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HOOK ANCHOR TESTS IN FROZEN AND UNFROZEN GROUND

Austin Kovacs

Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire

May 1975

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The findings of an exploratory study of the holding capacity of hook anchors in frozen and unfrozen ground are presented. Testing revealed that hook anchors are capable of being driven and retrieved from frozen silt and that their holding capacity was reasonably high in comparison to their size. Hook anchor capacity in the frozen silt at −2°C was found to be three times higher than in the unfrozen silt.

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PREFACE

This report presents the findings of an exploratory study of hook anchors load tested in both frozen and unfrozen ground. The study was performed by the U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL) for the U.S. Army Materiel Command under DA Project 1T062112A130, *Cold Regions Research*, Work Unit 001, *Military Anchorages in Frozen Materials.*

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HOOK ANCHOR TESTS IN FROZEN AND UNFROZEN GROUND

by

Austin Kovacs

Introduction

Anchoring is the technique used to support and stabilize guyed structures. Portable structures which are dismantled and moved to different sites present a complex tie-down problem. This results from the demand often placed upon the anchor system to be in fact a universal system capable of providing reliable anchorage under a wide range of soil conditions. Therefore, for many portable structures two or more anchor types are provided to contend with various soil conditions. Selection of anchors is based upon such factors as weight, ease of emplacement, reusability and holding capacity.

Providing anchorage in frozen ground is often a very difficult task due to the ground's resistance to displacement or disengagement. The strength of frozen ground varies markedly, being dependent upon such parameters as soil type, frozen water content and distribution and temperature. It is not uncommon to hear of instances where anchorage was not adequately provided because the anchor was structurally unfit for the hard driving required to emplace it, or the ground was simply too resistant for anchor penetration. It is also common to hear of situations where anchors had to be abandoned because it was impossible to extract them from the frozen ground in which they were embedded.

This report presents the findings of an exploratory study of the holding capacity of hook anchors (trade name Anker) in both frozen and unfrozen silt. Tne anchor is a relatively new modification of an old concept. It was selected for testing because it appeared structurally robust and particularly suited for frozen ground installation and retrieval.

Test sites

While another study was being conducted in Alaska in March 1970, time allowed for initial load testing of the hook anchor. The tests were conducted at the USA CRREL Alaska Field Station (now the Alaskan Projects Office) in Fairbanks. The soil at the test site was a silt having a bulk density of 88 lb/ft^3, a dry density of 60 lb/ft^3 and a moisture content of 45%.

In 1971 and 1972 additional load testing of the hook anchor was conducted in frozen and unfrozen silt behind the CRREL facility in Hanover, N.H. The 1971 anchor tests were conducted in soil having a bulk density of 110 lb/ft^3, a dry density of 86 lb/ft^3 and a moisture content of 29%. The soil's grain size gradation is shown in Figure 1. As would be expected, soil density and water content varied during the long winter to summer test season of 1972. An indication of the soil density and water content with depth during the winter and summer tests is given in Figure 2. The representative grain size distribution of the soil is presented in Figure 3.

Ground temperatures

At the Fairbanks test site the soil temperature 5 in. below the surface was recorded with a thermocouple. During the tests the soil at this depth remained at -2°C. Soil temperatures at the Hanover test site were obtained to the nearest 0.01°C from the thermocouples installed 1, 6, 12 and 18 in. below the ground surface. The temperature readings obtained are presented to the nearest 0.1°C in Table I.

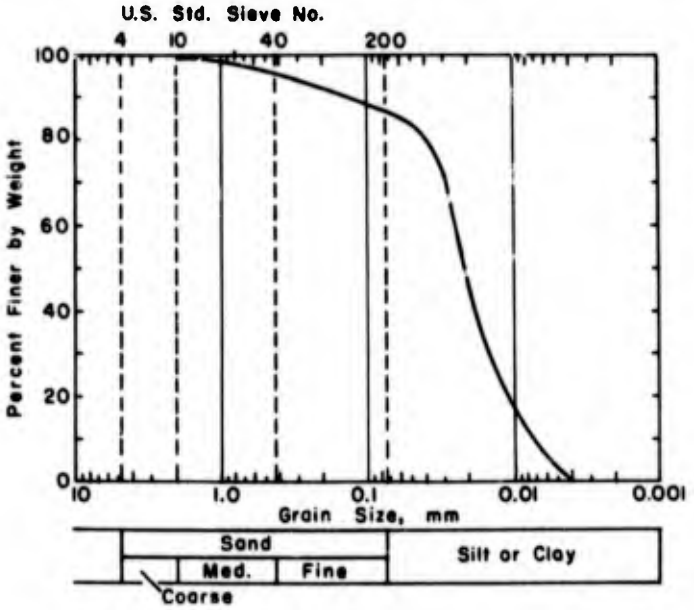


Figure 1. Grain size distribution of silt at the 1971 Hanover test site.

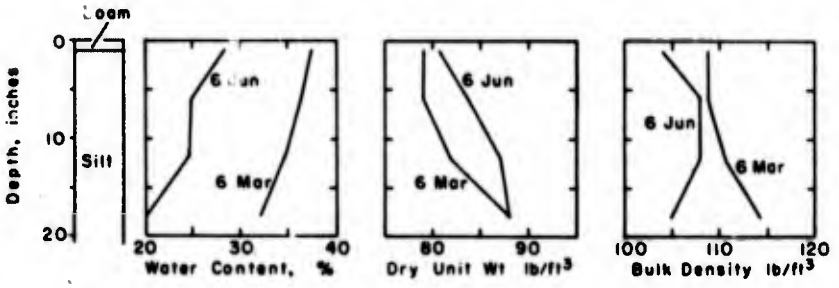


Figure 2. Soil water content and density at the Hanover test site on 6 March and 6 June 1972.

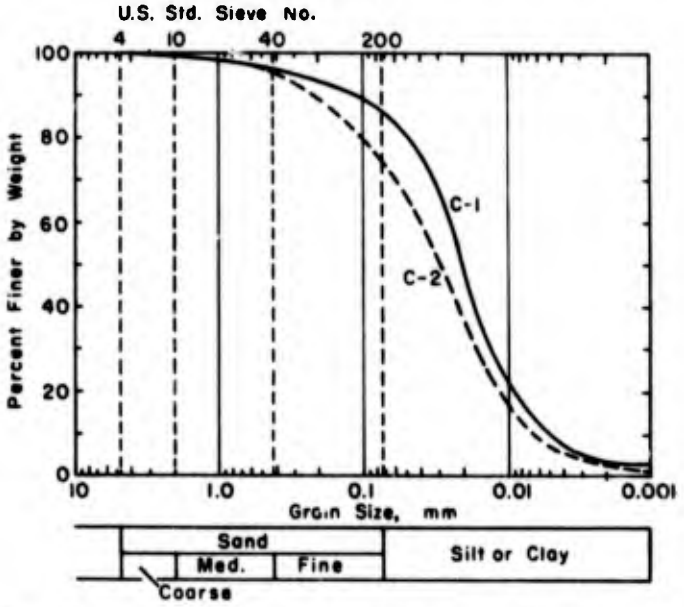


Figure 3. Grain size distribution of the silt at the 1972 Hanover test site. (Curves C-1 and C-2 represent two test site soils at two different locations.)

Table I. Ground temperature data.

Average of 8 a.m. and 4 p.m. ground temperatures (°C).

Date	*Depth, in.* 1	6	12	18
19 Feb 1971	-0.7	-1.2	-1.7	-1.6
22	-1.2	-1.2	-1.2	-1.0
23	-2.0	-1.7	-1.2	-0.9
24	-1.5	-1.5	-1.3	-1.0
25	-2.6	-2.5	-1.3	-1.6
26	-2.4	-2.3	-2.0	-1.2
1 Mar	-0.2	-0.5	-0.7	-0.7
2	-1.0	-0.7	-0.7	-0.3
3	-0.2	-0.5	-0.7	-0.6
4	-0.3	-0.5	-0.6	-0.6
5	-0.7	-0.6	-0.6	-0.6
8	-2.0	-0.9	-0.7	-0.6
9	-5.4	-3.3	-1.0	-0.6
10	-5.1	-4.4	-3.2	-1.3
11	-2.6	-2.7	-2.3	-1.8
12	-1.3	-1.7	-1.6	-1.2
13	-2.5	-2.3	-1.6	-1.1
15	-0.3	-0.8	-1.1	-1.0
16	-0.4	-0.4	-0.8	-0.8
17	-0.2	-0.5	-0.8	-0.8
18	-0.2	-0.4	-0.7	-0.7
23	-0.1	-0.3	-0.4	-0.4
24	-2.9	-1.0	-0.4	-0.4
25	-0.2	-2.3	-0.6	-0.5
26	-6.9	-3.4	-0.7	-0.4
29	-2.6	-0.4	-0.7	-0.6
30	-0.1	-0.4	-0.6	-0.6
31	-0.1	-0.3	-0.6	-0.5
1 Apr	-2.9	-0.2	-0.5	-0.7
2	-3.4	-0.2	-0.5	-0.5
5	-0.2	-0.1	-0.7	-0.7
11 Jan 1972	-0.2	-0.1	-0.2	-0.2
12	-0.2	-0.3	-0.3	0
13	-0.8	-0.6	-0.3	0
14	-0.2	-0.3	-0.2	0
17	-3.4	-2.9	-3.0	-1.9
18	-3.2	-3.2	-3.2	-2.0
19	-1.0	-1.6	-1.6	-1.0
20	-2.0	-1.8	-1.6	-1.0
21	-2.0	-1.9	-1.6	-1.2
24	-0.1	-0.2	-0.3	-0.1
25	0	0	-0.2	-0.2
26	-5.0	-5.0	-1.5	-0
27	-5.6	-4.7	-3.6	-0.5
28	-5.5	-4.8	-3.8	-1.0
31	-7.0	-5.2	-2.9	-1.2
1 Feb	-6.9	-5.8	-3.5	-1.4
2	-5.4	-4.6	-3.4	-2.0
3	-4.6	-3.8	-3.1	-1.8
4	-2.0	-1.9	-2.0	-1.7
8	-5.8	-5.4	-4.0	-2.5
9	-5.8	-5.2	-4.5	-2.2
11	-6.3	-5.1	-4.6	-2.1
14	-2.4	-0.8	-0.8	-0.9
15	-0.5	-0.7	-0.8	-0.1
16	-1.1	-0.8	-0.8	-0.4
17	-2.0	-1.3	-1.0	-0.7
18	-1.0	-1.0	-0.2	-0.2

Table I (cont'd). Ground temperature data.
Average of 8 a.m. and 4 p.m. ground temperatures (°C).

	Depth, in.			
Date	1	6	12	18
22 Feb 1972	-4.0	-3.4	-3.2	-2.7
22	-5.7	-5.6	-5.1	-3.5
25	-4.0	-4.1	-3.4	-3.0
28	-2.3	-1.3	-1.2	-0.9
29	-0.5	-0.8	-1.0	-0.9
1 Mar	-0.2	-0.8	-1.0	-1.0
2	0	-2.0	-0.4	-0.6
3	-0.5	-0.4	-0.6	-0.5
6	0	0	-0.4	-0.6
7	-0.2	-0.2	-0.4	-0.5
8	0	-0.1	-0.3	-0.4
9	0	-0.2	-0.7	-0.4
10	-1.6	-1.2	-0.8	-0.6
13	-0.3	-0.1	-0.4	-0.5
14	-0.2	-0.2	-0.4	-0.5
15	-1.4	-1.6	-1.4	-1.0
16	-1.3	-1.1	-0.9	-0.8
17	-0.5	-0.6	-0.5	-0.5
20	-0.7	-0.4	-0.5	-0.6
21	-0.4	-0.4	-0.4	-0.5
22	-0.1	-0.1	-0.3	-0.4
23	+0.8	-0.2	-0.3	-0.5
27	0	-0.2	-0.1	-0.3
28	+0.1	-0.1	-0.2	-0.3
29	+0.1	-0.1	-0.2	-0.3
30	+0.1	+0.1	-0.2	-0.2
3 Apr	0	-0.2	-0.2	-0.3
From this date on all temperatures above 0				

Anchor description

The hook anchor may be best described as having the shape of half a wire clothes hanger. A number of these anchors are shown in Figure 4 and a close-up view of a $^{5}/_{16}$-in.-diameter one with a shank length (that portion of the anchor driven into the ground) of 12 in. is shown in Figure 5. As can be seen in Figure 5 the arm of the anchor has a curved end. It is here that the guy wire or rope is attached to the anchor. The anchors are made of spring steel, and may be obtained with diameters ranging in $^{1}/_{8}$-in. increments from $^{1}/_{8}$ in. to $1^{1}/_{4}$ in. and shank lengths from 5 in. to $3^{1}/_{2}$ ft. The included angle between anchor arm and shank is either 30 or 45°.

While the hook anchor was the primary test anchor two other anchors underwent token testing. One was a military GP-112/G guy stake (Fig. 6) and the other was the Grizzly Mini Stake (GM) shown in Figure 7. The GP-112/G is a forged steel stake with the dimensions shown in Figure 8. The 12-in.-long GM stake is stamped from a $^{1}/_{64}$-in.-thick steel strip. The anchor is U-shaped, having a width of $^{3}/_{4}$ in. and a depth of $^{1}/_{2}$ in.

A list of the anchors tested along with information pertinent to each test is given in Table II.

Figure 4. Configuration of hook anchors tested.

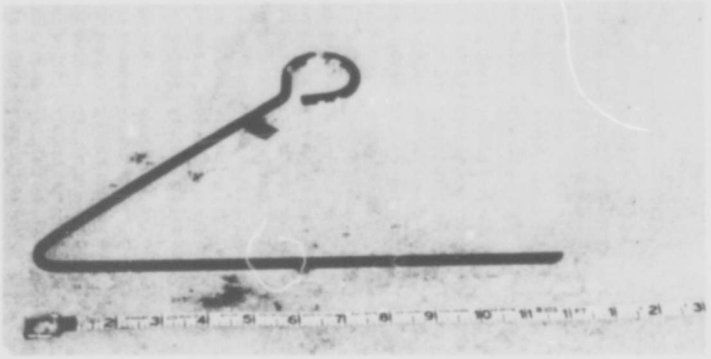


Figure 5. View of a $^{5}/_{16}$ in. diameter hook anchor with 12 in. shank.

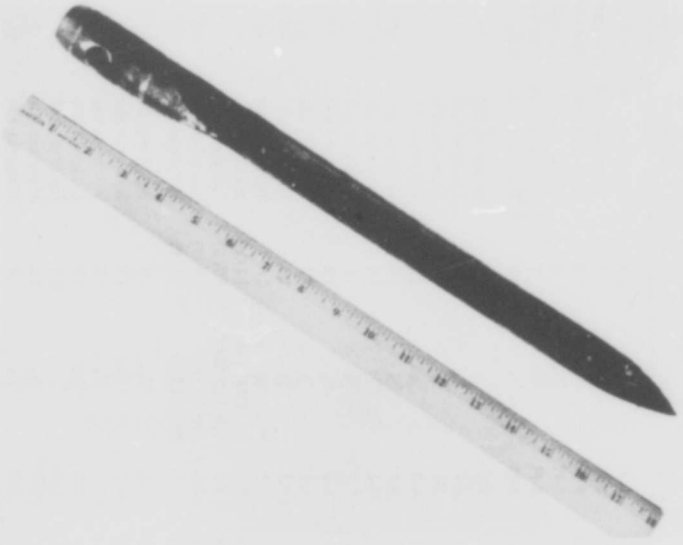


Figure 6. View of the GP-112/G guy stake.

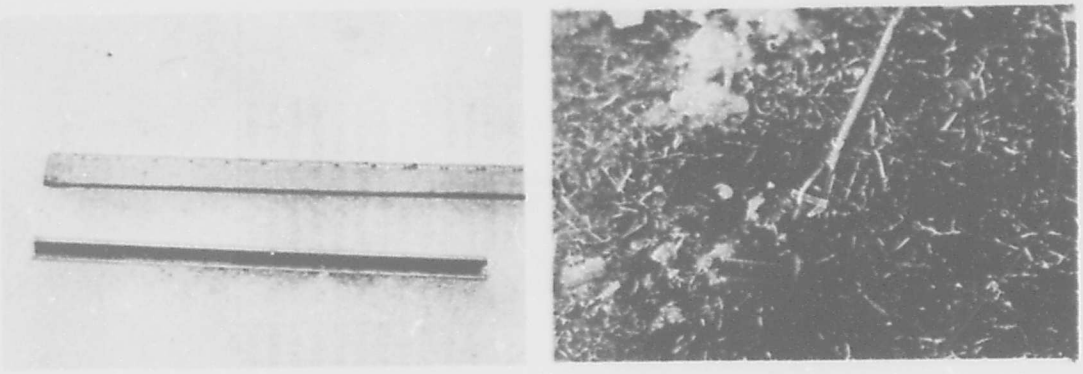
Table II. Anchor test data.

Date	Test	Anchor diam (in.)	Length* (in.)	Soil	Load angle	Max load (lb)	Remarks
29 Mar 70	1-H	1/8	18	Fairbanks silt	Horizontal	1000	See Fig. 13 for test history - anchor loaded to 1000 lb to observe creep for 1 hr
30 Mar 70	2-H	5/16	9	Fairbanks silt	Horizontal	250	See Fig. 14 for test history - anchor creep rate excessive
30 Mar 70	3-H	5/16	9	Fairbanks silt	Horizontal	250	See Fig. 15 for test history - anchor extracted
31 Mar 70	4-H	5/16	9	Fairbanks silt	Horizontal	250	See Fig. 17 for test history - anchor extracted
1 Apr 70	5-H	5/16	9	Fairbanks silt	Horizontal	400	See Fig. 18 for test history - anchor extracted
1 Apr 70	6-H	1/2	18	Fairbanks silt	Horizontal	1800	See Fig. 19 for test history - anchor extracted
18 Feb 71	1-J	1/2	18	Hanover silt	45°	1000	See Fig. 20 for test history - anchor bent- partially drawn out of ground
1 Mar 71	2-J	5/8	18	Hanover silt	45°	1500	See Fig. 21 for test history - anchor cut into soil during extraction
15 Mar 71	3-J	3/8	12	Hanover silt	45°	250	See Fig. 21 for test history - anchor failed structurally at elbow
23 Mar 71	4-J	3/8	12	Hanover silt	45°	250	See Fig. 21 for test history - anchor failed structurally at elbow
29 Mar 71	5-J	5/8	18	Hanover silt	45°	1000	See Fig. 21 for test history - anchor cut into soil during extraction - lever arm bent
27 May 71	6-J	5/8	18	Hanover silt	45°	375	See Fig. 22 for test history - anchor cut into soil during extraction - lever arm bent
9 Jun 71	7-J	5/8	18	Hanover silt	45°	375	See Fig. 23 for test history - anchor cut into soil during extraction - lever arm bent
25 Jun 71	8-J	3/8	12	Hanover silt	45°	150	See Fig. 23 for test history - anchor extracted - soil displaced by shank
2 Jul 71	9-J	3/8	12	Hanover silt	45°	150	See Fig. 24 for test history - anchor cut into soil during extraction
6 Jul 71	10-J	3/8	12	Hanover silt	45°	75	See Fig. 24 for test history - anchor failed at elbow
9 Jul 71	11-J	5/8	18	Hanover silt	45°	500	See Fig. 25 for test history - lever arm bent - soil cut by shank
11 Aug 71	12-J	GMS(1)	12(2)	Hanover silt	45°	112	See Fig. 26 for test history - anchor extracted - soil crept under anchor load
19 Aug 71	13-J	GP-112/G(3)	17(5)	Hanover silt	45°	375	See Fig. 27 for test history - anchor extracted - soil crept under anchor load
25 Aug 71	14-J	GP-112/G	17(5)	Hanover silt	45°	250	See Fig. 28 for test history - anchor extracted - soil crept under anchor load
25 Aug 71	15-J	GP-112/G	17(5)	Hanover silt	45°	300	See Fig. 28 for test history - anchor extracted - soil crept under anchor load
12 Jan 72	1-B	5/16	12	Hanover silt	55°	250	See Fig. 30 for test history - anchor partially extracted - soil displaced by anchor
13 Jan 72	16-J	5/16	12	Hanover silt	55°	575(4)	See Fig. 30 for test history - anchor extracted - soil displaced by anchor
24 Jan 72	17-J	5/16	12	Hanover silt	55°	450(4)	See Fig. 30 for test history - anchor extracted - soil displaced by anchor
25 Jan 72	18-J	5/16	12	Hanover silt	55°	380(4)	See Fig. 30 for test history - anchor extracted - soil displaced by anchor
26 Jan 72	2-B	5/16	12	Hanover silt	55°	450	See Fig. 31 for test history - anchor extracted - soil displaced by anchor
26 Jan 72	19-J	5/16	12	Hanover silt	55°	450(4)	See Fig. 31 for test history - anchor extracted - soil displaced by anchor
29 Jan 72	3-B	5/16	9	Hanover silt	55°	100	See Fig. 31 for test history - anchor extracted - soil displaced by anchor
9 Feb 72	20-J	5/16	12	Hanover silt	55°	450(4)	See Fig. 31 for test history - anchor extracted - soil displaced by anchor
11 Feb 72	21-J	1/4	15	Hanover silt	55°	400(4)	See Fig. 31 for test history - anchor extracted - soil displaced by anchor

Table II (cont'd).

Date	Test	Anchor diam (in.)	Length* (in.)	Soil	Load angle	Max load (lb)	Remarks
14 Feb 72	22-J	5/16	15	Hanover silt	55°	500(4)	See Fig. 31 for test history - anchor extracted - soil displaced by anchor
14 Feb 72	23-J	1/4	15	Hanover silt	55°	400(4)	See Fig. 31 for test history - anchor failed at elbow
14 Feb 72	4-B	3/16	9	Hanover silt	55°	100	See Fig. 31 for test history - anchor extracted - soil displaced by anchor
15 Feb 72	22-J	1/4	15	Hanover silt	55°	400(4)	See Fig. 31 for test history - anchor extracted - soil displaced by anchor
15 Feb 72	25-J	1/4	15	Hanover silt	55°	400(4)	See Fig. 31 for test history - anchor extracted - soil displaced by anchor
16 Feb 72	26-J	5/16	16	Hanover silt	55°	500(4)	See Fig. 31 for test history - anchor extracted - soil displaced by anchor
16 Feb 72	27-J	3/16	9	Hanover silt	55°	150(4)	See Fig. 31 for test history - anchor extracted - soil displaced by anchor
16 Feb 72	28-J	3/16	9	Hanover silt	55°	150(4)	See Fig. 31 for test history - anchor extracted - soil displaced by anchor
16 Feb 72	5-B	5/16	12	Hanover silt	55°	550	See Fig. 32 for test history - anchor failed at elbow - soil displaced by anchor
17 Feb 72	29-J	5/16	16	Hanover silt	55°	550(4)	See Fig. 32 for test history - anchor extracted - soil displaced by anchor
29 Feb 72	6-B	3/16	9	Hanover silt	55°	100	See Fig. 32 for test history - anchor extracted - soil displaced by anchor
2 Mar 72	7-B	1/4	15	Hanover silt	55°	400	See Fig. 33 for test history - anchor extracted - soil displaced by anchor
14 Mar 72	8-B	3/16	9	Hanover silt	55°	100	See Fig. 33 for test history - anchor extracted - soil displaced by anchor
17 Mar 72	9-B	1/8	6	Hanover silt	55°	45	See Fig. 33 for test history - anchor extracted - soil displaced by anchor
20 Mar 72	10-B	GMS	12	Hanover silt	55°	100	See Fig. 33 for test history - anchor extracted - soil displaced by anchor
22 Mar 72	11-B	GMS	12	Hanover silt	55°	100	See Fig. 33 for test history - anchor extracted - soil displaced by anchor
23 Mar 72	12-B	GMS	12	Hanover silt	55°	100	See Fig. 33 for test history - anchor extracted - soil displaced by anchor
29 Mar 72	13-B	1/8	6	Hanover silt	55°	45	See Fig. 33 for test history - anchor extracted - soil displaced by anchor
27 Apr 72	14-B	1/4	15	Hanover silt	55°	100	See Fig. 33 for test history - anchor extracted - soil displaced by anchor
2 May 72	15-B	1/4	15	Hanover silt	55°	75	See Fig. 33 for test history - anchor extracted - soil displaced by anchor
4 May 72	16-B	1/4	15	Hanover silt	55°	50	See Fig. 33 for test history - anchor extracted - soil displaced by anchor
5 May 72	17-B	1/4	15	Hanover silt	55°	125	See Fig. 33 for test history - anchor extracted - soil displaced by anchor
16 May 72	18-B	1/4	15	Hanover silt	55°	125	See Fig. 33 for test history - anchor extracted - soil displaced by anchor
22 May 72	19-B	1/4	15	Hanover silt	55°	125	See Fig. 33 for test history - anchor extracted - soil displaced by anchor
30 May 72	20-B	1/4	15	Hanover silt	55°	125	See Fig. 33 for test history - anchor extracted - soil displaced by anchor
5 Jun 72	21-B	1/4	15	Hanover silt	55°	175	See Fig. 33 for test history - anchor extracted - soil displaced by anchor
19 Jun 72	22-B	GMS	12	Hanover silt	55°	75	See Fig. 33 for test history - anchor extracted - soil displaced by anchor

* Shank and embedment length
1 Grizzly Mini Stake
2 Embedded 10 in.
3 Tapered steel military stake
4 Loaded in 50 lb increments each hour
5 Embedded 1/4 in.



a. Horizontal view. *b. End view during load test.*

Figure 7. Grizzly Mini Stake.

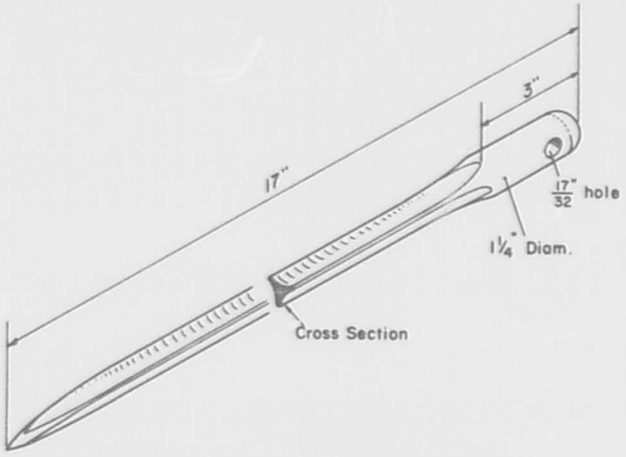


Figure 8. Dimensions of GP-112/G stake.

Anchor installation

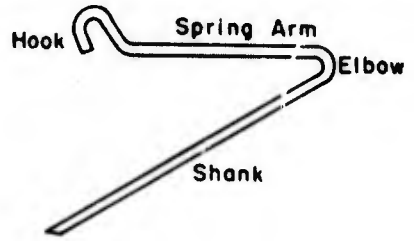
All anchors were installed using a 2-lb ball hammer. Driving time for most of the hook anchors was always less than one minute, and more often than not less than 30 sec. The hook anchors were driven the full length of their shank following the procedure outlined by the manufacturer (Fig. 9). The GP-112/G and GM stakes were driven at an angle of 45° to an embedment depth of 14 and 8 in. respectively.

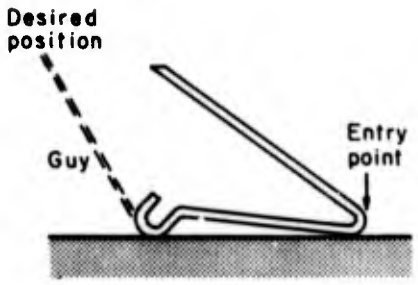
Test apparatus

In 1970 a hydraulic jack was used to apply an axial load to the Anker spring arm, i.e. a horizontal load was applied to the arm. The load was measured by a Hydroscale as shown in Figure 10.

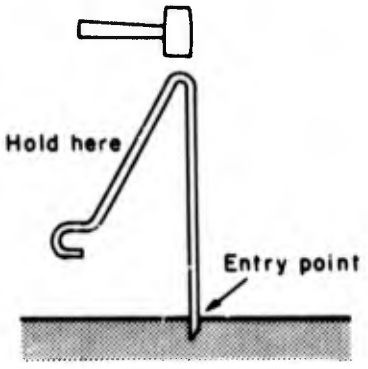
The load system used in 1971 consisted of a compressed gas pneumatic ram configured to apply a load to the hook anchor spring arm at a 45° angle. Pressure sensing gages on the load apparatus were able to maintain a set load automatically over an extended period of time. The load system is shown in Figure 11 loading a $^{5}/_{16}$-in.-diameter hook anchor.

The above load system was also used during the 1972 anchor tests. However, for these tests the ram was configured to apply anchor load at an angle of 60°. In addition to this device, a dead weight loading system

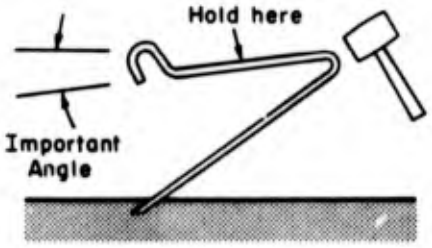




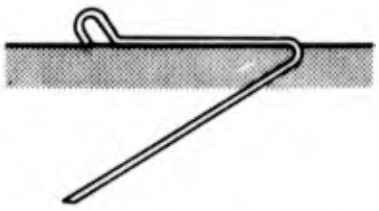
a. Using length of spring arm, measure for shank entry point as shown.



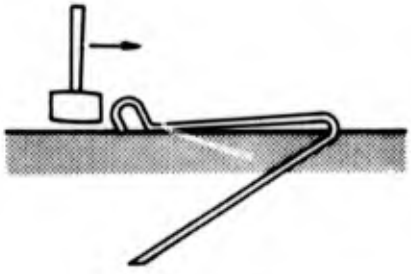
b. With shank of anchor held vertically at entry point, drive 2" into ground (½" in blacktop).



c. Move anchor over so that spring arm is at a small angle to the horizontal (5°-10° on grass, 2°-4° in blacktop). Drive home using firm grip on spring arm so that angle is maintained.



d. When driven home, the anchor should lie completely flat with the hook pressing sufficiently hard against the ground that normal guy tension will not raise it.



e. To remove, release guy and tap hook backward until there is sufficient room at elbow to insert finger and pull free.

Figure 9. Manufacturer's recommended procedure for driving and retrieving hook anchors.

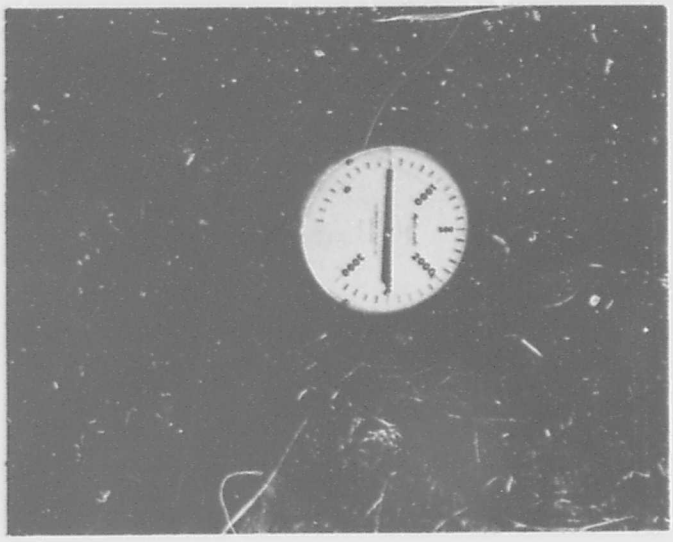


Figure 10. Loading arrangement used during the 1970 hook anchor tests in Fairbanks.

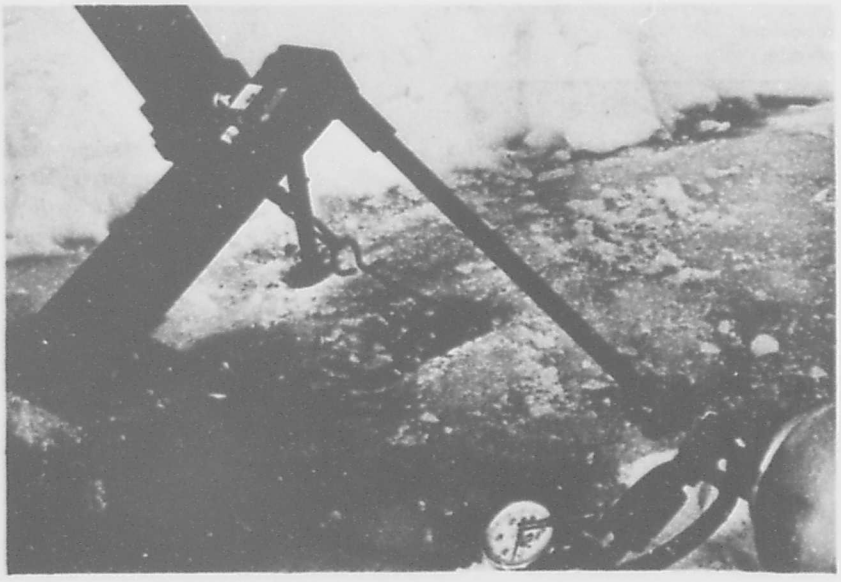


Figure 11. Pneumatic ram loading system used during the 1971 and 1972 anchor tests.

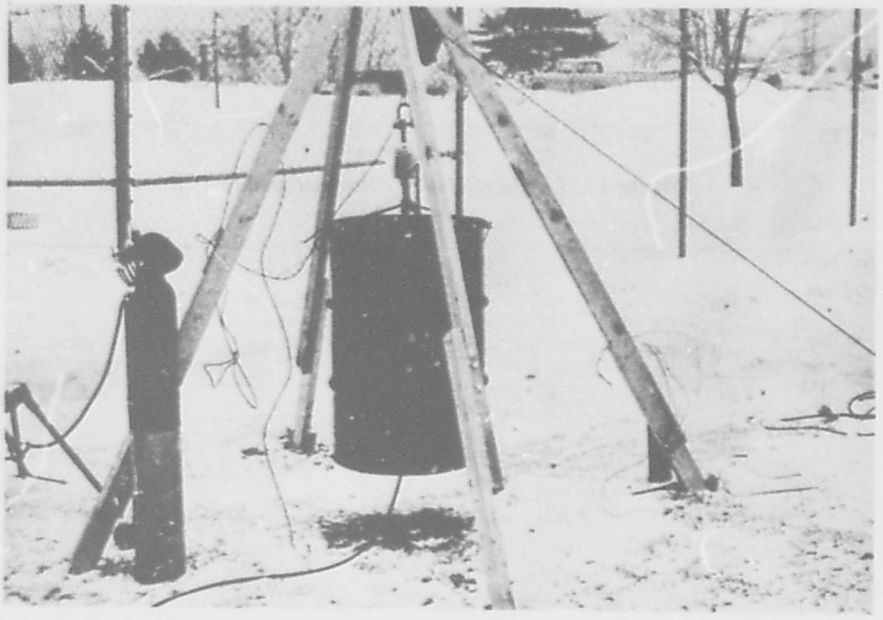


Figure 12. Dead weight loading system used to apply long term anchor loads in 1972.

was also used in 1972. This consisted of a 55-gal. drum suspended on a steel cable. The cable passed over a support sheave, suspended as shown in Figure 12, down to the test anchor. Dead weight consisted of the barrel weight and that of the nonfreezing solution pumped into the barrel. Anchor load was determined from a load cell suspended from the cable above the barrel (see Fig. 12). The load was recorded continuously on a strip chart recorder.

Anchor deflection was measured using an engineer's tape or determined from a strip chart record of the output from a displacement transducer.

1970 Anchor tests

The purpose of the 1970 anchor tests was to gather background information related to installation, removal and holding capacity of hook anchors in the frozen silt. Sixteen tests were conducted. All anchors were subjected to a load applied parallel to the ground.

One anchor was loaded at 1000 lb for one hour to observe its creep. Five anchors were loaded in increments until extraction or excessive creep occurred. Each load increment was maintained for 30 min. Ten anchors were subjected to an initial ram load of between 500 and 1000 lb.

The purpose of the latter tests was to observe load drop-off as a result of anchor creep vs time. The point at which no further load decay occurred as a result of anchor creep was noted. This load would then represent the long-term holding capacity of the anchor for the soil conditions existing at the time of the test. It was later discovered that load decay resulted not only from anchor creep but also from a loss of hydraulic pressure due to seepage of hydraulic oil past seals in the ram. These test results are therefore of little value and are not presented.

Anchor 1-H (½-in. diameter, 18-in. shank). Considerable resistance was experienced during the driving of this anchor. Driving time was about one minute.

A load of 1000 lb was applied to the anchor for one hour during which its deflection was recorded (Fig. 13). It is uncertain how long the anchor could have resisted this load, as its creep rate during the last 20 min of the test was on the order of ¼ in. per hour. Nevertheless, it is clear from Figure 13 that the anchor was able to resist a short-term load of 1000 lb without experiencing extraction or excessive creep.

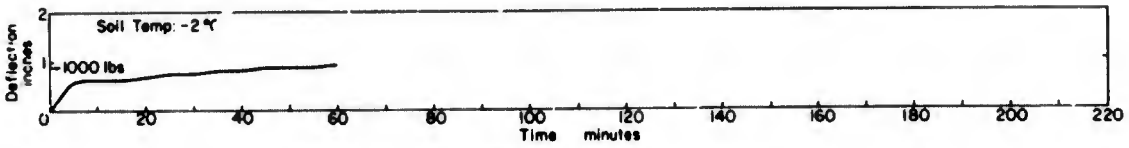


Figure 13. Load-deflection history of anchor 1-H.

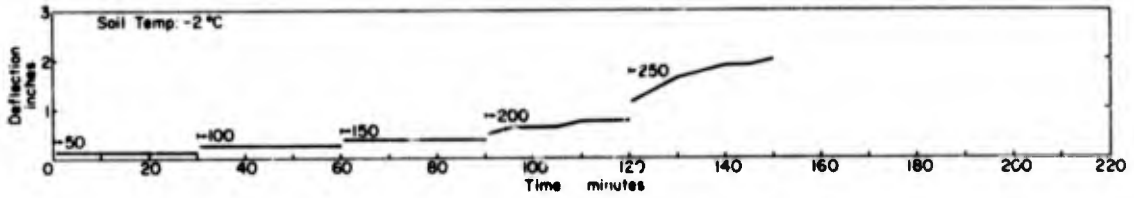


Figure 14. Load-deflection history of anchor 2-H.

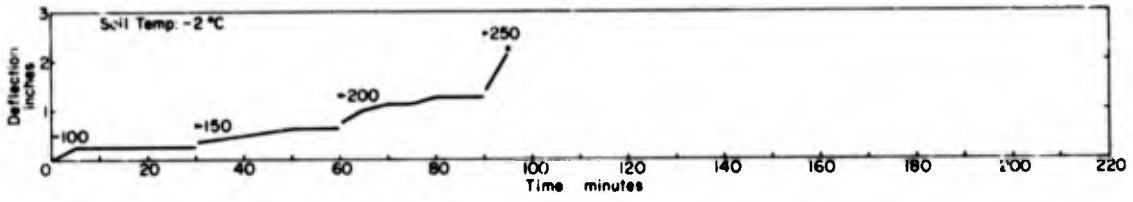


*Figure 15. Load-deflection history of anchor 3-H (*anchor extracted).*

The anchor was removed without great difficulty as outlined in Figure 9.

Anchor 2-H ($^3/_{16}$-in. diameter, 9-in. shank). The anchor was driven in less than one minute without excessive effort.

The anchor was loaded in 50-lb increments every 30 min to a total load of 250 lb (see Fig. 14). At the end of the 250-lb load period the anchor had crept forward 2 in. and appeared on the threshold of being withdrawn. The test was therefore terminated.

Upon removal the anchor's included angle was found somewhat enlarged and the shank was bent where it had been pulled against the soil. Although the anchor could be straightened and reused, it is suspected that it had suffered a slight reduction in its rigidity and would not perform as well under load again.

Anchor 3-H ($^3/_{16}$-in. diameter, 9-in. shank). The anchor was driven with difficulty but in less than one minute.

The load deflection history for this anchor is shown in Figure 15. The anchor appeared able to restrain a load of 200 lb but at 250 lb the anchor was gradually withdrawn from the ground.

After extraction the anchor's included angle had greatly increased and the shank was bent. While not a photo of this anchor, an example of the deformation sustained is shown in Figure 16. Anchor 3-H was re-straightened in a vice with the use of a 2-lb hammer.

Anchor 4-H ($^3/_{16}$-in. diameter, 9-in. shank). Hard hammer blows were required to embed this anchor. It is believed that a stiffer shank would have improved the driving performance of the anchor.

The load history of the anchor is presented in Figure 17. At the end of the 150-lb load period the anchor had been withdrawn $1\,^1/_2$ in. and was experiencing a creep rate on the order of $^1/_2$ in. per hour. At the end of the 200-lb load period, the anchor had been withdrawn nearly 4 in. and was being extracted at about 1 in. per hour. When 250 lb was applied to the anchor it was quickly withdrawn.

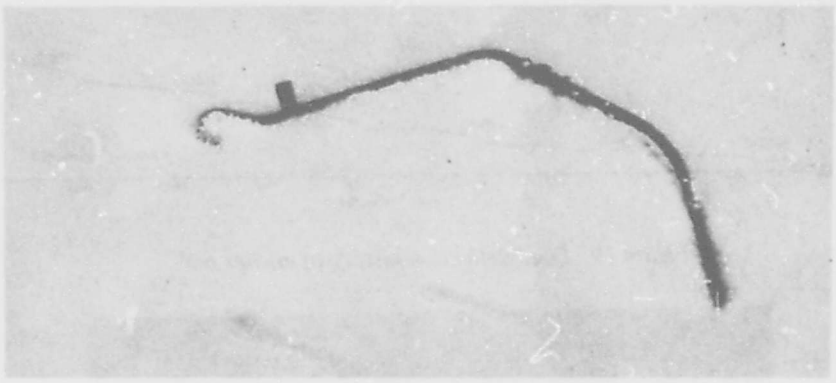


Figure 16. Typical deformation sustained by hook anchors drawn out of frozen ground.

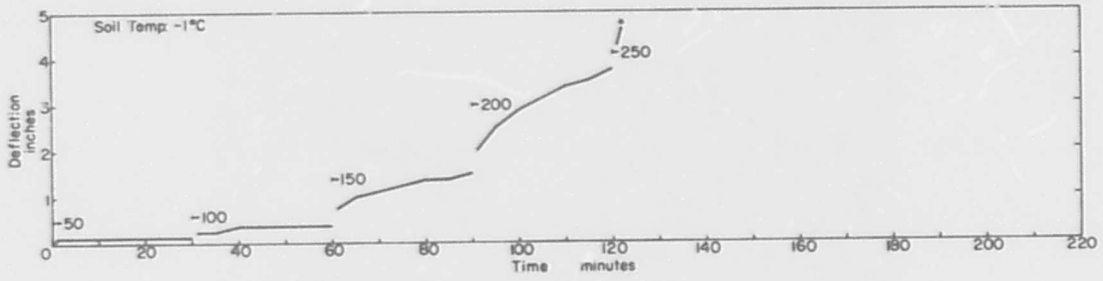


Figure 17. Load-deflection history of anchor 4-H.

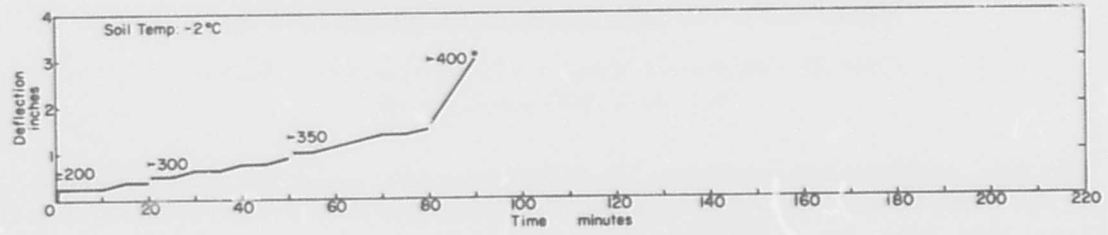


Figure 18. Load-deflection history of anchor 5-H.

The anchor had experienced structural deformation similar to that shown in Figure 16.

Anchor 5-H ($^3/_{16}$-in. diameter, 9-in. shank). Driving was found difficult. Shank flexing prevented efficient hammer impact energy transfer to the anchor's tip.

The load history for the anchor is shown in Figure 18. The anchor appeared able to resist transient loads (a few minutes' duration) as high as 400 lb. However, under the loads of 300 and 350 lb the anchor was undergoing lateral displacement on the order of 1 in. per min. After 10 min at a load of 400 lb, the anchor was pulled out of the ground.

The anchor's shape after extraction was similar to that shown in Figure 16.

Anchor 6-H ($^1/_2$-in. diameter, 18-in. shank). Hard driving was required to embed this anchor. Driving time was in excess of one minute.

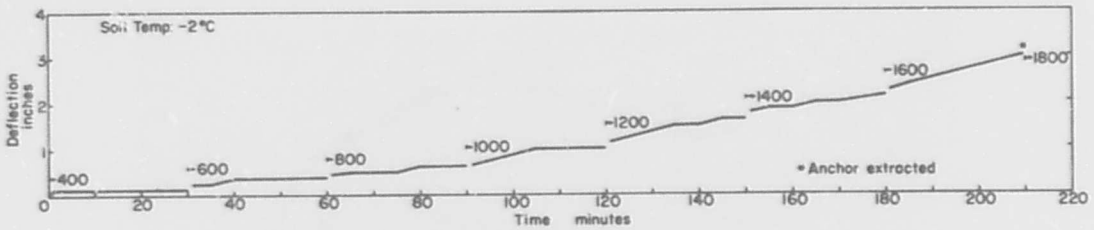


Figure 19. Load-deflection history of anchor 6-H.

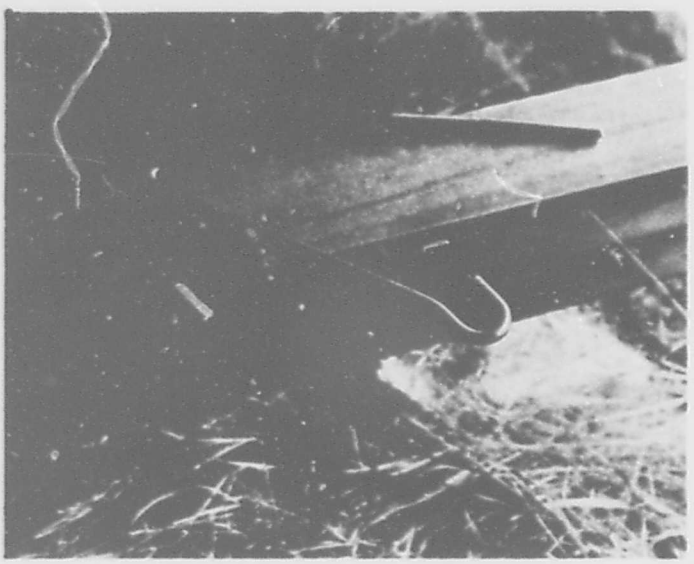


Figure 20. Configuration of anchor 6-H after it was drawn out of the frozen silt of the Fairbanks test site.

The anchor was loaded as shown in Figure 19. At 1000 lb the anchor experienced no measurable displacement during the second 15 minutes of loading. This would suggest that the anchor could hold the load for an extended time period. At 1600 lb the anchor was undergoing lateral displacement at $1\frac{1}{2}$ in. per hour. While clearly capable of resisting this load for a short duration, the anchor would not be able to hold the load over an extended time period. The anchor was withdrawn when the load was increased to 1800 lb.

The configuration of the anchor after extraction is shown in Figure 20.

Discussion of the 1970 anchor tests. The 1970 anchor tests showed that $\frac{3}{16}$- and $\frac{1}{2}$-in.-diam hook anchors could be driven into −2°C silt having a frozen water content of 45% and a dry density of 66 lb/ft^3. The driving revealed that the $\frac{3}{16}$-in.-diam shank was not stiff enough for good hammer impact energy transfer to the anchor tip. A minimum diameter of $\frac{1}{4}$ in. is suggested for a shank 9 in. long.

Load tests showed that $\frac{3}{16}$-in.-diam anchors were capable of resisting transient loads of up to 250 lb and sustained loads between 125 and 150 lb. The $\frac{1}{2}$-in.-diam anchors appear to be capable of resisting sustained loads on the order of 1000 lb and 50% higher transient loads.

The anchors were found to be retrievable; this is a decided advantage of the anchor.

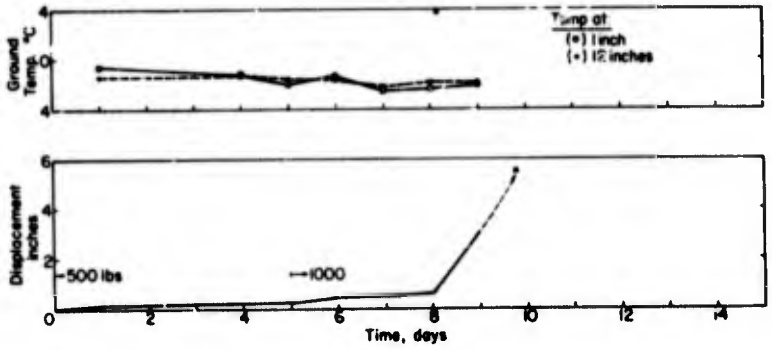


Figure 21. Test ground temperatures and load-deflection history of anchor 1-J.

1971 Anchor tests

Five hook anchors were load tested in frozen ground and one GM stake, three GP-112/G stakes and seven hook anchors were load tested in thawed ground. The anchors were loaded in increments. The force applied was dependent upon anchor size and expected capacity. Load duration varied as a result of such factors as anchor capacity and test load remaining over a weekend. All loads were applied at an angle of 45° ± 5°.

In addition, five hook anchors were driven into frozen ground and allowed to freeze in. The relative effort required to remove them was later determined.

Anchor 1-J ($^1/_2$-in. diameter, 18-in. shank). The anchor was driven in less than one minute. Hard driving was experienced.

Anchor load history and ground temperature conditions during the test are shown in Figure 21. During the last four days of the first load increment of 500 lb, the anchor was moving slowly at 0.02 in. per day. At the next load level of 1000 lb the anchor experienced a creep rate of 0.1 in. per day for three days followed by a sudden acceleration of over 1 in. during the fourth day and extraction on the fifth day.

The results suggest that for existing test conditions the anchor could resist a 500-lb load for an extended time period and short duration (hours) transient loads of 1000 lb.

Anchor 2-J ($^5/_8$-in. diameter, 18-in. shank). The anchor was driven in less than one minute.

Anchor load history and the ground temperature during the test are shown in Figure 22. The anchor was loaded in 500-lb increments. At a load of 1000 lb and during the first four days at 1500 lb the anchor was experiencing negligible creep. After the fourth day at a load of 1500 lb the anchor's creep rate increased to 0.05 in. per day for the next two days. The following day (the seventh day at 1500 lb) the anchor suddenly crept out of the ground. The increase in the anchor's movement on the fifth day and its eventual failure on the seventh is related to an increase in ground temperature which occurred at the time (see Fig. 22).

For the existing test conditions the anchor appeared to be capable of sustaining a load of 1000 lb and an intermittent load (one or two days) of up to 1500 lb.

Anchor 3-J ($^3/_8$-in. diameter, 12-in. shank). The anchor was driven in less than one minute.

Soil temperature during the test averaged −0.5°C. The anchor was loaded to 250 lb. At the end of the first day the anchor had moved approximately $^1/_2$ in. During the second load day the anchor snapped in two at the elbow.

Anchor 4-J ($^3/_8$-in. diameter, 12-in. shank). Driving of the anchor took less than one minute.

Soil temperature during the test was approximately −1°C. At the end of three days the anchor had moved less than 0.1 in. On the fourth day of loading the anchor broke in two at the elbow.

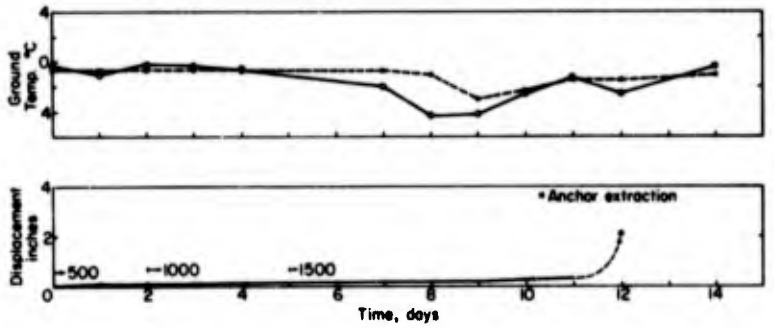


Figure 22. Test ground temperatures and load-deflection history of anchor 2-J.

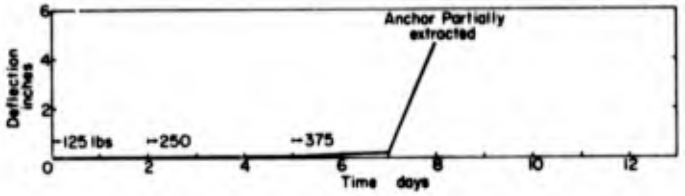


Figure 23. Load-deflection history of anchor 6-J.

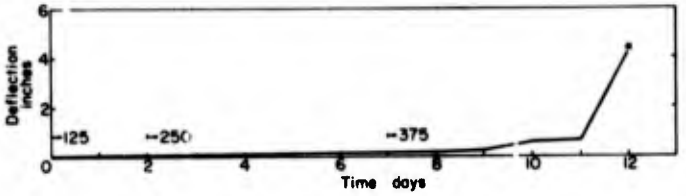


Figure 24. Load-deflection history of anchor 7-J.

Anchor 5-J (⅝-in. diameter, 18-in. shank). The anchor was driven in place in less than one minute.

Soil temperature during the test was approximately −0.5°C. The anchor appeared capable of holding a load of 500 lb without excessive creep (0.05 in. per day). When loaded from 500 lb to 1000 lb the anchor was quickly pulled from the ground.

Anchor 6-J (⅝-in. diameter, 18-in. shank). Anchor installation time was less than 30 sec into the thawed ground.

The anchor's load history is presented in Figure 23. After two days at a load of 125 lb and three days at a load of 250 lb the anchor experienced virtually no movement. The first two days at a load of 375 lb resulted in a deflection of 0.15 in. On the third day at this load the soil failed and the anchor was extracted as far as the ram would travel.

It may be summarized from the test data that the anchor could hold the second load increment of 250 lb and transient loads as high as 375 lb.

Anchor 7-J (⅝-in. diameter, 18-in. shank). The anchor was driven in less than 30 sec into the unfrozen ground.

The load test data are presented in Figure 24. The results indicate that the anchor could hold a load of 250 lb in the unfrozen silt and a temporary load (several days) on the order of 350 lb.

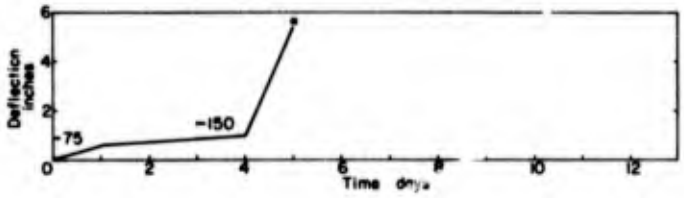


Figure 25. Load-deflection history of anchor 9-J.

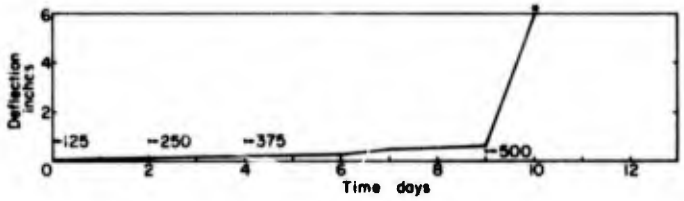


Figure 26. Load-deflection history of anchor 11-J.

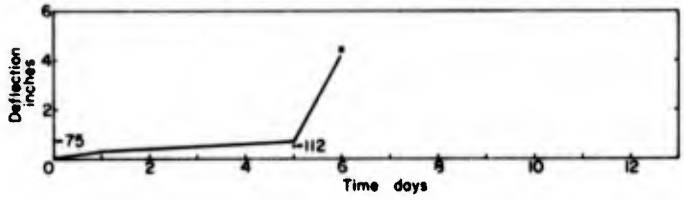


Figure 27. Load-deflection history of anchor 12-J.

Anchor 8–J ($^3/_8$-in. diameter, 12-in. shank). The anchor was driven in less than 30 sec.

A load of 150 lb was applied to the anchor. The soil, unable to resist the anchor load, failed and the anchor was pulled out of its embedment.

Anchor 9-J ($^3/_8$-in. diameter, 12-in. shank). Driving time for the anchor was less than 30 sec.

The anchor's load history is shown in Figure 25. At the end of the third day at a load of 75 lb, the anchor was creeping at approximately 0.1 in. per day. The anchor failed on the second day of the 150-lb loading.

Anchor 10-J ($^3/_8$-in. diameter, 12-in. shank). Driving of the anchor took less than 30 sec.

When loaded to 75 lb the anchor snapped off at the elbow.

Anchor 11-J ($^5/_8$-in. diameter, 18-in. shank). The anchor was driven in less than 30 sec.

The anchor's deflection vs load is shown in Figure 26. At a load of 375 lb the anchor was creeping at 0.05 in. per day. When the load was raised to 500 lb the anchor cut into the soil and eventually failed by being pulled out of the ground. The anchor appeared to have a sustained load capacity of 250 lb, a short term capacity (several weeks) of 375 and intermittent holding capacity (tens of minutes) of 500 lb.

Anchor 12-J (GM stake, embedded 10 in.). The stake was driven in less than 30 sec.

The deflection vs load history for the anchor is presented in Figure 27. The anchor was capable of resisting a load of 75 lb at a creep rate of 0.1 in. per day. During the first day at a load of 112 lb the soil failed, the anchor shank bent and the anchor was extracted. The anchor appears capable of resisting a sustained load of 50 lb and a short term load of 75 lb.

Anchor 13-J (GP-112/G stake, embedded 14 in.). Less than 30 sec was required to drive the stake.

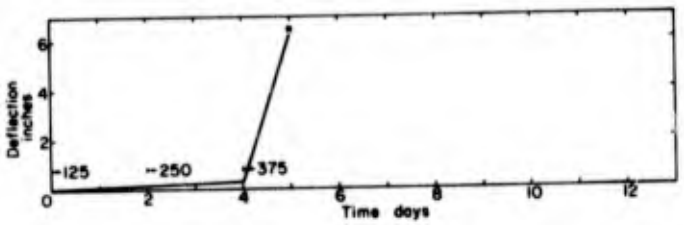


Figure 28. Load-deflection history of anchor 13-J.

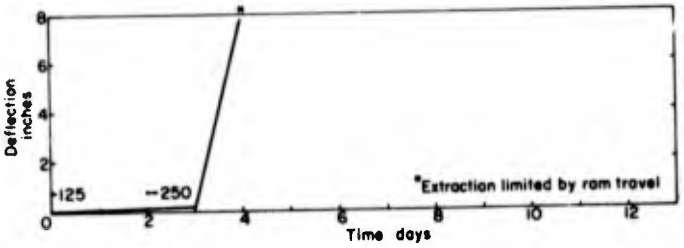


Figure 29. Load-deflection history of anchor 14-J.

The stake's deflection vs load is given in Figure 28. At a load of 250 lb the stake was creeping at less than 0.1 in. per day. On the first day at a load of 375 lb the stake failed. This low failure load was surprising considering the surface area of this anchor compared to a $^5/_8$-in.-diam hook anchor which resisted a higher load before being extracted. The stake appeared to be able to restrain a load of 250 lb.

Anchor 14-J (GP-112/G stake embedded 14 in.). The stake was driven in less than 30 sec.

The deflection vs load history for the stake is given in Figure 29. At a load of 125 lb the stake was creeping at approximately 0.05 in. per day. During the second day at a load of 250 lb the soil restraining the anchor failed and the anchor was extracted. Once again the anchor failed at a surprisingly low load.

Anchor 15-J (GP-112/G stake, embedded 14 in.). The stake was driven in less than 30 sec.

The stake was loaded in 100-lb increments to 300 lb. Stake creep at the load of 200 lb was approximately 0.05 in. per day. During the first day at the load of 300 lb the soil in front of the anchor crept excessively and the anchor was withdrawn.

Extraction of hook anchors. On 15 March five hook anchors were driven into the frozen silt at the CRREL test site. One week later the anchors were removed as follows. The anchors were struck on the front of the hook (see Fig. 9) with hard blows from a 2-lb hammer. At the same time the anchor arm was pushed from side to side to the extent ground clearance would allow. When the shank began to work free and ground clearance allowed, the spring arm at the elbow was pulled by hand in an upward direction parallel to the axis of the shank. At the same time the anchor arm was rotated back and forth. The effort required to remove the anchors was not an easy one, but the anchors could be and were extracted. This retrieval capability is of major importance to troops moving about in the field during the winter.

Discussion of 1971 anchor tests. During the winter tests, it was again shown that hook anchors could be driven into silt at −2° to −3°C having a dry density of 60 lb/ft^3 and a moisture content on the order of 29%. It was noted that the angle at the tip of the shank hampered the start of anchor penetration in frozen ground. The slope of the point face allowed the shank tip to skip across the ground without penetrating when step C in Figure 9.was attempted. To overcome this problem it is necessary that the shank tip be cut so that the point, instead of being on the inside of the shank as shown in Figure 9, would be reversed to the outside.

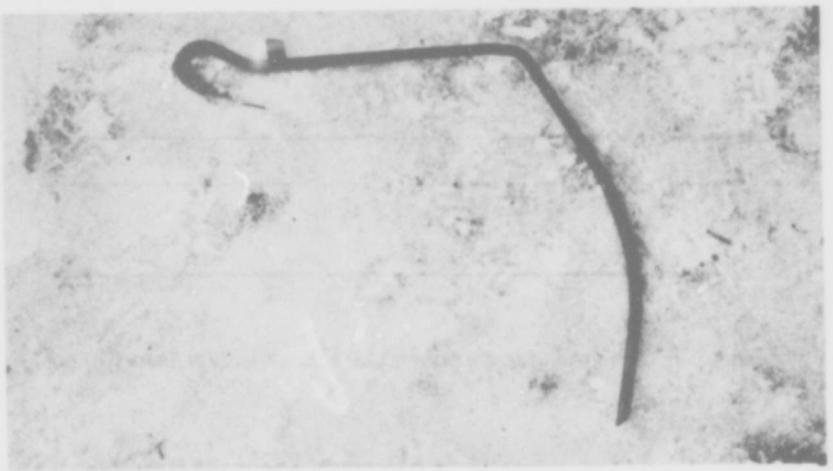


Figure 30. Post test configuration of an anchor with its included angle increased beyond 90° as a result of being drawn out of its frozen ground embedment.

When hook anchors were being driven into frozen ground the driving resistance was often high and required numerous hard blows with the 2-lb hammer. The elbows of some of these anchors became slightly peened and suffered stress weakening. As a result a number of these anchors snapped off at the elbow when the anchor was subjected to relatively light loading. It is therefore assumed that the use of existing commercial hook anchors in hard frozen soil will result in a gradual loss of anchors due to breakage.

The frozen and unfrozen ground load tests showed that for their size, hook anchors are capable of resisting relatively high transient and sustained loads. The load comparison between the $^5/_8$-in.-diam hook anchor driven 18 in. and the GP-112/G stake driven 14 in. shows that the lighter and less expensive hook anchor outperformed the stake in unfrozen ground. It was observed that the holding capacity of hook anchors in frozen soil at −1° to −2°C was two to three times their capacity in unfrozen ground. This shows the enormous effect soil moisture freezing has on the shear strength of the soil.

The hook anchors tested in frozen ground did not escape load extraction unharmed. Indeed, almost all anchors bent at the elbow. The included angle would at times increase to over 90° and the shanks of many anchors became curved as a result of being drawn out of the soil. Figure 30 shows an anchor whose included angle has been enlarged beyond 90° and whose shank has been bent.

1972 Anchor tests

In 1972 27 anchors were load tested in frozen ground and nine were tested in unfrozen ground. All but four tests were made on hook anchors (the four non-hook anchors tested were GM stakes). These anchors were $^1/_8$, $^3/_{16}$, $^1/_4$ and $^5/_{16}$ in. in diameter. They were therefore smaller in diameter than the hook anchors tested in 1971. Because of their size, these anchors would appear to be more practical to use with one- or two-man tents than the larger hook anchors previously tested.

All loads were applied in increments at an angle of 55° ± 5°. Fourteen tests were short term, i.e. the anchors were loaded to failure in 50-lb increments applied at one-hour intervals. These tests are denoted by the letter J after the anchor test number. The incremental loads applied to the remaining 12 anchors were maintained for at least two days. These tests are denoted by the letter B after the anchor test number.

Anchor 1-B ($^5/_{16}$-in. diameter, 12-in. shank). The load history for the anchor is presented in Figure 31. The results indicate that the anchor experienced very little movement at the load of 200 lb but failed during the second day at the load of 250 lb.

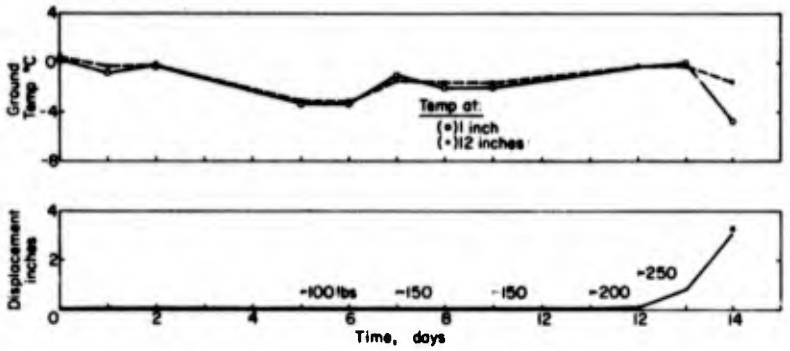


Figure 31. Test ground temperatures and load deflection history of anchor 1-B.

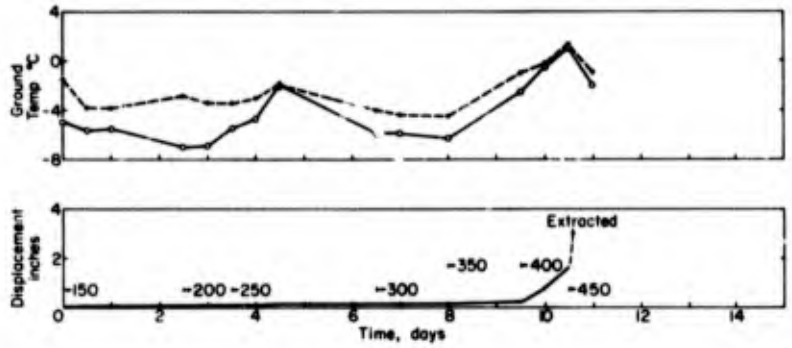


Figure 32. Test ground temperatures and load-deflection history of anchor 2-B.

Anchor 2-B ($^3/_{16}$-in. diameter, 9-in. shank). The anchor's deflection vs load is shown in Figure 32. At a load of 350 lb the anchor was moving at approximately 0.3 in. per day. When loaded to 400 lb for two days the anchor's creep accelerated to nearly $^3/_4$ in. per day, giving evidence that failure would soon occur under the rapidly rising soil temperatures When the load was raised to 450 lb, the anchor crept out of the soil within a few hours.

Anchor 3-B ($^3/_{16}$-in. diameter, 9-in. shank). The anchor was extracted from the ground within 12 hours at the initial load of 100 lb.

Anchor 4-B ($^3/_{16}$-in. diameter, 9-in. shank). The anchor was loaded in 100-lb increments every two days. At the load of 200 lb the creep was nearly zero. Anchor movement at the load of 300 lb was 0.2 in. per day. After two days at the load of 400 lb the anchor was slowly withdrawn from the frozen ground.

Anchor 5-B ($^5/_{16}$-in. diameter, 12-in. shank). The deflection vs load history for the anchor is given in Figure 33. The anchor experienced no movement for the two days it was loaded at 250 lb. However, the soil temperature was decreasing during this time and was therefore more resistant to displacement. At the load of 350 lb the anchor began to creep at 0.1 in. per day. This movement is attributed to both the higher anchor-soil stress level at this load as well as to the rapidly increasing ground temperatures shown in Figure 33. After two days at 450 lb, anchor movement increased to approximately 0.4 in. per day. At the next load level of 550 lb the anchor snapped off at the elbow.

Anchor 6-B ($^3/_{16}$-in. diameter, 9-in. shank). The anchor was extracted in less than 24 hours at an initial load of 100 lb. Soil temperature averaged −0.5°C during the test.

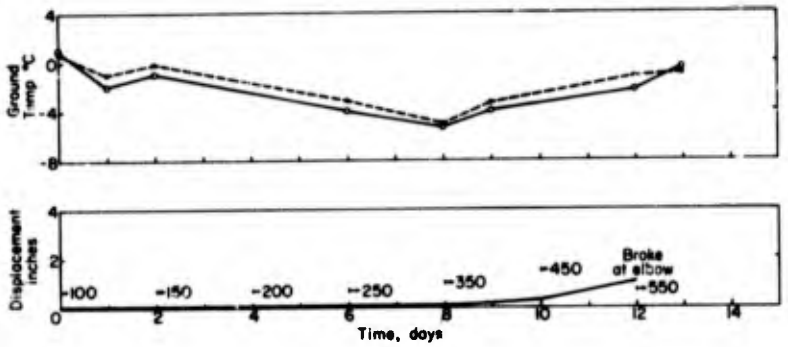


Figure 33. Test ground temperatures and load-deflection history of anchor 5-B.

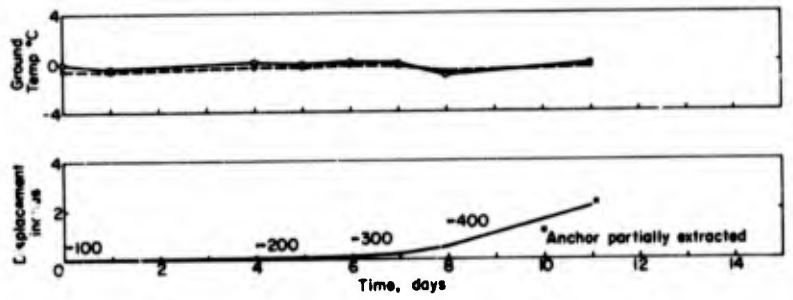


Figure 34. Test ground temperatures and load-deflection history of anchor 7-B.

Anchor 7-B ($^1/_4$-in. diameter, 15-in. shank). The load history of the anchor is presented in Figure 34. Ground temperatures during the test were for the most part higher than −0.5°C. Under the 300-lb loading the anchor was experiencing accelerated creep. At the end of the third day at the load of 400 lb the anchor would have been completely extracted if the travel of the load system had been greater. In any event the anchor failed at this load.

Anchor 8-B ($^3/_{16}$-in. diameter, 9-in. shank). Soil temperature during the test averaged −1°C. The anchor was loaded for two days at 50 lb without experiencing movement. During the first day at 100 lb the anchor remained immobile. However, during the second load day the soil gave way and the anchor was extracted.

Anchor 9-B ($^1/_8$-in. diameter, 6-in. shank). The anchor was immediately pulled from the ground at a load of 45 lb, the lowest load that could be applied with the load apparatus.

Anchors 10 through 12-B, GM stakes, embedded 10 in. The anchors resisted a load of 50 lb without excessive movement. At a load of 100 lb all the anchors were quickly extracted from the ground.

Anchor 13-B ($^1/_8$-in. diameter, 6-in. shank). The anchor was quickly extracted from the ground at the load of 45 lb.

Anchors 14-B through 21-B ($^1/_4$-in. diameter, 15-in. shank). These anchors were loaded every 2 days. The first load increment of 50 lb was followed by successive 25-lb increments. The anchors failed at the following load levels: 100, 75, 50, 125, 125, 125, 125, 175 and 75 lb or at an average load of 110 lb. The ground was unfrozen during these tests. The anchors appeared to be able to resist a long term load on the order of one quarter to one third less than their failure load.

Anchors 16-J through 29-J. These hook anchors, loaded hourly in 50-lb increments, were tested during January and February in frozen ground. The test date, anchor size and failure load for each anchor are given in Table II. The temperature of the ground for each test day is given in Table I.

The short term load capacity of these anchors may be summarized as follows. All four $^1/_4$-in.-diam anchors with 15-in.-long shanks failed at 400 lb. Three $^3/_{16}$-in.-diam anchors with 9-in. shanks failed at an average load of 130 lb. The five $^5/_{16}$ in.-diam anchors with 12-in. shanks failed at an average load of 460 lb while the three same size diameter anchors with 16-in. shanks all failed at 500 lb.

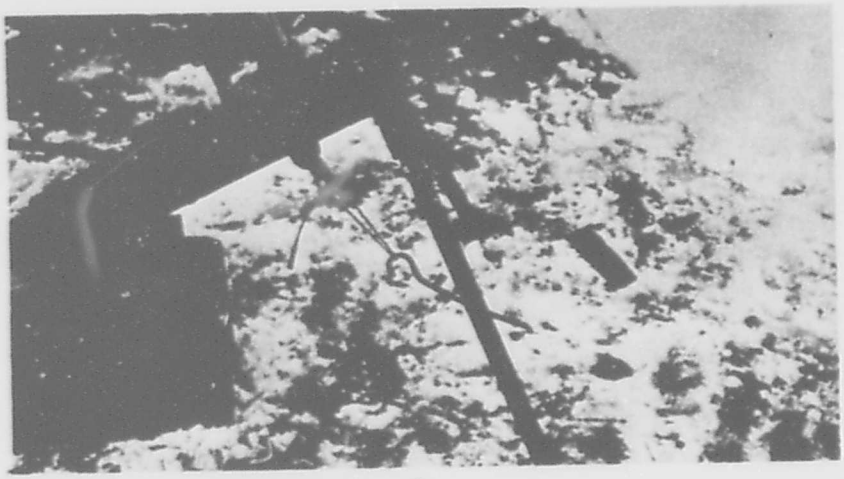
Only anchor 23-J ($^1/_4$ in. diam) failed structurally at the elbow. All other anchors failed by being drawn out of the ground. In the process of being extracted each anchor's included angle increased as a result of bending at the elbow and the shank became curved.

Discussions of 1972 anchor tests. As would be expected the tests showed that increasing the diameter of a hook anchor or increasing its shank length increased the holding capacity. For example, increasing the diameter from $^1/_4$ in. to $^5/_{16}$ in. increased the capacity of the anchor by 25%. Similarly, when the shank length of the $^5/_{16}$-in.-diam anchor increased from 12 to 16 in. the load capacity increased approximately 10%. Increasing the diameter has an apparent larger effect than increasing the shank length, i.e. embedment depth. The reason for this is undoubtedly twofold. First, the increased width of the anchor mobilizes a larger mass of soil into resisting anchor load, and second, the larger cross section stiffens the anchor, allowing for better load transfer down the anchor shank where the soil is more resistant to deformation.

Anchors tested in frozen ground again showed markedly higher holding capacity than similar anchors tested in unfrozen ground. This is typified by the $^1/_4$-in.-diam hook anchors 14-B through 21-B load tested in unfrozen ground and the $^1/_4$-in.-diam hook anchors 16-J through 29-J load tested in frozen ground. The anchors tested in unfrozen ground failed at an average load of 110 lb while those tested in frozen ground failed at 400 lb. It should be remembered, however, that the anchors tested in unfrozen ground were loaded in 25-lb increments every two days while those tested in frozen ground were loaded hourly in 50-lb increments. This difference in load application and duration undoubtedly had a great effect on the results too.

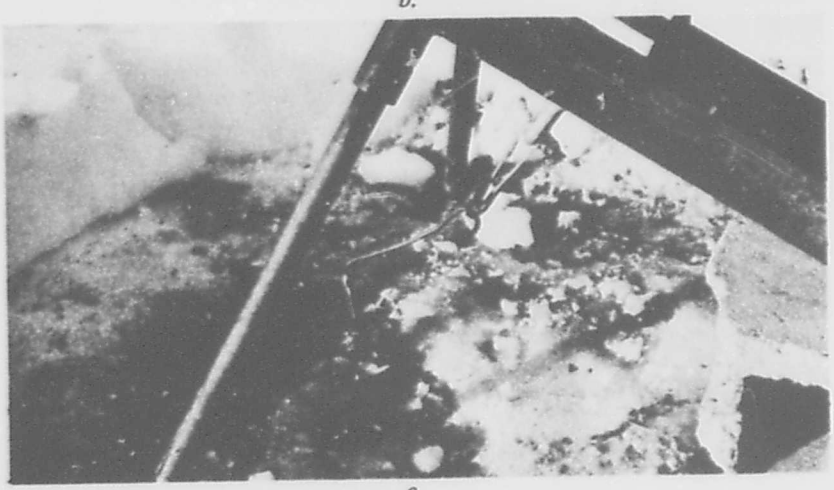
The load-deflection curves presented seem to indicate that hook anchors are capable of resisting long term loads on the order of two thirds of their failure load, provided the state of the soil remains unchanged. It was also observed that at two thirds the failure load, anchor shanks did not become permanently bent nor did the included angle become permanently enlarged.

A pictorial overview showing the configuration of a number of the 1972 anchors during and after testing is presented in Figures 35-39. The extreme bending of the hook anchors at the elbow when these anchors are subjected to moderate to high load is clearly shown in Figure 35. Because the anchor acts as a spring it can be expected that transient wind loads upon a guyed shelter will be gradually soaked up by arm flexure. This should reduce the stress at the guy-shelter connection and thus reduce the chance of the shelter tearing. Soil deformation and anchor configuration at the termination of load testing of hook anchors in frozen ground is shown in Figure 36. The anchors shown were only partially extracted at cessation of loading. Typical shapes of hook anchors loaded to failure, i.e. extracted, are shown in Figure 37. The anchor's included angle is shown to have increased to as much as 130° as a result of high loading. The shanks on two of the anchors shown are also bent. This occurred when the anchors were drawn out over the lip of the hole in which anchors were embedded. Two examples of hook anchors which failed structurally at the elbow are shown in Figure 38. The cause of failure is believed to be related to low temperature brittleness and deformation at the elbow as a result of hammer impact. The use of hook anchors in cold climates, where hard driving in frozen ground can be expected, may therefore result in a loss of anchors due to structural failure at the elbow when the anchors are subjected to moderately high loads. Further testing is required to verify if this will indeed occur and at what load level. The shape taken by two of the GM stakes when loaded to failure is shown in Figure 39. As can be seen the anchors were severely deformed. The anchors could not be straightened for reuse.



a.

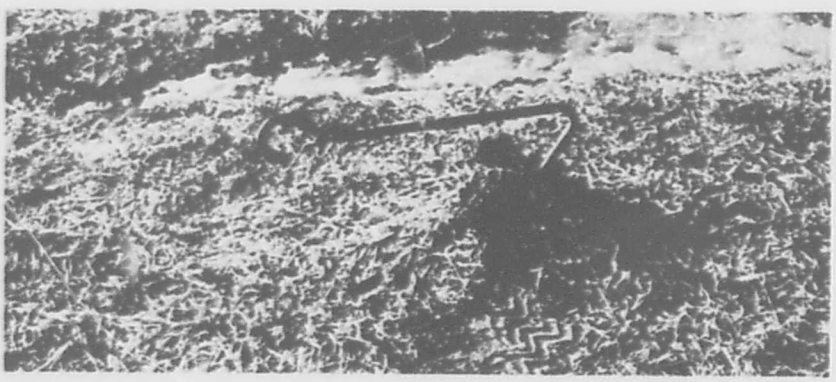
b.



c.

Figure 35. Examples of hook anchor deflection at moderately high loading.

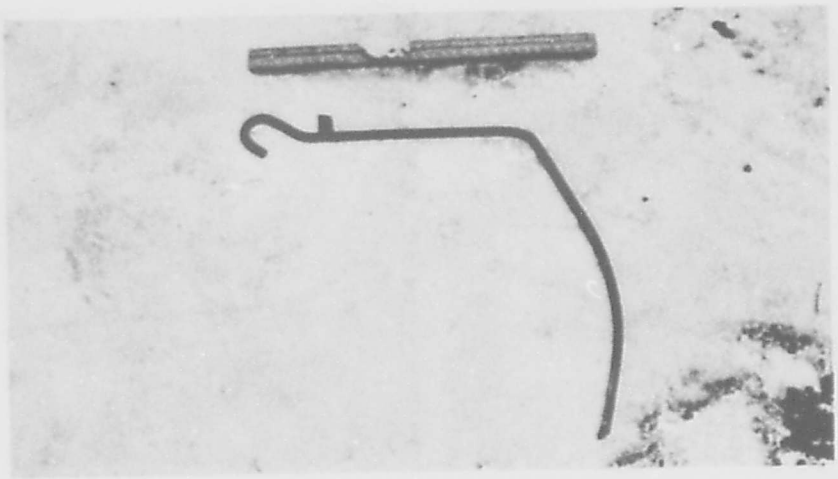
a.



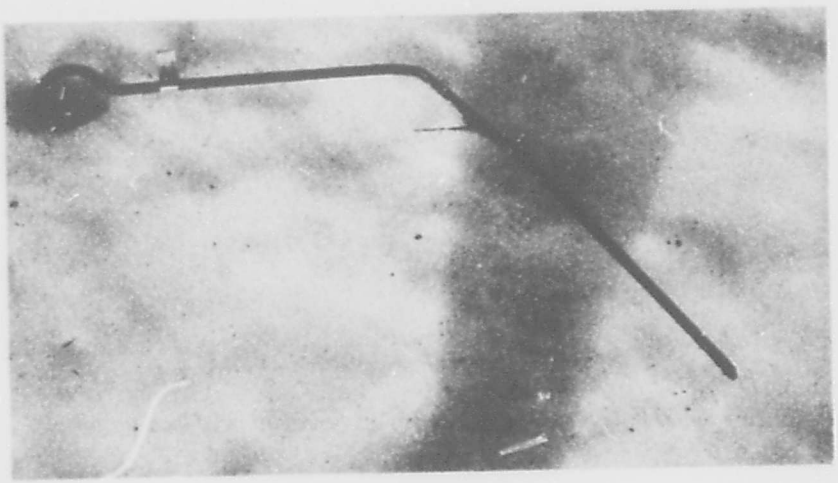
b.

c.

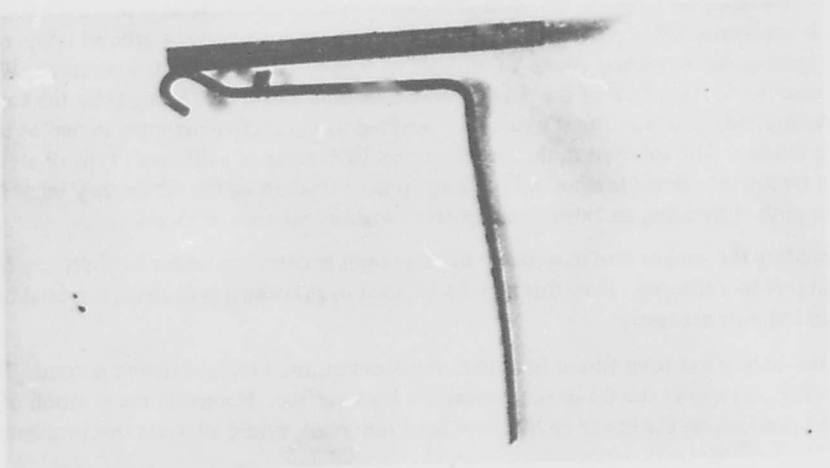
Figure 36. Views of hook anchors not loaded to complete extraction from frozen ground.



a.

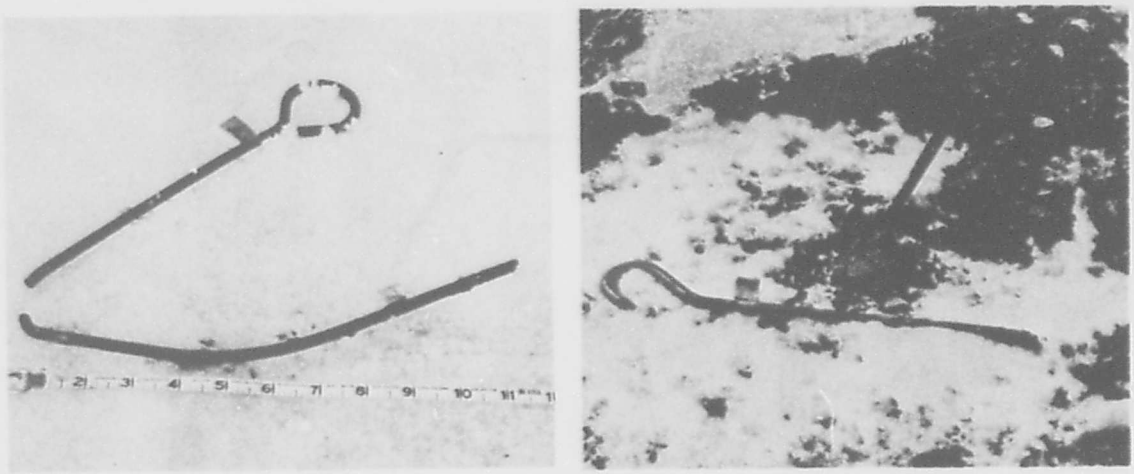


b.



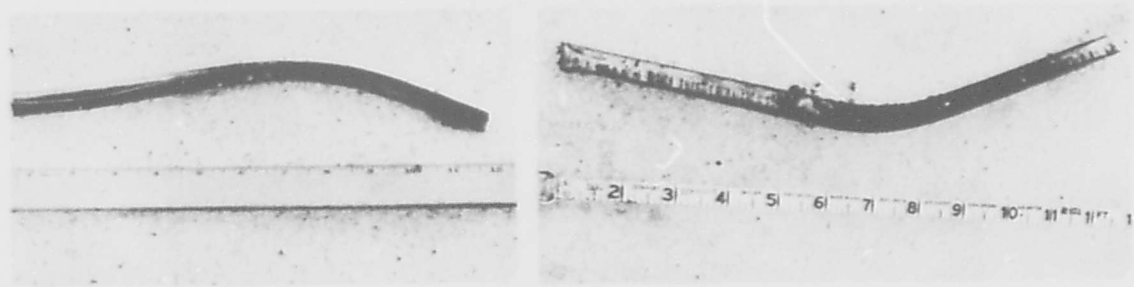
c.

Figure 37. Typical configuration of hook anchors completely extracted from frozen ground.



a. *b.*

Figure 38. Examples of hook anchors which failed at the elbow when loaded.



a. *b.*

Figure 39. Configuration of GM stakes at the cessation of load testing.

Discussion

The anchor tests reported were for the most part performed on commercial Anker anchors. It was found that these hook anchors could be driven into the silts of the test sites when the ground temperature was as low as −5°C. Driving resistance was found to increase with decreasing ground temperature. When hard ground was encountered the elbow of the anchor would become deformed (peened) by the hard repetitive hammer blows required. This structural weakening resulted in the anchor snapping in half at the elbow when the anchor was loaded. The solution to this problem may be the use of a different type of steel or a different case hardening treatment. Some method of building up the thickness of the elbow may be needed. This could be accomplished by using an extrusion process to manufacture the anchors.

The hand holding the anchor arm in position during initial penetration under hard driving conditions was on occasion subject to a stinging. How this may be avoided or prevented is unclear; a special holding device would be an undesirable accessory.

The tip of the anchor has been found to inhibit shank penetration in hard frozen ground. The present configuration (Fig. 30) allows the tip to skip across the hard surface. Reversing the position of the tip point from its present position on the inside to the outside of the shank would alleviate this problem.

Two views of the hook anchor during actual field use are shown in Figures 40 and 41. A suggested use of hook anchors for the tiedown of the Canadian Modular tent is shown in Figure 42. Here it is seen that two types of anchors are specified for the tiedown of this shelter.

Figure 40. Driving of hook anchor under field conditions.

Figure 41. Final drive seating of hook anchor after tent guy has been attached.

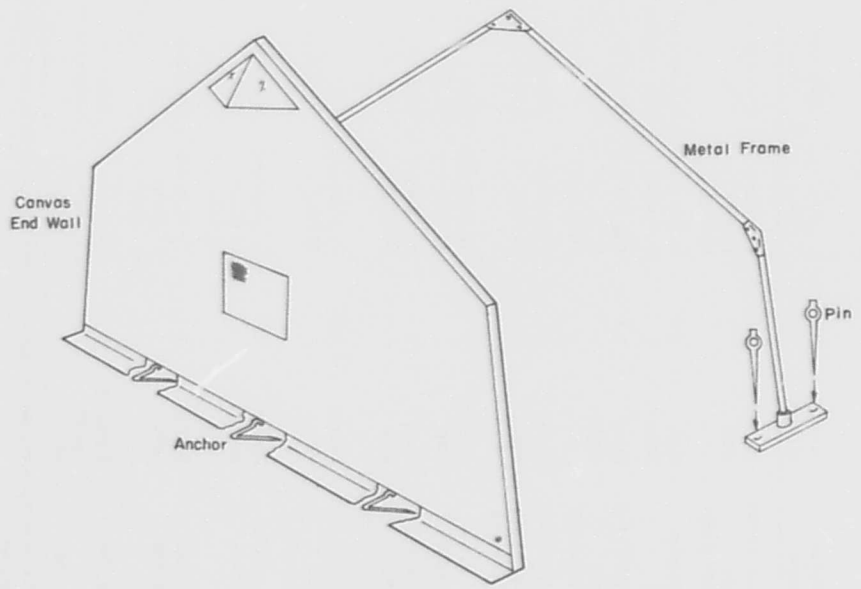


Figure 42. Location of hook anchors used with Canadian Armed Forces Modular tent.

Table III. Properties of guy stakes and anchors.

Anchor type	Anchor material	Weight (lb)	Size (in.)	Installation tool	Emplacement time (min)	Anchor capacity, lb — Soil class*						
						1A	2	3	4	5	6	
Stake GP-112/G Stake no. 4030-291-9354	Forged steel	3.6	1¼ diam 17 long tri-fluted	Hammer 4 lb	1–4	1350	1150 790	710 525	500 500	310 225		Max creep
4 in. Quarter master	Cast alum	0.5	Arrow head 4 in. sides	Special rod 4 lb hammer	2–4		2500 1900	1510 935	660 590			Max creep
Stake GP-111/G Stake no. 4030-097-8670	Steel angle	2.5	1¼ × 1¼ × 5/16 18½ long	Hammer 4 lb	1–2		1450 840	860 525	650	560		Max creep
Stake GP-108/U Stake no. 5975-223-4611	Steel angle	8	1 5/16 diam 36 long	Sledge 6–8 lb	2–5		2100 1200	1310 950	1230	950 875	680	350 Max creep
2¾ in. screw commercial	Forged steel	2	½ diam rod 32 long	Bar ¾ × 30 in.	4–6		4020 3700	2250 1700		900 660		Max creep
Stake GP-113/G Stake no. 4030-298-1382	Steel pipe	13	1¾ diam 46 long	Sledge 8 lb	3–6		4450 2590	2050 1940	2625	1900 1710	1750	1425 Max creep
3 in. screw SPO-850 Sig C Special	Forged steel	3.3	⅝ diam rod 36 long	Bar 1 × 36 in.	5–8		4010 3500	2300 1750		1210 740	500	230 Max creep
Anker (hook) commercial	Spring steel	2.7	⅝ diam rod 18 shank 12 Arm	Hammer 2 lb	1		1250 900			410 300		Max creep
Anker (hook) commerical	Spring steel	2	½ diam rod 18 Shank 15 Arm	Hammer 2 lb	1		1000 750			300 200		Max creep
Grizzly Mint Stake commercial	Stamped 1/64 in. steel	0.12	Shaped ¾ wide ½ deep	Hammer carpenter	1					100 75		Max creep

* See Table IV for soil class description. Load capacities given are averages of limited tests and should be used for guidance only.
1 Estimated.

Table IV. Simplified soil classification guide.

Class	*Type*	*Description*
1a	Solid ice	
2	Shale, sandstone, or soft rock (solid or in layers). Coral, frozen ground	
3	Hard pan	Hard and dry, requires the use of a digging bar or pick mattock to break the ground.
4	Crumbling, damp	Consists principally of clay, in a state that will crumble when an attempt is made to squeeze it into a ball with the hand.
5	Firm, moist	In many cases, clay is predominant, although the soil may contain small stones, gravel, or sand, and when squeezed with the hand, forms a firm ball. Most soils in well-drained areas, other than hillsides, fall into this classification.
6	Plastic, wet	In most cases, this soil is predominantly clay, as in Class 5. Because of unfavorable moisture conditions, such as areas subject to heavy seasonal rainfall, sufficient water is present to penetrate the soil to a considerable depth, even though the area may be fairly well drained. During such seasons the solid becomes plastic and, when squeezed in the hand, readily assumes any shape into which it is molded. This soil is frequently found in flat terrains, or near rivers and marshes.
7	Loose, dry	Usually found in arid regions where sand or gravel predominates. Filled-in or built-up areas in dry regions, or during very dry seasons, fall into this classification. Lack of bonding material to hold the particles together causes the soil to remain very loose.

As would be expected the holding capacity of hook anchors was always higher in frozen than in unfrozen ground but varied with anchor diameter and shank length. This is clearly shown in Figure 43. The load capacity given in Figure 43 represents the average maximum failure load applied to hook anchors of a given size. Anchors which failed structurally at the elbow were not included in the calculation.

The frozen ground results presented in Figure 43 were not adjusted for variations in ground temperature nor have the summer data been adjusted for variations in soil moisture content. Differences in the rate of loading or the load increment were not taken into consideration either. These variables are known to influence the load capacity of ground anchors. Nevertheless, the data plotted in Figure 43 show surprisingly little deviation from the rectilinear curve drawn through each set of data.

It is apparent from Figure 43 that for the soil conditions existing during the tests, the maximum capacity of hook anchors in frozen ground is three times that of the same size anchor in the unfrozen ground. It was postulated earlier that the long term load capacity of hook anchors is on the order of two thirds of the anchor's maximum load capacity. If this holds, then Figure 43 can be used as a guide for determining the long term holding capacity of various size anchors in silt.

The Research and Technical Support Activity of the U.S. Army Electronics Command, Fort Monmouth, has compiled information on the properties of a number of guy stakes and anchors. Table III presents the information pertaining to small anchors along with the data from the tests reported herein. The loads obtained from the latter tests are underlined in the table. The data in Table III show that $^1/_2$- and $^5/_8$-in.-diam hook anchors have a holding capacity comparable to the GP-112/G stake. It is therefore reasonable to assume that the lighter and much cheaper hook anchor (the GP-112/G stake costs nine dollars) could be a substitute for the GP-112/G stake for certain anchoring problems. Further tests would have to be undertaken to verify this assumption.

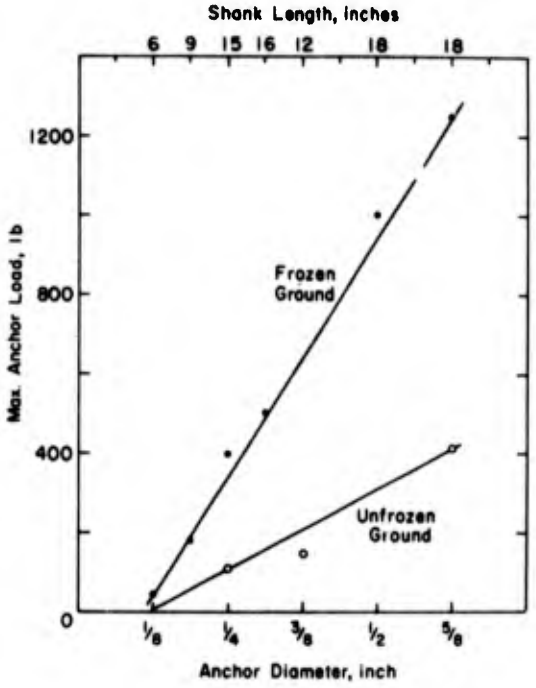


Figure 43. Graphic presentation of test results showing anchor load capacity vs anchor size and vs the frozen and unfrozen ground conditions existing during the tests reported.

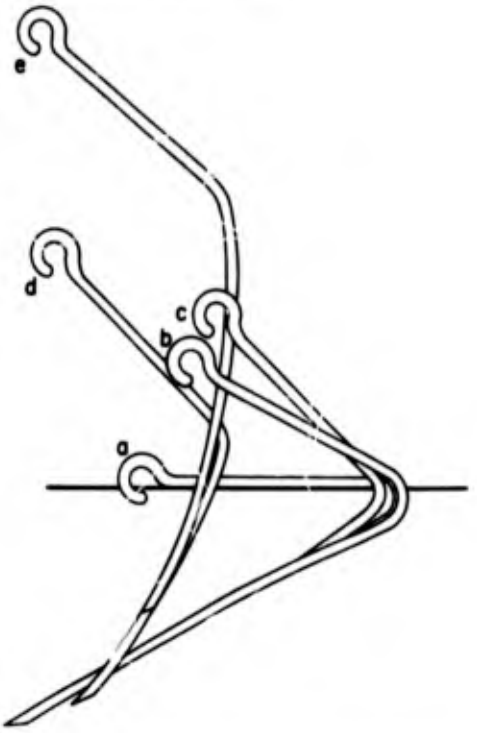


Figure 44. Generalized movement of hook anchors under increased loading. (a) Unloaded positions, (b) initial loading, (c) approximate position at 50% of maximum load, (d) forward movement and initial upward creep of anchor at 80% of maximum load, (e) configuration of anchor at time of withdrawal.

While their holding capacity is not doubted, it is questionable whether the GP-108/G stake, the GP-113/G stake, or the $2^3/_4$- and 3-in.-diam screw anchors listed in Table III can be emplaced in the time given or even at all in certain class 2 soils without considerable effort. In particular, the above anchors or stakes can not be emplaced in hard frozen ground without mechanized assistance. Similarly, retrieval from frozen ground would not be possible in many cases without some form of mechanized assistance. Even then, there is a good chance the anchors would suffer permanent damage during extraction. The use of these anchors in hard frozen ground can thus be expected to be restricted. An anchor similar to the hook anchor may offer a suitable substitute.

The flexure and movement of hook anchors under increased loading is shown in Figure 44. When an initial load of about one quarter of the anchor's capacity is applied at an angle of 45 to 60° the anchor moves from its unloaded position at A to position B. As shown, the anchor arm has raised off the ground, increasing the included angle, and the shank has in fact bent backward. When the load is increased to about one half the anchor's capacity the anchor arm is drawn higher and the shank forward to where it is again straight or now slightly curved forward as shown at position C. At 80% of the maximum load the anchor shank has been noted to cut into the soil and begin to slip upward as shown in position D. At failure the anchor takes the shape shown in position E as it is withdrawn. After withdrawal the anchor's shank is often found concave inward and the included angle has increased from 45° to as high as 130°. Although the bent anchors could be restored to their original shape without great difficulty (with the aid of a vice and hammer) it is likely that the anchors were permanently weakened from their ordeal. One must presume that they were and that

restored anchors will deform and fail at a lower load level than anchors which have not been subjected to bending loads.

The four load tests performed on GM stakes in unfrozen ground revealed that the stakes could resist a 50-lb load but at 100 lb they would bend and be quickly extracted from the ground. The stakes could not be straightened for reuse. They also could not be removed from frozen ground without being deformed. These stakes appear suitable for anchoring one- or two-man tents where the guy load is low or for use as a lightweight expendable anchor in frozen ground.

Conclusions and recommendations

It has been found that hook anchors can be driven and retrieved from frozen silt (soil test temperatures were at or above −5°C) and that the anchors have a reasonable holding capacity for their size in both frozen and unfrozen ground. As would be expected, anchor capacity increased with shank length and diameter and with increased soil resistance due to freezing. It was found that anchor capacity was more sensitive to anchor diameter than shank length for the anchors tested.

The anchors appear particularly suited for use in hard or frozen ground where the driving and retrieval of anchors is often found to be a difficult task. Even though refinements to the anchor are in order, it is suggested that the commercially available anchors be tried at this time by USARAL troops under field conditions. Their findings will supplement the findings of this report and hopefully provide suggestions on how to improve the anchor's performance. The size of the hook anchor suggested for field trial is $^5/_{16}$ in. diam, 9-in.-long shank and 7-in.-long arm.