Heave and Solifluction on Slopes

Rupert G. Tart, Jr., P.E.
Golder Associates, Inc., Anchorage, Alaska, USA

ABSTRACT: The Trans Alaska Pipeline System (TAPS) traverses three major mountain ranges. Steep rolling terrain makes up a significant part of the pipeline route. Some of the slopes are in permafrost and others are in thawed ground. In both cases pile have been used to support the pipeline above the ground. Some of these piles have heaved, settled, translated, and leaned. In many cases this has been related to the application or relaxation of the heave forces on the piles and slope. In addition the granular workpad on these slopes moves producing solifluction-like features on the slopes. In some cases mounds of workpad material can be seen on the piles and in other cases depressions as the pad moves away from the pile. This paper will address an interrelationship of these two observed slope behaviors. In doing this the interaction of slope seeps and the freeze front as it forms in fall then recedes in spring and summer is compared to observations of engineered projects.

1 INTRODUCTION

The purpose of this paper is to present information collected over the past 15 years that suggests that solifluction movements are a result of frost heaving subsequent thawing and that creep is not a significant part of the process. The following are the reasons for this hypothesis:

1. Creep is dependent on constant near freezing temperatures. If ground temperatures are too cold there is no creep and if they are too warm the ground thaws.
2. Surficial features such as solifluction lobes experience extreme variation in ground temperatures because they are shallow features that usually can feel all the changes in air temperature.
3. Ground temperatures have less fluctuation with depth and this is where creep appears more likely.
4. Creep is slow and continuous once it starts until there is a load change or temperature change.
5. All soils flow when adequately loose and saturated.
6. Surficial freezing can trap groundwater perched near the surface causing pore pressures to rise.
7. A freeze front with water available to it will expand pore space in most soils making them looser by lowering their density.
8. Solifluction is usually found on slopes where bedrock or impermeable soils are found under a thin mantle of more permeable soils.
9. Many solifluction lobes consist of saturated sands and gravels.

The following sections of this paper present examples of data that has been collected that seem to support the idea that solifluction is a heave phenomenon.

2 VSM HEAVE ON A DISCONTINUOUS PERMAFROST SLOPE

TAPS consists of about 400 miles of buried (B/G) pipe and an equal distance of aboveground (A/G) pipe. The A/G pipe is supported on 18-in. pipe piles, some of which are cooled by passive cooling devices called heat pipes. The A/G support system consists of two piles, a crossbeam, and a sliding shoe that is clamped to the 48 in. pipe and which slides on the crossbeam.

Along TAPS there are several slopes which have been monitored for almost 15 years. The monitoring has consisted of continuous and/or periodic ground and air temperature measurements, sporadic ground water level measurements, some settlement measurements, periodic VSM movement measurements, periodic inclinometer measurements, and continuous measurements of the relative position of the shoe and crossbeam on the aboveground structure. As a result of these measurements, trends of movements have been established for the slopes and the structures on the slopes.

One of the movements that has been studied in detail is the heaving of piles in areas where the ground is thawed beneath the pipes In places where this heave occurs, surficial sliding has also occurred. These areas are typically underlain by thawed moderately consolidated silty clays which were formed as by an ancient glacial lake that covered this area. Most slopes are results of drainages that have cut these lake sediments leaving steep approaches to streams. The pipeline was constructed by flattening some of the steeper slopes then placing a sand and gravel workpad on the surface of the graded slope to provide access for construction and maintenance. This workpad is frequently soft in some locations and flows in some of these areas. Figure 1 shows a picture of the workpad materials flowing around a pile and this is conceptualized in a sketch in Figure 2.

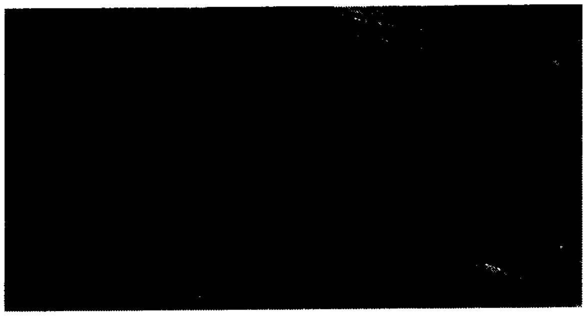

Figure 1. Workpad Flowing Around Pile

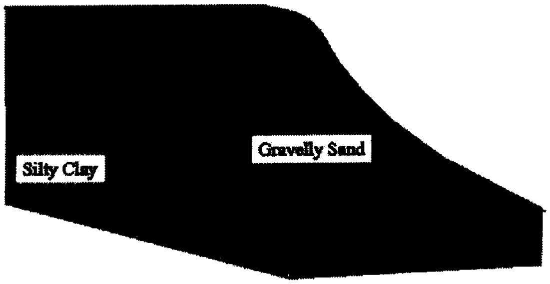

Figure 2. Conceptual Sketch of Flow Around Pile

Thermistor and inclinometer data from the vicinity in which the flowing has been observed are presented in Figures 3 and 4.

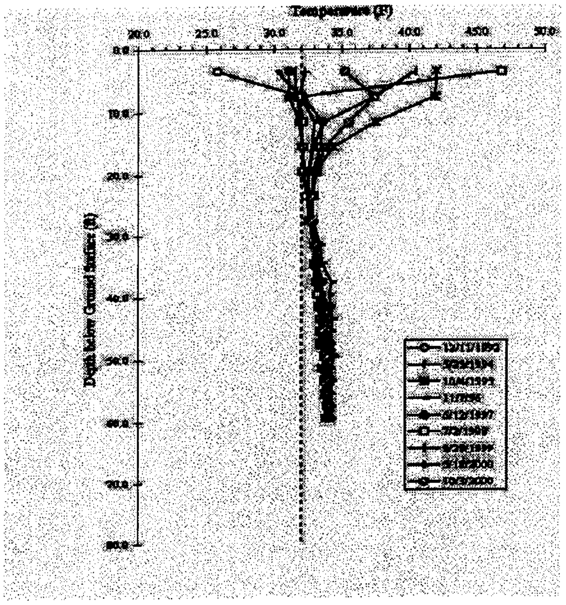

Figure 3. Ground Temperatures at Flowing Site

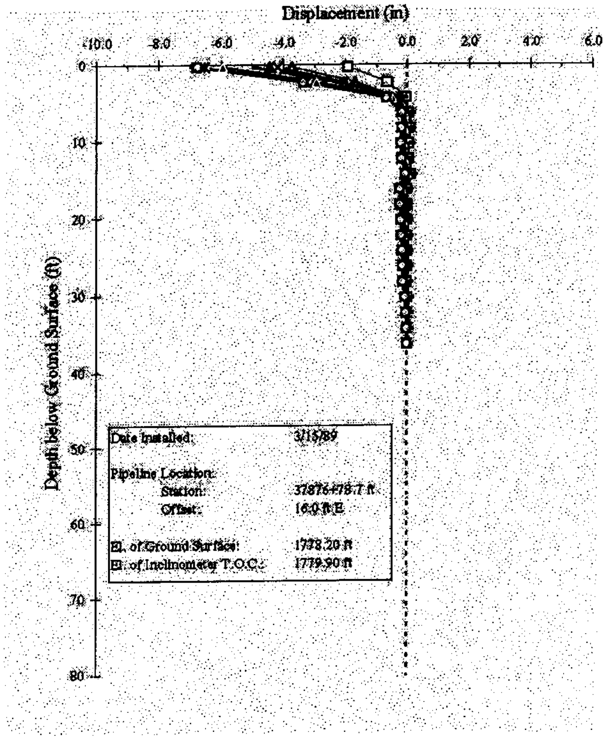

Figure 4. Ground Displacement at Flowing Site

These show only near surface movements and high variations in surficial ground temperature and thawed ground below the active layer.

Figure 5 shows the instrumentation and Figure 6 shows the results of the continuous measures of the relative movement of the shoe along the cross beam and a simultaneous record of the air temperature.

Figure 5. Shoe Monitoring Instrumentation

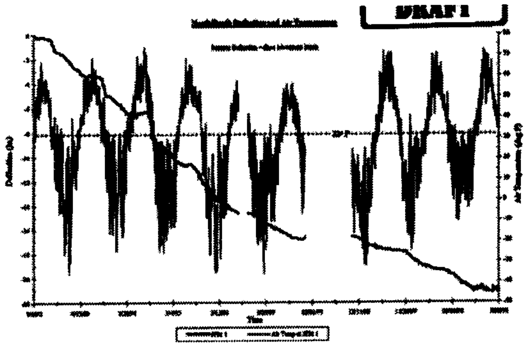

Figure 6. Continuous Temperature and Movement

The relative movement of shoe is result of the movement of the piles as they heave each year. These Figures were used to determine the time of movement, not the magnitudes. These figures show that movements start in the fall and stops in summer when temperatures are well about freezing each year.

In Figures 7, 8, 9, and 10 are a series of conceptual sketches that will be used to explain the process that is causing the workpad to flow.

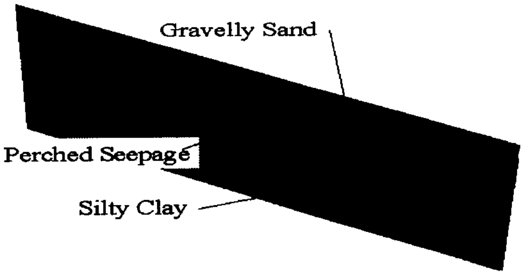

Figure 7. Perched Seepage in Early Fall

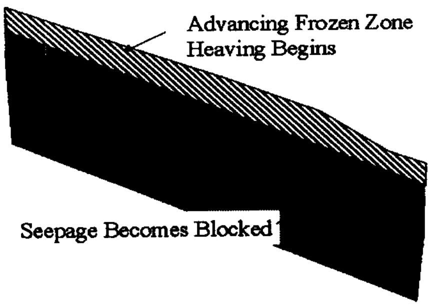

Figure 8. Frozen Zone Advancing in Winter

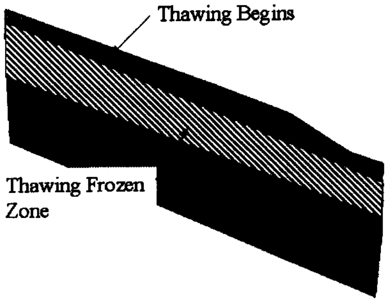

Figure 9. Thawing Begins in Early Spring

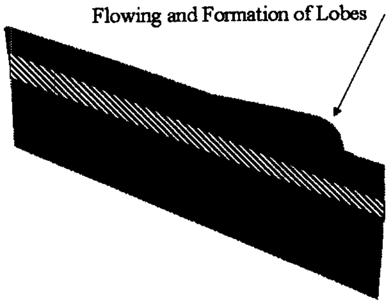

Figure 10. Workpad Flow in Later Spring

In Figure 7 the fall or late summer is represented. At this time the surface water and groundwater that permeate the granular workpad perch and flow on the impermeable silty clay. Figure 8 represents late fall or winter as the active layer begins to freeze. It proceeds down until it meets an undulation of the clay where it then can block the perched groundwater flow. Some pore pressure may build up in the granular workpad, but certainly water is readily available to the freeze front. This water expands as it freezes and may develop ice lenses. It causes over saturation and heaving of the workpad. As shown in Figure 9 thawing begins in spring. At that time the workpad is wet and loose and in some places wet enough to flow until it drains adequately to stop moving. This is shown in Figure 10. The result is a solifluction lobe or mound around a pile.

The remainder of this paper will discuss other examples that appear to some this mechanism of solifluction and similar types of movement.

3 CREEP ON A WARM PERMAFROST SLOPE

As stated earlier, one reason it is believed by the author that solifluction is not influenced by creep is that creep is only significant for a very small ground temperature range. In the following example creep on a slope has been monitored for more than 10 years. The creep occurs continuously in a ice-rich silt layer and terminates at the contact of this layer with a low ice-content silty sand. The slope covers an area of about 1 sq. mi. Inclinometers, surface survey monuments, and thermistors are located thoughout the area. TAPS crosses this area with an A/G section on a cleared workpad. The creep slide plane is below the pad, the bottoms of the piles and appears independent of the pipeline and its workpad. It is occurring in a zone of stable ground temperature that is near 0^0C.

Figures 11 and 12 show temperature and displacement data for one of the fastest moving locations in this area. This is in a relatively undisturbed area located about 500 ft off of the pipeline workpad.

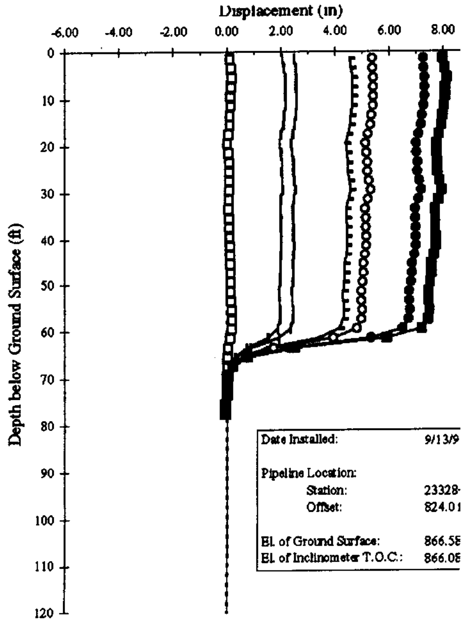

Figure 11. Ground Creep Displacements

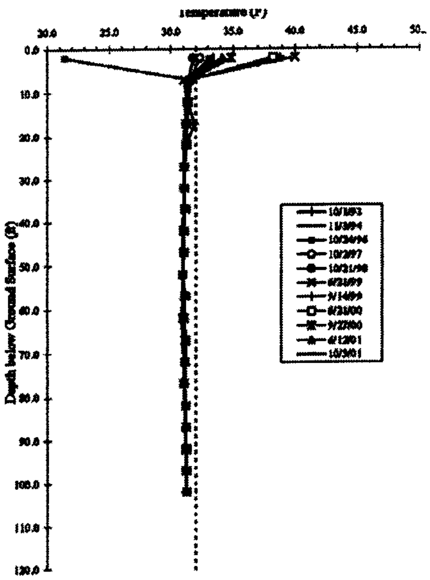

Figure 12. Ground Temperatures at Creeping Site

This site creeps because it is so ice rich and is at a near 32^0F temperature that has remained essentially constant for more than ten years. The ice provides the latent heat resistance to thawing, which is responsible for keeping the temperature constant. The displacement data only covers 2 seasons because, the displacements are so large that the original inclinometer casings became inaccessible and had to be replaced by those shown in the figure.

4 BULGING SPOIL PILES, NATURAL LANDSLIDES, AND DEBRIS FLOWS

Figure 12 shows natural landslides in a discontinuous permafrost area. We believe that this is a result of the same process that results in solifluction. Here there were likely seeps at the landslide locations. These seeps were confined by the freezing active

Figure 12. Natural Landslides in Discontinuous Permafrost

layer in the fall and winter. The landslide footprint became saturated and heaved throughout the winter. In spring the loose saturated surface materials began to slide. These "skin" slides are primarily saturated surficial materials.

At a coal mine site in Alaska, the spoils of the mining operation are fine silty sands which resulted from the breakdown of weakly bonded sandstone that had been moved during the mining process. The extracted mineral is found between layers of this sandstone and thus huge volumes of spoils are generated as the mineral is extracted. In some locations these spoils have been placed over slow flowing springs. The permeability of the spoils was assumed to be sufficient to allow the springs to drain. In summer this assumption may have been correct. In winter, ground freezing contains the spring water, causing bulging and significant downslope movement of the spoils. A photograph of these moving spoil piles is presented in Figure 13.

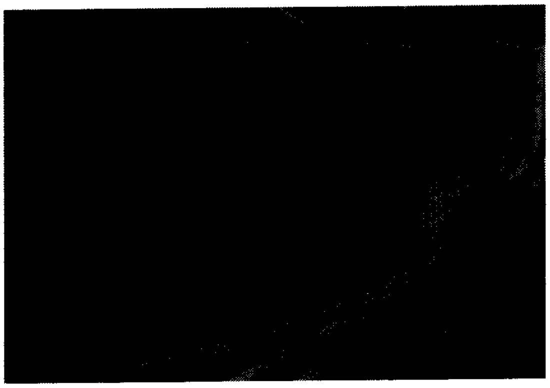

Figure 13. Bulging, Advancing Spoil Piles

The movements are so large that standard inclinometer casings can be made inaccessible in a single season. A large rock buttress has been used with success to stop some of the advancing of the spoil piles.

It is further suspected that other types of landslides, debris flows. and/or rock avalanches as shown in the pictures in Figures 14 and 15 are results of the same mechanism. Movements dependent on water being available at freezing, a granular upper stratum, and an impermeable under layer.

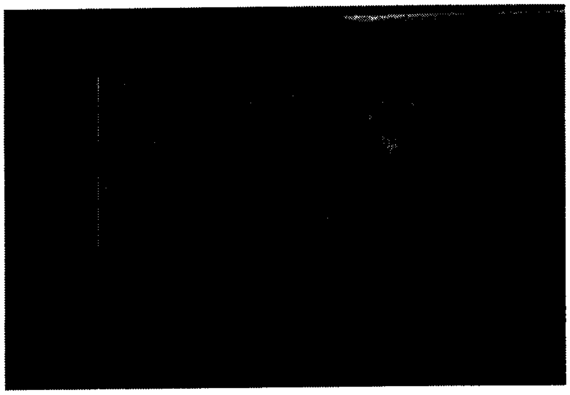

Figure 15. Bulging Landslide near Alaska Highway in Canada

Figure 16. Flowing Landslides in Chickaloon Pass, Alaska

These are just larger examples of the freezing mechanisms that also result in the solifluction landforms.

In each case it is believed that there is a relatively impermeable layer over which there are permeable granular deposits. Surface water, snow melt, and groundwater penetrate the surface deposits and perch on the impermeable layers. These impermeable layers could be clay, bedrock, permafrost, or thawing active layers. The freezing active layer begins to traps water in these masses in fall. In spring when the thaw is faster than the rate of drainage of these features, they flow until they sufficiently drain to become stable again.

In Figures 17, 18, and 19 present examples of solifluction features in Alaska and Kygystan.

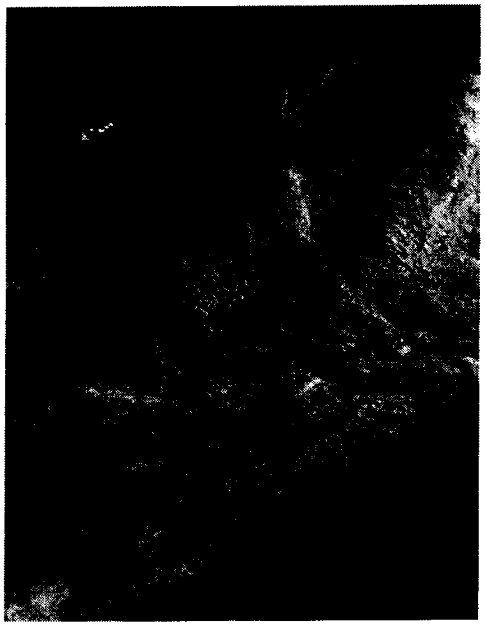

Figure 17. Solifluction Lobes in the Alaska Range

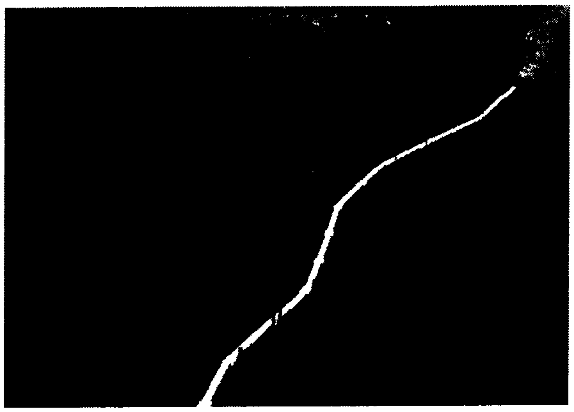

Figure 18. Solifluction along TAPS

Figure 19. Solifluction in Kygystan at 4000 meters

5 CONCLUSIONS

Based on the data reported and the observations of the author, it is his opinion that the mechanism of the formation of solifluction lobes and many of the other well-documented permafrost and cold regions landforms on slopes is essentially the same as the process observed and monitored on the TAPS slopes with the flowing workpads. Further, the process of heaving and the resulting mass density reduction is a key element in the development of flowing surficial materials which is characteristic of these cold regions landforms. The data that have been collected over the past ten years imply there is an explanation to these landforms that could be further verified with instrumentation methods similar to those used to collect the data presented in this paper.

6 ACKNOWLEDGEMENTS

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