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# DRIVEN PILES IN WARM PERMAFROST

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**Abstract**

Recently, pile driving techniques in permafrost have been developed and offer a fast as well as an economical solution to many foundation problems in warm permafrost conditions. Depending on the soil type and composition, temperature profile, logistics of economical transportation of pile driving equipment and so on, steel piles may be successfully driven for the foundation of single family houses to be constructed in warm permafrost regions.

Two contrasting projects are described, where H and circular steel piles were successfully driven in warm permafrost for single family housing in the Yukon-Kuskokwim Delta area, Alaska. The design approach and construction problems associated with H-type steel piles with heat tubes at one of the sites and circular steel piles without heat tubes used at the other site, are illustrated. Conclusions and recommendations are given for the proper installation of driven steel piles in warm permafrost.

## Introduction

In recent years, considerable knowledge has been gained on the physical and mechanical properties of frozen soils. Consequently, the design and construction of foundations in frozen soils encountered in permafrost regions has been advanced significantly. Commonly, drilled and slurry backfill type piles are used as structural support in permafrost. Various authors (Crory, 1973; Long, 1973; Morgenstern et al., 1980; Nixon and McRoberts, 1976; Nottingham and Christopherson, 1983; Phukan, 1985) have published on the design of both slurried and driven piles in permafrost. However, few case histories are available pertinent to driven steel piles in ice-rich or ice-poor warm permafrost.

In addition to the type and composition of soils (including presence of ice and temperature profile encountered at the project site), several other major factors must be considered for the type of foundation to be economically designed as structural supports for a single family housing project. These factors include: logistics of economical transportation of pile material and installation equipment, availability of local skilled labor, suitable construction material, health and safety requirements for the site environment (including cold temperatures and wind since most piles are installed during winter or early spring), remoteness of site and so on.

This paper presents two contrasting projects: Kongiganak and Bethel, located in the Yukon-Kuskowim Delta region, Alaska (shown in Figure 1), where driven steel piles were successfully designed and placed for new housing projects. Due to different subsoil conditions encountered at Kongiganak and Bethel, pile design considerations were different. Construction problems at the two sites also differed.

## Kongiganak housing project

Alaska Village Council of Presidents (ACVP) planned thirty single family housing units at Kongiganak which is located about 75 miles south-west of Bethel (see Figure 1). Phukan Consulting Engineers & Associates, Inc. (PCA), under a contract to Kumin Associates, Inc., investigated the subsoil conditions at the proposed housing site and foundation design recommendations were given on the project. PCA was also involved during the construction phase of pile foundations on the project.

Based on ten test holes at the site, the soil conditions generally consisted of 0.6 to 3.5 m. of brown organic peat (Pt) underlain by dark gray silt (ML). Generally, the thickness of peat is greater in the western section than in the eastern section. The upper organic layer is generally unfrozen to a depth of about 1m and visible to non-visible ice in the silty soil layer was encountered at depths ranging from 1.8 to 2.44 m. Moisture contents of peat ranged from 46 to 1700%, whereas in the silt, they ranged from 30 to 180%. The average ground temperature at the site is around -1.1$^{o}$ C.

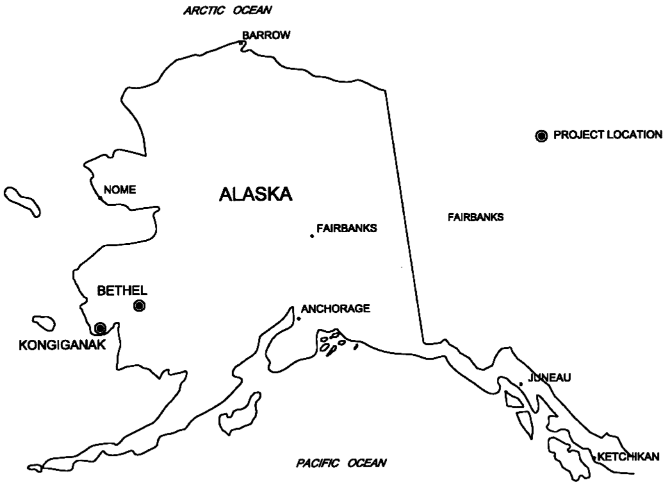


*Figure 1. Location of Projects.*

Based on the subsoil conditions and other factors indicated above, driven H-type steel piles with heat tubes to a depth of 3 m were designed to prevent thermal degradation of frozen soils with visible ice (encountered mainly to a depth of about 2.1 m). Design curves were developed based on the long term adfreeze strength of frozen silt at warm temperatures against the anticipated structural load (DiPasquale et al., 1983). A typical design curve is presented in Figure 2.

The recommended H-piles (H10x57) were driven with a diesel hammer at least 30kN-m, with channels (L76x76 mm) at least 3 m long (attached to the web side of H-piles) from the existing ground surface. Heat transfer calculations were made to arrive at a total length of heat tubes. Both the evaporator (3 m) and condenser (1.22 m) were inserted into the channels and backfilled with fine sands in the annular space between the heat tube and L-channel. The air space between the bottom of building floor and the existing ground surface was to be at least 0.92 m for proper air circulation to maintain existing thermal conditions of the project site.

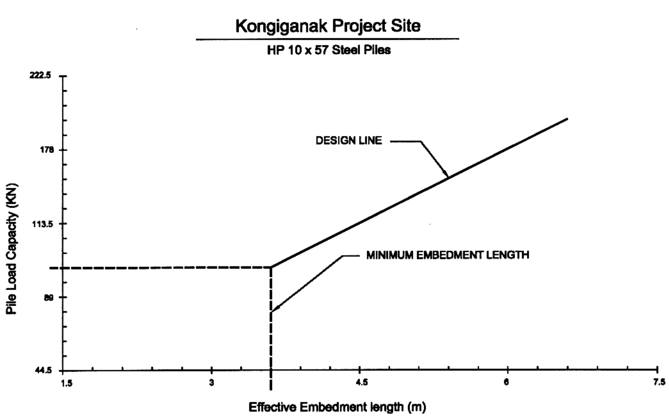


*Figure 2. Pile Load Capacity vs. Effective Embedment Length.*

*Figure 3. Installation of H-Piles, showing Crane and Hammer, Kongiganak Project*

Seven piles were driven for 2-4 bedroom homes and twelve piles for 5 bedroom homes. Typical installations of driven H-piles are shown in Figures 3 and 4. Piles were driven to a depth of 6.71 m and a typical blow count record is presented in Table 1. Generally the blow counts were higher below a depth 3 m. Due to soft and compressible surficial soil conditions, piles were installed during the cold months (February and March, 1996).

The main construction problem was to maintain the vertical and lateral alignment of piles according to the specifications. Some of the piles were "out of plumb" and exceeded the Uniform Building Code allowable steel stress (1.33x0.35FY) of 115.8 MPa. These "out of plumb" driven piles were re-evaluated in terms of bending stress and the structural loads (both vertical and lateral). As an adequate factor of safety was obtained from the calculations, all driven piles were accepted for the final placements of superstructures.

## Bethel housing project

AVCP hired Osborne Construction/Kelly Ryan, Inc. (OCC/KRI) joint venture for the 35 unit design-build housing project in Bethel, Alaska. PCA provided design build review and construction inspection of pile installation for AVCP on the project. The proposed residential development consisted of 2 to 5 bedroom single family housing units with modular framed construction.

The 10 acre site was subdivided into 39 residential lots with an open space/recreational area and platted as Block 2 of the Martina Oscar Subdivision. The site is located in the northwest corner of the City of Bethel, Alaska. The Environmental Atlas of Alaska (1984) reports that the Bethel area is generally underlain by continuous permafrost (Mean Annual Air Temperature of -1.1°C) and is in seismic probability Zone 1. This area

*Figure 4. Installed Heat Tubes in H-Piles, Kongiganak Project Site.*

**Table 1. Driven H-Pile Installation Record, Kongiganak Housing Project Block 2, Lot 14, 4 Bedroom Unit (7 Piles)**

| Depth ((Ft/m) | A1 | A2 | Blows Per Foot/ Pile A3 | B1 | C1 | C2 | C3 |
|---|---|---|---|---|---|---|---|
| 1/0.3 | 11 | 9 | 7 | 8 | 8 | 11 | 8 |
| 2/0.6 | 11 | 10 | 19 | 21 | 15 | 20 | 18 |
| 3/0.9 | 19 | 19 | 21 | 18 | 18 | 24 | 17 |
| 4/1.22 | 19 | 19 | 18 | 21 | 20 | 22 | 20 |
| 5/1.52 | 20 | 20 | 25 | 26 | 16 | 25 | 21 |
| 6/1.83 | 15 | 23 | 20 | 22 | 12 | 22 | 20 |
| 7/2.13 | 14 | 21 | 19 | 16 | 14 | 24 | 20 |
| 8/2.44 | 15 | 18 | 10 | 15 | 13 | 2 | 19 |
| 9/2.74 | 14 | 12 | 16 | 14 | 16 | 21 | 20 |
| 10/3.05 | 15 | 16 | 17 | 17 | 14 | 18 | 19 |
| 11/3.35 | 13 | 15 | 18 | 16 | 13 | 20 | 22 |
| 12/3.66 | 15 | 16 | 20 | 17 | 18 | 20 | 20 |
| 13/3.96 | 16 | 17 | 23 | 19 | 20 | 19 | 22 |
| 14/4.27 | 19 | 20 | 24 | 20 | 24 | 20 | 23 |
| 15/4.57 | 22 | 24 | 25 | 22 | 25 | 20 | 22 |
| 16/4.88 | 20 | 24 | 28 | 23 | 26 | 22 | 24 |
| 17/5.18 | 22 | 26 | 26 | 24 | 25 | 22 | 24 |
| 18/5.49 | 23 | 27 | 27 | 24 | 25 | 22 | 24 |
| 19/5.79 | 20 | 27 | 27 | 25 | 25 | 23 | 24 |
| 20/6.10 | 24 | 28 | 27 | 23 | 25 | 23 | 22 |
| 21/6.40 | 24 | 27 | 28 | 23 | 25 | 20 | 22 |
| 22/6.70 | 23 | 27 | 28 | 32 | 25 | 20 | 22 |

is defined as a minor structural damage potential or Richter Magnitude 3.0 to 4.5. The design wind and snow loads are reported to be 0.96 to 1.44 kPa, respectively. The mean annual snowfall is approximately 127 cm to 152 cm. More recent studies and data returns may have resulted in increased snow loading, which may require design snow load increases. The mean annual precipitation shown for the area is 104 cm. High

*Figure 5. Installation of Circular Steel Piles, showing Crane and Hammer, BethelProject Site.*

winds on the order of 160 km per hour may be expected in this area, with the prevailing winds from the north-east. The site is located on an area of relatively high ground in Bethel and consequently, significant snow drifting may occur around the new buildings during winter months.

The site slopes very gently (less than 4 percent) toward the south and west in the Kuskowim River drainage basin. The site is in no danger of flooding by this river. The area itself is a relict river terrace of the river drainage system. The site soils are water lain, inter-bedded deposits of fine, poorly graded, sand and silt with varying amounts of organics. These deposits also appear to have been wind worked. Surface vegetation consists of tundra grasses, mosses, and peat. Tree growth is essentially absent, with the presence of small shrubs (willows and berry bushes) in the lower southwest corner of the project.

Based on eight test borings to a maximum depth of 6 m (highway auger limit), the soil conditions at the site

*Figure 6. Installation of Circular Steel Piles, showing Hammer and Final check, Bethel Project Site.*

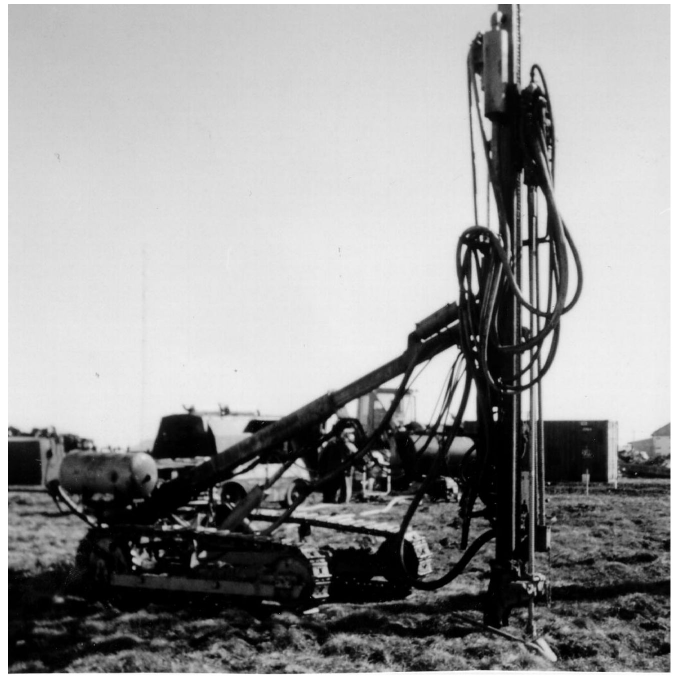

*Figure 7. Drilling of Pilot Holes at Driven Piles refusal locations, Bethel Project Site.*

consist of 1.5 to 107 cm of peat (Pt) underlain by organic silt, silt, sandy silt to silty sand which overlies sand to silty sand with an exception near T.H.#1, T.H.#6 and T.H.#7 where peat was encountered to significant depths. Historic ground temperature data below a depth of 2 m indicate temperatures around -0.55ºC.

Various foundation types such as slurried piles, driven piles, 'Triodetic' shallow foundation system and insulated pad continuous/spread foundations were evaluated for the project. Ultimately, driven 17.8 cm diameter steel piles were selected for the project on the basis of availability, cost comparison, and time-schedule of the project. The following design criteria were used for the driven circular piles:

(1) Maximum pile axial load of 93.4 kN

(2) Creep Equation developed by Morgenstern et al. (1980) with n=3, and the creep parameter of B =1.02 x $10^{-2}$ MN $m^{-2}$ $yr^{-1}$ (after DiPasquale et al., 1983)

(3) No resistance for peat

(4) Design Period of 30 years

(5) Allowable adfreeze strength of 20.7 kPa (after Crory, 1973)

(6) The pile embedment length should be increased by 30.5 cm per 30.5 cm of peat and ice encountered.

(7) At least two test holes at each house should be drilled to verify the thickness of peat and ice encountered at the site. These test holes may used as "pre-drilled" holes for the driven piles.

(8) The minimum total pile length of 945 cm (effective embedment length of 823 cm) below the ground surface should be used near in areas T.H.#1, T.H.#6 and T.H.#7. All pile lengths should be increased according to test hole conditions found under (7). The worst condition encountered at the test holes should be used for the increment of pile length.

All 568 piles for the house and utility were driven at the site during March and April, 1997 (see Figures 5 and 6) with the exception of 29 piles which met refusal at depths ranging from about 3 m to 4.88 m. Pre-drilled holes of about 8 cm in diameter were drilled (see Figure 7) at the locations where pile refusal occurred and then the piles were re-driven. A temperature measurement during the 'pre-drilled' condition showed a relative cold temperature inversion of about -2ºC around the refusal depth which was very unusual in the Bethel area. As indicated earlier, the site had the geological background of relict river terrace with interbedded sand and silt and organic layer intrusion which might have caused the insulation effect, creating colder temperatures. At some locations where the surficial peat thickness was significant, the piles moved freely to a depth of 1 to 2m during the hammering period.

## Conclusions and recommendations

H-Steel piles may be successfully driven in "warm" ice-rich silts. The rate of installation of piles was 3 piles per hour. The principal advantages are speed of installation, minimal disturbance to the environment, immediate loading, and relative cost savings. Construction problems may be resolved with proper design analysis to reflect the actual site conditions encountered. The long-term performance of the driven H-piles with heat tubes, should be monitored to evaluate the cost-savings (at least 60%) or effectiveness of the heat-transfer device installed at the site.

(1) Circular steel piles may be driven in "warm" permafrost consisting of peat, silt and sand. However, temperature profiles must be obtained at the site for the selection of pile installation techniques such as pre-drilled holes and/or thermally modified holes.

(2) The performance of driven piles should be monitored to examine the relative cost savings. A proper field test program for driven piles in warm permafrost should be developed which will determine the long-term allowable adfreeze strength for ice-rich and ice-poor soil conditions at temperatures -2ºC to -0.55ºC.

(3) Proper pile installation records during the construction phase helped to resolve the construction problems encountered (without change in design) resulting in cost savings in both projects.

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## References

**Crory, F.E.** (1973). Installation of driven test piles in permafrost at Bethel Air Force Station Alaska. *U.S. Army Cold Regions Research Engineering Laboratory, Technical Report*, **139**.

**DiPasquale, L., Gerlek, S. and Phukan, A.** (1983). Design and construction of Pile Foundations in the Yukon-Kuskowin Delta, Alaska. In *Proceedings Fourth International Permafrost Conference, Fairbanks, July 17-22*. National Academy of Science, Washington, D.C., pp. 233-237.

**Hartman C.W. and Johnson, P.R.** (1984). *Environmental Atlas of Alaska*. University of Alaska Fairbanks, Alaska.

**Long, L.E.** (1973). Designing Friction Piles for Increased Stability at Lower Installed Cost in Permafrost. In *Second International Permafrost Conference, North American Contribution*. National Academy of Science, Washington, D.C., pp. 693-699.

**Morgenstern, N.R., Roggensack, W.D. and Weaver, J.S.** (1980). The behavior of friction piles in ice and ice-rich soils. *Canadian Geotechnical Journal*, **17**, 405-415.

**Nixon, J.F. and McRoberts, E.C.** (1976). A design approach for pile foundations in permafrost. *Canadian Geotechnical Journal*, **13**, 40-57.

**Nottingham, D. and Christopherson, A.B.** (1983). Driven Piles in Permafrost, State of the Art. In *Proceedings Fourth International Permafrost Conference, Fairbanks, July 17-22*. National Academy of Science, Washington, D.C., pp. 928-933.

**Phukan, A.** (1985). *Frozen Ground Engineering*. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.