Study of Pipeline-Environment Interactions Using a Controlled Environment Facility

Alan Judge and Margo Burgess

Geothermal Service of Canada

Internal Report No. 81-1

Division of Seismology and Geothermal Studies

Earth Physics Branch

Department of Energy, Mines and Resources

Background

A large proportion of the Canadian landmass and an unknown area of the near-offshore is underlain by permafrost. Much of the rest of the country is subject to seasonal frost of varying severity (Fig. 1). Recent development hearings[1] and Canadian and U.S. reports on Arctic research[2,3] have stressed the deficiencies in our knowledge of permafrost, frost-related phenomena and techniques of engineering in permafrost regions.

The cost of the Alyeska pipeline inflated to some eight times the original estimate because the engineering consequences of frost-related effects on the buried pipe were completely underestimated. Inadequate understanding of frost-heave related processes were a major technical issue in the hearings associated with the Mackenzie Valley gas pipeline[4,5] and again in the more recently proposed Alaska Highway gas pipeline[6,7]. Although pipeline-related problems are currently to the fore, the existence and behaviour of permafrost represents increased cost and problems to all aspects of living, development and transportation in the north. Seasonal frost effects present continuing problems to many aspects of life in southern Canada; perhaps most dramatically in highway construction and maintenance[8]. In preparation for future northern pipelines and for adequate design and assessment of all future northern development, it is essential, from both economic and environmental standpoints, that a proper understanding be obtained of water transport phenomena and heat transfer processes in northern terrains. An additional understanding of mechanical properties, stress fields, behaviour of materials and performance of prototype structures in the northern environment is needed.

Proposal

In a memorandum of October 1980, Peter Williams of Carleton University has proposed a "France-Canada Joint Operation of a French Full-Scale Facility for Modelling Heat and Moisture Flows in Freezing Ground and Buried Pipes". The proposal grew from a meeting held 23 September 1980 attended by Peter Williams, a member of the Canadian Embassy in Paris and a number of French scientists. Basically it proposes, as summarised in Appendix 1, to make joint use for two years of a French facility in Caen which is presently under-utilised. The total operating costs are estimated at 600,000 Francs which would be apportioned 2/3 to 1/3 Canada and France. Each country would provide a single graduate student to conduct the research programme but the French would provide technical assistance under the operating costs. Support of the Canadian graduate student, necessary supporting laboratory research in Canada, travel costs to and from the facility and management costs in Canada, would be in addition to the above costs. The facility proposed is attached to the Centre National de la Recherche Scientifique at Caen, close to the Normandy coast about 200 km from Paris, and easy of access from Canada.

The Facility

"La Station de Gel de Caen"[10] consists of a cooled shed of interior dimensions 17.8 m long, 7.75 m wide and 5.00 m high with an excavated chamber 1.70 m deep and two adjoining rooms housing the cooling units and the recording apparatus[9]. At the base of the excavation, above an impermeable membrane, is 10 cm of clean sand containing a network of perforated plastic tubing to control water supply to the soil placed in the excavation and thus to create an effective water-table. Two compressors provide a cooling capacity of 18,000 frigories/hour (calories/hour) sufficient to maintain an air temperature in the shed of -15°C against an external ambient temperature of +22°C. Thaw can be simulated through the addition of a portable heating apparatus consisting of 18 infra-red tubes each of 1500 watts. No coils exist to control the temperature at the base of the excavation, nor at present does a means exist of controlling the pipe temperature for the simulated performance of a chilled pipeline.

The facility was primarily built to study the effect of freeze-thaw on sections representing different types of highway construction; the relevant measurements being the air temperature in the shed, at the surface of the highway and in the subsurface of the construction. Subsurface temperatures were measured with up to 50 small platinum resistance sensors fed through a programmable switch to record on an out-of-balance voltage on a Speedomax recorder yielding a precision of ± 0.2°C.

Constructed in 1967 at a cost of $500,000 the facility was used extensively for highway experiments, lasting from 8 to 10 months each, between 1968 to 1975. Since that time it does not appear to have been used and some uncertainty seems to exist as to the present condition. The facility is adjacent to the Centre de Géomophologie du Centre National de la Recherche Scientifique after being established jointly by the above group, the Laboratoire d'Aérothermique du C.N.R.S. and the Ecole National des Ponts et Chaussées (ENPC) and thus can draw upon the technical and professional expertise of these organisations.

A similar facility to that in Caen exists at Lausanne in Switzerland[11]. Although the latter facility has some advantages in terms of equipment for pipe-handling in the initial setting-up of the experiments, its overall dimensions of 11 m long by 5 m wide and a 2 m deep excavated chamber are more restricted for pipeline-related experiments.

Comments on the Facility at Caen

1. The geometry of the system was designed for unidirectional experiments on slabs simulating highways.

2. No means exist of controlling the temperature at the base of the excavation, or of controlling the temperature of the installed simulated pipe.

3. Design of the original instrumentation was largely to monitor temperature change in the soil in response to transient air temperature changes.

4. The measuring equipment and the data acquisition system is primitive and of low accuracy. Replacement would need to be considered. For ease of data handling and analysis, acquisition should be directly on magnetic tape or disc. Data transfer from the present paper record would be very time consuming.

5. In a serious experiment a number of other parameters would need to be monitored such as surface heave of the soil, pore pressures, unfrozen water contents, freezing front position, effective soil permeability. At present provision for such measurements does not appear to exist.

6. It is not clear how accurately the ambient temperature at the surface of the soil can be controlled or what the response of the system would be to changes in external air and soil temperatures outside the facility.

Comments on Proposal

Pilot experimental studies of this nature under controlled conditions are a logical extension of the basic science work being carried out at present by Carleton and Waterloo Universities through funding from the OERD Programme (Task 5 - Energy Transportation and Transmission). In addition it should provide the important interface to the large-scale uncontrolled test-loops of the type operated and funded by industry.

A facility of this nature is badly needed in Canada as has been documented in many reports by and to government agencies. Use of the French facility at Caen will provide very important "hands-on" experience for the design of a Canadian controlled low-temperature facility.

The programme will need to be much broader in scope than previous French experiments which have been largely confined to monitoring isotherms. As a minimum parameters such as listed under item (5) of the previous section should be monitored. Careful thought will need to be given to those operating conditions which will yield the best data returns.

If E.M.R. is to fund the entire proposal, and this is certainly the best way to get the optimum yield from the experiments, it is essential to consider other experiments than straight-forward frost heave. In fact the more investigations that can be "piggy-backed" the lower the effective cost per experiment. Certainly the addition of experiments to monitor pipe stress should be considered. Perhaps at some stage pipe performance through artificial ice-wedges or pipe crossings between soils of high and low frost susceptability might be considered. Although problems uppermost at present relate to induced permafrost growth and the consequent frost-heave of soils around a chilled pipeline, problems relating to warm pipelines in cold soils need investigation. Other investigations should include geomorphic phenomenon such as rock-ice interactions, solifluction and other processes relating to slope instability.

Serious thought should be given to upgrading the data acquisition system to improve accuracy, increase flexibility, streamline the data acquisition and produce data in a computer-compatible format. In addition to possible discussions with the French on an upgrading of the measuring system and related costs, we need assurance that Canada will have an adequate input into the actual experimental programme. Research results of particular interest to the French applicable to very cold LNG pipelines may not be relevant to cool pipelines since freezing rates strongly govern the active phenomena such as ice-lens growth.

Summary

With some provisos outlined in the previous section, the proposed programme could yield considerable immediate benefits to Canada at a faster rate and a lower cost than waiting for a Canadian controlled environment facility. In addition some useful experience could be obtained towards the design and operation of that facility. The currently estimated Canadian portion of the operating cost at $55k per year is probably too low; however even at cost 100% higher the scientific return could be a bargain. We will require assurance that the facility can carry out the research proposal and at a fixed previously agreed upon cost; 66% of the unknown or uncertain total operating costs would be an unacceptable arrangement.

We might want to consider purchasing and installing our own data acquisition system to use at the facility but which would remain E.M.R. property. Prices for purchase of such a system would be a minimum of around $30k to which must be added transportation and installation costs. The number of useful experiments which might be envisaged warrants upgrading the programme to comprise additional investigations and investigators (e.g. the addition of an engineering student to look at pipe stress). If E.M.R. funds the entire project, tight progress reporting and invoicing will be necessary in a contract where complex international contacts are involved.

As must be apparent from the text there are, at present, many questions still to be answered concerning the operating conditions of the facility, its adaptability to the desired experiments and the options available should modification prove limited. Details of the scientific, technical and financial management of the project also need to be worked out. Further discussion and negotiation among the French, Carleton University and the funding agent (EMR and/or others) will be necessary to resolve these matters once the project has been approved in principle.

References

1. Federal Environmental Assessment Review Office - Arctic Pilot Project, Panel Report No. 14, 1980.

2. National Research Council of Canada - Research and Development for Engineering in Cold Regions, Special Public No. 5 DBR, NRCC 17829, 40p., 1979.

3. National Academy of Sciences - Opportunities for Permafrost-related Research Associated with the Trans-Alaska Pipeline System, 37p., 1975.

4. Berger, T.R. - Northern Frontier, Northern Homeland; The Report of the Mackenzie Valley Pipeline Inquiry, 2 volumes, 1977.

5. National Energy Board - Reasons for Decision, Northern Pipeline, 3 volumes, 1977.

6. Federal Environmental Assessment Review Office - Alaska Highway Gas Pipeline Project, Yukon Public Hearings, 61p., 1979.

7. Judge, A.S. - Environmental Impact Statement for Alaska Gas Pipeline Project: Technical Review of Permafrost - Related Problems, 18p., 1979.

8. Williams, P.J. and Frémond, M. - Soil Freezing and Highway Construction Geotechnical Science Laboratories, Carleton University, 105p., 1977.

9. As above p. 16, 17.

10. Philippe, A; J. Aguirre-Puente, and H. Bertouille - Etude en simulation des effets du gel sur les structures routières et leur sols support, Colloque International de géomorphologie, Bull. No. 13 à 15 de Centre de Géomorphologie de CNRS, 1972.

11. Ecole Polytechnique Fédérale de Lausanne - La Nouvelle Halle "Fosses" et l'Ecole polytechnique fédérale de Lausanne, Communication du Laboratoire de géotechnique No. 46, 12p., 1978.

APPENDIX I

Proposal for France-Canada Joint Operation of Full-Scale Facility for Modelling Heat and Moisture Flows in Freezing Ground Around Buried Pipes.

by P.J. Williams

Carleton University

MEMORANDUM

Re: Proposal for France - Canada Joint Operation of Full-Scale Facility for Modelling Heat and Moisture Flows in Freezing Ground around Buried Pipes.

Background:

The Ecole Nationale des Ponts et Chaussées, (ENPC), the Centre Nationale de la Recherche Scientifique, (CNRS), the Laboratoire Centrale des Ponts et Chaussées, (LCPC) and Carleton University Geotechnical Science Laboratories, have co-operated on the questions of ground freezing in relation to pipelines and highways, for seven years. Scientist exchanges (including two under the Canada - France Scientific Exchange Agreement), and joint seminars[1] in Ottawa, (1977) and Paris, (1980) for senior officials in government and industry, have now led to a French proposal (initially November 1979) for a joint research project using the "station de gel" at Caen. This is a 144 square metre indoor structure with a controlled environment, including soil thermal and hydrologic monitoring from 2 control rooms. The project would involve French and Canadian scientists and graduate students, in an experimental study of soil-pipeline interactions. The half-million dollar facility, used in recent years for highway modelling[2], would be modified

1 Soil Freezing and Highway Construction. (Eds: Fremond and Williams), Ottawa 1977. 105 pp. (also as: Gel des Sols et des Chaussées, Paris 1978, 82 pp.) - published by ENPR and Carleton University.

2 La Station de Gel de Caen - presentation; premiere experimentation 1970, 22 pp., 37 figs., 12 pls. Deuxieme et troisieme experimentations: Aspect geotechnique et thermique 1974, 103 pp. Quatrieme experimentations: Aspect geotechnique et thermique 1975, 90 pp. - published by LCPC; Laboratoire d'Aerothermique du CNRS; Centre de Geomorphologie du CNRS.

with burial of a pipe section. Observations of temperature and moisture distribution and frost heave during a two-year period with cooling of the pipe, and detailed measurement of soil thermal and hydrologic properties according to methods developed at Carleton, would be combined with mathematical modelling procedures developed in Paris. The outcome would be increased knowledge of temperature patterns, soil displacements and pressures, associated with freezing around buried pipes, Analysis of suitable models for field prediction in association with gas and oil pipelines in the Candian North would be one ultimate aim. The results would also apply to problems of LNG storage and transmission in temperate lands.

Advantages of the Proposal:

1. The main technical barrier to northern pipeline development is the relationship of buried pipes to freezing soils, and the thermal and hydrologic interactions. Without substantially increased knowledge of these phenomena the construction of major gas pipelines in northern Canada cannot yet be relied upon.

2. Canadian access would be assured, immediately, to a ready-made facility, which would otherwise cost in excess of $500,000 and take substantial time to construct in Canada.

3. The testing of mathematical models, and development of reliable assessment methods for soils, requires experimentation under well controlled conditions. Field experimentation (on natural soils, in the North) is

attractive to engineers responsible for construction, but the natural variability of soils, microclimate, etc. makes impossible the clarification of fundamental processes and relationships. A model facility has a vital role additional to field experimentation, especially in developing predictive procedures.

4. Joint operation of the facility would expedite international co-operation in these complex problems where Canada's expertise is not well balanced and needs to be increased urgently, in accordance with national energy goals. Associations with graduate students of Canadian and French universities would enhance the pedagogic role of the project. This would contribute, modestly, to providing trained specialists, urgently needed by the industry.

5. By combining specialist expertise from Canada and France the project will allow a properly balanced team for development and analysis of the experiment. Obviously the French initiative arises from interest in low temperature gas storage and transmission, and in recent Canadian findings relating to freezing soils. Placing these findings in the context of French thermal and hydrologic analyses and theoretical work will be of value to Canadian scientists and engineers.

Administration and Finance:

The facility would be operated with permanent French technical staff from CNRS and LCPC maintaining equipment. Because the facility is a part of the main CNRS research station at Caen with a large technical and professional staff, maintenance, and technical services for scientists, of high standard, will be on hand. According to the French proposal, general scientific direction would be under M. Fremond, Chief, Mathematical Services, LCPC, and Professor, ENPC, and the undersigned, Geotechnical Science Laboratories, Carleton University and Geotechnical Advisor, Federal Environmental Assessment Review Office. Materials, samples, and special equipment will be shipped between Canada and France as appropriate.

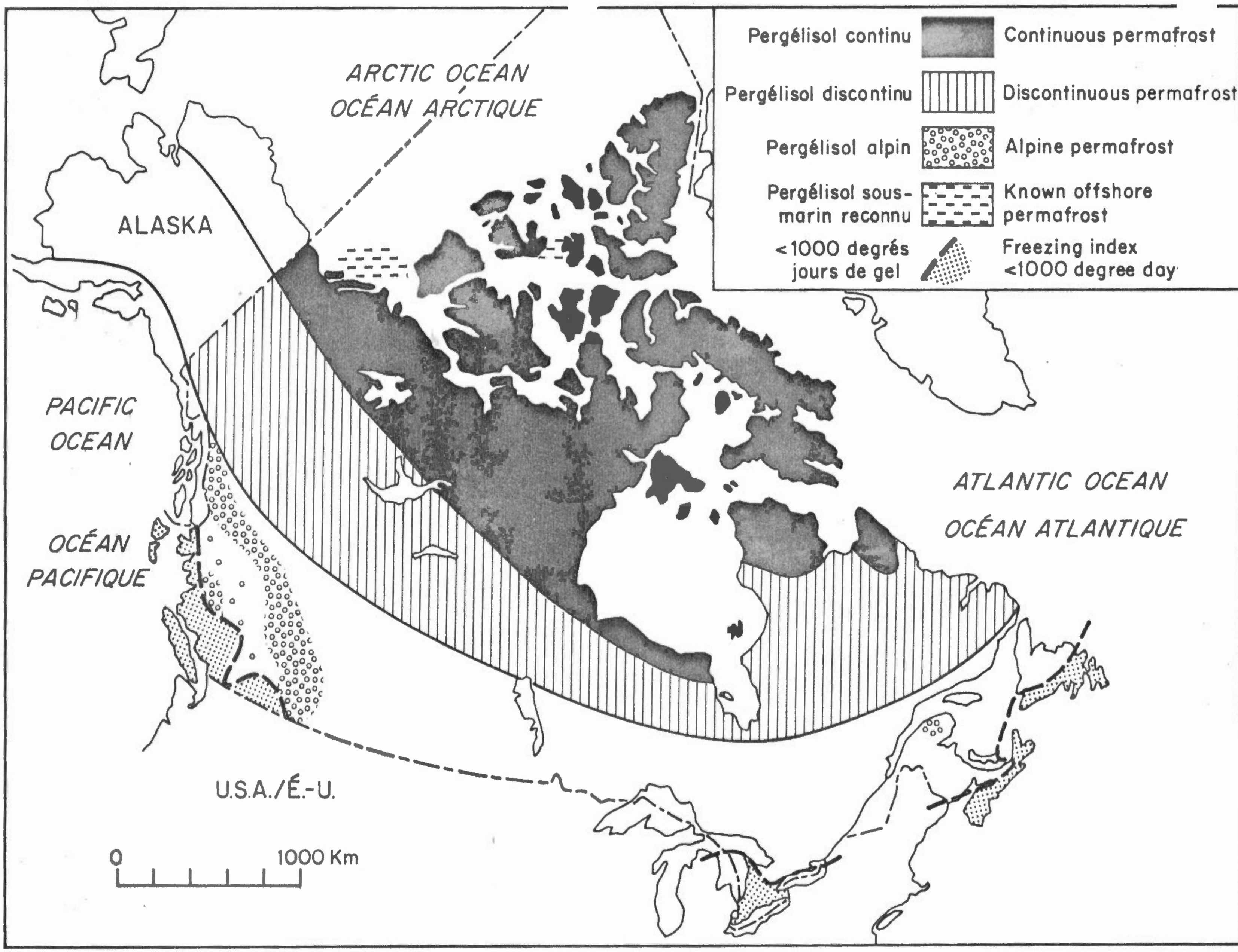
The French estimate of operating expenses is Fr. 600,000 over two years. Use of the facility will be provided rent-free while the operating expenses will be divided one-third France and two-thirds Canada (i.e. $55,000 per year for Canada). Recognizing the capital costs of the facility this appears a generous sub-division. In addition, an estimated $40,000 per year would be required from Canadian sources for graduate student bursary, accommodation and travel expenses, the cost of specialized testing in Canadian laboratories, travel by scientific personnel, and administration. To some extent this sum is already covered in that a qualified graduate student normally holds a fellowship or similar, and ongoing contracts (Federal Government) for studies of frozen soils could be profitably linked with the proposed study.

Present Situation:

Responsible personnel in LCPC, ENPC, CNRS back this project and the Délégation à la Recherche Scientifique et Technique have allocated key funding for the French contribution. Confirmation of Canadian interest in the project is required by December 31st, 1980, or this funding will be jeopardized. French natural gas interests are also expected to contribute. The Canadian Embassy in Paris favours the association of these esteemed French bodies with Canadian industrial research needs. The undersigned has discussed the proposal informally with several government and industry people in Canada. It has also been preliminarily raised before the Committee for Needed Northern Research. However, no definite action had been undertaken at the time of my recent visit to Paris on other business, at which the advanced stage of French planning was made clear together with the need for early decision.

Members of the Geotechnical Science Laboratories at Carleton have been much involved in research into soil freezing and pipelines and also as advisors in the regulatory process. From both these points of view it is our opinion that this is a very significant project. However, Carleton University's financial position would not allow any subsidizing of the project. The necessary scientific milieu, and a well-qualified francophone graduate student could be made available. The University would not be in a position to be substantially associated with the project unless funding was fully assured from industry and/or government sources. It would appear desirable that industrial consultants presently engaged in geothermal design problems, should also have close contact with the project and findings.

October, 1980 P.J. Williams.



Pergélisol continu
Continuous permafrost
Pergélisol discontinu
Discontinuous permafrost
Pergélisol alpin
Alpine permafrost
Pergélisol sous-marin reconnu
Known offshore permafrost
<1000 degrés jours de gel
Freezing index <1000 degree day
ARCTIC OCEAN
OCÉAN ARCTIQUE
ALASKA
PACIFIC OCEAN
OCÉAN PACIFIQUE
ATLANTIC OCEAN
OCÉAN ATLANTIQUE
U.S.A./É.-U.
0
1000 Km

RD398/02/81