The maintenance is undertaken by the University of Washington control staff as part of the overally heating plant system. This is very convienient for the QRC as all operational/maintenance problems are looked after by a competent group.

6.0 OPERATIONAL MANAGEMENT

6.1 Staff

There are four professional (academic) staff and one full time and one part time basis secretary. All technical assistance is done by students who informal advice wherever they can find it. There are about ten adjunct staff from other faculties. All equipment and maintenance functions are provided by the University and are not QRC staff positions.

6.2 Budget

Funding comes from U.S. government grants, primarily National Science foundation and U.S. Army.

About $30,000 per year is required to maintain the facility and keep equipment running in addition to free electric power provided by the university.

6.3 Outside Support

The test facilities have not been used directly by outside agencies but there is no restriction in principle to such use.

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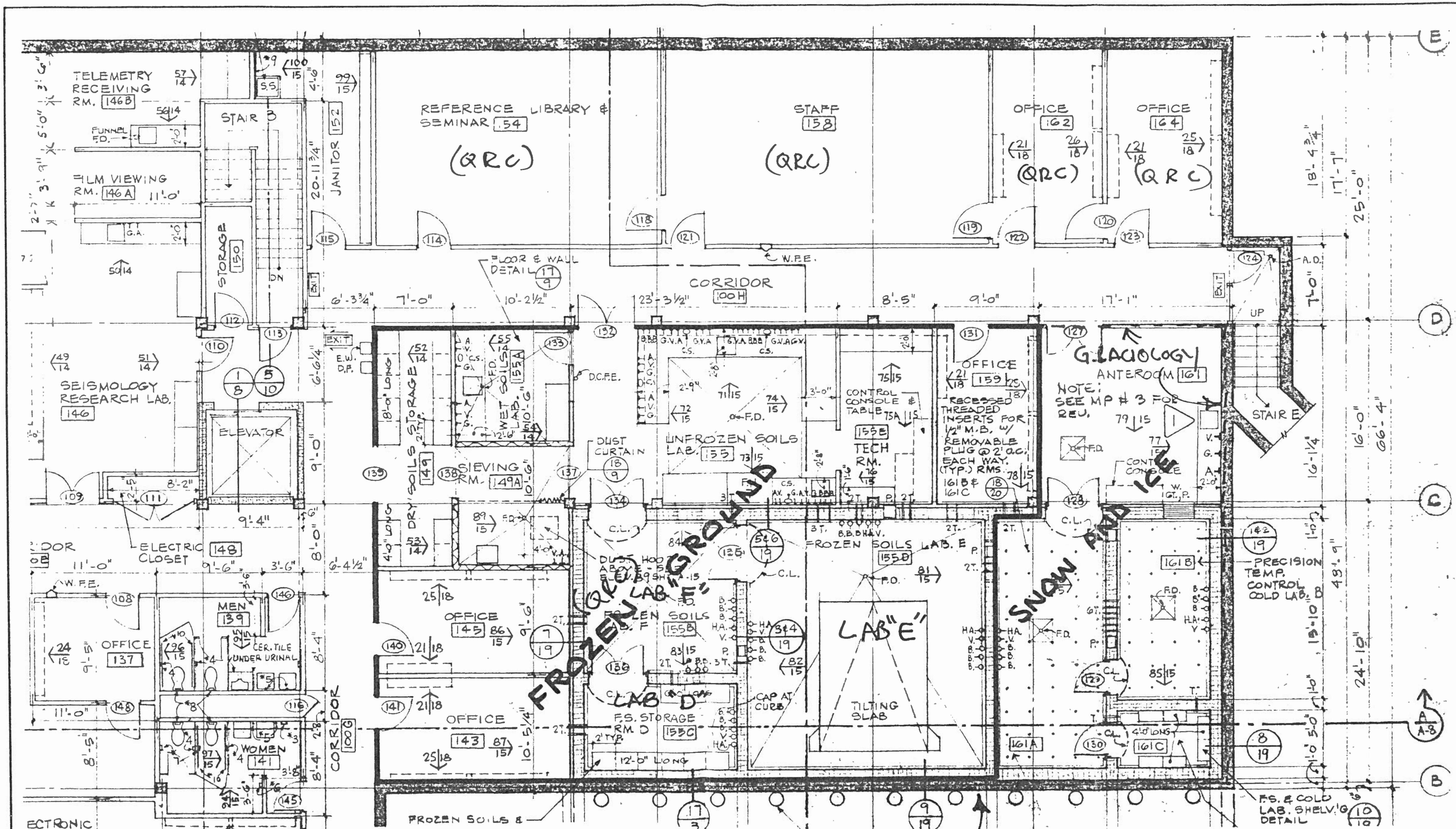

REVISIONS	REFERENCES		
	DURHAM, ADERSON, FREED ARCHITECTS DRURG # 224-A39	SCALE DATE MADE CHKD. APPD.	HARDY ASSOCIATES (1978) LTD. CONSULTING ENGINEERING & PROFESSIONAL SERVICES

QRC - FIRST FLOOR PLAN

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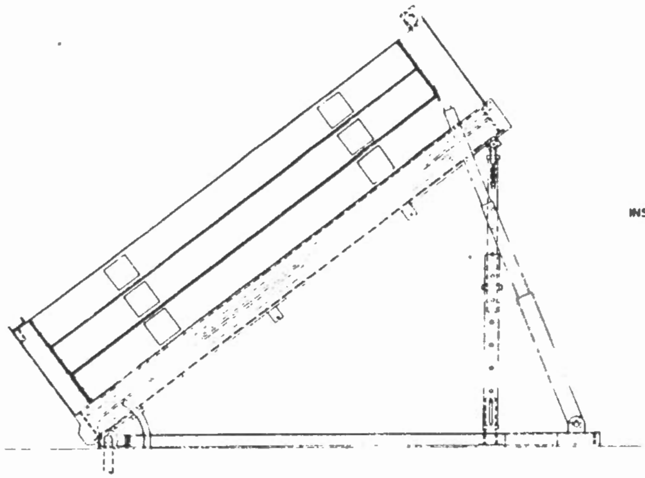
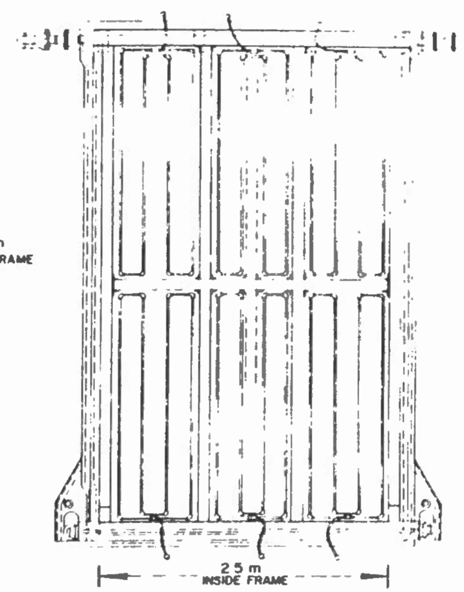
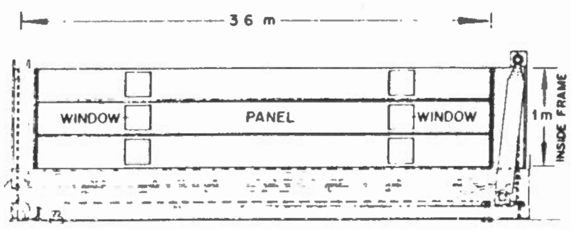
FIGURE E.1



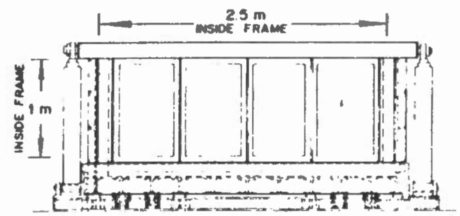
SIDE ELEVATION OF SLAB TILTED



PLAN



SIDE ELEVATION



END ELEVATION

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DETAILS OF TILTING SLAB
AT QRC CENTRE — SEATTLE

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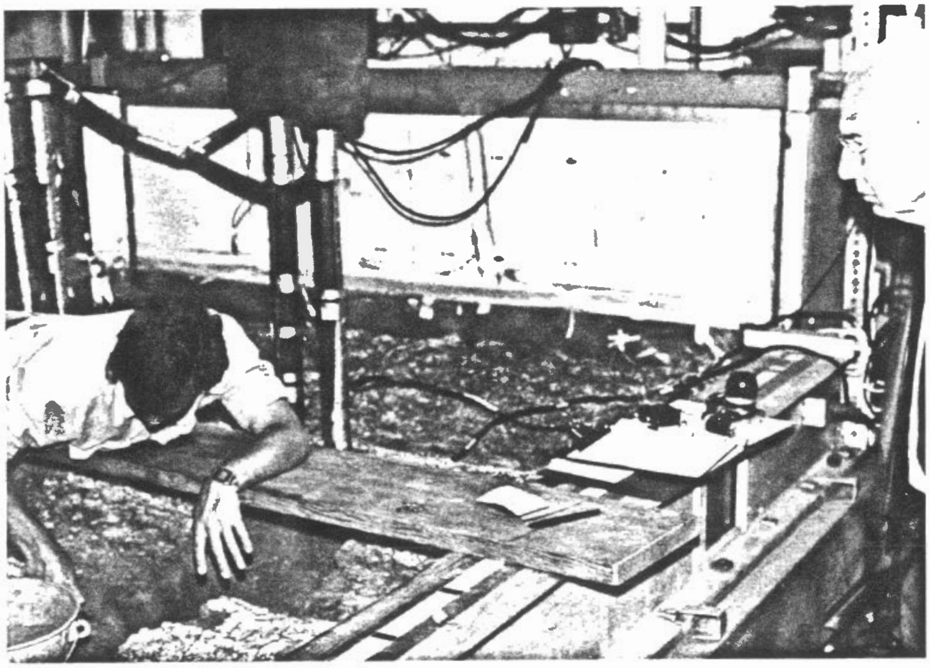
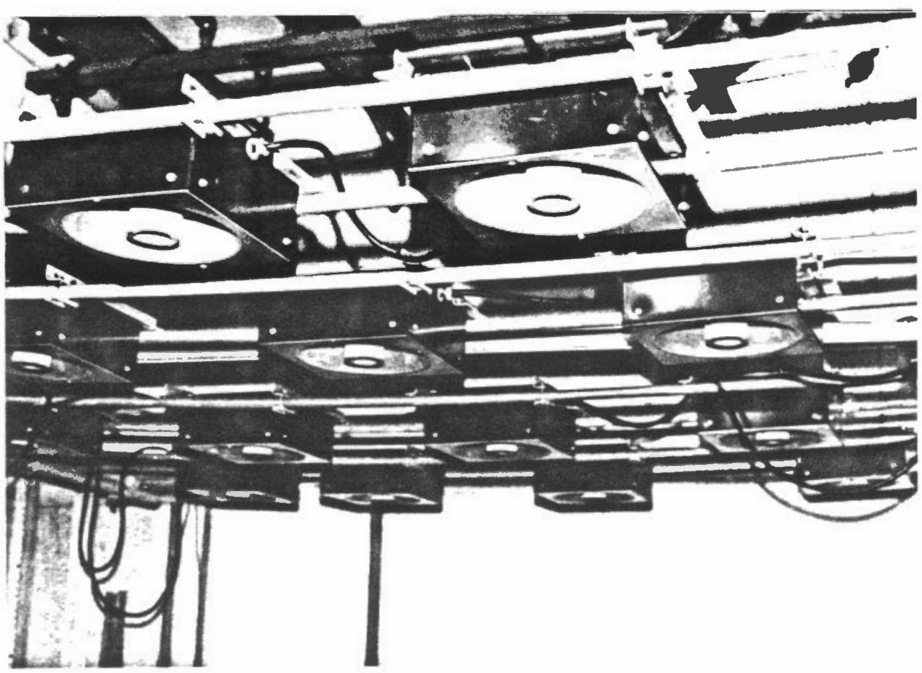
FIGURE E.2



a) TILTING SLAB AND SOIL SAMPLING



b) ARRAY OF INFRA-RED HEATERS ABOVE SLAB

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PHOTOGRAPHS OF
SEATTLE, WASHINGTON INSTALLATION

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FIGURE E.3

PUBLICATIONS

Mackay, J. R. and Burrous, C. M., 1979, Uplift of objects by an upfreezing ice surface: Canadian Geotechnical Journal, vol. 16, no. 3, p. 609-613.

Rein, R. G., Jr., and Hathi, V. V., 1978, The effect of stress on strain at the onset of tertiary creep of frozen soils: Canadian Geotechnical Journal, vol. 15, no. 3, p. 424-426.

Sherif, Mehmet, Ding, Wing, and Ishibashi, I., 1976, Frost-heave potential of silty soils: Proc. Second International Symposium on Cold Regions Engineering, Univ. Alaska, Fairbanks, Alaska.

Sherif, Mehmet, Ishibashi, I., and Ding, Wing, 1976, Frost-heave potential and exudation pressure of silty sands: Univ. Washington Soil Eng. Rept. 12, 38 pp.

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Sherif, Mehmet, and Perry, John, 1974, Frost susceptibility of soils: Univ. Washington Soil Eng. Rept. 9, 60 pp.

Tice, A. R., Burrous, C. M., and Anderson, D. M., 1978, Determination of unfrozen water in frozen soil by pulsed nuclear magnetic resonance: p. 149-155 in Proceedings of the Third International Conference on Permafrost (July 10-13, 1978, Edmonton, Canada), vol. 1, National Research Council of Canada, Ottawa, 947 pp.

Tice, A. R., Burrous, C. M., and Anderson, D. M., 1978, Phase composition measurements on soils at very high water contents by the pulsed nuclear magnetic resonance technique: National Academy of Sciences Transportation Research Record 675 (Moisture and Frost-Related Soil Properties), p. 11-14.

Washburn, A. L., 1979, Geocryology - a survey of periglacial processes and environments: Edward Arnold, London; John Wiley, New York. (In press.)

Washburn, A. L., Burrous, C. M., and Rein, R. G., Jr., 1978, Soil deformation resulting from some laboratory freeze-thaw experiments: p. 756-764 in Proceedings of the Third International Conference on Permafrost (July 10-13, 1978, Edmonton, Canada), vol. 1, National Research Council of Canada, Ottawa, 947 pp.

Publications in Preparation or Submitted

Burrous, C. M., Experimental upfreezing of objects: Effects of object geometry. (In preparation.)

Mackay, J. R., Model experiments on the growth of pingos and frost mounds. (In preparation.)

Rein, R. G., Jr., and Burrous, C. M., Laboratory measurements of subsurface displacements during thaw of low-angle slopes of a frost-susceptible soil. (Submitted to Arctic and Alpine Research.)

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QRC - PERIGLACIAL RESEARCH - Int Rpt. #3

PROCEDURE FOR LOADING SOIL INTO THE TILTING SLAB

DECEMBER 1973

APPENDIX "F"

PROCEDURES FOR LOADING SOIL INTO THE TILTING SLAB AT QRC RESEARCH FACILITY - SEATTLE, WASHINGTON

In the following, the details of the final installation of the soil slab and the loading procedure of the soil are described.

Water supply and water drainage:

To make the slab water tight, polyethylene sheets (0.060" thick) were taped to the walls and to the bottom pan (galvanized steel) of the slab (Fig. 1). "Duck Seal" sealing compound was used to fill seams and gaps in the construction. A drainage pipe was installed in the designated position through the polyethylene and into the drainage outlet in the wall, and was sealed around. The bottom pan was covered with canvas tarp followed in succession by two polyethylene sheets (each 0.004" thick), another canvas tarp, and finally another polyethylene sheet. The polyethylene sheets were extended to a height of about 50cm above the bottom, to cover completely the walls of the box. They served to contain the soil and water and prevent contact between them and the walls as well as to reduce the danger of leaks. The canvas was designed to protect the polyethylene from the abrasive action of the sand loaded in the bottom of the box. A drain pipe was passed through the liners and to the previous drain pipe.

Three spray-heads (Fig. 2) were placed above the liners and connected to the water supply (tap water). The spray heads were 0.5" galvanized steel pipes, perforated every 25cm. They were fitted with heating elements (resistance wire with rating of 25 watt/foot).

Coarse Filter:

Muslin cloth sheet was placed above the spray heads and a layer of coarse quartz sand (DelMonte #8, fresh water leached) was put to a height of 7cm. Another muslin cloth sheet was layed above the sand to act as a filter, and was secured at the edges. The soil was placed above this muslin cloth.

Soil:

On December 20, 1973, the box was loaded with soil. The soil was in semi-moist condition and in the same aggregation state as brought from the field. Fifteen cans of soil (volume of can 140 liter) were loaded, with only slight compaction applied. During the operation, no artificial localized compaction was allowed by avoiding any stepping on the soil. After loading water was supplied to the bottom of the soil through the spray heads. The water level was checked through the piezometer and was adjusted roughly to coincide with the sand-soil interface. It was kept there by intermittent additions of water to supplement the water taken by the soil.

Instrumentation (see Fig. 2):

A piezometer made of 1.5"OD PVC pipe was installed in the soil. Two thermocouples (TC) were installed beneath the sand layer (just above the spray head pipes). Two thermocouples were used to monitor the room temperature. Three groups of TC were used to obtain thermal profiles in three different locations in the box. Designation and location of the thermocouples are given in Table 1 and Fig. 2. The main purpose, at present, is to check the performance of the system as a whole, the stability and accuracy of thermal control in the room, the box cold-plate and the box walls. Type T thermocouples were used in all cases, giving thermal sensitivity of 40 μVolt/deg C.

An imaginary grid was agreed upon for designating locations in the box. The origin is the left, lower corner of the box, where the walls meet. The coordinates of any point in the box will be given according to this grid using metric units.

Observations:

Rapid and extensive settling of the soil was observed immediately after admission of the water. In few places along the edges of the box water was pushed to the top of the soil, probably by slumps and collapses of the lower layers. In most of the box area, however, water rised mainly by capillary rise, to wet the top soil. An intricate system of cracks had developed in the soil and was recorded photographically.

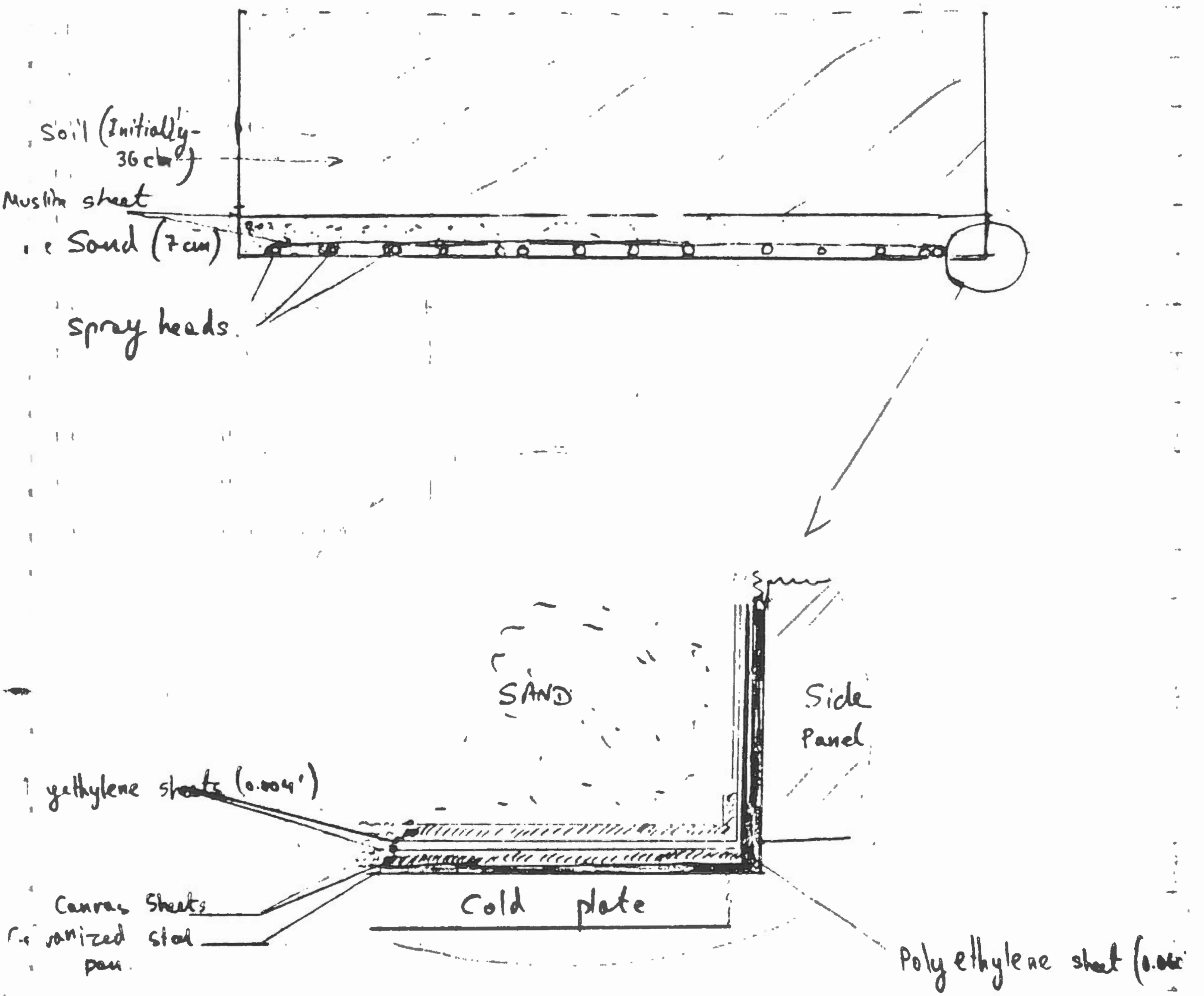
After 3 to 4 days, water uptake slowed down and the soil water content stabilized. Further loses of water (as shown by lowering of the water table in the piezometer) were small and mainly due to evaporation from the top of the soil. Consolidation was still continuing at a slow rate.

December 21, 1973

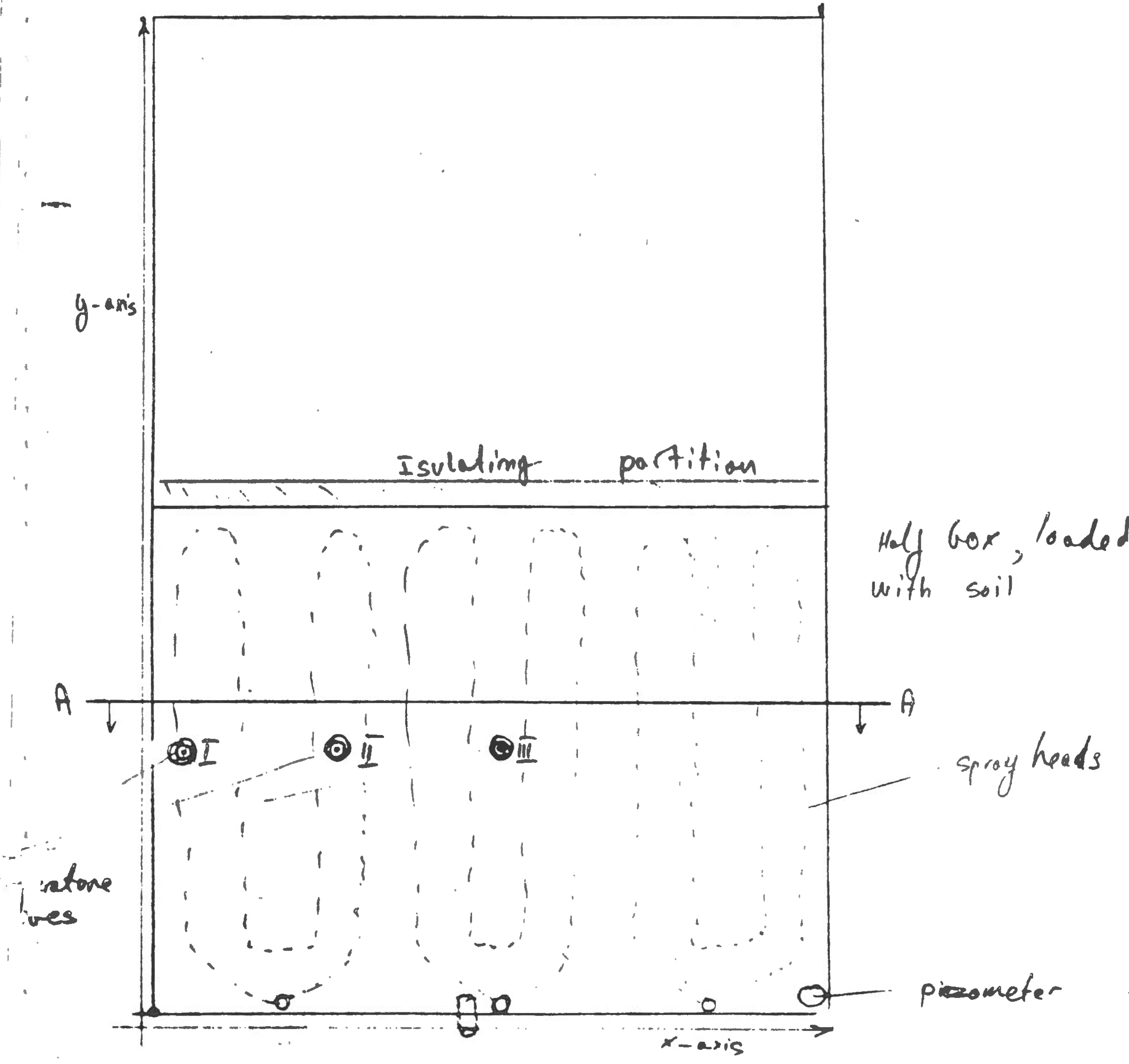
Table 1: TC Locations and Channel Designation

Recorder Channel	TC	Level, cm above pan	Level, cm above sand	Level, cm below rim	Probe No.	Coordinates, cm (x, y)
1	5C4	7.0	0	36	I	
2	6C4	17.0	10	26	I	
3	7C4	27.0	20	16	I	
4	8C4	37.0	30	6	I	
5	5C3	7.0	0	36	II	
6	6C3	17.0	10	26	II	
7	7C3	27.0	20	16	II	
8	8C3	37.0	30	6	II	
9	5R1	7.0	0	36	III	
10	6R1	12.0	5	31	III	
11	7R1	17.0	10	26	III	
12	8R1	22.0	15	21	III	
13	9R1	27.0	20	16	III	
14	W_2R_1	32.0	25	11	III	
15	W_2R_1	37.0	30	6	III	
16	W_2C_3	Air Temp.				
17	W_3C_3	Air Temp.				
18	W_2C_4	Bottom Temp.				56, 49
19	W_3C_4	Bottom Temp.				56, 122
20	Calibration Signal					

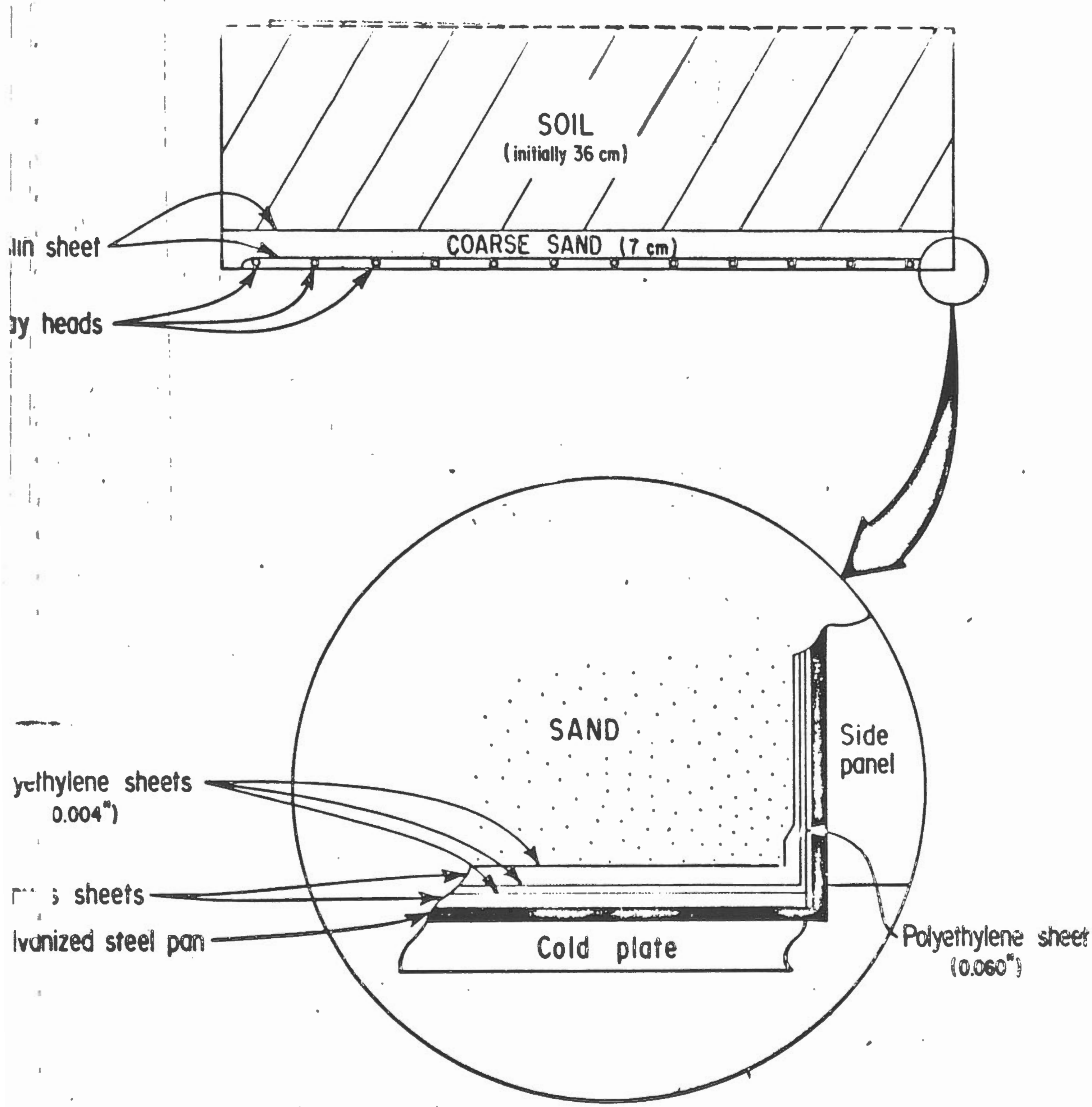
① side view and cross section(A-



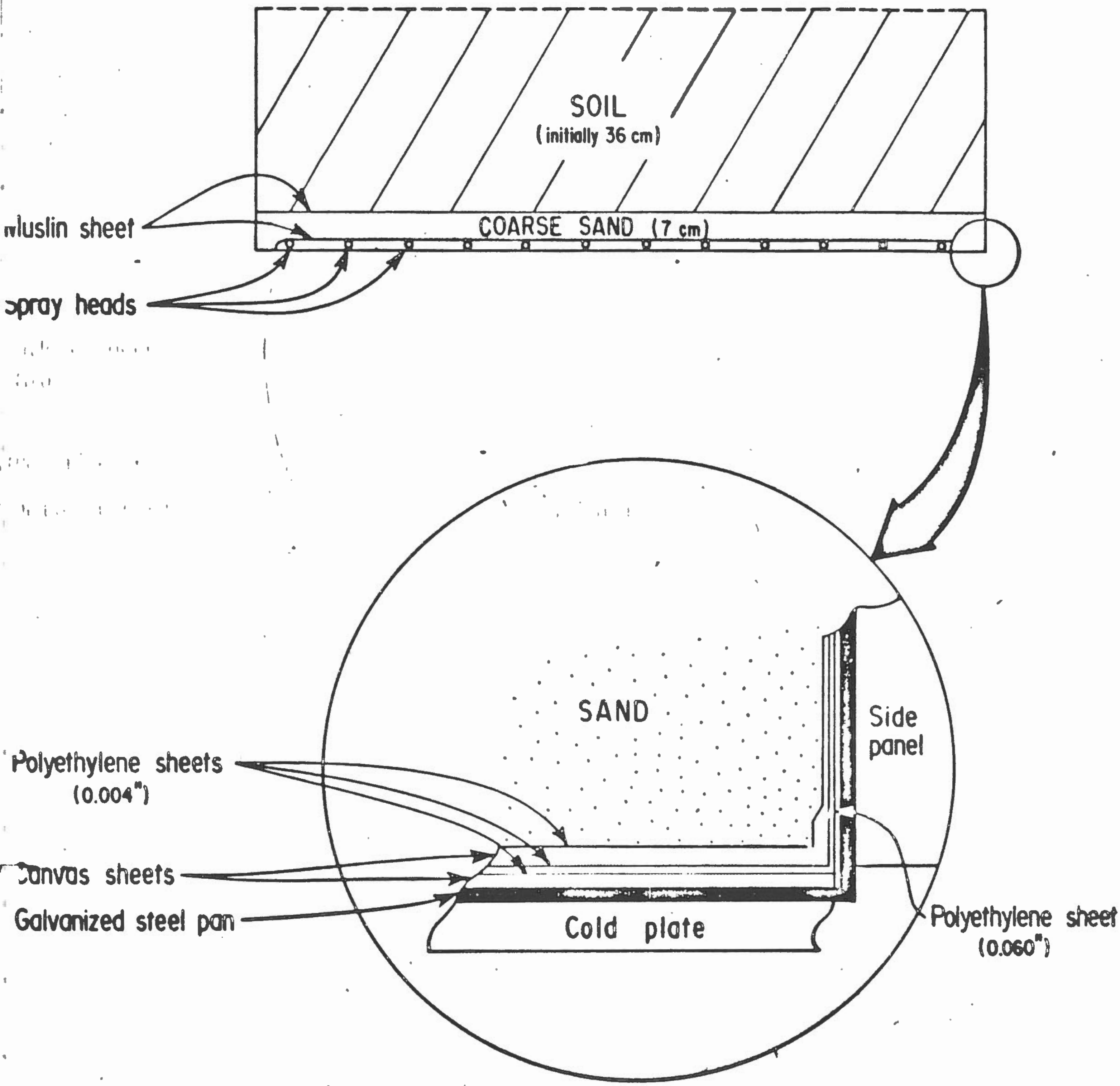
② Top view:


y-axis
Isulating partition
Half box, loaded with soil
A
A
I
II
III
spray heads
piezometer
x-axis

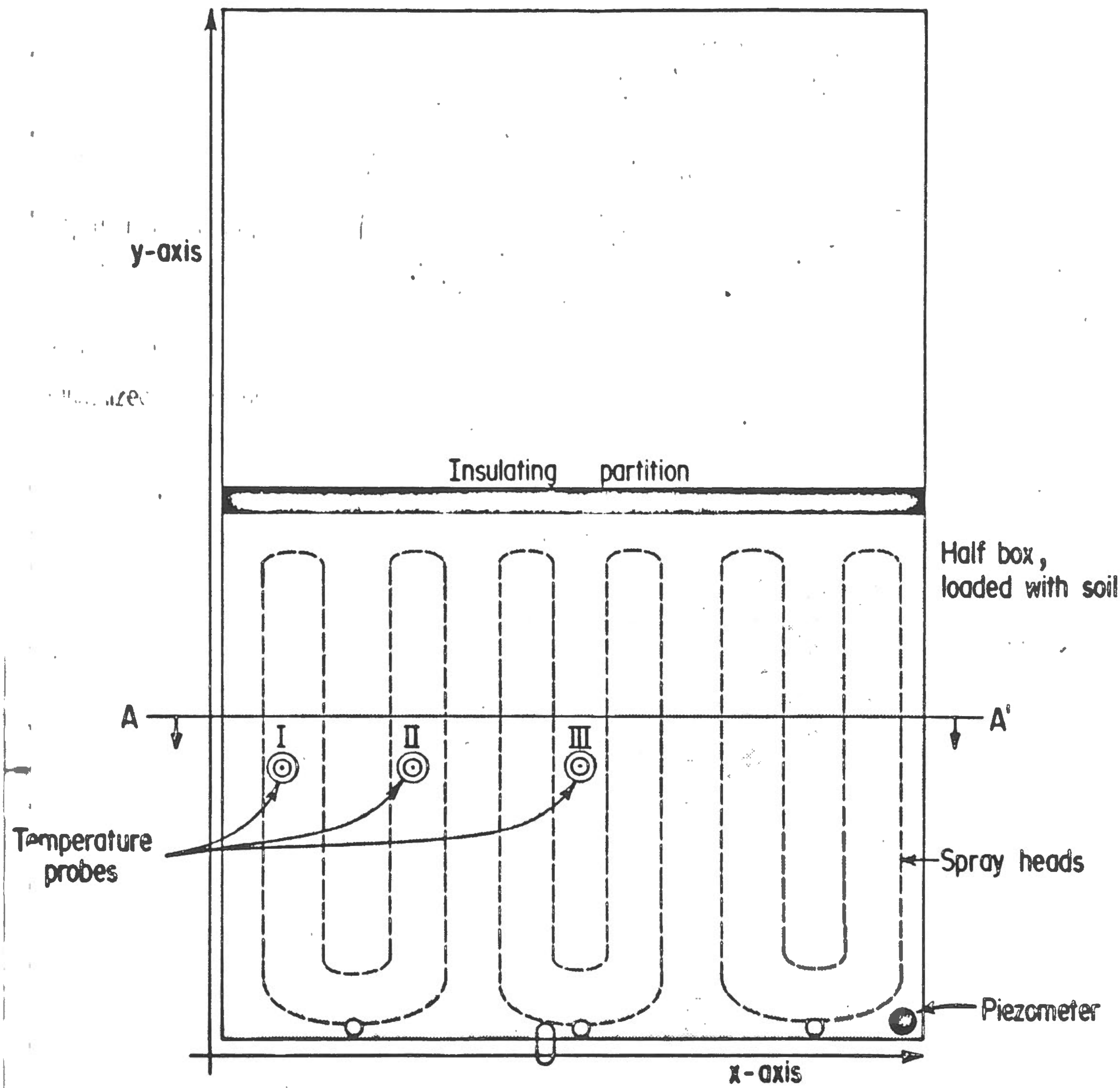
1 SIDE VIEW AND CROSS SECTIONS (A-A')



① SIDE VIEW AND CROSS SECTIONS (A-A')



② TOP VIEW



y-axis
Insulating partition
Half box, loaded with soil
A
A'
I
II
III
Temperature probes
Spray heads
Piezometer
x-axis

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APPENDIX "G"

LETTER REPORT FROM SWEDISH FACILITY

STATENS VÄG- OCH TRAFIKINSTITUT

National Swedish Road and Traffic Research Institute
Institut National Suédois de Recherches Routières et de la Circulation
Staatliches Schwedisches Strassen- und Verkehrsforschungsinstitut

Road Division
R Gandahl/eh

Date/Datum
August 18, 1982

Our No./Notre n°/Unsere Nr.
V 776/82-524:3

Dr. J.F. Nixon
Hardy Associates Ltd.
18 Street S.E.
Calgary
Alberta T2E 6J5 Canada

Dear Derick:

Re: Information on Controlled Temperature Road Research Facility

Thank you for your letter of August 5, 1982. I can see from your letter that you have been busy making interesting journeys.

You are interested in receiving some more information on our Controlled Temperature Road Research Facility. I think that the drawings that are enclosed with this letter may be of help to you. The cost of constructing the described facility was 5.6 million Sw.Cr. in 1976. Later, certain additions have been made, and so a cost of almost 6 million Sw.C.r (1976) is to be reckoned. The cost of a short-term test in the Controlled Temperature Facility can be estimated at 200.000 Sw.Cr.. The cost of a long-term test during a three-year period would probably amount to 2 million Sw.Cr..

I, too, have a small request to make. Unfortunately, I lost all copies of your publications on my travel from Moscow. I should, therefore, be very grateful if you could send me another set so that we can discuss your ideas in our frost group.

Yours truly,

Rune Gandahl

Rune Gandahl
Chief Engineer

Note: 4.75 Sw.Cr. ≈ $1.00 Can

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