THREAD BAR PILE FOR PERMAFROST

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Abstract

The capacity of sand slurried pipe piles in ice poor permafrost soil can be limited by the low bond strength between the sand slurry and smooth steel pipe wall. To improve the capacity of pipe piles, protrusions can be added to the pipe. An alternative design is a steel thread bar backfilled with either grout or clean gravelly sand. The smaller diameter thread bar section provides a larger annulus between the steel and commonly used air track drill hole for easier backfill placement and it develops greater load capacities. A grout thread bar pile, in short term pile load test, developed about three times the capacity of a sand slurry pipe pile and a thread bar pile backfilled with a gravelly sand developed about twice the capacity of a sand slurry pipe pile. The concepts and development of these pile designs and field pile load tests are presented.

Résumé

La capacité portante des pieux d'acier circulaires installés dans un pergélisol à faible teneur en glace à l'aide d'un coulis eau-sable est souvent limitée par la faible adhérence entre le coulis eau-sable et la paroi lisse du pieu d'acier. Afin d'augmenter cette capacité portante, des nervures peuvent être ajoutées au pieu. Une des alternatives pour la conception est l'utilisation de barres crénelées scellées par un coulis de ciment ou par du sable graveleux propre. Ceci permet d'obtenir une plus grande capacité portante en générant un espace annulaire plus grand et en facilitant ainsi la mise en place du coulis ou du matériau de remplissage entre l'acier du pieu et la paroi du trou, généralement réalisé à l'aide d'une foreuse à percussion (air track). Les pieux d'acier avec barres crénelées, lorsqu'ils sont soumis à un essai de chargement à court terme, développent, par rapport aux pieux installés dans un coulis eau-sable, une capacité portante trois fois supérieure, s'ils sont enrobés de coulis de ciment, et jusqu'à deux fois plus élevée si le remplissage est de sable graveleux. La mise au point des principes de conception et les résultats des essais de chargement de ces pieux sont traités dans cet article.

Introduction

The smooth steel pipe pile backfilled with a sand water slurry (sand slurry) is a common pile foundation in permafrost. Its limitation may be low load capacity and availability of drilling equipment in the arctic to drill sufficiently large holes to provide desirable sized annulus for quality sand slurry placement. Very low load capacities can exist for piles with long term loading in "warm" permafrost and/or saline soil conditions. The steel pipe for the piles is normally limited to diameters from 114 mm to 140 mm because available drill equipment can drill readily a 165 m hole and with downhole hammer attachment up to a maximum drill hole of about 190 mm. For ideal sand slurry installation it is desirable to have pile holes with a 50 mm annulus which require hole diameters of 214 to 240 mm.

The above limitations and the need to design economic pile foundations with large loads for Short Range Radar Stations in the Canadian arctic lead to the search of alternative pile design. This resulted in the development of a grouted pile for permafrost (Holubec and Brzezinski, 1989 and, Biggar and Sego, 1989). This paper discusses the use of a thread bar pile backfilled with either a grout or clean uniformly graded coarse sand or fine gravel as an alternative to the sand slurry pipe pile. This steel section is proposed for light structures and for sites where it is uneconomical to drill holes sufficiently large for pipe pile sand slurry placement. The concepts and results are also applicable for pipe sections with corrugations but these piles require much greater drill holes.

The development of the grout pile for permafrost soil was discussed by Holubec and Brzezinski (1989) and its increased load capacity as compared to the sand slurry pile was shown in relative short-term field load tests in saline soil permafrost in Iqaluit by Biggar and Sego (1989). The latter reported that the grout thread bar pile has a load capacity in short term pull-out test nearly 10 times that of a smooth pipe pile. Since large capacity piles are normally not needed for many of the arctic community structures and the cost of the grout and the cost of transportation of the steel and grout are relatively high, an alternative lower capacity pile based on a thread bar backfilled with either a clean uniform coarse sand or fine gravel was investigated. The concepts in the development of the grout and granular thread bar piles are discussed and field load test results are given to compare the capacities of the two proposed pile designs against the sand slurry pipe pile in short term creep tests.

Background

The most common pile foundation in permafrost is the sand slurry smooth steel pipe pile (Crory, 1966, Johnston, 1981, and Hyedinger, 1987). This pile design involves the drilling of an oversized hole in the frozen soil, lowering a smooth steel pipe into the hole and backfilling the annulus between the pipe and frozen soil with a sand slurry. Depending on soil type, the load capacity of the sand slurry pile is normally dependent on the long-term adfreeze strength between the sand slurry and steel pipe which controls the total settlement over the life span of the structure.

Early studies made for the Aleyaska Oil Pipeline (1974) had concluded that the bond at the slurry-pile interface on the steel pile almost always governs the pile capacity. This was also observed in fast rate load field pile load tests conducted at Yellowknife (Holubec, 1988) and short term model pile load tests conducted for the Canadian Department of National Defence (Sego & Smith, 1989) which showed that pipe piles backfilled with various materials (soils, grout and ice) had the failure always occurring at the pipe/backfill interface. There is ample evidence that the pile/backfill adfreeze strength can be increased by roughening the pile surface or adding corrugations to the pile. (Naval Civil Engineering Laboratory, 1970, Weaver and Morgenstern and Andersland and Alwahhab, 1983). Furthermore, Long (1973) quotes Newcombe and Vialov who show that the strength can be increased by a factor of 3 to 7 by causing the failure to occur through the frozen soil at the same rate of loading.

The above observations indicate that the capacity of a pile in permafrost can be increased considerably if the design of the pile surface/geometry and type of backfill is selected so that the failure or creep is transferred to the backfill/frozen soil interface or even completely to the native frozen soil. The capacity increase, as a minimum, will be equivalent to the perimeter increase of the failure surface. It is postulated that in dense ice poor granular soils the shear may be completely transferred to the compact frozen granular soil.

This concept was investigated by installing and testing short sections of two proposed pile designs, namely, a thread bar backfilled with grout (GTB) and a thread bar backfilled with gravel sand (STB) (fig.1). The results of tension loads were compared to a sand slurry pipe pile (PIPE).

The thread bar pile design consists of a threaded reinforcing bar with a surface conductor pipe to provide lateral capacity for the above ground pipe section. In the Tuktoyaktuk load test, the thread bar had a nominal diameter of 43.0 mm and the outside surface of the threads had a diameter of 47.3 mm. The below ground length of the conductor pipe is a function of the magnitude of the lateral loads and depth of the active layer. Generally a 1 m burial depth of the conductor pipe in frozen ground below the active layer will provide sufficient lateral load capacity. The annulus between the thread bar and frozen ground can be filled with either grout or water saturated clean uniform coarse sand or fine gravel. It was anticipated that the grout thread bar (GTB) would have a greater capacity than the sand thread bar (STB) since the grout is a stronger backfill material. The concepts of these two piles are discussed in the next two sections.

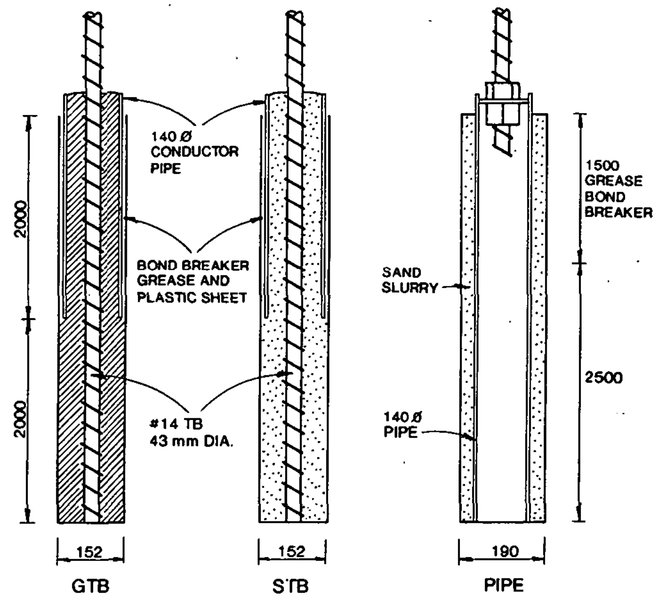

Figure 1. Pile designs.

Sand thread bar pile

The sand slurry pipe pile develops the adfreeze strength through the cohesion provided by the ice frozen to the steel and the friction between the sand and steel surface. The strength of the pile can be increased by forcing the failure envelope through the frozen soil by using corrugations on the pile surface. In this case the strength is largely governed by the geometry and spacing of the protrusions and the type of soil. The ideal pile should have continuous spiral corrugations with a densified clean uniform coarse sand or fine gravel backfill. A continuous spiral will transfer the shear stress from the steel to the backfill/soil uniformly, as opposed to horizontal rings which concentrate the stress, and allow easier flow of the granular soil in the annulus during backfilling. A clean uniform coarser backfill will flow readily in the space between the soil and pile and can readily be densified by vibrating the pile section. In this design the pile will cause strain in the sand/gravel backfill, which in turn will dilate. The dilation of the backfill will apply normal pressure and transfer the shear to the native soil. The increase of the strength of the pile will be governed by the corrugation geometry of the pile and dilatancy capability of the backfill.

Grout thread bar pile

The concept of this pile design is to transfer the load from the steel section to the native frozen soil by means of a strong grout. The grout increases the steel section capacity by increasing the perimeter area of the pile and may provide a greater shear resistance between the rough grout/native soil interface than is available between the sand slurry and plain pipe surface.

It should be noted that using a grout with plain steep pipe does not usually provide a good bond between grout and steel causing the pile to fail at the pipe/grout face as demonstrated in laboratory and field tests (Sego & Smith, 1989, and Holubec, 1988, respectively).

Cold room curing of grouts in frozen sand at -10°C identified two grouts which are suitable for permafrost application (Holubec and Brzezinski, 1989). The two grouts are Set-45 and Cement Fondu with an accelerator distributed as SikaGrout Arctic 100. The Set-45 is magnesium phosphate grout which requires a small quantity of water (0.075 water/cement ratio) and the mixed grout is not affected by freezing to -10°C tested. The SikaGrout Arctic 100 must be prepared under controlled temperature conditions with the grout being at 20°C and a good installation procedure has to be followed.

Factual information

Site conditions

The grout pile test installation was conducted just northwest of a new gravel pad prepared for the construction of a new school in Tuktoyaktuk. The undisturbed ground condition in this area consists of a 1 m layer of organic silt underlain by 1.4 to 4 m of the silty/sandy gravel with little to no excess ice followed by a sandy silt and/or silty sand with some excess ice (fig. 2). Conductivity tests indicated a salinity ranging between 0.9 and 2.0 parts per thousand.

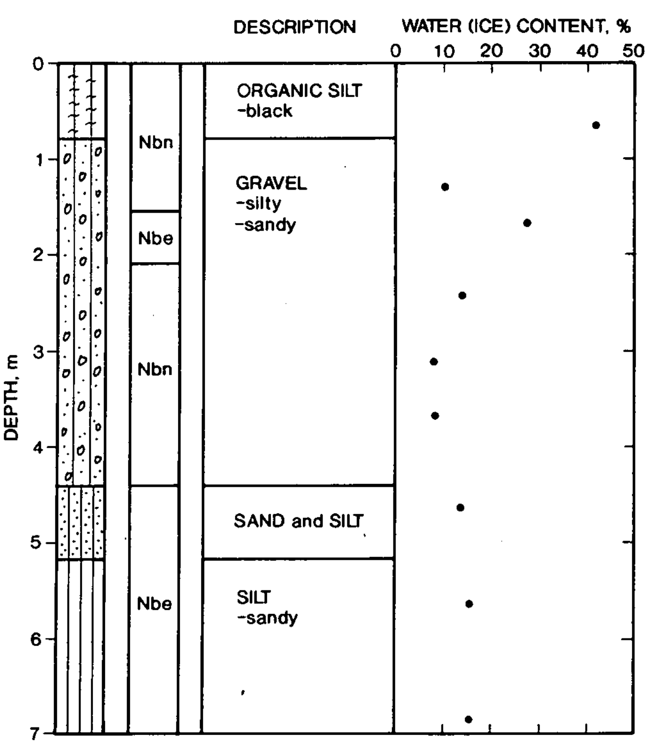

Figure 2. Soil stratigraphy.

The ground temperatures measured on May 18, 1989 where the piles were installed varied from -8.5 to -11.5°C as shown on Figure 3.

Pile design and installation

The initial intent was to install a total of six piles consisting of three designs. The three designs were: a) a grouted thread bar pile (GTB), b) a thread bar pile backfilled with a gravelly sand (STB) and c) a pipe pile backfilled with a sand slurry (PIPE) to serve as a reference pile (Figure 1). The reference pile was similar in design to the piles used for the foundation of the new school under construction.

The piles had a total length of 4 m and an effective bonding length of two meters so that it would be possible to fail the piles with a hundred ton jack. The grout and sand thread bar piles consisted of a 43 mm diameter thread bar for the length of the pile and it extended one meter above the ground so that it would pass through the centre hole of the jack sitting on a load frame. A 140 mm diameter conductor pipe was provided for the top 2 m of the pile. The conductor pipe was greased and wrapped in a plastic sheeting so that the load resisting capacity would be provided predominantly by the lower 2 m length of the pile. The reference sand slurry pipe pile had a 140 mm diameter, was 4 m long and the upper 1.5 m length was greased as a bond breaker.

Pile installation

On arrival at the site on May 17 it was discovered that the drilling contractor was not able to drill the larger diameter hole required for sand slurry placement. As a result only the four thread bar piles were installed in 152 mm holes at that time. The available 140 mm diameter steel pipe pile was installed in about a 190 mm drill hole about two weeks later. The layout of the piles is shown on Figure 4.

The grout thread bars were backfilled with Set -45 grout which was mixed in a paddle type mixer. The grout temperature after mixing was about +4°C. Of the two sand

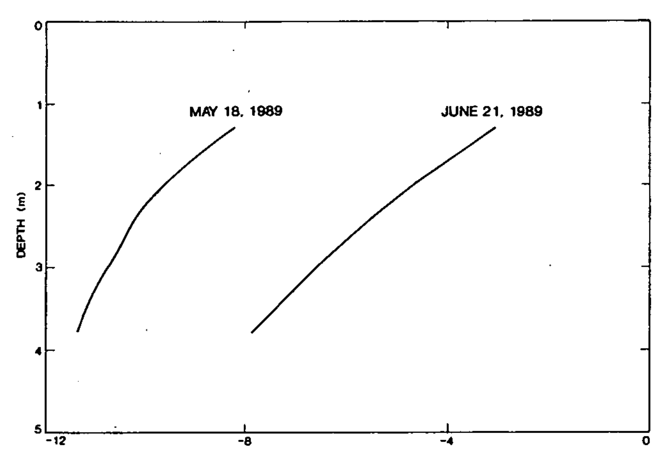

Figure 3. Ground temperatures.

thread bar piles, Pile STB 1, was backfilled with a gravelly sand which was used for the school gravel pad and the second pile, STB 2, was backfilled with air track cuttings which had a gravelly silty sand gradation. Gradation curves of the two sands are shown on Figure 5.

The installation of the grout and sand thread bar piles were as follows. Five four meter deep and 152 mm diameter holes were drilled, conductor pipes with the bond breakers were installed, thread bars were lowered and centred in the drill holes and finally the thread bars were backfilled with either grout or water sand slurry. In the case of the sand thread bar pile, the sand was densified by vibrating the in place sand slurry through the thread bar using the air track drill.

After placement of the grout and sand backfills, the backfill temperatures were monitored for the next 18 hours. The initial ground temperature on May 18, 1989 is shown on Figure 3. Figure 6 shows the backfill freeze back with time at a 3.3 m depth for the three types piles. It should be noted that the sand thread bar initially cooled to about -5°C after which it warmed to about zero one hour after placement. Subsequently it cooled in similar fashion, but delayed, as the grout piles. It is believed that the initial cold temperature was due to the thread bar being too long in the cold hole before sand placement and therefore the initial cold temperature reflected the temperature of the hole before grout placement and not the sand slurry. The bar was then warmed by the wet sand slurry and stayed at about 0° for a longer period because of the latent heat of water in the sand slurry. After about six hours, the backfills were approaching the adjacent ground temperature.

Testing procedures

The testing equipment and procedure were relatively simple because of limited funds and time available to conduct this testing. It is felt that the testing was sufficient to be able to compare the relative capacities of the grout pile against the sand pipe pile design used at the school and evaluate the load capacity of a sand thread bar pile. The pile load test setup consisted of a 100 ton centre hole jack supported by two wide flange beams which in turn were supported on 200 mm square timbers. The surface organic silt was excavated to the frozen sandy gravel and backfilled with a compacted sandy gravel. The timbers were then placed on the sandy gravel. The faces of the timbers were 600 mm away from the pipe pile surface. The load deflection was measured by a dial gauge reading to 0.025 mm supported by an independent support system.

It was felt that the closeness of the timbers to the pipe would have minimal affect on the pile capacity because of the short duration of the tests and the bond breaker between the frozen soil and pipe in the upper 2 m depth. The testing procedure was to test one grout and one sand thread bar pile at a fast rate, (about 15 minutes per load increment) to establish the maximum load and then load the subsequent piles by maintaining each load increment for about 30 minutes.

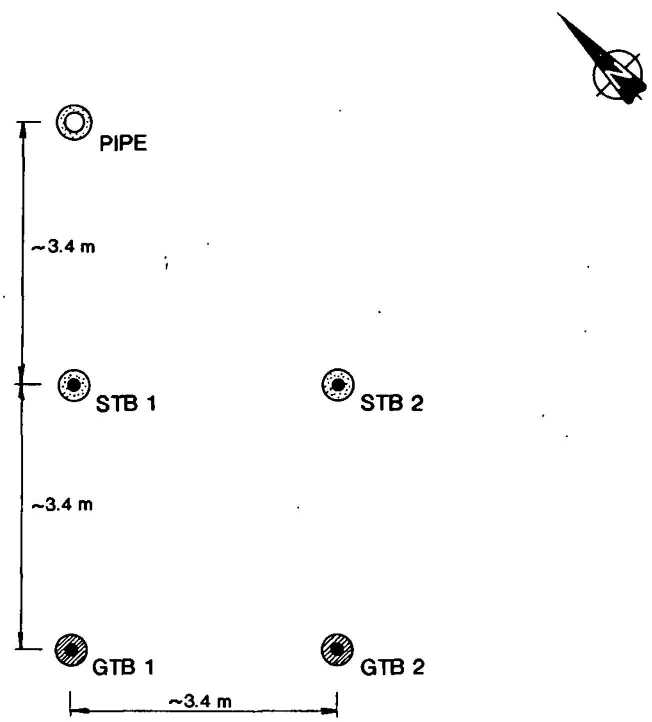

Figure 4. Pile locations.

Test results

Summary of the load deformation curves of the five piles tested are shown on Figure 7. In the tests it was found that the maximum loads of the thread bar piles exceeded the yield strength of the steel thread bars. The maximum load was 900 kN while the yield strength of the thread was about 600 kN. Therefore the deformations for loads above 600 kN are composed of both the yielding of the steel thread bar and creep of the backfill or adjacent frozen ground. Since the yielding of the steel occurred only during the first few minutes after load application, it is believed that the creep rate determined from the last part of the deformation versus time curve is a good representation of the sand slurry or native soil creep. For comparing the three pile designs, the sand slurry pipe pile loads obtained with a 140 mm diameter pipe were reduced to represent a 114 mm diameter pipe installed in a 152 mm diameter hole as was used in the thread bar installation.

The adfreeze strengths were calculated by assuming that the creep and failure of the plain pipe occurred at the pipe/sand backfill interface with the critical surface with a 114 mm diameter. For the thread bar designs with sand slurry and grout backfill it was assumed that the creep and failure surfaces were at the backfill/native soil interface with a 152 mm diameter.

The pile capacities were compared for loads which would produce 0.1 mm per hour creep and a maximum load based on a 15 mm total deformation criteria. It should be noted that the 15 mm deformation criteria is conservative for the grouted thread bars because of the yielding of the steel after the 600 kN load. If the thread bars had not yielded their true ultimate strength would have been greater. The comparison of load capacities for the 2 m pile embedment and based on the above criteria are shown on Table 1. The results on Table 1 show that the plain pipe has the lowest capacity followed with the thread bar backfilled with air track cuttings. The capacity of the thread bar increases substantially when it is backfilled with a gravelly sand instead of the air track cuttings. It is postulated that the increase is the result of the clean gravelly sand providing greater interlocking and dilation pressures upon shearing than the finer material from the air track cuttings. The air track cuttings contained about 15 percent of fines while the clean gravelly sand had only about 3 percent of fines. The largest capacity was provided by the grouted thread bar.

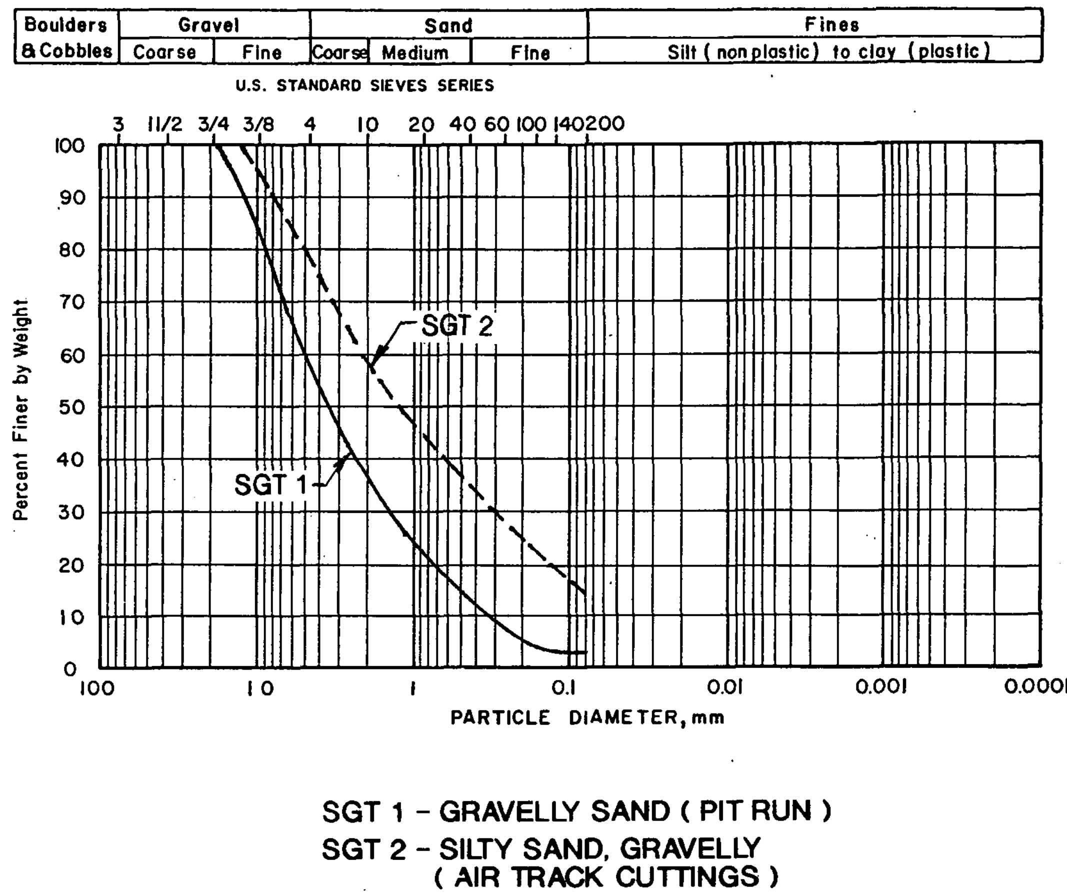

Figure 5. Ground Temperatures.

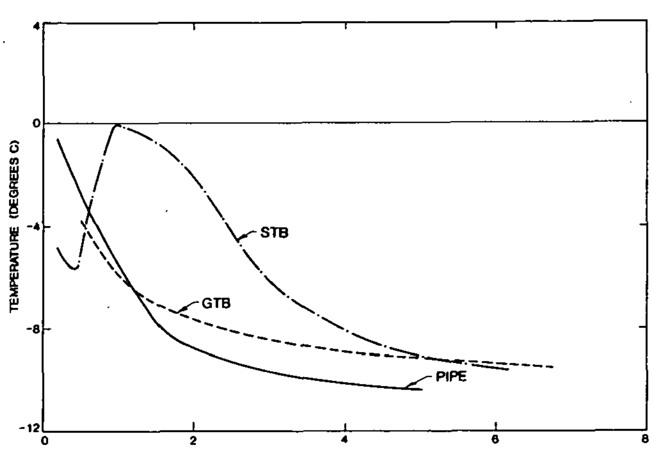

Figure 6. Backfill Curing at 3.3 m.

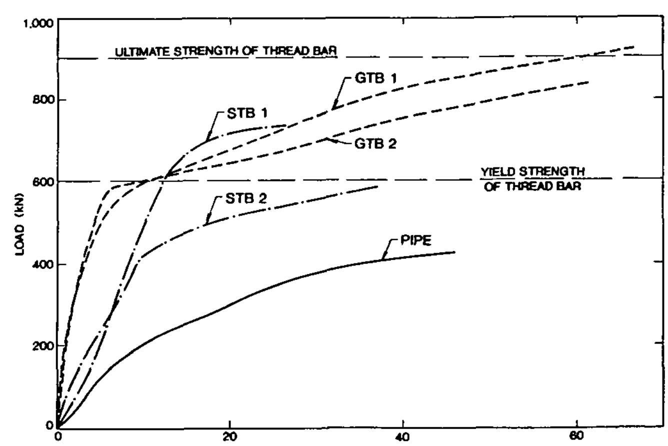

Figure 7. Pile Load Tests.

Table I. Comparison of pile capacities for 2000 mm pile length from tuktoyaktuk test.

	Based On 0.1 mm/hr Creep	At Failure (a)
Plain Pipe	165 kN	200 kN (b)
Thread Bar Cuttings	220	480 kN
Thread Bar Gravelly Sand	315	670 kN
Grouted Thread Bar	478	750 kN (c)

NOTES: a) Failure load taken at 15 mm deformation.
b) Based on 114 mm diameter pipe.
c) Estimated failure load.

The adfreeze strength at the 0.1 mm/hour creep was interpreted by first plotting the deformation against time on Figure 8 and then plotting the creep for different loads on Figure 9. The 0.1 mm/hour creep was selected so that the results could be compared to the results obtained by Biggar and Sego (1989). Based on this creep rate, the bond strength from the Tuktoyaktuk pile load test along with adfreeze strengths obtained from the Iqaluit tests are given on Table 2. The comparison of the adfreeze strengths of the different designs and at the two sites shows that the grout thread bar piles at both sites have similar adfreeze strengths, i.e. 500 kPa at Tuktoyaktuk and 450 kPa at Igaluit but different adfreeze strengths were obtained for both the plain pipe and thread bar/pipe with lugs at the two different sites. It is postulated that the different capacities of the pile designs with granular slurry backfill is due to the ground temperatures at Tuktoyaktuk being slightly lower, -6° as compared to -5° at Iqaluit, and that the Iqaluit soils are saline with the salinity range being 15 to 25 parts per thousand while the native soils at Tuktoyaktuk had a salinity between 1 to 2 parts per thousand.

The adfreeze strengths of the grout piles were about twice as great as the plain pipe at Tuktoyaktuk and about 5.5 times as great at Iqaluit.

To compare the capacities of the three pile designs, the pile capacities for 1 m length of pile at 0.1 mm per hour

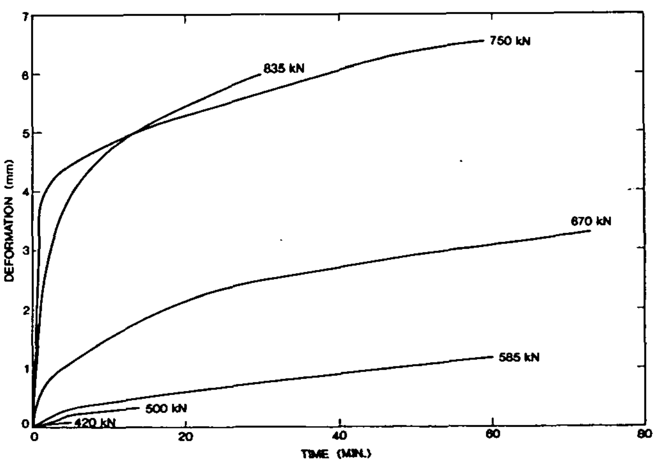

Figure 8. Time - Deformation for GTB Pile.

Table II. Comparison of adfreeze strengths based on 0.1 mm/hour creep.

Pile Design	Location of Stress	Adfreeze Strength, kPa Tuktoyaktuk	Iqaluit
Plain Pipe	Pipe/Sand	230	80
Thread Bar Cuttings	Sand/Native Soil	230	--
Thread Bar and Pipe with Lugs Gravelly Sand	Sand/Native Soil	330	128 (a)
Grouted	Grout/Native Soil	500	450

a) Based on diameter measured to outside of lugs.

creep were calculated for Tuktoyaktuk and Iqaluit and at failure for Tuktoyaktuk, Iqaluit and Yellowknife (shown on Table 3). The capacities were then related to the sand slurry pipe pile by a ratio of the thread bar and pipe with lugs pile capacities to the capacity of the sand slurry pipe pile.

This comparison indicates that the sand thread bar pile or a pipe pile with corrugation has about twice the capacity of the plain sand slurry pipe pile while a grouted thread bar pile has three to eight times the capacity of the plain pipe pile under the conditions at the three sites (table 4).

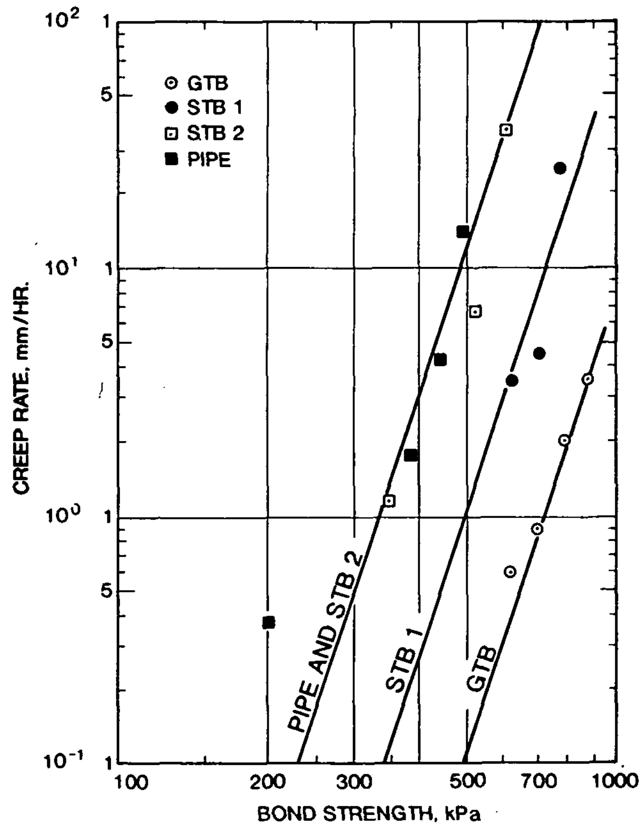

Figure 9. Bond Strength at Different Creep.

Table III. Comparison of pile designs (based on one metre pile length and at about -5 °c.

	Plain Pipe		Sand TB OR Lugged Pipe		Grouted TB	
	Load (kN)	Ratio	Load (kN)	Ratio	Load (kN)	Ratio
<u>At 0.1 mm/hr Creep</u>						
Tuktoyaktuk	83	1.0	158	1.9	239	2.9
Iqaluit	28	1.0	54	1.9	233	8.3
<u>At Failure</u>						
Tuktoyaktuk	100	1.0	335	3.4	375	3.8
Iqaluit	70	1.0	150	2.1	600	8.6
Yellowknife	75	1.0	170	2.3	230	3.1

NOTE: Yellowknife load is for 1.5 m pile length with ground temperature of -2 °C.

Discussion

The Tuktoyaktuk pile load tests have shown that a thread bar backfilled with either a granular soil or grout has a greater capacity than the sand slurry plain pipe pile when tested at a relatively fast rate and when the loads are compared at a creep rate of 0.01 mm/hr. or at the maximum load. It is postulated that the thread bar or pipe with corrugations pile designs will also demonstrate greater load capacities than the sand slurry pile under long term loading where creep rate governs the pile design.

The load capacity increase can be explained by 1) increase of the effective pile perimeter through the shifting of the failure surface from the pile/sand slurry interface to the grout (or sand/gravel)/native soil and 2) by the rougher surface at the grout (or sand/gravel)/native soil interface. The magnitude of the first increase is directly related to the perimeter increase. The second load increase is greatly dependent on the roughness of the backfill/soil interface and the type, temperature and salinity of the native frozen material which may be ice-poor frozen, dense sand or gravel, ice-rich soil (either non-saline or saline) or just pure ice. In ice poor frozen dense sand and gravel the second increase will be significant since the native soils are competent even in unfrozen condition. In the case of the ice rich soil or pure ice, the increase may be small or negligible depending on the load transfer at the backfill/native material interface and the creep of the native material itself. It is postulated that even in ice rich soils the creep strength may be greater than the adfreeze bond between sand slurry and smooth steel pipe piles. The design magnitudes will have to be determined at a future date during long term pile load testing.

Aside of the increased capacity of the thread bar designs, the other advantage of these pile designs is that the thread bar provides a greater annulus for backfill placement. For lightly loaded structures, the drill hole diameter could be decreased to a size that allows the placement of the conductor pipe and provides some freedom of the conductor pipe for location adjustment. A 140 mm diameter hole for a pile with a 114 mm diameter conductor pipe may be appropriate.

Finally it should be noted, that since both the sand and grout backfilled thread bars have a greater bond strength than the adfreeze strength of the sand slurry pipe pile, it may be possible to design shorter piles in situations where frost jacking governs the pile design. This saving is only possible where a conductor pipe is used and the annulus between the conductor pipe and native soil is backfilled with sand. The bond strength at the thread bar pile would be greater than the bond strength at the conductor pipe, thereby reducing the length of the frost jacking resisting length.

Table IV. Capacity and cost comparison of pile designs (See Figure 7)

	Sand Slurry	Sand Thread Bar	Grout Thread Bar	
			Neat	Extended
Capacity, kN	72	156	234	234
Weight, kg				
steel	134	70	77	77
grout	0	0	159	138
Total wt, kg	134	70	237	215

Conclusions

The pile load tests conducted in Tuktoyaktuk show that there are promising alternative pile designs which could provide savings and larger capacity piles.

The grout pile design is in an advanced design stage with pipe piles with spiral corrugation being installed and tested at ten western short range radar stations. This data will be greatly augmented when long term load test data becomes available from these installations.

The sand thread bar pile is a new concept and should be used with conservatism. The observed greater bond capacity is consistent with theory and is indirectly supported by published information. However the range of bond strengths which can be used for design will have to be developed by future installations and testing.

Acknowledgements

The concept of using the thread bar for a pile design is the result of several assignments on the construction of radar installations by the Canadian Department of Defence. The present Tuktoyaktuk pile load tests were sponsored by the Architectural Division of the Northwest Territories Public Works and Highways and supported by Master Builders Company Limited and Dywidag International Systems. Their support is gratefully acknowledged.

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