INSTALLATION OF DRIVEN TEST PILES IN PERMAFROST AT BETHEL AIR FORCE STATION ALASKA

Frederick E. Crory

December 1973

PREPARED FOR
DIRECTORATE OF MILITARY CONSTRUCTION
OFFICE, CHIEF OF ENGINEERS
DA PROJECT 4A162121A894
BY
CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

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PREFACE

This report was prepared by Frederick E. Crory, Chief, Foundation and Materials Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL). Authority for the investigation was contained in FY 1961 Instructions and Outline, Military Construction Investigations, Engineering Criteria and Investigations and Studies, Investigation of Arctic Construction; Pile Installation Methods in Permafrost. The study was initiated by the Arctic Construction and Frost Effects Laboratory (ACFEL) of the U.S. Army Engineer Division, New England. ACFEL was merged with the U.S. Army Snow, Ice and Permafrost Research Establishment in 1961 to form USA CRREL. This report is published under DA Project 4A162121A894, Engineering in Cold Environments, Task 23, Cold Regions Earth Materials and Foundation Systems for Military Facilities, Work Unit 001, Design Criteria for Foundations in Cold Regions.

Contract negotiations and inspection were performed by the U.S. Army Engineer District, Alaska. B. Sturgelowski and G. Heming, of the Western Alaska residency, were coordinators and project engineers for the installation of the test piles and construction of the radar tower. The Alcan Pacific Company, prime contractor for the radar tower construction, installed the piles under the supervision of E. Billinek. Mr. Crory, the project leader, was present during the installation of the test piles, performed the analysis of the pile test results, and authored this report. The pile testing assembly was fabricated by personnel from the Alaska Field Station at Fairbanks. The load test was conducted by R.C. Freese of the Alaska Field Station.

The contributions of Professor A. Casagrande of Harvard University, Professor K. Woods of Purdue University, and Dr. P. Rutledge of the firm Moran, Proctor, Muesser and Rutledge, consultants on this and related programs, and the support and assistance rendered by the U.S. Army Engineer District, Alaska, are gratefully acknowledged.

The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products.
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### METRIC CONVERSION FACTORS

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INSTALLATION OF DRIVEN TEST PILES IN PERMAFROST
AT BETHEL AIR FORCE STATION, ALASKA

by

Frederick E. Crory

INTRODUCTION

Purpose and scope

Prior to construction of a radar tower foundation at Bethel Air Force Station, Alaska, six test piles were driven near the proposed tower location for the following reasons:

1. To obtain information on driving steel H-piles in permafrost by conventional methods.
2. To investigate the effect of attached refrigeration pipes on the driving of piles to the design depth of penetration in permafrost.
3. To provide piles for load testing in connection with improvement of pile foundation design procedures and verification of the capacity of the adjacent radar tower piles.

This report describes the installation of six test piles driven on 15-16 June 1960 and the load test performed on one of the piles using two others as anchors. The performance data from the single load test in this group and the load test results from a driven pile at the nearby White Alice site were utilized to predict the capacity of the longer and larger piles used in the adjacent radar tower foundation (Fig. 1).

Figure 1. Completed radar tower with test piles in foreground.
Background and previous work

Pile foundations for structures, incorporating an air space between the floor and the ground surface, have been used effectively in Alaska where permafrost conditions exist. The elevated floor permits the circulation of outside air by wind or natural convection which keeps the permafrost frozen and removes the heat lost through the floor. Generally, such foundation piles have been installed in augered or drilled holes. Soil, usually in the form of a slurry, is placed in the annular space around the pile. The natural cold reserve of the surrounding permafrost has been used in some areas to freeze the piles in place. In other installations, freezeback has been aided by artificial refrigeration, by circulation of cold brine or refrigerants through pipes or tubing attached to the piles.

As part of its program for development and improvement of engineering and construction methods in cold regions, the Arctic Construction and Frost Effects Laboratory of the Corps of Engineers demonstrated in experimental installations of test piles in 1954 and 1955 that H-sections and open-ended pipe piles could be successfully driven into the permanently frozen silt at the Alaska Field Station at Fairbanks at the ground temperatures prevalent there (Kitze 1957).

The Bethel Aircraft Control and Warning Station was designed and constructed in 1955 and 1956 by the U.S. Army Engineer District, Alaska, for the U.S. Air Force. It consists of a multipurpose or composite building and various support buildings and towers, all founded on timber piles. The pilings were installed in dry-augered holes and backfilled with machine-mixed sand/water slurry. The slurry was frozen in place by a mechanical refrigeration system to ensure rapid and positive initial freezing in view of the relatively warm permafrost in this area (USA CRREL 1963).

In November 1955 the Alaska District drove three 14BP73 structural-steel experimental piles into permafrost near the composite building with a Vulcan No. 1 hammer. This experimental driving was conducted to determine the feasibility of using conventional driving methods for the construction of a White Alice communication station about ½ mile south of the AC & W station. Two piles with square-cut bottom ends were effectively driven to 45 and 60 ft without adverse difficulties and without reaching refusal. The third pile, with a pointed bottom, met refusal at 17.5 ft, probably because of structural failure of the pointed bottom, although the cause was not specifically determined.

To further evaluate the effectiveness of driving piles in permafrost and to determine the bearing capacity of driven piles, the Alaska District drove a 14BP73 structural-steel pile 40 ft long adjacent to the proposed White Alice site (U.S. Army Corps of Engineers 1957). This square-ended pile was driven to refusal at a depth of 35.8 ft, with the upper 8 ft being unsupported in a dry-augered pilot hole. During the period 19-26 March 1957, the pile was tested, in three cycles, to loads of 20, 40 and 120 tons. In the 120-ton load test the pile experienced gross deflection of 0.109 in. and a net settlement of 0.051 in. after rebound. After the full depth of pile embedment had been excavated it was seen that the bottom 15 ft of the test pile had undergone considerable twisting and bending. This damage was attributed to the eccentricity produced by a 2-in. pipe, spot-welded along the pile length at the intersection of the web and one of the pile flanges. This pipe housed a thermocouple assembly for determining ground temperatures during the stabilization period after driving and throughout the test period.

In the summer of 1957, pile foundations for the White Alice facilities were installed by conventional driving methods using a Vulcan No. 1 hammer. Many of the various-sized piles used, however, met refusal with this hammer before reaching design depths.* Each pile was equipped with a 2-in. refrigeration pipe protected by a 3 x 3 x ¼-in. angle iron between the web and flange for the full length. Other selected piles had a 1.5-in. pipe, similarly protected, attached to the opposite flange as a permanent thermocouple casing.

*Data enclosed with letter from District Engineer, U.S. Army Engineer District, Alaska, to ACFEL, dated 2 March 1959, subject "White Alice Foundations."
In addition to H-sections 8-in. pipe piles were driven at the Bethel White Alice facilities for auxiliary foundations. During the same period 8-in. pipe piles were also successfully driven, though with a diesel hammer, for the foundation of the TACAN building at the Kotzebue Air Force Station. Soil conditions at Kotzebue consisted of silts with massive ice wedges, and ground temperatures substantially lower than those at Bethel.

The requirements of large flexural stability and high load-bearing capacity per pile at the White Alice and AC & W facilities favored the use of steel rather than timber piles. Also, the introduction of heat by the large volume of slurry required to backfill around a structural steel pile in a dry-augered hole would have required artificial refrigeration to ensure rapid and positive freezeback because of the limited reserve of natural cold in the permafrost of this area. Driven piles introduce a minimum of heat which quickly dissipates into the permafrost, thereby permitting construction to be essentially continuous with the foundation installation.

**SITE CONDITIONS**

**General**

The test pile area was located at the Bethel AC & W Station, about 4 miles west of the village of Bethel on one of the smooth rolling hills of the broad Kuskokwim Delta Plains. The tundra surface of this delta area is predominantly hummocky bunch grass and moss similar to the vegetative cover more commonly found in areas further north where the annual temperatures are much lower. Occasional stands of willow, alder, and other small trees and shrubs occur in sloughs and along the riverbanks.

The climate at Bethel is affected by mild maritime air masses moving from the southwest and dry continental air masses moving from the northeast. Based on continuous climatological records from 1924 to 1960, the mean annual precipitation is 18.2 in.; the highest monthly mean rainfall, 4.0 in., occurs in August, the lowest, 0.6 in., in April. Snowfall occurs from September to May, averaging about 50 in./yr. The mean annual temperature is 29.6°F; January is the coldest month with a mean monthly temperature of 6.8°F, and July the warmest with 54.5°F.

Air temperature fluctuations of as much as 60°F in 36 hours are common in the winter because of the alternating air mass types. The mean freezing index is 3987 degree-days, and the mean thawing index is 2643 degree-days for the period 1945 to 1955, inclusive. Wind direction forecasting from previous records is highly uncertain because of the constant shifting between maritime and continental air masses. The average wind velocity is about 10 mph, although winds up to 70 mph have been recorded.

**Pile test area**

The pile test area (Fig. 2) is about 45 ft west of the centerline of the road between the AC & W and White Alice sites, about 200 ft south-southwest of the new radar tower location. The test site has natural drainage in a southerly direction and, before installation of the piles, possessed an undisturbed tundra cover. A 1-ft layer of local fine sand was placed on the 30 x 50-ft test area to provide a working surface for the heavy pile-driving equipment.

The six test piles were arranged to provide for two separate load tests: piles BR-1, -2 and -3 were positioned in a straight line (Fig. 3) to permit testing of the center pile, BR-2, in load-settlement by jacking, using piles BR-1 and -3 as anchors. The other three piles, BR-4, -5 and -6, were positioned in a triangle to support a triangular load box for a future static-load test to determine
creep and failure-load levels under long-term loading. The pile lengths, location of welds, and overall driven depths are also shown in Figure 3.

All the test piles were 8BP36 structural-steel sections with square-cut bottom ends. Pile BR-1 was composed of two sections butt-welded together and driven to a depth of 33.7 ft*: the first section was 17.5 ft long and the second 24.5 ft. Pile BR-2 was a single 24.4-ft-long section, driven to a depth of 20 ft, and pile BR-3 was identical to pile BR-1 but had a ¾-in. refrigeration pipe spot-welded to the top section on each side of the web center. Piles BR-4, -5 and -6 were 17.5 ft long, driven to a depth of 16 ft.

Soil conditions

Subsurface explorations were not made within the limits of the test site itself. Previous explorations at the composite building showed the tundra vegetation of the vicinity varying in thickness

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*All depths refer to top of 1-ft-thick sand-fill working surface.
Figure 3. Details of test and anchor piles.
from 0.5 to 1 ft. The vegetation was underlain by a layer of silt or sandy silt and peat to a depth of 2 to 6 ft. The soil beneath the silt and peat is a silty fine sand (Fig. 4) to an explored depth of 32 ft at Tower C. Numerous other explorations in the AC & W station area have shown the silty fine sand to extend to at least 45 ft (USA CRREL 1963). The water content of 30 samples from an augered hole just north of the new radar tower ranged between 18 and 25%. Water contents were higher at the shallow depths in the silt and peat and at the 24- to 28-ft depth where thin ice lenses were observed. A well drilled in a swale approximately ¼ mile east of the site showed silts, silty sand, and sand to a depth of 195 ft.

Soil temperature and thaw conditions during installation of test piles

Subsurface temperatures were not obtained within the test area itself during the pile installation period (although, as described subsequently, they were obtained later during load tests). Instead, ground temperatures were measured during the pile-driving period beneath Radar Tower C (Fig. 2). A plot of ground temperatures with depth on 16 June 1960 is shown in Figure 5. Ground temperatures were also measured at a thermocouple assembly (previously installed by the Morrison-Knudsen Co.) about 100 ft north of the pile test area (Fig. 2) where the ground cover was about the same as at the test area. Temperatures at this assembly ranged from 28.7° to 30.0°F during the test pile installation period.

Probings were made adjacent to each pile with a ½-in. metal rod to determine the depth of thaw at the time of driving. All probes were referenced to the top of the pile and then converted to actual elevations, using the frost-free benchmark at the AC & W station. Table I shows the elevation of the tip of the pile, embedment length, and depth to frozen ground for each of the six test piles.

Table I.

<table>
<thead>
<tr>
<th></th>
<th>BR-1</th>
<th>BR-2</th>
<th>BR-3</th>
<th>BR-4</th>
<th>BR-5</th>
<th>BR-6</th>
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<td>16.0</td>
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<tr>
<td>Depth to frozen ground (ft)†</td>
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<td>2.09</td>
<td>1.58</td>
<td>1.83</td>
<td>1.75</td>
<td>1.83</td>
</tr>
</tbody>
</table>

*Tip of pile to surface of sand-fill working surface (approximate elevation 177.50 ft).
†Top of sand-fill working surface to frozen soil. Measured by probe rod on 17 June.

PILE INSTALLATION

Pile-driving equipment

The pile-driving equipment consisted of a Delmag D-12 diesel pile hammer supported on fixed leads attached to a crawler crane (Fig. 6). The diesel hammer had an overall weight of 5290 lb,
which included a piston weighing 2750 lb and an anvil weighing 754 lb. Energy output per blow of the hammer, as reported by the manufacturer, is 22,600 ft-lb, with a maximum explosion pressure on the pile of 93,700 lb. The hammer was operated at a rate of 46 to 50 blows/min, with the major portion of the driving at the higher rate.

Installation of triangular load-platform piles

The three piles to support the triangular load platform, BR-4, -5 and -6, were installed first. These piles, with an overall length of 17.5 ft, were installed to a depth of 16 ft on 15 June 1960, in the order BR-6, -4 and -5. These shorter piles, without refrigeration pipes, were driven first to evaluate the effectiveness of the driving method and to correct any deficiencies in the installation equipment or procedure. The driving records are shown in Figure 7. The average blow count for the last 10 ft of pile driving, neglecting all blow counts immediately following stops exceeding 1 minute, was about 21 blows/ft for the three piles. The penetration of these piles was relatively constant with depth and no indication of increased resistance with depth was evident. The average actual driving time for the 16-ft embedment was 6 min/pile.

Installation of load-test pile and two anchor piles

Two anchor piles and a center load-test pile were installed on an east-west line (Fig. 3). The two anchor piles, BR-1 and -3, were each driven in two sections on 15 June 1960. They were driven
before test pile BR-2 so that the depth of embedment of the anchor piles would control the depth of embedment of the test pile. In addition, it was desired to verify that this type of pile could be driven to a depth of 33.7 ft, the design depth of the tower foundation piles. The first sections, 17.5 ft long, were driven to the 15- or 16-ft depth and then the second sections, 24.5 ft long, were joined to the first sections by butt-welding and driven to final grade. The driving records for piles BR-1, -2 and -3 are shown in Figure 8.
The two anchor piles were identical except that two refrigeration pipes were attached to pile BR-3. These 3/4-in.-diam pipes were fastened to each side of the pile web at the centerline by tack welds at 2-ft intervals. The pipes extended from about 3 ft below the top of the pile to a point 19 ft from the bottom of the pile, with the loop through the web of the pile at the lower level being protected by a 2½ x 2½ x 1/4-in. angle iron on each side. The refrigeration pipes were shop-fabricated on the 24.5-ft section and required no further field modifications or connections. The bottom of the pipe loop was 1.5 ft from the bottom of the upper or 24.5-ft section. Fabrication details of the refrigeration pipes are shown in Figure 3.

The two anchor piles were driven to the design depth of the proposed radar tower piling. The contrast between the driving resistance patterns of the two anchor piles (Fig. 8) clearly shows the additional resistance to driving that resulted from the attached refrigeration pipes. Pile BR-1 required about 20 blows/ft to the 16-ft depth where driving was stopped for welding of the second section. Continuation of driving then required 49 blows from 16 to 17 ft. The number of blows per foot thereafter decreased with depth from about 30 to 20 blows/ft. This decrease in resistance is attributed principally to the reduction of energy losses in the unsupported pile length above permafrost as the pile was driven. An inspection of the pile length above ground indicated no apparent structural damage as a result of the driving.

The driving record of the first section of anchor pile BR-3 was similar to that of BR-1, except that the driving was stopped at the 15-ft depth to add the second section. Upon restart of driving after welding, a total of 67 blows was needed from the 15- to 16-ft depth; this included a 15-minute stop at the 15.4-ft depth, after 28 blows, to refuel the hammer. The number of blows per foot from 16 to 20 ft decreased in a manner almost identical to that experienced in driving pile BR-1. However, the number of blows per foot increased rapidly from the 20.8-ft depth, where the refrigeration pipe protective angles entered the permafrost, to the design depth of 33.7 ft. Of interest is the abrupt decrease in resistance to driving caused by the attachment of a sling for the alignment of the pile while driving at the 25.3-ft depth. The last full foot of driving (32 to 33 ft) required 155 blows; the last 0.7 ft required 105 blows. No structural damage to the pile head or the exposed pile length above ground was evident in the inspection performed immediately following the driving of this pile.

Test pile BR-2, with an overall length of 24.4 ft and without refrigeration pipes, was driven without difficulty midway between the two anchor piles on 16 June. From 6 to 20 ft, excluding the blow count from 8 to 9 ft because of delays required for alignment, the average number of blows per foot was 22.2, with no apparent increase or decrease in resistance with depth (Fig. 8).

The test piles and a general view of the test area are shown in Figure 9.

Installation of radar tower piles

Installation of the new radar tower foundation was started immediately after driving the last test pile on 16 June. The tower piles were arranged in two concentric circles of 12 piles each (Fig. 10). The piles were 8BP36 sections equipped with refrigeration pipes identical to those previously described for anchor pile BR-3. Three 10BP42 sections were symmetrically placed inside the two rows of exterior piling. These piles were also equipped with refrigeration pipes on each side of the web. Installation depths were referenced to the finish grade of the sand fill that was placed just prior to the driving operation. Depth of fill was approximately 2.5 ft.

Driving resistances of the 24 exterior piles were similar or identical to those of test pile BR-3. The flanges on two of the exterior piles buckled during driving at depths of about 30.5 ft.
Figure 9. Looking north at test piles BR-1, -2 and -3 following installation. Septic tank house at left, Tower D right center, Tower C at extreme right.

Design depth of installation:
- Exterior Piles (8BP36): 32.5 ft.
- Interior Piles (10BP42): 36.5 ft.

Figure 10. Radar tower foundation.
The damaged sections, just above the fill elevation, were cut off and replaced. The driving records of two exterior sections, including one on which the flange buckled, are shown in Figure 11.

The driving resistances of the three interior (10BP42) piles were similar to those of the exterior piles, although the average blow count from the 30 to 36-ft depth was somewhat less than that for the 8-in. sections. The average actual driving time for both pile types was 31 minutes. "Down time" for welding the two sections of each pile together averaged 56 minutes. Installation of the 24 exterior and 3 interior piles was completed the morning of 24 June 1960.

LOAD TEST

Load test equipment

Since insufficient dead weight, except soil, would have been available at the site for application of loads using a conventional load box, it was decided to perform the load test on pile BR-2 using a reaction beam held in place by two anchor piles (BR-1 and BR-3). The reaction beam was fabricated in two sections from surplus 8-in. structural steel sections available at the site (Fig. 12). A 100-ton hydraulic jack was used to produce the required load by positioning the ram atop the pile head to bear against a short crossbeam positioned midway beneath the two reaction beams. To accommodate the jack, 4.3 ft of the test pile was cut off and a plate fixed to the pile head. A spherical bearing block was used between the ram head and the crossbeam to eliminate application of eccentric loads.

Instrumentation

So that ground temperatures could be observed within the test area during the load test period, thermocouple assemblies were installed within the refrigeration pipes attached to the web of
anchor pile BR-3. To facilitate this installation, thermocouples for the shallow depths were placed in one pipe and those for the deeper depths in the opposite pipe. Following installation, the annular space surrounding the wires was filled with cold, dry sand to provide a conductive contact between the wires and the pipe and to eliminate errors caused by convective air movements. The assemblies were installed a week in advance of the start of the load test to allow them to come to equilibrium with the existing ground temperatures.

Deflection gauges, graduated to 0.001 in., recorded the displacement of the test and anchor piles during the load test. Four dials were positioned equidistant from the center of the test pile at points 1 in. from the ends of two 2 × 2 × ½ × 12-in. angle irons welded to the pile for the reference plane. Two deflection gauges also monitored the upward motion of each anchor pile during the load test. The reference points on each anchor pile were located 1 in. from diagonally opposite corners on two angle irons welded at the same elevation. Deflection gauges were mounted on 3 × 3 × ½-in. angle irons 15 ft long that were supported by ½-in. pipes manually driven into the permafrost. The support pipes were located 6.5 ft from their respective piles and were cased to a depth of 2.5 ft with ½-in. pipe to prevent any disturbance of the instrumentation beams by surface frost heave. The annular space between the two pipes was filled with a cold, heavyweight oil. To protect the instrumentation beams and deflection gauges from the disturbances of wind, snow and sunshine, the entire assembly was covered with a tarpaulin.

**Test procedures and results**

Loads were applied to the test pile in 5-ton increments at 24-hour intervals. Deflection readings were taken just prior to, and at frequent intervals immediately following, application of each load.
increment. Deflection readings and jack adjustments were made throughout the remainder of the 24-hour period at intervals of 1 to 2 hours, to establish the settlement with time under each load increment. A total load of 85 tons was applied. Application of greater loads was not practical or safe because of excessive deflection of one reaction beam at the 85-ton load. Deflection of the beam caused the load to drop from 85 tons to 80 tons overnight. After the maximum load was maintained for 19 hours, it was released to zero in less than 5 minutes. Deflection readings at the zero load were continued for an additional 24 hours to establish the rebound of the test and anchor piles. The load test was started on 27 November 1960 and continued until the release of the maximum load of 85 tons on 14 December.

At the start of the test the average depth of frozen soil at the ground surface was 1.1 ft. To eliminate the adhesion of the frozen surface, the soil was excavated to a depth of approximately 1.5 ft immediately adjacent to the test pile prior to the start of the test. Immediately following excavation, the area around the test pile was filled, and covered, with conventional building insulation. A heating tape installed beneath this insulation was operated intermittently to prevent any further frost penetration in the underlying thawed soil surrounding the test pile. Thus the surficial temperatures observed throughout the test period at anchor pile BR-3, which was not equipped with insulation or a heating tape, do not reflect the thawed condition maintained in the active layer at the test pile. The depth of the active layer or depth to permafrost, which is relatively stable at this time of the year, was determined (by probing adjacent to the test pile) to be 3.2 ft. Ground temperatures observed at anchor pile BR-3 during the test period are shown in Figure 13. Similar temperatures were obtained in measurements made at weekly intervals during the test period at the thermocouple assembly located 100 ft north of the test area and at Tower C (see p. 6). The load test was purposely delayed until late fall, when ground temperatures within the permafrost are warmest and the corresponding supporting capacity is at a minimum.

**Discussion of test results**

The load-settlement test results for pile BR-2 are shown in Figure 14. At loads greater than 35 tons, hereafter referred to as the yield-point load, the pile exhibited a constant plastic deflection similar to that commonly experienced in unfrozen sand, where the pile does not fail by plunging into the ground, but continues to settle a constant amount under each additional load increment along an inclined tangent (Peck, Hanson and Thornburn 1953).

The unit adfreeze stress at the yield point load for pile BR-2 was computed to be 7.3 psi. This unit adfreeze stress can be multiplied by the surface area below ground of longer or larger piles to estimate their yield point loads. The same ground temperatures and soil types must be present in both cases, however, for this extrapolation to be valid.

The extrapolated load-settlement curves for the longer exterior and larger interior radar-tower piles are shown in Figure 15, along with the actual results of test pile BR-2. The curves reflect the effect of greater length and surface areas on supporting capacity.

To evaluate the accuracy of the extrapolation of the load test results to the longer and larger piles, similar computations were made to predict the performance of the previously tested White Alice pile. The empirical performance of this 14BP73 test pile, 27.0 ft in permafrost, is also shown in Figure 15. Unfortunately the actual test results (Fig. 16) can not be directly compared, as the rate of load application (5 tons/11-min interval) was not the same as for test pile BR-2 (5 tons/24-hr interval). Only the overall settlement at the end of the 69.5-hr period at the maximum load of 120 tons is believed comparable. As shown in Figure 16, the gross deflection at the end of this sustained load period was about 0.124 in. This value, assumed to have occurred irrespective of the rate of load application, is plotted in Figure 15. This point, for all purposes, lies on
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Figure 13. Ground temperatures with depth at pile BR-3 during pile load test.

Extrapolated from Tower C and M-K Assemblies

Legend
- 25 Nov '60
- 27 Nov '60
- 3 Dec '60
- 9 Dec '60

0 to 4 ft depth
Heater tape installed to maintain thawed condition on BR-2.

4 to 20 ft depth
Average temp: 30.9°F

Figure 14. Load test on driven pile BR-2.

Load applied in 5 ton per 24 hour increments
Figure 15. Extrapolated load-settlement curves for the longer exterior and larger interior radar-tower piles.

Figure 16. Load test on driven White Alice test pile. Load applied in 5 ton/11 min increments. Not shown is load cycle to zero prior to maintaining 120-ton load caused by hydraulic jack failure; no observations taken.

the predicted load-settlement curve, just below the yield point, at the beginning of the inclined tangent. Although the results of the White Alice test pile are in apparent accord with the theoretical performance of the longer and larger piles, the actual performance of such piles remains of course unproven. Further tests at the same site and in the same environment are needed to substantiate the accuracy of the predicted load-settlement curves. The empirical curves in Figure 16 are considered suitable only for estimating the performance and the safety factor of each pile in the foundation and verifying the design criteria.
The results of the single load settlement test on pile BR-2, when loaded at a rate of 10 kips/day, provides little information as to the amount of secondary settlement or creep which may occur during the life of the structure. In the absence of such information from relatively short duration load tests, present design practice is to employ larger safety factors than are commonly used in thawed soils.

RESULTS AND CONCLUSIONS

Results

Driving 8BP36 structural-steel test piles in permafrost with a high-energy diesel hammer proved to be very effective. Driving the test piles to a maximum depth of 30 ft in permafrost (without attached refrigeration pipes) required about 22 blows/ft with this type of hammer and soil condition. Except for the first few feet of driving, there was no increase in driving resistance with depth. Conversely, test pile BR-3 with attached refrigeration pipes showed a definite increase in resistance with depth after the refrigeration pipes entered the frozen soil. The angle irons protecting the refrigeration piles increased the cross-sectional area of the 8-in. and 10-in. sections by 71% and 61% respectively. This area increase is particularly significant because it was concentrated at the very center of the piles.

Under the adopted installation method, excellent vertical and horizontal alignment of the test piles was achieved. The maximum horizontal variation of pile locations from those desired was less than 0.5 in. Piles BR-1, -2 and -3 were driven to such perfect alignment that no variation between the three piles was noted. The time for driving both the test and production piles, even when using refrigeration pipes, was shorter than is normally required in the auger-slurry method. The rapidity with which the bearing capacity is acquired following driving, as shown by the increase in driving resistance after the short periods required for welding, supports the contention of construction continuity.

The load test on pile BR-2, performed at a relatively slow rate of loading, provided an approximation of the capacity of the tower piles, at the minimum load capacity period of the early winter months. The extrapolated load test results were in close agreement with those previously obtained in the load test of the driven pile at the nearby White Alice facility. At the normal minimum permafrost temperatures encountered at this site, driven piles have an adfreeze bond strength of approximately 1000 lb/ft² at the yield point.

Conclusions

Under the soil and ground temperature conditions which existed during these experiments, the driving of plain structural steel piles in permafrost was demonstrated to be an efficient and relatively trouble-free method. When H-piles not equipped with refrigeration pipes were driven, no limiting driving depth was reached, either during this installation or in the experimental driving of 1955.

The attachment of refrigeration pipes to the piles significantly increases the driving resistance. The design depth to which piles equipped with refrigeration pipes were driven, 33.5 ft, appears to be about the maximum depth to which this particular pile section could be safely driven without suffering structural failure under high energy hammers. The size of the pile had little effect on the driving resistance in comparison with the effect of the refrigeration pipes.
Recommendations

Based on the success of the installation reported here, it is recommended that investigations concerning driving of steel piles in permafrost be continued, and be extended to other soil types and soil temperature conditions.

Where possible, future investigations should be conducted prior to or in conjunction with actual construction to reduce the normally high cost of such tests and to provide test results which are directly applicable to the actual foundation piling. Because the type of refrigeration pipes used in these tests increased driving resistance, it is recommended that other means of foundation refrigeration be utilized. Comparative cost and performance evaluations should be made between two-section piles welded in the field using shop-fabricated refrigeration pipes, and single-section piles, not equipped with refrigeration pipes, which can attain greater depth. Future studies should also include a comparison of the capacity of driven piles with the capacity of identical sections installed by the auger-slurry method. Consistent test conditions and procedures should be employed to minimize the number of parameters involved in the analysis.

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Installation of Driven Test Piles in Permafrost at Bethel Air Force Station, Alaska

The installation, testing, and analysis of driven test piles installed at Bethel, Alaska, in conjunction with the construction of a radar tower foundation are discussed in detail. Investigations were conducted to obtain further information on driving piles in permafrost, studying effects of auxiliary refrigeration pipes on driving resistance, and verification of design assumptions. Test and production piles, 8- and 10-in. H-beams, were installed to maximum depth (34 ft) using a high-energy diesel hammer. While the size of the pile had little effect, the refrigeration pipes on both sides of the web increased driving resistance significantly. The load test results of a pile driven to a depth of 20 ft were extended to evaluate the capacity of the longer or larger radar tower piling. Recommendations on extending the use of the driving method of installing piles in frozen ground to different soil types and colder temperatures are presented.