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Abstract

Interprovincial Pipe Line (NW) Limited (IPL) operates a crude oil pipeline through an area of discontinuous permafrost in the northwest of Canada. The pipeline is the first, fully buried pipeline in permafrost in North America and has operated successfully for over 12 years. During the 1994 and 1995 forest fire seasons, fires traversed the pipeline right-of-way in two main areas, which included a number of permafrost slopes insulated with wood chips to compensate for construction disturbance.

This paper briefly reviews the original design basis for the permafrost slopes and the effects of the fires on the pipeline right-of-way and slopes, and some of the impacts on adjacent slopes. The paper also discusses remediation measures and the ongoing monitoring of the effects of the forest fires.

Introduction

The Norman Wells pipeline is a 324 mm diameter oil pipeline that runs 869 km through an area of discontinuous permafrost from Norman Wells, Northwest Territories to Zama Lake, Alberta. This pipeline was constructed during the winter seasons of 1983-84 and 1984-85 and began delivering crude oil in April 1985. Approximately 5,000 m³ (30,000 barrels) per day of oil are presently transported through the system.

An outline of the slopes design approach and the performance of these slopes since the start of operation in 1985, have been presented by Hanna and McRoberts (1988), Hanna et al. (1994) and Oswell et al. (1998). The design for numerous ice-rich slopes called for a layer of wood chip insulation (90 to 150 cm) to be placed over the slopes, in order to compensate for the thermal impact of construction disturbance on the permafrost. Apart from some initial lingering heat problems in decaying wood chips on limited areas on a small percentage of slopes, the wood chips have been performing well. However, during some forest fires in 1994 and 1995, the wood chip insulated slopes were considered a particular concern as it was unknown how they would be impacted by the fires.

Several methods have been utilized in order to monitor the pipeline right-of-way, the conditions of the slopes and the pipeline itself. These methods include weekly pipeline patrols by helicopter to look for conditions that may adversely affect the pipeline, such as movement of the slopes, washout or erosion due to rain or high water levels, or any other occurrences that may indicate potential problems.

In addition to these aerial patrols, monthly and quarterly instrumentation readings are taken at many of the slopes along the pipeline. Instrumentation includes thermistors that measure pipeline temperature and ground temperature at various depths to indicate the extent to which the ground is thawing. Piezometers are used to measure the pore pressures in several of the slopes, to indicate the extent to which excess pore water pressures were developing as thaw occurred. This data, in conjunction with other parameters, was used to assess the factor of safety of the more significant slopes on an annual basis.

Alan J. Hanna, et al.
In-line pipeline inspection tools are also used to provide an indication of the condition of the pipeline. The in-line inspection tools used are internal geometry tools (GEOPIG) and corrosion tools (Ultrasonic and Magnetic Flux Leakage). Internal geometry tools provide measurements on the shape of the pipeline, the pipeline profile and provide data on the pipe curvature and the location of the line. By assessing the pipe curvatures and the pipe strain data, it is possible to determine from year to year whether any pipe movement has occurred, due to settlement, frost heave, or slope movement. This assessment has become a valuable component in the yearly analysis of the pipeline.

**Description of the 1994 and 1995 fires**

During the summer of 1994, a forest fire, initiated by an electrical storm, burned an area paralleling approximately 90 km of the pipeline right-of-way, as shown on Figure 1. Of this 90 km, only 20-40% of the right-of-way was damaged by the fire. Overall, the fire consumed an estimated 200,000 hectares of forest.

In the summer of 1995, a second forest fire, initiated by a long-smouldering coal seam fire approximately 5 km south of Fort Norman, burned an area along an additional 53 km of the right-of-way and consumed an estimated 58,500 hectares of forest. As in the previous year, only 20-30% of the right-of-way (within the burn area) was damaged.

Prior to the fires reaching the right-of-way, measures were implemented to minimize the impact of the fires on the pipeline system and in particular, on the wood chip insulated slopes. Pumps and sprinkler systems were set up and water was pumped up from adjacent creeks or rivers in order to saturate the wood chips.

**Fire impact and remediation of the pipeline right-of-way**

In most cases, the impact on the right-of-way by the fire was minimal. The fire remained in the trees and caused a great deal of damage to the forest and the organic mat on the forest floor (due to falling cinders, etc.). For the most part, grass on the right-of-way was essentially unaffected by the fire as it passed, although peatlands and some areas of dry vegetation were scorched. Overall estimates are that approximately 70 to 80% of the right-of-way remained unburned through the areas where the fire travelled.

All of the thermistors on the wood chip slopes are manually read, therefore, there is no ground temperature data available as the fire crossed the slopes. Readings taken approximately two weeks before the fire and two weeks after the fire showed very little change in the ground temperatures of the slopes. In most cases the temperatures beneath the wood chips were actually lower by 0.5 to 1°C after the fires had passed, indicating that the slopes were well insulated from the heat of the fire.

The impact on the wood chip surface was observed to be minimal, in that only the top layer of chips (20 to 70 mm) was scorched. This top layer was then raked away since the charred wood chips would absorb additional heat into the slope. Raking the burned chips exposed the unaffected layer beneath, and returned the surface of the slope to its pre-fire condition. This reduction in wood chip thickness was an extremely small percentage of the original thickness placed during construction.

In addition to raking the woodchips, hydro-seeding of the area adjacent to some of the slopes and around valve sites was also performed to help quickly restore vegetation on these areas and to cover the blackened, heat-absorbing surface that remained after the fire passed.

Results of the GEOPIG geometry tool have not indicated any movement of the pipe that can be attributed to any impacts from the forest fires. Up to now, the effects of the fire do not seem to be impacting the pipeline or the right-of-way in a negative manner. However, specific monitoring of the system is continuing to ensure that fire-impact conditions adjacent to the right-of-way do not have an impact on the pipeline.

The sites that were affected the most by the fires were the wood chip insulated slope at Kilometre Post (KP) 94 and the area around KP 182.
KP 94 Burnt cribbing and wood chips

Slope 33, at KP 94 has a timber cribbing at the toe of the wood chip insulation to keep the chips in place during times of high water such as spring runoff. This cribbing was destroyed in the 1995 fire and had to be replaced. The upslope portion of the crib structure was built into the wood chips and remained intact. Remediation consisted of cutting off the charred ends of the cribbing and tying new log cribbing to the support structure.

Adjacent Instabilities at KP 182

The most significant impact of the fires has occurred near KP 182. This site was burnt in the 1994 fire, and has experienced shallow flow slides on areas immediately adjacent to the right-of-way. The route at this section of the pipeline follows a previous clearing and traverses a short distance along the crest of a valley (see Figure 2).

Shortly after the fire in 1994, helicopter patrols and IPL personnel noted a small flow slide adjacent to the right-of-way immediately south of the pipeline slope (see Figure 2). A second slide was noticed further north along an old clearing for a telegraph line. The slide areas are further affected by the loss of shade, the insulating organic mat and the increased thermal impact due to exposed mineral soil. There was a potential for these slides to extend back onto the pipeline right-of-way.

In order to stabilize these slides, the ground in the immediate slide area was seeded and a coconut fibre mat was placed over the area to minimize the exposure to sunlight and provide some nominal erosion protection to the slopes. The coconut fibre will naturally decay, by which time the newly formed grass matting would be established to help protect the exposed mineral soil areas.

Inspections of the areas in the spring/summer of 1995 revealed that the southerly 1994 slide area continued to slide as additional seasonal thaw occurred. At that time it was decided to place wood chips over the upper portion of the slide area and this work was completed in the fall of 1995.

The coconut mat on the northerly 1994 slide area was quite effective and by the end of the summer of 1995, approximately 80% of the slope was covered with a substantial grass mat. There was a small area that showed continued movement, however, it was considered that this small area could stabilize itself. Since this slide area was not immediately adjacent to the pipeline right-of-way, no further remediation was attempted at this location.

During the spring and summer of 1995, additional flow slides and slumping were noted along the valley wall that paralleled the pipeline (see Figure 2). These slides were occurring perpendicular to the pipeline. IPL commissioned a geotechnical evaluation of these instabilities and a determination of what impact they might have on the right-of-way and the pipeline. Table 1 summarizes the remediation options considered.

Since, the geotechnical evaluation indicated that the short term risk of the flow slides retrogressing back onto the right-of-way was minimal, it was decided to adopt a “wait and see” approach - Option 2 in Table 1. It was decided to drill boreholes and install thermistors and piezometers during the winter to obtain more spe-
cific ground conditions to assist in determining the mid
to long term impact and the optimum stabilization
requirements. Then depending on what was subse-
quently observed, prepare remedial plans for imple-
mentation as seems necessary.

The field investigation consisted of drilling a total of
12 boreholes in the vicinity of the slide area, determi-
ing the soil stratigraphy and ice conditions and
installing temperature thermistors, piezometers, and
reference pipes for monitoring slope movement. The
soil stratigraphy consists of four main strata, illustrated
on Figure 3. Generally, there is an upper low-plastic
clay unit followed by a medium plastic clay unit which
in turn overlies a clay (till) material, overlying a gravely
cobbley sandy clay till material.

The upper portion of Figure 3 shows the variable sur-
face thermal boundary conditions applied in a finite
element geothermal analysis to predict the 20-year thaw
profile, which is also shown on Figure 3. The findings
of the geothermal analysis indicated that there would
be some continued thawing of the disturbed areas (i.e.,
the pipeline right-of-way, the old clearing along a tele-
graph line, and the flow slide), but that the tempera-
tures between the head scarp of the flow slide and the
telegraph line are predicted to remain relatively cool
with essentially no long term degradation of the per-
mafrost. In this location, there is less disturbance of the
vegetative cover and there is a slight sloping down-
wards toward the east (i.e., the direct impact of sunlight
is somewhat reduced). This area tends to form a natural
thermal barrier along the crest of the valley wall.
Because of this phenomenon, it was not considered nec-
essary to place wood chips or other insulating materials
along the crest in order to prevent additional thawing.

Observed temperatures in Borehole T1 (see Figure 3)
have confirmed cool ground conditions at this location
to this stage, as follows:

<table>
<thead>
<tr>
<th>Temperature at 6 m depth:</th>
<th>Sept 1996</th>
<th>Sept 1997</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1.6°C</td>
<td>-1.2°C</td>
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**CONCLUSIONS FOR INSTABILITIES AT KP 182**

The summary findings of the assessment of the flow
slides at KP 182 indicated that the flow slides are most
likely within the weak colluvium found on most valley
walls. There is little potential for any further progres-
sion of failure surfaces into the generally more compe-
tent clay till material.

The fact that the flow slide areas are of a finite width
means that they can have limited impact on the overall
slope. The 1995 flow slide area was actually in a slight
natural draw on the side of the valley wall, with minor
knolls on either side that are more stable.

It is expected that measures to re-establish good vege-
tation cover on all areas directly damaged by the fire
and where mineral soil is exposed due to sliding, will
reduce the increased summer heat input into the
ground. However, simply re-establishing grass cover on

| Table 1. Remediation Options for Flow Slide Failure Adjacent to ROW at KP 182 |
|---|---|
| Options | Risk to Pipeline |
| 1. Do nothing, at least for one year; see what happens; respond only when absolutely necessary. | Negligible risk initially; increasing risk with time; the available remedial solutions may become more limited with time. |
| 2. Do no remediation in winter of (1995-96); drill boreholes in winter to determine stabilization requirements and the mid to long term impact; see what happens in summer 1996; prepare remedial plans for implementation as seems necessary. | Negligible risk; plan to address in most appropriate manner in reasonable time. |
| 3. Place wood chips over the 1995 failed and slumping areas. | Minimal risk, however may prove to be overkill in short term. |
| 4. Place wood chips over 1995 failed and slumping areas and along crest parallel to right-of-way for about 350 m. | Minimal risk, however, most likely overkill in short term. |
an area where much of the very good tree cover, insulating moss and peat have been lost, will never restore these original natural surface thermal conditions.

The deeper thaw zone beneath the telegraph line acts as an additional buffer zone to protect the right-of-way. If the head scarp should regress back in a “thawing permafrost” mode of failure, this form of regression will be arrested once the unfrozen zone beneath the telegraph line is reached. Within this unfrozen zone it will be easier to physically cut a more stable upper slope which should remain stable in the long term. In this manner it should be possible to contain further slumping of the present head scarp away from the right-of-way. Subsequent monitoring of the area around KP 182 has confirmed that there is still no significant further sliding or slumping that is likely to pose a threat to the pipeline.

Up to the present, the fact that the majority of the right-of-way, including the organic mat and the insulated slopes were undamaged by the fire, provides a high degree of confidence that there will be no major impacts on the pipeline. In certain areas, a greater concern was that conditions immediately adjacent to the right-of-way, where there was extensive damage to the protective organic mat, might result in thawing and instability that could encroach onto the right-of-way. Some additional concerns about adjacent right-of-way effects have been presented by Savigny et al. (1995). However, the hydro-seeding of most of the adjacent areas severely affected by the burning has created good new vegetation cover. To date, there is very little indication that these adjacent burned areas will have much impact on the integrity of the pipeline slopes.

**Conclusions**

After the 1994 fire, it was determined that additional precautions should be taken to safeguard certain above ground facilities. These facilities included valve sites which are fuelled by propane tanks, pump stations, and storage sites for equipment and helicopter fuel. Fire breaks around the valve sites were expanded and new fire breaks were placed around the pump stations and storage facilities.
References


