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ARCTIC TENT STAKE

by

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Munitions Branch

May 1974

Final Report

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

U. S. ARMY LAND WARFARE LABORATORY
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In 1971 a need was expressed by US Army Alaska personnel for a means of driving tent stakes into arctic ice and permafrost without depleting human energy in that harsh environment. The manual driving of conventional stakes and pins required expenditure of an unacceptable level of human energy. Heavy conventional stake drivers weighed 30 to 70 pounds and were unacceptable for contemplated tactical operations.

Initial development in 1972 to reduce the soldier's effort produced a muzzle
(Continued on Reverse)

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BLOCK 20. ABSTRACT CON'T

attachment for the M16A1 Rifle. This attachment, the Arctic Tent Stake Driver, employed blank 5.56mm ammunition for the power source to emplace standard tent stakes and pins. Performance of the completed Arctic Tent Stake Driver was reported by the contractor to be marginal with conventional stakes. Comparative testing with this device indicated that the design of conventional stakes was not conducive to efficient penetration of permafrost.

Based on test results generated by the contractor, LWL investigated and developed a new type tent stake specifically for use in arctic permafrost and ice. This item, the Arctic Tent Stake was successfully tested at Arctic Test Center, Alaska under USATECOM Project No. 8-EG-445-000-001.

INTRODUCTION

LWL Liaison Officers in Alaska in 1971 reported that troops could not emplace tent stakes in the permafrost or ice without an unacceptable expenditure of energy. The problem is compounded by the harsh arctic environment which requires an inordinate amount of effort for the accomplishment of many other normally routine tasks.

A variety of devices have been used as tent stakes in the Arctic. A solid, 1.1-pound Arctic Tent Pin (FSN 8340-823-7451) made from welded hardened 5/8-inch diameter 4140-type steel rod is the current official tent stake for arctic use. The 0.32 pound Engineering Spike (FSN 5315-162-3135) made from a cold-headed 3/8-inch diameter mild steel rod is widely used due to its lighter weight. An expensive ($3.07) item, the Tubular Mountain Ice Piton (FSN 8465-240-2974) weighing 0.37 pounds, is occasionally used in the role of an expendable tent stake. The orange colored standard Aluminum Tent Stake (FSN 8340-261-9749) is but rarely used since it bends easily.

This task began with the development of a device to emplace existing stakes. When it became apparent that a device rugged enough to function would necessarily be too heavy to be practical the effort was redirected toward overcoming shortcomings in the stakes which had by then become apparent. This report records the events which comprise the development of an arctic tent stake.

DEVELOPMENT

General

During the period 1962-64, the problem of driving stakes into frozen ground surfaced in connection with grounding electrical equipment. Under the auspices of the US Army Electronics Command a ballistic mechanism was developed which could drive GP-112/G and GP-113/G ground stakes to a depth of almost 9 inches. This device utilized a modified M1 Carbine mechanism and employed blank ammunition for the driving impetus. References 1, 2 and 3 document this effort. Reference 4 is a survey of this and other stake-driving tools.

The previous work done in this area indicated that it would be feasible to develop a device which would attach to the M16 Rifle (the current standard weapon) and which would drive in tent stakes, the item of concern at this time. Initial concept work on a feasibility study and design was performed under Work Assignment #11 of contract DAAD05-71-C-0270 by the AAI Corp., which had been involved in the development of the previous M1 Carbine-activated device. Feasibility was generally indicated and further work was undertaken to develop a rifle mounted tent stake driver under contract DAAD05-72-C-0447. See Annex A for details of the development of the M16-mounted "Arctic Tent Stake Driver." This device was overweight, cumbersome and performed marginally, having the same stake driving velocity as a hammer. It did not meet the four-pound weight limit imposed by US Army Alaska. The driver was, however, a useful research tool which provided a repeatable impulse to a variety of candidate standard stakes. Penetration testing in frozen saturated Ottawa quartz sand indicated that the design of current stakes left much to be desired in terms of efficient penetration. The devices which exhibited rapid rate of penetration of the frozen simulation of permafrost were the hollow tubular Mountain Ice Piton (FSN 8465-240-2974) and certain experimental tubular stake designs provided by US Army Land Warfare Laboratory (LWL). Contractor effort on the mechanical driver ceased with termination of the contract at the end of the initial development phase (see Annex A).

Stake Development

High stiffness-to-weight ratio is a characteristic of tubular shapes. The ratio of stiffness to presented area, which is important for penetration purposes, is also high. These characteristics formed the basis for design of the prototype Arctic Tent Stake, based on lessons learned during the contract development effort.

The correct diameter and wall thickness of tubular penetrators were determined by empirical means for samples of different size tubing. Diameters ranged from 1/4-inch to 1 1/8-inch. The smaller diameter tubing, 1/4 and 1/2-inch, bent and buckled after a few blows from a 2.3-pound hand sledge. The larger sizes, 7/8-inch to 1 1/8-inch diameters, generally exhibited bending at the mid-section and subsequent collapse due to the extreme eccentricity of random blows around the rim of the tubing. The rate of penetration was greater for the 5/8-inch and 3/4-inch diameter tubes than for any of the others. There was a small difference in these two rates of penetration, but designs in both sizes were carried through to the prototype evaluation stage.

A wall thickness of standard 0.049 inch proved to be required for serious penetration attempts. Thinner tubing samples, having a standard 0.035 inch wall, failed during driving attempts. Mode of failure was either buckling and bending in a "U" shape or sequential circumferential undulation of the tubing (collapsed like an accordian) just under the head of the stake. Thickner walls will permit acceptable driving, but the added weight penalty is neither necessary nor acceptable.

Two basically different head designs for the stakes were investigated in depth after an initial screening of various designs. One was a three-piece undercut sloped head design (see Annex B), having either a solid end plug or a hallow end plug. The machined plug retained a standard 1 1/2-inch O.D. washer between it and the end of the tube. A variation of this design incorporated the washer and plug together in a single machined piece. The other was a two-pieced beaded tube design having a co-axially assembled washer longitudinally trapped on the outside of the tube by either double expanded beads, similar to the piton design, or by two forced-fitted steel rings.

Tests of the head designs indicated that the three-piece stake exhibited a tendency to bend just under the head, regardless of the length of the plug or the degree of interference fit or lack thereof. The two-piece stake design proved to be the better in terms of survivability. The stake is shown in Annex C.

Human engineering aspects of the LWL two-piece stake design appeared acceptable. An Infantry NCO was asked during conduct of a test to determine ease of handling of the stakes wearing Arctic mittens, FSN 8415-782-6715, and they were ranked in order:

Arctic Tent Stake (5/8-inch dia.)
Arctic Tent Stake (3/4-inch dia.)
Aluminum Tent Stake
Engineer Spike
Hardened Arctic Tent Pin, 1.1-pound

Cost estimates of the stake designs indicated that the beaded two-piece design would be the cheapest to produce in quantity due to the small number of operations. Operations to fabricate included only tube cut-off and chamfer, assembly of a standard washer, beading, and optional painting or application of another type preservative. Price for the double beaded Arctic Tent Stake was estimated by LWL Technical Support Division to be about 50 cents. This is only about one-sixth of the cost of the Mountain Ice Piton and is still less than cost of the 1.1-pound hardened Arctic Tent Pin which costs $1.33. It was decided to produce evaluation prototypes of the two-piece Arctic Tent Stake in 5/8 and 3/4-inch diameters.

In a test conducted on 5 October 73, LWL personnel using a 2.3-pound hand sledge and wearing arctic mittens drove samples of two LWL Arctic Tent Stakes, Aluminum Tent Stakes, Engineer Spikes, and 1.1-pound hardened Arctic Tent Pins into buckets of frozen, saturated sand at -25°F. To summarize, the 5/8-inch Arctic Tent Stake appeared to go in easiest with an average of 18 blows required to penetrate 2 inches, 30 blows to 3 inches, 45 blows to 4 inches, and 68 blows for 5 inches. Penetration of the 3/4-inch Arctic Tent Stake was

18 blows for 2 inches, 35 blows for 3 inches, 55 blows for 4 inches, and 70 blows for 5 inches (see Annex B for graph of this information). The Engineer Spike penetration was difficult to measure because of the continual fracture of the medium. On one of the driving attempts a total of 27 blows were required for 2 inches of penetration, 40 blows for 3 inches, but then the Engineer Spike bent. The Aluminum Tent Stake penetration was 1 inch after 24 blows, but bending occurred soon thereafter. The Aluminum Tent Stake did not hold. The red 1.1-pound hardened Arctic Tent Pin also fractured the medium severely. Penetration was 1 inch after 40 blows, 1 1/2 inches after 70 blows, but the pin did not hold.

At the conclusion of the aforementioned test the NCO was asked to rank the stakes in the order in which he would like to carry them on an Arctic tactical operation. The order is:

5/8-inch Arctic Tent Stake
3/4-inch Arctic Tent Stake
Engineer Spike
Aluminum Tent Stake
Hardened Arctic Tent Pin, 1.1-pound

One of the beaded heads of the tubular LWL Arctic Tent Stakes tested fractured and a piece of metal flew off during the test (one out of about 30 tested to date). It was therefore recommended that arctic soldiers conducting the evaluation of the prototype wear either safety glasses or the Arctic Sun Goggle FSN 8465-161-4068, which has cellulose acetate butyrate lenses, good for cold temperature impact, until the extent of this difficulty could be assessed. An attempt to eliminate a chance breakage or fragment by addition of 80% steel-filled Devcon epoxy to the head proved ineffective. The LWL Safety Committee evaluating this design determined that a Safety Statement was not necessary.

In another test at ambient temperature (70°F) in a rocky medium, the bottom edge of the tubular stake was flared outward after penetration of several inches. Removal of the stake from the ground was very difficult due to this flared-end condition.

The design of the inside of the tube and the periphery of the washer was such that the Arctic Tent Stake could possibly be utilized with an automatic stake driver at a later date. Anyone contemplating the development of an automatic stake driver should read the excellent report by Kovacs and Atkins on stake driving tools (Reference 4).

Fifty each of the 5/8-inch and the 3/4-inch diameter Arctic Tent Stakes were sent to Arctic Test Center, Alaska, in January 1974 for evaluation.

RESULTS, CONCLUSIONS AND RECOMMENDATION

Results

The results of this evaluation have been published under USATECOM Project No. 8-EG-445-000-001, Product Improvement Test of Arctic Tent Stakes, 1 May 1974.

Conclusions

1. The prototype arctic tent stake performed significantly better than other stakes in ice, frozen muskeg, and frozen silt under arctic conditions.

2. The prototype arctic tent stake was comparable to other stakes in rock-filled glacial moraine, however, the 3/4-inch diameter Arctic Tent Stake was preferred since it was the easiest to drive into the ground.

3. The Arctic Tent Stake offers no safety hazard based upon results of the Arctic Test Center evaluation.

Recommendation

It is recommended that the designated Parent Agency accomplish the necessary standardization procedures to introduce the Arctic Tent Stake into the supply system.

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2. Engineering Report 3246, Rapid Emplacement and Retrieving Device for Ground Stakes GP-112/G and GP-113/G Ballistic Hammer MX6321, AAI Corp, Cockeysville, MD, 1964

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ANNEX A

ARCTIC TENT STAKE DRIVER, CONTRACTOR'S FINAL REPORT

ARCTIC TENT STAKE DRIVER

FINAL REPORT

By:

R. W. Schnepfe

O. L. Shifflett

AAI Corporation

Contract No. DAAD05-72-C-0447

ER-7479
Report No.

December, 1973
Date

ABSTRACT

The Arctic Tent Stake Driver developed under this program provides the capability of driving stakes into frozen arctic terrain without the great expenditure of effort normally required for stake implanting using a hammer. The device is attached to the muzzle of the M16 rifle and is powered by the standard 5.56MM blank cartridge which can be magazine-fed into the rifle. When fired, the gases drive a piston which delivers a blow to the stake. In simulated operation against 90% saturated, frozen Ottawa quartz sand at -65°F the average penetration experienced with five (5) firings was 6.3 inches with the Ice Piton.

The device may be utilized by an operator wearing arctic mittens and it has the capability of being attached to the rifle or removed in less than two minutes.

Although most design goals were met, further effort would be required to achieve the goals of simplicity, low weight, and semi-automatic rifle functioning.

FOREWORD

This program was conducted for the USA Land Warfare Laboratory, Aberdeen Proving Ground, Maryland. The initial design effort was conducted under Work Assignment 11 of Contract DAAD05-71-C-0270. The design, development and testing of a prototype was conducted under the terms of Phase I of Contract DAAD05-72-C-0447. The prototype was tested against simulations of a representative frozen soil. Based on the test results, the design was upgraded and two (2) improved prototypes were fabricated.

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INTRODUCTION

As a result of strenuous conditions encountered in the Arctic, it became necessary to have a simple mechanical device capable of driving stakes into ice and frozen ground without expending available human energy. The objective of this program was to provide a stake driver capable of being attached to the M16A1 Rifle and using 5.56MM blank ammunition drive a standard tubular Ice Piton into ice and frozen ground.

The initial design was conceived under Work Assignment No. 11 of Contract DAAD05-71-C-0270. This report under terms of Phase I of Contract DAAD05-72-C-0447 summarizes the subsequent development and performance of the prototype Arctic Tent Stake Driver.

The design goals of the stake driver include the following physical and performance characteristics:

Additional design objectives were:

- One or two major components
- Four pounds or less weight
- Climatic category 8 (Arctic) functional capabilities
- Parachute airdrop capabilities
- Man, air, and vehicle transportable
- Indefinite storage life
- Functions with the M16A1 Rifle in the semiautomatic mode
- Functions with 97% reliability in arctic environment to accomplish driving a standard Ice Piton to maximum possible depth.
- Installs to (and removes from) M16A1 Rifle in 2 minutes or less when wearing arctic clothing and mittens.
- Completely safe to fire with 5.56MM Blank Cartridge in the M16A1 Rifle. If inadvertent firing with ammunition other than blank cartridges should occur, it is desirable that there be no hazard to personnel greater than that imposed by normal firing of the weapon.
- Low maintenance.
- Safe.

CONCLUSIONS

The Arctic Tent Stake Driver effectively provides a means of driving stakes into arctic terrain without exhausting available human energy. The optimum stake driving capability of the stake driver was never realized during Phase I of the contract. A problem of unburned propellant was evident throughout the functional testing of the device, thus, maximum energy was never imparted to the piston. The reduction in the check valve orifice diameter encouraged more complete burning of the propellant, but never completely eliminated the problem.

The final prototype stake driver was overweight but areas available to immediate material reduction are the split latch assembly and the piston housing. An immediate weight savings of 0.7 pounds can be realized by shortening the piston housing and milling slots in the split latch. The overall length of the stake driver unit can also be reduced by 1.25 inches due to the reduction of the piston stroke.

The requirement for semi-automatic cycling of the M16A1 Rifle was not met. It would be advantageous to arctic personnel if the Arctic Tent Stake Driver would recycle the weapon. It could then be used with the M61A1 Rifle in the semi-automatic mode. Although the current prototype requires hand cycling of the weapon, this inconvenience is considerably less exhausting than driving stakes into arctic terrain with the use of heavy striking tools.

THEORY/APPROACH

The Arctic Tent Stake Driver is a gas-operated piston-type impact device, used in conjunction with the M16A1 Rifle, and serves as a tent stake driving tool capable of implanting a tent stake in ice or frozen ground. In use, the device is attached to the muzzle of the M16A1 Rifle and actuated by the gases of a 5.56MM blank cartridge fired in the rifle. Each blank firing provides the actuating gases for one impact stroke of the device.

Figure 1. Arctic Tent Stake Driver
Attached to M16A1 Rifle

Contained within the piston is a gas system for porting gases forward of the piston for the purpose of buffing the kinetic energy of the piston after stake impact or if inadvertently fired with no stake in place.

When the 5.56MM blank cartridge is fired in the M16A1 Rifle the gases enter the device and begin to accelerate the piston for the power stroke. A check valve in the piston allows some of the propellant gases to bleed into the piston and out through radial ports, into the cylinder, forward of the sealing flange on the piston. As the piston moves these gases are compressed during the power stroke. The check valve prevents a reverse flow. The compressed gas acts as a buffer to absorb the kinetic energy of the piston at the end of the stroke. The piston is returned to its original starting position by a spring powered linkage attached to the Stake Driver's extension.

A computer model describing the M16A1 Rifle and Arctic Tent Stake Driver as a two-volume system was used to determine the final velocity attained by the piston when the device was operated without a stake being implanted.

The standard interior ballistics computer program developed by AAI considers the burning of the propellant grains in some initial volume and expands the propellant gas being created by the burning of the grains until the condition of all-burnt occurs. This interior ballistic program was based on the equations in Corner for defining the propellant burning. The burning rate, web size, and impetus of the propellant are necessary inputs for this program. These parameter values are computed empirically at AAI based on the actual pressure versus time curve; which results from burning the propellant in a closed pressure vessel. The parameters used include those previously mentioned, and the form function equation based on the propellant grain geometry.

$$Z = (f)$$

where:

Z = fraction of the propellant weight burned at some time t

f = fraction of the web remaining at some time t

Most standard type grains shapes, spheres, tubes, flakes, or discs, and perforated grains can be defined readily; however, some porous type grains are very fast burning and required empirical solutions to define the form functions.

This interior ballistic program is one-dimentional in nature, and does not consider such items as boundary layer effects, heat losses from the propellant to the barrel, or the propagation of shock waves and shock wave reflection and interactions. However, by carefully defining the interior ballistic inputs and the propellant properties, excellent theoretical results are obtained. AAI has used this computer program to predict peak chamber pressures, muzzle velocities, and pressure versus time curves for numerous weapon systems. Detailed comparisons have been made between experimental firing data and the theoretical results predicted by the computer program. The theoretical results were within 5 to 7% of the average peak pressure and muzzle velocity.

The theory for defining the necessary interior ballistic equations is presented by Corner in his "Theory of the Interior Ballistics of Guns." The burning of the propellant is described by the following equation:

$$\frac{df}{dt} = \frac{P^n}{D}$$

where:

f = fraction of initial web remaining
t = time
  = propellant burning rate
D = web size
P = gas pressure
n = pressure index

The computer run including input and output data from the interior ballistic program developed for this design study is shown on the following page. The results include the gas pressure, temperature and fraction burning as a function of time. Also, the projectile travel and velocity are computed as a fraction of time.

The parameters established for the Stake Driver are:

Piston Weight	-	1.12 lbs
Piston Stroke	-	3.0 inches
Initial Chamber Volume	-	.145 cubic inches

The answers or results of the computer run are given in the following terms:

t = time in seconds

PH = gas pressure in psi

X = piston stroke in inches

V = piston velocity in feet per second

As seen in the computer run, the predicted peak pressure is 3500 psi and the piston reaches a velocity of 141 fps in a 3-inch stroke. The results from this computer run were used to conduct a performance and stress analysis of the Stake Driver Assembly.

The highest loads possible in the Stake Driver occur when the blank cartridge is fired and a stake is not in place to absorb the resultant piston velocity and energy. The forces generated by this condition were used to perform a simple shear and tensile analysis on all Stake Driver details and all joints including the attachment of the stake driver to the muzzle device.

N= 11

TABLE OF PHI VS F

PHI	F
0.000000000	1.000000000
0.281000000	0.900000000
0.488000000	0.800000000
0.657000000	0.700000000
0.784000000	0.600000000
0.875000000	0.500000000
0.936000000	0.400000000
0.973000000	0.300000000
0.992000000	0.200000000
0.999000000	0.100000000
1.000000000	0.000000000

```
BURNING RATE COEF ........ BETA=          0.156000000 (IN/SEC/PSI)
PROPELLANT WEB SIZE...........D=          1.000000000 (IN)
PROJECTILE WEIGHT ............W=          1.120000000(LBS)
PROJECTILE BASE AREA.........AP=          1.760000000 (SQ.IN.)
RESISTANCE TO MOTION..........R=          0.000000000 (LBS)
PROPELLANT WEIGHT.............C=          0.001000000 (LBS)
PROPELLANT IMPETUS............F=     329999.999990000 (FT)
PROPELLANT DENSITY........DELTA=          0.060000000 (LB/CU.IN.)
HIGH CHAMBER VOLUME.........VHO=          0.903000000 (CU.IN.)
LOW CHAMBER VOLUME..........VLO=          0.145000000 (CU.IN.)
FLOW RATE COEFFICIENT.........K=          0.013700000 (1/SEC)
ORIFICE AREA.................AO=          0.027500000 (SQ.IN.)
RATIO OF SPECIFIC HEATS...GAMMA=          1.240000000 (-)
DIAPHRAGM BURST PRESSURE.....PB=       3499.999999900 (PSI)
CONSTANT VOLUME GAS TEMP.....TO=       5829.999999900 (DEG R)
STOP AT PROJECTILE TRAVEL..XEND=          3.000000000 (IN)
PHASE 2 TIME INCREMENT......DT2=          0.000001000 (SEC)
PHASE 3 TIME INCREMENT......DT3=          0.000050000 (SEC)
PHASE 4 TIME INCREMENT......DT4=          0.000050000 (SEC)
PHASE 5 TIME INCREMENT......DT5=          0.000050000 (SEC)
PRESSURE EXPONENT.............N=          1.000000000
PRIMER PRESSURE .............PHO=       199.999999990 (PSI)
```

ANSWERS

T (SEC)	PH (PSI)	PL (PSI)	PHIO	X (IN)	V (FT/SEC)	TEMP (DEG R)
0.00000000	200.0000	14.7000	0.0000	0.0000	0.0000	530.0000
0.00150983	3500.0000	14.7000	0.7951	0.0000	0.0000	530.0800

BURSTING PRESSURE REACHED

MOTION BEGINS

T (SEC)	PH (PSI)	PL (PSI)	PHIO	X (IN)	V (FT/SEC)	TEMP (DEG R)
0.00155983	3318.8197	1807.7426	0.8199	0.0000	0.0372	5830.0000
0.00160983	3295.7870	2584.2773	0.8435	0.0008	4.6065	5829.7359
0.00165983	3338.2802	2832.3081	0.8669	0.0028	11.1386	5789.5262
0.00170983	3376.8132	2807.2059	0.8854	0.0095	18.2977	5697.2756
0.00175983	3399.2569	2664.7333	0.9015	0.0204	25.3933	5568.9083
0.00180983	3408.5052	2490.7862	0.9177	0.0357	32.1288	5430.5336
0.00185983	3402.7862	2322.3977	0.9339	0.0556	38.4246	5301.4764
0.00190983	3359.5135	2170.0273	0.9445	0.0788	44.2948	5189.6830
0.00195983	3303.1204	2029.9327	0.9542	0.1046	49.7798	5094.1754
0.00200983	3239.1239	1903.1689	0.9638	0.1345	54.9108	5013.3036
0.00205983	3168.9040	1789.2677	0.9731	0.1674	59.7213	4944.7108
0.00210983	3075.2148	1686.8321	0.9778	0.2032	64.2440	4885.9786
0.00215983	2980.2176	1592.2899	0.9823	0.2418	68.5077	4833.8821
0.00220983	2884.6639	1505.4405	0.9867	0.2829	72.5324	4787.3318
0.00225983	2789.2311	1425.7170	0.9910	0.3264	76.3376	4745.3616
0.00230983	2685.8926	1352.4493	0.9932	0.3722	79.9413	4707.1629
0.00235983	2582.0854	1284.3849	0.9946	0.4202	83.3598	4671.6142
0.00240983	2480.9909	1221.0226	0.9960	0.4702	86.6063	4638.2206
0.00245983	2382.7791	1162.0539	0.9974	0.5222	89.6926	4606.7137
0.00250983	2287.5813	1107.1446	0.9987	0.5760	92.6299	4576.8521
0.00255983	2191.9949	1055.9643	0.9991	0.6316	95.4283	4548.4253
0.00260983	2098.8895	1008.0497	0.9993	0.6888	98.0974	4521.0866
0.00265983	2009.4863	963.1255	0.9995	0.7477	100.6454	4494.6783
0.00270983	1923.7278	920.9837	0.9996	0.8081	103.0799	4469.1178
0.00275983	1841.5438	881.4236	0.9998	0.8699	105.4078	4444.3286
0.00280983	1762.8536	844.2555	0.9999	0.9331	107.6357	4420.2414

BURNOUT OCCURS

T (SEC)	PH (PSI)	PL (PSI)	PHIO	X (IN)	V (FT/SEC)	TEMP (DEG R)
0.00283921	1718.6175	823.1219	1.0000	0.9711	108.8896	4405.7138
0.00288921	1644.6410	789.4458	1.0000	1.0364	110.9701	4382.6974
0.00293921	1573.9936	757.7065	1.0000	1.1030	112.9656	4360.1989
0.00298921	1506.5604	727.7676	1.0000	1.1708	114.8808	4338.1813
0.00303921	1442.2246	699.5029	1.0000	1.2397	116.7203	4316.6114
0.00308921	1380.8687	672.7961	1.0000	1.3097	118.4884	4295.4593
0.00313921	1322.3750	647.5400	1.0000	1.3808	120.1890	4274.6984
0.00318921	1266.6272	623.6358	1.0000	1.4530	121.8257	4254.3054
0.00323921	1213.5099	600.9926	1.0000	1.5260	123.4021	4234.2591
0.00328921	1162.9101	579.5269	1.0000	1.6001	124.9212	4214.5410
0.00333921	1114.7170	559.1614	1.0000	1.6750	126.3860	4195.1347
0.00338921	1068.8227	539.8253	1.0000	1.7509	127.7994	4176.0255
0.00343921	1025.1225	521.4529	1.0000	1.8276	129.1638	4157.2005
0.00348921	983.5145	503.9835	1.0000	1.9051	130.4819	4138.6479
0.00353921	943.9006	487.3614	1.0000	1.9833	131.7558	4120.3576
0.00358921	906.1861	471.5346	1.0000	2.0624	132.9877	4102.3202
0.00363921	870.2797	456.4551	1.0000	2.1422	134.1795	4084.5275
0.00368921	836.0938	442.0784	1.0000	2.2227	135.3333	4066.9721
0.00373921	803.5443	428.3632	1.0000	2.3039	136.4507	4049.6473
0.00378921	772.5507	415.2711	1.0000	2.3858	137.5334	4032.5470
0.00383921	743.0360	402.7662	1.0000	2.4683	138.5831	4015.6658
0.00388921	714.9264	390.8154	1.0000	2.5514	139.6012	3998.9986
0.00393921	688.1517	379.3876	1.0000	2.6352	140.5890	3982.5408
0.00398921	662.6449	368.4539	1.0000	2.7196	141.5479	3966.2883
0.00403921	638.3418	357.9873	1.0000	2.8145	142.4793	3950.2370
0.00408921	615.1819	347.9624	1.0000	2.8908	143.3841	3934.3835
0.00413921	593.1070	338.3558	1.0000	2.9768	144.2637	3918.7243
0.00418921	572.0621	329.1453	1.0000	3.0626	145.1189	3903.2562

DESCRIPTION OF APPARATUS

The Stake Driver consists of a movable, gas driven piston which operates inside a steel cylinder. The piston at actuation delivers the impact blow to the stake.

The physical characteristics of the Stake Driver are:

- weight - 6.91 pounds
- length - 12.75 inches
- diameter - 2.50 inches

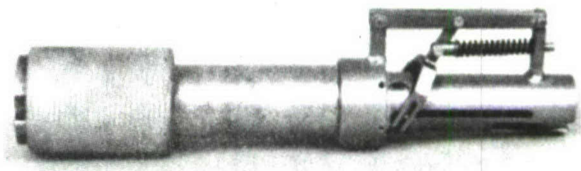


Figure 2. Arctic Tent Stake Driver

The cylinder at one end has a split collet for attaching the device onto the muzzle of the M16A1 rifle. The threaded sleeve is turned forward until the split collet is cleared and the Stake Driver is slipped over the flash suppressor. The device is positioned against the ground and the M16A1 Rifle is pressed down firmly with the shoulder against the rifle butt as the collet halves are squeezed closed over the washer at the rear of the flash suppressor. The threaded sleeve is turned rearward, locking the Stake Driver onto the M16A1 rifle barrel.

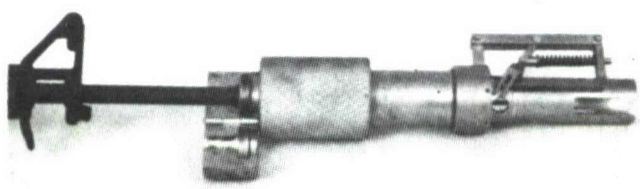


Figure 3. Arctic Tent Stake Driver Attached to M16A1 Rifle Flash Suppressor

At the other end of the cylinder is an extension for holding and aligning the stake to be implanted. The stake is inserted into the extension, point outward with the tie ring at the stake in the appropriate corresponding slot in the extension.

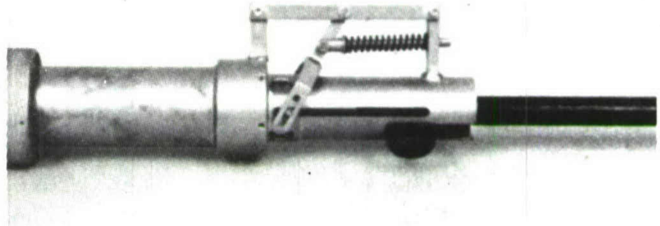


Figure 4. Tent Stake Inserted in Arctic Tent Stake Driver Extension

The piston weighs 1.53 pounds and is designed with a chamber to provide an entrapment for ball ammunition inadvertently fired in the weapon during operation of the Stake Driver. Contained within the piston and ahead of the bullet entrapment is a gas system for porting gases forward of the piston's sealing flange for the purpose of buffing the kinetic energy of the piston after stake impact or if the device is inadvertently fired with no stake in place.

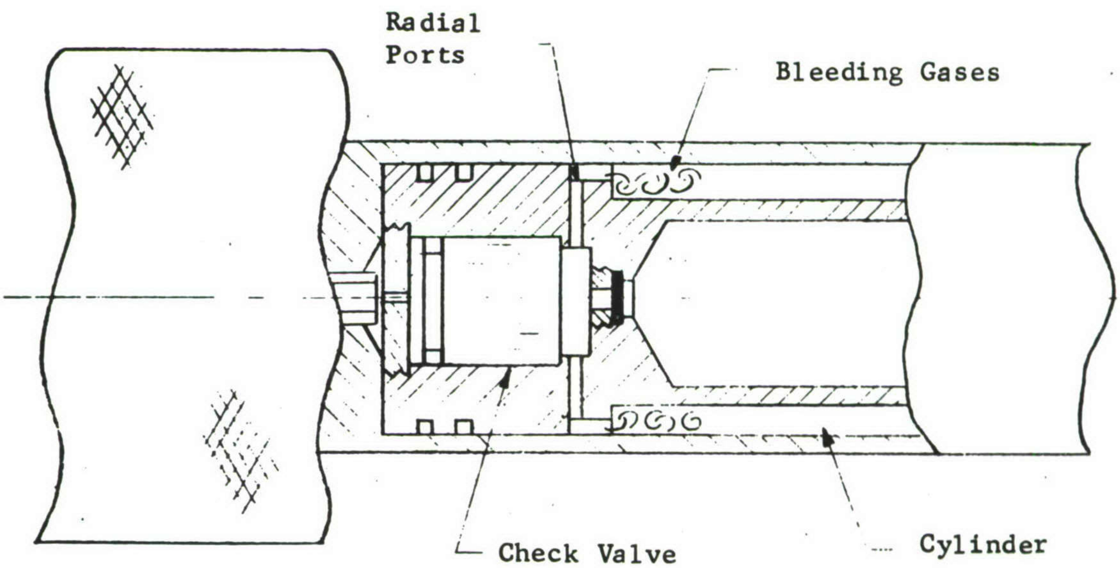
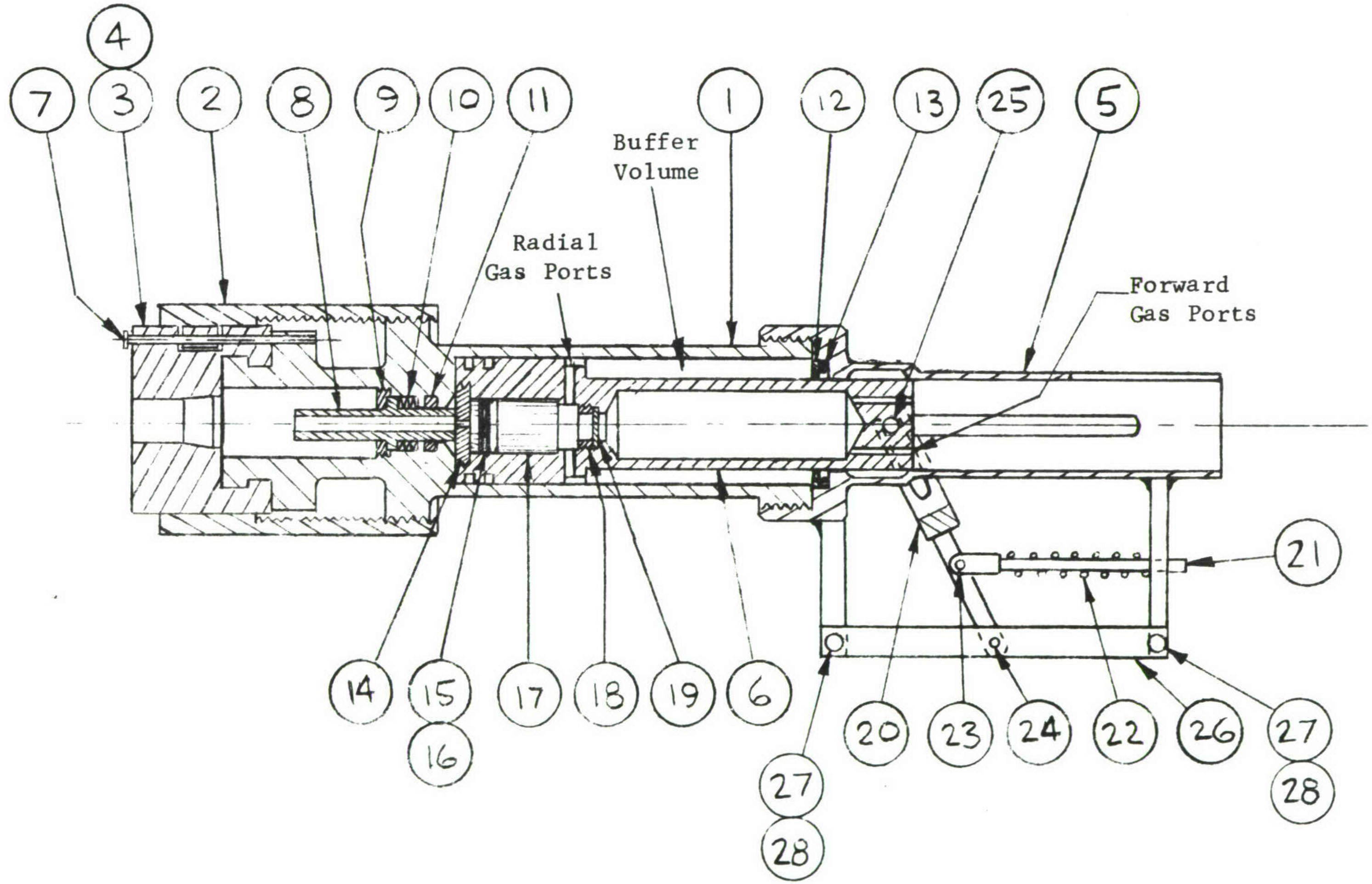


Figure 5. Porting of Gases to Outer Chamber Through Check Valve of Piston

When the 5.56MM blank cartridge is fired in M16A1 rifle the gases enter the device and begin to accelerate the piston for the power stroke. A check valve in the piston allows some of the propellant gases to bleed into the piston and out through radial ports, into the cylinder, forward of the sealing flange on the piston. As the piston moves these gases are compressed during the power stroke; the check valve prevents a reverse flow of gases. The compressed gas acts as a buffer to absorb the kinetic energy of the piston at the end of the stroke. The total stroke is 2.5 inches and impact with the stake occurs at a piston displacement of 1.5 inches. Any residual kinetic energy not absorbed by the stake impact will be buffed by the compressed gas.

After the power stroke, the piston is returned to its original starting position by a spring powered linkage consisting of a pivoting yoke which interfaces with the piston, a spring guide rod combination, and a supporting bracket for the whole assembly.(Refer to Figure 6.) The spring opposes the movement of the piston so that during the power stroke, the spring is loaded by the moving piston. When the power stroke is completed, and the gas is ported, the spring returns the piston to its rearward position.



STAKE DRIVER ASSEMBLY

Scale: 1/2

Figure 6

PARTS LIST

Item No.	Qty. Req.	Part Number	Nomenclature
1	1	040097003-1	Cylinder
2	1	040097008-1	Collar
3	1	040097019-1	Split Collet, Right Half
4	1	040097018-1	Split Collet, Left Half
5	1	040097002-10	Extension Assembly
6	1	040097001-10	Piston
7	1	040097021-1	Collet Pin
8	1	040097009-1	Gas Tube
9	1	040097010-1	Tube Retainer
10	10	040097028-1	Bellville Spring Washer
11	1	2-012,S604-7;Parker	O-Ring
12	1	040097015-1	Ring
13	1	2-219,S604-7; Parker	O-Ring Pad
14	1	040097011-1	Check Valve Retainer
15	1	2-113,S604-7; Parker	O-Ring
16	1	8-113,N300-9; Parker	Back-Up Ring
17	1	C249S-1Q; Circle Seal	Check Valve
18	1	040097013-1	Burst Disc Retainer
19	1	040097012	Burst Disc
20	1	040097022-1	Yoke
21	1	040097023-1	Spring Rod
22	1	040097029-1	Spring
23	1	040097030-1	Spring Rod Pivot Pin
24	1	040097031-1	Yoke Pivot Pin
25	1	040097024-1	Piston Pivot Pin
26	2	040097025-1	Pivot Support
27	2	MS 21042L06; 6-32	Self-Locking Nut
28	2	MS 16995-18; 6-32 x 1/2	Socket Head Cap Screw

PROCEDURES

The initial design proposed under Work Assignment 11 of Contract DAAD05-71-C-0270 was evaluated in greater detail to determine the major design parameters. Tests conducted included pressure vs time measurements occuring in the device and velocity measurements of the gas operated piston. The pressure vs time measurements were determined using a mock-up device simulating the initial volume immediately behind the piston. The mock-up was designed such that the orifice diameter ahead of the simulated volume could be opened, thus producing comparable results needed to determine an optimum orifice diameter required to provide maximum impetus to the piston while at the same time facilitating the recycling of the weapon.

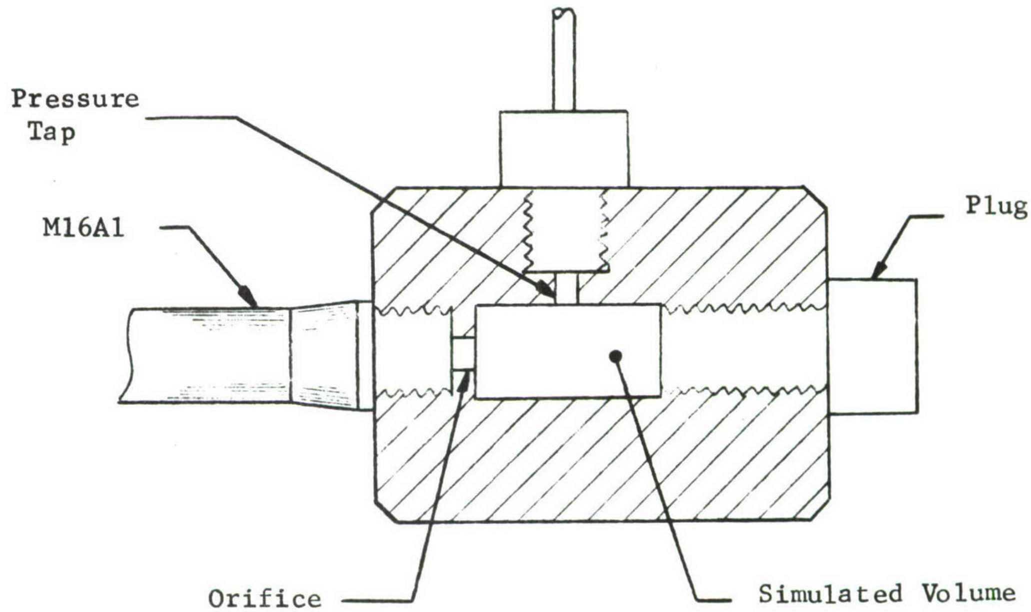


FIGURE 7. PRESSURE MEASUREMENT MOCK-UP

It was found that the weapon recycled each time it was fired with the mock-up attachment. The pressure in the simulated volume increased from 1,220 psi for a .065 inches diameter orifice to 3,400 psi for a .228 inches diameter orifice (the bore size of the M16A1 Rifle). The test results were inconclusive in that the initial volume remained constant and did not accurately simulate the change in volume due to the moving piston in front of the expanding gas.

After determining the pressure obtainable behind the piston, another mock-up attachment was built to determine piston velocity. The model was designed to provide a 3.0-inch stroke using a 1.26-pound piston as proposed under Work Assignment 11 of Contract DAAD05-71-C-0270. The total stroke of the initially designed stake driver was 3.8 inch, but the piston is in contact with the stake for the remaining 0.8 inch of stroke. The orifice size was .288 inches diameter to provide an initial pressure of 3,400 psi behind the piston. A velocity of 150 fps was measured at the end of the three inch stroke. The piston was then reduced to one pound in .125 pound increments, and the velocities were measured. The final velocity attained with the one pound piston was 120 fps. The energy calculated for the one pound piston traveling at 120 fps was 2,683 in-lbs.

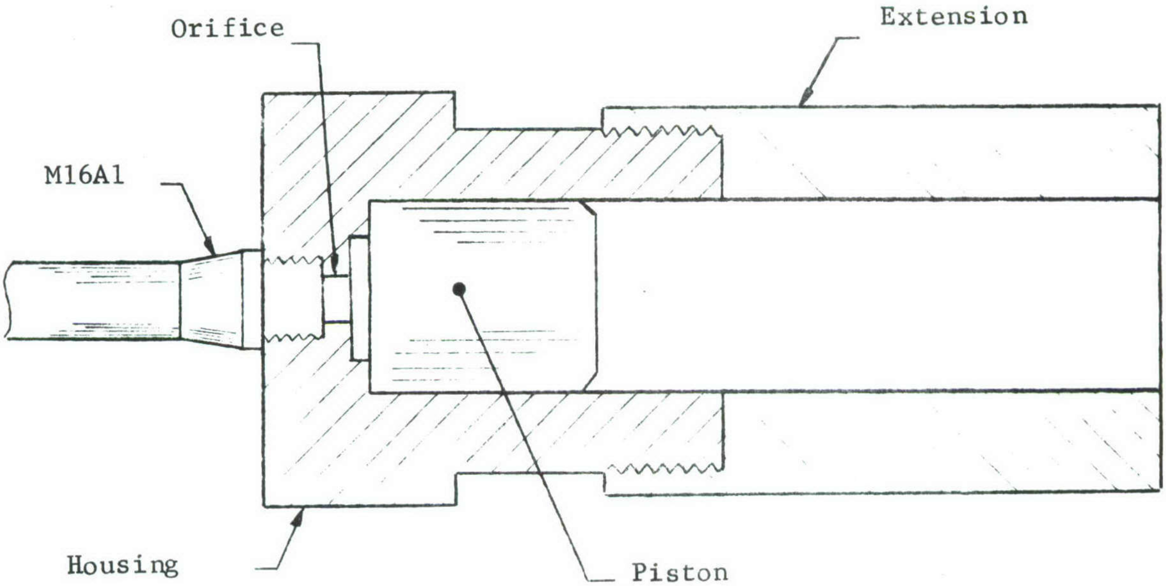


FIGURE 8. ARCTIC TENT STAKE DRIVER MOCK-UP

After pressure and piston energy levels were determined, the original design was strengthened at the critically stressed areas. A weight analysis was conducted on the redesigned stake driver and it was found to weigh slightly more than ten pounds. In an attempt to comply with the weight requirements of the contract, a new material with better strength characteristics than AISI 4340 was sought. An 18% Nickel 300 series Maraging Steel was chosen because it exhibits high strength and good toughness. The maraging steel requires simple heat treatment, is machiable, weldable, and exhibits low distortion and low dimensional change after heat treatment. The tent stake driver was designed for a stress of 236,000 psi in tension and 133,000 psi in shear. No major configuration changes were made to the former design other than a reduction of the wall thicknesses previously required for the stake driver made of AISI 4340 steel.

After determining the energy level present it was concluded that the latch mechanism designed to attach the stake driver to the M16A1 Rifle was inadequate. The initially proposed latch consisted of four levers which cammed down into the grooves on the M16A1 Rifle's muzzle device when the collar was threaded rearward. When the collar was threaded forward, the levers disengaged and allowed the stake driver to be removed from the weapon.

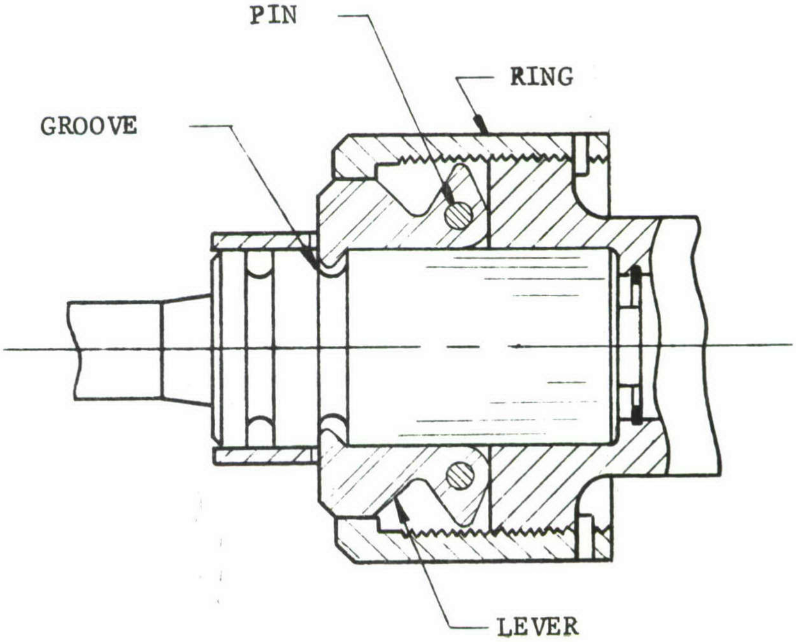


Figure 9. Initial Barrel Latch Attachment Lever Design

After stressing the lever pivot pins, it was determined that the pins would fail in shear if the device was fired without a stake in place.

A split collet design was chosen to facilitate latching the stake driver to the weapon. The rifle muzzle is inserted into the stake driver and the collet halves are squeezed closed until the collet snaps completely closed. The collar is then threaded rearward over the collet until it reaches a stop.

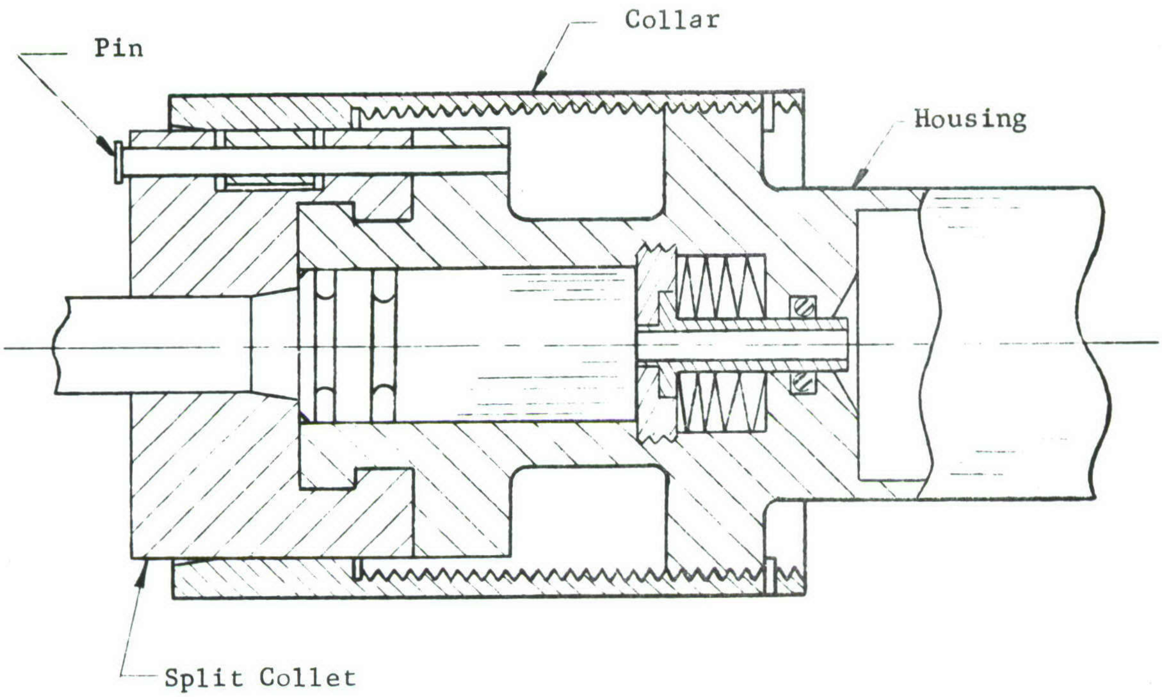


Figure 10. Final Barrel Latch Attachment - Split Collet Design

The new latch design is such that loads imposed when fired without a stake in place are taken in both shear and tension by the latch. The latch is designed such that it will bottom on the taper of the rifle barrel when the device is fired, thus reducing any stress levels incurred on the thread stock of the rifle barrel.

While awaiting the completion of the first prototype, the three stakes specified in the contract for use with the stake driver were tested with the stake driver mock-up device against a sand mixture completely saturated with water and conditioned at -65°F for a minimum of twelve hours. The piston used in the mock-up weighed one pound and had a free stroke of three inches. The total stroke of the piston in the mock-up was not limited and no piston return mechanism was attached.

TABLE I. DETERMINATION OF MAXIMUM PENETRATION ATTAINABLE USING CONTRACT SPECIFIED STAKES AGAINST A SOIL SAMPLE CONDITIONED AT -65°F

Stake Type	Number of Hits	Penetration
Standard Metal Tent Stake	2	1.75 inches
Standard Metal Tent Stake	2	1.66 inches
Standard Metal Tent Stake	2	.87 inches
Arctic Tent Pin	1	Broke at Weld
Arctic Tent Pin	4	.687 inches
10-in. Engineer's Spike	4	2.12 inches

The three standard metal tent stakes bent badly on the third hit, making further penetration impossible. When driving the two arctic tent pins, the first broke at the weld after the first hit. The second arctic tent pin was hit four times and penetrated .687 inches into the sample, but the stake gouged out the soil and fell over after the stake driver mock-up was removed. The 10-inch engineer spike that was tested, penetrated 2.12 inches after three hits. On the fourth hit, the engineer spike bent badly and further penetration was impossible.

A follow-up series of tests were conducted to determine the penetration capabilities of the same stakes against a sand mixture saturated with water and conditioned at 0°F for a minimum of twelve hours. Again, the stake driver mock-up was used with a one-pound piston with a three-inch free stroke.

TABLE II. DETERMINATION OF MAXIMUM PENETRATION ATTAINABLE USING CONTRACT SPECIFIED STAKES AGAINST A SOIL SAMPLE CONDITIONED AT 0^{o}F.

Stake Type	Number of Hits	Penetration
Standard Metal Tent Stake	3	2.0 inches
Arctic Tent Pin	8	1.4 inches
Arctic Tent Pin	1	Broke at Weld
10-in. Engineer Spike	5	3.2 inches

All of the stakes tested against the medium sample conditioned at 0^{o}F failed to penetrate to a desired depth of 5.0 inches. The need for a stronger stake for use with the stake driver was demonstrated.

Six alternate stake designs were investigated for use with the prototype stake driver. All of the prototype stakes were tested with the stake driver mock-up against a sand mixture completely saturated with water and conditioned at 0^{o}F for a minimum of twelve hours. Three of the stake designs were a hollow-tube design; the first being an existing stake, the Ice Piton (FSN8465-240-2974). The second was a stake made from 1.0 inch O.D. steel tube with a .063 inch wall thickness capped at one end and tapered 60^{o} at the other. The third stake was AISI 1015 steel tube with a .625 inch O.D. and .065 inch wall thickness. The third stake was capped at one end and squared off at the other with a .031 x 45^{o} inch inside chamfer. Two stakes were made such that a cruciform stake configuration could be evaluated. The first cruciform stake was made of AISI 1018 steel and the other was made of AISI 4130 steel. A final stake configuration tested was made of .5 inch diameter drill rod, which resembled the 10-inch Engineer Spike specified in the contract. (See Appendix C: Experimental Stake Design).

Table III summarizes the penetrations achieved with the six experimental stakes. Both the drill rod and the 1.0-inch O.D. steel tube failed to penetrate appreciably and testing was stopped.

TABLE III. PENETRATIONS ATTAINED WITH EXPERIMENTAL STAKES AGAINST SOIL SAMPLE CONDITIONED AT $0^{o}F$

Stake Type	Number of Hits	Penetration
Ice Piton, 0.625 dia.	7	4.18 inches
AISI 1015 Steel Tube, 0.625 dia.	7	3.75 inches
AISI 1018 Cruciform	6	3.50 inches
AISI 4130 Cruciform	9	3.37 inches
.5 in. O.D. Drill Rod	5	2.80 inches
1.0 in. O.D. Steel Tube	2	2.0 inches

All the stakes tested against the medium sample conditioned at $0^{o}F$ again failed to penetrate to a depth of 5.0 inches. The Ice Piton along with the .625 inch O.D. AISI 1015 steel tube exhibited sufficient column strength necessary to withstand the impact of the piston when attempting to break the shear force of the medium. The tubular stakes provide sufficient column strength without presenting a large surface area against the medium being penetrated. Also, the reduced mass of the stake allows for greater stake velocity after impact by the piston when being driven against the soil sample. The Ice Piton was established as the control stake throughout the development of the prototype stake driver since it exists as part of the Military's inventory.

The prototypes were manufactured and operational tests were initiated using the Ice Piton as the tent stake and medium samples conditioned at $-65^{o}F$. After evaluating the initial results it became apparent that the device was not driving the stakes to a desired depth utilizing an optimum number of shots. It was concluded that an excess amount of gas was ported to the outer chamber, thus producing too great a buffing action. This prevented the piston from imparting optimum energy to the stake being driven into the sample.

The check valve retainer proved to be the likely area to restrict the gas ported to the outer chamber while maintaining maximum pressure behind the piston. The orifice of the check valve retainer was reduced to .031-inch diameter or a reduction in orifice area to 1.47% of the original. The modified piston was tested using the Ice Piton against a soil sample prepared at $-65^{o}F$. On the first shot the piston bottomed severely against the buffering ring, breaking off the piston's sealing flange. The .031-inch diameter orifice did not provide an effective enough buffering of the piston's stroke. After determining the cause of the piston failure, the velocity measurement from the stake driver mock-up and the computer model of stake driver's working cycle were again evaluated. The piston stroke was reduced to 2.5 inches total stroke from the originally designed total stroke of 3.8 inches. A heavier piston (1.53 pounds) was also introduced during d development to help reduce the velocity present before impacting the stake. The slower moving piston would reduce the danger of destroying the piston's sealing flange when bottoming and also would reduce the likelihood of bending the stake when attempting to break the shear force of the medium.

The check valve retainer orifice was reduced a second time to .144-inch diameter, or a reduction in the orifice's area to 33% of the original orifice area. The heavier piston was tested and compared to the original piston. Although the final results were not conclusive, it was observed that the heavier piston exhibited a faster rate of penetration during the first five hits.

The orifice size was again reduced to provide more gas behind the piston, lending more energy to the piston. The orifice diameter was reduced to .093-inch diameter, or the area of the orifice was reduced to 13% of the original orifice area. At this time it was noted that the weapon started to recycle when fired with the stake driver attached.

In an effort to encourage recylcing of the weapon, the orifice diameter was reduced to .063-inch diameter or 6% of the originally designed orifice area. This orifice diameter represented the smallest orifice diameter tested in the mock-up. The weapon had partial extraction, but would not completely extract the spent cartridge case. Reduction in orifice diameter was stopped at .063-inch diameter because of the Project Delivery Schedule.

Table IV summarizes the penetration attained using the prototype stake driver and Ice Piton.

Table IV summarizes the penetration attained using the prototype stake driver and Ice Piton.

TABLE IV. STAKE EMPLACEMENT RESULTS ATTAINED DURING DEVELOPMENT OF THE ARCTIC TEST STAKE DRIVER

Soil Temperature (°F)	Piston Weight (lbs)	Check Valve Orifice Diameter (inches)	Number Of Hits	Penetration (inches)
-65	1.13	.144	6	2.5
-65	1.53	.144	7	2.7
0	1.13	.144	13	2.5
0	1.53	.144	10	6.3
0	1.13	.144	14	5.3
0	1.53	.144	14	4.4
0	1.13	.144	10	4.0
0	1.53	.144	12	4.5
-10	1.53	.144	7	2.7
-10	1.53	.093	14	4.2
-10	1.53	.063	8	3.7
-65	1.53	.063	12	7.2
-65	1.53	.063	12	4.0
-65	1.56	.063	6	4.2

During all the operational tests, the piston failed to recycle. It was concluded that the porting of the gases to the outer chamber provided an effective buffer, but was unable to return the piston to its rearward position. It was determined that a mechanical return mechanism was required to return the piston to its original position. A spring powered linkage system consisting of a pivoting yoke which interfaces the piston, a spring and guide rod combination, and a supporting bracket for the whole assembly was added to the stake driver unit.

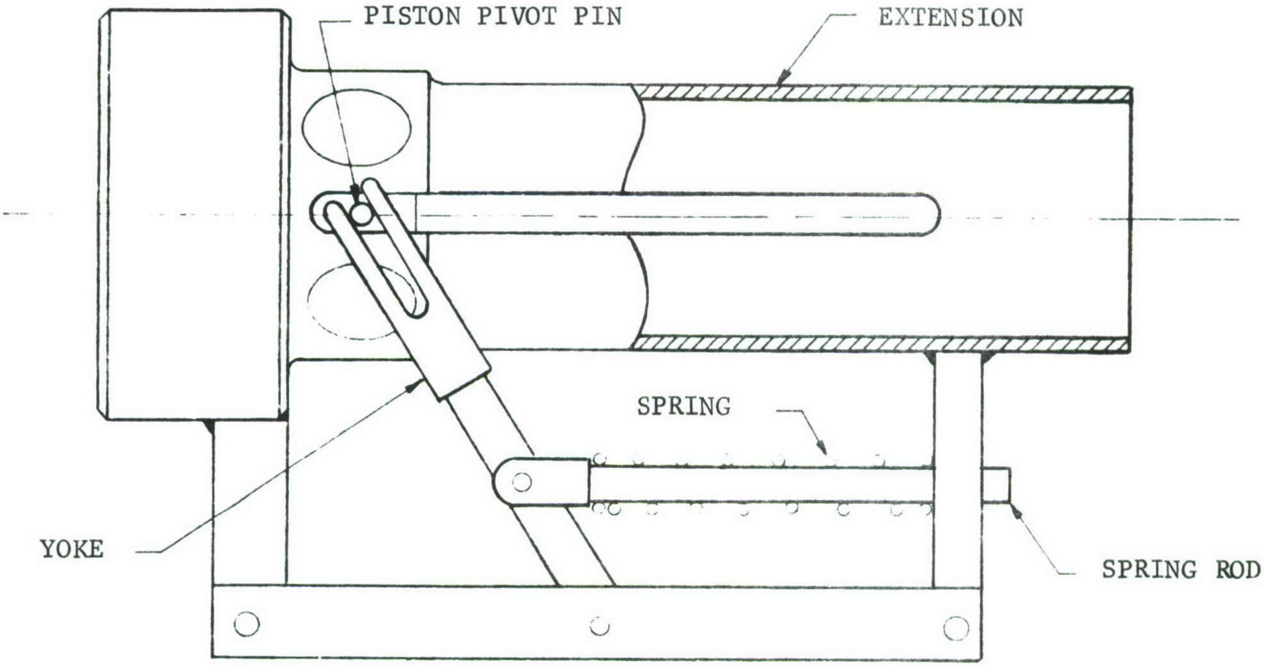


Figure 11. Piston Return Mechanism

After the addition of the spring-return mechanism, the prototype stake driver unit was submitted to an abbreviated series of timed operational tests. At this point, the prototype reflected a final design, the piston's total stroke was reduced to 2.5 inches and the piston's weight was increased to 1.53 pounds.

RESULTS

A. Penetration Results Using The Ice Piton

The Arctic Tent Stake Driver was used with the Ice Piton against a soil sample of Ottawa Quartz sand saturated with water 90% by weight and conditioned at -65°F for a minimum of twelve hours. The subject personnel conducting the operational tests was six feet, two inches tall and weighed 200 pounds.

The following table summarizes the results of the operational testing of the Arctic Tent Stake Driver.

TABLE V. STAKE EMPLACEMENT RESULTS ATTAINED DURING OPERATIONAL EVALUATION OF THE ARCTIC TENT STAKE DRIVER WITH ICE PITON

Test No.	No. of Hits	Penetration (inches)	Elapsed Time (seconds)
1	5	6.4	30
2	5	6.0	30
3	6	3.75	35
4	5	6.5	30
5	8	5.3	40
6	4	4.1	30

All stakes tested were new and unused except for Stake No. 3 which had been driven into a conditioned sample previously. During testing, operation of the stake driver ceased after the stake failed to penetrate appreciably with the succeeding shot. Test Stake No. 3 was examined after the sample was allowed to thaw, and found to have split and peeled back, thus hindering penetration. Splitting of the Ice Piton had been experienced in earlier tests, each time the split stake had been used in previous penetration tests. Due to the smallness of the sample size (five test results-excluding test No. 3), a statistical analysis relating penetration attained by the stake to the number of hits imparted by the Arctic Tent Stake Driver was impractical. It was noted that the mean penetration attained with five hits was 6.3 inches, and the standard deviation was .187 inches based on three tests. When examining the results of Test No. 5, better penetration would be expected due to the increased number of hits, but contrary results were experienced.

During testing, the weapon required hand cycling while the piston return mechanism performed satisfactorily. Only once did the operator experience difficulty hand cycling the weapon. This difficulty was attributed to the blank swelling in the weapon's chamber.

It was observed on the first shot that the recoil forced the stake driver to disengage with the stake being driven. No further problem of the stake driver disengaging the stake occurred after the first impact. Recoil of the weapon was not considered overpowering.

B. Determination of Expected Ice Piton Penetration

Knowing the velocity of the stake driver's piston prior to impact with the Ice Piton, (Appendix A: Interior Ballistic Velocity Determination of the Arctic Tent Stake Driver) an expected penetration resulting from each hit was determined. The following penetrations were based on the assumption that refreezing occurs around the presented surface area of the Ice Piton between succeeding shots of the stake driver. It was assumed that a shear force, S_s, of 1000 psi would act on the surface area of the stake.

Piston velocity = 54.906 fps

Piston weight = 1.53 lbs.

Stake weight = .37 lbs.

The velocity of the stake resulting from impact by the piston was determined using equation 2.1;

2.1 $$MV_1 + mv_1 = MV_2 + mv_2$$

where V_1 = velocity of piston (M) before impact

V_2 = velocity of piston (M) after impact

v_1 = velocity of stake (m) before impact

v_2 = velocity of stake (m) after impact

$$MV_1 + mv_1 = MV_2 + mv_2$$

$$v_1 = 0$$

$$MV_1 = MV_2 + mv_2$$

$$mv_2 = MV_1 - MV_2$$

$$v_2 = \frac{M}{m} (V_1 - V_2)$$

Assuming an inelastic collision, and an energy loss, the coefficient of restitution, e, for steel was used to relate the velocity of separation $v_2 - V_2$ to the velocity of approach $V_1 - v_1$.

2.2 $$e = \frac{v_2 - V_2}{V_1 - v_1}$$

where:

$$e = .6$$

$$v_1 = 0$$

$$.6 = \frac{v_2 - V_2}{V_1}$$

$$V_2 = v_2 - .6V_1$$

substituting back to equation 2.1:

$$v_2 = \frac{M}{m}[V_1 - (v_2 - .6V_1)]$$

and solving for the velocity of the stake v_2;

$$v_2 = 4.056\ [54.906 - (v_2 - 32.95)]$$

$$v_2 = 4.056\ [87.856 - v_2]$$

$$v_2 = 356.344 - 4.056v_2$$

$$v_2 = 70.48 \text{ fps}$$

The energy of stake penetrating the permafrost was determined using equation 2.3;

2.3 $$E = 1/2\ mv^2$$

$$E = 1/2(.01149)(70.48)^2$$

$$E = 28.54 \text{ ft-lbs}$$

$$E = 342.48 \text{ in-lbs}$$

Penetration for each shot of the stake driver was determined using equation 2.4;

$$2.4 \qquad E = Fd_i$$

where E = energy of stake

F = force required to shear permafrost

d_i = depth penetrated

using equation 2.5

$$2.5 \qquad F = S_s\ A_s$$

where S_s = 1000 psi - shear force exerted on stake by permafrost

$A_s = 1.96\ d_i$ = shear area

and substituting into equation 2.4;

$$E = S_s A_s d_i$$

and solving for penetration d_i,

<u>1st Shot</u>

$$E = (1000)(1.96\ d_1)d_1$$

$$E = (1960\ d_1^2)$$

using E = 342.48 in-lbs

d_1 = .418 inch

To find the penetrations attained with each succeeding shot, equation 2.6 was applied;

$$2.6 \qquad E = F_{di} + S_s A_s\ s$$

where $A_s = 1.96 \sum d_i$ = shear area presented to permafrost

s = .025 inches = increment of movement to break free of permafrost

2nd Shot

$$E = Fd_2 + S_s A_s s$$

$$342.48 = 1960\, d_2^2 + 1000\, [(1.96)(.418)]\, (.025)$$

$$342.48 = 1960\, d_2^2 + 20.48$$

$$d_2 = .405 \text{ inch}$$

34d Shot

$$d_3 = .393 \text{ inch}$$

4th Shot

$$d_4 = .384 \text{ inch}$$

5th Shot

$$d_5 = .367 \text{ inch}$$

6th Shot

$$d_6 = .354 \text{ inch}$$

7th Shot

$$d_7 = .342 \text{ inch}$$

8th Shot

$$d_8 = .329 \text{ inch}$$

9th Shot

$$d_9 = .316 \text{ inch}$$

10th Shot

$$d_{10} = .304 \text{ inch}$$

The total penetration anticipated using the Ice Piton, assuming that the permafrost presents a shear force of S_s, 1000 psi was 3.194 inches after ten hits. It is noted that the prototype stake driver exceeded the expected penetrations. Test results contrary to the expected penetrations indicate that the medium samples were not representative of the shear force, S_s, 1000 psi used in the calculation of sequential penetration.

APPENDIX A

INTERIOR BALLISTIC VELOCITY DETERMINATION OF THE ARCTIC TENT STAKE DRIVER

The method of Interior Ballistic Velocity Detemination was used to determine the piston velocity just before impact with the stake. The stake driver mock-up (Figure 8, page 12) was used to record a pressure vs. time curve for a 1.53 pound slug moving inside the simulated stake driver housing. The stroke of 1.53 pound slug was not limited, and the pressure vs. time curve provided a means to determine the simulated piston's velocity after a piston displacement of 1.5 inches. The piston's velocity was determined to be 54.906 fps for a piston displacement of 1.483 inches.

Using equation 1.1;

1.1 $$F_i = \overline{P}_i \times A$$

where $\overline{P}_i$ = average pressure measured directly from pressure vs. time curve over Δt_i

A = surface area presented to the expanding gas

the force, F, acting on the piston for time increment Δt_i is calculated.

Substituting the calculated force, F, acting on the piston and the known mass, m, of the piston into equation 1.2;

1.2 $$F_i = ma_i$$

the acceleration, a_i, for the piston during the time increment, Δt_i, is determined. The velocity Δv_i for the time, Δt_i is calculated using equation 1.3;

1.3 $$\Delta v_i = a_i \Delta t_i$$

and the piston displacement, Δx_i, for time, Δt_i, is determined using equation 1.4;

1.4 $$\Delta x_i = v_i \Delta t_i$$

The force, F_i, acting on the piston for each succeeding Δt_i, is determined using equation 1.1, and the acceleration, a_i, during the time Δt_i is found using equation 1.2. The velocity, Δv_i, and displacement, Δx_i, for each succeeding Δt_i is found using equations 1.3 and 1.4, respectively.

At any time, t, the velocity, v, and displacement x can be determined by equations 1.5 and 1.6, respectively.

1.5 $v = \sum \Delta v_i$ at time t

1.6 $x = \sum \Delta x_i$ at time t

The following table summarizes the method of Interior Ballistic Velocity Determination.

$A = 1.756 \text{ in}^2$

$\Delta t_i = .0001 \text{ sec}$

$m = .0466 \text{ slugs}$

t (sec)	P (psi)	F (lbs)	a (ft/sec^2)	Δv (ft/sec)	v (ft/sec)	Δx (in)	x (in)
.0001							
	468	822	17639	1.764		.00211	
.0002					1.764		.00211
	736	1292	27725	2.770		.00544	
.0003					4.534		.00755
	888	1559	33454	3.345		.00945	
.0004					7.879		.01730
	1080	1896	40686	4.069		.01400	
.0005					11.950		.03130
	1016	2673	57360	5.736		.02120	
.0006					17.700		.05250
	934	1640	35193	3.520		.02540	
.0007					21.220		.07790
	876	1538	33004	3.300		.02940	
.0008					24.520		.10730
	818	1436	30815	3.082		.03300	
.0009					27.600		.14030
	746	1310	28111	2.811		.03640	
.0010					30.410		.17670
	654	1148	24635	2.460		.03940	
.0011					32.87		.21610
	584	1025	21995	2.200		.04210	
.0012					35.07		.25820
	527	925	19850	1.985		.04440	
.0013					37.055		.30260
	467	820	17596	1.759		.04660	
.0014					37.814		.34920
	426	748	16051	1.605		.04850	
.0015					39.419		.39770
	391	686	14721	1.470		.05020	
.0016					40.889		.44790
	380	667	14319	1.430		.05190	
.0017					42.319		.49980
	351	616	13226	1.322		.05350	
.0018					43.641		.55330
	322	565	12134	1.213		.05500	
.0019					44.854		.60830
	292	513	11003	1.100		.05630	
.0020					45.954		.66460
	274	481	10325	1.033		.05800	
.0021					46.987		.72260
	240	421	9044	.904		.05900	
.0022					47.891		.78160
	234	411	8818	.822		.05900	
.0023					48.713		.84060
	211	371	7961	.796		.06100	
.0024					49.509		.90160
	205	360	7725	.773		.06200	
.0025					50.282		.96360
	187	328	7046	.705		.06200	
.0026					50.987		1.02560
	176	309	6632	.663		.06300	
.0027					51.650		1.08860
	164	288	6180	.618		.06400	
.0028					52.268		1.15260
	152	267	5728	.573		.06500	
.0029					52.841		1.21760
	146	256	5502	.550		.06530	
.0030					53.391		1.28290
	140	246	5276	.528		.06600	
.0031					53.919		1.34890
	134	235	5049	.505		.06700	
.0032					54.424		1.41590
	128	225	4823	.482		.06710	
.0033					54.906		1.48300
	123	216	4635	.464		.06800	
.0034					55.370		1.55100

The following graph illustrates the operation of the stake driver's piston prior to contact with the stake. The graph relates both the piston's velocity and the piston's displacement to the pressure presented inside the simulated piston housing.

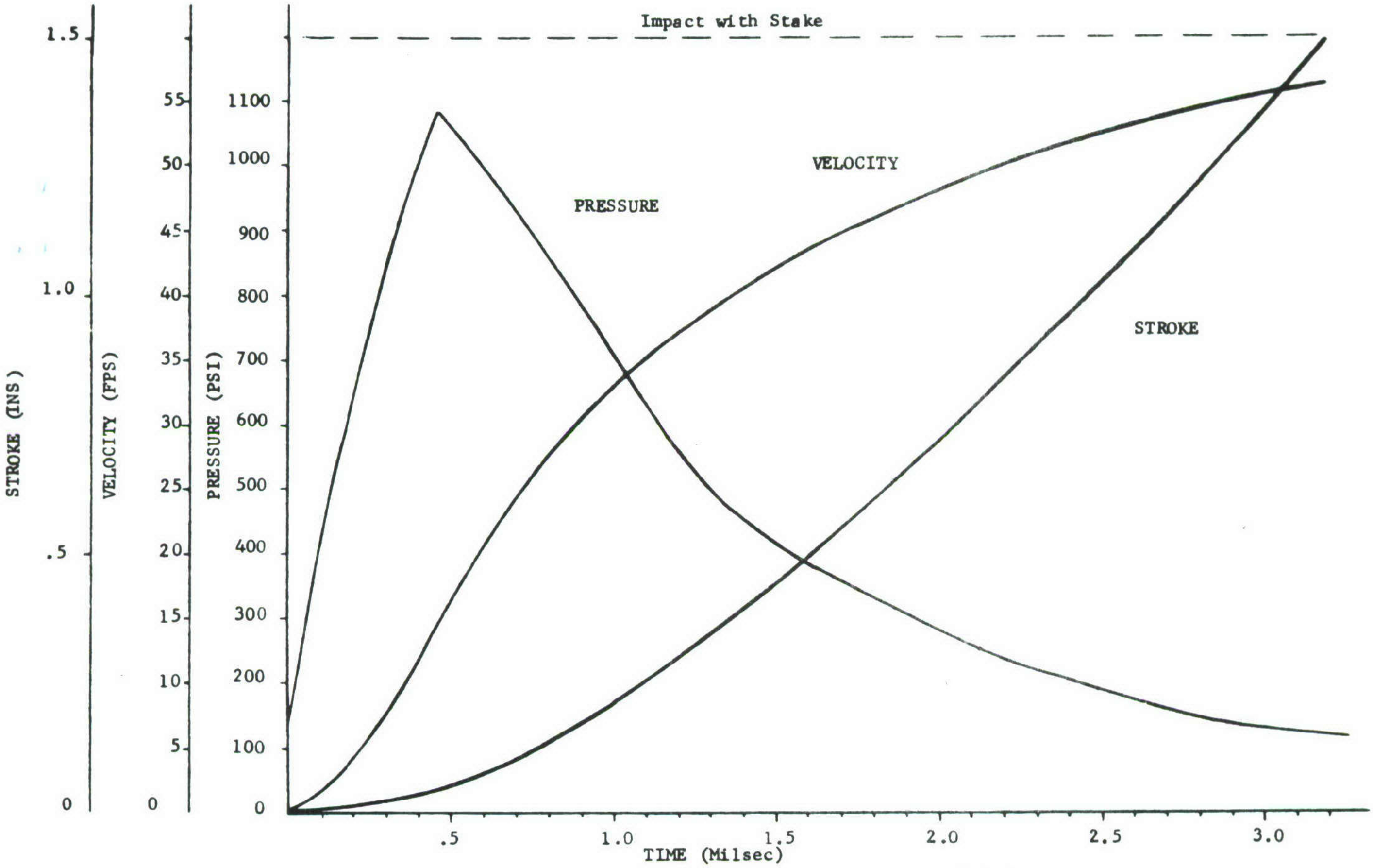


FIGURE A-1: ONE DIMENSIONAL REPRESENTATION OF PISTON PRIOR TO IMPACT WITH STAKE

APPENDIX B

PREPARATION OF SOIL SAMPLES

With the cooperation of personnel from the Cold Regions Research and Engineering Laboratory, Hanover, N.H., a representative sample of arctic soil conditions was established. Ottawa Quartz Sand (Ref: ASTM C-109) saturated 90% by weight with water was chosen as the test medium against which the stake driver's capabilities were evaluated.

The soil samples were prepared in insulated buckets measuring 10.5 inches diameter and 9.625 inches deep. The buckets were attached to a pedestal to facilitate effective insulation of the bucket and to provide a strengthened base to protect the buckets from damage due to the impact energy imparted by the stake driver. (Figure A-1).

The buckets were insulated with foam plastic around the diameter and base with the top exposed to induce freezing from the top of the sample. As the medium freezes the water in the sample begins to freeze and expand, pushing the unfrozen water into unfrozen areas of the sample. To maintain a homogeneous mixture, excess water was allowed to drain out of the sample during freezing. Freezing of the soil samples in this manner prevented a core of ice concentration in the center of the sample.

The insulation around the sample bucket provided a useable medium for approximately thirty minutes of testing before melting to any significant degree occurred.

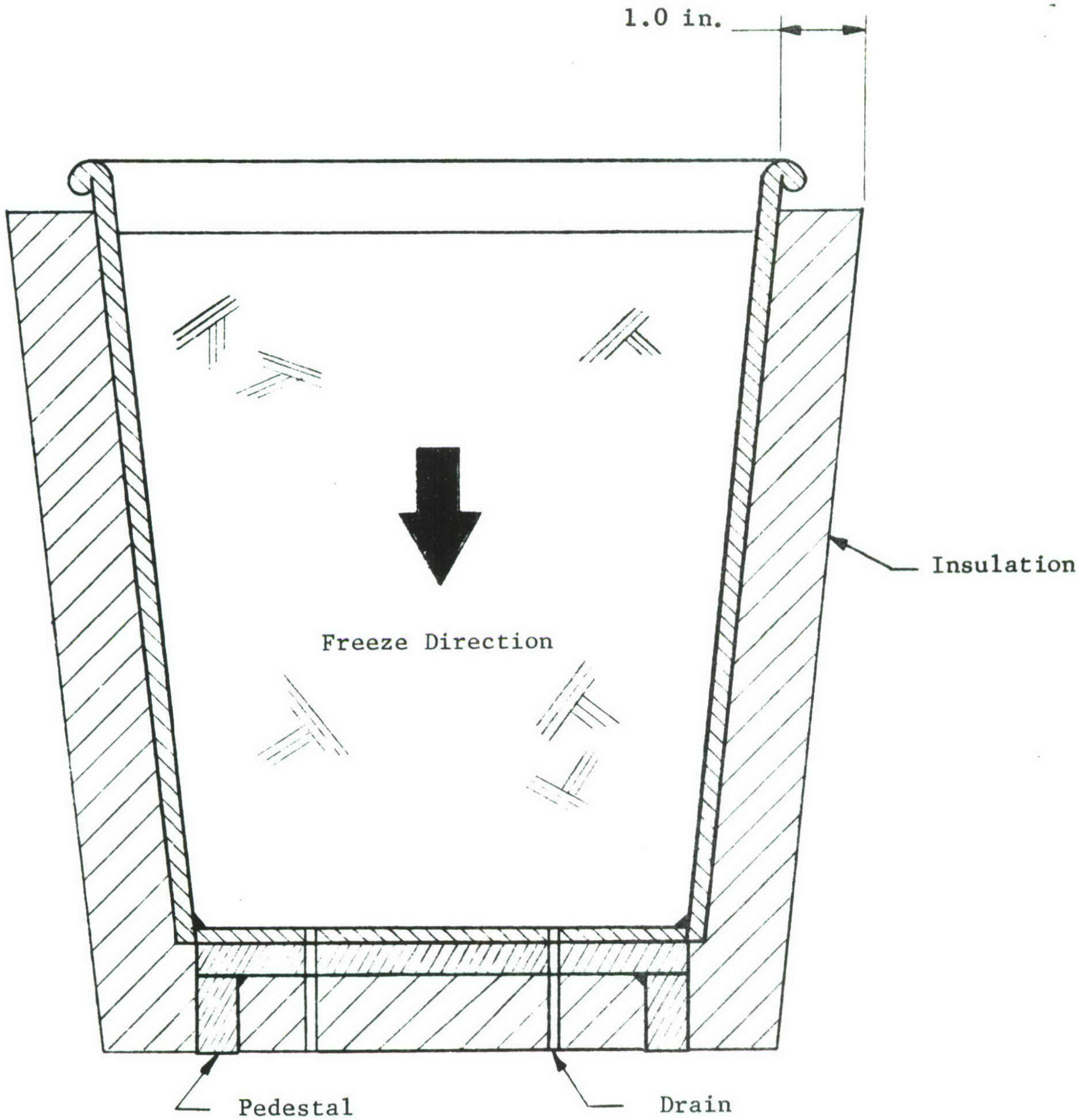


FIGURE A1 - SOIL SAMPLE BUCKET

APPENDIX C

EXPERIMENTAL STAKE DESIGN

Five experimental stake designs were investigated for use with the prototype stake driver. These prototype stakes were tested against a sand mixture completely saturated with water and conditioned at $0^{o}F$ for a minimum of twelve hours. The five experimental stakes were of three distinct configurations, hollow tube, solid rod and cruciform. The AISI 1015 Steel Tube, .625-inch diameter performed better than the other prototype stakes tested. However, an existing stake, the .625-inch diameter Ice Piton experienced a 11.4% increase in penetration over the AISI 1015 Steel Tube. The tubular Ice Piton was established as the control stake for operational tests.

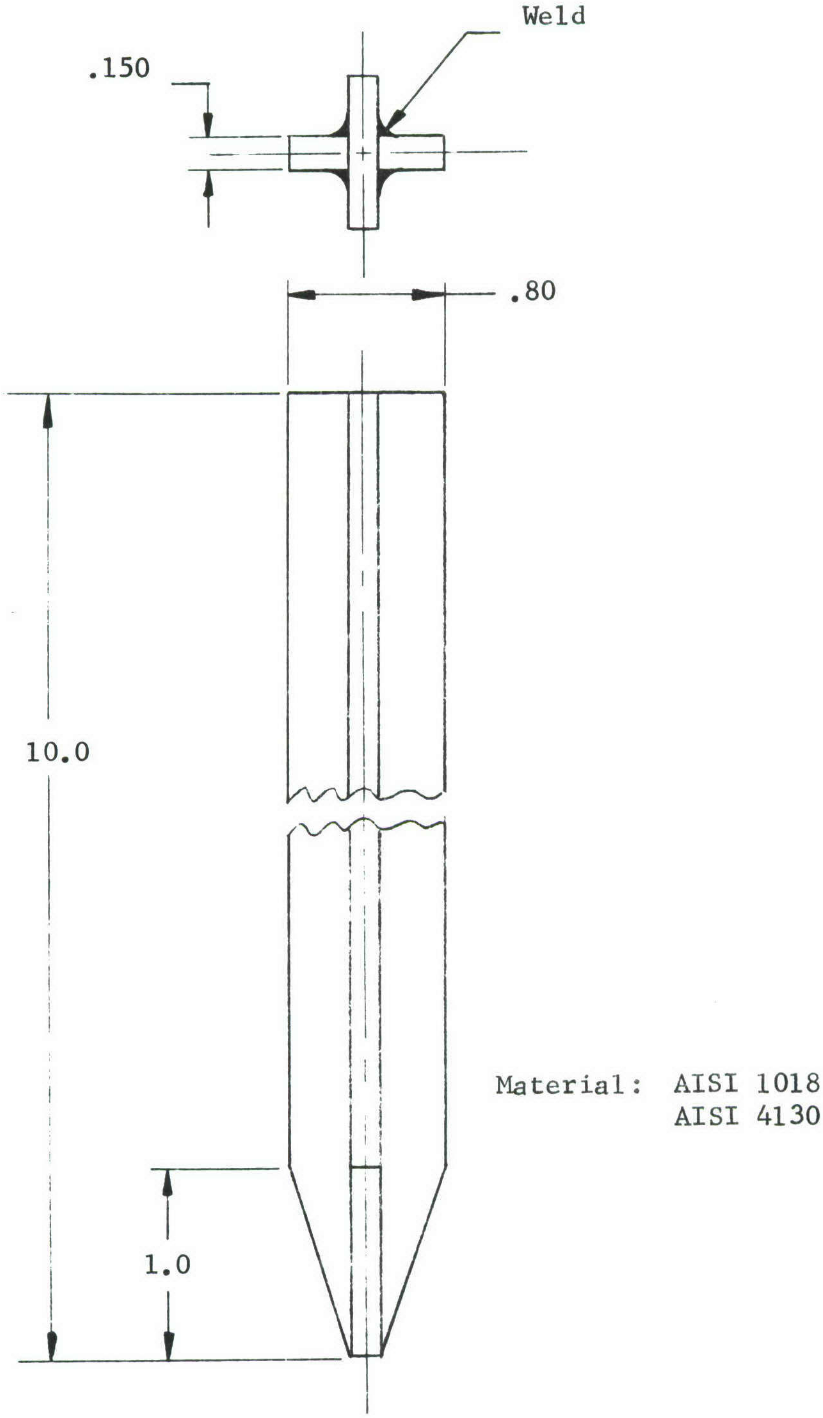


FIGURE C-1. CRUCIFORM STAKE

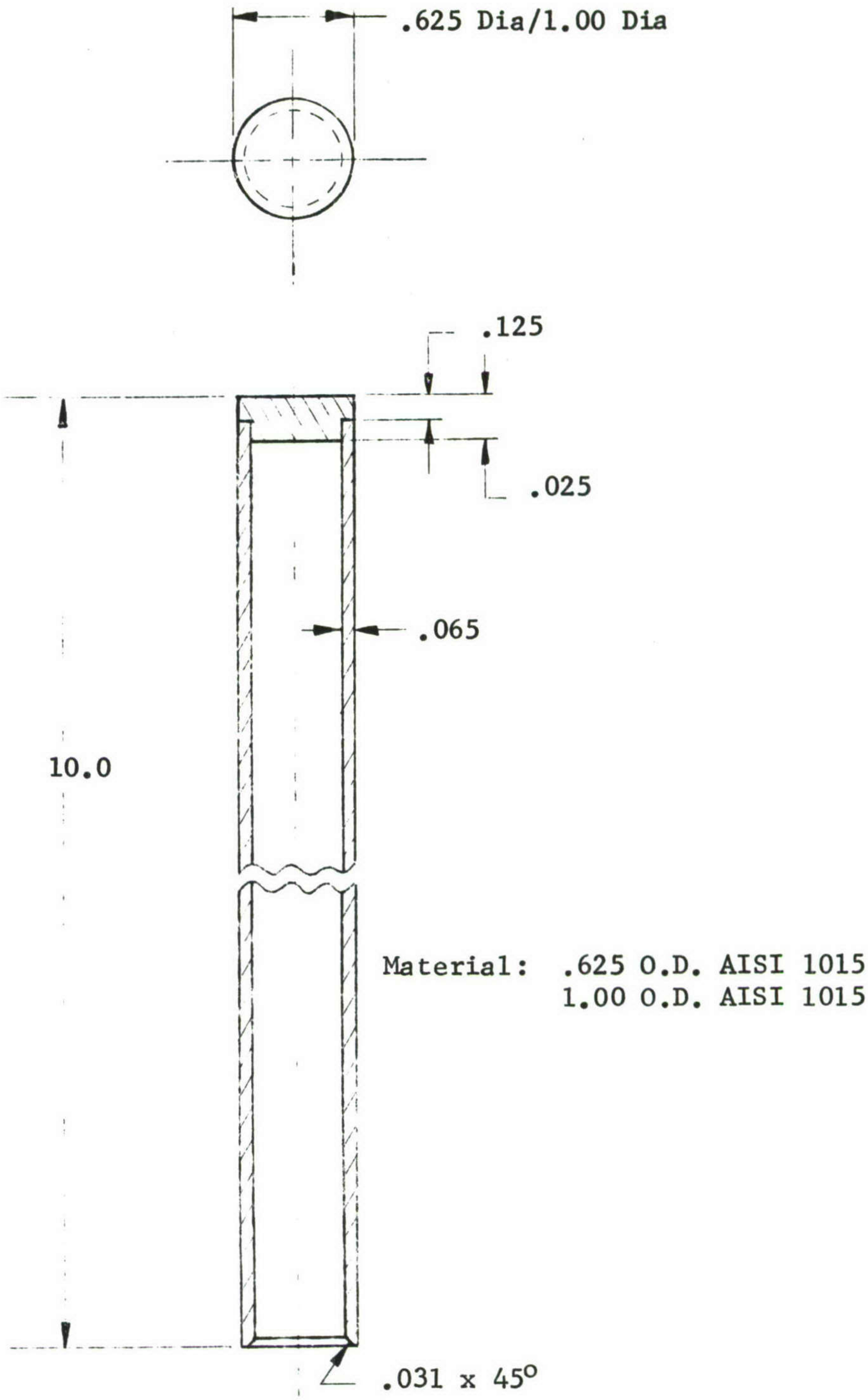


FIGURE C-2. TUBULAR STAKE

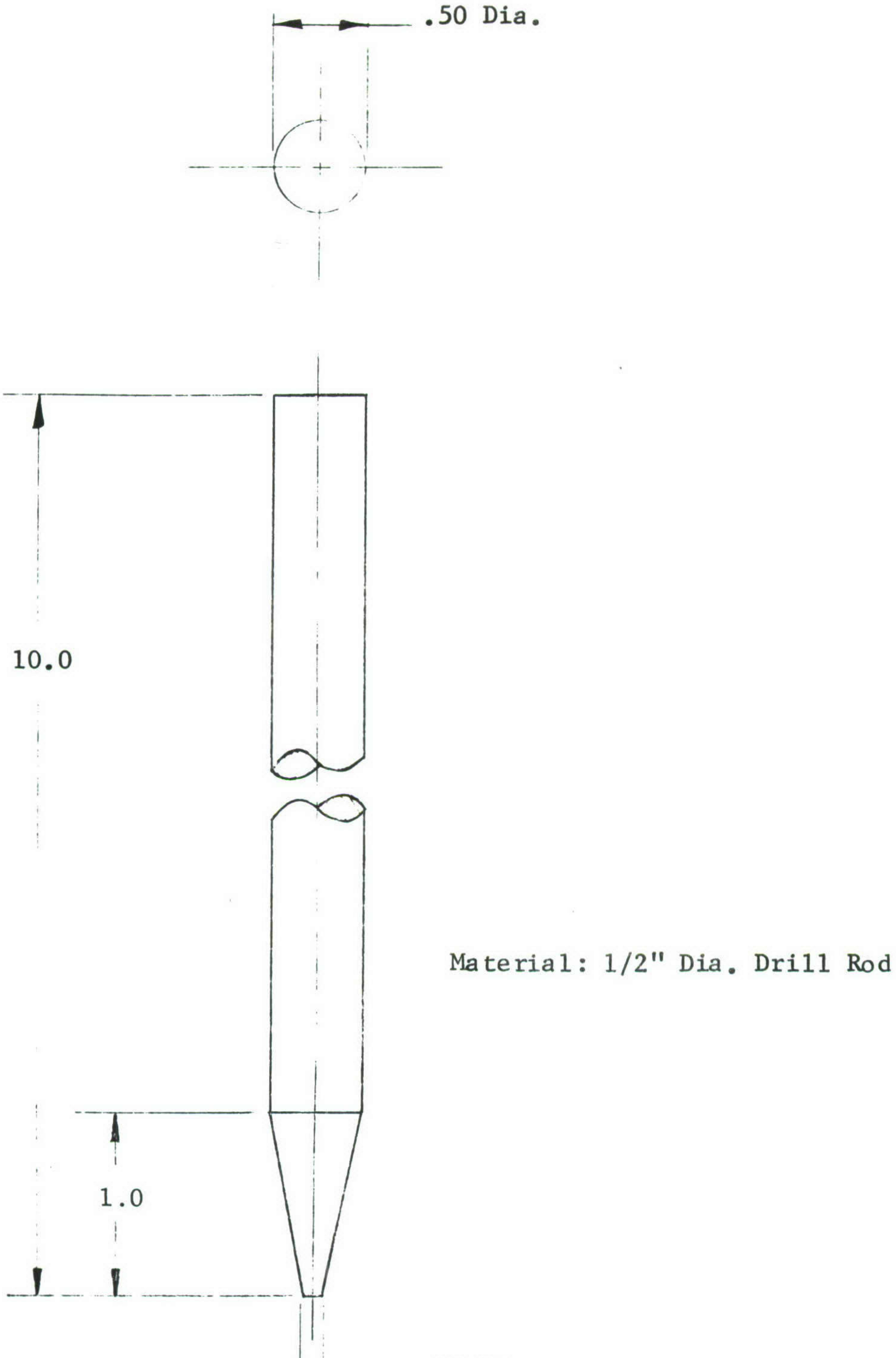


FIGURE C-3. EXPERIMENTAL SPIKE

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Arctic Tent Stake Driver
Ice Piton
Experimental Stake Design
Penetration Results
Expected Ice Piton Penetration

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Arctic Tent Stake Driver developed under this program provides the capability of driving stakes into frozen arctic terrain without the great expenditure of effort normally required for stake implanting using a hammer. The device is attached to the muzzle of the M16 rifle and is powered by the standard 5.56MM blank cartridge which can be magazine-fed into the rifle. When fired, the gases drive a piston which delivers a blow to the stake. In simulated operation against 90% saturated, frozen Ottawa quartz sand at -65°F

the average penetration experienced with five (5) firings was 6.3 inches with the Ice Piton.

The device may be utilized by an operator wearing arctic mittens and it has the capability of being attached to the rifle or removed in less than two minutes.

Although most design goals were met, further effort would be required to achieve the goals of simplicity, low weight, and semi-automatic rifle functioning.

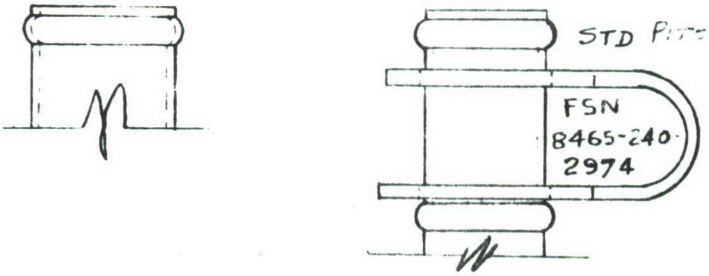
ANNEX B

PRELIMINARY STAKE DESIGNS

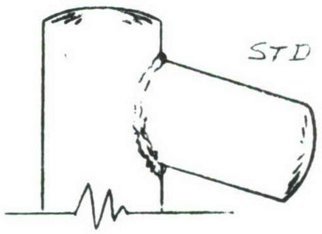
ARCTIC TENT STAKE

TYPES OF HEADS TESTED

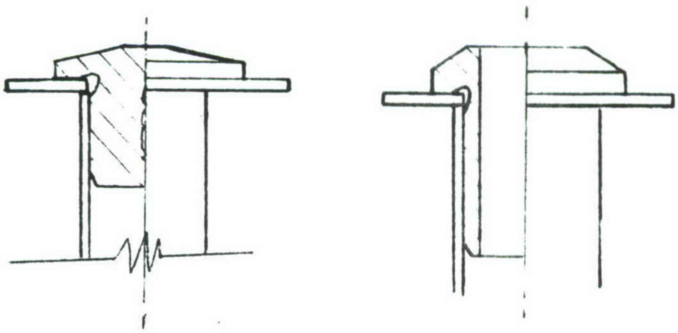
BEADED, TUBE



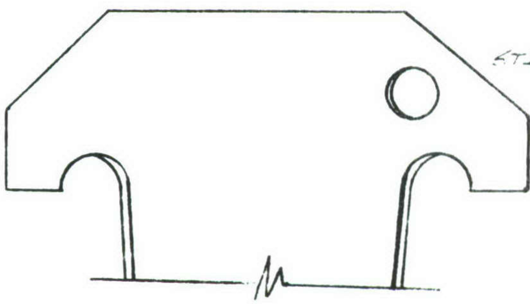
WELDED ROD



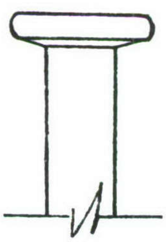
UNDERCUT
SLOPED HD.



INTEGRAL,
SHEET AL.

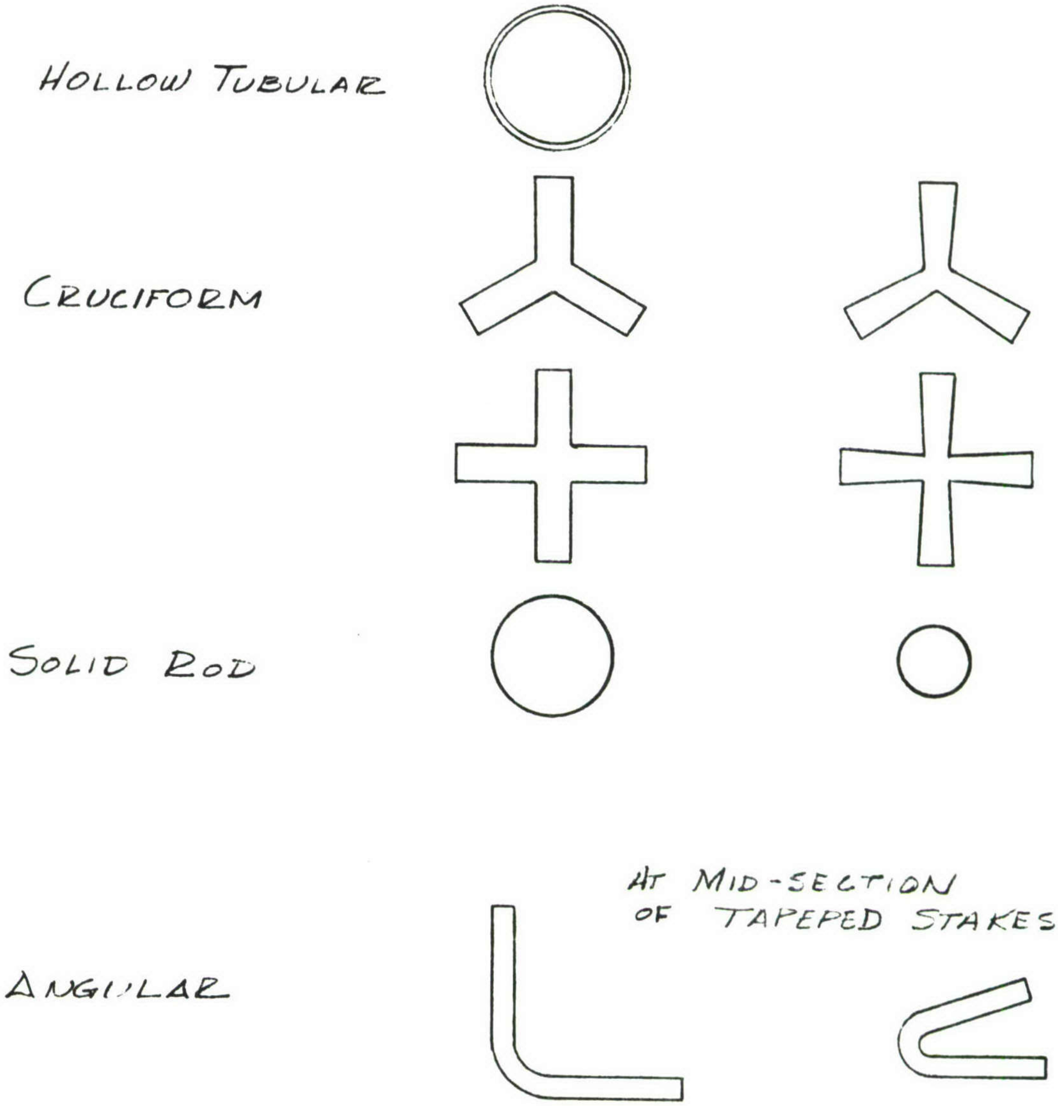


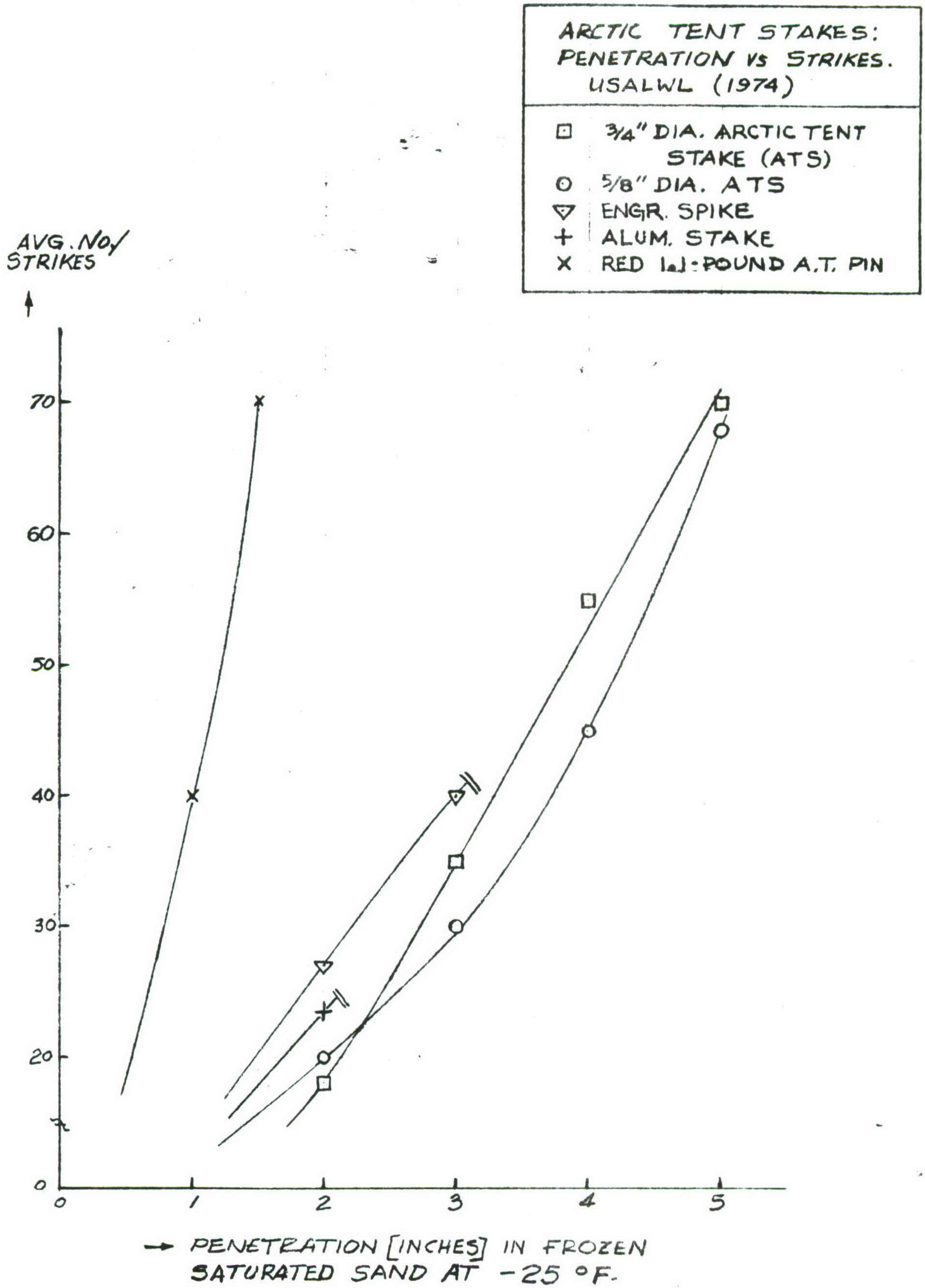
UPSET



Arctic Tent Stake

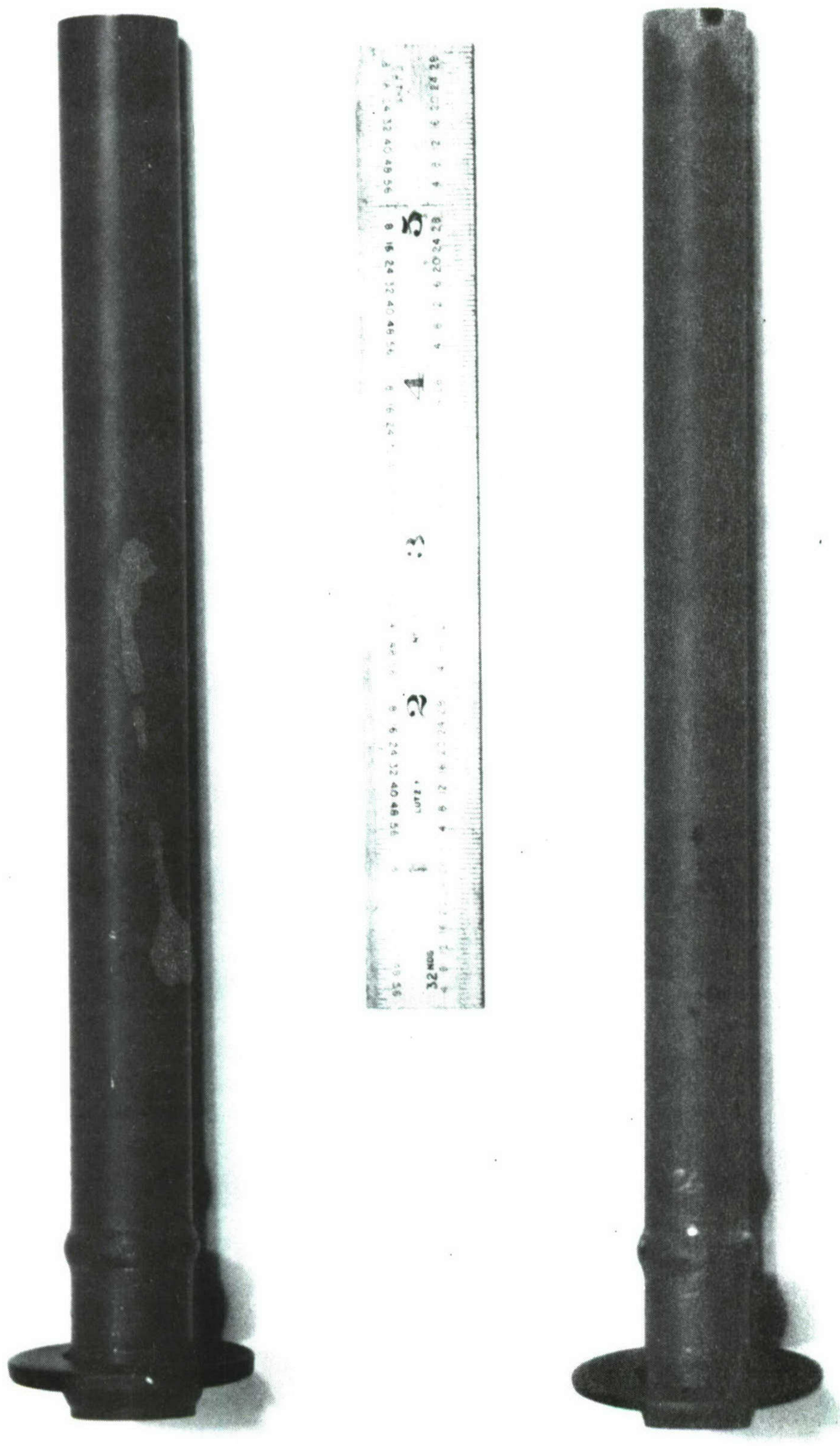
Cross Sections of Stakes




ARCTIC TENT STAKES:
PENETRATION VS STRIKES.
USALWL (1974)
3/4" DIA. ARCTIC TENT STAKE (ATS)
5/8" DIA. ATS
ENGR. SPIKE
ALUM. STAKE
RED 1.1-POUND A.T. PIN
AVG. NO/ STRIKES
70
60
50
40
30
20
0
0
1
2
3
4
5
PENETRATION [INCHES] IN FROZEN SATURATED SAND AT -25 °F.

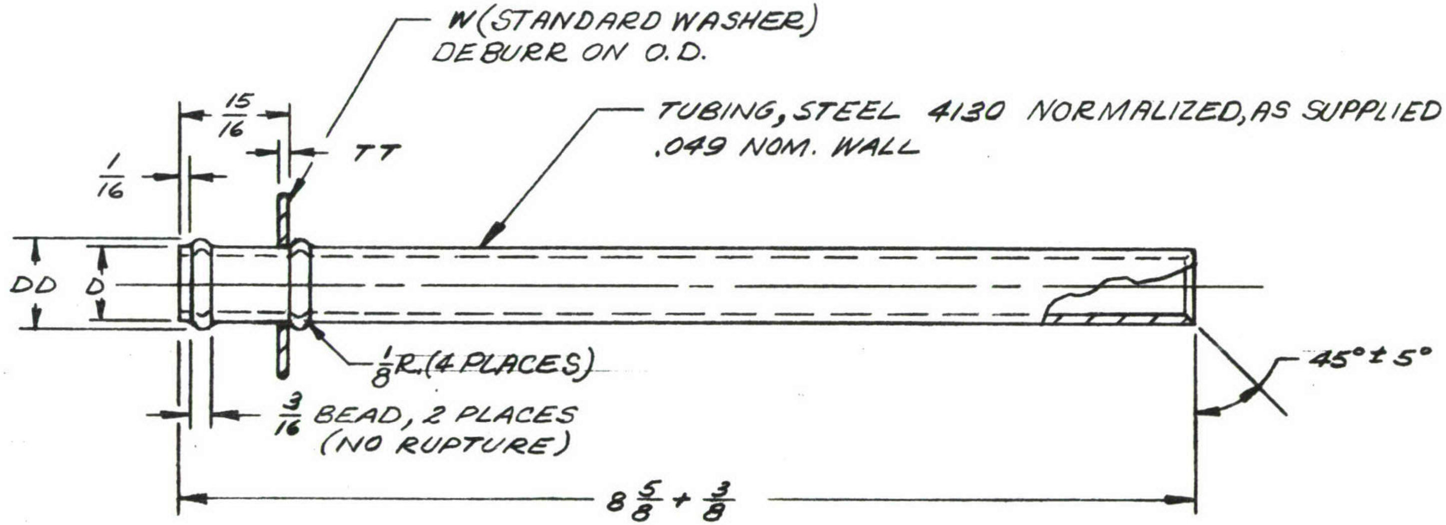
ANNEX C

PHOTOGRAPH AND DRAWING



Arctic Tent Stakes

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



DASH NO.	-1	-2
D	5/8 NOM.	3/4 NOM.
DD (SEE NOTE 1)	.700 MIN.	.825 MIN.
TT	.078 NOM.	9/64 NOM.
W, SIZE	1 1/2 O.D. x 11/16 I.D.	1 1/2 O.D. x 13/16 I.D.
STYLE	ATS-G	ATS-B
COLOR	GREEN	BROWN

NOTE 1: DIM "DD" GREATER THAN WASHER I.D.

QTY	NEXT ASSY	USED ON
APPLICATION		

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TOLERANCES ON
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