Final Report

Foundation Stabilization Research Studies on a Foundation on ice poor Permafrost in Fairbanks, Alaska

Introduction

In 1988 an engineering report prepared by Stutzmann Engineering Inc. designated the foundation of this house as being potentially unstable due to permafrost soil. The house was subsequently deeded to the Permafrost Technology Foundation by Alaska Housing Finance Corporation for the purpose of research to develop economic techniques for stabilizing the foundations of permafrost-sited houses.
Permafrost underlying the foundation was suspected due to cracks found in the wallboard on the exterior wall of one of the bedrooms. Two test holes were drilled and revealed permafrost in sandy gravel soils at depths of 23 and 25 feet. Moisture content of the permafrost was sampled at four depths and was reported to be 5.4%, 8.8%, 13.3% and 21.4%. The 21.4% sample was taken at the top of the permafrost. Saturation of gravels and sands is dependent on the density of the soils but typically occurs at moisture contents of between 20% for loose soils and 9% for highly compacted soils. Soils with moisture contents below saturation are generally considered to be thaw-stable and to not undergo settlement. Since these soils had exhibited loose characteristics during drilling, indicating less dense soils, all the moisture contents could be within saturation limits, and even if they are slightly above saturation, the amount of settlement could be very small. The loose soils might settle during an earthquake or other dynamic event, but the melting of the permafrost would probably not incur any settlement.

In the beginning of the project, the Permafrost Technology Foundation was not aware of the original engineering reports on the house by Stutzman Engineering (they were not transferred to PTF). Therefore, when PTF received the house another permafrost exploration hole was drilled. This hole was located near the northeast corner of the house, and it discovered permafrost at 30.5 feet. The hole was drilled into the permafrost to a depth of 49 feet.

Due to the borderline nature of the permafrost moisture content and because the house showed almost no settlement damage in the wallboard (a few cracks of hairline and slightly larger width on the inside wallboard of the house were the only manifestations of possible settlement) there was a question as to whether or not there was thaw unstable permafrost at the site. In the absence of serious damage that would indicate permafrost settlement, it was decided to monitor the foundation for a period of time to see if any settlement or danger signs of settlement occurred. When no evidence of settlement was found after a year of monitoring the structure, the decision was made to continue the monitoring to determine the ultimate stability of the foundation and to gain data on what can be expected at a site with this type of permafrost at a depth that approximates the mature thaw bulb depth for a house of this size.

Structure Description

This house is a split level design with the garage and an unfinished basement room on the ground-level floor (see Floorplan). The front entrance opens to a landing midway between the two floors with stairs leading to the two levels. The garage occupies slightly over one half of the ground level. The basement room that occupies the other half of the ground floor is used as a family room, although it is unfinished and has no covering over the studs and insulation. There are three bedrooms, two baths, living room, dining room, and kitchen on the upper floor. The house has a concrete block foundation with frame construction. The lower floor is concrete slab. Exterior siding is T-111 painted light brown. There is a small deck on the upper level at the rear of the house that is accessible from the dining room. The driveway is dirt with a concrete pad (with numerous cracks) in front of the garage door. The driveway leads to the street which is approximately 25 feet away.

Level Measurements

Level measurements were taken to determine the relative elevation of the floor. The level measurements were made using a small precise telescopic level mounted on a tripod (sometime referred to as a "contractor's level") and a rod calibrated in millimeters. The millimeter rod was used instead of a standard surveyor's rod to give more precision to the measurements. Since the distance from the level to the rod was rarely over 15 feet, the rod could easily be read to the nearest millimeter (0.04 in.).

It should be noted, however, that when level measurement are this precise, that perturbations can and do occur due to the placement of the rod from one measurement set to the next. Often the rod had to be placed behind furniture, and it was impossible to determine if it was sitting on the exact spot as the previous measurement or if it was sitting on an electrical cord or a magazine etc. (even the thickness of several sheets of paper will show up at this precision). There was also the possibility for a gross error in reading the level, since the level had the standard three cross hairs (center, upper, and lower) used for measuring distances in surveying. If the operator was inexperienced (student labor was used for these measurements), a reading could be made using either the upper or lower cross hair instead of the center crosshair. This error would yield an elevation that was in error from several tens of millimeters to as much as a few inches. These errors however are readily discernible when the data is shown plotted as a function of time.

Level data on the concrete slab floor in the lower level was collected several times a year and accumulated for a period of six years. The level data is plotted against time. Each measurement location is designated on the floor plan by a letter. Different groups of letters were plotted together on the charts to show relevant comparisons such as the south wall or the diagonal across the structure. In each chart, all levels are referenced to a single reference point "A". This allows the elevation of each point to be compared as a relative elevation on the floor plan to point A. From this data, differential elevations between various parts of the floor can be seen easily and can be tracked with time.

This system, however, does not give information as to the absolute elevation of the house with respect to the ground outside, and therefore any elevation variation of point A is also reflected in all other points. Determining absolute elevations requires a stable surveyor's benchmark or other stable reference outside of the structure. At this location there was no such stable reference available, but relative elevations allow differential settlement to be tracked, and that is the most important information for these studies.

For perspective, a differential elevation of one to two inches (25 mm to 50 mm) across the length of an average room is not readily noticeable to the unaided eye. Up to four inches (100 mm) over the distance across a normal room, although noticeable, is not an overly unpleasant condition with which to live.

Temperature Measurement

When the permafrost test boring was drilled, a thermistor string with 12 thermistors was placed in the hole. The thermistor string was positioned to measure temperatures at the surface of the ground and at depths of 5, 10, 15, 20, 21, 21.5, 22, 23, 25, 35 and 45 feet. These temperatures were monitored periodically at the same time the level measurements were taken (and sometimes more often) resulting in a data base of five years of soil temperatures for the site. The temperature data was plotted with respect to time on charts to give a graphic indication of the soil temperature trends over the duration of the study. These charts are included in the appendix of this report.
Thermistors are capable of measuring temperature to the nearest one thousandth of a degree Celsius. Thermistors were used because they are more accurate and easier to read than thermocouples; however, they have the disadvantage of being more fragile, and they can drift a few thousands of a degree over time. To obtain the maximum accuracy the strings must be calibrated in a reference bath both before and after their use. These thermistor strings were calibrated before placing them in the hole, but since once installed they are buried, it is impractical to remove them without destroying them, therefore the secondary calibration cannot be made. The temperatures, therefore, are reliable to about a tenth of a degree. However, for the purposes required for these studies, an accuracy of one tenth of a degree Celsius is adequate.

Thermistors located at various depths allow the temperatures at those depths to be tracked to determine if the permafrost is getting deeper, remaining stable, or actually rising. The data also points out any anomalies in temperature that may occur due to outside influences such as new construction nearby, landscaping modifications, or damage or deterioration of protective insulation.

Geotechnical Exploration

In order to determine the condition of the soils below the structure, a borehole was drilled and samples of the soil were taken at regular intervals of depth. Samples were collected by driving a split-spoon sample core barrel through the hollow stem using a 300 pound hammer and a 30 inch drop. The number of hammer blows required to drive the core barrel gives information on the competency of the soil at each sample depth. These samples are considered "disturbed samples." However, since they are retrieved essentially intact in their natural state, they provide useful information about the soil. This method of sampling was continued until frozen ground was encountered. Below this the soils were sampled with a dry core barrel. This brings to the surface a five-foot-long, three-inch-diameter, intact soil sample. Representative soil samples were then sent to the laboratory for analysis of grain size and water content. With this data, a model of the soil conditions and types was constructed for the hole. This does not necessarily apply to the soils under the structure since soil conditions can, and often do, change radically over short distances, but if boreholes on both sides of the structure are similar in nature, then the soils beneath the house can be at least inferred.

Results and Conclusions

Temperature measurements: The trend of the temperature of the soils at depth (15 feet and below) over the five year period was a gradual rise by as much as 0.5 °C (~1 °F). The temperature at the 8 meter (25 foot) depth started just below freezing (approximately -0.05°C, indicating the top of the permafrost in 1992) but rose above freezing sometime during the summer of 1993 and continued to rise to nearly +0.5 °C at the last reading in 1996. This indicates that the top of the permafrost subsided to a greater depth during this period. The temperature at the 35 foot depth remained below freezing for the entire period. The permafrost had not receded to that depth.

This temperature data is interesting for several reasons. First, since the borehole in which the thermistor string is located is over 10 feet away from the house, the effect of heat from the house is only one perturbation in the thermal regime of the soil. This suggests that the permafrost in this area might be receding even if the house were not there. The fact that prior to construction, the area was cleared of its original vegetation of black spruce, willows, and other brush is in itself a large influence on the soil thermal regime and is usually enough to cause the permafrost to subside from several feet to several tens of feet (Johnston 1981, McFadden 1991).

Secondly, and perhaps more importantly to our concerns with the foundation, since the permafrost outside the house has subsided, it can be assumed that the permafrost under the house has subsided even deeper. The outside temperature reference location is subject to over 8 months each year of freezing weather during which time there is reinforcement of the permafrost. Beneath the house, on the other hand, there is a positive heat input for 12 continuous months. This reasoning implies that the permafrost subsidence under the house is probably several feet. A permafrost subsidence under the house of this amount without any detectable settlement of the house further reinforces the possibility that the sandy gravel permafrost at this depth is thaw stable.

If a thaw-unstable layer exists below the depth of the sandy gravel in the borehole (the borehole extended to a depth of 49 feet without finding unstable permafrost) and the permafrost beneath the house subsides into it, then it is possible for settlement to begin. This however will be several decades in the future if at all since the thaw must reach below 49 feet and possibly much deeper if it is to find thaw-unstable soil. This could be explored further with a deeper borehole, but the lifetime of the house is probably less than the time required for the thaw bulb to reach unstable soils (if any do exist at this site) below the 49 foot depth.

Finally, the subsidence of the permafrost outside the boundaries of the structure suggests that the permafrost in the entire subdivision may be receding and will continue to do so until a thermal balance between input from the surface environment and the geothermal input is reestablished. This could mean that the permafrost will melt to a depth several tens of feet deeper than it is presently, or in an area such as Fairbanks where permafrost is very marginal, it could disappear entirely. Total melting of all of the permafrost will take from many decades to over a century. Our exploration borehole was drilled to 49 feet, and at that depth the soil was still frozen when the last temperature reading was taken in October 1996.

With the possibility of thawing of the permafrost over the entire area of the subdivision in mind, an inspection of other structures in the area could provide useful information. Keeping in mind that the homeowner who is willing to allow his house to be inspected for possible permafrost damage is rare, this inspection had to be of the exterior of the houses and somewhat casual. Inspection of the houses in the subdivision as a whole, at this time, does not show any gross damage that might be attributed to thaw-unstable permafrost. At least no obvious settlement-damaged houses such as those seen in other parts of Fairbanks are readily apparent. Of course if an owner was very diligent about upkeep and repair on a structure, this type of damage would be difficult to detect from the street.

Level measurements confirm what the temperature readings have indicated. There was some initial level difference at the time the structure was transferred to the Permafrost Technology Foundation. This was small enough that it could be attributed to initial construction, lack of compaction of the initial fill, poor craftsmanship, or subsidence of shallower layers of permafrost as they melted.

However, the subsidence was not enough to cause problems in the livability of the structure and has, for now at least, stopped and has not produced additional settlement for the past 5 years.

The initial differential level in the concrete slab floor from the southeast corner of the garage to the northwest corner of the family room was between 15 mm and 25 mm (3/4 to 1 inch) overall. Across just the family room, the differential was as small as 5 mm (less than ¼ inch). During the six years of monitoring the level of the floor, this variation remained remarkably constant. The diagonal distance from the southeast corner of the garage to the northwest corner of the family room is 48 ft 10 in. At the beginning of these studies, the differential elevation between these two corners was 22 mm (7/8 in.); at the end of the studies it was 17 mm (3/4 in.). This change is only 5mm (less than ¼ in.) in 48 feet and indicates good foundation stability. A line lengthwise across the house from the center of the east wall of the garage to the center of the west wall of the family room (points B to O) is 42 ft 2 in. and shows a very similar stability. Initial differential was 24.5 mm, and the end-of-study differential was 24 mm, a 0.5 mm (less than 1/32 in.) difference in 6 years. A similar comparison along the width of the house from the northeast wall to the southeast wall of the family room (points S to K) shows no measurable change in relative elevation over the six year period. Initial level and final level measurements were made at the same time of the year (January/February), thus largely removing the effects of seasonal variations.

Loose soils also raise the concern of settlement during a dynamic event such as an earthquake. During the period over which the level measurements were made on this house there were 15 earthquakes over Richter 4.0 in the Fairbanks vicinity (approximately a 30 mile radius). Of those, one was 5.0 on Nov 1, 1992 and one was 6.2 on October 6, 1995. This last one was the most significant event, since it was not only the largest but also the shallowest at only 9 kilometers below the surface. It was felt very strongly by residents of Fairbanks. However, reviewing the data on level measurements shows that no significant measurable settlement can be identified in our data during any of these events. This suggests that either settlement into the loose soils beneath the structure was not triggered by a dynamic event of this magnitude or that settlement into the loose soils was already complete before the Permafrost Technology Foundation started monitoring the structure. These circumstances and observations do not preclude the possibility of settlement during a more severe earthquake or other type of dynamic event.

If a structure is settling differentially, one of the first manifestations of that settlement can be seen in the concrete block foundation wall. One of the weakest links in the foundation wall is the joint between the concrete block and the grout bonding the blocks together. No cracks of any kind are evident in the exposed portion of the block foundation wall of this structure either inside or outside the building. This suggests that the out-of-level condition found in the first level measurement was more likely built into the structure at the time of its initial construction rather than caused by subsequent settlement (which should have cracked the foundation wall). The absence of cracks in the block wall also provides another independent indication of the apparent stability of this structure at this time.

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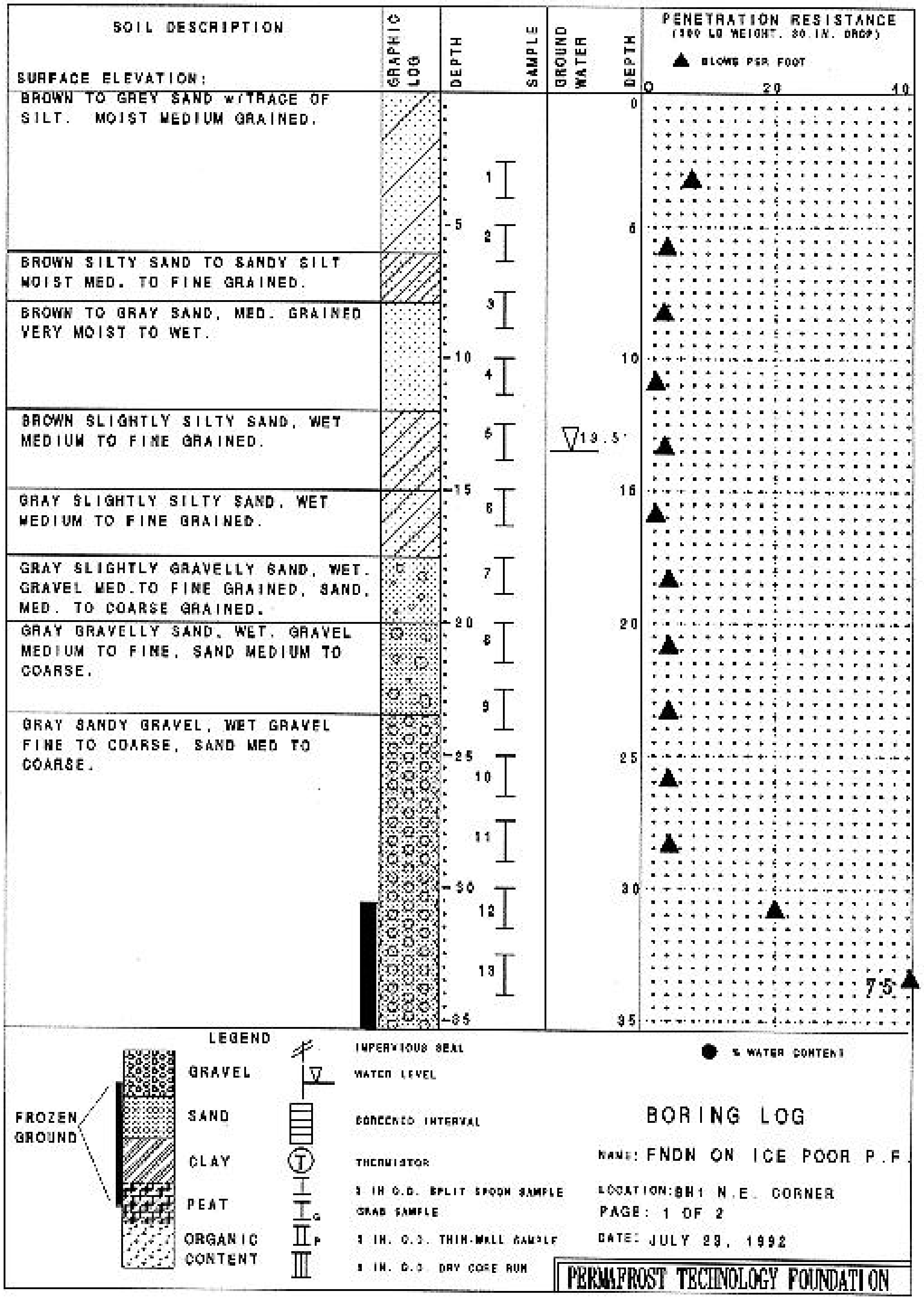
Appendicies
Bore Hole Logs



BORING LOG

SOIL DESCRIPTION	GRAPHIC LOG	DEPTH	SAMPLE	GROUND WATER	DEPTH	PENETRATION RESISTANCE (300 LB WEIGHT, 30 IN. DROP) ▲ BLOWS PER FOOT
SURFACE ELEVATION:						0 — 20 — 40
GRAY SANDY GRAVEL, Nf TO Nbn, WET, GRAVEL COARSE TO FINE		35	14		35	90@ 6"
GREY SLIGHTLY GRAVELLY SAND, Nbn, MED GR. SAND, FINE TO COARSE GRAVEL.			15			80@ 6"
GRAY SANDY GRAVEL, Nf, WET GRAVEL COARSE TO FINE, SAND MED.		40	16		40	75@ 6"
			17			75@ 3"
		45	18		45	50@ 6"
			19			80@ 2"
BOH 49'						
		50			50	
		55			55	
		60			60	
		65			65	
		70			70	

LEGEND

- SILT
- GRAVEL
- SAND
- CLAY
- PEAT
- ORGANIC CONTENT
- FROZEN GROUND
- IMPERVIOUS SEAL
- WATER LEVEL
- SCREENED INTERVAL
- THERMISTOR
- 3 IN O.D. SPLIT SPOON SAMPLE
- GRAB SAMPLE
- 3 IN. O.D. THIN-WALL SAMPLE
- 3 IN. O.D. DRY CORE RUN
- ● % WATER CONTENT

BORING LOG

NAME: FNDN ON ICE POOR P.F.

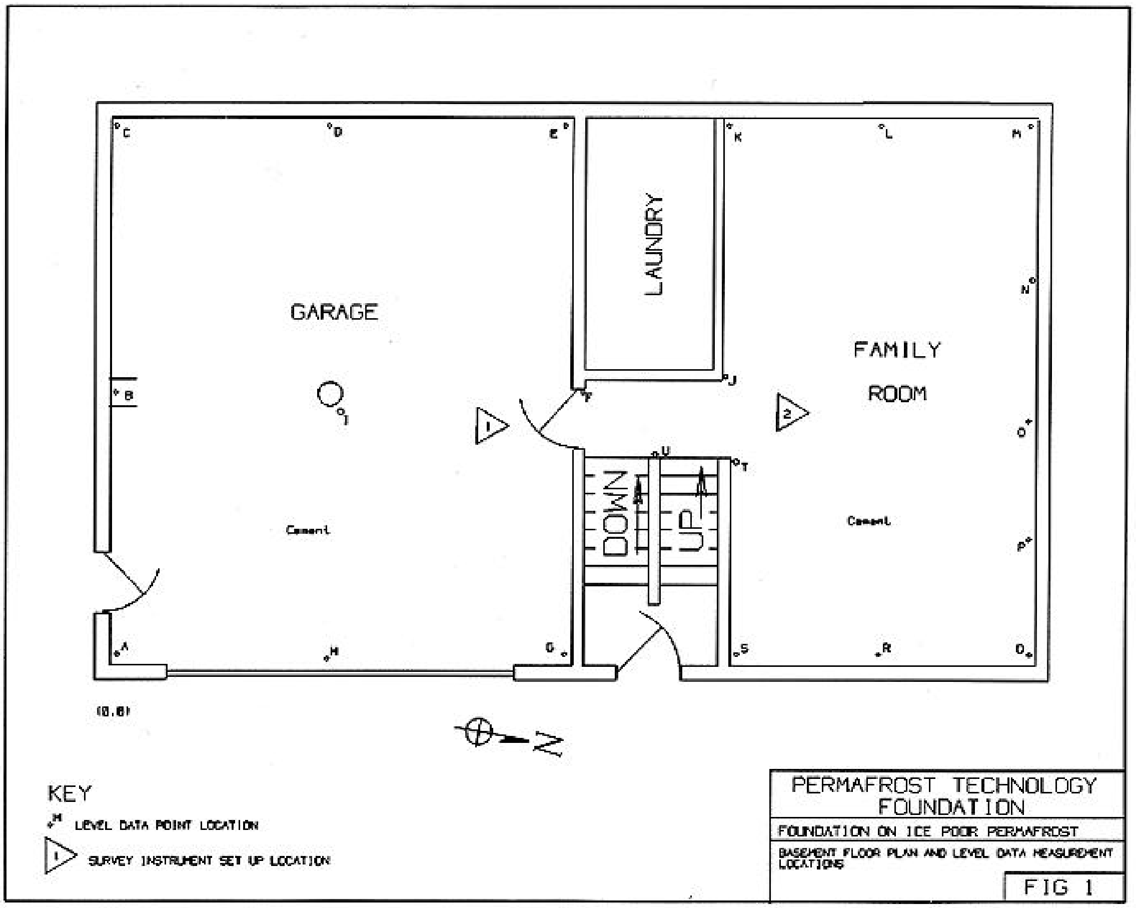
LOCATION: BH1-N.E.CORNER (CONT.)

PAGE: TWO OF TWO

DATE: JULY 23, 1992

PERMAFROST TECHNOLOGY FOUNDATION

Floorplan



GARAGE
LAUNDRY
FAMILY
ROOM
DOWN
UP
Cement
Cement
(0,0)
KEY
LEVEL DATA POINT LOCATION
SURVEY INSTRUMENT SET UP LOCATION
PERMAFROST TECHNOLOGY FOUNDATION
FOUNDATION ON ICE POOR PERMAFROST
BASEMENT FLOOR PLAN AND LEVEL DATA MEASUREMENT LOCATIONS
FIG 1
