



A Novel Approach to Anchoring a Stake in Sand

Toughstake™ Sand and Snow Stake

Load Capacity of Toughstake™ Sand Stakes versus Top Affixed Sand Stakes

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ABSTRACT

Over the course of history the most challenging soil type to permanently set an anchor is sand. This challenge stems from the unique physical properties of sandy type soil. In general sand can be considered a homogenous matrix with little cohesion on the micro or macro scale. These physical properties contribute to the difficulty of anchoring a stake in sand.

For structures such as tents, portable communication masts, forward operating base's, VSAT's, large canopies, awnings, boats, kites and similar, the current sand stake technology has relied on geometric variations of Top Affixed Stakes. In general a stake is driven into the ground and a guyline or similar is attached to the top of the stake.

Over the course of the last century variations have evolved in stake geometry, however the attachment point is still above grade. These current designs result in low load capability and stake pull out failure. The Patented Toughstake™ Technology utilizes a Deep Anchor Tension System (DATS) transferring the pull point from the top of the stake to a sub-terranean location. The novel patented Toughstake™ technology increases ultimate load capabilities exceeding a standard top affixed sand stake.

INTRODUCTION

Many structures or objects such as tents, awnings, canopies, communication towers, VSAT's, kites, boats, etc., require a sand anchor or sand stake to be used. These structures rely on stakes driven into sand. The sand stake is then attached by a guyline from the structure to the top of the stake (Fig 1).

For this discussion we will define these types of sand stakes as a "Top Affixed Sand Stake". When trying to properly secure a structure in sandy soils there arises many difficulties. First, sand exhibits idealistic material properties as the matrix is homogenous and lacks micro or macro cohesion. Depending upon the moisture content of the sand the material properties have a wide range of load capabilities. The fluid nature of sand (a function of the water and clay content) is the underlying physical property resulting in low load capability. The second fundamental problem with anchoring any object in sand is cyclic loading derived from wind, waves, or other natural occurring forces. These forces tend to "work" the Top Affixed Sand Stake out of the sand over time (Fig 3). Subjecting a Top Affixed Sand Stake to low amplitude cyclic loading will result in stake or anchor failure. Failure begins when any movement of the stake is present. The moment there is slack in the attachment guyline occurs, stake pull out failure is accelerated. This is primarily due to the impulse forces of a "flapping" guyline.

Over the course of history many variations in geometry have been developed and implemented in the field. The variations in geometry have ranged from a wider wedge to a longer stake. Ultimately these changes in geometry do little to prevent the top of the stake from moving when loaded with a static or small cyclic load.

Eventually all Top Affixed Stakes will pull free from the loose matrix of sand or snow. This is especially evident in cases where the stake is subject to cyclic loading due to natural occurring forces

The patented Toughstake™ Sand and Snow Stake technology has addressed the problem of the small load capacity and common failures of the Top Affixed Sand Stake. The Toughstake™ technology utilizes a Deep Anchor Tension System (DATS) which is a unique feature of the Toughstake™ Sand and Snow Anchor (Fig 4). This novel design allows for increased load capacity compared to standard Top Affixed Sand Stakes.

In review of the experimental data from the Top Affixed Stakes versus the Toughstake™ Sand and Snow Anchor the maximum load prior to stake displacement of the Toughstake™ is substantially greater than Top Affixed Stakes.

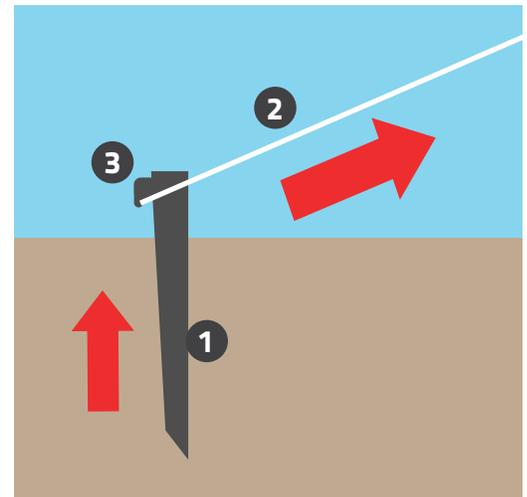


Fig 1 - Top Affixed Sand Stake

Standard Top Affixed Sand Stake (1) generally used to anchor objects in Sand or Snow. All Top Affixed Stakes are driven into the sand or snow and then the guyline (2) is attached to the top of the stake (3). When subjected to small loads the Top Affixed Sand Stake begins to pull free from the soil.



Fig 2 Toughstake™ Sand and Snow Stake.

The Toughstake™ Sand and Snow Anchor (1) is coupled with a Deep Anchor Tension System (2) to achieve maximum load. Unlike a Top Affixed Stake the "pull point" is from the bottom of the stake (3).

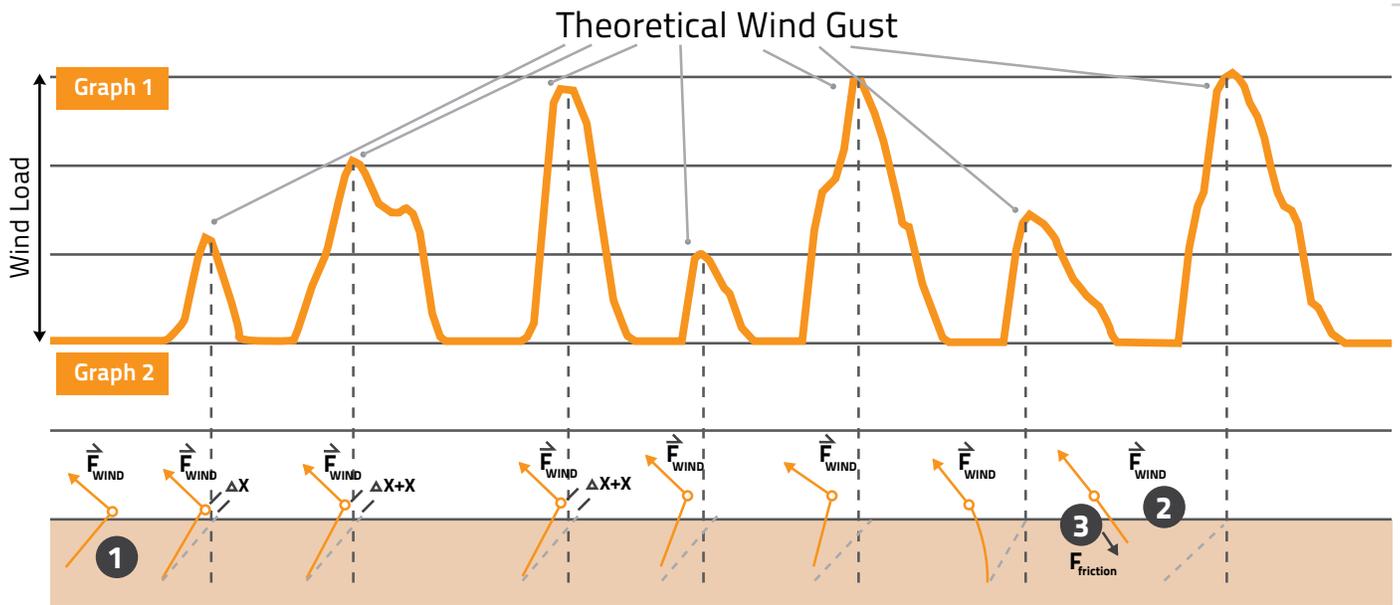


Fig 3 - Top Affixed Sand Stake subject to theoretical wind loading.

Realistic environmental conditions result in cyclic loading. This can occur from wind, waves, or other natural occurring cyclic forces. **Graph 1 in figure 3 shows** a theoretical cyclic load over time (such as wind loading on a tent or similar object). The magnitude in the force applied would normally result from varying natural occurrence's. **Graph 2** depicts a Top Affixed Stake (1) in sand as subject to the loading curve of Graph 1. As the Top Affixed Stake is subject to the small amplitude loading, the Sand Stake is slowly worked free from the soil. Failure begins when any small differential displacement Δx occurs. Upon any displacement Δx , an impulse force is added and amplifies to normal load. Ultimately when the stake is in line with the load vector (2), the only force holding the stake from the soil is a Frictional Force, $F_{friction}$. At this point the stake is easily pulled from the soil (3).

When reviewing the theoretical wind loading versus Top Affixed Stake displacement in Fig 3, it can be seen that for small loads, a Top Affixed Stake begins to fail. As long as the maximum wind loads are less than the maximum load of the Toughstake™ Sand Anchor failure due to cyclic loading will not occur. The Toughstake™ has virtually eliminated low amplitude cyclic fatigue which slowly works the Top Affixed Stakes free from the sandy soil.

Fig 4 depicts an actual Toughstake™ which has been driven into the sand and excavated away so a cross section can be seen. Installation of the Toughstake™ is simple. First the guyline is attached to the stake. The Toughstake™ is then driven into the sand as the guyline is pulled taught. Once the Toughstake™ is set, the Toughstake™ is ready for the guyline from the structure or object trying to be tethered. The Patented Toughstake™ system results in a Sand Stake that can withstand high loads and constant low amplitude cyclic loading. Figure 5 shows a sequence of photos taken as a Toughstake™ is driven into sand.



Fig 4 Toughstake™ in sand.

An excavated cross section of a Toughstake™ Sand and Snow Anchor can be seen in sandy soil. The Deep Anchor Tension System (1) is couple to the Toughstake™ Sand and Snow Anchor (2). The guyline from the object needing securement is then attached to the System Ring (3)



BACKGROUND STUDIES

Before discussing any results of pull-out tests on the Toughstake™ Sand and Snow Stake versus other Top Affixed Sand Anchors, it would be instructive to present a brief review of related work on anchor systems in cohesionless type soils.

A common technique for anchoring much larger structures such as transmission towers, is to excavate an area to the desired depth, placing an anchor either horizontal or vertical with an attachment cable and then back filling the excavation. The anchor is thus buried in the soil. Initial research for this technique dates back to the work Balla (1961). Much later with the advent of Finite Element analysis, the behavior of soil anchor systems could be modeled. Computer modeling, however, requires knowledge of the material properties of the soil such as the internal friction, cohesiveness, soil dilatancy, anchor roughness and initial stress state. For large structures, there is incentive to obtain these properties in and around the proposed site to insure the integrity of the anchor and thus the structure. But for smaller structures such as tents, sign posts, small field antenna installations, VSAT's, Forward Operating Bases, boat tie-up anchors, wind kites or beach shade structures the standard technique is to utilize a Top Affixed Sand Stake.

A great deal experimental and numerical analysis has been performed on buried soil anchors positioned either vertically or horizontally depending on the structure requiring support. Fig. 6 shows the diagram used in numerical analysis of buried plate problems.

Numerical analysis of buried anchors in both cohesion and cohesionless soils can be found in the works of Merifield and Sloan (2006), Merifield, Lyamin and Sloan (2006), and Merifield, Lyamin and Sloan (2005). The ultimate anchor pullout capacity, q_u in cohesionless soil is usually expressed as a function of the soil unit weight (γ), the embedment depth (H) and the break-out factor N_γ . It is worthy to note that N_γ is a function of orientation, embedment ratio, friction angle and anchor roughness.

Equation 1 Anchor Pullout Capacity

$$q_u = \gamma H N_\gamma$$

Where q_u is the pullout capacity in terms of soil stress on the anchor. The pull-out force, F_y is the area of the anchor plate multiplied by the pullout capacity, q_u

Equation 2 Pullout Force

$$F_y = \gamma H N_\gamma A$$

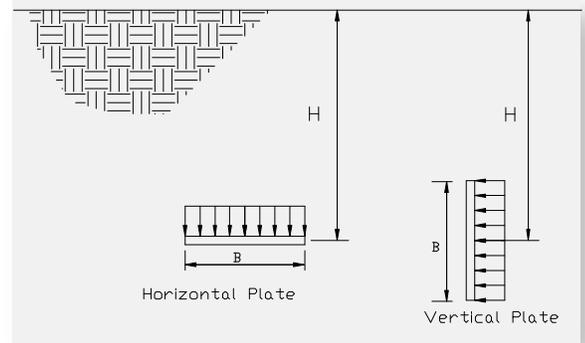


Fig. 6 Buried Plate Analysis.

Typical buried plate diagram used in the numerical analysis of anchors. H is typically the distance from the surface to the anchor and B is the anchor dimension, either square plate, circular plate or infinite strip plane a strain analysis.

The installation of the Toughstake™ is depicted in Fig 5. Not only is the installation very easy, the Toughstake™ has been designed to minimize the area for storage. This small spatial footprint is maximized by two factors. First, the Toughstake™ can be removed from the guyline. Decoupling allows for the Toughstake™ Sand Stakes to readily “nest” together creating a very low storage to volume ratio.



Fig 5

Installation of the Toughstake™ Sand and Snow Anchor is simple. First the Deep Anchor Tension System (1) is attached to the load attachment point of the Toughstake™ Sand Stake (2). This couple system ensures permanent affixation to the Toughstake™. The Toughstake™ (3) is then placed in the soil and by either using a mallet or similar, the Toughstake™ is driven into the Sand. During this process the Deep Anchor Tension System Guyline is pulled tight (4). Upon the top of the Toughstake™ being flush with the soil (5), the Guy Line is again pulled tight (6). At this point the attachment ring (7) can be used to secure the object.

Experimental modeling and field tests have been used to develop Semi-Empirical data that can be used to estimate the anchor capacity in cohesionless soils. Table 1 lists some of the researchers in these early studies.

Table 1 - Laboratory model tests on horizontal anchors in cohesionless soil

Author	Test Type	Anchor Shape	Anchor Size (mm)	Friction Angle (deg)
Hanna& Carr (1971)	Chamber	Circular	38	37
Hanna et al. (1971)	Chamber and Field	Circular	38 and 150	37
Das & Seeley (1975)	Chamber	Rectangle	51	31
Rowe (1978)	Chamber	Square Rectangle	51	32
Andreadis et al. (1981)	Chamber	Circular	50 - 150	37,42.5
Ovesen (1981)	Centrifuge Field	Circular Square	20	29.5 - 37.7
Murray & Geddes (1978)	Chamber	Circular Rectangle	50-8	44 dense 36 medium
Sakai and Finlay (1990)	Chamber	Circular	37.5	33.8,39,43.7
Pearce (2000)	Chamber	Circular	50-125	Loose to dense
Ilamparuhi et al. (2002)	Chamber	Circular	100-400	Loose to dense

Breakout factors for both horizontally and vertically placed anchors in cohesionless soils have been calculated by various numerical techniques including the displacement finite element formulation SNAC described in Abbo (1997) and Abbo&Sloan (2000). Table 2 lists theoretical and computational studies on anchors in cohesionless soils. Many of these studies compare numerical results with experimental results.

Table 2 - Theoretical studies on horizontal anchors in cohesionless soil.

Author	Analysis Method	Anchor Shape	Friction Angle (deg)
Vesie (1971)	Cavity Expansion	Strip/circular	0-50
Rowe & Davis (1982)	Elastoplastic finite element	Strip	0-45
Vermeer & Sutjiadi (1985)	Elastoplastic finite element	Strip	All
Tagaya et al. (1988)	Elastoplastic finite element	Circular/Rectangle	31.6, 35.1
Sarac (1989)	Limit Equilibrium	Strip/Circular	0-50
Kanakapura et al. (1994)	Method of Characteristics	Strip	5-50
Sakai & Tanaka (1998)	Elastoplastic finite element	Circular	Dense
Smith (1998)	Limit analysis: lower bound	Strip	25-50

The Toughstake™ Sand and Snow Anchor can be modeled using the buried plate concept. Unlike most conventional Top Affixed Stakes where the guyline is attached to the Top of the Stake (Fig. 1 the Toughstake™ Sand and Snow Anchor has the attachment point below ground (Fig. 4).

There is limited analysis of stake pull-out data available for the standard Top Affixed Sand Stakes. In this study a laboratory test frame was designed to hold approximately 10ft³ of dry blow sand. This allowed for both the Top Affixed Sand Stakes and the Toughstake™ Sand Anchors to be tested for pull out capacity. A linear activator was used to load to the many stakes tested. A data acquisition system was designed to record the load versus displacement. Load was measured using a load cell inline with the pull cable. These tests compare pull-out loads for various stakes. The load-displacement data allow calculating equivalent break out factors as described in eq 1,2. Fig. 7 shows a picture of the test setup.

Sand exhibits many different physical properties. These properties change depending upon the percent water, clay, binding agents, or similar.

For this study desert blow sand was used. To achieve idealistic conditions the sand was strained and dried prior to the test. The Internal Friction Angle (ϕ) for cohesionless soils is often used as a measure of the mechanical properties of sand. This angle (ϕ) was determined by first measuring the angle of repose, θ . Work by Ghazavi et al. (2008) found the relationship between the friction angle ϕ and the angle of repose θ could be expressed by the equation:

Eq 3 - Internal Friction Angle

$$\phi = 0.36 * \theta + 21.2$$

Sand used in this study had an angle of repose of 30.1. Using Eq 3 the Internal Friction Angle (ϕ) for the sand used in this experiment was calculated to be 32.0.

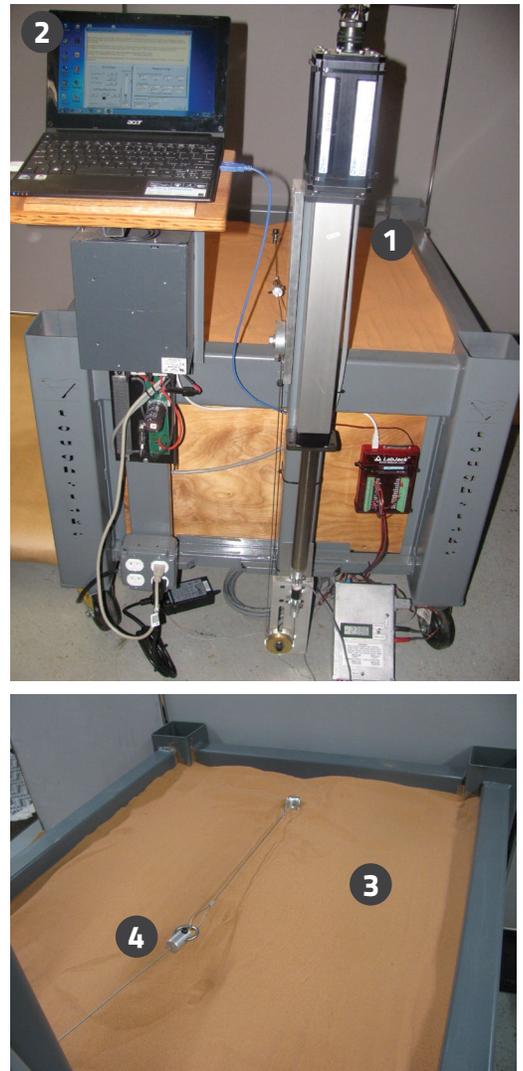


Fig.7 Load Frame experimental test set-up.

Experimental Test Apparatus for pulling stakes out of sand. A linear actuator (1) was used in conjunction with a data acquisition system (2) for applying load to the Sand Stakes. A 10ft³ box (3) of dry blow sand was used for the simulated soil. Using a steel cable (4), each of the stakes were driven into the sand then pulled to failure.

EXPERIMENTAL TEST RESULTS

To show the effectiveness of a Toughstake™ anchor, a Toughstake™ (length = 13 in, 33 cm wt = 4.4 oz, 124 g) and a Top Affixed Military Issue Sand Stake (Part # 97403-13227E0136 length = 12 in, 30 cm, wt = 3.6 oz, 102 g) were compared for maximum load capacity (Fig 8).

The pull rate was set at 0.2 in/s (.51 cm/s). Figure 9 depicts the load versus displaced for the Toughstake™ Sand Anchor and the Top Affixed Military Issue Sand Stake.

As can be seen in Fig. 9 the maximum load recorded for the Toughstake™ was approximately a factor of 5 greater than the Top Affixed Military Sand Stake. Following the analysis of Merifield, we can use Eq. 1, Eq. 2 to compute the effective break-out factor for both stakes. Since there is no agreed upon definition of when a stake fails, we assume failure to be at the maximum pull-out load, that occurs in the interval of 0 to 2 inches. Beyond 2 inches the tie down straps slacken and the structure (tent awning etc.) becomes unreliable.

For the tests shown in Figure 9, failure for the Toughstake™ occurred at a load of 98.6 lbs and a load of 20.1 lbs for the Top Affixed Military Sand Stake.



Fig. 8

A standard issue US Military Sand Stake next to the Toughstake™ Sand and Snow Anchor.

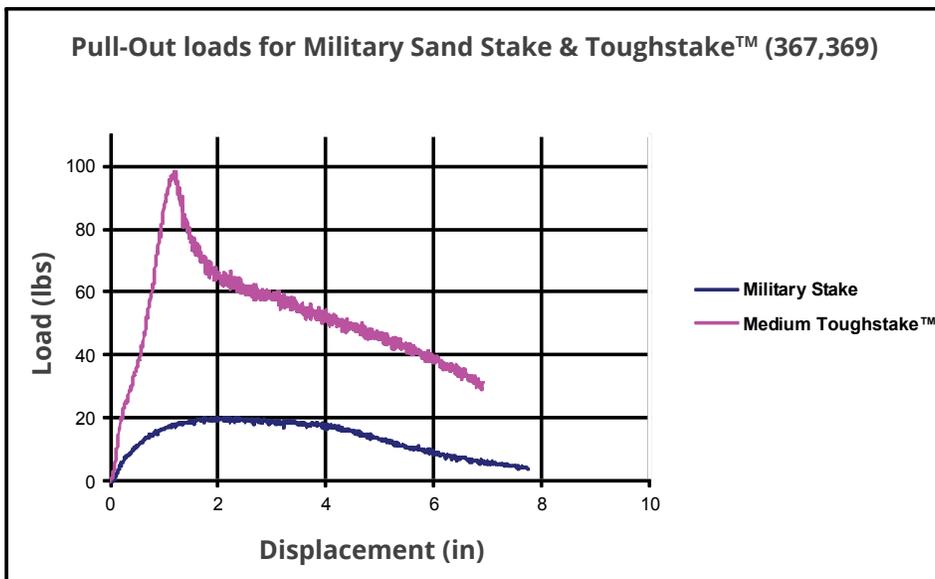


Fig. 9 Experimental Test Results.

Displacement curves for a medium Toughstake™ and a Military Issue sand stake

From these experimental data, the anchor break-out factor, N_y (Eq. 4) can be calculated.

Eq 4 - Anchor Break Out Factor.

$$N_y = F_y / (\gamma * H * A)$$

Where $\gamma = 0.0793 \text{ lb/in}^3$

Table 3 - Break-out factors for a 13" Toughstake™ and the Military Sand Stake

Stake	Pull-Out = Force F_y (lbs)	Area (in ²)	H (in)	Break-Out Factor N_y
Toughstake™	98.6	14	10.9	8.15
Military Stake	20.1	13.75	5.5	3.35

The break-out factor N_y is consistent with numerical calculations and experimental measurements for buried anchors in cohesionless sandy soils (Merifield 2006). The work by (Rowe & Davis, 1982) on the behavior of anchor plates placed vertically and horizontally in sand found the break out factor to be higher for vertical plates than horizontal plates. Toughstakes™ are normally placed at an angle of about 60 deg. One would expect the break out factor to be nearly that of a vertical plate. For vertical anchors in sand ($\phi = 32^\circ$) Rowe and Davis (1982) give a break-out factor of 6.1 for $H/B = 4$. The reason for a larger value for the Toughstake™ (8.1) is likely due to the added resistance of the stake shaft causing a higher pull-out load.

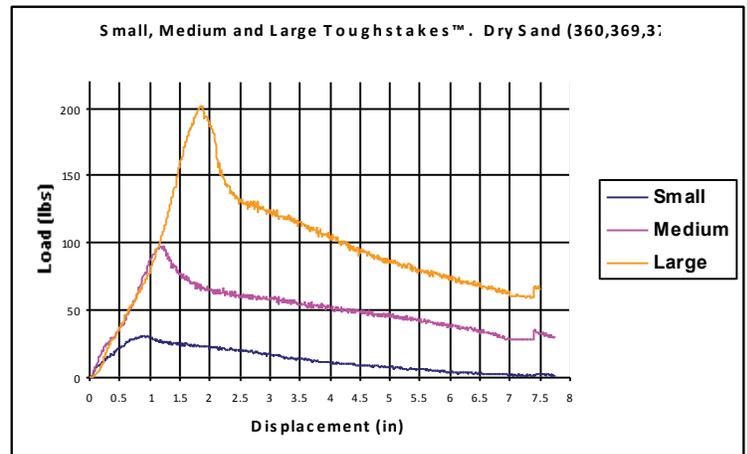


Fig. 10
The three sizes of Toughstake™.

There is virtually no numerical data in the literature to analyze the common sand tent stake. It is far easier and less costly to determine the numbers experimentally. However, numerical modeling may be quite useful in the design of geometries of both the Toughstake™ and conventional stakes in cohesionless soils.

For comparison purposes, pull-out data for three different lengths of Toughstake™ Sand and Snow Anchors were completed. The lengths of the 3 Toughstake™ Sand and Snow Anchors were 9.5", (24.1 cm) 13.0 (33. 0 cm)" and 17.5" (44.4 cm) respectively. Figure 10 shows a picture of these stakes.

Graph 3 is the experimental data collecting when each of the three length of Toughstake's were pulled to failure.



Graph 3

Pull-out data for small, medium and large Toughstakes™

For comparison purposes, a collection of standard Top Affixed Stakes were tested against a Small (9") Tough-stake. Figure 11 shows each of the individual stakes compared, and Graph 4 is the experimental data collected for maximum load. The Toughstake Sand and Snow Anchor outperformed all standard Top Affixed Sand Stakes.

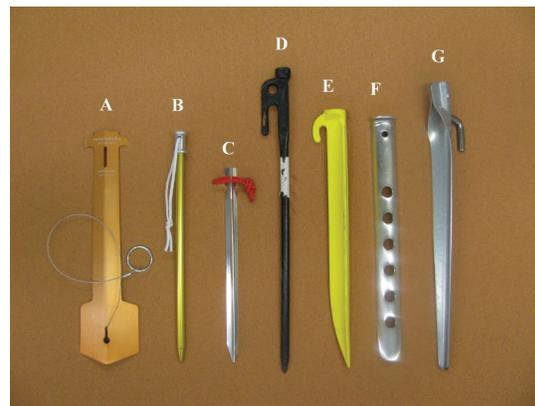
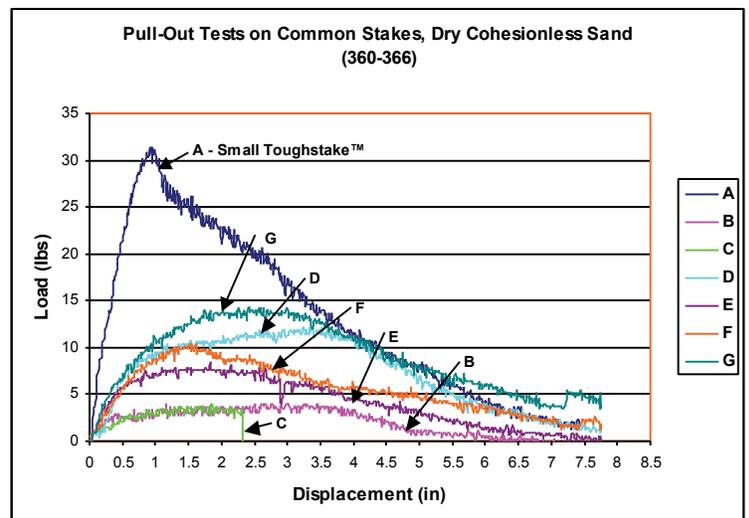


Fig. 10

Stakes used in Experimental Load Test in sandy soil.



Graph 4

Pull-out loads for the Stakes shown in Figure 10.

Table 4 - Break-Out factors for stakes tested in this study

Stake	Pull-Out = Force F_y (lbs)	Area (in ²)	H (in)	Break-Out Factor N_y
Small Toughstake™	31.4	8.5	5.0	9.3
Medium Toughstake™	98.6	10.9	14	8.15
Large Toughstake™	202	16.5	24.75	6.23
Top Affixed Military Sand Stake	20.1	5.5	13.75	2.29
Stake - B	3.05	4.0	2.72	3.53
Stake - C	3.36	3.5	3.25	3.72
Stake - D	10.68	5.5	3.52	7.03
Stake - E	7.63	4.5	6.75	3.16
Stake - F	10.38	4.5	9.0	3.23
Stake - G	13.73	5.0	10.0	3.46

Failures of conventional stakes used to secure loads in sands arise from several mechanisms. First, the load is just too high to be supported by the stake and the stake pulls free of the sand when tightening the cables/straps/ropes. Second, and perhaps the most common failure mode is due to natural occurring cyclic loading (usually wind or water). Wind loading failure may be thought of as a low cycle fatigue problem. When a square wave loading was applied to top affixed stakes in the test frame, it was noticed the stake would move forward slightly and sand grains would immediately fall in behind the stake preventing the stake from returning to its original position. After a number of cycles, the stake moved so far forward, it would be considered to have failed. The results of these tests will be discussed in a future paper.

CONCLUSION

The introduction of the Novel Toughstake™ Sand and Snow Anchor was described. In addition the Toughstake™ Sand Anchor design was compared both theoretically and experimentally versus other Top Affixed Sand Stakes. These comparison's used both previously developed mathematical formulas for buried vertical and horizontal plates in conjunction with the experimental data results. The experimental data and the theoretical calculations correlated to the expected values. It was found the Toughstake™ Sand and Snow Anchor exhibits far greater performance in load rating than any standard Top Affixed Sand Stake in sandy cohesionless soils.

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