RE-70-101

INVESTIGATION OF A BIOLOGICALLY CONCEIVED STAKE FOR USE IN NONCOHESIVE SOIL

TECHNICAL REPORT

Harry C. Muffley

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ABSTRACT

Techniques for anchoring lightweight artillery were investigated from a biomechanic approach by personnel of the Science and Technology Laboratory. The feasibility of a concept stake was established by comparison of the forces involved in the firing of lightweight artillery with the theoretical holding capacity of the stake established from soil mechanics computation. A prototype stake was driven in sand of different densities demonstrating the operational capability.

CONTENTS

OBJECTIVE

The objective of this study was to improve the anchoring of air-borne lightweight artillery on loose or semisolid soil.

INTRODUCTION

The anchoring of air-borne lightweight artillery such as M102 Howitzer, is a problem in Southeast Asia. The M102 is typical of the trend in artillery toward lightweight equipment. Lightweight materials and construction create a problem in anchoring because the force-resistant mass of the equipment is reduced. As a result, the conventional anchoring system (driven stakes) is ineffective in situations involving loose soil, sand, and mud.

When the methods are considered by which biological organisms anchor to their substrate, the following four techniques are used:

1. Secretion of adhesive
2. Creation of vacuum,
3. Claws
4. Roots

The root system was selected as the appropriate method of staking artillery because this method will resist a force regardless of the direction in which it is applied. The extension of blades beneath the surface of the soil is analogous[1] to a secondary root system and will provide an increase in the following characteristics:

1. Effective bearing surface of the stake
2. Resistance to rotation beneath the surface of the soil
3. Resistance to a vertical force on the stake

APPROACH

A prototype stake diagramed in Figure 1 was constructed having extendible blades. The main body of the stake was a cylinder 2.875 inches outside diameter and 30.0 inches long. The lower end was fitted with a point. 4.375 inches above the point of the stake, two blades were extended by means of a mechanical linkage. Each blade extended eight inches outside the main body of the stake and were 1.50 inches wide. When the two blades were extended, the plane area of the blades

1 Heck, G., "Selected Biomechanical Analogs For Application To Anchoring and Related Areas," U. S. Army Weapons Command, Rock Island Arsenal, Research and Engineering Division Technical Report 68-2278, August 1968.

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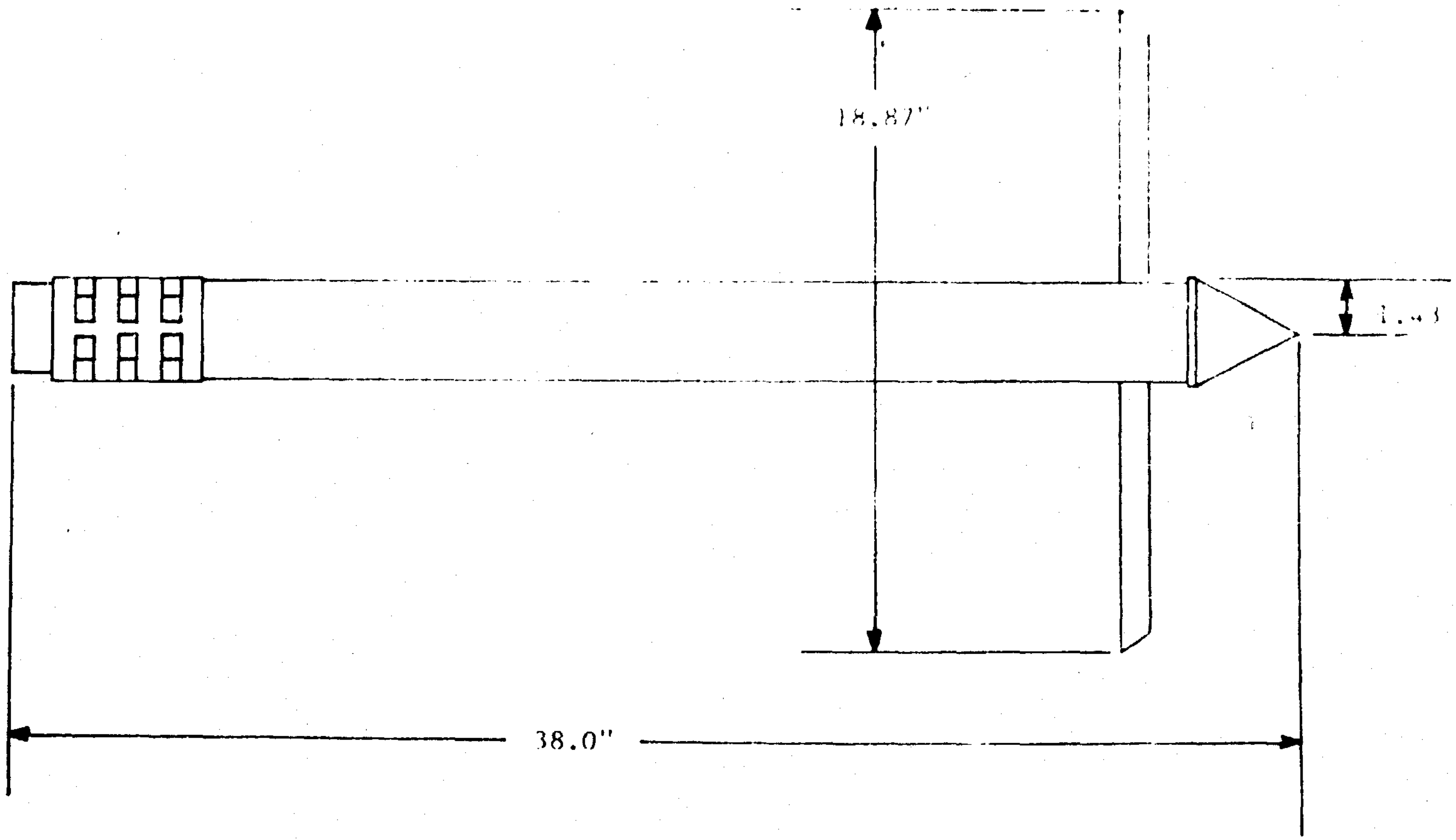

FIGURE 1 DIAGRAM OF PROTOTYPE STAKE

was 24 square inches. This area was designed to provide the greater resistance to uplift than was obtained by a straight cylindrical stake. The main body of the stake was installed by driving it in, with the blades retracted, to a predetermined depth. The extendible blades were then driven out as shown in the operational sequence of Figure 2, by means of a mechanical linkage, to a position of 90 degrees to the axis of the stake body at which the blades were locked. The stake was removed from the ground by first unlocking the extended blades and then by drawing them back into the main body; then the stake was retrieved in the usual manner.

To determine the feasibility of a stake of this type, it was necessary to establish the approximate forces involved in the firing of lightweight weapons and comparing these forces with the theoretical holding capacity of the stake derived from soil mechanics computations.

The weapon selected for the force analysis was supported on a circular base plate, 44.62 inches (O.D.). The plate has eight 3-inch diameter holes on a 40-inch diameter circle through which stakes are driven to anchor the plate to the ground. The weight of the weapon was 3200 pounds, and the weapon exerted a recoil force, horizontally at a height of 30 inches, which was assumed for these computations. A measure of the thrust was obtained from the results of a firing test (Figure 3) in which the tensile forces on three holding straps were measured. The resultant force of these forces was 9480 pounds functioning in the opposite direction of the recoil.

The effect of the thrust is to cause the base plate to tilt to the rear which in turn causes an uplift force on the stakes on the front side of the plate. The magnitude of the uplift force was calculated only after assumptions were made for the stiffness of the soil and the load-displacement characteristics of the stakes. For these computations, it was assumed that the base plate rotated about Line D, Figure 4, that the resultant resistance to compression was on Line E, and that the stake uplift loads were proportional to their distances from Line D.

The results of these computations indicate a maximum uplift force of 1950 pounds on Stake A; a total uplift of 6770 pounds on the five uplift stakes in Lines A, B, and C; and an average uplift of 1350 pounds for these stakes.

In brief, the computation indicates that each stake must have an uplift capacity of about 2000 pounds. This load was thought to be reasonable and was used as a basis for establishing the feasibility of the stakes with regard to the soil mechanics involved.

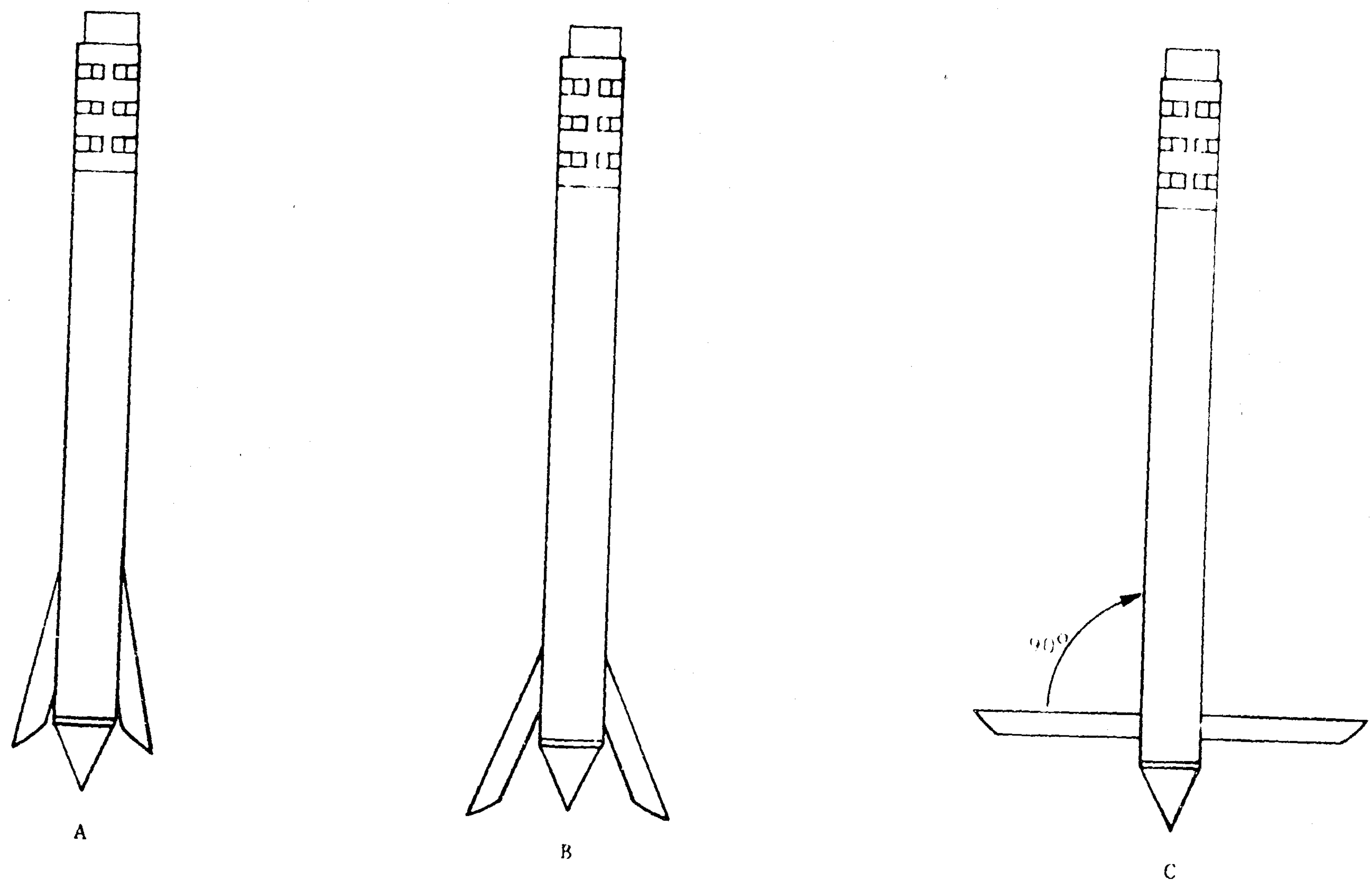

FIGURE 2

PROTOTYPE STAKE OPERATIONAL SEQUENCE

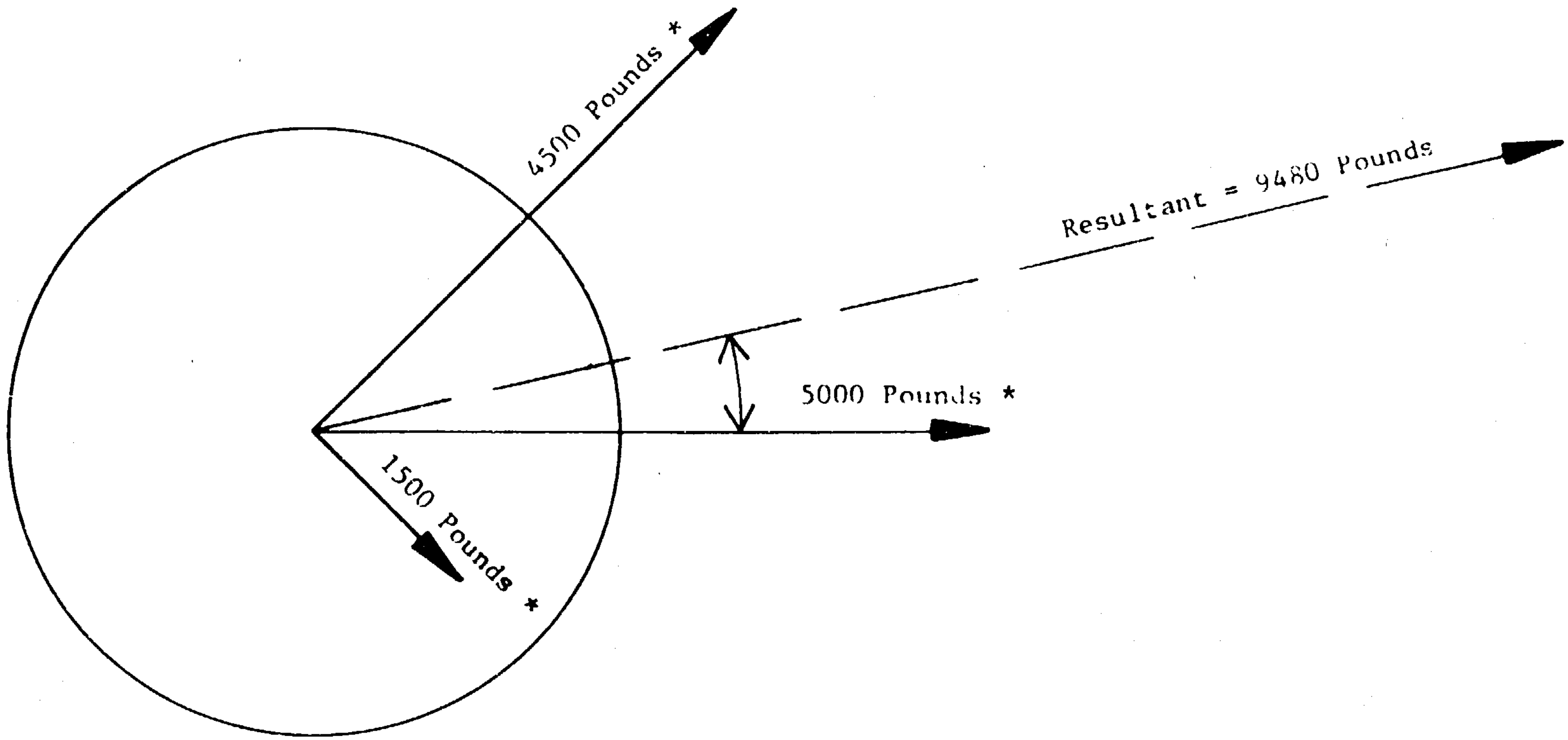

FIGURE 3

THRUST MEASUREMENTS

* LOADS MEASURED DURING FIRING TEST

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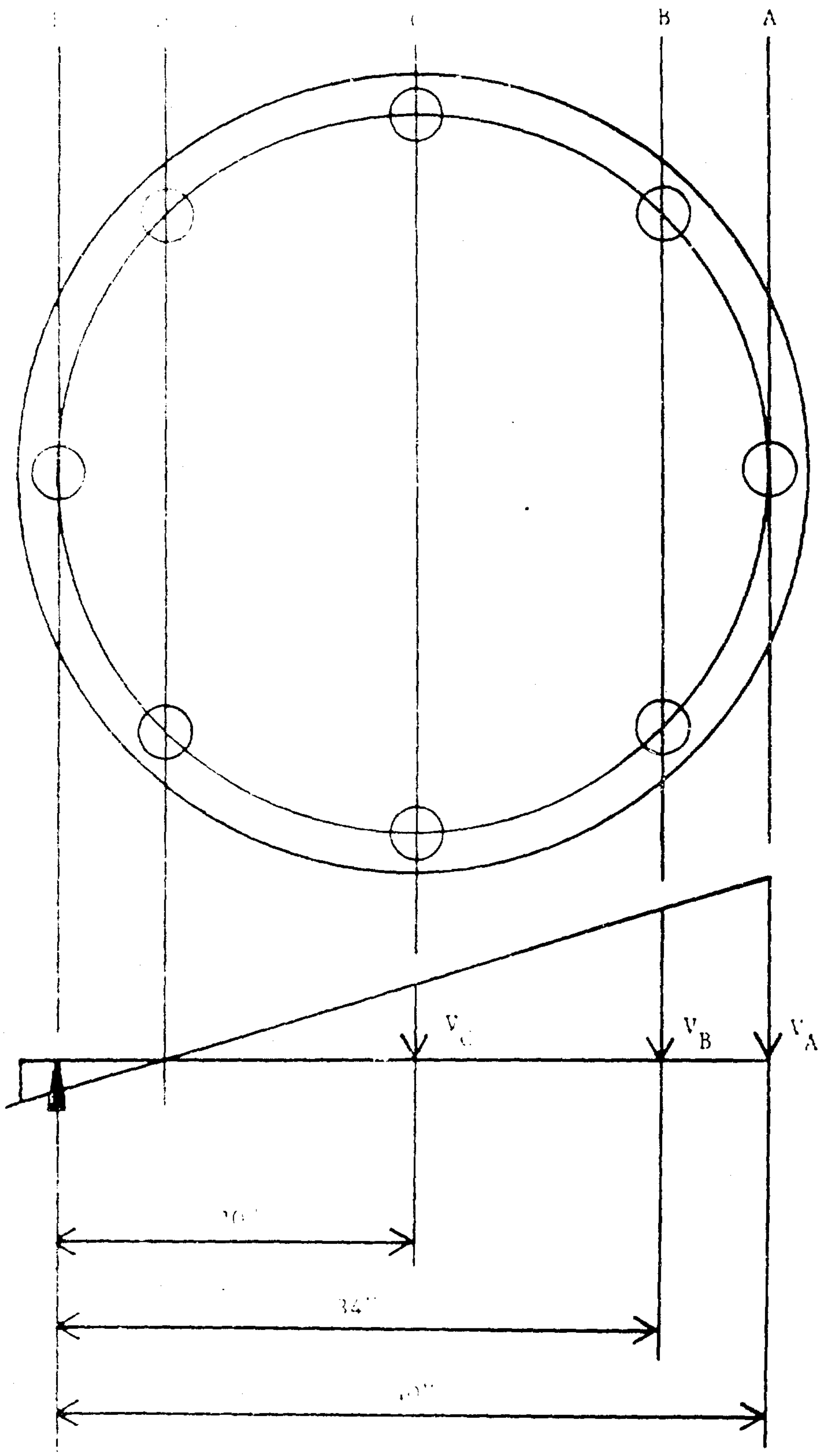

Resultant
Compression

FIGURE 4 LOADS ON STAKES

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The predicted behavior of the stakes must be considered from two points of view. First, the capacity of the individual stake to resist uplift must be adequate. Second, the stakes acting as a group must be considered since their interaction may preclude mobilization of the individual capacities.

In making the computations, it was necessary to assume that the sand was of medium density, well-graded, having a dry unit weight of 115 pounds per cubic foot and an angle of internal friction of 38 degrees.

INDIVIDUAL ACTION

For the simplicity of calculation, the stake was assumed to be 3 inches in outside diameter and 3 feet long. The length can be increased as stipulated by the requirements.

The uplift resistance of a plain 3-inch outside diameter pipe stake, 3 feet long, without blades, was calculated (Appendix A) to be 1330 pounds by use of a procedure derived by Yoshimi[2] that worked well with model piles. Because of the use of the parameter K_p, the coefficient of passive earth pressure, in this computation, the computed capacity is probably an upper limit and the actual capacity could be as little as half this value, depending on how the stake was installed.

If identical assumptions were made in which the stake has the blades extended, the capacity would be 4900 pounds. However, a more realistic result was obtained by the assumption that the percentage of the available resistance, which is actually mobilized, diminishes from 100 percent at the bottom to zero at the surface. In this instance, the capacity was 3280 pounds. Finally, the uplift capacity of the leaves could not exceed the capacity to resist a load operating downward. This capacity was 3580 pounds.

In summation of the individual stake action, the uplift resistance of the 3-foot stake with leaves should be approximately 2-1/2 times that of the plain stake (3280 pounds vs 1330 pounds).

Since an uplift resistance of 2000 pounds was required, the stake with leaves would provide the necessary holding capacity. The capacity of the stake with the extendible blades or the plain stake would be increased by lengthening the stake and driving it deeper.

GROUP ACTION

The uplift capacity of an individual stake was derived from the weight of some volume of soil surrounding the stake. For example, the plain stake with an uplift capacity of 1330 pounds must, in effect, have a volume of soil with this weight, i.e., a cylinder 2.2 feet in diameter by 3 feet high. If a group of these stakes were spaced closer than 2.2 feet, center to center, then the soil cylinders would overlap; thus the group capacity would be smaller than the sum of the individual capacities.

The effect of the stakes holding the base plate is to cause a volume of soil below the base plate to operate in combination with the plate in resisting the uplift force. An estimate of the weight available was made and is shown in Appendix B. If it is assumed that the soil within 1 foot of the center line of the stake is effective, the total weight available for the 5 stakes and a 3-foot depth will be 4840 pounds. This is significantly less than the total uplift resistance required of 6770 pounds. Also, if a volume, 2 feet from the center line, is assumed, the resistance will be 9100 pounds. Again, the weight of the soil involved will increase linearly as the depth the stake is driven into the ground.

These computations indicate the nature of the problem. It may be necessary to have a stake with an individual capacity in excess of that required so that the group capacity will be adequate. The leaves will be particularly effective in extending the zone of influence when they are radially oriented.

FIELD TEST

The uplift resistance of the prototype stake was determined by driving the stake into three different densities of sand and by pulling it out with the blades retracted and with the blades extended. The tension required to withdraw the stake was measured by means of a load cell attached to a bridge amplifier meter. The results of these tests were compared and an additional comparison was made with the tension required to pull a conventional 24-inch stake. The results of these tests are given in the following table:

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TABLE I

FIELD TEST RESULTS

	Prototype Stake		Conventional Stake
	Blades Retracted	Blades Extended	
Type of Soil	Pounds	Pounds	Pounds
Loose Sand	186	730	35
Packed Sand	300	1265	50
Sand with Dirt	95*	1520**	9.6*

* Difficulty was encountered with the hoist which resulted in an erratic pulling action.

** One blade was sheared off and the other bent when the stake was removed from the soil.

CONCLUSIONS

The preliminary study of the prototype stake with extendible blades revealed the feasibility of the stake for adaptation to the anchoring of lightweight artillery. The limited field evaluation of the stake demonstrated the stake will operate in loose sand with the blades being extended to a position of 90 degrees to the main body of the stake. This stake has the advantage over other stakes with extendible blades in the fact that it can be retrieved from the ground and reused.

The results of the field tests showed the prototype stake required greater tension to pull than a conventional 24-inch stake. In addition, the extension of the blades increased the tension approximately four times that required to pull the prototype stake with the blades retracted.

In addition, based on the soil mechanics computations, the following conclusions were drawn:

1. The prototype stake, with the leaves extended, will provide sufficient uplift resistance for the assumed conditions based on the action of the individual stake.

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2. If a group of these stakes is spaced closer than 2.2 feet, center to center, the group capacity will be smaller than the sum of the individual capacities.

3. The blades will have a greater effect if they are radially oriented to the base plate by the extension of the zone of influence past the limits of the base plate

RECOMMENDATIONS

An engineering study of the prototype stake should be made to determine optimal dimensions with regard to blade length and width. The selection of materials should be considered to permit the production of the stake at a reasonable cost.

The fixity of the stake in the base plate should be taken into consideration since the resistance of the stake will increase by three times.

It is recommended that a prototype stake equal in length of a conventional 24-inch stake be evaluated in the field and compared with the results obtained with the longer stake.

The application of a stake similar to the prototype stake constructed will minimize the rotation of the base plate from occurring with each repeated impulse thereby increasing weapon accuracy and fire power

APPENDIX A

UPLIFT RESISTANCE OF STAKE

CASE A: Resistance of Single Pile to Uplift, Yoshimi.[2]

$V = 1/2\ \gamma\ C\ L^2\ K_p \tan\phi$

γ = Dry unit weight of sand (115 lb/ft^3)

C = Circumference of stake (0.785 ft)

L = Length of stake (3 ft)

K_p = Coefficient of passive earth pressure (4.2)

ϕ = Angle of internal friction (38^o)

$1/2 \times 115 \times 0.785 \times 3^2 \times 4.2 \times 0.78 = 1330$ pounds

CASE B: Resistance with Blades Extended.

Assume S is same as for single stake uplift in Case A.

$C = 2\ (16 + 1\text{-}1/2) = 2.9$ feet

$V = 1/2\ \gamma\ C\ L^2\ K_p \tan\phi$

$1/2 \times 115 \times 2.9 \times 3^2 \times 4.2 \times 0.78 = 4900$ pounds

CASE C: Assume shear mobilized on present surface diminishes from 100 percent of strength at bottom to zero at the surface.

Maximum shear at depth $= S_Z = \gamma\ Z\ K_p \tan\phi$

Mobilized Shear $= Sm = \frac{Z}{L} S_Z = \gamma\ K_p \tan\phi\ \frac{Z^2}{L}$

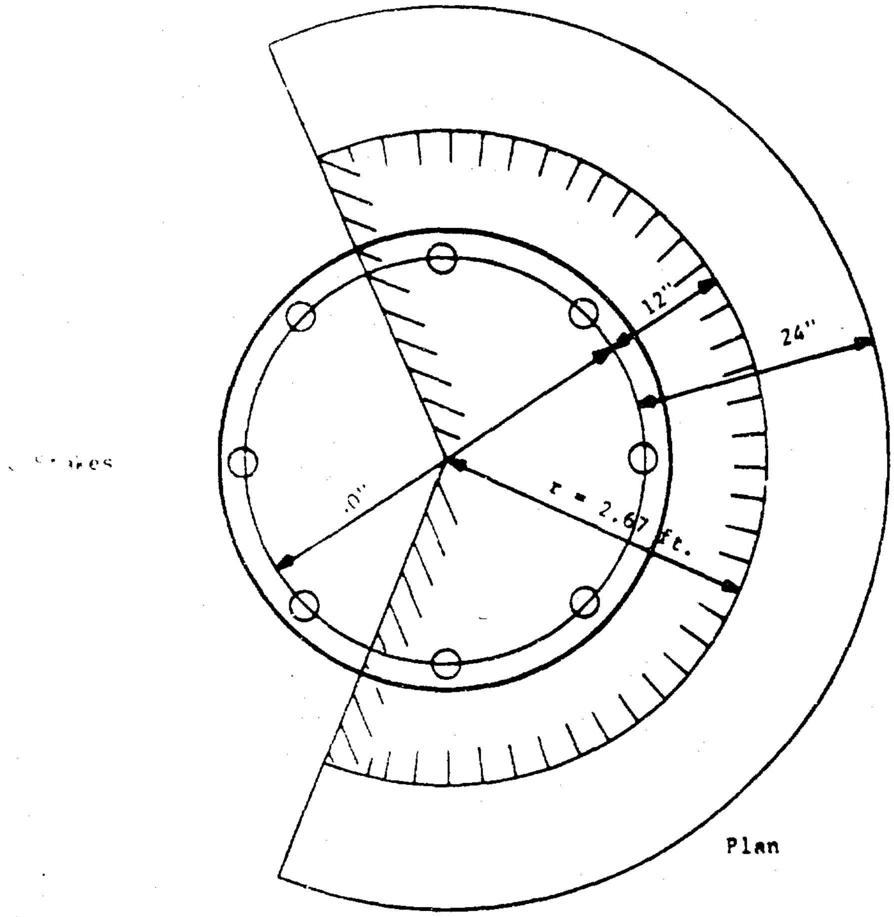
$$V = \int_o^L C\ \gamma\ K_p = \tan\phi\ \frac{Z^2}{L}\ dZ = 1/3\ C\ \gamma\ K_p \tan\phi\ L^2$$

$\therefore V = 1/3 \times 2.9 \times 115 \times 4.2 \times 0.78 \times 3^2 = 3280$ pounds

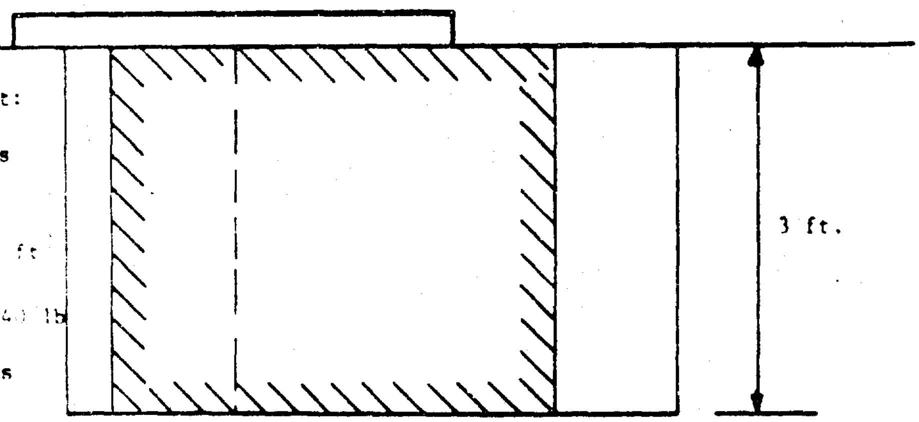
[2] Yoshimi, Yoshiaki, "Piles in Cohesionless Soil Subject to Oblique Pull," Journal of the Soil Mechanics and Foundation Division, ASCE, Vol. 90, No. SM6, November 1964, pp. 11-24.

APPENDIX B

WEIGHT OF SOIL RESISTING UPLIFT



Plan



ELEVATION

Weight of soil to resist uplift:

a. Assume 12" outside ¢ stakes
(Hatched volume)

Area = $\frac{5}{8}\pi r^2 = \frac{5}{8}\pi(2.67)^2 = 14.0\ ft^2$

Weight = 14.0 x 3.0 x 115 = 4840 lb

b. Assume 24" outside ¢ stakes

Weight = 9100 lb

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13. ABSTRACT

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1. Biomechanics						
2. Energy Absorption						
3. Anchoring						
4. Stabilization						

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