NBS BUILDING SCIENCE SERIES 107

Soil and Rock Anchors for Mobile Homes - A State-of-the-Art Report

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Soil and Rock Anchors for Mobile Homes - A State-of-the-Art Report

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Soil and Rock Anchors for Mobile Homes
A State of the Art Report

by

William D. Kovacs and Felix Y. Yokel

Available anchor hardware is surveyed and evaluated and pull-out capacity data are compared with hypotheses for predicting anchor pull-out capacity based on soil mechanics principles. The evidence suggests that our ability to predict anchor pull-out capacity by soil mechanics principles is inadequate, and that there is a need for the standardization of test procedures and soil classification and for further test data. Suggestions for future research are presented.

Key words: Anchors; mobile home foundations; soil anchors; soil mechanics; wind upset

Cover: *Due to the widespread use of mobile homes, the safety of their construction is a growing problem in the U.S.*

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NOTATIONS

A	projected surface area of anchor Plate or Helix
B	width of anchor (least width)
c	undrained shear strength of cohesive soil
C	allowable stress in shear in cement grout
D	depth of anchor below ground surface
f'_c	unconfined compressive strength of concrete or grout
L	length of grouted hole
N_u	uplift or pull-out factor for cohesive soils
N_{qu}	uplift or pull-out factor for granular soils
Q	pull-out capacity of anchors
S	anchor shaft resistance
α	angle of inclination from the vertical, in degrees
β	reduction factor (for use in equation 3);
γ	weight of soil per unit volume
ϕ	angle of internal friction (shearing resistance) in degrees

SUMMARY AND RECOMMENDATIONS

1. AVAILABLE ANCHORING SYSTEMS

A wide variety of soil and rock anchors, and some other methods to tie down a mobile home are commercially available. The anchoring may be made directly in natural or compacted soil, rock, coral, or directly to concrete slabs or other foundation elements. Based on the limited pull-out test data available, it appears that most of the anchor types discussed in this report can be installed to adequately meet the loading requirements in present standards.

2. SOIL CLASSIFICATION

An industry-wide nomenclature describing soils and rock is nonexistent. Different organizations call the same soil type by different names and assign to it different anchor pull-out capacities. As a result, it is difficult to interpret and correlate available test data and develop sound empirical design procedures. However, in areas where local field experience has been accumulated, satisfactory anchoring of mobile homes is accomplished by adequate characterization of regional soil conditions.

The present practice of assigning pull-out capacities to various anchor types on the basis of visual descriptions of soil types is potentially misleading and unsafe. Such "soil descriptions" seldom take into account the actual soil properties and conditions that govern the pull-out capacity. It is concluded that there is a need for an industry-wide consensus on terminology for describing, and methods of characterizing soils and rocks.

3. ENGINEERING CORRELATIONS BETWEEN SOIL PROPERTIES AND ANCHOR PULL-OUT CAPACITY

Hypotheses and equations for predicting anchor pull-out capacity have been developed and are presented in this report. Correlation between measured and calculated anchor capacity is poor, particularly for granular soil. The mobile home industry uses the Standard Penetration Test (SPT), Soil Test Probe (STP) or visual soil descriptions to select anchors for given site conditions. The SPT provides a fairly reliable indication of soil properties for granular soils but only a very crude approximation when cohesive soils are investigated. It is questioned if those who use the SPT for anchor design are aware of these facts. The Soil Test Probe may provide an indirect measurement of soil shear strength which governs the pull-out capacity of anchors. However, based on the available data (or perhaps because of the absence of adequate data), the correlation between the STP readings and pull-out capacity is not obvious and further experimental (field) study is required.

Since some soils change strength and therefore anchor holding capacity seasonally, some method of taking this strength change into account for design purposes is required. Available information and present design procedures do not account for this problem. Similarly, little information is available on adequate design of mobile home anchors in expansive soils and soils that undergo seasonal frost heave.

There is an almost complete lack of information on the effects of cyclic (Dynamic) loading on anchor capacity. Since wind loads are cyclic and soil strength generally deteriorates with increasing numbers of loading cycles, dynamic loading effects should be further investigated.

4. TEST STANDARDIZATION

One of the main reasons for our inability to correlate soil and rock properties with pull-out capacity is the overall lack of adequate data in the mobile home anchor literature. In order to determine this correlation, test data should convey the following information:

A. Complete load versus uplift displacement data in order to establish the ultimate loads as well as displacement characteristics for a given anchor and depth of embedment in a specific soil condition.

B. Complete description of the anchors used, their depth of embedment, method of installation, and installation torque (if applicable).

C. An evaluation of the soil properties and the location of the ground water table at the site. The soil properties determined should include the shear strength parameters and the soil weight per unit volume (density). These properties should be determined by field and/or laboratory tests other than the SPT or STP.

D. The results of Standard Penetration Tests, Soil Test Probe tests, and other in-situ tests that could later be used to predict anchor capacity.

All four items should be provided together to develop correlations. Typically only 2 or at best 3 of the 4 items are available in existing data.

In Item A above, the need for pull-out load-displacement data is mentioned. Presently, there is no standard method for performing pull-out tests in the mobile home anchoring industry. As a result, the precision, accuracy, and amount of information typically provided in a pull-out test report is deficient when compared with a typical ASTM standard test. Most available load test reports list the soil class as determined visually without any shear strength indicator.

5. RECOMMENDATIONS

The following is recommended on the basis of this study:

° To adopt an industry-wide soil classification system including a standard nomenclature to define soils and rock;

° to prepare a standard method of performing anchor pull-out tests in the field, including minimum requirements for the characterization of soils;

° to conduct a test program in order to establish correlations between anchor pull-out capacity and several in-situ tests, and to determine effects of dynamic, cyclic, and sustained loading, loading which is not in the direction of the anchor shaft, and anticipated seasonal changes in the moisture content of the soil;

° to develop a standard performance test by which the adequacy of anchors can be determined.

Facing page: *The need for anchoring systems for mobile homes was recognized by industry and several products were developed.*

1. INTRODUCTION

The weight of a typical mobile home ranges from 17 to 25 lb/ft^2 of floor area (83-122 Kg/m^2). The federal Mobile Home Construction Safety Standard [34][1/] requires that mobile homes be designed to resist an uplift force (wind) of 15 lb/ft^2 (720 N/m^2) and a lateral force of 25 lb/ft^2 (1200 N/m^2) in hurricane regions and an uplift force of 9 lb/ft^2 (430 N/m^2) and a lateral force of 15 lb/ft^2 (720 N/m^2) in all

[1/] Figures in brackets are literature references listed in Section 11.

other regions. Recent field measurements indicate that these forces should be increased [71]. Thus, a foundation system designed to prevent sliding, overturning and separation of the mobile home from its supports must have the capability of resisting horizontal and uplift forces. Since most mobile homes are supported by piers which rest on top of the ground, have relatively little weight and generally have no ties to connect them with the supporting piers, uplift and horizontal forces must be resisted by soil anchors.

Industry recognized the need for providing anchoring systems for mobile homes and developed a variety of products which are readily available and can be installed inexpensively. However, data on the performance of these anchoring systems are relatively scarce, are not very well correlated with soil properties, and have not been systematically compiled.

The purpose of this study was to compile available information, assess our ability to predict the pull-out capacity of anchors in various soils, and determine what additional information or standards could improve the reliability of anchoring systems.

Background information on the need for anchoring and anchoring standards and procedures is provided in Chapter 2; Chapter 4 gives an overview of available anchoring hardware; the state of knowledge with respect to theoretical prediction of anchor pull-out capacity is discussed in Chapter 5; Chapter 6 provides information on empirical methods presently used to predict pull out capacity; load test data that could be located by the authors are presented and analyzed in Chapter 7; environmental effects on anchor pull-out capacity are discussed in Chapter 8; and needed research to fill most important information gaps is discussed in Chapter 9.

Facing page: *Mobile home damaged by wind upset.*

2. BACKGROUND INFORMATION

2.1 NEED FOR MOBILE HOME ANCHORS

All areas of the United States at one time or another are subjected to winds of sufficient intensity and duration to cause damage to mobile homes [39, 46, 71, 78]. Areas adjacent to the oceans and the Gulf of Mexico may be subjected to hurricane-force winds. Furthermore most areas, particularly those in the interior of the U.S., may be subjected to tornadoes. Wind forces on mobile homes situated in open areas generally exceed those acting on mobile homes sheltered by trees and surrounding structures (other mobile homes) [46]. A discussion on windstorm characteristics related to mobile home damage was presented by Vann and McDonald, 1978 [Ref. 102a].

The soil anchor is an important component of the foundation system which provides structural stability for an installed mobile home. It is part of a structural chain of components that includes the mobile home structural frame and floor, roof-wall, and wall-floor joints, foundation blocking, anchor straps, connecting hardware between the anchor straps and anchor, and finally the anchor embedded in the soil and/or rock. Failure of any one of these components could result in damage to the mobile home and its contents and injury to its inhabitants during windstorms.

Data on the actual percentages of anchored and unanchored mobile homes that were damaged during severe windstorms are very scarce. Several insurance companies and state agencies active in mobile home programs in one way or another were contacted. Although all parties concerned agreed that anchoring a mobile home is very beneficial, significant data substantiating the effects of anchors on the behavior of mobile homes during windstorms could not be produced. The following references provide limited information:

> Pickard (1978) [84a] reported the following: In the November 12-13, 1972, tornadoes in Dallas County Texas, 100 mobile homes that were situated broadside to the wind were destroyed, whereas those mobile homes that were facing into the wind were undamaged. There were no numbers available on the actual percentage in each category, nor do we know the wind speed.
>
> In the same storm in the same county at Whispering Oaks Mobile Home Park, 26 mobile homes were subjected to these winds. Twelve of the 26 mobile homes were anchored. Eleven of these suffered less than $1,000 damage while the 12th suffered approximately $1,500 damage. Of the 14 mobile homes that were not anchored, 11 were completely

destroyed and 3 were severely damaged. The damage to the anchored mobile homes was primarily caused by flying debris from the destroyed mobile homes.

In the Amber Mobile Home Park, in a different location in the same storm and county, 6 units were subjected to the windstorm. The 4 mobile homes that were tied down suffered nominal damage, while the 2 units that were not tied down were completely destroyed; one rolled over and one blew away.

One June 12, 1972, in Hurricane Cecilia, in Del Rio, Texas, 15 mobile homes [in one park] were subjected to strong winds. Of the 7 mobile homes that were anchored, 1 was destroyed (the unit was hit by an unanchored mobile home), 2 suffered minor damage and 4 escaped injury. Of the 8 mobile homes that were unanchored, 6 were totally destroyed and 2 suffered minor damage.

The following mobile home damage report on Hurricane Eloise in Florida, in 1975, was prepared by Wayne Haddock of Minuteman Anchors, Inc., in East Flatrock, North Carolina: In the Reids Trailor Park and Sea Gull Trailer Park in Panama City, Florida, in almost every instance, those mobile homes that had no anchors were blown over or were destroyed in the September 23, 1975, Hurricane (Eloise). In the Fort Walton area, approximately 300 mobile homes were located in the Shalimar Mobile Home Park located approximately 15 miles (24 Km) inland. The only home that blew over was not tied down. The remaining homes were predominantly anchored according to the Florida state code and showed very little damage. In Dothan, Alabama, where wind speeds reached 88 mph (140 Km/h), 75 percent of the 70 mobile homes in the Ridgewood Estates Mobile Home Park were blown off their blocks and 4 homes [in the park] were destroyed. None of the (anchored) mobile homes were moved.

In the March 24, 1975, tornado at Traveler's Rest, South Carolina, a total of 8 mobile homes were hit by high winds. Six of the 8 mobile homes were not anchored; 2 were completely demolished and the remaining 4 were damaged. Those 2 remaining mobile homes were anchored and suffered no damage.

2.2 NATIONAL AND STATE STANDARDS

Besides the National Standard [10, 34, 69], there are various state rules, regulations and laws regarding the anchoring of mobile homes. Some states (for example, Alabama, [7, 8]) require that any new mobile home occupied after a certain date, (January 1, 1976, in Alabama), must be tied down in accordance with ANSI Standard A119.1/NFPA 501B [69]. These standards, summarized by Cooke, et al. [29], and Waldrip [105], are intended to protect the occupants and are advocated by the companies who insure mobile homes against loss due to high winds. Specific recommendations for anchoring equipment are given in paragraph 4.4. of the "Standard for the Installation of Mobile Homes" Manufactured Housing Institute and National Fire Protection Association [69] [NFPA 501A; ANSI 119.3]. The basic provision is that the anchoring equipment should be capable of resisting an allowable working load equal to or exceeding 3150 lb (14.0 kN) when installed. The term "allowable working load" means that the anchor capacity should be greater, providing a factor of safety. The provision stipulates a factor of safety by stating that the anchor should be capable of withstanding a 50 percent overload (which comes out to be 4725 lb (21kN), total) without failure of either the anchoring equipment or the structural hardware which anchors the mobile home or which ties the mobile home to the soil anchor itself. Section 5.5.1 of the NFPA Standard, entitled "Capacity of Anchors," defines failure as the condition when the point of connection between the tie and the anchor moves more than two inches (50 mm) at the 50 percent overload or 4725 lb (21kN) in the vertical direction. In addition, it is further prescribed that in the event the load is other than from the vertical direction, the anchor shall withstand 3150 lb (14kN) at an angle of 45° from the horizontal without a displacement of more than 4 inches (0.10 m) in the horizontal direction at the location where the tiedown attaches to the soil anchor (or rock anchor).

The Standard also presents a table relating three types of soil and sound hard rock with the blowcount of the Standard Penetration Test (SPT)(ASTM D1586-67, R74) [12] and a "soil test probe" (STP) torque value. These two field tests will be described in detail later on in this report.

2.3 TYPICAL ANCHORING PROCEDURES

There are several procedures and methods by which mobile homes may be anchored to the ground. These include both over-the-top strap anchoring and below-the mobile-home frame anchoring. Typical anchoring arrangements are described by the Defense Civil Preparedness Agency [36]; by the Foremost Insurance Company [39], and by various mobile home manufacturers. Many anchor hardware manufacturers supply the hardware connections from the anchor to the mobile home.

In an early study published in 1962 (Harris [46]), ten recommendations were made for the installation of anchors for mobile homes. They are presented (verbatim) along with the drawing shown in figure 2.1. Some of these recommendations continue to be used by the mobile home industry. These recommendations are:

1. Blocking should be installed beneath the main longitudinal frame of the mobile home at the same interval of spacing as the tie-down anchors and should be in line with them.

2. Blocking should be of steel or concrete. If concrete building blocks are used, cores should be placed vertical with a solid 4 inch (0.10 m) concrete cap block on the top beneath the frame. Class "A" block should be used which meets American Society for Testing and Materials Specifications for manufacture.

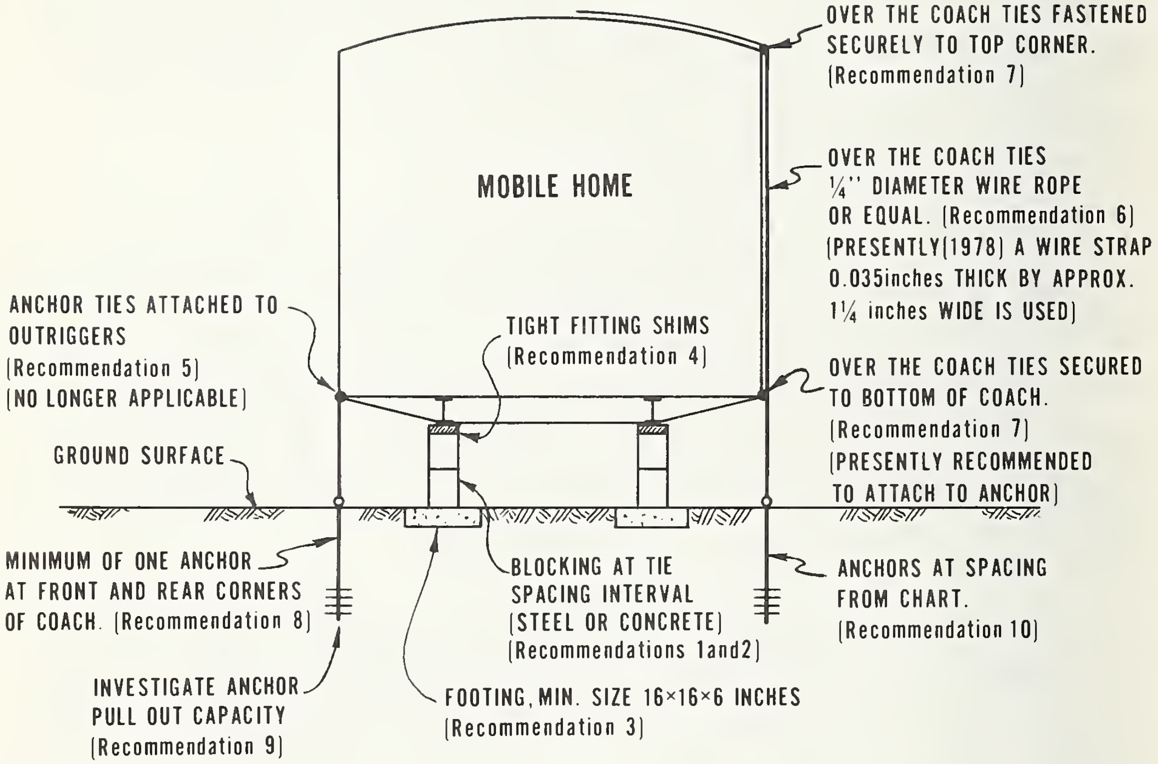


Figure 2.1 Summary of Recommendations for Installation of Anchors by Harris [46]

3. Footings beneath blocking should be firm, in good condition, and not less than 16 x 16 inches (0.41 x 0.41 m) in plan dimension. Footing thickness should be a minimum of 6 inches (0.15 m). If a concrete slab at least as wide and as long as the mobile home is used the thickness may be a minimum of 4 inches (0.10 m).

4. Shimming between the blocking pier and the steel frame should be of treated wood of first quality or other firm material. Shims should be fitted tightly to prevent rocking of the unit under the action of wind gusts.

5. In the absence of test information on the strength of the coach, anchor ties either attached to the ends of the outriggers of the frame or passing over the coach may be accepted. The anchor ties to the frame outriggers appear to be sufficient at this time and have the prior recommendation. [NOTE AUTHOR COMMENT: This recommendation is now considered outdated. However, the statement could be used with the following qualification: "use only if specifically stated in the manufacturer's installation instruction."]

6. Ties passing over the coach should be at least 1/4 inch diameter wire rope, 1/2 inch diameter manila rope, 3/8 inch diameter nylon rope, webbed straps, or equal. Over the coach ties should be able to sustain a minimum load of 2,800 pounds (12.5 kN) before breaking for an anchor spacing of 10 feet (3.05 m). Ties should be doubled or of increased capacity for greater anchor spacings. [NOTE AUTHOR COMMENT: In current practice (1979), a 0.035 inch (0.9 mm) thick metal strap about 1-1/4 inches (32 mm) wide is used instead of the wire rope mentioned above in the 1962 report. Also, a minimum load of 3150 pounds (14 kN) with a 50 percent overload is now used. (See reference 69.)]

7. Ties passing over the coach should be snug and fastened to the coach body at both top corners. In addition ties passing over the coach should be perpendicular to the ground and secured to the coach body as close to the bottom as practical. (NOTE AUTHOR COMMENT: In current practice it is recommended that over-the top ties should not be structurally attached to the mobile home body.]

8. At least one anchor should be placed near each front and rear corner of the coach.

9. If a quantity of a particular type of anchor is to be installed in a given area, or if any installation is to be made in an area of uncertain soil conditions, a special investigation of ultimate pull out capacity of the anchor should be conducted in the field.

10. A recommended safety factor of 1.5 and a gust factor of 1.3 may be applied to the ultimate pull out capacity giving a total factor of safety of 2.0 and the anchor spacing can be determined from the chart on page 47 in the Appendix. [NOTE AUTHOR COMMENT: This chart is not reproduced in this report.]

"In addition to the above recommendations for installation, it is recommended that when skirts are used they should be of the free-standing variety and not attached to the coach. They should also have perforation or lattice configurations.

"In those instances where coaches are on dealer's lots, a practice of providing temporary anchors at a 50 percent capacity, or double spacing, would appear to be sufficient to protect the units and adjacent property.

"While it is undoubtedly up to the mobile home owner to provide for his own anchoring protection, certainly new mobile home parks should have anchors installed at the time of construction along with other facilities such as water, sewer, power, etc." Harris noted that it could also be profitable for present park operators to install the anchors as a service to their tenants. However, it is felt that this approach is no longer applicable due to the wide variation of mobile home designs.

Harris [46] and McKeown and Brittain [78] analyzed anchor systems for mobile homes and gave recommendations for anchoring requirements based on selected soil types. However, they made no reference to field tests or analytical techniques used to arrive at these capacities [105]. Waldrip [105] extended these studies and provided information on tests and evaluation of anchoring systems currently used in practice.

Waldrip [105] also studied the various factors that contributed to the poor performance of mobile homes during wind storms with special attention given to current anchoring systems and anchoring construction practices. He evaluated the various types of failures that a mobile home can undergo during a wind storm. These include:

1. Anchor connection failure between the mobile home and the soil/rock anchor rod.

2. Failure of the steel straps over and under the mobile home.

3. Sliding failure due to improper blocking of the mobile home on its foundation support.

4. Underframe-floor separation.

5. Floor-wall separation.

6. Other structural failures of the mobile home itself. (Waldrip did not consider structural failure of the anchor itself which is also possible).

In his studies, Waldrip performed 22 pull-out tests with 4, 6 and 8-inch (0.10, 0.15 and 0.20 m) diameter helix anchors with total embedment depths ranging from 17 to 46 inches (0.43 - 1.17 m). All of these tests were performed in one type of soil having the Unified Soil Classification symbol SM-SC (see Section 5.1 for further discussion on soil classifications). Only 3 of the 22 pull-out tests performed met the combined criteria of pull-out load and maximum deflection according to the mobile home standard [69]. These 3 tests were on helix anchors that were installed by first digging a hole, installing the anchor and then backfilling and compacting (not a typical procedure for Helix Anchors). Thus, "variations in the backfilling and compacting procedures, the only variable in the installation method used for the anchors . . . may have been responsible for the 3 anchors which met performance specification . . ." [105].

Vann and McDonald [102a] present a thorough discussion and analysis of damage experience to mobile homes by wind storms, as well as recommendations for the design, construction and anchoring of mobile homes.

The references mentioned thus far may be considered the primary works on the anchoring of mobile homes in soil and rock. However, a close review of these references will demonstrate that very little information from a geotechnical engineering viewpoint has been published.

Facing page: *Measuring horizontal displacement in anchor test.*

3. SCOPE OF STUDY

3.1 GENERAL

This study primarily concerns itself with the geotechnical engineering aspects of the performance of soil anchors. The anchors are typically made of metallic materials and usually will have a strength which is equal to or higher than the capacity of the soil to resist deformation. Assessment of the structural load capacity of various anchors discussed herein is not within the scope of this report.

3.2 ASSESSMENT OF AVAILABLE SOIL AND ROCK ANCHOR HARDWARE

Product data of existing anchoring hardware have been collected from military research laboratories, commercial anchor companies, and telephone, utility and power companies.

3.3 REVIEW OF THE THEORETICAL ASPECTS OF ANCHOR HOLDING CAPACITY

Available references that discuss theoretical aspects of anchor pull-out capacity and design procedures for the various types of anchors that are currently used in industry are reviewed. Parameters considered include the various soil types and environmental conditions that one would find under field situations. The environmental conditions include frost heave, swelling soils, and chemical or electrical attacks on the anchor material.

3.4 REVIEW OF AVAILABLE FIELD AND LABORATORY TEST DATA ON ANCHOR CAPACITY

Detailed test data, which include load-displacement curves for various types of anchors in various soil types were obtained from the geotechnical engineering literature as well as from various commercial anchor companies that were contacted. Where applicable, pull-out capacity is correlated with soil properties as determined by field or laboratory tests and with proposed analytical approaches in order to determine whether there is a basis for a realistic, rational design approach.

3.5 GEOTECHNICAL ASSESSMENT OF FIELD AND LABORATORY TEST DATA

The above mentioned laboratory and field data are critically reviewed to provide a preliminary assessment of the applicability of present design methods. A program of research with the objective of relating pull-out resistance to basic soil properties, installation torque or resistance in the Standard Penetration Test [12] is proposed.

Facing page: *Many of the anchors on the market are specifically designed for mobile homes.*

4. AVAILABLE TYPES OF SOIL ANCHOR HARDWARE

4.1 INTRODUCTION

There are a multitude of anchor types on the market today. Many of these anchors have been specifically designed for mobile homes while others, designed for other purposes, could also be used to anchor mobile homes. Much of the technology and many of the products were developed primarily for military, power, and communications applications. The communications applications include the guying (tying down) of telephone and transmission lines as well as the securing of cables on the ocean floor. Some of the mass-produced anchors to be discussed have been developed specifically for mobile home applications, while many other designs resulted from backyard or garage operations by single owners to meet the needs of the mobile home industry. State agencies that enforce the mobile home anchoring laws usually require anchor manufacturers to submit plans and specifications of their anchors as well as field pull-out test data to show that the anchors will meet the minimum requirements. Typically, manufacturers will submit their anchors to a testing laboratory where pull-out tests are conducted in various types of soil.

4.2 ANCHORS DEVELOPED FOR MILITARY APPLICATIONS

4.2.1 General

The military has various needs for soil anchors. Applications include large tents, inflatable structures, various pieces of equipment that require restraint (such as weapons), and specialized membranes used to cover poor soil for use as landing pads. In addition, the Air Force uses anchors to hold down aircraft and the Navy uses anchors to moor vessels. These latter anchors require substantial load capacities and are outside the scope of this report. Many of the anchors and associated hardware for military use have the additional requirements of light weight, portability, and ease of installation and possibly retrieval under sometimes unfavorable conditions.

Berus [21] presents test results of anchor holding capacities for 14 commercial anchors, 8 experimental tie down anchors, 7 dead man anchors, and 12 ship and helix anchors. Tests on ten of the ship anchors were performed on scale models while the rest were performed on prototype anchors. Unfortunately, the soils were only very generally classified such as "hard," "dry" or "wet sand" or just plain "sand." The tests, nonetheless, covered a wide range of anchor types, sizes (areas of elements resisting pull-out), depths and soil types. Of all the ground anchors reviewed in his study, Berus mentioned that one anchor stands out as a potential mobile home anchor; this anchor is called the universal ground anchor by the military [86, 100] and is known commercially as the arrowhead or triangular shaped anchor and is discussed in detail in the next section.

4.2.2 Triangular or Arrowhead Ground Anchor

The arrowhead-shaped earth anchor is driven directly into the supporting soil. Anchors are typically one piece malleable iron castings, stamped steel, or aluminum in certain sizes, with attached wire, cable or metal rods as shown in figure 4.1. Some anchors have coatings protecting them from rusting. The anchors range in size from 2 inches to 17 inches (50 mm to .43 m) with a base width and height of the same dimension. For example, a 6 inch (150 mm) anchor is one having a top width of 6 inches and a height from top to arrowhead tip of 6 inches. The triangular-shaped ground anchors are driven by a steel driving rod which is positioned over the anchor spindle and driven at the desired angle with respect to the horizontal by means of repeated blows of some hammer. The method of driving depends on the soil type, anchor size, and desired depth of penetration. The anchor is driven to the desired depth (at least 6 times the anchor size) and the driving rod is removed. The anchor has an attached guy line or metal rod which follows the driving of the anchor. The guy line is attached off the center of gravity of the anchor such that when a pull-out force is applied, it causes the anchor to rotate in the ground through an angle of approximately 90°. In this way, the full triangular bearing surface becomes more or less perpendicular to the direction of pull and maximum pull-out resistance is developed. <u>This means that preloading of the anchor after it is driven is an important aspect of the anchor installation</u>.

The origins of the triangular anchor go back to the early 1950's. One of the earliest geotechnical investigations of the triangular shaped

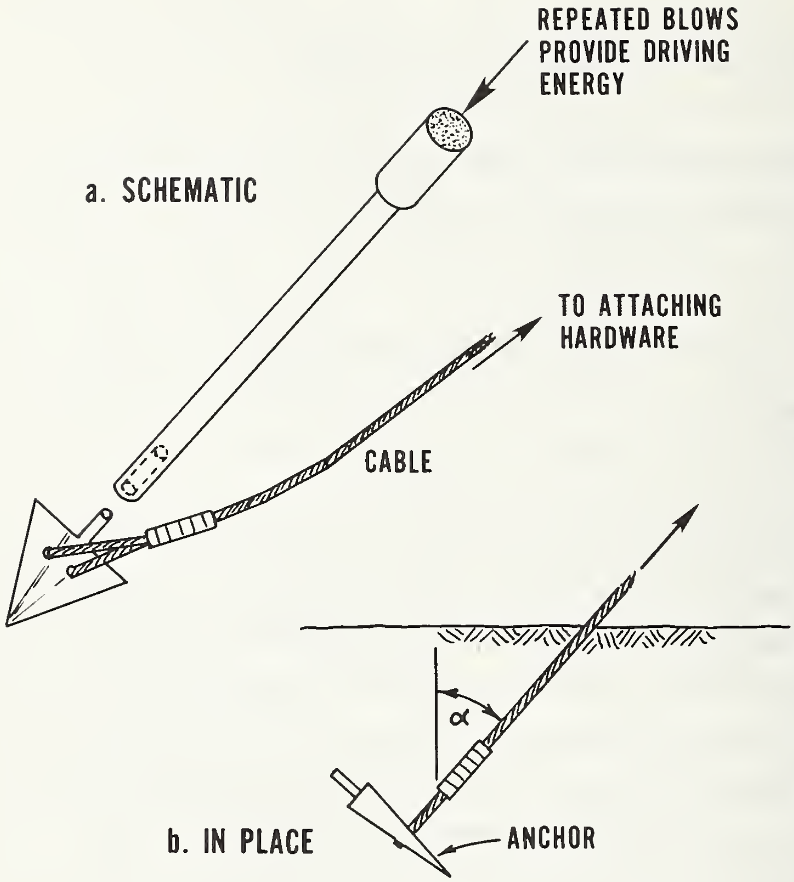


Figure 4.1 Triangular Ground Anchor

ground anchor was performed by Haley and Aldrich for the Laconia Malleable Iron Company [44]. A U.S. Army Quartermaster report [86] documents initial tests on what is now the Army's universal ground anchor. Other anchors investigated by the military but excluded from further study in this report due to their low holding capacity include: the Air Force Standard Arrow Anchor, used to moor lightweight aircraft; the modified Standard Arrow Anchor; the Seaplane Auger, the Barbed Wire Entanglement Securing Pin; the Experimental Spade Pin; the Barbed Wire Picket Pin [20].

The federal supply system has a guy anchor that consists of a 2 foot (0.61-m) long, 3/4-inch (19-mm) diameter reinforcing rod welded to a 1/8-inch (3 mm) thick 12-inch (0.30-m) diameter steel plate. These anchors weigh 6 1/2 pounds (3.0 kg). These anchors were studied, together with a disc type anchor, a two leg anchor, and the universal arrowhead anchor, to see which anchor would be most suitable in holding down membrane surfaced assault airfields [104]. Not all of these anchors are capable of meeting the requirements for a mobile home soil anchor.

Tucker [97] studied the ability of flat plate anchors as well as 4-inch (0.10-m) arrowhead anchors used to hold in place a neoprene coated nylon membrane to be used as an Army helicopter landing pad. In all cases he found that the arrowhead anchor was superior to the flat plate anchor. However, the actual pull out capacity of these anchors was below that which is required for mobile homes due to the size of the anchors [4 inches (0.10 m)] and limited depth of embedment [30 inches (0.76 m) only]. The above results were confirmed in another study by Grau [43] in which the guy anchor, the disc anchor, the two-legged anchor and the arrowhead anchor were studied. For the prevailing soil conditions and depths of embedment, the arrowhead anchor proved to have the greatest holding capacity.

4.2.3 Other Government Studies on Anchor Types

Taylor et al., 1975 [92] lists approximately 2 dozen types of anchors of various sizes and manufacture that are primarily used in the marine environment. The types of anchors identified and documented include propellant-actuated direct-embedment anchors, vibrated direct-embedment anchors, screw-in anchors, driven anchors, drilled anchors, dead weight anchors, and free fall anchors. Most of the anchors discussed in this excellent handbook have capacities in excess of 10,000 lbf (44 kN) and would not be directly applicable to the anchoring of mobile homes. However, some of the types mentioned, namely screw-in anchors and, driven anchors, when properly scaled down in size, could provide suitable tiedown for mobile homes. These anchors will be discussed in greater detail in the section dealing with commercial anchors.

Other military anchors include ballistic or explosive earth anchoring systems in which an explosive, or charge, or high pressure device would be used to drive an anchor into the ground. The suitability of such anchors in the mobile home industry is questioned for reasons of safety as well as licensing problems that no doubt would occur. These anchors were not further studied nor referenced.

4.3 ANCHORS AND PROPRIETARY EQUIPMENT AVAILABLE FROM COMMERCIAL COMPANIES

4.3.1 General

Many types of commercial anchors are available for different soil and rock conditions and for conditions where the mobile home is to be tied directly to a concrete slab. Available anchors are identified generically and according to their intended use in certain soil and rock deposits. Although an all-inclusive description of available anchors was attempted, undoubtedly a few anchors escaped the attention of the authors.

The following discussions of anchor types are presented in random order and should not be construed to imply rating in terms of potential use.

There are many ways in which a mobile home anchor can be installed. For example, depending upon their type, soil anchors can be driven, turned in (twisted) under a normal (vertical or inclined) load, or placed in a partially excavated hole and then either driven or turned in. In the case of rock anchors, a hole is usually excavated and the anchor is installed either by tightening of the anchor shaft itself or by filling the space around the rock anchor with cement grout (a mixture of water, sand, and cement in appropriate ratios to adequately bond the anchor to the rock). The various types of anchors are discussed in the following sections.

4.3.2 Helix and Multi-Helix Anchors

One of the more common (mobile home) anchors is the helix or multi-helix anchor (see figure 4.2). Anchor sizes range from 3-in (0.08-m) diameter to 15-inch (0.38-m) diameter (for very high capacity anchors not used for mobile homes). Anchors are also available in twin 4-in or twin 6-in helix arrangement. Typical installation is performed by applying a vertical load to the anchor while it is "turned" into the ground to the desired depth. This turning or torquing can be done either by hand or by a power tool. Under these latter conditions it is appropriate to measure the installation torque in units of ft-lb or in-lb. In accordance with information obtained from anchor manufacturers, the pull-out capacity in lb is approximately 10 times the installation torque in ft-lb. This number should be field verified in each location. Minimum recommendations for anchor rod diameter and depth of embedment for both 6- and 8-inch diameter helix anchors suggested by Harris [46] are shown in figure 4.3. Klym's [60a] experiences at Ontario Hydro indicate that, to be fully effective, the helix anchor should have a minimum embedment of 5 helix diameters and that the top helix should be below the anticipated frost line. For multi-helix anchors, the pitch [and spacing] of the helix are designed to make the top helix follow the same helical path as the bottom helix to ensure minimum soil disturbance. In some soils, disturbance will cause a significant reduction in the holding capacity of the anchor. These considerations are discussed in the following sections of this report. Multi-helix anchors were found to be more suitable when installed in medium to stiff clays and medium

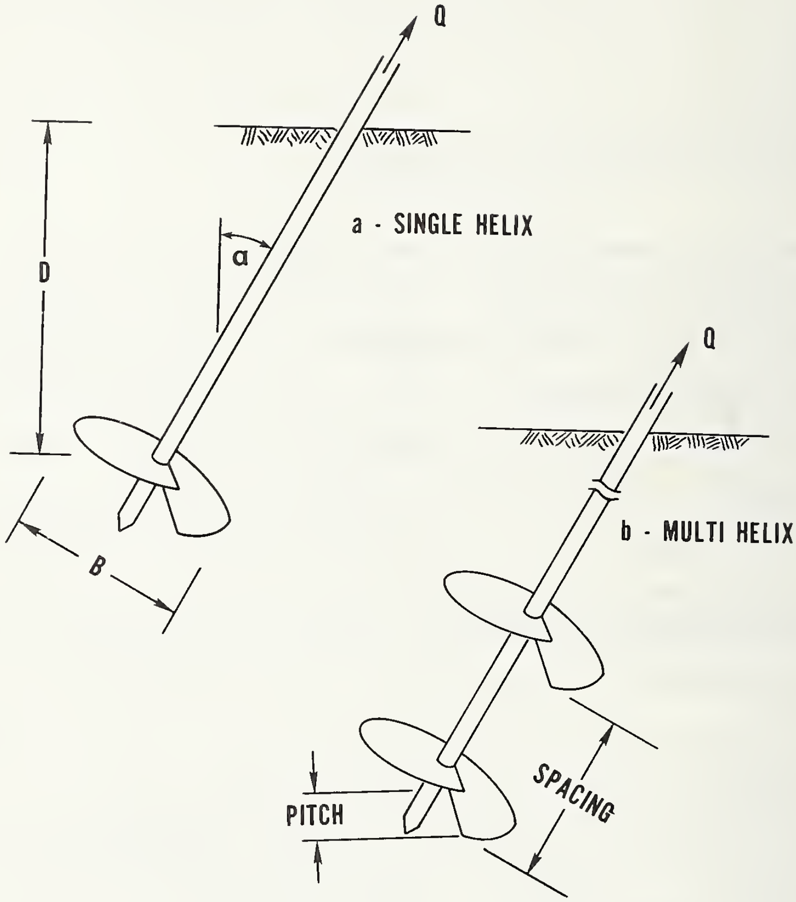
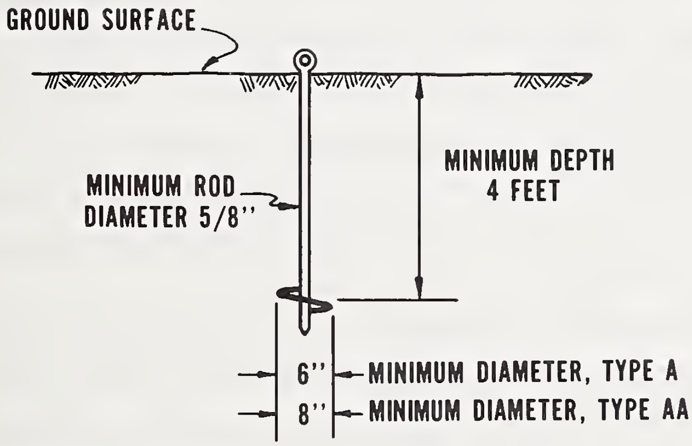


Figure 4.2 Helix and Multi-helix Anchors

Type A - A screw auger of minimum auger diameter of 6 inches with a minimum 5/8 inch diameter rod installed with a minimum depth of 4 feet. Also 8 inch size Arrowhead anchor.

Type AA - Same as Type A except minimum auger diameter is 8 inches. Also 10 inch size Arrowhead anchor.



NOTE: 1 in = 25.4 mm
1 ft = 0.30 m

Figure 4.3 Minimum Dimensions Recommended by Harris for Helix Anchors [46] density sands. According to Robinson [87], their use in very hard and dense materials or soils containing gravel and cobbles is very limited.

An alternative method for the installation of helix anchors is to partially excavate a hole to some depth, say for example 2 feet (0.6 m). Next, the helix anchor is installed and turned into the soil from the depth of 2 feet to the designed depth, typically 4 feet (1.2 m). Finally, the hole may be backfilled by tamping or compacting the soil, or perhaps better yet, filled with lean concrete. Filling the hole with concrete serves several useful functions. These are: added weight that the anchor must pull against; an increase in side resistance to a vertical pull-out; and an increased resistance to horizontal loads because of the increased bearing area of the concrete surrounding the shaft. The comments about horizontal anchor capacity apply to all of the types of anchors mentioned, since typically the diameter of the anchor shaft at the ground surface is very small (in the order of an inch (25 mm) or less) and, therefore, has a very small bearing area to transmit horizontal load to the soil. Proponents of the Helix Anchor will argue, and perhaps rightly so, if only vertical pull-out is considered, that [to achieve maximum pull-out capacity] the anchor should be torqued or twisted into place, never installed in a partially excavated hole and then backfilled. Further field tests are necessary to establish behavior under various installation conditions.

4.3.3 Triangular Anchors

The triangular (arrowhead) anchor is available on a commercial basis. The size that is typically available is the 6-inch (0.15-m) anchor. Harris [46] considered an 8-inch (0.20-m) arrowhead anchor to be comparable to a 6-inch (0.15-m) Helix anchor; and a 10-inch (0.25-m) arrowhead anchor equivalent to an 8-inch (0.20-m) diameter Helix anchor. The arrowhead anchor has been described in section 4.2.

4.3.4 Buried Expanding Plate and Shaft Anchors

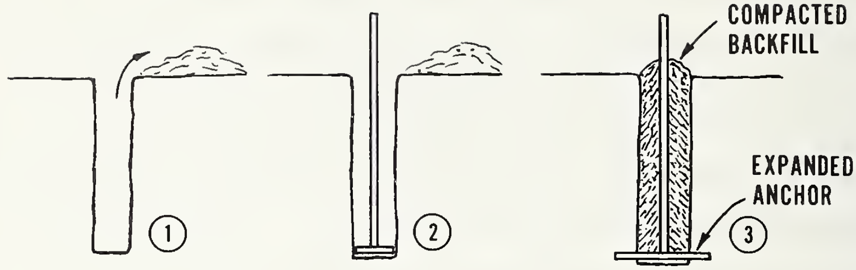
Two types of expanding plate anchors are available. One type, having a head and shaft similar to previously discussed anchors, consists of two plates 6 inches (0.15 m) in diameter at the base of the shaft. The anchor is installed in a 6-inch diameter hole excavated to the desired depth. [Manufacturer suggests a 22-inch (0.56-m) depth for soil groups 3 and 4 and a 24 inch (0.61 m) depth for soil groups 5 and 6 (the soil groups will be described in Section 6]. The anchors are so designed that the head and shaft are rotated 180 degrees which allows movement of the bottom plate relative to the top plate. The bottom plate is fixed to the shaft and head of the anchor while the top plate is free to rotate. What was initially a 6 inch (0.15 m) diameter set of circular plates becomes a set of two overlapping circular plates, approximately 9 1/2 inches (0.24 m) long by 6 inches (0.15 m) wide. Figure 4.4b(1) shows the above described expanding plate anchor.

The second type of expanding plate anchor is shown schematically in figure 4.4b(2). Again, the anchor is installed in a hole wide enough to accommodate the unexpanded anchor. Once the anchor is in position at the base of the hole, the anchor rod is twisted, causing the prefabricated anchor to expand into undisturbed soil. To complete the installation, backfill is placed and compacted.

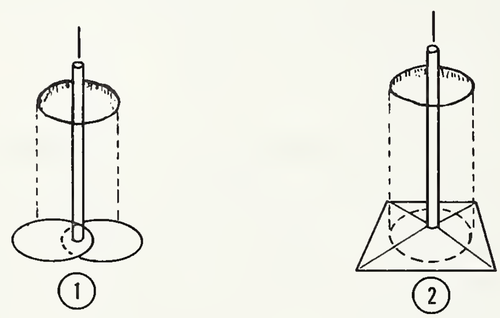
Harris [46] recommended a minimum anchor size of 6 inches (0.15 m) and a minimum placement depth of 5 feet (1.5 m), regardless of the soil type. His recommendation does not take into account the soil's shear strength and other factors to be discussed later in this report that govern the pull-out capacity of anchors.

4.3.5 Expanding Rock Anchor

At mobile home sites where it is impossible to install any of the above discussed anchors either by means of driving, excavation, or turning, it may be necessary to install an expanding rock anchor. An expansion



a. PROCEDURE (1) EXCAVATE HOLE. (2) INSTALL ANCHOR. (3) EXPAND ANCHOR AND BACKFILL.



b. TWO AVAILABLE TYPES. (1) ECCENTRIC PLATES. (2) EXPANDING SCREW DOWN PLATES.

Figure 4.4 Expanding Plate Anchors

type anchor is shown in figure 4.5. To install this type of anchor, it is necessary for a hole to be drilled slightly larger than the expansion parts. The hole is usually made with an auger and bit capable of penetrating the existing rocky soil or rock-like material. For harder rock, air-percussion or core drilling may be necessary. The expanding rock anchor may be anywhere from 24 to 48 inches (0.6 - 1.2 m) in overall length. The installation principle is very simple. Once the hole has been cleaned out to the desired depth, the anchor is inserted to the appropriate depth. The anchor head is turned, forcing the two anchor components to slide upon each other and thereby increasing their diameter. The anchor is turned until the installation torque, as specified by the manufacturer, is reached which allows the expandable part of the anchor to bear against the sides of the hole surface. The anchor is then available for immediate loading.

In softer or weathered rocks, there may be a tendency for the outside portion of the rock anchor to punch into the sides of the hole, allowing the center portion to slip out. If this is the case, then grouting is necessary to hold the anchor in place. Under these conditions, a second anchor is installed, tightened to a lower torque (less chance of wall punching), and the hole is filled with grout (91b).

Another type of anchor may be used in soil or rock locations where drilling is necessary. This circular shaft anchor is inserted into a pre-drilled hole 30 to 48 inches (0.8-1.2 m) in length and about 2 inches. (50 mm) in diameter, then expanded by means of hydraulic pressure. The hydraulic pressure forces out a multiple internal split tube anchor, forming six individual curved prongs which enter into or bear against the soil or rock hole. Finally, the top portion of the anchor tube is expanded. This type of anchor performs very well in softer or weathered rocks, as intimate contact is made with the side walls.

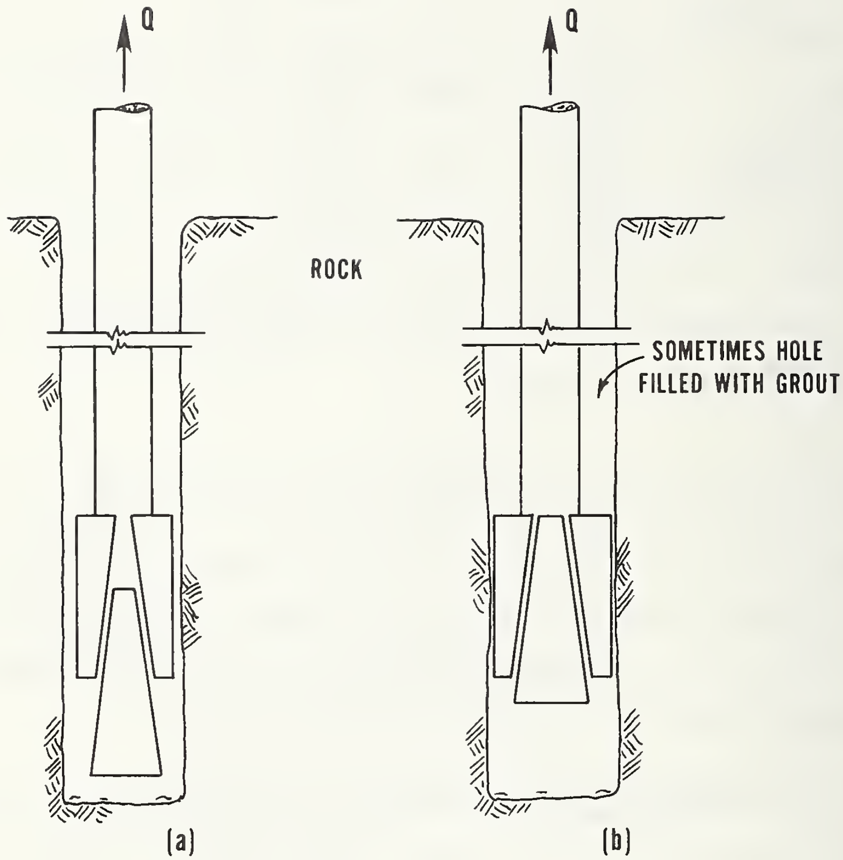


Figure 4.5 Principle of Expanding Rock Anchor: (A) Inserted in Drilled Hole; (B) In Expanded Position

4.3.6 Miscellaneous Anchors

Several other anchor types are either presently available for mobile home use or could be modified to serve this purpose. Some of these are discussed hereafter.

Several manufacturers offer an "X" type anchor for use in rock or rock-like material. Manufacturers suggest that this type of anchor be used when it is impossible to install, for example, a helix anchor due to rocky conditions. Pointed rods approximately 3/4 inch (19 mm) in diameter and 3 to 4 feet (0.9 - 1.2 m) long are either driven directly into the ground or into a pre-drilled hole at an angle of 45° from the horizontal. A second member is driven at an angle of 90° to the first anchor rod. The anchors are driven so that they fit inside a welded brace made of tubing as shown in figure 4.6. Anchor straps are attached to hardware which is welded to the top of the X-brace. This type of anchor obtains its load capacity when both members bear against the surrounding foundation material. In the event that this material yields under this load, or if bending occurs in the steel rods, the resulting displacement may exceed the allowable displacement. The soil conditions under which this anchor is useful appear to be limited. In order for the anchor to be installed, the foundation material has to be soft enough for penetration, yet hard enough to resist lateral deformation. Test data on this device are limited.

It has been found that grouted rods provide economical anchorage in relatively firm soils, such as dense sands and gravels, stiff clays, glacial tills, and weathered rock. Typically, a 6-inch (0.15-m) diameter hole (sometimes having a bell at the bottom) is made, and deformed or plain steel rods up to approximately 1-inch (25-mm) in diameter or heavy duty chains are inserted in the hole. The top of the rods or chains must contain some mechanism to tie down the mobile home. The hole is either partially or completely filled with grout and allowed to cure. [The grout generally used consists of equal amount of sand and Portland cement

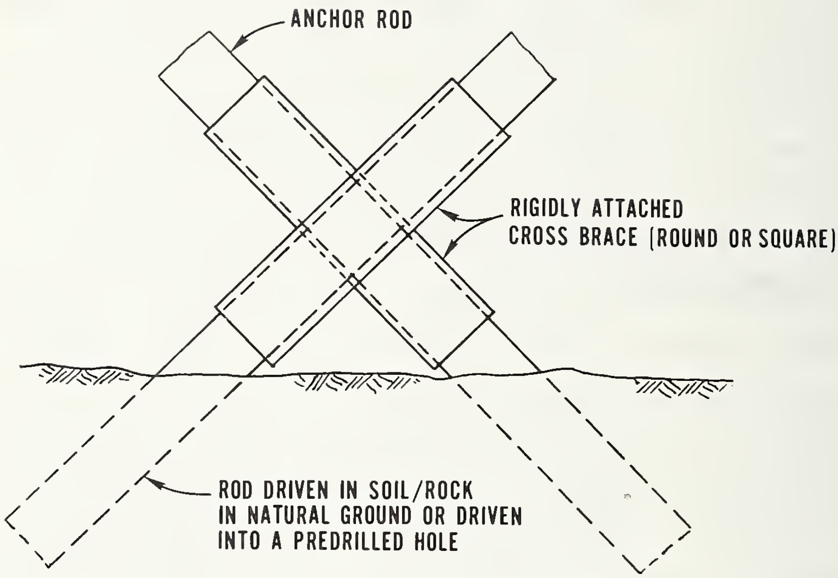


Figure 4.6 "X Type Rock" Anchor

with a water-cement ratio approximately 0.5 [87].] The larger diameter of the grouted hole provides considerable horizontal load resistance to the anchor.

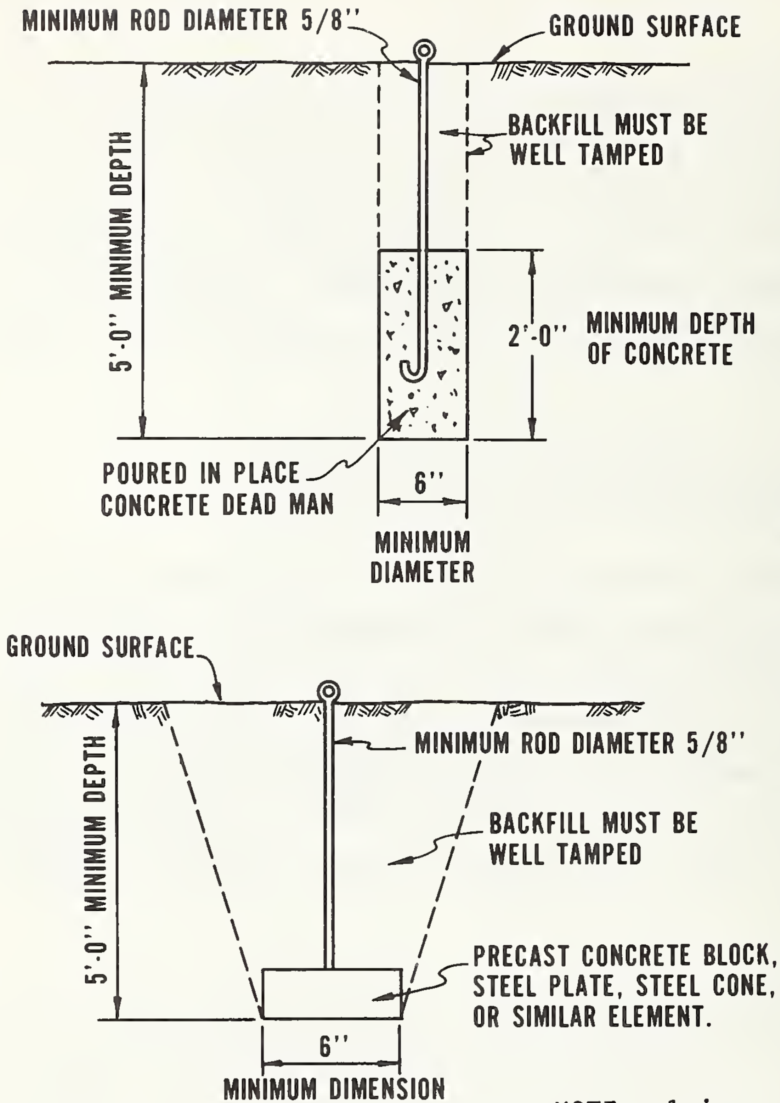
Economical tiedowns can also be provided by dead-man anchors. They can be improvised in many different ways, provided the system is durable enough. Examples of dead-man anchors are shown in figure 4.7. In both examples in the figure a hole is dug and either a J-shaped anchor rod is placed in concrete and properly backfilled or an anchor rod is attached to some element and placed at a minimum depth of at least 5 feet (1.5 m) [46].

4.3.7 Tie-down Systems Other Than Soil Anchors

Tie-down of mobile homes can also be provided by methods which do not require the use of soil anchors. These could include footings similar to those used for conventional single-family homes or any other suitably durable system capable of resisting the vertical and horizontal forces exerted by the mobile home when subjected to extreme wind or flood conditions. Safety factors against sliding and overturning should not be less than 1.5 and factors against bearing capacity failures not less than 2.

Examples of such tie-down systems are shown in figure 4.8. These systems are 4 in. (0.10 m) thick wire mesh reinforced concrete slabs on grade, which may have other configurations in addition to the ones shown. Examples of tie-down connections to the slabs are shown in figure 4.9. The tie rods may be installed in finished slabs by drilling a hole and inserting a bolt, as shown in the figure. A single excavation would then be required to gain access for installation and tightening of the nut and washer. Alternately, commercially available expanding concrete inserts could be used.

Another option is to use the J or L shaped anchors shown in figure 4.9b. Problems may arise with the use of cast-in-place anchor bolts if the



NOTE: 1 in = 25 mm
1 ft = 0.3 m

Figure 4.7 Examples of Dead-man Anchor Installation and their Minimum Requirements [46]

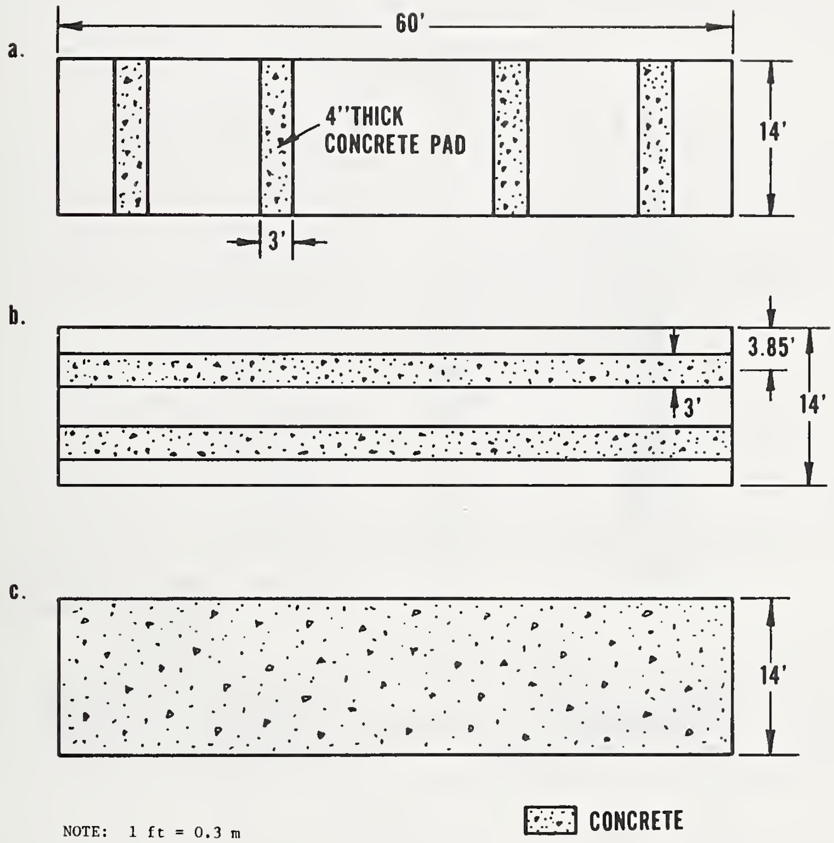


Figure 4.8 Concrete Slab System

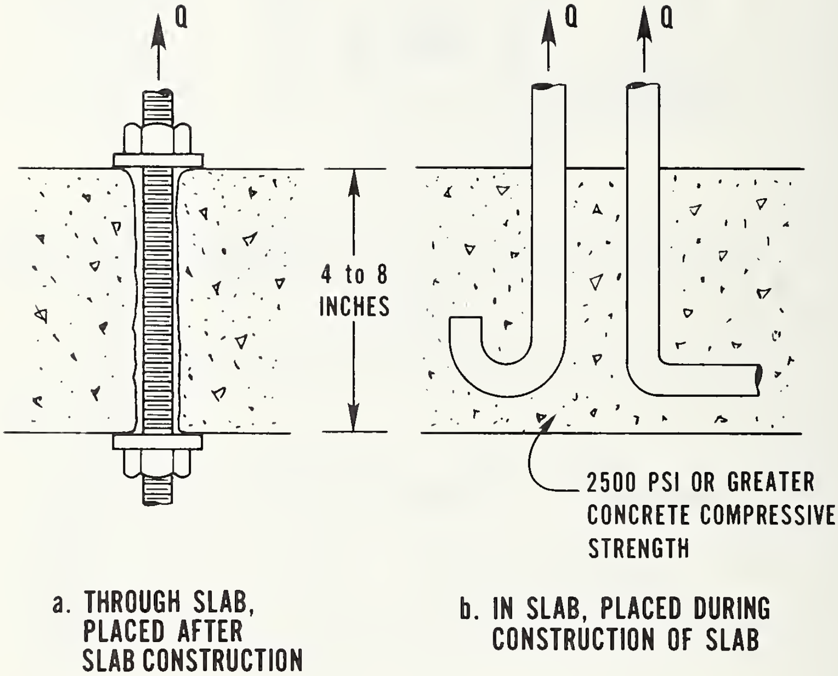


Figure 4.9 Concrete Slab Anchors

tie-down straps of the mobile home are not located over the anchors. Regardless of the anchor bolt configuration used, the slab must provide the weight necessary to stabilize the mobile home, and must have adequate moment and shear capacity to resist failure under the forces exerted by the tie-down straps, by the supporting piers, or by swelling soils. The constituent concrete must also be designed to resist weathering effects, such as those associated with freezing and thawing.

Another possible approach is the use of pier foundations. A pier (sometimes called caisson) is defined as a shaft, typically of concrete, installed to a sufficient depth below the zone of environmental changes to provide both downward (gravity) support as well as uplift and sliding resistance during windstorms. The usual construction method for piers is to drill or auger a series of holes 6 to 24 in (0.15 to 0.61 m) in diameter to a depth sufficient for the conditions described above and fill the hole with concrete and some reinforcing steel. The piers, perhaps four to eight on each side of the mobile home, would be located below the main structural support.

The mobile home is leveled with blocking material placed between the pier and the mobile home frame and is then anchored to the pier as described by Vann and McDonald [102a] or by any structurally sound method.

Comparable support is provided by a self-contained prefabricated foundation system which combines tie-down resistance with vertical support members. The system consists of steel pipe piles which are driven into the ground or grouted into a pre-drilled hole, adjustable pipe columns which telescope into these pipe piles, cross beams between these columns which are bolted to the mobile home frame and intermediate support piers which are bolted to the mobile home frame and rest on top of the ground. Such a system performs the same functions as soil anchors and supporting piers.

4.4 HARDWARE AVAILABLE FROM TELEPHONE AND POWER COMPANIES

Telephone companies throughout the United States use anchors to guy their poles and towers for telephone lines and transmission lines. Typically the loads on these anchors will be two to five times greater than that required for mobile home tie-down capacity. Due to the proprietary nature of soil anchoring technology used by telephone companies, information on the design of these anchors is not available to the public. However, the applicability of the design curves of manufacturers of anchors in the United States has been confirmed by telephone companies [90]. The power companies may use anchors to guy large transmission towers and their load requirements are up to 20 times the load capacity required for mobile home installation. Some transmission lines cover many hundreds of miles; geotechnical investigations along the routes of anchor locations are commonly performed. It is not uncommon for a typical transmission tower to use 4 to 12 anchors and savings of a few dollars per anchor, when multiplied by the number of anchors in the entire transmission line, can be substantial. Besides using helix anchors, the power companies also use grillage type anchors, dead-man anchors, grouted anchor rods, and straight shaft and belled caissons [27, 38, 52, 53, 54, 55, 60, 70, 73, 76, 79, 84, 98, 107, 108].

Facing page: *Examples of conditions arising when mobile homes are located in steep terrain.*

5. THEORETICAL PREDICTION OF ANCHOR PULL OUT CAPACITY

5.1 INTRODUCTION

In this section, published theoretical formulatins for pull-out capacity of soil anchors are discussed [16, 17, 67, 75, 102, 103, 106].

Even though, for the case of cohesionless soils, correlations between measured pull-out capacities and those predicted by present hypotheses do not appear to be very good [19], it is still reasonable to assume that there is a correlation between the pull-out capacity of anchors and the shear strength of the surrounding soil. Thus, any soil classification used in conjunction with predictions of anchor pull-out capacities should reasonably reflect the shear strength of the soils. Unfortunately, methods and terminologies presently used by the mobile home industry for classifying soils are neither consistent among themselves, nor do they convey much information on the shear strength of the soil. This inconsistency is a source of considerable confusion which should be eliminated.

Since the various terminologies and definitions associated with soil classification which are used by the mobile home industry differ from those accepted by the geotechnical engineering profession, it is necessary to first discuss professionally accepted methods of soil classification. Present confusion in terminology may lead to misunderstandings between the parties concerned with the selection and installation of soil anchors, namely the soils engineer, the mobile home owner, the anchor installer and the anchor manufacturer.

5.2 DEFINITIONS OF TERMS USED IN SOIL CLASSIFICATION

ASTM [11] defines soil as "sediments or other unconsolidated accumulations of solid particles produced by the physical and chemical disintegration of rocks, and which may or may not contain organic matter." Rock is defined as "natural solid mineral matter occurring in large masses or fragments." To further subdivide definitions for soil, we use the terms cobbles, gravel, sand, and fines. Fines can be either silt or clay. According to the Unified Soil Classification System [101] which is widely used in geotechnical engineering, these specific names are used to designate the size ranges of soil particles. The gravel and the sand sizes are further subdivided as shown in table 5.1. The boundaries between one soil type and another have been arbitrarily made and they are based on U.S. standard sieve sizes given in the table. For example, a fine sand would mean that the majority of a sample of sand would have particle sizes that would be between the number 40 and 200 sieve. To further classify the fines

TABLE 5.1 SOIL DESCRIPTORS AND SIZE RANGE

Component	Size Range
Cobbles	Above 3 inches (76 mm)
Gravel	3 inches to No. 4 sieve (4.76 mm)
Coarse Gravel	3 inches to 3/4 inch (19 mm)
Fine Gravel	3/4 inch to No. 4 sieve (4.76 mm)
Sand	No. 4 sieve to No. 200 sieve (0.074 mm)
Coarse Sand	No. 4 sieve to No. 10 sieve (2.0 mm)
Medium Sand	No. 10 sieve to No. 40 sieve (0.42 mm)
Fine Sand	No. 40 sieve to No. 200 sieve
Fines (Silt or Clay)	Below No. 200 sieve

(silts and clays), it is necessary to use geotechnical engineering laboratory tests which are beyond the scope of this report.

Typically, silts are defined as any fine-grained materials that will pass through the No. 200 sieve and exhibit little or no strength when the particles are in an air-dry state. By strength we mean its ability to hold shape under pressure from the fingers, for example. Arbitrarily, silt size is usually defined as those particles which are smaller than the No. 200 sieve (0.74 mm) but larger than .002 mm. After the individual soil particles can no longer be seen by the naked eye, the individual soil grains are finer than the No. 200 sieve size.

Clays, too, have two arbitrary classifications. One is by size and the other is by the mineralogical composition of the soil. Clay size is arbitrarily defined as any soil particle that is smaller than .002 mm.

Clay soils may be made up of particles of weathered rock that are smaller than .002 mm but more usually the definition is used for soil particles that are made up of clay minerals. Clay minerals are plates of microscopic size with very ordered atomic structures. The engineering properties of clays are the result of physical and chemical forces between the clay particles. Sand and silt particles are so large compared to clay particles that their engineering behavior is not dominated by the chemical and electrical forces that dominate clay soil behavior. By far the most significant characteristic of a clay soil is its ability to exhibit plasticity. Clay plasticity is that property which allows the soil to be moved around, for example, by the hand and still retain its deformed shape. Another definition of clay plasticity is for the soil to be rolled into a very thin thread (for example, 1/8 in (3.2 mm) in diameter) and still hold together. When these (plastic) clay soils are allowed to dry out, they will exhibit considerable strength upon drying. By this we mean the dried clay lump will be difficult to crumble by the hand and only great pressure would cause disintegration. All of these comments on soil classification are adequately covered in ASTM standards [11, 13, 14, 15].

It will be shown later that the pull-out capacity of an anchor is assumed to be a function of the shear strength of the material in which the anchor is embedded. When an anchor is pulled out of the soil, it can be said that it shears against the soil; or the soil immediately above a helix anchor, for example, shears the soil surrounding the anchor. The higher the shear strength of the soil, the harder it will be to pull out the the anchor. Before one can describe those tests which are used by the mobile home industry to determine anchor capacity, it is necessary to discuss terms describing the shear strength of the soils that have now been standardized to some extent.

Many states utilize the "Standard Penetration Test" as a means of classifying soils. The Standard Penetration Test (SPT) [12] is a field test in which a standard sampler which is approximately 30 inches (0.76 m) in length, 2 inches (51 mm) in outside diameter and 1 3/8 inches (35 mm) in inside diameter is attached to a drill rod and placed at the bottom of the properly cleaned out boring. A 140-lb (63.5-kg) weight raised 30 inches (0.76 m) above an anvil or striker plate is allowed to fall freely, imparting its energy to the drill rod to which the sampler is attached. The standard sampler is advanced in three 6-inch (0.15 m) increments and the number of blows it takes for the hammer to penetrate the second and third 6-inch increment is added and is called the "blow count" or "N" value. The SPT N value is fairly reliable in determining relative properties of granular soils (sands, silts and gravels). The Standard Penetration Test is over 40 years old and soils engineers have correlated many engineering properties of soil with the Standard Penetration Test N value. Table 5.2 presents an accepted soils engineering relationship between blow counts and descriptive terms used to describe relative density of sands. The term "relative density" is used to describe the weight per unit volume (or density) of granular soils "relative" to the maximum dry density and minimum dry density. For example, a soil whose natural density is close to the minimum dry density would be described as "loose." It is suggested that the terms used in table 5.2 be used in all future soil classification charts with respect to granular materials (sands). Words like "compact," which is a geologic term, should be avoided.

TABLE 5.2 PENETRATION RESISTANCE AND ENGINEERING PROPERTIES OF SANDS

Number of Blows per ft, N	Relative Density
0-4	Very loose
4-10	Loose
10-30	Medium dense
30-50	Dense
Over 50	Very dense

Note: 1 ft = 0.3 m

The correlation between blow count and the shear strength of clays should be considered a crude correlation at best. The term "consistency" is used with clay soils to describe a range of shear strength. Terms such as soft, stiff or firm, and hard are reserved for clays, but they are not used to describe sands. Qualitative and quantitative expressions for clay consistency are presented in Table 5.3. The primary intent of this table is to present the terms describing relative values of shear strength which are useful for classifying a soil for anchor holding capacity. Although Standard Penetration Test blow counts are included in the table and are associated with a "consistency," it has been noted that this correlation is "crude at best." A discussion of the use of the SPT and consistency may be found in Peck, et al. [83] where they describe why the test is unreliable in clays. It should be pointed out that the words stiff and firm are synonymous. Later we will attempt to correlate the shear strength with field and/or laboratory properties. In the field or in the laboratory, the shear strength of a cohesive soil may be determined by a pocket Penetrometer or a Torvane, both of which are hand held devices and are calibrated to read shear strength directly. In order to perform this test in the field or laboratory, an undisturbed sample needs to be obtained, or a test pit excavated at the mobile home anchor site and the test performed in the ground on natural material. This type of test described is only applicable for cohesive soils. Another approximation of the shear strength of cohesive soils may be obtained by the crude field identification tests outlined in table 5.3 or, more accurately, by laboratory tests.

Another term that is frequently encountered is the word "loam". Loam is another word for top soil as it contains organic matter along with any possible combination of sands, silts, or clays. Humus is the specific name of the organic material. Humus may be composed of either animal or vegetable matter that has decayed.

Perhaps the word "fill" is the least understood term of all. Generally when fills are encountered, they are automatically classified as a rather

TABLE 5.3 QUALITATIVE AND QUANTITATIVE MEASURES FOR CONSISTENCY OF CLAYS (83)

Consistency	Field Identification	Unconfined Compressive Strength q_u (tons/sq ft)	Undrained Shear Strength (tons/sq ft)	Number of Blows per ft, N (Rather Unreliable)
Very Soft	Easily penetrated several inches by fist	Less than 0.25	0-0.125	Below 2
Soft	Easily penetrated several inches by thumb	0.25-0.5	0.125-0.25	2-4
Medium Stiff or Medium Firm	Can be penetrated several inches by thumb with moderate effort	0.5-1.0	0.25-0.5	4-8
Stiff or Firm	Readily indented by thumb but penetrated only with great effort	1.0-2.0	0.5-1	8-15
Very Stiff or Very Firm	Readily indented by thumbnail	2.0-4.0	1-2	15-30
Hard	Indented with difficulty by thumbnail	Over 4.0	Over 2	Over 30

NOTE: 1 ton/sp. ft = 96 kPa
1 ft = 0.3 m

poor supporting soils. This may not necessarily be the case and one should differentiate between fills which are merely dumped and could contain any possible combination of materials that might be discarded in a dump and an "engineered" or "controlled fill" which is carefully compacted in place by appropriate earth moving and earth working equipment. Usually "compacted earth fills" are performed under appropriate engineering specifications and supervision (control) and result in a substantial improvement in engineering properties over natural soil. Fill material could be granular, cohesive or some combination of the two general soil types. Its relative density or consistency can be determined by the Standard Penetration Test or the two field tests previously described.

Terzaghi and Peck [93] proposed the categories in table 5.4 which apply to the amount of saturation in sandy soils only. The term "degree of saturation" is the amount of water as a percentage of the void spaces within a soil mass. If all of the voids of a natural soil sample are filled with water, the soil is said to be saturated. Such would be the case for any soil deposited under water. In order to determine the degree of saturation, it is necessary to perform laboratory tests which are beyond the scope of this report. More than likely, most fine grained sands would be defined as moist or wet and the coarse grained sands and gravels, at best would be described as humid or damp.

TABLE 5.4 DEGREE OF SATURATION OF SAND IN VARIOUS STATES [93]

Condition of Sand	Degree of Saturation (Percent)
Dry	0
Humid	1-25
Damp	26-50
Moist	51-75
Wet	76-99
Saturated	100

It will be shown later in this section that the pull-out capacity of anchors in clays (cohesive soils) has been found to be a function of the shear strength of the clay. Shear strength of clays is described by their consistency as shown in table 5.3.

Some states use the words "wet clay" and "dry clay" exclusively when classifying clays in relation to the holding capacity of anchors. This implies that the degree of saturation is the only significant parameter. While this may be the case in some localized areas (dry clays may behave more like granular soils or rock, may crumble when the anchor is inserted and may be affected by fissures), clays tend to be wet in most areas, since they have been formed under water and tend to maintain a high degree of saturation because of their low permeability. In most cases only a very thin layer at the surface will be "dry." Where this is the case it is important to include consistency in the soil classification. Thus, better approaches are needed to describe the pull-out capacity of anchors in cohesive soils than exclusive reliance on "wetness" or "dryness."

5.3 THEORETICAL PREDICTION OF PULL-OUT CAPACITY

5.3.1 General

In this discussion "pull-out capacity" is defined as the maximum load or pull exerted when removing an anchor from the soil. The load could be in line (coaxial) with the anchor shaft or at some angle to it. The anchor is not necessarily installed in a vertical direction. Anchor response to load is measured by the displacement of the anchor head, which is measured either by its vertical component, by a vertical and a horizontal component, or as a distance in the direction of the applied load. The term "uplift deflection" is sometimes used to designate the the displacement in the direction of the applied load.

Pull-out capacity is discussed separately for cohesive and granular soils, since anchor behavior differs for the two types of soils. The reader may consider a soil that has 30 percent of the clay sizes mixed with 70 percent of the granular materials. How will this soil behave?

Probably the soil will behave like a cohesive soil because it may be possible that the clay component will completely surround all the granular particles, not allowing them to touch and the soil can thus be considered cohesive. As the percent of granular particles increases to a point where, on the average, the individual soil grains are touching, then the soil behaves as a granular material which has entirely different behavioral properties than cohesive soils. Granular soils have no tensile strength and therefore obey the laws of friction. The friction resistance between particles increases as the normal load upon them increases. Thus, the deeper an anchor is located in granular materials, the higher will be the pull-out capacity.

5.3.2 Pull-Out Capacity in Cohesive Soils

As stated in section 5.2, clay soils are defined as having very small particles, with individual soil grains invisible to the naked eye, as well as having an attribute we describe as plasticity. Plasticity was defined as the ability of the soil to deform under load and remain in that deformed position upon removal of the load.

Without discussing the technical aspects which can be found, for example, in references 3, 56, 61, 72, 73, 74, 75, 92, 102 and 103, suffice it to say that the pull-out capacity of an anchor buried or installed in cohesive soils is dependent on the anchor depth-to-width ratio up to a point, and is also a function of the shear strength of the soil. Each soil has a bearing capacity which is a pressure (load divided by the area over which the load acts) above which failure would be said to occur. Shear strength of cohesive soils can be shown to be inversely proportional to the water content. The higher the water content, the lower will be the shear strength of the soil. Stated in the form of an equation the pull-out capacity in cohesive soils is given by:

$$Q = N_u \, c \, A + S \qquad \ldots \quad \text{(eq. 1)}$$

where A = projected area of the plate or helix,

c = undrained shear strength of the soil just above the top of the anchor plate,

N_u = an uplift capacity factor or pull-out coefficient, a function of the D (Depth)/B (Anchor Width) Ratio, (u signifies "uplift"),

Q = pull-out load capacity,

S = shaft resistance which is equal to the product of the average adhesive stress (equal to or less than c) on the anchor shaft and the anchor shaft surface area.

The purpose of this equation is to show that the pull-out capacity of an anchor plate or helix depends on the shear strength of the soil, c, and the area of the anchor plate or helix. The pull-out coefficient N_u, has been found to vary with the ratio of anchor depth (D) to anchor width (B). Such a relationship is shown in figure 5.1 [33]. A typical 6 inch (0.15 m) helix anchor (B = 6"), placed at a depth of 4 feet (1.2 m) (D = 4') has a corresponding D/B ratio of 48"/6" or 8. The value of D/B is entered at the bottom of the curve. Following the arrows, a pull-out factor N_u of 6.5 is obtained that would be used in equation 1. It can be seen from figure 5.1, that below a certain depth the pull-out capacity of anchors is independent of depth; this is only true for cohesive soils. Field tests have shown that the pull-out capacity of an anchor is about equal to the bearing capacity of the anchor against downward loads, for D/B ratios greater than 6 [6]. Typically, for mobile home anchors the contribution from the shaft capacity (the term "S" in equation 1) is small compared to that of the anchor plate or helix. This means that, for the same strength, pull-out load capacity can be increased by using a larger

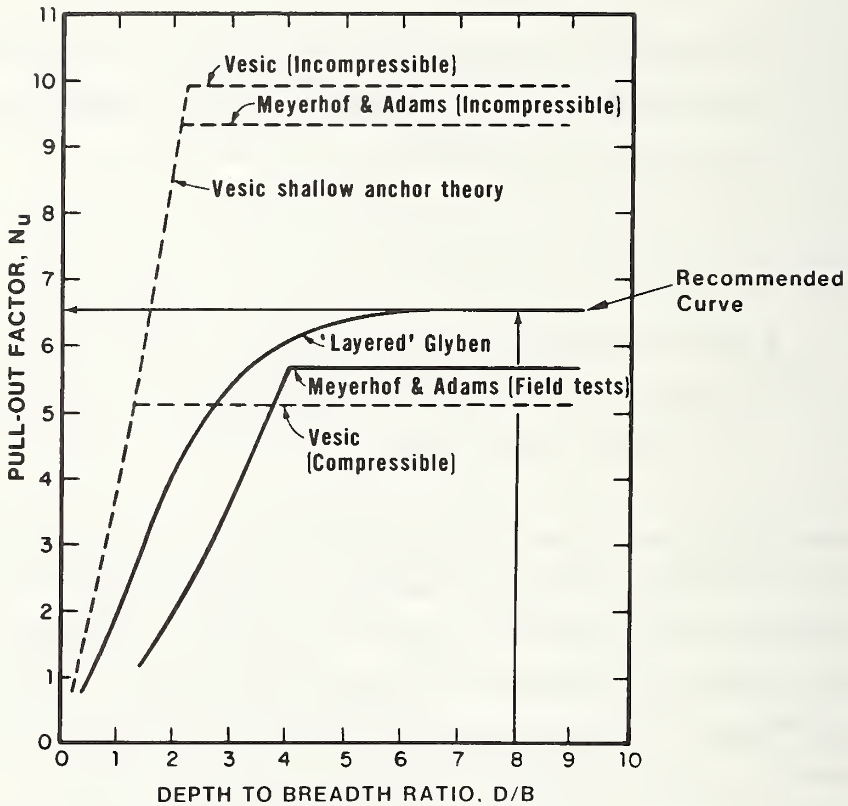


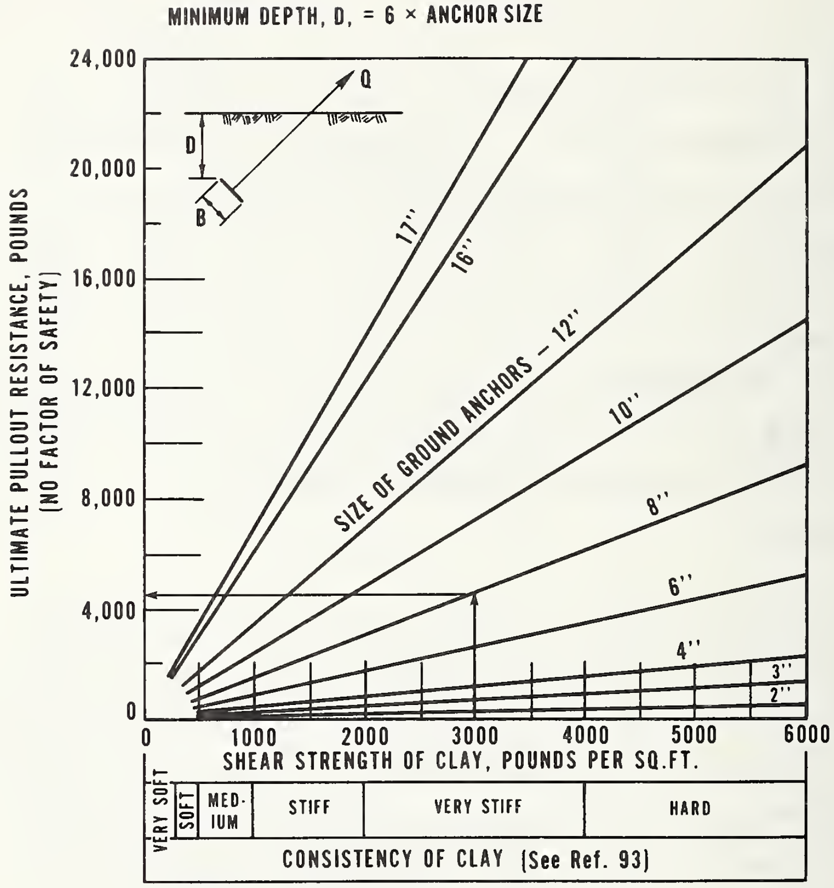
Figure 5.1 Pull-out factor N_u, versus D/B Ratio for Cohesive Soils [33]

anchor. However, if a larger anchor plate or helix is used, it must be structurally designed to take the additional load.

Haley and Aldrich [44] use a pull-out factor, N_u, equal to 7 for cohesive soils. For this given value of the pull-out factor, a graph relating ultimate pull-out resistance versus the shear strength of clay (in psf) for various size triangular anchors from 2 to 17 inches (50 to 430 mm) is presented in figure 5.2 [66]. The consistency of the clay conforms to the definitions used in table 5.3. To use this design chart, which is based on equation 1 with a value of the pull-out factor equal to 7, one determines the shear strength of the clay, enters the graph for a given size of ground anchor and reads the ultimate pull-out capacity directly. For example, for a shear strength of 300 psf (14 kPa) and an 8-in (0.2-m) arrowhead anchor, the pull-out capacity would be approximately 4700 pounds if the anchor was at a depth of at least 4 feet (1.2 in) below the ground surface.

Full scale pull-out tests [2, 4] have been summarized by Adams and Radhakrishna [5]. They found the long term capacity of anchors in clay soils to be smaller than the capacity of short term loaded anchors. The soil appears to be loaded in tension at least at the shallow depths. This probably results in negative pore water pressures thus increasing the shear strength of the clay. (If there is negative pore water pressure, the pressure of the water within the pores of the soil is less than the hydrostatic pressure attributable to the ground water level in the soil). With time, these negative pore pressures dissipate under long term loading, resulting in a corresponding reduction in shear strength and pull-out capacity [5]. In contrast, for normally consolidated clays, [on the ocean floor], the long term capacity has been observed to be significantly larger than the short term capacity [91b].

Typically the shear strength of soils increases with depth and as a result the pull-out capacity will be larger as the depth increases. However, there are some cases where a dried out crust of cohesive soil will exist above a softer clay layer of lesser shear strength. In this



NOTE: 1 in = 25.4 mm
1 lb ≈ 4.4 N
1 lb/ft^2 = 48 pa

Figure 5.2 Ultimate Pull-out Capacity of Triangular Anchors versus Shear Strength of Clays [66] particular case the pull-out capacity would be a function of the soil shear strength immediately above the anchor plate or helix [103]. The soil shear strength just above the anchor could only be determined by a suitable engineering site investigation.

5.3.3 Failure Mechanisms for Shallow Anchors

Baker and Kondner [16] and Ali [9] have summarized the failure hypotheses for shallow anchors by the "friction cylinder method," the "soil cone method" and Balla's method. The shapes of the corresponding failure surfaces are shown in figure 5.3. In the friction cylinder method, the pull-out load, Q, is resisted by the weight of soil, W_s, immediately above the anchor as well as the shear resistance, S, between the soil at the circular boundary (for a circular embedded plate). In the soil cone method, the pull-out load Q is resisted solely by the weight of the soil contained in the truncated cone (unless the soil has tensile strength). In Balla's method [17] the pull-out load, Q, is resisted by the weight of soil within the assumed failure surface (see figure 5.3c) and the side shear resistance.

5.3.4 Pull-out Capacity in Granular Soils

The pull-out capacity in granular materials is more complicated in theory than that for cohesive soils. A short discussion of the shear strength of sand is necessary to appreciate the pull-out behavior of anchors in sand. As stated previously, the shear strength of sand depends upon the frictional forces between individual sand grains. These frictional forces are proportional to the normal load that is exerted on the grains themselves. This normal load is proportional to the depth below the ground surface and is commonly referred to as the "overburden pressure." This pressure is the product of the unit weight of the soil and the depth below the suface. This means that for a given soil deposit, the shear strength will increase as the depth is increased. Perhaps the most important factor contributing to the shear strength of granular materials is the density of the granular materials itself.

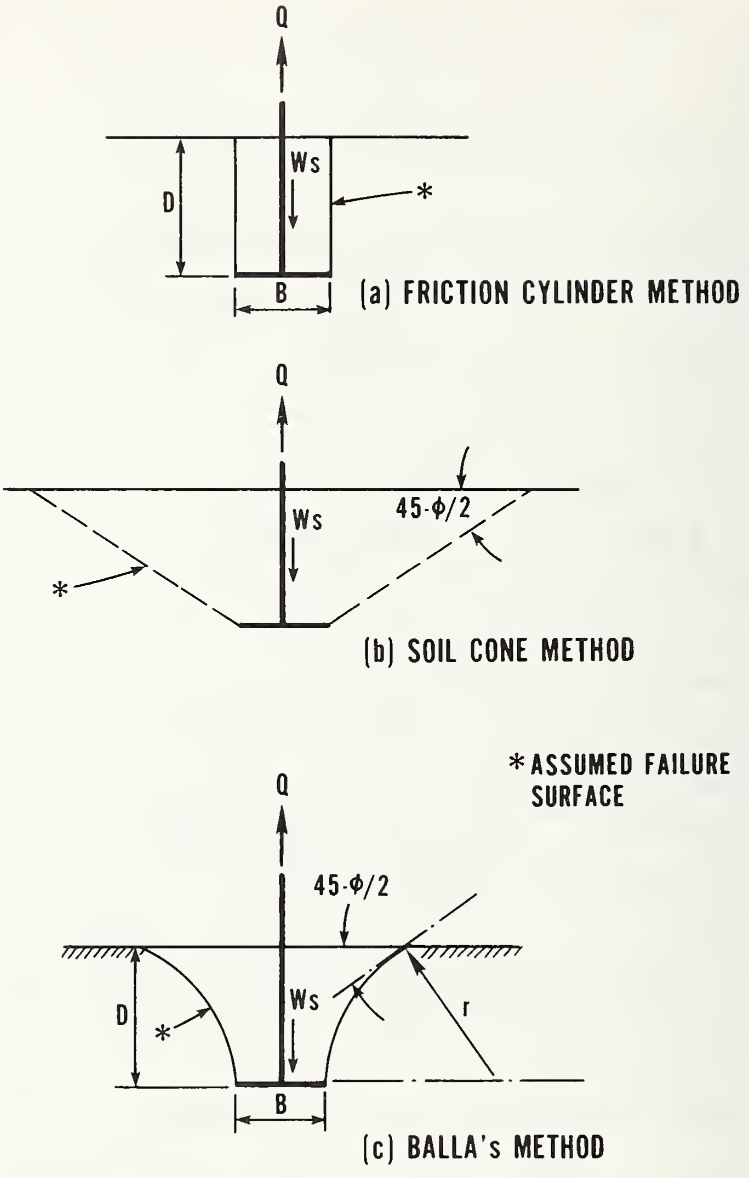


Figure 5.3 Methods of Calculating Pull-out Load Capacity [9]

Engineers also use the term "relative density," a value which is difficult to measure. It can be shown that it should be possible to predict the pull-out capacity of a buried circular plate, such as a helix anchor, by the following equation:

$$Q = \gamma D N_{qu} A \qquad \ldots \text{ (eq. 2)}$$

where

A = projected area of the plate or helix

D = depth of the anchor plate below the ground surface

N_{qu} = a pull-out factor for granular material which is a function of the angle of shearing resistance of the sand, and the D/B ratio (u signifies "uplift")

Q = pull-out capacity

γ = weight per unit volume of the soil (for soils that are below the ground water table, the buoyant or submerged weight per unit volume should be used)

The "angle of shearing resistance" or "angle of internal friction," ϕ, is a soil parameter used to describe the shear strength of a granular soil and depends primarily on the density. Before it was mentioned that the shear strength of sand depends upon the normal forces acting on individual sand grains. It can be shown that the ratio of the shear force to the normal force is equal to the tangent of ϕ, a measure of the coefficient of friction between individual sand grains. An approximate relationship exists between the Standard Penetration Test N value and the angle of shearing resistance, ϕ, and is shown in figure 5.4. Notice that we have taken the relative density terms from table 5.2 and superimposed them on figure 5.4. Knowing the Standard Penetration Test blow count, one could use figure 5.4 and establish the angle of shearing resistance, and then the pull-out coefficient N_{qu}, from a suitable reference. For

APPROXIMATE EMPIRICAL RELATIONSHIP
BETWEEN $\phi°$ AND SPT BLOW COUNT, N.

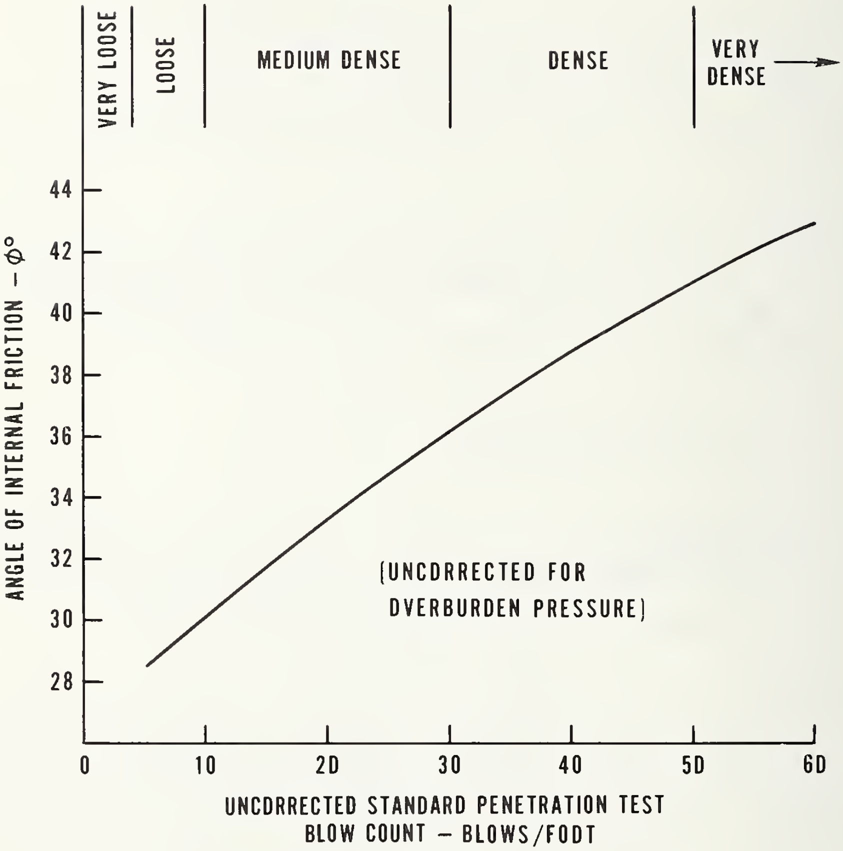


Figure 5.4 Angle of Internal Friction (Shearing Resistance) versus (Uncorrected) SPT Blow Count for Sands [83]

example, Vesic [103] tabulates the pull-out coefficient for given values of ϕ. However, for a six inch (0.15 m) anchor, these pull-out coefficients are only applicable up to a depth of 30 inches (0.76 m) which is perhaps too shallow for helix anchors in sands.

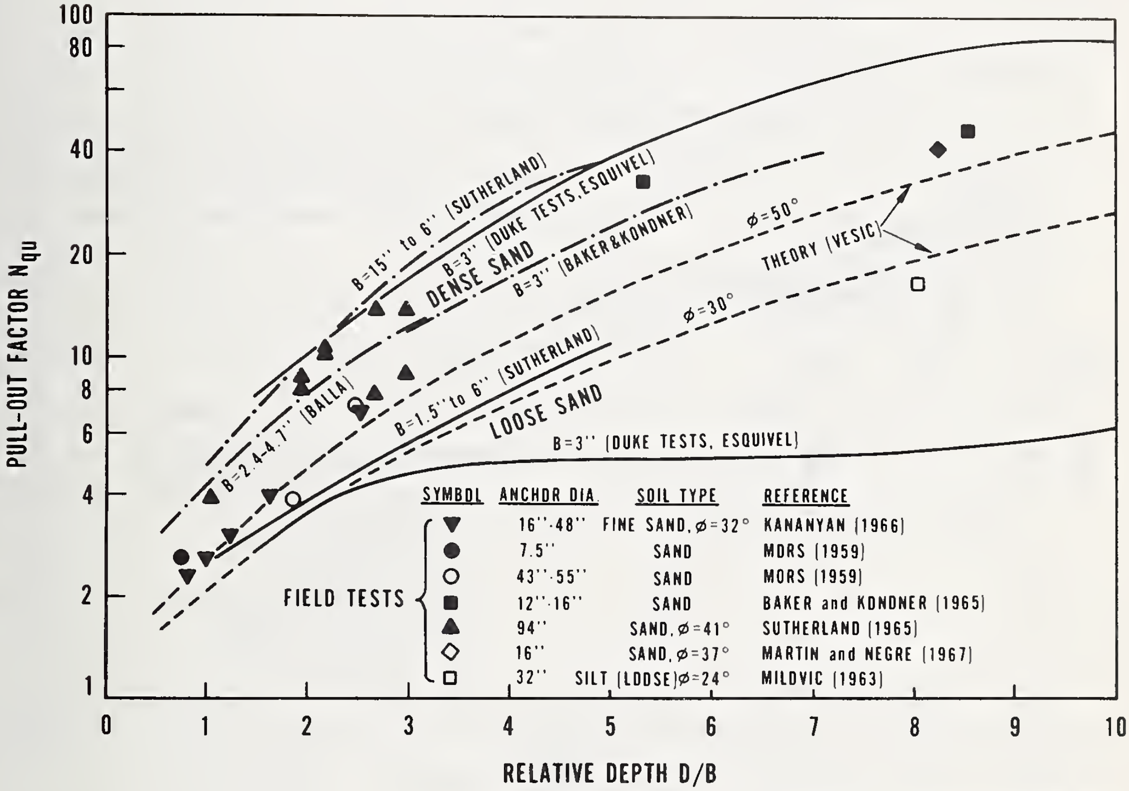
When Healy [48] performed both model and field pull-out tests in granular materials, he found that the pull-out resistance of small anchors (6 inches - 0.15 m) when placed in sand varied directly with the depth (another way of describing the overburden pressure) provided that the anchors have D/B ratios equal to or greater than 6 in dense sand and D/B ratios equal to or greater than 2 in loose sand.

Baker and Kondner [16] performed model tests on circular steel plates up to 3 inches (76 mm) in diameter and depths of burial up to 21 inches (530 mm) in sands. Load was applied to the bearing plates by means of a flexible cable. This approach does not simulate the loading condition of the typical mobile home plate with the exception of the triangular anchor which does not have a rigid connection at the anchor. They defined a "shallow" anchor as D/B ratios less than 6 and a "deep" anchor as D/B ratios greater than 6. They found that Balla's method [17] predicts a greater pull-out capacity than actually developed when the D/B ratio is greater than 6.

Adams and Hayes [2] photographed model pull-out tests in sand for D/B ratios between 2 and 4.5. The failure surfaces change with relative density and D/B ratio. At shallow depths (D/B $\approx$2), regardless of the density, the failure shape very closely approximated the friction cylinder method assumption. At greater depths (D/B = 4.5), the failure zone was "local" for a loose sand condition while for the dense sand tests, the failure zone reached the ground surface. Assumed failure surfaces for three therories were shown in figure 5.3.

For a range of D/B ratios from 0 to 10, Vesic [103] has prepared figure 5.5, pull-out factor, N_{qu} vs D/B ratio for sands. Adams and Klym [3] report N_{qu} values ranging from 21.4 to 33 for ϕ = 35° and values of 36 and 43 for $\phi = 45°$. They back figured the values of N_{qu} from multi-helix tests in which each helix was assumed to act independently. These values agree with Vesic's data shown in figure 5.5 at high D/B ratios. However, it seems reasonable to assume for dense sands that the failure surface (mechanism) may extend to the ground surface and multi-helix anchors may develop one uniform cylindrical failure surface as opposed to independent failure surfaces for each helix for $D/B \leq 10$.

It is interesting to note the comparison of pull-out capacity of a specific anchor (a 55 in^2 (0.035 m^2) Y fluke) for various depths of embedment as calculated by seven different theoretical methods. A comparison of calculated capacities and capacities obtained in field loading test is shown in figure 5.6 [19]. It appears that there is some semblance of agreement between predicted and measured values for D/B ratios less than 3. At a D/B ratio of 4, the predicted pull-out capacity varies from 270 pounds to 1460 pounds (1.2 to 6.5kN) as shown on figure 5.6. As the anchor is embedded further, only the friction cylinder hypothesis gives reasonably conservative results. This was also observed by Das and Seeley [32]. Comparisons such as this are the only true way to evaluate the adequacy of any theoretical computation. In addition to the questionable validity of assumed failure surfaces, the soil property numbers that go into the various equations are no better than the field and laboratory testing made to obtain these parameters. If an adequate soils investigation is not made, then we must rely upon full-scale prototype pull-out tests. Based on the wide scatter for the pull-out factor, N_{qu}, vs D/B relationship presented in a graph similar to figure 5.5, Esquivel-Diaz [37] concluded that no satisfactory theory is available for the determination of the pull out capacity of earth anchors in sands. This conclusion was reiterated by Bhatnagar [22] when he compared his model pull-out tests in silty clay with several theoretical assumptions. He found that none of the existing hypotheses give satisfactory predictions of the pull-out load for plate anchors at <u>all</u> depths. In geographic areas where experience and knowledge



NOTE: 1 in = 25.4 mm

Figure 5.5 Pull-out Factor, N_{qu}, versus D/B Ratio for Sands [103]

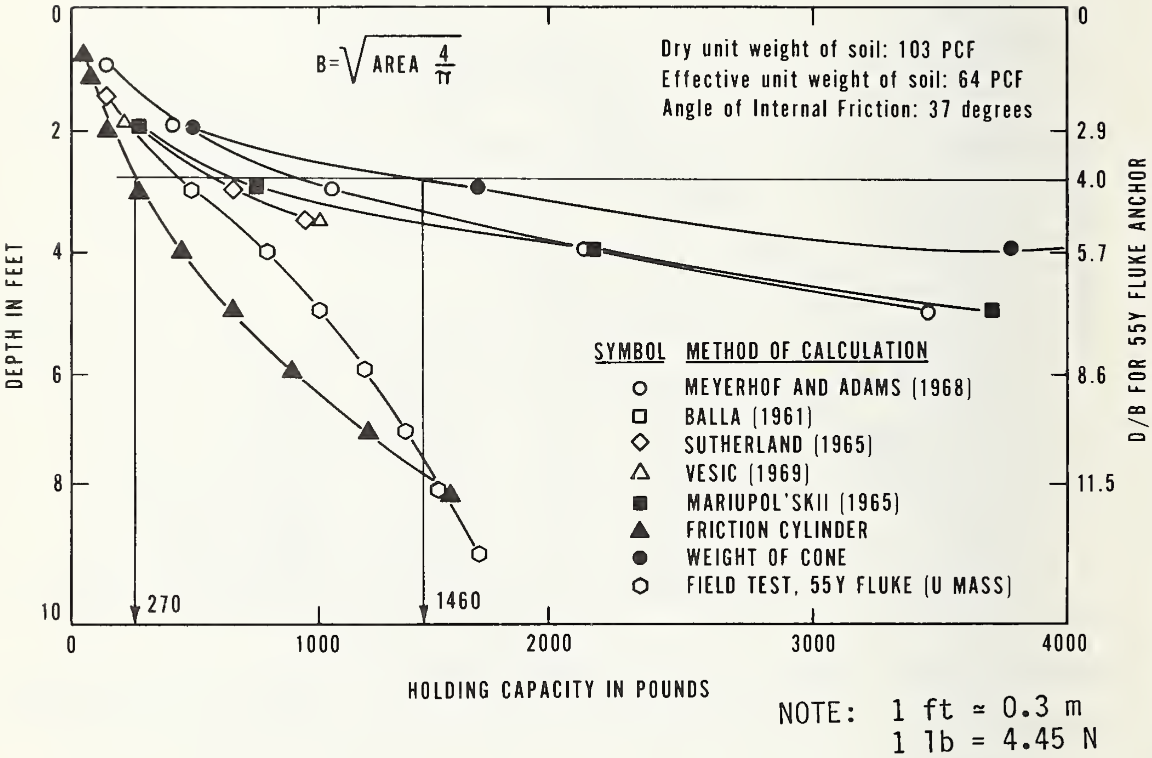


Figure 5.6 *Comparison of the Holding Capacity of an Assumed 55 Square Inch Fluke in Anchor Saturated Sand Using Available Methods of Calculations* [19]

of pull-out capacity is lacking, only full scale pull-out tests can provide a reasonable basis for predicting pull-out capacity.

Tabulated values of pull-out capacity for triangular-shaped anchors have been prepared in table 5.5 with the explanatory terms presented in table 5.6 [66]. These values are based on equation 5.2 but with the modification that a factor of 0.8 is applied to equation 5.2 to take into account eccentricity in loading and other uncertainties in pressure distribution [46]. In addition, the values of the pull-out factor, N_{qu} are taken from Reference 93 for deep foundation conditions, that is, for D/B equal to or greater than 5 or 6. In order to use table 5.5, one would have to satisfactorily classify the soil according to one of the four soil classes given in table 5.6. The terms that are used in this table come directly from the correlation between Standard Penetration Test blow count and relative density presented in table 5.2 and shown on figure 5.4. Thus, the Standard Penetration Test would, no doubt, have to be performed to indirectly measure the angle of internal friction of the soil in order to select a suitable pull-out coefficient, N_{qu}.

5.3.5 Pull-out Capacity in Rock

For purposes in this report, rock is described in two different ways. The first is the kind of rock that we would properly classify as "rock" but in terms of behavior, it more or less should be called soil. Rock of this particular type may easily be dug by hand with a shovel and pick or with a pneumatic spade. Cemented sands and gravels, for example, may also be grouped as "rock like" but can be dug and should be treated as soil. A further arbitrary classification is that any rock that has an unconfined compressive strength of 125 lb/sq in (862 kPa) or less should be treated as a soil. The unconfined compressive strength test must be performed on a core sample in a testing laboratory under controlled conditions, a procedure probably unnecessarily complex for the users of this report. Under these conditions, a mobile home owner would be well advised to determine local experience for this "soil condition" from local anchor installers or manufacturers, if available.

TABLE 5.5 TABULATED VALUES OF ULTIMATE PULLOUT RESISTANCE FOR TRIANGULAR SHAPED ANCHORS [66]

Size of Arrowhead Anchor (inches)	Minimum Vertical Depth (1) (feet)	Ultimate Pullout Resistance At Minimum Depth in Pounds (No Factor of Safety) SOIL CLASS(2) (See Table 5.6 for Description)					Percent Reduction For Ground Water Above Anchor(3)	Percent Increase for Additional Depth (4)	
		Hardpan	1	2	3	4		Above Ground Water	Below Ground Water
2	2	600	300	170	100	50	20	30	15
3	2-1/2	1,300	700	450	240	120	15	25	15
4	2-1/2	2,300	1,200	750	400	200	15	25	15
6	3-1/2	5,000	3,000	2,000	1,200	600	12	20	10
8	4	9,000	6,500	3,500	2,220	1,250	10	20	10
10	5	14,000	11,000	7,000	4,000	2,400	8	15	8
12	6	20,000	17,000	11,500	7,000	4,000	7	15	8
16	8	40,000	34,000	24,000	16,000	9,000	6	10	5
17	8	45,000	37,000	26,000	18,000	10,500	6	10	5

1 in = 25.4 mm, 1 ft = 0.30 m, 1 lb = 4.45N

Notes:

1. In determining vertical depth to the ground anchor, the thickness of topsoil, peat, soft clay and similar soft soils at ground surface should not be included.

2. The applicable class of soil is that present within a zone from the ground anchor to a point from one to three feet above the anchor, depending upon the anchor size.

3. For ground anchors at minimum depth in Soil Classes 1-4, reduce ultimate pullout resistance by percentage given for each foot ground water table is above anchor. No reduction is required for hardpan.

4. For ground anchors driven to depths greater than the minimum in Soil Class 1-4, the ultimate pullout resistance may be increased by the percentage given for each additional foot below the specified minimum. The ultimate pullout resistance shall not exceed twice the tabulated value, however. No allowance for additional depth is made for hardpan.

TABLE 5.6 TERMS USED IN TABLE 4.5 [66]

SOIL CLASSIFICATION:

Hardpan: A very compact (dense) heterogeneous mixture of soil particles ranging from those of silt and clay size to sand, gravel and perhaps boulders and generally exhibiting very high dry strength. Excavation of hardpan by pick and shovel is difficult.

Soil Classes 1 - 4: Cohesionless sands and gravels which are nonplastic in the wet state and which possess no strength or cohesion between individual mineral particles or rock fragments in the dry state.

SOIL CLASS	DESCRIPTION
1.	Dense gravel; Dense well-graded sand and gravel with angular particles.
2.	Medium-dense sandy gravel and gravelly sand; Medium-dense to dense well-graded sand.
3.	Loose to medium dense well-graded sand. Medium dense to dense, medium to fine sand.
4.	Loose fine sand and loose medium sand with well-rounded particles; Uncompacted sand fill.

SAFETY FACTOR:

A minimum factor of safety equal to two is recommended when a reliable soil classification is available. Where uncertainities in soil classification and loading exist, use a factor of safety equal to or greater than three. The factor of safety should be applied after tabulated values have been corrected for ground water and additional depth.

The second type of rock to which this section addresses itself is the type of rock that would ring when struck with a hammer. Without bothering to classify the rock with respect to its geological origin (or go into an elaborate classification system as had been done for soils) consider an intact rock that is solid and can not easily be broken up by a pick and shovel or pneumatic spade as described before. Under these conditions it is necessary to drill a hole in order to install the anchor. A hole may be bored by a core boring bit or by a percussion type rock bit. A jack hammer may also be used.

One type of rock anchor is the expanded rock bolt. A crude approximation of the minimum pull-out capacity of expanded rock bolts, actually applicable to all types of rock anchors, may be found by assuming anchor penetration to some depth, d, below the ground surface. For a vertical applied load, consider a failure surface in the shape of a cone with a 30° apex angle from the vertical. The pull-out capacity would be at least equal to the weight of the rock inside this cone. It is accepted engineering practice to assume a cone angle between 30° and 45°. This approach is extremely conservative since the tensile strength of the rock is disregarded. Obviously, considerable judgment must be exercised in the event that the surface rock is fractured or contains structural discontinuities. A plot of pull-out capacity versus anchor depth for a rock anchor, assuming that only the weight of the rock contributes to pull-out capacity is shown in figure 5.7. It is further assumed that a 30° conical failure surface exists and that the unit weight of the rock is 150 lb/cu ft (2400 ton/m^3), a conservative value. In accordance with this graph, in order to meet the requirements for a mobile home tiedown anchor, it is necessary to install the anchor at least 4 1/2 ft (1.4 m) deep. More than likely, the holding capacity of such a rock anchor would be many times that which is required for mobile home tiedowns. Much shallower embedment is possible if the tensile strength of the rock can be relied on. Local experience in a specific type of rock formation would be invaluable under these conditions. "Holding cannot be estimated analytically in rock and coral. In those materials field tests and general experience must be relied upon" [92].

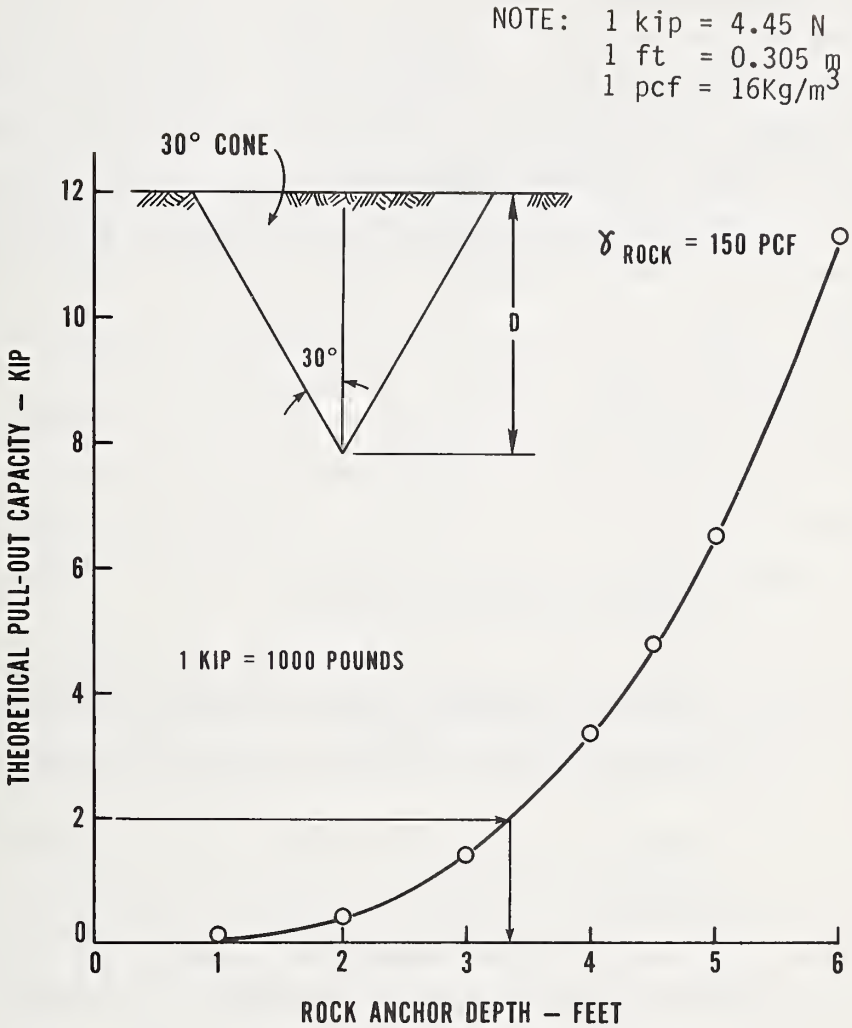


Figure 5.7 Theoretical Pull-out Capacity versus Rock Anchor Depth

A second type of rock anchor can be constructed by drilling a hole as mentioned above and inserting either a steel structural shape such as a steel angle iron or rod, or a piece of cable tendon. After the chosen device is in place, the hole is filled with a lean grout consisting of Portland cement, sand and water. (A lean grout can be considered to consist of 1 part of Portland cement and 5 parts of sand, by volume.) Technical assistance may be required to ensure proper grout strength. The theoretical pull-out capacity of such an anchor is given by equation 3.

$$Q = \pi D \; L \; C \; \beta \qquad \ldots \text{(eq. 3)}$$

where

β = a strength reduction factor

C = allowable stress in shear in cement grout frequently taken as $0.045 \; f'_c$ [158 psi (1.09 MPa) max],

D = diameter of the hole in which grout and anchor was placed

f'_c = unconfined compressive strength of the cement grout

L = length of the hole that contains grout

Q = ultimate pull-out capacity

For a grouted anchor in rock, the value of β in this case would be equal to 1.0. Use of equation 3 is limited to where the compressive strength of the grout is equal to or less than the compressive strength of the rock. In the event that the strength of the rock is smaller than that of the grout, the value of the lowest compressive strength should be used in lieu of f'_c.

The capacity of grouted rock anchors depends not only upon the shear strength of the rock and the grout, but upon the surface roughness of the anchor hole as well. If the hole is drilled pneumatically, the sides of the hole will be considerably roughened. If the strength of the rock is less than the strength of the grout, then the capacity of the anchor is going to be a function of the strength of the rock. However, if the rock is stronger than the grout, the anchor capacity could be controlled by the bond strength between the grout and the anchor rod [6].

Brown [24] performed 48 rock anchor pull-out tests in order to determine the effect of depth of embedment, bar diameter, steel strength, and anchor rod surface features on the anchor capacity and the mode of failure. He found pull-out capacity to be proportional to the surface area of the bar embedded in the grout for both straight and deformed rods. Deformed anchors had about 5 times the capacity of plain or smooth anchor rods [24].

Grouted anchor rods have been successfully used in soils as well [1, 82]. Equation 3 is also applicable to a grouted anchor rod in cohesive soils. A different formulation would be used for a grouted rod anchor in granular materials [3].

One cannot overestimate the value of using local experience in the prediction of pull-out capacity for anchors installed in rock. A state-of-the-art work on the design of rock anchors has been presented by Littlejohn [68]. Other useful references include extensive discussions by Hobst and Zajic [50] and by Coates [28].

5.3.6 Effects of Cyclic Loading On Pull-out Capacity

Very little information is contained in the mobile home anchor literature on the effects of cyclic loading on anchor pull-out capacity. If and when anchors do fail during windstorms, it is entirely possible that they fail due to what might be loosely termed "soil fatigue." It is well documented in the geotechnical engineering literature that cyclic loading of soils reduces the soil shear strength and therefore the anchor pull-out capacity [89].

The amount of reduction that is experienced by a soil is a function of many variables. These variables include:

1. The amount of sustained load. The sustained load is defined in this case as the average load acting over a period of time.

2. The magnitude of the load fluctuations.

3. The number of cycles of load fluctuations.

To take into account the effect of cyclic loading, it has been suggested that the pull-out capacity be multiplied by a reduction coefficient ranging from 0.5 to 0.8 depending upon the soil type, consistency, and whether granular soils are saturated or dry [65, 66].

Very rarely would an anchor be subjected to reversed loading, that is, both pull out or tension and a compression load. Typically, the loads on an anchor will be in tension only. Generally it can be said that the shear strength of the soil (and therefore the holding capacity of the anchor) will decrease with an increase in the sustained load magnitude, an increase in the magnitude of load fluctuation, an increase in the number of load cycles, or any combination of increases of these variables. The behavior of cohesive soils under dynamic loads have been studied by Seed and Chan [89] and Theirs and Seed [94], among others. More recently Gouda and True studied the effect of dynamic loading on anchor capacity [42].

Taylor, et al. [92] considered several types of loading of marine anchors that could apply to mobile home anchors as well. For both sands and clays they considered:

a. short term static loading

b. long term repeated loading

c. long term static loading.

When a mobile home is anchored for the first time, usually the anchor is put under a small tension (uplift) load as the tension straps (over the mobile home) are tightened. This may be considered to be a long term static load.

During cyclic wind occurrences, the mobile home is subjected to repeated loading that may be considered short term repeated loading if a "windy day or so" occurs. A severe storm lasting many days with variable gusts acting in conjunction with a sustained wind may be considered long term repeated loading.

Presently much data on dynamic loading of mobile homes exist in raw form at the National Bureau of Standards [71]. These data could be reduced to information that would be useful in the design of mobile home anchors subjected to cyclic loads. For example, what is needed is a time history of anchor load. This information would be in the form of a graph of load versus time showing load fluctuation during a typical storm. It is estimated that the frequency of loading during a wind storm is in the order of 1 cycle per second. By this criterion, a typical thunderstorm lasting for about 5 minutes would develop approximately 300 cycles of load. Similarly, a hurricane lasting for 90 minutes would develop over 5,000 loading cycles. As was stated before, the pull-out capacity will be a function of the shear strength of the holding soil which in turn can be affected by the number of cycles of loading [94].

As far as can be determined, present information on wind loads and cyclic pull-out capacity of mobile home anchors is not adequate to enable us to simulate a wind storm. The method used by Gouda & True [42] for the cyclic capacity of marine propellant anchors employs a pseudo-dynamic approach. The pull-out capacity is computed as in the static case (for example according to Eq. 1 and 2) and a strength reduction or magnification factor is applied to the results depending on how cyclic loading affects the soil's shear strength and the inertia of the soil-anchor mass. In the absence of any data to the contrary, use could be made of a strength reduction chart based on the ratio of the peak cyclic strain of an anchor to the failure strain of an anchor in a static test [95]. Very limited data are available on this subject.

Design curves for both monotonic and cyclic loading are presented by Bemben and Kupferman [18, 65] for fluke shaped marine anchors embedded in saturated sands, silty sand and clay soils. It was found that cyclic loads for this type of anchor tested in sands and clays caused cyclic creep that increased for the duration of cyclic load application. The authors suggested that the cyclic load capacity be assumed equal to 40 percent of the static holding capacity and that a factor of safety of 5 be applied to determine allowable displacements [18]. These relationships are satisfactory for this type of anchor with a maximum projected (surface) area of 220 in^2 (0.14 m^2).

Cyclic load tests were performed on both belled and cylindrical footings 5 ft (1.5 m) in diameter and 8 and 12 ft (2.7 and 3.7 m) in depth in stiff clays. Each footing was cycled 5 times between approximately 30 and 60 percent of the estimated ultimate load capacity. Two other cyclic tests were performed on footings 2 ft (0.61 m) in diameter both at a depth of 6 ft (1.8 m). In all of these tests, the increase in the vertical deflection under uplift cyclic loads was slight [5].

Another possible failure condition that may occur with a mobile home anchor under dynamic or cyclic loading could be caused by the phenomenon known as liquefaction. This phenomenon has been observed widely in earthquakes, where a loose, saturated sand below the ground water table is subjected to dynamic loading. This dynamic loading produces an increase in the pore water pressure within the soil voids which reduces the normal force between sand grains, causing a drastic reduction in shear strength. When the normal force between individual sand grains approaches zero, there is a complete loss of shear strength. This condition is possible in a mobile home anchor installation in loose sand. However, in loose sand the anchor would probably not have an adequate pull-out capacity to begin with and would be installed at a greater depth. Nevertheless, it is possible that anchors embedded in loose saturated sand could fail or move excessively by liquefaction.

5.3.7 Effect of the Angle of Pull On Pull-Out Capacity

Most mobile home tiedown schemes apply both a vertical and a horizontal load component to the soil anchor. The resultant force may or may not be coaxial with the anchor shaft. Several methods of securing against horizontal loads are shown in Reference 36. Based on scale model testing of inclined anchors buried in sand by Harvey and Burley [47], it has been shown that the coaxial pull-out capacities of inclined and vertical anchors at the same vertical depth of embedment are approximately the same for shallow anchors in granular soils ($D/B \leq 6$). The tests were run with D/B ratios up to 14. For a 6-inch (0.15 m) diameter helix anchor, this would correspond to a depth of 7 feet (2.1 m). No data were obtained for loads acting at an angle to the anchor shaft.

When single helix anchors were pulled coaxially in stiff clay ($D/B = 10$) by Adams et al. [6] no appreciable difference in pull-out capacity was noticed between anchors pulled out vertically and those pulled out at an angle of 50° from the vertical. However, at any given load, the anchor pulled at an angle other than vertical had more than twice the displacement of the vertically pulled anchor. Other information [58a] indicates that, below a minimum depth that is a function of the helix-shaft assembly and soil type, no difference in pull-out capacity has been observed for helix anchors when installed at different angles of inclination.

Kananyan [59] and Meyerhof [75] performed model anchor pull-out tests in sands and they found an increase in pull-out capacity under loads inclined to the vertical. As the angle of inclination, α (see figure 4.1b), increases, the pull-out capacity increases. This contradicts the findings of Harvey and Burley [47]. Care should be taken when comparing model test data of a buried plate as opposed to a helix anchor that is installed by following a helical path.

All of the above referenced tests were performed on anchors for which the anchor shaft was rigidly connected to the anchor plate. Since the anchor plate is perpendicular to the anchor rod, the plate is not in a horizontal plane when α is greater than zero. In a study of models of square anchors in dry sand by Das and Seeley [31], anchors were subjected to inclined loads applied with a non-rigid connection. During initial testing, the anchor plate remained horizontal while the cable was pulled at an angle α from the vertical. Pull-out capacity for these horizontal anchors at any D/B ratio generally increased with the angle of load inclination. The increase in failure load was attributed to the unsymmetrical failure zone developed around the anchor [31, 59, and 75].

Colp [28a] conducted model tests on plates embedded in steel rollers (1/8 inch (3.2 mm) diameter by 3/4 inches (19 mm) long), and in dry dense Ottawa Sand, saturated dense Ottawa Sand and on a remolded sea floor clay) using a 3-inch (76-mm) diameter plate, 1/4 inch (6 mm) thick. The tests using the steel rollers were essentially two dimensional while those with the natural soil were three dimensional pull-out tests. In each case, a 1/8 inch (3 mm) diameter stainless steel cable was (non-rigidly) connected to the anchor plate (initially horizontal) and tests were performed at D/B (anchor depth to anchor width) ratios of 2 and 8, while the angle of pull (α) varied from 0 to 45 degrees from the vertical. As the angle α changed from 0 to 45 degrees, the pull-out capacity increased for both the steel rollers and dry sand for both values of the D/B ratio. In the case of submerged dense sand, the pull-out capacity was lower for α = 45 degrees. Colp attributed this behavior to "pore water dynamic effects on the strength of the sand being sheared." The effect of the angle of pull for the soft remolded marine clays was less pronounced; only a slight increase in pull-out capacity was observed as α increased from 0 to 45 degrees. Colp also studied the effect of eccentric loading of the 3 inch (76 mm) diameter plate. It was found that the pull-out capacity decreased as the eccentricity increased.

Pull-out factors (for use in equations 1 and 2) are given by Meyerhof for values of ϕ to 45° and for angles of inclination up to 90° for shallow and deep strip anchors and for deep square anchors [75].

Increasing the angle of pull also increases the pull-out capacity for arrowhead shaped anchors. This will be shown by the load test data presented in section 7 of this report.

All of the data in section 5.3.7 are for situations where the applied force is coaxial with the anchor shaft. When more than one strap is attached to a mobile home anchor, it is highly probable that the resulting force is not coaxial with the anchor shaft; as a result, an unknown horizontal component of deflection will occur. For anchor shafts of about 1 inch (25 mm) diameter, little horizontal soil resistance is provided by acting against the soil-anchor shaft. As far as can be determined, only one reference [106] describes effects of non-coaxial pull-out. However, this study considered only 5/8-inch and 3/4-inch (16- and 19-mm) rods and only one soil type, and anchors developed a maximum capacity of only 145 pounds (645 N). The only reference to this problem that was found in this study are the recommendations given in References [36] and 102a].

5.3.8 Effect of Group Action on Anchor Capacity

In some applications it is desirable to use more than one anchor to develop the required load capacity. There are a variety of ways in which multiple anchors can be used. For example, a multi-helix anchor can be used in place of a single helix anchor. However, this is nothing more than two or more circular plates (helixes) on one axial shaft. Some insight in the problem can be derived from our knowledge of group action effects on foundation piles. Generally, in cohesive soils, the capacity of a pile group is usually less than the capacity of a single pile multipled by the number of piles in the group. However, in granular soils, when displacement piles (piles that displace a significant amount of soil during driving) are used, the capacity of a group of piles is equal to or sometimes greater than the capacity of a single pile multiplied by the number of piles in the group. A helix anchor is not a "displacement" anchor and displaces very little soil volume when installed; as a result the density of the soil in the vicinity of the anchor does not increase appreciably.

Many efficiency ("efficiency" is the ratio between the group capacity and the sum of the capacities of the individual piles) formulas are available for the unwary engineer to use in computing the ultimate capacity of a pile group. None of these formulas take into account the factors that actually govern the ultimate capacity of the pile group itself. Likewise, there are no hard and fast rules to use when predicting the pull-out capacity of multiple anchors. Based upon load tests [18] it can only be concluded that multiple anchors are not 100 percent efficient. Hanna et al. [45] performed pull-out tests of models in sands. They concluded that when the anchor spacing was approximately 4 diameters, ultimate capacity of the anchor group was nearly 100 percent of the capacity of a like number of individual anchors. Further, they stated that the group theory proposed by Meyerhof and Adams [74] predicted trends of group behavior, but they felt it was in considerable error.

Adams et al. [6] tested a group of four multiple helix anchors in a cohesive soil. The anchors were installed to a depth of 14.5 feet (4.42 m) at the corners of a 3.5-foot (1.1-m) square. Each anchor had 3 helixes each measuring approximately, 1 ft (0.3 m) in diameter. Load tests performed on both the single anchor and the group anchor showed that the group effect was fairly insignificant and the efficiency was greater than 90 percent.

The effects of load cycling and group action on the uplift capacity have been investigated and it was found that if the load levels acting on the anchors are below 50 percent of load capacity, the cyclic loading does not lead to excessive displacements [5].

Facing page: *Mobile home with factory installed anchor straps.*

6. EMPIRICALLY BASED METHODS OF PREDICTING ANCHOR PULL-OUT CAPACITY

6.1 GENERAL

Several empirical approaches are presently used to predict anchor pull-out capacity. These fall generally into three categories:

1. Correlation of pull-out capacity with in-situ tests
2. Local experience
3. Field tests on full-scale or prototype anchors in similar soil conditions

6.2 CORRELATION OF PULL-OUT CAPACITY WITH IN-SITU TESTS

6.2.1 Soil and Rock Class Types and In-situ Tests

At present, various soil types have been grouped based on the soils potential ability to provide anchor restraint. What we are about to describe is not a complete soil classification system as was described in section 5.2, but a means of classifying the given soil's ability to hold a certain size anchor. Table 6.1 shows the National Fire Protection Association (NFPA) Standard 501A-1975 [69] soil type definitions. Also shown in this table is the correlation between blow count as measured by the Standard Penetration Test (SPT) [12] and torque in inch-pounds as measured by the "Soil Test Probe (STP)." The "soil test probe" is a patented commercial device, consisting of a helix of 10.75 in (273 mm) overall length 1.25 in (32 mm) major diameter and 0.56 (9/16) in (14.3 mm) minor diameter which is attached to a 0.56 in diameter shaft which is turned by a torque wrench. The torque repaired to insert this probe has been empirically related to anchor pull-out capacity. The test probe is currently being used by industry to predict anchor pull-out capacity and has been further investigated by Fry and Hollander [40, 41].

The Standard Penetration Test is described in section 5.2. It should be noted that the ASTM standard for this test [12] is not explicit enough to ensure that the testing equipment is operated in such a way that energy delivered to the sampler by the hammer does not vary. Until this deficiency is remedied, it is recommended that the following precautions be taken: the hammer used to advance the sampler be raised by wrapping a rope around a pulley (cathead); operators wrap the rope either twice or three times around this pulley; two wraps of rope around the cathead should be used when performing Standard Penetration Tests as it has been found that the number of turns greatly influences the amount of energy imparted to the sampler [62].

Both the SPT and STP tests indirectly measure the shear strength of the soil, one of the key parameters in determining anchor pull-out capacity.

TABLE 6.1 NFPA [49] SOIL TYPE DEFINITIONS

Types of Soils	Blow Count (ASTM D1586)	Test Probe[1] Torque Value[2]
Sound Hard Rock	NA	NA
Very-dense and/or cemented sands, coarse gravel and cobbles, preloaded silts, clays, and corals	40-up	more than 550 inch-lbs
Medium-dense coarse sands, sandy gravels, very stiff silts and clays	24-39	350-549 inch-lbs
Loose to medium dense sands, firm to stiff clays and silts, alluvial fill.	14-23[3]	200 to 349 inch-lbs

[1*] The test probe is a device for measuring the torque value of soils to assist in evaluating the holding capability of the soils in which the anchor is placed. The test probe has a helix on it. The overall length of the helical section is 10.75 inches; the major diameter is 1.25 inches; the minor diameter is 0.81 inches; the pitch is 1.75 inches. The shaft must be of suitable length for anchor depth.

[2] A measure synonymous with moment of a force when distributed around the shaft of the test probe.

[3] Below these values, a professional engineer should be consulted.

Note: 1 in. = 25.4 mm
1 inch-lb = 0.11 N-m

*The description in 1 was taken verbatim from its source. NBS measurements indicate that the minor diameter of the helix is 0.56 in. and not 0.81 in.

However, it should be noted again that the Standard Penetration Test is a fairly reliable indicator of shear strength of granular soils, but is a crude predictor of the shear strength of cohesive soils. This is explained by Peck et al. [85]: When sampling stiff to very stiff clays, for example, the blow count can vary considerably depending on whether the soil is saturated or partially saturated. In a partially saturated cohesive soil, many air voids exist and in the process of penetrating, the SPT sampler merely collapses the air voids, resulting in a much lower blow count than would be found in a saturated soil of the same shear strength. This is one of the major reasons why the SPT test is unreliable in cohesive soils.

A problem arising in the use of soil classifications such as those shown in table 6.1 is evident from examinations of the descriptions of the various soil types. In table 5.2 we find that loose, medium and dense sands are commonly defined as having blow counts (SPT) of 4 - 20, 10 - 30, and 30 - 50 respectively. In table 6.1, the words "very-dense" are used to describe granular materials with blow counts as low as 40. The definitions used by NFPA in terms of blow count criteria do not match the definitions in table 5.2. Likewise, in the soil description in table 6.1 which was prepared for anchor design, the words "medium-dense" correspond to a blow count of 24 to 39 blows per foot. This slightly exceeds the definition of medium dense in table 5.2, and so on. The intent is not to criticize the various definitions but only to point out that in conjunction with anchor design there is presently no uniform definition of soil types. NFPA data from table 6.1 are shown graphically in figure 6.1, Soil Test Probe torque versus Standard Penetration Test N value. The density and consistency terms from tables 5.2 and 5.3 have been added to figure 6.1 for comparison.

A second and third set of presently used definitions or correlations with Standard Penetration Test and Soil Test Probe values are given in tables 6.2 [26] and 6.3 [58]. The term RQD in table 6.2 means Rock Quality Designation and is used to describe the relative intactness of rock when obtained with diamond coring techniques [83]. These tables

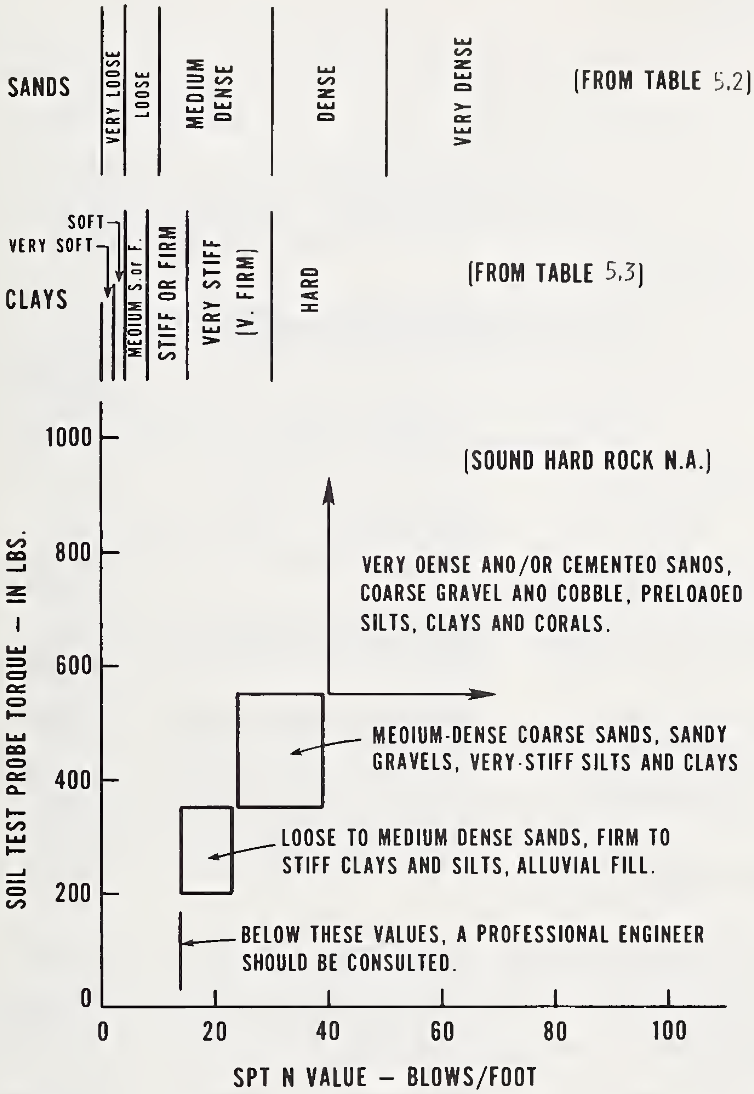


Figure 6.1 Soil Test Probe Torque versus SPT N Value [69]

TABLE 6.2 SOIL TYPE DEFINITIONS [26]

SOIL CLASSIFICATION DATA

Class		Familiar Names[2]	Soil Test Probe Values in-lb (N-m)	Typical Blow Count "N" per ASTM-D1586
0	Sound hard rock, unweathered	Granite, Basalt, Massive Limestone	N.A.	N.A. RQD = 50%
1	Very dense and/or cemented sand; coarse gravel and cobles (1)	Caliche, weathered sandstone	750-1600 (90-208)	60-100+
2	Dense fine sand; (1) very hard silts and clays (may be proloaded)	Basal till; boulder clay; caliche; weathered laminated rock	600-750 (78-98)	45-60
3	Dense clayey sands and gravel; (1) hard silts and clays	Glacial till; weathered shales, schist, gneiss and siltstone	500-600 (65-78)	35-50
4	Medium dense sandy gravel; (1) very still to hard silts and clays	Glacial till; hardpan; marls	400-500 (52-65)	24-40
5	Medium dense coarse sand and sand gravels; stiff to very stiff silts and clays	Saprolites, residual soils	300-400 (39-52)	14-25
6	Loose to medium dense fine to coarse sand; firm to stiff clays and silts	Dense hydraulic fill; compacted fill; residual soils	200-300 (26-39)	7-14
7	Loose fine sand; Alluvium; Loess; soft-firm clays; varved clays; fill	Flood plain soils; lake clays; adobe; gumbo, fill	(100-200) (13-26)	4-8
8	Peat, organic silts; inundated silts, fly ash	Miscellaneous fill, swamp marsh	less than 100 (0-13)	0-5

[1] These soils are difficult to probe consistently and the ASTM blow count may be questionable value.

[2] These names may mean different soils in different areas.

TABLE 6.3 SOIL TYPE DEFINITIONS (FOR A SCREW ANCHOR APPLICATION) [58]

Soil Class Number	Description of Soil	Standard Penetration Test Blows/Foot
1	Solid bedrock	
2	Hardpan; Dense - Very Dense Sand; Compact Gravel; Laminated Rock; Slate Schist; Sandstone	41-48
3	Hard Clay; Dense Sand; Shale; Broken Bedrock; Compact Clay Gravel Mixtures	34-41
4	Very Stiff-Hard Clay; Claypan; Medium-Dense Sand; Gravel; Compact Gravel and Sand	27-34
5	Very Stiff Clay; Medium Sand; Loose Sand and Gravel	20-27
6	Stiff-Very Stiff Clay; Medium Sand; Clayey Silt	13-20
7	Medium-Stiff Clay; Loose Sand; Fill; Silt	6-13
8	Very Soft-Soft Clay; Very Loose Sand; Swamp; Marsh; Saturated Silt; Humus	-6

are summarized in figure 6.2, Soil Test Probe torque versus SPT N value. It can be seen from figure 6.2 that soil classes are defined differently by various industry groups.

Dewberry [35] presented a nomograph on the pull-out strength of anchors based on the volume of a 30° cone starting from the edge of the buried anchor for anchors with areas up to 100 square inches (6.5×10^4 mm^2) and depths from 4 to 10 feet (1.2-3.0 m). The calculated pull-out strength was multiplied by a factor ranging from 0.5 (class 7 soil: loose, dry) to 1.2 (class 3 soil: Hardpan). No account was taken of the shear strength of the soil and it is felt the "class of soil" is subject

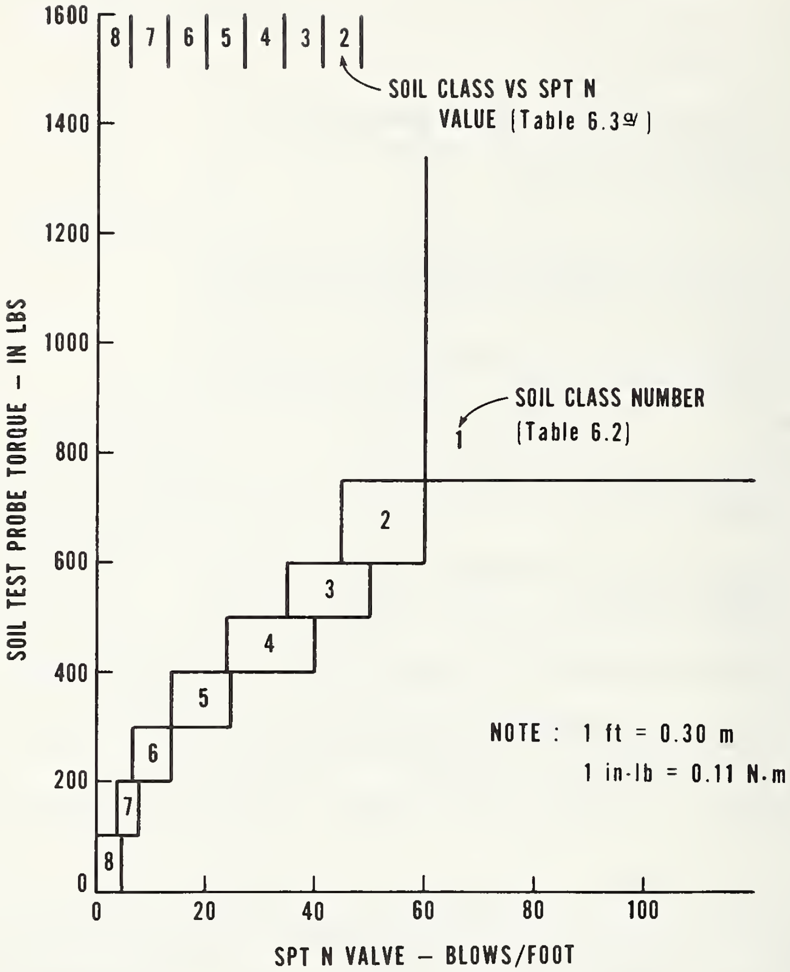


Figure 6.2 Soil Test Probe Torque versus SPT N Value [26, 58]

to considerable interpretation. Various states also have their own soil classification systems as shown in table 6.4 [77].

The information contained in tables 6.1 through 6.4 is presented to show the need for standardization of soil classes and methods of estimating pull-out capacities. What is not mentioned in any of these tables is that it is entirely possible for the Soil Test Probe reading or the Standard Penetration Test N value to change seasonally. An anchor may have its highest pull-out capacity during the winter months when the soil is frozen (depending upon geographical location) and its lowest capacity during the spring thaw or rainy season. It is questioned whether pull-out test results presented to state agencies for anchor approval are performed under spring thaw or rainy season conditions when the soil's shear strength is probably weakest.

A possible approach that could eliminate ambiguities would be to eliminate the verbal descriptions of the soils themselves and to correlate the pull-out capacity of potential soil anchor sites with some in-situ measurement, such as the Standard Penetration Test blow count, the Soil Test Probe reading, or anchor installation torque. There are many other ways to investigate the in-situ soil properties besides the three methods mentioned, but they too require careful field or laboratory tests by qualified engineers or technicians. This latter consideration could raise the cost of a mobile home anchoring system.

6.2.2 Correlation of STP Measurement With the Shear Strength of Soils

As previously mentioned, the Standard Penetration Test and the Soil Test Probe are to some extent indirect measurements of the shear strength of the soil, one of the main parameters governing the pull-out capacity of a soil anchor. The only data correlating the shear strength of soils and the STP that could be located are those given by Adams and Klym [3] for four separate sites: 1) relating the Soil Test Probe torque wih a two-inch (51 mm) cone test (site no. 2); 2) Soil Test Probe torque and unconfined compressive strength of cohesive soils (site no. 4);

TABLE 6.4 SOIL CLASS BY VARIOUS STATES [77]

Florida

Class	Description of Soil	Blow Count (ASTM D1586)	Test Probe* Torque Value**
A	Hard rock .	NA	NA
B(1)	Very dense and/or cemented sands, coarse gravel & cobbles, preloaded silts & clays	40-up	more than 550 lbs inch
B(2)	Corals	40-up	more than 550 lbs inch
C	Medium dense coarse sands sandy gravels, very stiff silts & clays	24-39	350 to 549 lbs inch
D	Loose to medium dense sands firm to stiff clays & silts, alluvium fill.	14-23***	200 to 349 lbs inch
E	Concrete slab		

Tensioning devices for use in concrete pad runner, etc. shall be tested (same an anchors) and specifications as to P.S.I and cure time of concrete, reinforcement size and thickness of concrete, size and depth of bolt hole, type and kind of shield if permissible. Minimum distance at which tensioning device can be installed from edge or end of slab, pad runner etc. shall be specified. INSTRUCTION SHIPPED WITH EACH TENSIONING DEVICE SHALL INCLUDE THE ABOVE.

Missouri

Class	Description of Soil
(1)	Sound hard rock
(2)	Very dense and/or cemented sands, coarse gravel and cobbles, preloaded silts & clays
(3)	Medium dense coarse sands gravels, very stiff silts and clays
(4)	Loose to medium dense sands, firm to stiff clays and silts, alluvium fill

Texas

Class	Description of Soil	Probe Value** *
1.	Solid Bed Rock	----------
2.	Dense Clay; Compact Gravel; Dense Fine Sand; Laminated Rock; Slate; Schist; Sandstone	Over 600 inch lbs
3	Shale; Broken Bed Rock; Hardpan; Compact, Clay-Gravel Mixtures	500-600 inch lbs
4.	Gravel, Compact Gravel and Sand Claypan	400-500 inch lbs
5	Medium Firm Clay; Loose Sand and Gravel; Compact Coarse Sand	300-400 inch lbs
6	Soft-Plastic Clay; Loose Coarse Sand; Clay Silt; Compact Fine Sand	200-300 inch lbs
7	Fill; Loose Fine Sand; Wet Clays; Silt	100-200 inch lbs
8	Swamp; Marsh; Saturated Silt; Humus	Under 100 inch lbs

Proposed NFPA 501A/ANSI A119.3 anchorage soil classifications are the same as those adopted by Floridat with the exception of Classes B(2) and E, which are not included by NFPA/ANSI.

* The test probe is a device for measuring the torque value of soils to assist in evaluating the holding capability of the soils in which the anchor is placed The test probe has a on it. The overall length of the helical section is 10.75 inches; the major diameter is 1.25 inches; the minor diameter is 0.81 inches; the pitch is 1 75 inches The shaft must be of suitable length for anchor depth.

** A measure synonymous with moment of a force when distubted around the shaft of the test probe.

*** Below these values, a professional engineer should be consulted

3) Soil Test Probe and unconfined compressive strength and the field vane strength of cohesive soil deposits (site no. 5); and 4) data from site no. 6 in which installation torque of helical anchors, Soil Test Probe torque, blow counts from a two-inch dynamic cone test, and field vane shear strength of cohesive soils were determined. It is not a widely accepted practice in the United States to use the two-inch dynamic cone test; therefore, it will not be discussed further. However, the data from site 5 have been plotted in figure 6.3 which shows both the Soil Test Probe torque reading and the soil's shear strength versus depth. As can be seen, the two curves "follow" each other with depth except at a depth of around 100 feet (30 m). As the soil strength decreases, the torque obtained on the Soil Test Probe also decreases. The opposite is also true. However, when all the data taken from Reference 3 are plotted in figure 6.4, which compares shear strength of cohesive soils with Soil Test Probe torque reading, there is no apparent correlation. It should be noted, however, that some of the data are from very great depths compared to what will normally be encountered using the Soil Test Probe for mobile home anchor installations. It is quite possible that at the great depths of which the Soil Test Probe was used in this reference, an increase in indicated torque resulted from side friction along the connecting rod to the bottom of the Soil Test Probe. Some of the data contained in figure 6.4 were obtained from tests performed at depths as great as 100 feet (30 m). This may explain some of the high Soil Test Probe readings in the lower right hand portion of figure 6.4 for very low shear strengths of the soil. It appears that further field study is required to adequately correlate the Soil Test Probe torque reading with the shear strengths of cohesive soils to account for some of the variables that affect the data presented in figure 6.4. However, Taylor [91b] mentions that in normally consolidated marine clays, a consistent relationship between shear strength and Soil Test Probe torque is obtained.

6.2.3 Correlation of Pull-Out Capacity With Soil Class

Typical curves of anchor pull-out capacities versus helix diameter are presented in figures 6.5 [25] and 6.6 [58]. These graphs are presented

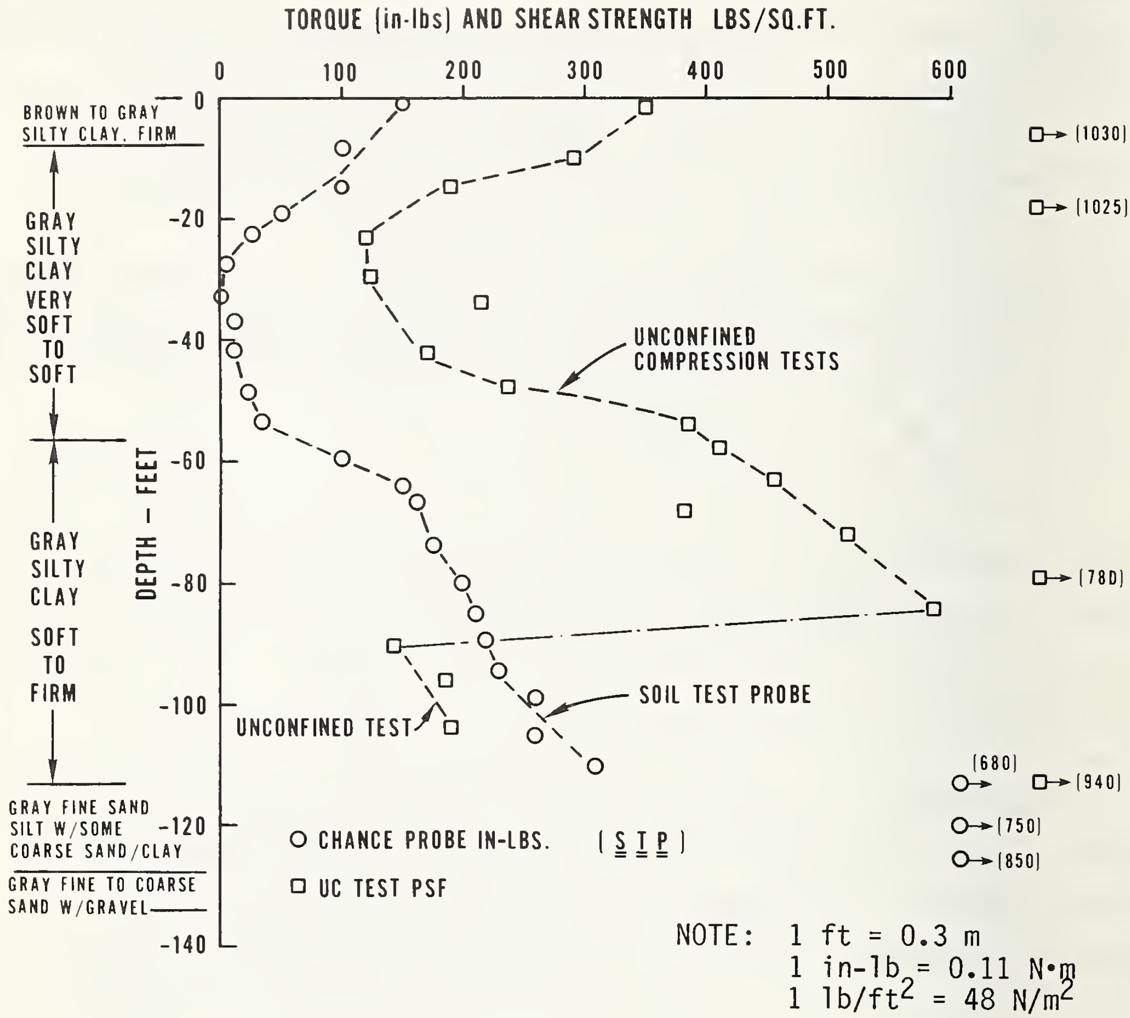


Figure 6.3 Soil Test Probe Torque and Shear Strength versus Depth for Site 5 [3]

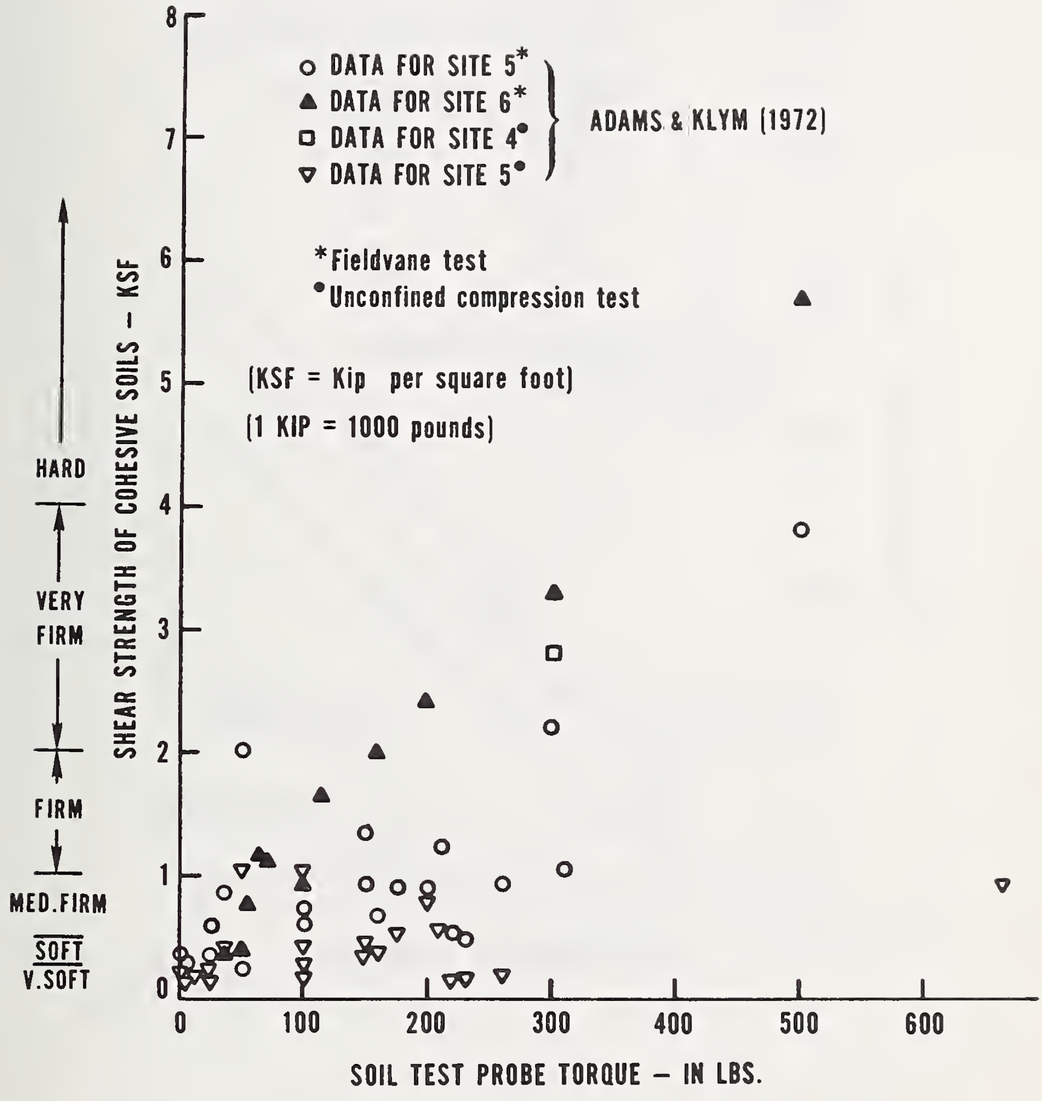


Figure 6.4 Shear Strength of Cohesive Soils versus Soil Test Probe Torque [3]

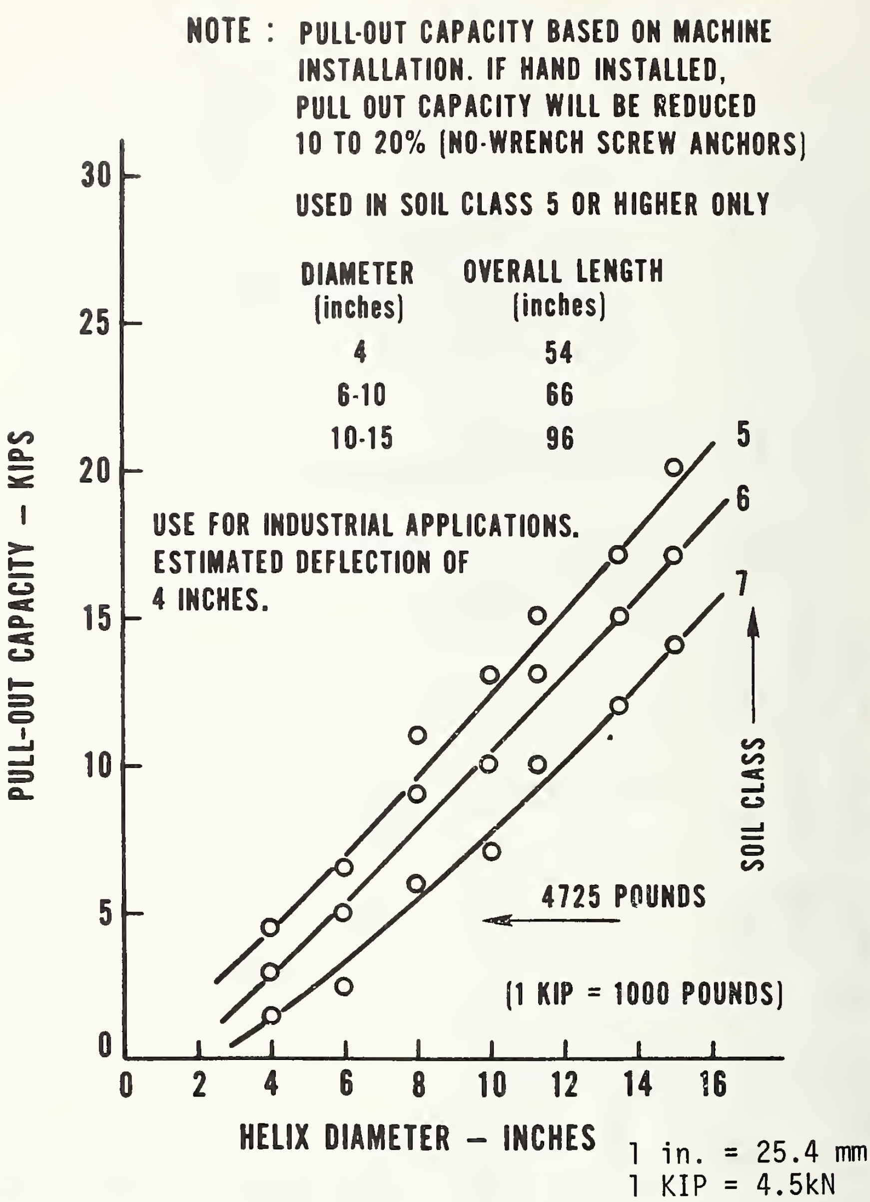


Figure 6.5 Pull-out Capacity versus Helix Diameter [25]

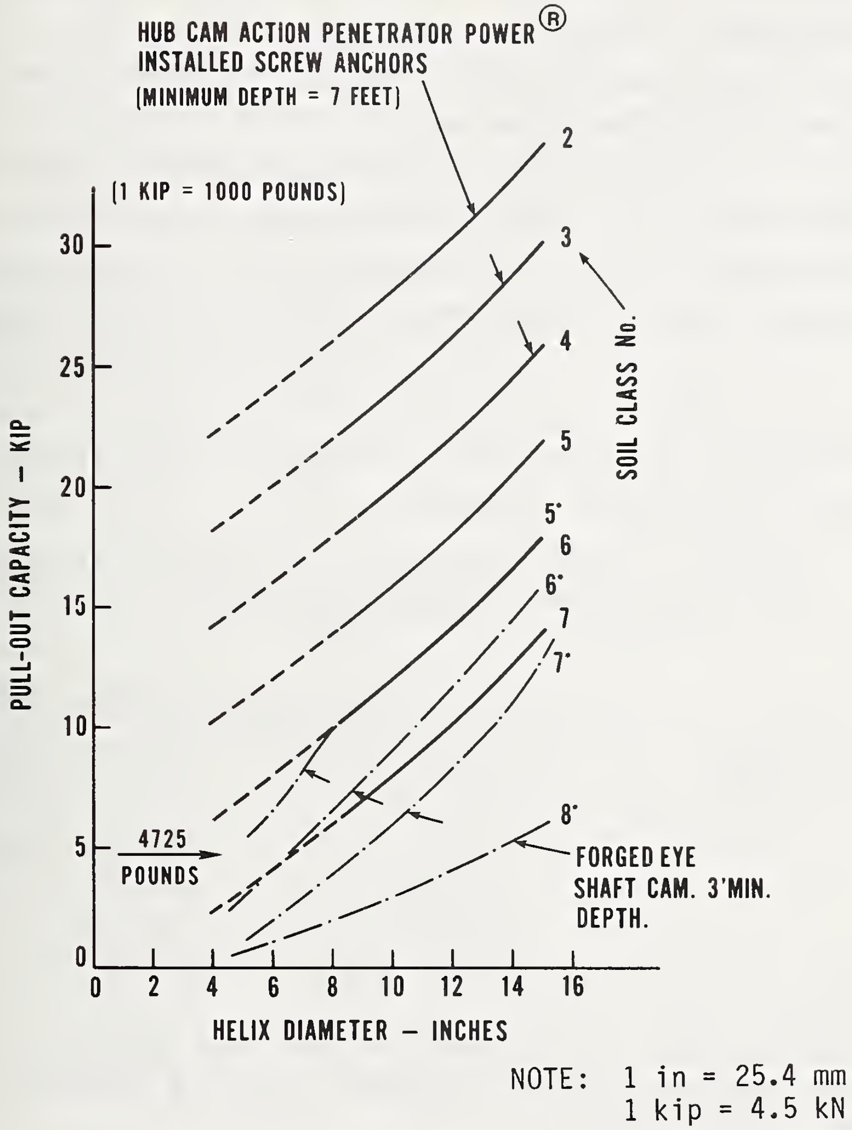


Figure 6.6 Pull-out Capacity versus Helix Diameter [58]

as example types only and are not to be used for mobile home anchor design as they are for industrial applications where maximum deflections up to 4 inches (0.1 m) may be tolerated. Both of these graphs show how the pull out capacity increases as the diameter of a single helix anchor increases, for various soil classes. The minimum pull-out capacity required by NFPA 501A-1975 [69] of 4725 lb (21 kN) is also shown on these figures. Using these graphs and noting the minimum requirements of pull-out capacity, one can obtain the minimum diameter of a single helix from the data in figures 6.5 and 6.6. This has been done in table 6.5 which shows that, for a given soil class, designs based on figures 6.5 and 6.6 differ. This difference is largely due to the differences in the definition of the soil classes shown in figure 6.2. These discrepancies do not imply that an adequate design cannot be accomplished by experienced installers.

TABLE 6.5 EXAMPLES OF ANCHOR SIZE REQUIRED TO ATTAIN 4725 POUNDS* BASED ON DATA GIVEN IN FIGURES 6.5 AND 6.6

Soil Class	Helix Diameter Required, (Inches)**	
(As given by MFCR)	From Fig. 6.5	From Fig. 6.6
5	4.4 (6)	4.7 extrapolated (6)
6	5.5 (6)	6.5 (8)
7	7.5 (8)	8.8 (10)
8	-	13. (13-1/2)

Note: Data in this table are from industrial anchor design with design loads occurring at deflections greater than the NFPA [69] 2 inch maximum requirement.

* No deflection criteria given. Mobile home owner assumes anchor will meet deflection criteria as anchors have prior approval from state agency.

** Number in parenthesis is next higher size commercially available and would be required.

Note: 1 in = 25.4 mm
1 lb = 4.45 N

In an early study of wind forces on mobile homes prepared for the Foremost Insurance Company of Grand Rapids, Michigan, Harris [46] documented the wind forces on mobile homes using wind tunnel tests on model mobile homes. He considered isolated mobile homes as well as those in various positions adjacent to each other. Besides summarizing recommendations for the installation of anchors and appropriate foundations and anchor requirements, he also illustrated five different anchor types and provided anchor spacing charts for the various types of anchors. These charts were based on four general "types" of soil conditions that could be found at typical mobile home sites and include consideration of vertical and horizontal wind pressures.

The design approach is based on the wind speed with a 50-year mean recurrence interval shown in the map in figure 6.7. A 50-year mean recurrence interval means that there is a 2 percent probability that the wind speeds shown in the map will be exceeded in any one year.

The design approach proceeds in this manner: from a fifty-year mean recurrence interval map [10] for the United States, the designer picks the design wind speed in miles per hour for his mobile home site. Next, the relationship shown in figure 6.8 between anchor load in pounds per linear foot of mobile home length and wind velocity is used to calculate the anchor load for a selected mobile home. Finally, for the given anchor load in pounds per foot of length of mobile home side wall, the anchor spacing is determined as shown in figure 6.9 for a given type of anchor and for one of the four soil conditions as shown in figure 6.10. Notice that the terms used to describe soils in the anchor spacing chart conform to the accepted terminology as presented in table 5.2. Harris admonishes the reader that considerable judgment must be exercised when using his proposed design methods. In other words, the soil conditions should be carefully reviewed to ensure that the appropriate soil resistance values are used. Note that horizontal anchor loads have not been considered. This approach could be refined by using some indirect measure of the soil shear strength instead of generic descriptions and by using updated wind pressure calculations and considering horizontal load components.

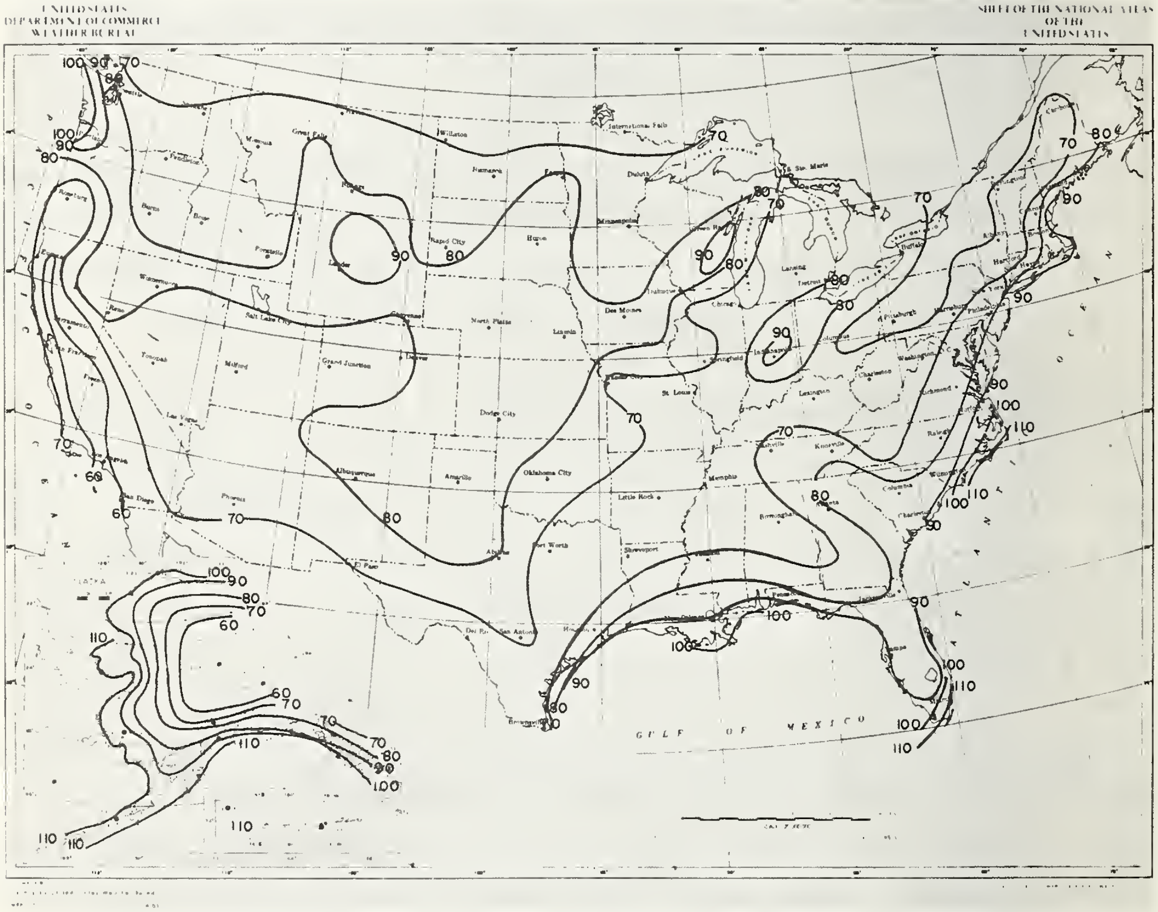


Figure 6.7 Basic Wind Speed in Miles Per Hour (mph). Annual Extreme Fastest Mile Speed 30 ft above ground, 50-year Mean Recurrence Interval [10]

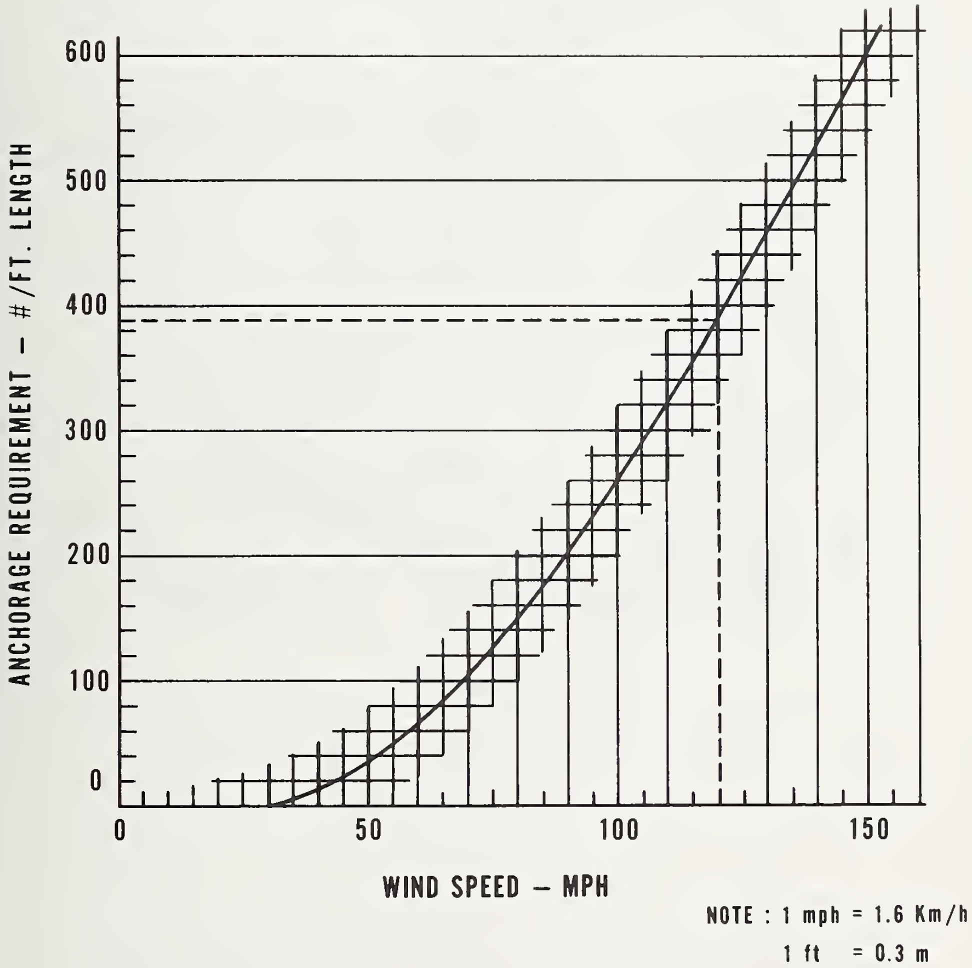


Figure 6.8 Recommended Wind Velocity - Anchorage Requirement Curve by Harris [46]

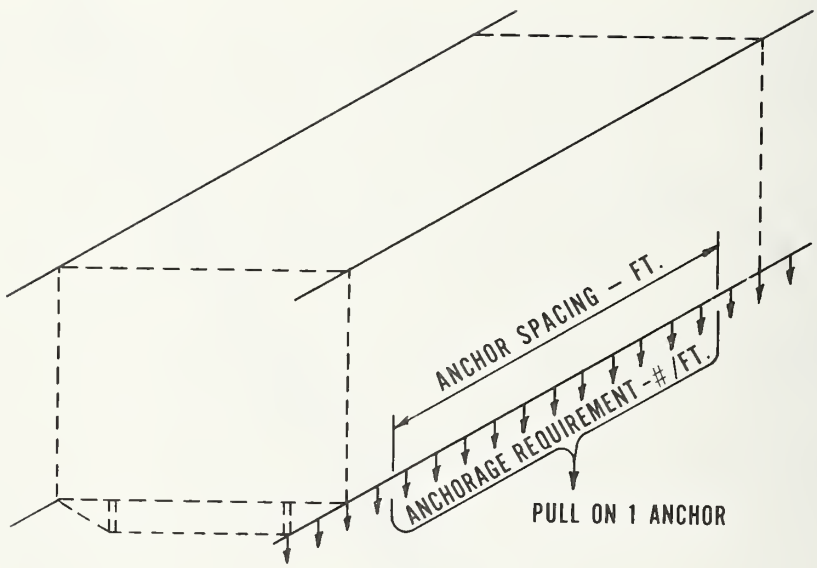


Figure 6.9 Relationship Between Anchor Spacing and Anchorage Requirement for the Pull on One Anchor [46]

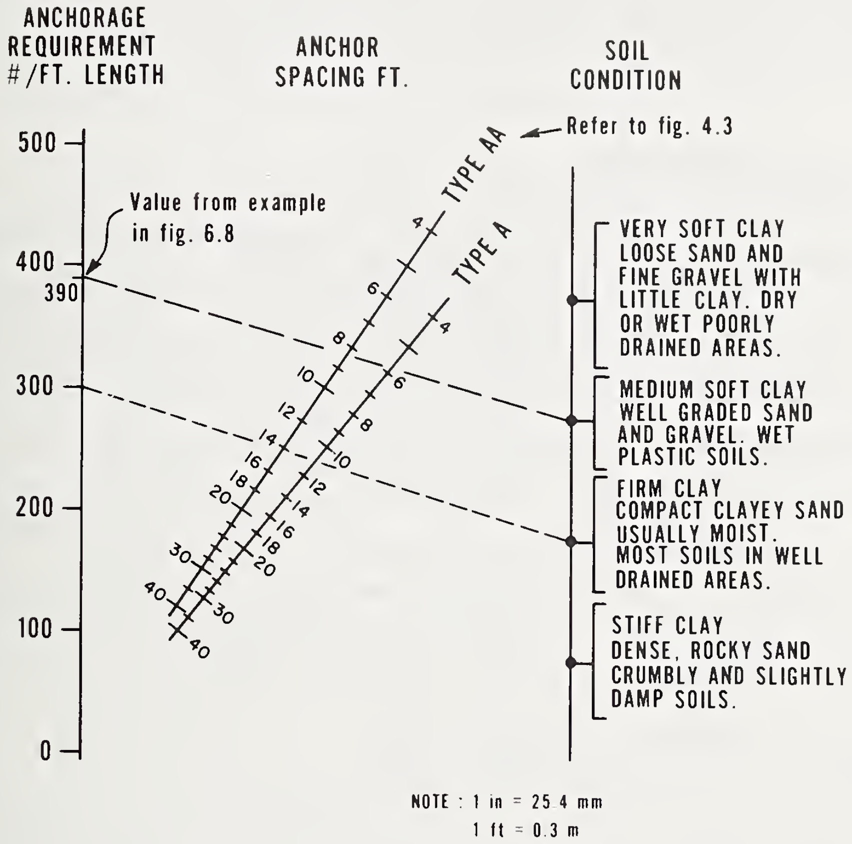


Figure 6.10 Anchor Spacing Chart, Type A and AA Anchors (6-inch Helix and 10-inch Arrowhead Shaped Anchors, Respectively) [46]

Instead of the generic description of soil types, N values from the Standard Penetration Tests or torque readings from the Soil Test Probe could be used. Recently, Marshall [71] has provided design pressures for 70 mph and 90 mph windstorms. These design pressures, based on measurements on a prototype mobile home, could be used to update the anchor load requirements.

6.3 USE OF LOCAL EXPERIENCE

Local experience can play an important part in assisting local installers in meeting the needs of the mobile home community. Over a period of months or perhaps years, individual installers become experienced in predicting the pull-out capacity of certain types of anchors installed in soils with which they are familiar. These installers may know little of the theory behind anchor pull-out capacity prediction, but they have demonstrated adequate know-how to choose and install anchors which perform successfully. However, the know-how had to be initially gained by some experiments, such as anchor pull-out tests.

6.4 THE USE OF PROTOTYPE PULL-OUT TESTS

The only conclusive way to establish the pull-out capacity as well as the load-displacement curve for an anchor is to run a prototype load test at the mobile home site in the soil where the anchor is going to be installed. This is usually beyond the resources and the skill of the mobile home owner but it is the only way to obtain a true indication of anchor behavior.

There are generally two types of load test results that are found in the unpublished literature available either from anchor manufacturers or, with permission, from field or laboratory data acquired by testing firms. The load tests will either be presented in terms of (a) pull-out capacity for a given soil class or (b) a complete load versus displacement curve.

The pull out capacity of an anchor is defined as the point where the anchor continues to move in the direction of the anchor pull without any further increase in applied load. A load-deflection curve, on the other hand, is a complete record of how the anchor head moves during the application of load. According to NFPA 501A-1975 [69] all that is required is that an anchor be able to hold 4725 lb (21 kN) at a deflection of two inches (51 mm) or less.

Regulatory agencies in many states presently require to validate the adequacy of anchors by testing. Mobile home anchor manufacturers must submit their anchors to (an independent agency) for testing. The agency then goes out and finds typical soil deposits according to Class and perform pull-out tests. The pull-out tests are summarized and a letter report is written to the appropriate state agency showing conformance of an individual's hardware to the state's requirement for loads and displacements.

Unfortunately, most of the reports on load tests, many of which are reported in the unpublished literature, do not give adequate information on the engineering soil properties of the soil such as the shear strength or the in-place unit weight. Thus, only in a very general way can the data that are available be used to further engineering knowledge of the behavior of soil and rock mobile home anchors under load. It is suggested that the procedure used in future pull-out load tests be standardized so that the information may advance the state of the art and benefit mobile home owners. Available test data are discussed in the following section.

Facing page: *Anchor pulled out by hurricane wind.*

7. AVAILABLE LOAD TEST DATA ON SOIL ANCHORS

7.1 LOAD TEST DATA FROM HELIX ANCHOR TESTS

The helix anchor was chosen to be discussed first because it tends to produce smooth load deflection curves. The displacement of the anchor head, herein referred to as uplift deflection, observed in a typical test is shown in figure 7.1. The test data presented (source of this information has not been identified at the request of the supplier) in

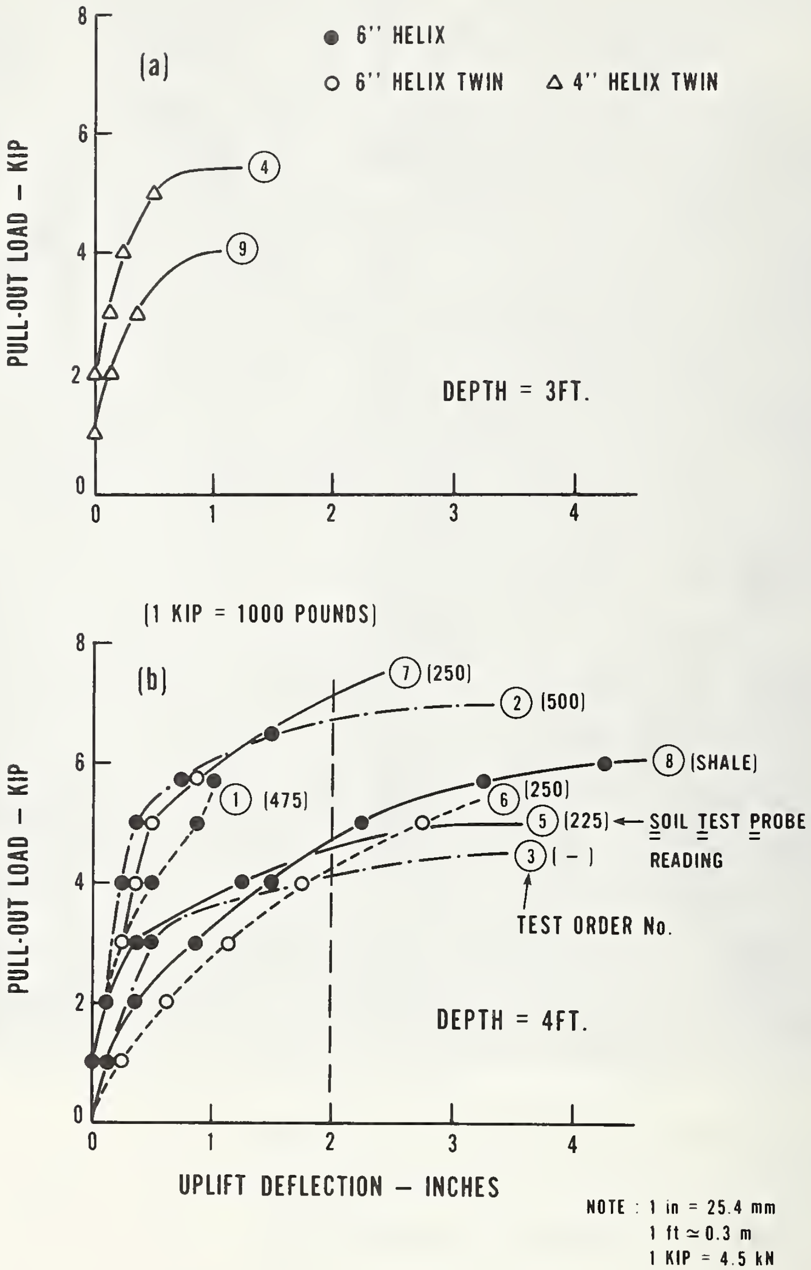
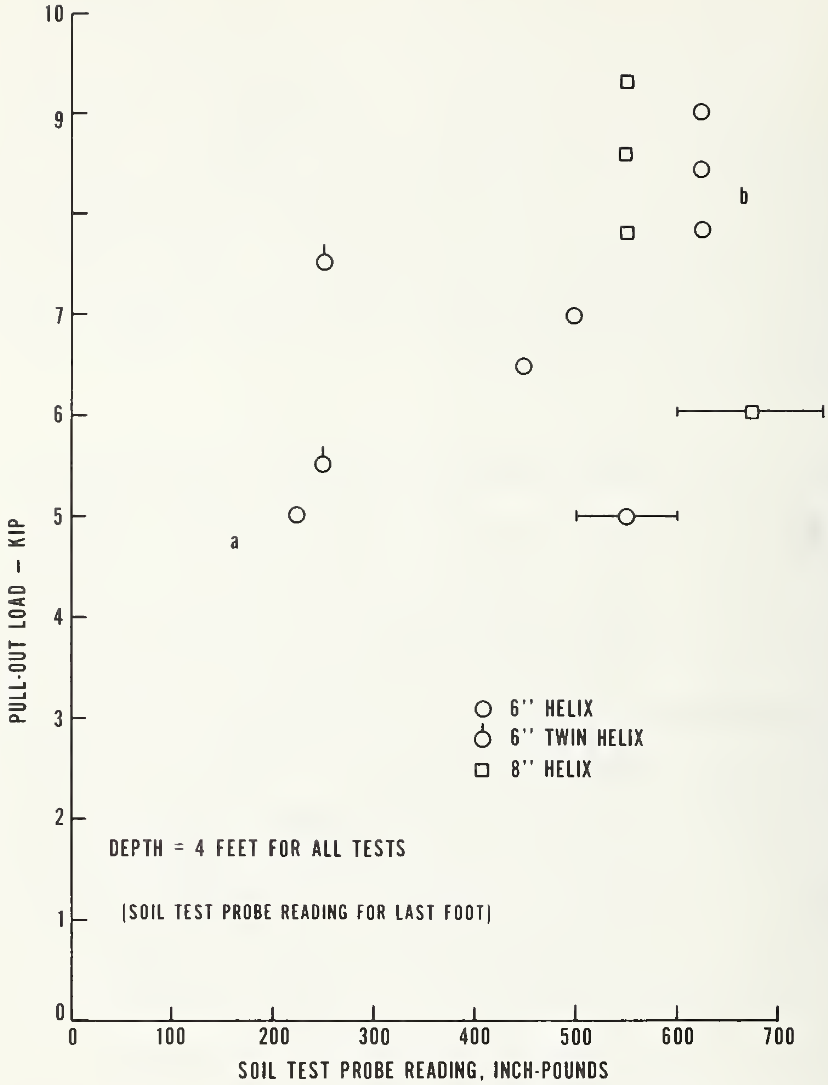


Figure 7.1 *Pull-out Load versus Uplift Deflection for Helix Anchors. (A) 4-inch Anchors at 3-foot depth; and (B) 6-inch Anchors at 4-foot depth*

figure 7.1 are shown for four inch and six inch single helix anchors as well as for four inch and six inch twin helix anchors. The upper curve shows load-deflection curves for an anchor with an embedment depth of three feet while the lower curve is for anchors installed at a depth of four feet. The number in parentheses adjacent to the test order number is the Soil Test Probe (STP) reading in inch-pounds at the depth of the (bottom) of the helix. Using NFPA 501A-1975 failure criteria [69] only tests 4, 7, 2, 1, and 8 meet the requirements. Actual failure load is indicated with the exception of tests numbers 1 and 7. The failure loads for tests 1 and 7 are undefined because the anchors were not loaded to the pull-out load.

Unfortunately, when these tests were conducted, no further information on soil properties was obtained other than classifying the soil according to its Soil Test Probe reading. Of all the field pull-out test data that were supplied by numerous helpful anchor manufacturers, there are only about 6 tests with adequate information concerning pull-out capacity versus load-displacement data and their correlation with soil properties that can be used to establish a rational design approach. However these data are so scattered that no empirical relationships are apparent. Realizing that the relationship between pull-out capacity and soil classification will be very general, a plot of pull-out capacity versus Soil Test Probe reading can be constructed as shown in figure 7.2. Data from four, six, and eight inch (0.10, 0.15 and 0.20 m) helix tests are presented in this graph for tests in which all the anchors were embedded four feet (1.2 m). One may be tempted to draw a curve from points A to B on this graph for a six-inch single helix for a depth of four feet. However, due to insufficient data, it is felt that no such curve is justified. No additional data could be located.

Many times load tests are conducted with a load cell or dynamometer installed between the anchor and the pull-out device. The pull-out device is sometimes a backhoe or drilling machine as opposed to equipment that can carefully control the load. No data could be located on cyclic loading of mobile home anchors.



NOTE: 1 kip = 4.5 kN
1 in-lb = 0.11 N•m
1 in = 25.4 mm

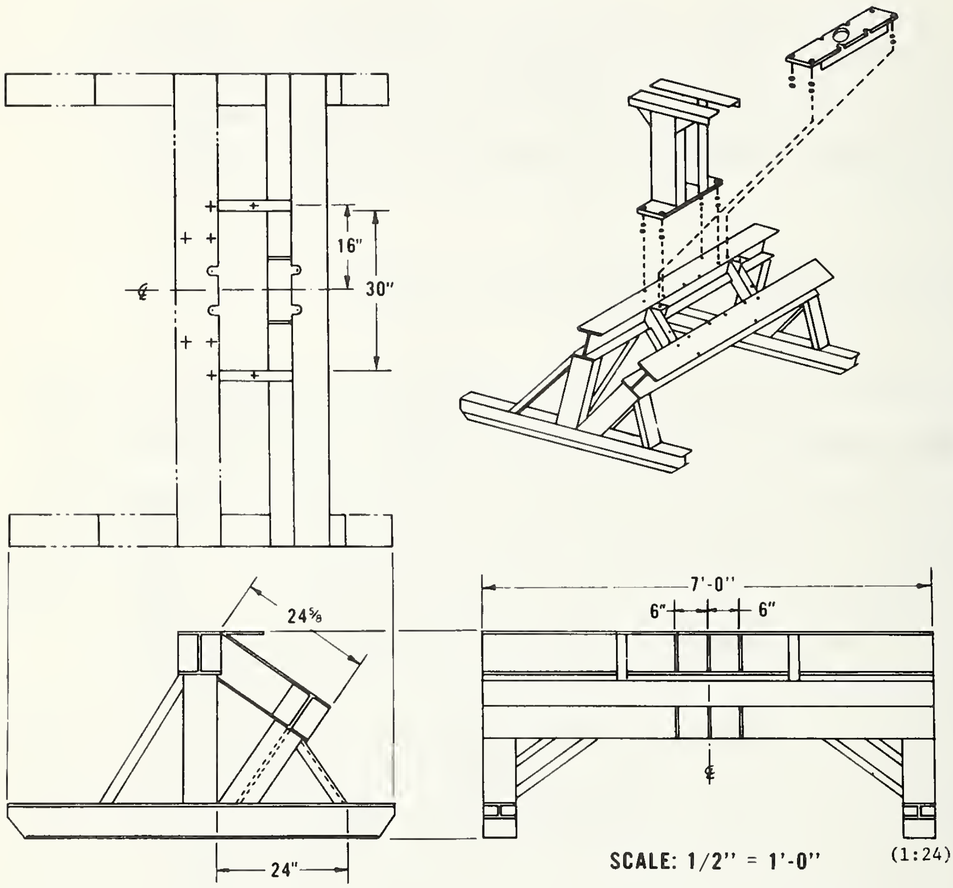
Figure 7.2 Pull-out Load versus STP for Various Anchor Types

Several other load-displacement curves could be presented. However, they more or less duplicate the general information that is presented in figure 7.1. All available useful data are presented in figure 7.2.

An interesting case history of load tests on multihelix anchors is presented by Robinson [87]. He recommends that the pull-out loads calculated from Soil Test Probe (STP) readings in accordance with anchor manufacturers' catalog data should be used with a factor of safety of 2 or more.

7.2 LOAD TEST DATA FROM TRIANGULAR SHAPED ANCHORS

An extensive study of triangular shaped anchors was performed at the U.S. Army Natick Research and Development Command Laboratory [85]; it has since been summarized and brought up to date with supplemental data [91]. Although no load-displacement data are presented for these tests, there is an abundance of data relating pull-out capacity to anchor depth, anchor size, and the direction in which the anchors were pulled out. The loading frame used to perform these carefully controlled field tests, is shown in figure 7.3. By using such a load frame along with an appropriate loading device, load may be applied to the test anchor vertically as well as at an angle of 35° from the vertical. Table 7.1 summarizes the pull-out capacity test data for four-inch arrowhead anchors for depths of emplacement of 20, 30, and 40 inches (0.51, 0.76 and 1.22 m) with both single and double anchors were loaded both vertically and at an angle 35° from the vertical. Double anchors were spaced 30 inches (0.76 m) apart for all cases. These test results are shown graphically in figure 7.4 where pull out capacity is plotted versus anchor depth for the 4-in (0.10 m) arrowhead anchors for site number one, a sand site. Although data are available for the grain size distribution of the underlying granular material at this site, no soil shear strength data or soil density data are available.



NOTE: 1 in = 25.4 mm
1 ft = 0.305 m

Figure 7.3 Details of Load Test Frame Used to Test Triangular Shaped Anchors [85]

TABLE 7.1 SUMMARY OF PULL-OUT TEST DATA FOR 4 INCH ARROWHEAD ANCHORS [85]

Test Site #1 - Sand

Anchor Loads - Range and Average Value in Pounds

Depth of Emplacement (Inches)	Single Anchor Load		Double Anchor Load	
	Vertical	Angular	Vertical	Angular
20	551-551	551-1105	919-1515	1200-1675
	551 (5)	736 (6)	1138 (6)	1438 (6)
30	1200-1515	1675-2245	2075-2245	2400-3145
	1391 (7)	1877 (6)	2171 (6)	2897 (6)
40	1920-2155	2485-3145	2815-5000	4500-4800
	2063 (6)	2678 (6)	3693 (6)	4583 (6)

( ) number of samples represented by average value

No anchor assembly failures were recorded for this site -- 90 percent of the anchors retrieved were reusable.

Double anchor spacing was kept at 30 inches for all tests.

1 in = 25.4 mm
1 lb = 4.45 N

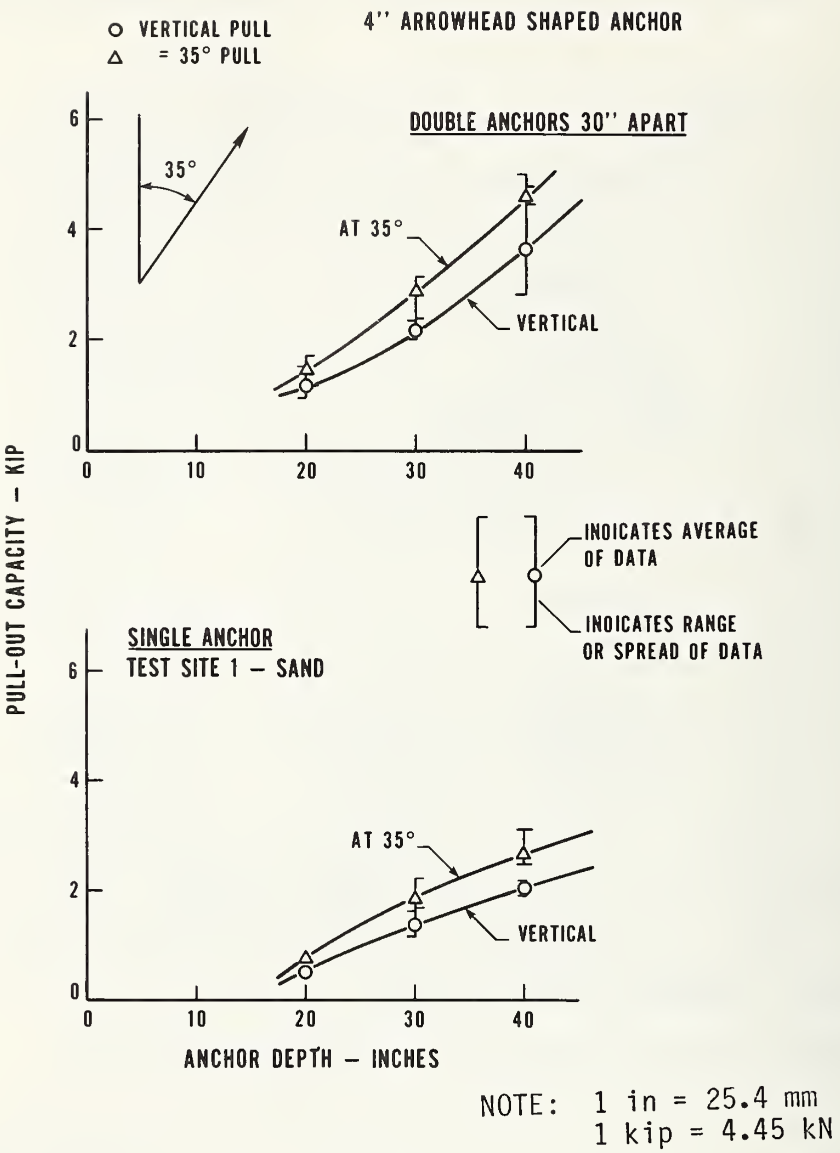


Figure 7.4 *Summary of Pull-out Test Data for 4-inch Arrowhead Shaped Anchors, Sand Site* [85]

As can be seen from figure 7.4, the capacity of the anchors increases with increasing depth of embedment. In addition, double anchors give a higher capacity than single anchors. Finally, four-inch arrowhead anchors pulled at an angle of 35° from the vertical give a higher pull-out capacity than similar anchors polled vertically. Grau [43] found that 4 inch (0.10 m) arrowhead anchors pulled at an angle of 60° from the vertical also had higher pull-out capacities than those pulled vertically. This is an important point and needs to be discussed further.

As mentioned earlier in section 4.2.2, part of the recommended installation procedure for arrowhead anchors requires that they be "set" by a substantial preloading of the anchor in tension. This is analogous to setting the hook when fishing. It is important that the arrowhead anchor turn in the ground under load so as to expose its bearing surface normal to the direction of pulling. In the event that the arrowhead anchors are not set properly, there is a good chance that the arrowhead does not rotate sufficiently and as a result its pull-out capacity will be impaired. Those arrowhead anchors tested at an angle of 35° from the vertical are already rotated relative to the direction of the pull if the direction of the pull differs from the direction in which they were inserted. In other words, the direction of the bearing surface is already inclined to the direction of the pull at the onset of testing. This may be one possible explanation for the reason why the pull-out capacity of both single and double anchors was higher when they are pulled from an angle other than from the vertical.

In addition, it is also reasonable to assume that the greater the anchor depths, the larger the anchor capacity. This is shown theoretically by equations 1 and 2. Likewise, we would expect two anchors to have a greater pull out capacity than a single anchor. However, the data in figure 7.4 show that a 100 percent increase was not achieved by going from one to two anchors. Table 7.2 summarizes the percent changes due to increases in depth for both single and double anchors as well as the

TABLE 7.2 SUMMARY OF PERCENT STRENGTH INCREASE DUE TO ANGULAR PULL-OUT, DEPTH CHANGE, AND SWITCH FROM SINGLE TO DOUBLE ANCHOR INSTALLATION FOR 4 INCH ARROWHEAD ANCHORS [85]

Test Site No. 1 - Sand

A. Percent Increase in Pull Out Capacity for Anchors Extracted at 35° to the Vertical as Compared to Those Vertically Extracted

Depth (in)	Single Anchors	Double Anchors
20	34%	26%
30	35%	33%
40	30%	24%

B. Effect of Depth on Increasing Pull-Out Capability

Depth Increase, (in)	
20 to 30	Single Vertical 152% - Double Vertical 91% Single Angular 155% - Double Angular 101%
30 to 40	Single Vertical 48% - Double Vertical 70% Single Angular 43% - Double Angular 58%

C. Strength Increase by Shifting From a Single Anchor to a Double Anchor Installation

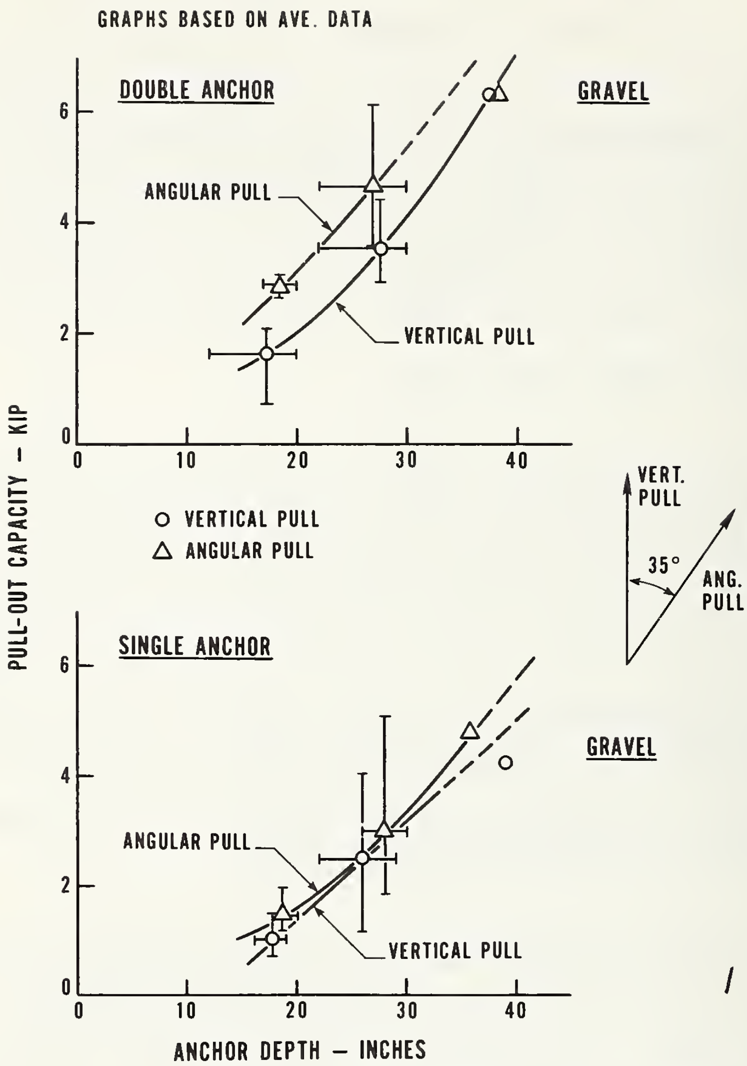
	Single to Double	
Depth (in)	Vertical	Angular
20	107%	95%
30	56%	54%
40	79%	71%

1 in = 25.4 mm

effects of increasing the number of anchors at various depths. For example, as shown in the very bottom line of table 7.2, only a 79 percent increase in pull out capacity is achieved at a depth of 40 inches (1.0 m) for a 4-inch (0.10 m) arrowhead anchor when a second anchor is added. More than double the capacity is obtained for this conditon at a depth of 20 inches (0.51 m). If a failure pattern such as the one shown in figure 5.3c is assumed, then the deeper an anchor is placed, the more chance there is that its failure surface will intersect its neighbor's and result in a reduction in pull-out capacity. At shallow depths such as 20 inches, the failure patterns may not overlap while at a depth of 40 inches, they may.

Data similar to those shown in figure 7.4 are shown for 4-inch (0.10 m) arrowhead anchors tested in a gravel site in figure 7.5. Although these plots of pull-out capacity versus anchor depths are based on the averaged data, considerable scatter of the test data was found. Scatter is much more apparent in this figure than in the previous figure. This indicates that extra precautions should be taken to ensure adequate pull-out capacity in gravel soils. The percent changes due to angular pull-out, depth changes and use of single and double anchors for 4-inch arrowhead anchors in gravel soils are summarized in table 7.3.

Additional data are presented for a site that is described as "Silt With Varying Amounts on Clay and Sand," for vertical pull only. These data, presented in figure 7.6, show the pull-out capacity versus anchor depth for 4 different anchors sizes that range from 2 to 8 inches (0.05 to 0.20 m). The data that were used to make up figure 7.6 are presented in the upper part of the figure. It may be surprising to see that the curves for 4 and 6-inch (0.10 to 0.15 m) anchors size essentially lie on top of each other. It is also of interest to note that the pull-out capacity of an 8 inch (0.20 m) arrowhead anchor is not much greater than that of 4 or 6 inch arrowhead anchor. A possible reason for this behavior may be related to the pull-out factor, N_u, shown in figure 5.1. As the anchor area increases, the D/B ratio becomes smaller for the same



NOTE: 1 in = 25.4 mm
1 kip = 4.45 kN

Figure 7.5 *Pull-out Capacity versus Anchor Depth for 4-inch Arrowhead Shaped Anchors, Gravel Site* [85]

TABLE 7.3 SUMMARY OF PERCENT STRENGTH INCREASE DUE TO ANGULAR PULL-OUT, DEPTH CHANGE, AND SHIFT FROM SINGLE TO DOUBLE ANCHOR INSTALLATION FOR 4 INCH ARROWHEAD ANCHORS [85]

Test Site No. 2 - Gravel

Percent Increase in Pullout Capacity for Anchors Extracted 35° to the Vertical as Compared to Those Vertically Extracted

Depth (in)	Single Anchors	Double Anchors
20	44%	75%
30	19%	32%
40	13%	0%

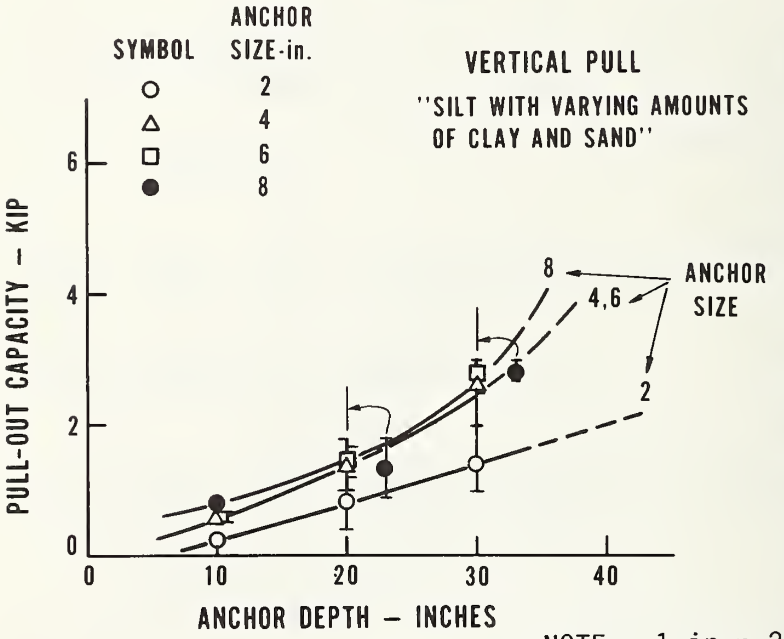
Depth (in)	Effect of Depth on Increasing Pull Out Capacity
20 to 30	Single Vertical 144% - Double Vertical 115% - Single Angular 101% - Double Angular 62%
30 to 40	Single Vertical 69% - Double Vertical 80% - Single Angular 61% - Double Angular 37%

Strength Increase by Shifting From a Single Anchor to a Double Anchor Installations

Depth (in)	Single to Double	
	Vertical	Angular
20	58%	93%
30	39%	55%
40	49%	31%

1 in = 25.4 mm

ANCHOR SIZE INCH	DEPTH INCH	AVG. PULLOUT LOAD POUNDS	PULLOUT RANGE POUNDS
2	10	250	250 (1 TEST)
	20	800	400-1000
	30	1400	1000-2000
4	10	600	600 (5 TESTS)
	20	1360	1000-1800
	30	2590	2000-3000
6	10	580	500-700
	20	1410	1200-1700
	30	2760	2500-3000
8	10	800	800 (2 TESTS)
	20	1350	910-1800
	30	2800	2700-3000



NOTE: 1 in = 25.4 mm
1 lb = 4.45 N

Figure 7.6 Pull-out Capacity versus Anchor Depth for 2-, 4-, 6-, and 8-inch Arrowhead Anchors, Silty Site [85] depth, and as a consequence the pull-out coefficient decreases. The effects of increasing area and decreasing D/B ratio may cancel each other resulting in similar capacities. Another, and probably more likely reason why the 4, 6, and 8 inch (0.10, 0.15 and 0.20 m) arrowhead anchors give approximately the same results may be seen in table 7.4. In this table, for the 4 various size anchors emplaced at three different depths, the number of tests that were observed in three different categories are shown. These categories are the "upset" anchors, "partially upset" anchors and the anchors that were not upset during installation and testing. By "upset" we mean those anchors that after installation were "set" by applying a substantial pull-out load in order to key or to turn the face of the anchor perpendicular to the angle of pulling. It seems reasonable to say that the smaller the anchor size, the easier it could be rotated in the ground for a given load; a smaller anchor has less soil to disturb during its rotation. The number of upset anchors appears in column 4 and the numbers are highest for the smaller anchor size. Likewise, the number of anchors not upset is shown in column 6 and increases as the anchor size becomes larger. It appears that for the 6-inch anchor size emplaced at a depth of 10 inches (0.25 m), there was not sufficient depth in which to support the preload before the anchor failed, and as a result, the anchor was not upset.

It appears that considerable experience may be necessary to insure that an arrowhead anchor is properly set in the ground prior to the anchoring of a mobile home.

Vertical pull-out load versus uplift deflection for a 6 inch (0.15) m) triangular anchor emplaced at a depth of 3 feet (0.91 m) in a class 6 soil is shown in figure 7.7. It is assumed that the anchors were properly upset prior to testing. The straight line relationship is based on the average of at least 3 pull out tests for the same conditions. In this figure, the average of 3 data points is shown by a circle and the range of variation is shown by the exended horizontal lines. Note the wavy

TABLE 7.4 SUMMARY OF DATA ON ARROWHEAD ANCHORS INSTALLATION DEFECTS (30)

Anchor Size in (1)	Depth, in (2)	No. of Tests (3)	No. Upset (4)	No. Partially Upset (5)	No. Not Upset (6)
2	10	1	-	1	-
	20	4	1	1	2
	30	5	4	1	-
4	10	5	3	1	1
	20	7	4	1	2
	30	7	6	0	0
6	10	5	0	0	5
	20	7	3	2	3
	30	7	4	2	1
8	10	3	-	-	2
	20	4	-	2	2
	30	4	-	2	2

appearance of the trend of the data points. The straight line drawn through the data points is an interpretation of how the load varies with deformation.

The results of an individual test of a 6 inch (0.15 m) triangular anchor emplaced at a depth of 3 1/2 feet (1.1 m) in a class 2 soil and subjected to vertical loading are shown in figure 7.8. Obviously the test was not carried out to failure but was terminated at a maximum load of 5,000 pounds (22 kN). This particular anchor fulfills the NFPA requirements for pull-out capacity. Figure 7.9 shows the relationship of pull-out load versus uplift deflection for another 6-inch triangular anchor. This anchor was emplaced 3 feet (0.91 m) in a class 4 soil subjected to vertical loading. (A drastic shift in response is clearly apparent in this diagram.) The discontinuity in this curve is a good indication of what happens during the preloading of an arrowhead anchor. Point a on the graph is probably where the anchor was actually "set" under a preload of

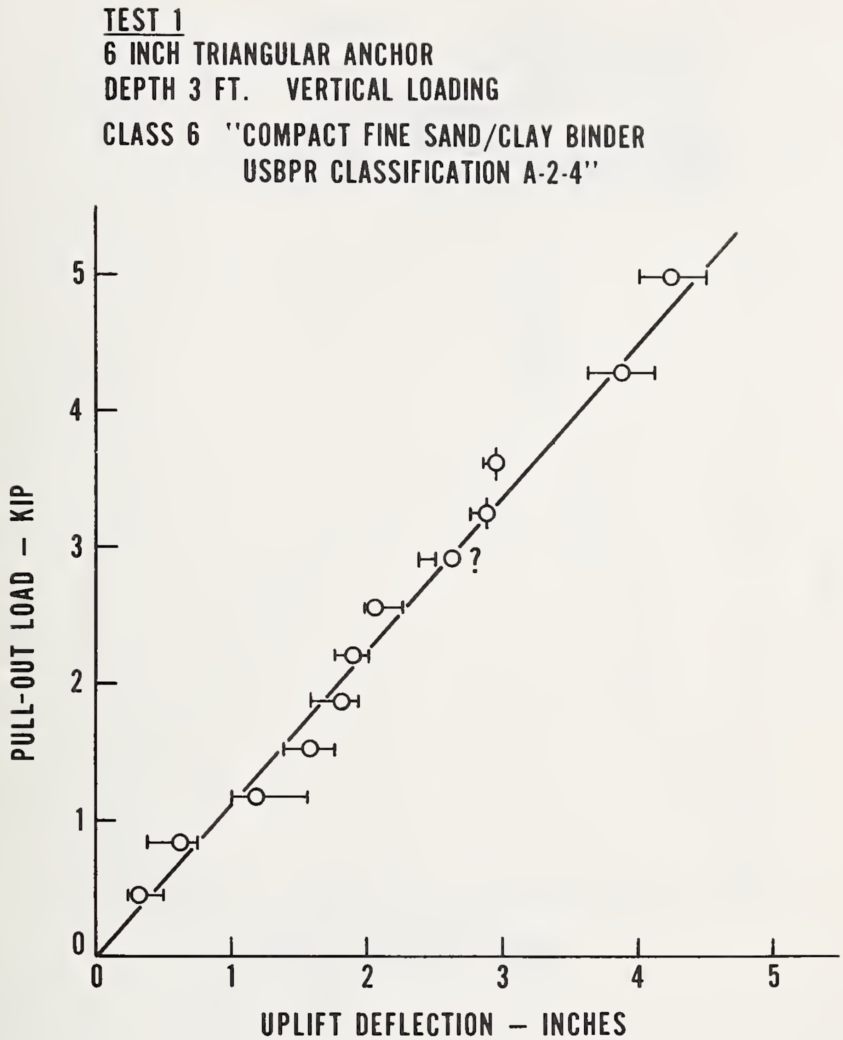


Figure 7.7 Pull-out Load versus Uplift Deflection for a 6-inch Arrowhead Anchor

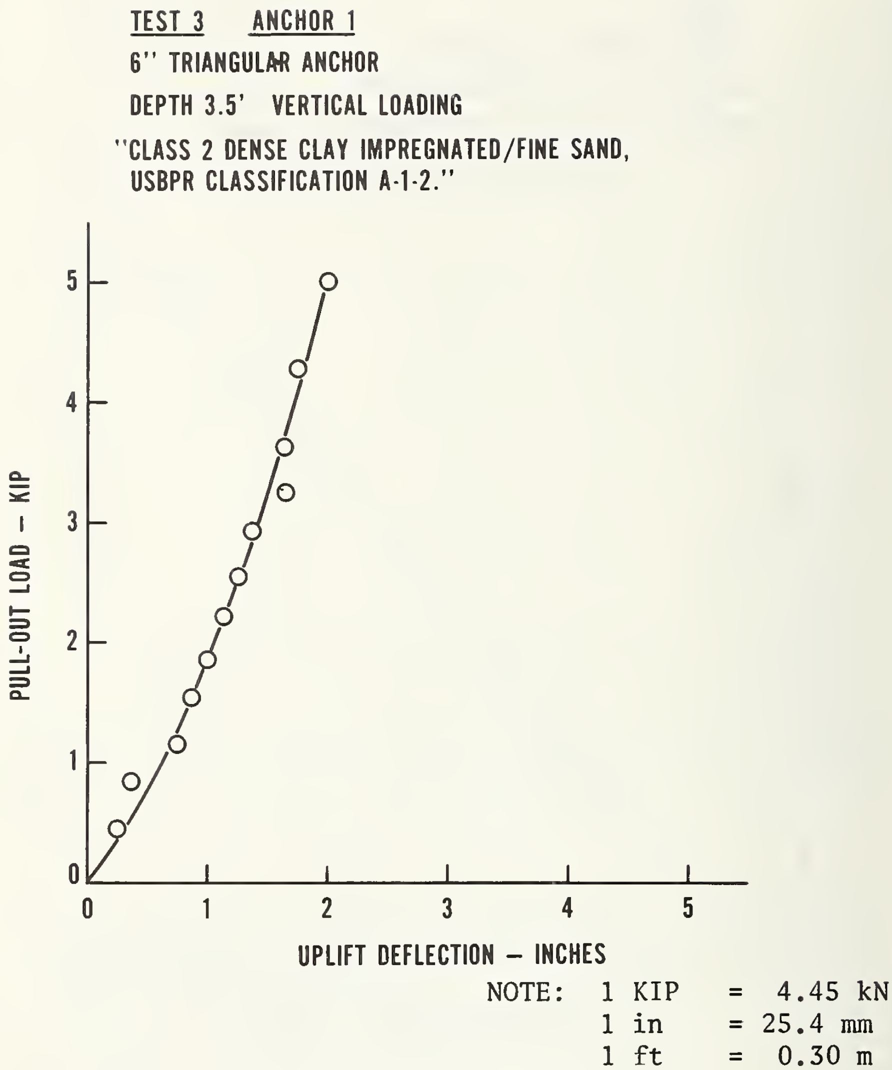


Figure 7.8 Pull-out Load versus Uplift Deflection for a 6-inch Arrowhead Anchor

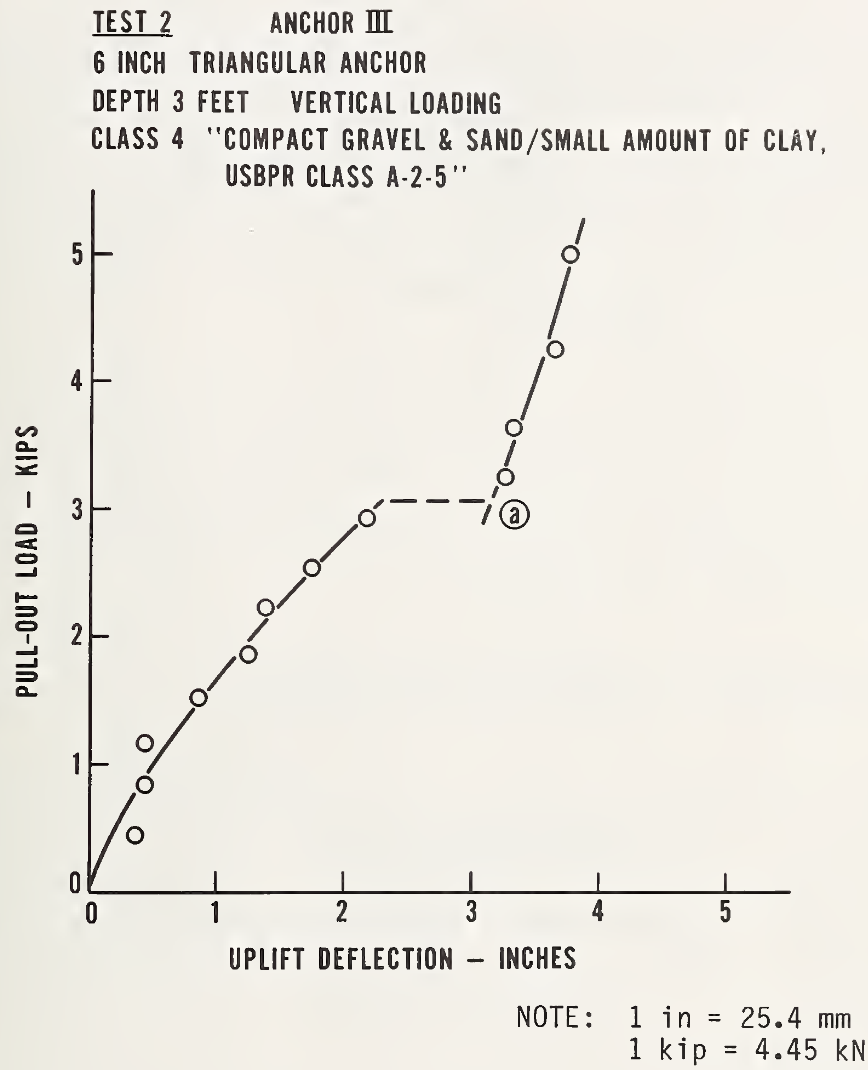


Figure 7.9 *Pull-out Load versus Uplift Deflection for a 6-inch Arrowhead Anchor*

approximately 3 kip (13 kN). This assumption is based on the fact that the slope of the load-deflection curve is steeper after a load of 3 kip was applied to the anchor than from zero up to the 3 kip load.

Because of the fact that arrowhead anchors require turning to be effective, it is felt that further experimental study in the field is needed to more adequately assess what fraction of the ultimate load needs to be applied to ensure that the anchor is upset. The answer to this question appears to be that in many cases the load required to upset the anchor is close to the pull-out capacity [91b].

Studies by Siegel [90a] have indicated that in medium firm to firm and stronger cohesive soils, preloading an arrowhead anchor statically will allow the anchor to exit exactly as it was emplaced into the soil. However, by very rapid loading or "jerking," the anchor may be set in certain such soils, but not always.

7.3 <u>LOAD TEST DATA FROM EXPANDING PLATE ANCHORS</u>

As stated previously, the expanding type anchor gains much of its pull out capacity from the shear strength of undisturbed soil which holds the anchor in place. To a certain extent, the triangular shaped anchor acts in the same way. In both anchors the actual area of the plate bearing against the soil during pull-out is larger than the area inserted during installation.

Very little information is available on pull-out tests for expanding plate anchors. Data from 6 pull-out tests are shown in figure 7.10 for 6 different soil types [99]. Only test number 6 meets the minimum requirements for mobile homes. However, these tests were conducted prior to the more stringent regulations now governing pull-out capacity with regard to minimum deflections [69]. In addition, all of these tests were conducted with expanding plate anchors at a depth of approximately 2 feet. If these anchors were placed at a greater depth, no doubt their

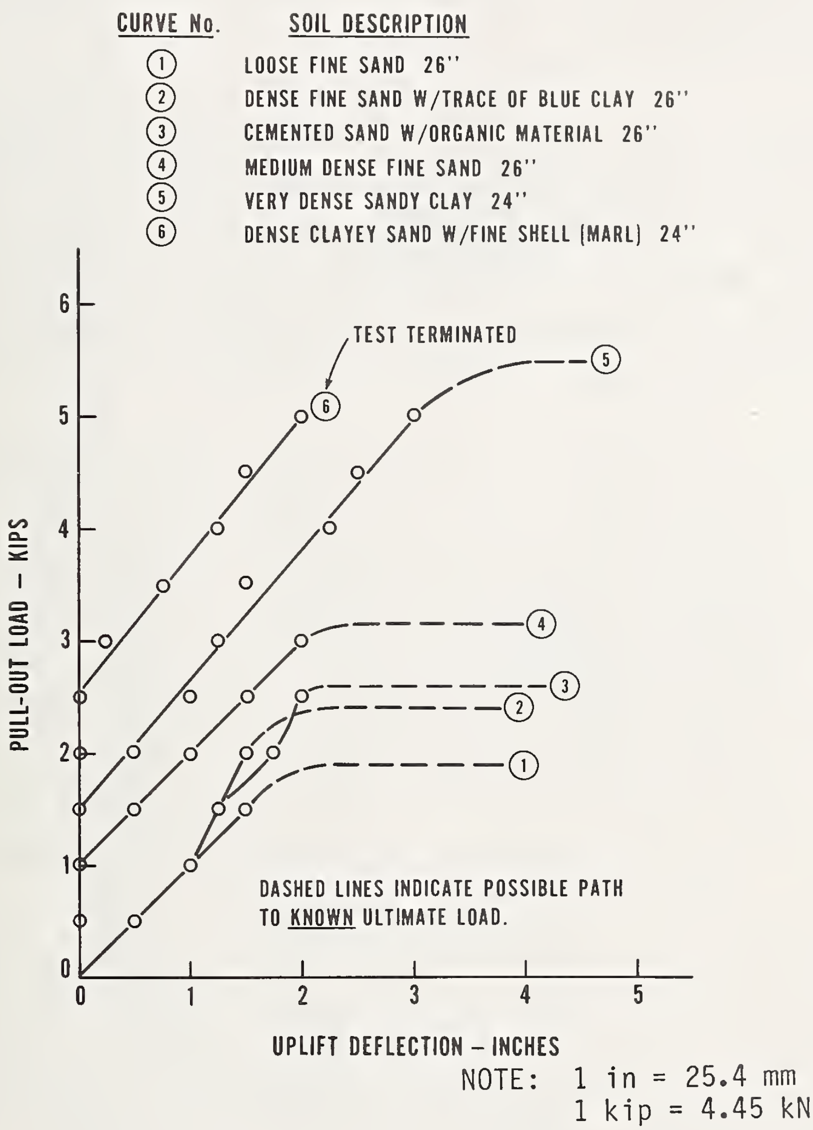


Figure 7.10 Pull-out Load versus Uplift Deflection for Expanding Plate Anchor [99]

capacity would be much higher, as shown by equations 1 and 2. Unfortunately, no additional data are available on the shear strength of the soils in which the anchors were tested other than the visual description contained on figure 7.10.

As can be seen in the figure, the load-deflection curves show 0 deflection until certain load levels, such as the 2,500 lb (11 kN) load for test number 6, are reached. Since measurements were only taken to the nearest 1/4 inch, it is possible that the measurement accuracy did not permit measurement of initial deflections. Another possible explanation is that the initial (zero) recording was taken after a load was applied.

Tests with the same anchor at the same depths of 22 to 26 inches (0.56 - 0.66 m) below the ground surface are presented in figure 7.11 [99]. Notice the detailed deflection readings below 1/2 inch (13 mm). What is interesting in this figure is the small amount of deflection at the design load. It should be pointed out that the individual test results that were plotted were taken arbitrarily from a set of data for three load-deflection curves. The highest deflections at failure were registered in load tests for soil type 5 and 6 (incidated by the box symbol). Again, no data are provided on the shear strength of the soils that were tested.

The difference in the shapes of the pull-out load versus uplift deflection curves given in figures 7.10 and 7.11 illustrates the need for a uniform method of testing anchors for uplift capacity. For example, the accuracy of the measured pull-out load and uplift deflection should be specified in a standard and used throughout the industry.

7.4 LOAD TEST DATA FROM ROCK ANCHORS

Data on expanding anchors with an initial outside diameter of about 2 inches are presented in figure 7.12 for two conditions [23]. Test number 1 was performed in a very stiff, preloaded silty clay containing 29 to 30 percent chert. (Chert is rock, usually irregular in shape and

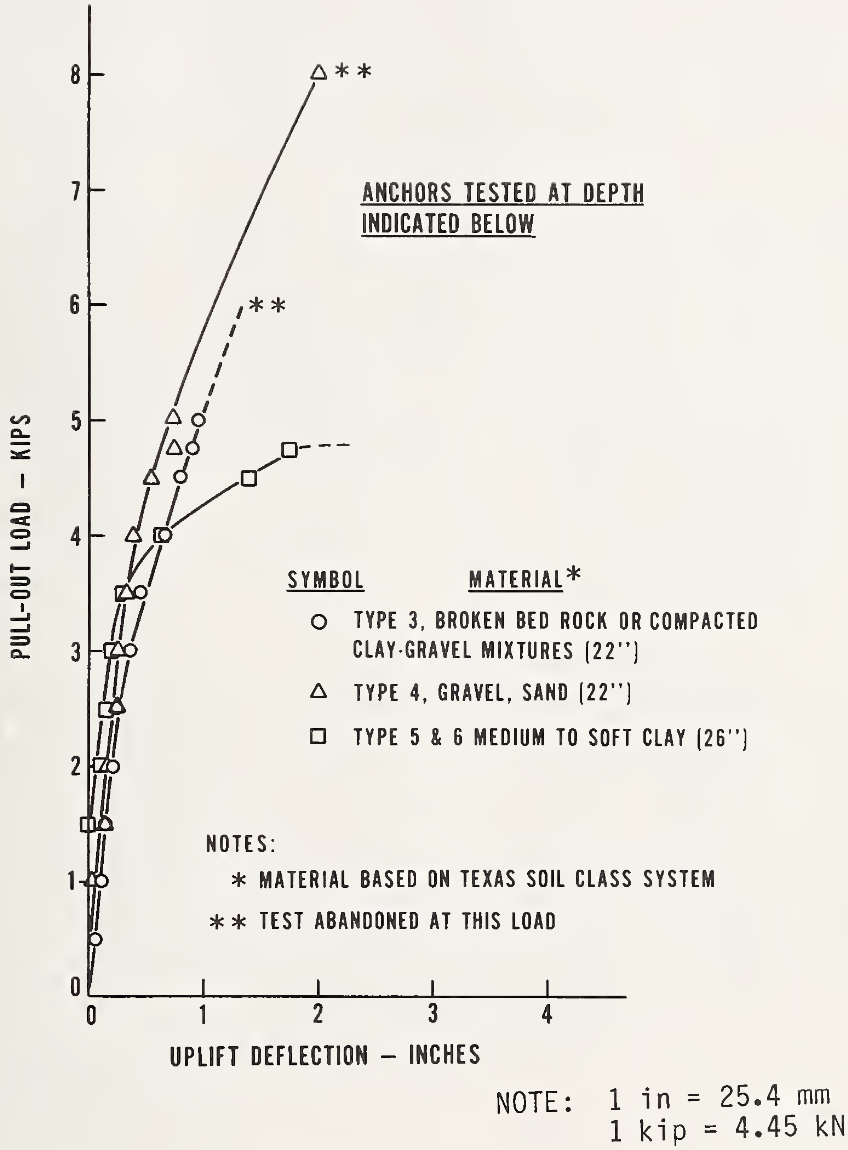
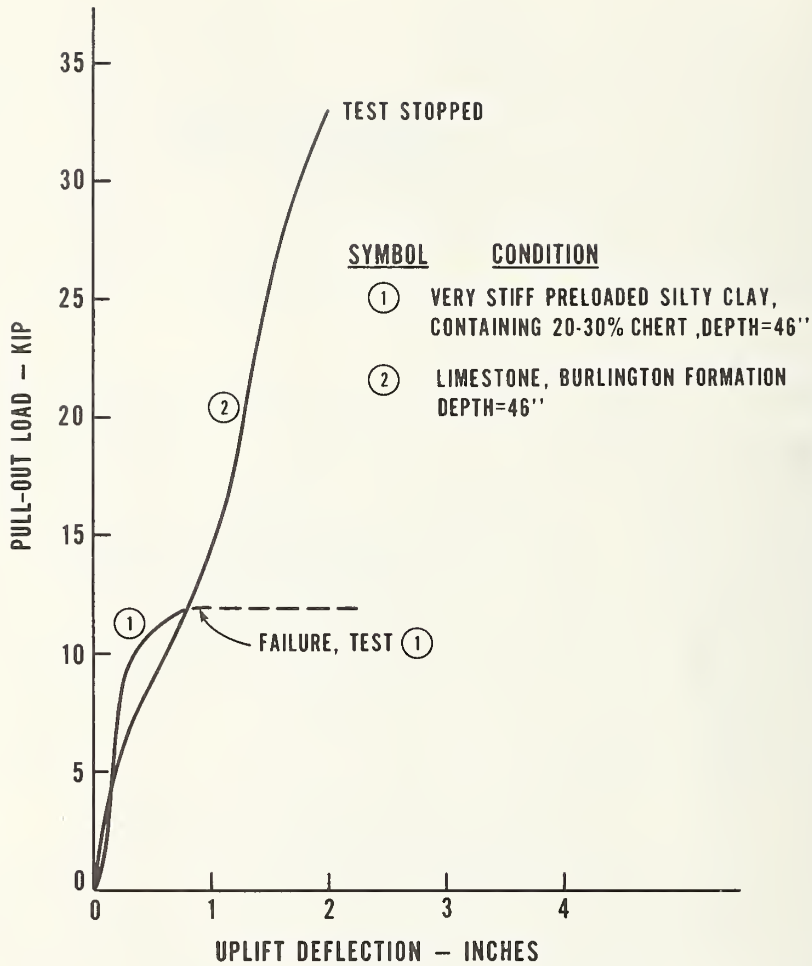


Figure 7.11 Pull-out Load versus Uplift Deflection for Expanding-Type Anchor [99]



NOTE: 1 in = 25.4 mm
1 kip = 4.45 kN

Figure 7.12 Pull-out Load versus Uplift Deflection for Expanding-Anchors in Rocky Material [23] composed of amorphous silica.) The second test was performed on intact (?) limestone of the Burlington Formation. (Geologists used the word "intact" to describe rock that is free from defects such as joints, bedding planes, etc.) Unfortunately, no other soil or rock information was given. For these two ground conditions, the anchor performed well with respect to the NFPA 501A-1975 requirements [69].

For the anchor described above, a hole is drilled by whatever means is feasible, keeping the hole to a minimum diameter so that when the expandable type anchor is inserted, it has a minimum of clearance. With this particular anchor, a hydraulically applied compression load deforms the anchor plate and increases the normal force between the anchor and the surrounding hole; this provides a large frictional resistance against pull-out. In principle, this type of anchor is very similar to other types of expanding rock anchors, but it appears to work well in "stiff" or "hard" soils.

Besides the load test data presented in figure 7.12, the only other test data obtained on the pull-out capacity of expanding rock anchors is for one case in a blue shale of unknown strength. Using (probably improperly) an expanding anchor of the type shown in figure 4.5, the maximum pull-out capacity was 3,000 pounds (13 kN) while using the multiple internal split tube type anchor, capacities of 16,000 and 19,000 pounds (7 to 85 kN) were obtained with less than one inch of deflection. Further proprietary information could not be obtained.

7.5 DISCUSSION OF TEST DATA

Several things should be apparent to the reader regarding the determination of pull-out capacity from field tests. Although many tests have been performed, the actual prediction of pull-out capacity of anchors is far from precise. Just because anchors meet the NFPA [69] requirements for pull-out load at a minimum deflection in a specific soil deposit in some states, does not necessarily mean that similar pull-out capacities will be achieved in another part of the state for the same visual soil classification. Samples of the best pull-out load test data have been presented. However, very few pieces of literature available from anchor manufacturers contain enough information on soil shear strength and depth of embedment to corroborate present pull-out capacity hypotheses by back calculation.

Although pull-out load tests for possibly up to seven or eight soil classes may meet the requirements of a state agency, it is felt that they would not pass the scrutiny of a soils engineer if he were given the responsibility to design the anchor for a given pull-out capacity and deflection. In other words, the pull-out test data that have been shown cannot be used to further the state of the art since the test data do not provide sufficient information on the strength and characteristics of the soil.

Clearly, what is needed is a standard for field pull-out tests which would require the reporting of the load-displacement characteristics, the pull out capacity and the pertinent soil parameter.

Facing page: *Soils need to be identified to design against advers environmental factors such as expansive and freezing soils.*

8. ENVIRONMENTAL EFFECTS ON ANCHORS

8.1 INTRODUCTION

In addition to being required to resist wind and flood induced loads, anchors are subjected to other environmental effects which not only exert loads but reduce load resistance as well. Some of these effects are discussed below. Flood effects such as scour, soil saturation, or wave impact are beyond the scope of this report.

In order to design against adverse environmental factors such as expansive soils or freezing soils, the soils need to be identified. The following paragraphs discuss the appropriate site investigations required to identify potential soil problems and make recommendations for adequate design.

8.2 ANCHORS IN EXPANSIVE SOILS

The geotechnical engineering literature contains much information (for example, Reference 83) on the design of Building foundations in expansive soils that is also applicable to mobile homes. An expansive soil is one that changes volume seasonally due to the addition or removal of water. During the "wet season", the soil absorbs water and swells, raising any lightweight foundation that happens to be above it. Likewise, during the dry season, the soil shrinks due to evaporation and, as a result, settlement occurs. If this movement, both upward and downward, occurs at different rates and different amounts on the same structure, considerable distortion may occur which will cause architectural distress and possible damage to the structure as well.

The main objectives when building on an expansive soil are to either maintain a constant soil water content or to support the structure on a stable soil stratum. If the water content remains stable, neither shrinkage nor swelling will take place. Seasonal changes in the weather and the watering of lawns and gardens both contribute to changes in the soil water content. Sources of information on expansive soil are given by Hilf, [49] and the Canadian Manual on Foundation Engineering [80]. Further problems of heaving are discussed in the next section.

Though it is conceivable that mobile home foundations in expansive soil could be affected by the relative movement between the anchors and the mobile home, no evidence of significant damage to mobile homes could be found. It is, however, reasonable to assume that seasonal adjustment of strap tension is advisable in some areas.

8.3 ANCHORS IN SOILS SUSCEPTIBLE TO FROST

Anchors embedded in soils susceptible to seasonal freezing experience problems similar to those of anchors embedded in expansive soils. Only in this case, as the ground freezes from the top down, ice lenses may form and cause the ground surface or individual foundation elements to rise. If the anchors do not experience a similar upward movement, such heaving could be detrimental to the structural components of a mobile home and its anchoring system. Likewise, during the spring thaw, the mobile home may settle, perhaps differentially, and the tie-down anchors may lose their supporting capacity as the soils above the anchor which hold it in place lose their strength due to drastic increases in water content upon thawing.

Johnston and Ladanyi [57] performed field tests on 8, 10 and 15-inch (0.20, 0.25 and 0.38 m) diameter power installed screw anchors embedded in permafrost in northern Manitoba. The frozen soils at the site consisted of stratified silts and clays containing ice at a temperature just below freezing. The pull-out tests showed behavior similar to that of soils that were not frozen. However, it was found that the anchors required relatively large displacements to attain their ultimate pull-out capacities. These large displacements develop under small loads and as a result may exceed the maximum allowable deflection criteria for mobile home applications. The authors concluded that for those site conditions under which they performed tests on helix anchors, grouted rod anchors would have been much more reliable, efficient and economical.

The external forces imposed upon a mobile home during heave are illustrated in figure 8.1. In part a of this figure, the mobile home is shown at the initial condition with over-the-top tie downs connected to anchors A. In parts b and c of this figure, an exaggerated heave is shown by the dashed line. If the soil above an anchor heaves, it will cause a reaction, 1, on the underside of the mobile home frame which is in turn resisted by the over-the-top ties connected to the anchor. This

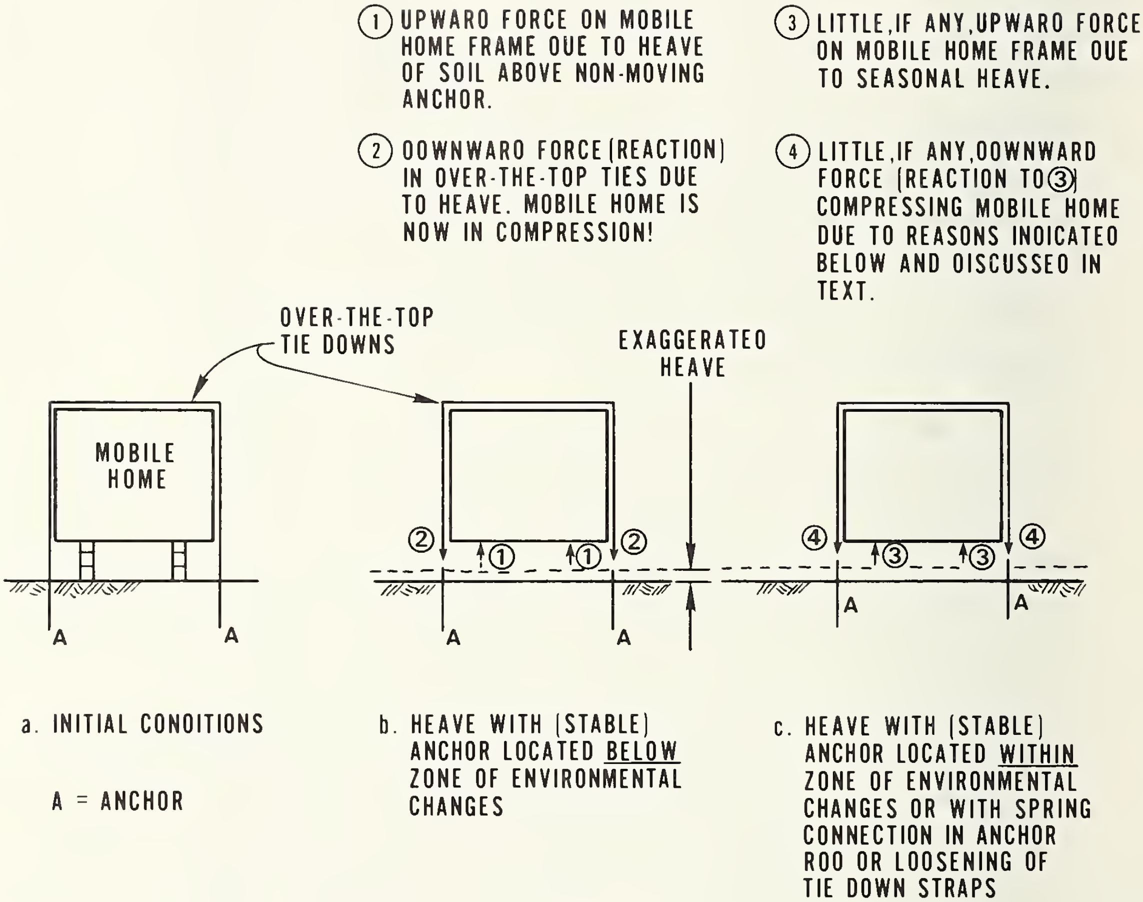


Figure 8.1 Compressive Loading of Mobile Home During Heave of the Upper Soils when Over-the-Top tie-downs are used

reaction could be as large as the anchor pull out capacity, if the anchor is embedded below the zone of environmental changes and therefore does not move. Thus, heaving causes compression of the mobile home under these conditions. Similar conditions would apply if the heave was caused by expansive soils.

The induced forces could be reduced by several possible methods. These methods include:

1. Seasonally loosening the tie-down straps where they connect to the anchor. This would require periodic retightening of the straps when the heaving is reversed.

2. Special spring loaded connectors which would reduce the forces induced by relative movement but at the same time could develop adequate wind resistance. These devices would have to take into account the expected amount of travel or heave that would occur seasonally. Vertical creep might occur and the soil would have to be investigated for this possibility.

3. Placing an anchor within the zone of environmental changes such that when heave occurred, the anchor would also heave along with the mobile home. Under these conditions, the mobile home would be loaded by forces 3 and 4 shown in part c of figure 8.1 as the relative movement between the mobile home and the anchor would be kept at a minimum. This latter situation presents a problem in that it requires an anchor to have the capability of supporting the minimum required anchor load at a shallow depth without exceeding the maximum allowable displacement.

Information to evaluate a soil for its frost heave potential are given in reference [81] and in references [63 and 64] by Krizek which specifically relate to mobile homes.

8.4 EFFECTS OF CORROSION ON ANCHOR CAPACITY

Corrosion of the metallic parts of the mobile home anchoring mechanism will reduce cross sectional areas, resulting in higher stresses which could lead to failure. Such problems may go undetected as most of the anchoring mechanism is underground and unavailable for inspection.

Corrosion of metal parts of the anchoring mechanism in contact with soil may result from stray electrical currents in the ground from external sources, corrosive chemicals within the soil, and bacterial action. The physical property of soils that is most influential in determining the amount of corrosion that will take place is the soil's permeability to air and water. Generally, sands have a much higher permeability than clays. Therefore, for loose sands and gravels where there is good drainage and the air is free to circulate, the corrosion will approach the atmospheric type. In highly cohesive (impermeable) soils and below the water table, where there is a marked reduction in air (oxygen), corrosion takes place at a reduced rate. Corrosion may take place at accelerated levels as a result of human activities or induced pollution.

The most corrosive soils are generally found in swampy areas, peat bogs and very acidic and very alkaline deposits. Man-made fill areas that contain coal storage, industrial chemical wastes, acids and recently dumped cinder fill, may also promote corrosion. However, such areas would be undesirable mobile home locations as well.

A chemical analysis of the soil, normally beyond the scope of a routine investigation for a mobile home site, would assist in evaluating corrosiveness. The pH value of a soil (a value that represents the logarithm of the reciprocal of the hydrogen ion concentration) alone is not sufficiently indicative of corrosiveness; total acidity of the soil is a better indicator. Soils with a high resistivity have been found to be noncorrosive. Studies on corrosion were published by Romonoff, 1957 [88a] and Uhlig, 1948 [99a].

Practical preventive measures for the mobile home owner concerned about corrosion include:

1. Purchase of corrosion resistant anchors.

2. Purchase of "heavy duty" anchors which have thicker metal sections than may ordinarily be used. Corrosion may take place, but it will not reduce the structural capacity of the anchor below some minimum requirement.

3. Determination if existing anchors at nearby mobile homes have bad corrosion problems. If no information is available, the mobile home owner should inspect his anchors below ground on a periodic basis.

4. Replacement of corroded anchors on a periodic basis, as required.

Facing page: *The safety of mobile home construction is a growing problem in the U.S.*

9. SUGGESTIONS FOR FUTURE RESEARCH

Based on shortcomings observed in this study, the following research is suggested to improve anchoring technology, design and regulation.

1. Preparation of standard nomenclature to be used to describe soils and rock for anchoring purposes. This information is readily available and merely needs to be adopted as an industry-wide standard and presented in a form usable by all segments of the industry.

2. Preparation of a standard method for performing field pull-out tests. This standard should address such items as type and size of a load test frame used to apply the pull-out load; accuracy of load-deflection measurements; minimum requirements for soils and rock classification including strength determination by in-situ tests; and details on the information that the test report should contain.

3. A field test program considering response of available anchor types in various soil and rock types to establish a correlation between pull-out capacity and such field tests as the standard penetration test, the soil test probe, and others. Particular attention should be paid to the amount of displacement undergone by an anchor head, which, it is felt, has largely been ignored in the past. The field testing should include both static and dynamic (cyclic) testing with particular emphasis on the displacement occurring under repeated loads, and loading which is not coaxial with the shaft of the anchor, similar to that actually experienced by mobile homes anchors. As a result of this test program information should be available on the effects of cyclic and sustained loading and saturation of the supporting soil.

4. Development of standard performance tests (pull out as well as proof) by which the adequacy of installed anchors can be determined.

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Available anchor hardware is surveyed and evaluated and pull-out capacity data are compared with hypotheses for predicting anchor pull-out capacity based on soil mechanics principles. The evidence suggests that our ability to predict anchor pull-out capacity by soil mechanics principles is inadequate, and that there is a need for the standardization of test procedures and soil classification and for further test data. Suggestions for future research are presented.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

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