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July 14, 2006

UNAVCO PBO
1200 East 76th Ave
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Attention: Benjamin A. Pauk (pauk@unavco.org)
cc: Chuck Kurnik (kurnik@unavco.org)

Subject: Geotechnical consultation
Permafrost foundation
Plate Boundary Observatory (PBO), Alaska
DMA Job No. 4222.001, UNAVCO P.O. No. 01434

We are pleased to present this design analysis for a foundation system suitable for UNAVCO's use in areas with permafrost. Our work has been performed in accordance with our proposal to you of February 28, 2005, and your purchase order of April 3, 2006. We presented preliminary options to Mr. Chuck Kurnick on June 14, 2006, and received notice of your selection of a preferred option on June 30.

The PBO consists of an array of Continuously Operating Reference Stations (COR Station) each of which takes a GPS reading of its position every 15 seconds. These readings are transmitted via satellite to Colorado where they are available for research. The resolution of the readings is about 1 mm. The units weigh about 20 pounds, are about 18 inches in height and diameter, and are installed with their base at 50 to 62 inches above grade. The antenna unit is attached to the foundation using a 1.25-inch NPT threaded stainless steel coupler.

The standard foundation system for unfrozen sites consists of inclined legs. In permafrost areas, the installation of the foundation might cause a disturbance to the permafrost that could lead to thaw and settlement. Also the seasonal active layer freezes and thaws. And with each annual cycle, the surface of the ground moves up and down. Large frost heave forces would be imposed on inclined legs penetrating through the active layer. The frost heave forces could cause permanent deformations of the legs, and the deformations could be cumulative from year to year.

The object of our work was to develop a foundation design that will prevent frost action from moving the system and to preserve the permafrost. At this time UNAVCO is considering units at six permafrost sites in northern Alaska: Kotzebue, Sagwon, Arctic Village, Coldfoot, Wales and Fort Yukon.

The vertical support must be stiff enough to resist wind and ice loads. Little horizontal support is expected from the active layer when it is unfrozen. The system must be able to resist the frost heave force or the frost heave force must be reduced to an allowable level. The foundation should also be constructible using relatively lightweight drilling equipment that can be mobilized to remote sites such as Arctic Village, Wales and Fort Yukon using small aircraft such as a Casa or Skyvan.

Our analysis has been based on our experience at the locations or at similar sites. We have not performed any field exploration to confirm the site specific soil and permafrost conditions. We have assumed that the site is undisturbed and underlain by permafrost with an active layer no deeper than 5 feet.

The antenna is so light that the controlling loadings will be the frost heave load on the foundation and the lateral loads during extreme ice and wind conditions. Consequently, we recommend a single pile be used to support the antenna with the pipe diameter large enough to resist the lateral loads. We considered a multiple set of vertical piles, but the system becomes much more complex and correspondingly costly. To prevent frost heave and to maintain the frozen condition, the pile should be a thermopile.

A thermopile consists of a pressure vessel charged with a single compound, carbon dioxide, under pressure so that both liquid and vapor are present. When the top of the two-phase thermopile is cooled by winter air to below the temperature of the warmer liquid, the vapor condenses and the condensate flows by gravity towards the lower section of the pipe. The condensation reduces the vapor pressure, causing the warmer liquid to boil. The resulting cycle of condensation and vaporization is a highly effective, one-way heat transfer system and is passive with no need for external energy. The thermopile is manufactured by Arctic Foundations, Inc., in Anchorage (Ed Yarmak, P.E., chief engineer, 907-562-2741).

Thermopiles have been used in Alaska since 1960. Unless their charge is lost through a faulty valve or they have contaminants in the charge, they have a record of good performance. Their performance is easily monitored at the start of the winter season when they have a surface temperature warmer than the air temperature. The pressure inside the pipe can also be checked in the summer to verify that they are properly charged.

Since the thermopile freezes the active layer in a radial direction, frost heave forces do not exert a significant upward force on the pile (frost heave forces are parallel to the direction of freezing).

To establish an appropriate pile size, we assumed that the base of the antenna is 50 inches above finish grade. In the winter when the antenna and pipe could be coated with rime ice, the thermopile will have refrozen the active layer so the point of fixity for the moment arm is the surface of the ground. The wind load was calculated using the procedures in the 1991 Uniform Building

Code and assuming the most severe shape, exposure and importance factors for the analysis.

The active layer will vary from site to site with the shallower active layer expected at Kotzebue, at Wales and at Sagwon on the north side of the Brooks Range (an active layer of 2 to 3 feet in undisturbed tundra). The deeper active layers are expected at interior sites such as Fort Yukon, Coldfoot or Arctic Village. Compensating for the deeper active layer at the interior sites is a lower peak wind velocity as compared to the coastal sites.

Our analysis of lateral deflections shows that with a 120 mph wind (appropriate as a coastal maximum) and a 3-foot thick active layer, the base of the antenna would move 8 mm if supported on a 4-inch diameter Schedule 40 pipe. For an interior site, the wind is not expected to exceed 80 mph but the active layer could be 5 feet deep. For such a condition, the 4-inch pipe has a maximum deflection of 7 mm. These deflections are transient and elastic, so do not result in a cumulative movement of the antenna.

A 4-inch diameter thermopile (4.5-inch outside diameter) will be installed in a predrilled, oversized hole. The overall length of the pipe will be 20 feet with the top of the pile at 48 inches or more above finish grade. This requires drilling a hole to a depth of about 16 feet below ground surface. The top of the pressure vessel will be just a few inches below the top plate and pipe connection on the pile.

To allow for placement to a plumb alignment and account for a possibly irregular hole, the drilled hole should be about 8-inch diameter. A 6-inch diameter hole would also be acceptable if the hole is drilled plumb and straight. These size holes can be drilled in frozen soils using conventional rotary drills equipped with solid flight or hollow stem augers or with an air-rotary drill.

Because of the very light, sustained loads, the annulus of the hole can be backfilled with potable water. Using water for backfill poses three drawbacks: 1) the pipe has no support until the backfill has frozen, 2) the time for freezeback is longer than if mineral soil is part of the backfill, and 3) the active layer needs to be backfilled with natural soils. However, potable water is readily available, requires no mixing, and will penetrate to the tip of the pile so full adfreeze is developed along the length of the pile. If water with cuttings or sand were used for backfill, the annulus would need to be large enough so that a concrete vibrator or tamper can be used to prevent bridging of the backfill. The pile should be set on the bottom of the hole and then restrained with wooden wedges at the top before the water is added.

In the summer the time for freezeback of the water backfill depends on the temperature of the permafrost. The table on the following page shows our estimates of the time needed to freeze a water backfill for various ground temperatures. If the work is performed in the winter, the thermopile will freeze the water in a day or two or less with cold air temperatures. To prevent flash freezing and ice blockage that would stop the deeper flow of water, the top of the thermopile should be wrapped with an insulating blanket until the water is placed.

Freezeback times for a water backfill

Ground Temperature	28°F	29°F	30°F	31°F
8″ hole freezeback	6 days	9 days	13 days	30 days
6″ hole freezeback	2 days	3 days	5 days	10 days

To further reduce the possible effects of freezing and thawing of the seasonal active layer, the upper portion of the buried pile should be wrapped with three layers of 10-mil visqueen (polyethylene wrap) that is taped to the pile before it is placed in the hole.

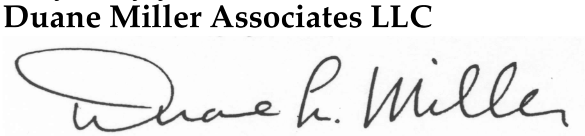
The backfill through the active layer should consist of the natural soils saved from the drilling. The soils should be placed in lifts and tamped into place with a small diameter pipe (1/2-inch). If placed in the winter the material should be mounded up about 12 inches around the pile to compensate for the thaw settlement that will occur in the first summer. To avoid having to wait for the water backfill to freeze, an annular plug of fiberglass batt insulation could be placed near the base of the active layer to restrain the shallower backfill of natural soil.

If the pile is used in saline soils or in highly plastic clays, the permafrost might contain large amounts of unfrozen water even with temperatures below 32°F. The thermopile freezes beneath its tip and heave from the freezing of the unfrozen water could cause a heave of the pile. We do not expect this condition at any of the six sites; however, soil conditions should be monitored when the piles are installed to verify this assumption.

The conditions found in the drilling should be logged and typical samples of the soil should be collected at depths of approximately 5, 10 and 15 feet. The samples should be sealed in Ziplock bags, should be labeled by site and depth, and should be returned to Anchorage where they should be visually classified and tested for moisture content and salinity.

If you have any questions, please call. We can provide additional consultation if unusual or unexpected conditions are found during the pile installations.

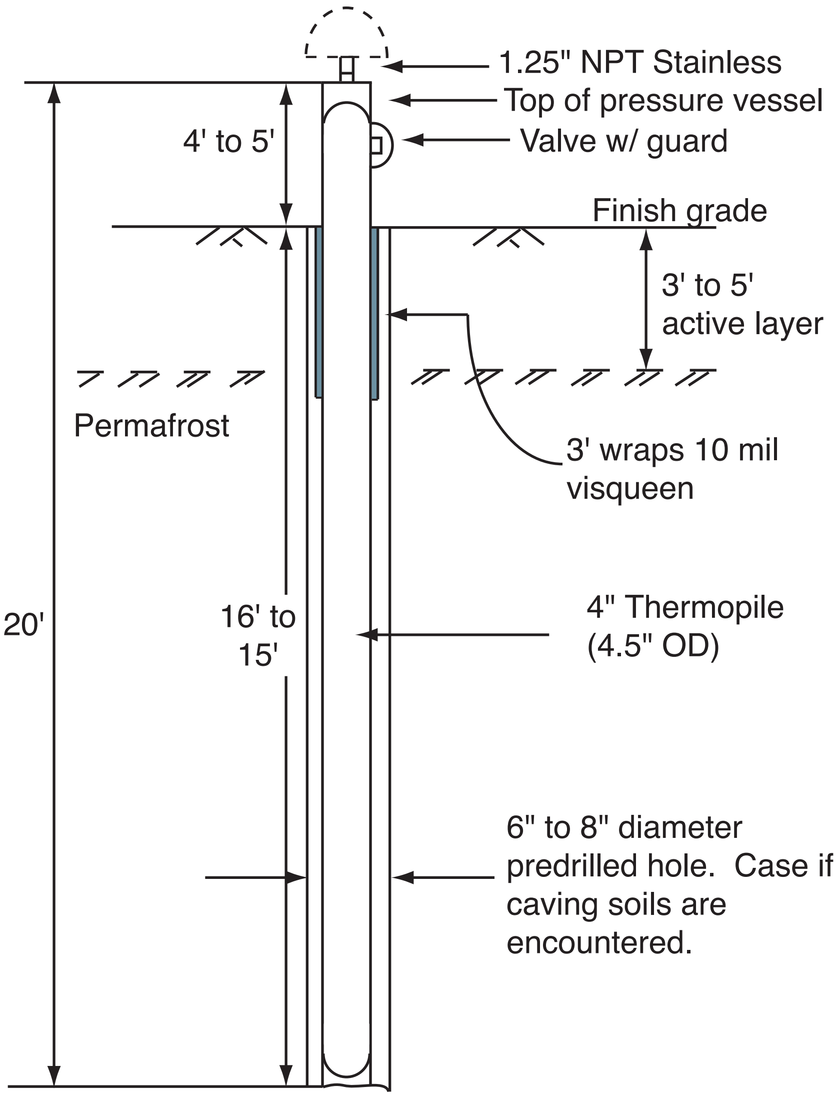
Very truly yours,
Duane Miller Associates LLC



Duane L. Miller, P.E.

Attachment: Plate 1, Proposed Thermopile for PBO support

PBO - PERMAFROST MONUMENT
NTS



Fill annulus of active layer w/ natural soil on frozen ice or fiberglass insulation plug and then soil.

Backfill w/ potable water to surface of permafrost. If winter conditions, insulate the exposed section of pile before adding water.