Geothermal -
Internal Report.
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Trip Report

Geotechnical Inspection of Alyeska Pipeline:
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M. Burgess

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Crustal Studies Section
Gravity, Geothermics & Geodynamics Division
Earth Physics Branch
Energy, Mines and Resources
1 Observatory Crescent
Ottawa, Canada, K1A OY3

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1. INTRODUCTION

The 800 mile long Alyeska oil pipeline is constructed almost entirely within permafrost terrain. The 48 inch diameter (122 cm) pipe carries 1.6 million barrels of oil per day and is built both in the conventional below ground mode and in a novel above ground design where thaw-unstable frozen ground was encountered. Slightly more than half of the line is above ground. The geotechnical engineering of the pipeline had to deal with many terrain types and difficulties, e.g. thaw-unstable soils, soils sensitive to liquefication, earthquakes, fault crossings, slopes, river and stream crossings, road and animal crossings. In addition many sections of the line had to be remoded (e.g. burial mode changed to above ground mode), either as drilling and ditching revealed unexpected conditions, or as instability and settlements were noted after operations began.

Michael Metz, president of GeoTec Services Inc., is a geotechnical engineer who saw the geotechnical aspects of the pipeline construction through from start to finish, i.e. some 3 years. Metz was also involved in many of the remodes that took place in the first few years of the pipeline operation. As such, his familiarity with the terrain, the design, field procedure, problems encountered and solutions adopted is unequalled. From Sept. 13 to 16, Metz along with Jim Neuenschwander, a project manager with Sohio (1/3 owner of Alyeska) who was particularly involved with the design of the Valdez terminal, hosted a tour of the terminal and the pipeline route from Valdez north to Fairbanks (Fig. 1). This section of the pipeline lies within the discontinuous permafrost zone, except for the southernmost part. The tour was prepared for Canadians who would be involved in the monitoring of the Norman Wells to Zama oil pipeline, also largely built in discontinuous permafrost terrain.

Participants in the tour were:

Margo Burgess - representing Earth Physics Branch, EMR
Alan Heginbottom - representing GSC, Terrain Sciences
David Harry - representing GSC, Terrain Sciences
Bruce Clarida - representing NEB.

Several stops were made each day to examine special geotechnical designs, remodes and monitoring sites. In each case the soil conditions were reviewed and the procedures leading toward the final mode outlined. In addition, the Valdez terminal, Pump Station 10 and the Frost Heave Test Facility (Fairbanks) were also visited. An itinerary, briefly listing and describing the stops, is included in the appendix.

Many informal discussions were also held on the organization of the geotechnical program, on the monitoring and on the proposed Norman Wells programs.

Most remodes during construction and problems after the start of operations have related to settlement, or potential settlement, of thaw-unstable soils. Up to 18 inches of frost heaving of vertical support membranes (VSM's) has been observed and select VSM's are being monitored. The heaving appears to be due to seasonal frost jacking and, as yet, has not necessitated any remode. To some extent the problem is not as critical in that the position of the split rings, which support the crossbeam of the VSM, can be re-adjusted, as can the height of the shoes on the crossbeams.

The sequence of events in the geotechnical design, construction and monitoring of the Alyeska pipeline was very carefully thought out and executed. A summary of some of the relevant procedures at each stage follows.

2. GEOTECHNICAL CONCERNS

2.1 Determination of natural conditions

Initially a minimum of 2 or 3 boreholes were drilled per map sheet (~ 13 km x 26 km), and a terrain unit map constructed. All transitions were drilled, with increased drilling in more important soil types and critical transitions. There was no minimum spacing of boreholes. As more holes were drilled the detailed design relied more and more upon them. Over 12,000 boreholes were ultimately drilled (10,000 over pipe centreline) and laboratory analyses were performed on 45,000 samples.

A computerized soil data bank was established, filing raw data on the boreholes: distance along line, terrain unit, boundaries, and physical properties. The system permitted the compilation of statistics on a unit, e.g. G+L, glaciofluvial plus lacustrine terrains, were statistically the worst conditions for thaw instability. Quick retrieval of information was also possible, as well as rapid location of areas of concern; e.g. when a problem was encountered in a particular spot, the location of sites with similar soil conditions could be rapidly determined.

The determination of thawed/frozen boundaries, in terms of transition from one terrain type to another, was initially based on visual inspection of landforms and vegetation types. Ultimately the boundaries were based on the boreholes. Each borehole (average depth 15 m) was logged in the field by a geotechnical engineer, using the visual ice log system. Metz felt that the engineers in the first few years of the project were not as adept at discerning frozen from unfrozen conditions. For this reason, some frozen sites may not necessarily have been described as such initially and may only have been discovered during confirmation drilling.

No temperature measurements were recorded in these boreholes. During construction 100 thermistor strings were installed. The number of thermistor strings later increased to 400-500 (after remodes); special above ground thermal designs, selected piles, below ground modes in thaw unstable terrain, and special remodes are monitored. All of the temperature sensors are installed on the pipeline right of way; there are none on or beyond the work pad.

The topography of the proposed pipe centreline was initially surveyed (at 75 m (?) intervals) for input into design modelling. Ground water conditions were determined by noting when drilling hit water and by observing the water levels afterwards in the boreholes. No geophysical techniques, continuous or otherwise, were used to map terrain types or thawed/frozen conditions between boreholes.

2.2 Prognosis and design

With the above information, the above or below ground mode was selected for each section. Below ground construction was only permitted in bedrock, or when initial soil conditions were thawed (and not susceptible to liquefication should an earthquake occur), or if the frozen material was thaw stable (i.e. gravels and sands). Special below ground modes were also designed for animal crossings in areas of thaw unstable soils, e.g. the pipe might be insulated and a mechanical refrigeration system installed, or free standing heat pipes might be used.

The precise design was determined using computer modelling: EXXON's thermal model and PIPLIN. At the time a computer run for one section took 4 days. The precise location of the work pad was then also determined; in the above ground mode the zig-zag configuration to accommodate seasonal expansion and contraction had to be followed. Standard zig-zag width was 90 ft (27 m).

The work pad was then built and confirmation holes were drilled before either the ditching or the VSM drilling began. An elaborate set of field design change procedures and design verification was prepared. Engineers on the line were equipped with 4 volumes of field procedures and they continuously checked their borehole logs and ditch logs against the prognosis. Eighty-five (85) percent of the time trench results confirmed the predictions. When unexpected conditions were discovered, certain lower level decisions could be made in the field, e.g. changing burial depth. Critical conditions required remodelling and new computer runs by the consultant, approval by Alyeska and then by the government (both state and federal*). Three hundred (300) design changes were made.

Ultimately the design was done on a foot by foot basis. The geotechnical engineering team had essentially "carte blanche" in selecting the design, i.e. no budgetary restraints. The Alyeska philosophy was to avoid short cuts, as these could later prove to be very costly. Similarly there were no budget levels for the remodes; the quickest solution and the testing of as many different techniques as possible were of prime concern.

There were a few unique situations where, e.g. for political reasons or topography, access could not be gained until a work pad route was selected. Thus no initial drilling was available. Occasionally unexpected conditions were uncovered and remodes were required: e.g. at Forty-Three Mile Hill where an unexpected pocket of thaw unstable permafrost on a steep slope necessitated excavating to bedrock to bury the pipe.

* Alyeska initially agreed to certain terms and conditions set by the government. Any major design changes had to be approved. One federal representative was selected for all federal agencies, and one for all state agencies. In this way coordination within each government level and between the two was achieved. Alyeska thus dealt with these two agents, who were on site in Alaska, rather than with individual agencies.

2.3 Construction

Permafrost sections were generally built in the winter, unfrozen sections in the summer.

In the above ground mode, the pipe rests on a shoe which is free to slide on a crossbeam supported by two VSM's; where necessary each VSM contains two heat pipes (heat exchangers using ammonia). Each set of VSM'S is separated by 60 ft (18 m). Apparently there is a 200% redundancy in this spacing and they could have been 180 ft (55 m) apart, i.e. two consecutive pilings could fail.

The pilings are of a large diameter (45.7 cm) and the low load makes them more susceptible to heave. In fact 99% of VSM problems are with heave, only 1% with settlement.

In all 88,000 VSM holes were drilled and logged and each VSM individually designed by engineers in the field, i.e. length and type (thermal, slurried and freeze, friction with cement grout, or end bearing).

These borehole logs provided much additional soil information. The following statistics summarize the logging:

10,000 boreholes on pipe centreline: ~ 1 borehole/150 m

640 km of logged trench

~ 640 km, of above ground mode with ~ 44,000 VSM sites: ~ 70 VSM holes/km

Many unique construction modes were adopted and several of these were inspected on the tour. These include:

1) Thompson Pass area: steep terrain necessitated building a cable car system in order to dig trench, lay pipe and backfill with concrete.
2) Special shorter zig-zag configurations.

3) Special thermal design sections: i) large number of heat pipes to ensure integrity of frozen state in soils prone to liquefication, ii) short rigid VSM section with heat pipes to deal with small thaw unstable pocket.
4) Buried sag bend animal crossings with free standing heat pipes.
5) Elevated animal crossings with more than 10 ft (3 m) clearance below pipe.
6) Buried, insulated and mechanically refrigerated road and animal crossings.
7) Suspension bridges over rivers.
8) Stream crossings where high flood levels required special VSM protection from ice and VSM's were in casings.
9) Denali fault crossings: 1) main McKinley strand built on gravel pad, pipe rests on long steel beams and is free to slide up to 6 m laterally and displace 1.8 m vertically, ii) nearby smaller strand located in stream floodplain combines features to protect VSM's against ice with a wider crossbeam to allow horizontal displacement. The height and width of crossbeams necessitated 3 VSM's per support.
10) Special slope drainage features, ditches, benches.
11) Snow work pad section, no permanent gravel pad because of very high ice content in soils.
12) Roadcrossings: buried, refrigerated, above ground in culverts.
13) Remodes when settlement problems occurred, i) involving installing VSM's to support buried pipe, ii) excavating around buried pipe and installing above ground mode (but in a trench).

2.4 Post construction testing and performance monitoring

A hydrotest was performed before oil flow began to fully load the pipe and test pile performance.

The pipeline route is flown over by security personnel daily. Technical surveillance (driving and walking the route) is performed once a week (?).

Four thousand (4,000) settlement rods and 400-500 thermistor strings are installed for monitoring pipe movements and terrain disturbance. Some of these were installed during construction although most were installed after operation began and problems appeared. The difficulty with these later installations is that no good reference data for initial pipe position or ground temperature was available.

Movement of selected VSM's is also monitored. All the performance monitoring is done by Alyeska. The frequency of monitoring of thermistors or rods depends on the severity of the problem, and thus varies from site to site. Data acquisition is manual and there is no telemetering of these temperatures or rod displacements.

Thermopile (heat pipe) performance is also monitored once a year with infrared airborne photography. Several reference thermopiles, attached to VSM's but not in the ground, are located along the route. One hundred percent (100) redundancy was built into the heat pipes (i.e. twice as many as needed). At the moment Alyeska is experiencing some difficulty with their performance; non condensible gas collects at the top and reduces the efficiency. Methods to remove the gas, e.g. by molecular diffusion, are being examined.

No attempt has been made to see how the pipeline and work pad have influenced snow distribution and hence ground thermal regimes. Changes in snow patterns have been observed.

The mechanically refrigerated sections (with the pipe insulated and buried) have presented persistent problems. Metz cautions to avoid this mode if at all possible. Insulation breakdown and corrosion of the pipe, and less efficient refrigeration seem to be occurring.

There is no university involvement in the performance monitoring. There was only slight university involvement during design (U. of Alaska and U. of Illinois (?), the latter for soil properties).

Sites selected for monitoring were those of concern to Alyeska - areas of special design or of problems after construction. The government did not impose certain criteria in terms of locations or types of instrumentation and does not seem to be involved in checking the monitoring. There is no government monitoring, apparently their experience is that government personnel are not reliable and don't provide enough interest or continuity.

We did however visit ADEC, the Alaska Department of Environmental Conservation, where monitoring of oil spills and revegetation are a main concern. The ADEC were also involved in monitoring water quality and solid waste disposal during construction.

Neither of our guides was intimately involved with the monitoring programs and frequencies, or with the most recent remodes. Apparently since the oil spills at M.P. 734 and Atigun Pass some budgetary restraints have been imposed on future remode design.

3. DOCUMENTATION

A suite of supporting documents, describing in detail the case histories of many of the sites visited and the geotechnical aspects of the project were supplied. Many of the points mentioned in this report are outlined in much greater detail in these papers. A small amount of the information is proprietary. The table of contents for the binder of supporting documents is reproduced in Table 1.

Metz has offered to send us more information, e.g. drilling logs, on the case histories, if needed.

A series of photographs were taken at each stop. A slide collection and individual site descriptions are available.

4. CONCLUSION

The Trans Alaska pipeline is an outstanding engineering achievement in which geotechnical engineers played a key role. The geotechnical program impresses one as being very well thought out, managed and undertaken. Terrain disturbance appears minimal and revegetation is progressing well.

Post construction monitoring focuses on pipe performance. No attempts have been made to monitor climatic changes. Quite often settlement rods or thermistor strings were only installed once a problem appeared. Thus no good reference, baseline data exists.

Two aspects were continually emphasized by our hosts as important to future pipeline projects:

1) the only way to know the position of the pipeline is via rods (either welded or strapped) to the pipe,*

2) good "as built" data should be carefully collected - be it ditch logs, height of working pad, pipe position, ground temperatures - so that changes can be assessed, problems judged. Settlement problems that have been observed where no settlement rods existed, were often detected by pigs (devices which travel through the pipeline and are capable of cleaning the pipe as well as monitoring corrosion and "out of round") or in some cases by thermistor strings. In these cases, however, no reference position of the pipe was available.

* The use of fibre optics to measure pipe deformation is being examined by Metz, and apparently shows potential.

The EPB monitoring program for Norman Wells will provide the necessary background for understanding and perhaps predicting pipe performance. A tie in of the thermal regime monitoring, ground disturbance and vegetation programs, with pipe performance monitoring (via rods) would be useful.

A reciprocal tour is planned for next winter to show aspects of the Norman Wells-Zama pipeline construction and of the monitoring programs.

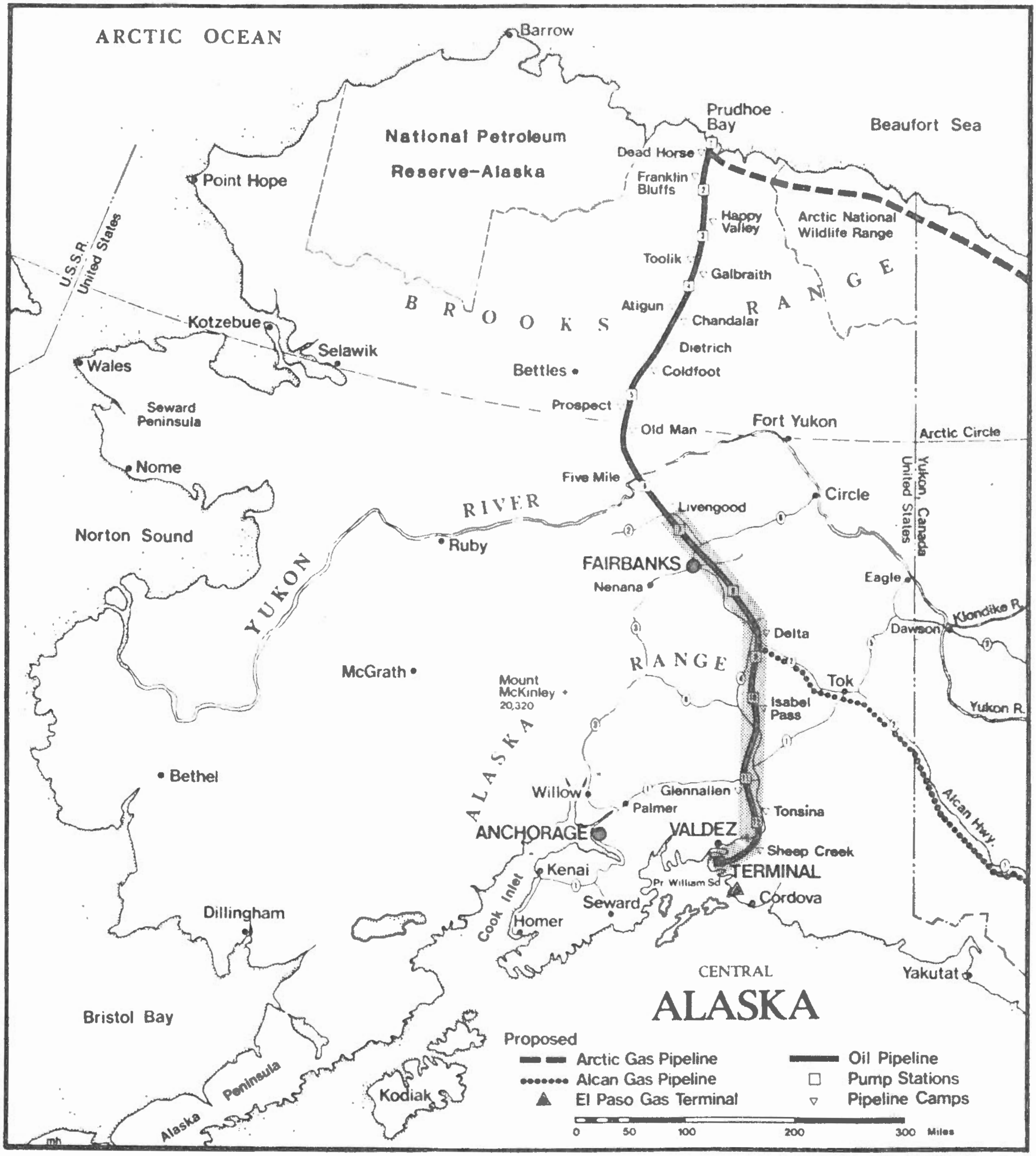

FIGURE 1. ALYESKA PIPELINE INSPECTION TOUR

TABLE 1. CONTENTS OF DOCUMENTATION BINDER

Subject	Tab
Pipeline Location Map--General	1
Pipeline Route Maps	2
Geotechnical Aspects of TAPS	3
Stability Problems of Rock Cuts--TAPS	4
Field Design Change Procedures and Design Verification	5
TAPS--Operating and Maintenance of Aboveground Pipelines in the Arctic	6
Buried Oil Pipeline Design and Operation in the Arctic	7
Forty-Three Mile Hill	8
Study Cases A & B, A.S. 12	9
Study Cases C & H, A.S. 13	10
Special Thermal Design to Prevent Thaw Settlement and Liquefaction	11
Study Case E, A.S. 17	12
Study Case F, A.S. 17	13
Remode Event, A.S. 28	14
TAPS Data Sheets	15
Haines - Fairbanks Pipeline Design, Construction and Operation	16
Report on The Davidson Ditch	17

Appendix

Itinerary

September 13, 1983

- Valdez Terminal (operations and geotechnical tour)
- Keystone Canyon - 900 ft cliff
- Lodging in Valdez

September 14, 1983

- Thompson Pass - cable car construction, concrete backfilled trench
- Worthington Glacier - retreating; buried pipeline
- Forty-Three mile hill - southernmost permafrost occurrence
- Case A&B: 2nd southernmost permafrost occurrence buried because next permafrost occurrence was not anticipated for quite some distance
- Case C & H - 3rd southermost permafrost occurrence, only a few miles from case A & B, unexpected, access problems, special zig-zag configuration
- M.P. 734 - oilspill, small pocket of permafrost, rapid transition, below ground mode, remode with buried VSM's
- Special thermal design - many heat pipes, liquefication problems potentially
- Squirrel Creek Cut - drainage and erosion control devices
- Special sagbend animal crossing
- Glenn Highway refrigerated crossing (mechanical system) and Tazlina River suspension bridge, slope failure site
- Gulkana River Bridge and very long refrigerated caribou crossing
- Special thermal design - short rigid above ground section
- Lodging in Paxson

September 15, 1983

- Denali fault crossing - pipe resting on beams allowing 6 m of lateral displacement
- Special design VSM, Lower Miller Creek and Castner Creek: flood levels, ice problems, fault crossing
- Pump Station 10 - control room, refinery, generators, turbines, pumps, pig discharge and input, oil spill contingency, DRA (drag reducing agent) injection
- River Training Structures (Delta River floodplain): revetements, spurs
- Special Thermal Design road crossing
- Tanana River suspension bridge
- Haines Pipeline pump station
- Shaw Creek Crossing
- Lodging in Fairbanks

September 16, 1983

- Tour of frost heave test facility - in particular, differential heave sections
- above ground remode in trench - settlement problems
- Snow work pad site - no permanent gravel pad, high ice content soils
- Above ground road crossing in culvert - similar to Inuvik utilidor.