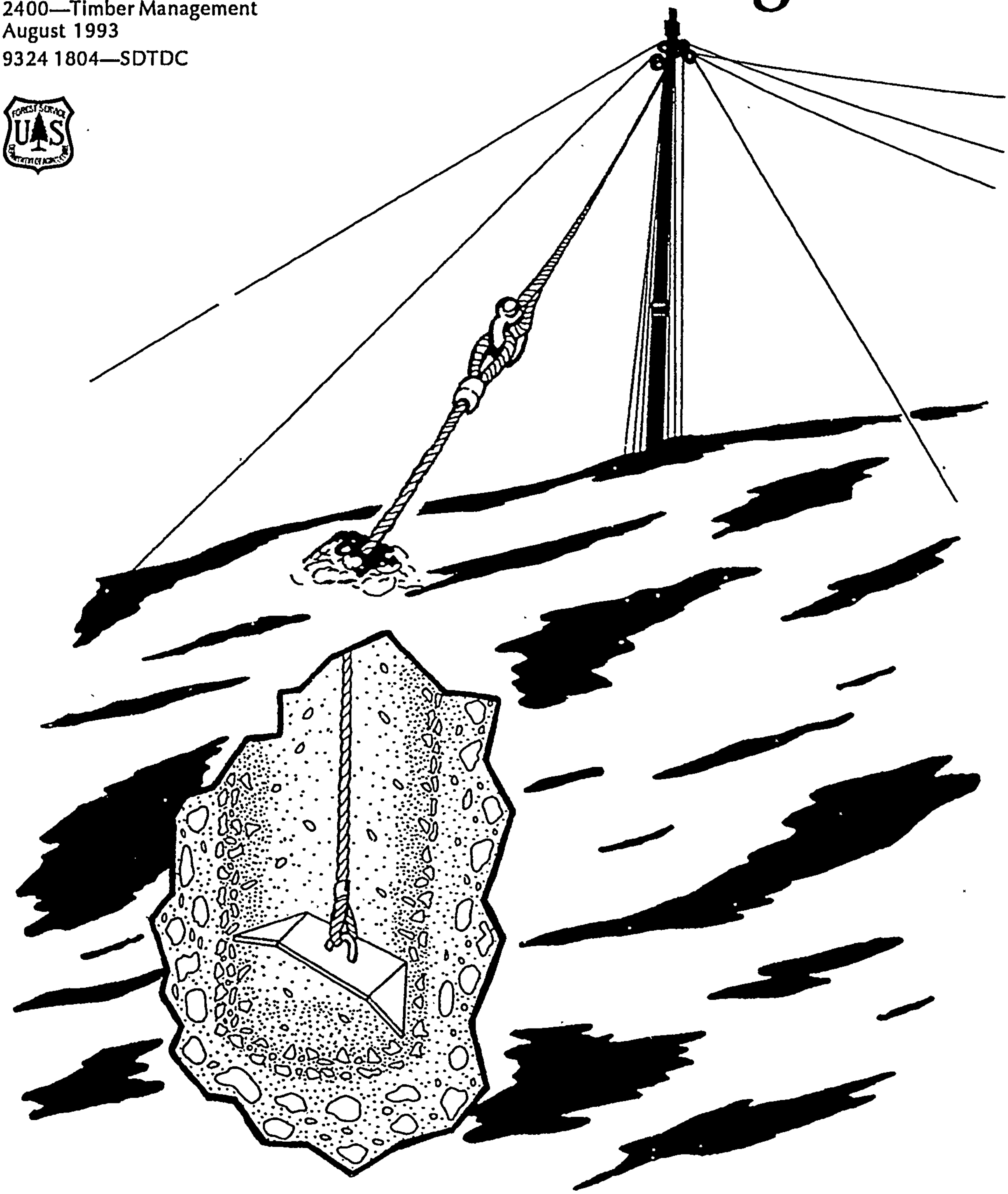
United States
Department of
Agriculture

Forest Service

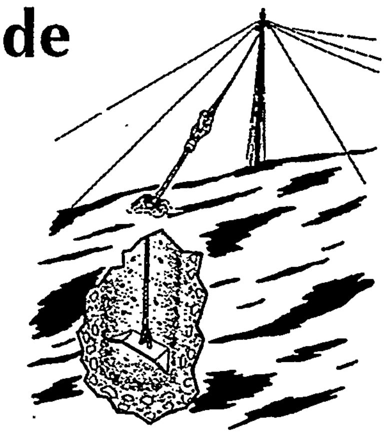
Technology &
Development
Program

2400—Timber Management
August 1993
9324 1804—SDTDC

An Earth Anchor System: Installation and Design Guide



An Earth Anchor System: Installation and Design Guide



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TE01125
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August 1993

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ABSTRACT
Copstead, R.L.; Studier, D.D.; Simonson, R.J.; 1992. An Earth Anchor System: Installation and Design Guide. Spcl. Rep. 9324 1804—SDTDC. San Dimas, CA: U.S. Department of Agriculture, Forest Service. **25** p.

A system for anchoring the guylines and skylines of cable yarding equipment is presented, along with a description of three types of tipping-plate anchors, and the installation equipment and methods specific to each type. Procedures for estimating the number of anchors to install are included, along with guidelines for installing the anchors so that they will withstand the expected forces imposed on them in this application. Charts for estimating the number of anchors to install are included in appendix 1. Appendices also give results of tests that were conducted and specifications for anchors and installation equipment. Information presented is based primarily on field tests conducted under a variety of conditions in California, Oregon, and Washington.

Keywords: Logging, earth anchors, anchors, cable yarding, machine anchors, soft earth anchoring.

BACKGROUND AND ACKNOWLEDGMENTS
As commercial forests evolve to a more intensively managed resource with younger, smaller diameter trees, new methods and technologies—such as the anchoring system described here—will be required if we are to sustain or enhance productivity and meet silvicultural and environmental goals. In this program, the Forest Service first staged numerous anchor installation demonstrations and worked with industry, safety and trade organizations, private companies, and independent contractors and consultants to stimulate development of feasible anchoring alternatives.

Collaboration of the authors with Briar Cook, civil engineer, San Dimas Technology and Development Center (SDTDC), resulted in much of this material being originally written as notes distributed at an earth anchor training workshop in November 1988 at SDTDC. The material then served as a basis for the publication of General Technical Report PNW-GTR-257 (July 1990), which had the same title as this present publication.

With the successful field use of anchors in numerous harvesting applications, and additional input from Dan Feeney, former logging engineer, Region 6, this revised publication supersedes PNW-GTR-257 and much of the workshop material. This Guide is one of many outcomes of the effort to find alternatives for anchoring harvesting machinery. A video tape presentation, which covers the use of anchors and their associated installation equipment, is also available: *Earth Anchoring Systems for Cable Yarding*, 1991, No. V9124-SDTDC-01. Inquiries regarding further development of the technology should be directed to:

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INTRODUCTION

Skyline logging systems require anchors for tying down tower guylines and securing a skyline at the tailhold. Stumps have been the most convenient, cheapest, and—therefore—the most widely used anchor. In many areas, sound stumps of adequate size and proper location relative to the landing are becoming scarce. Older, large stumps and their root systems become rotten and their holding capacity is difficult to predict. Quite often, new stumps are smaller than required for anchoring skyline machinery.

The USDA Forest Service has completed research and development of anchors that could be used as substitutes for stumps. The objective of this research was to develop an inexpensive and portable anchoring system that could be used in rough terrain. One anchoring system meeting these criteria is the tipping-plate anchor (fig. 1). This document describes tipping-plate anchors, installation equipment, and procedures for designing and installing anchorages made from tipping-plate anchors bridled together. Results of pull-to-failure tests for a few specific conditions are included in appendix 2.

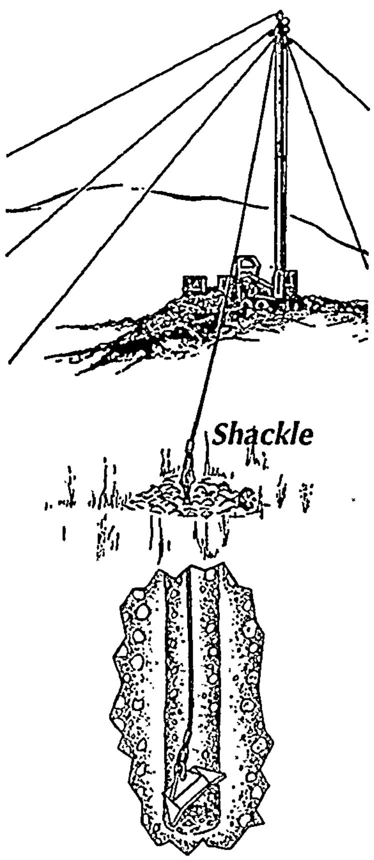


Figure 1. Guyline attached to a tipping-plate anchor.

Holding capacities of these anchors differ greatly with the soil conditions and are generally low enough so that two or more anchors must be bridled to provide a safe anchorage for a guyline or tailhold. Rigging and bridling procedures are important and are discussed, as is a method for estimating the number of anchors to withstand the expected load. The design procedure requires the installation of tipping-plate anchors and pulling each to failure or to some predetermined load. ***Extrapolation of test data from one site to another is not recommended.***

TIPPING-PLATE ANCHORS

Two anchors that we tested were the arrowhead anchor (Laconia Malleable Iron Company) and the Manta Ray MR-1 anchor (Foresight Products, Inc). A third, the soil toggle anchor, was designed and fabricated by the Forest Service and is now being produced by Foresight Products, Inc.

Arrowhead Anchor

This anchor is shaped like an arrowhead and is cast with ductile iron. Two holes through the anchor allow attachment of wire rope (fig. 2). The wire rope may be attached as shown in figure 2 or looped through the anchor to increase the strength of the anchor assembly. The diameters of available wire rope are 1/8, 3/16, 1/4, and 5/16 inch. The anchor size is specified by the width as measured across the top at the broadest point. Arrowhead anchor sizes, bearing areas, weights, and cable diameters are shown in table 1.

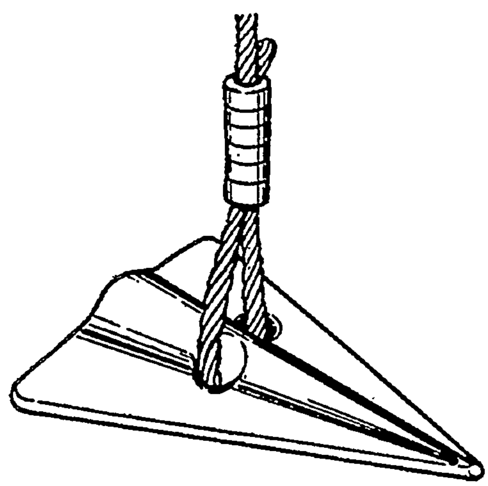


Figure 2. Arrowhead anchor.

Table 1. Physical characteristics of Laconia Arrowhead anchors made from malleable iron

Size (inches)	*Bearing Area (square inches)*	*Weight (pounds)*	*Cable Diameter (inch)*
2	2	0.16	1/8
3	4.5	0.39	1/8
4	8	0.91	3/16
6	18	2.2	3/16
8	32	3.7	1/4
10	50	9.0	5/16
12	72	12.0	5/16

Manta Ray MR-1 Anchor

The Manta Ray MR-1 anchor is 7 inches wide and 12 inches long, is made of mild steel, and weighs 12 pounds (fig. 3). A wire rope 3/4 or 5/8 inch in diameter is permanently attached to the anchor with a pressed eye; the free end of the wire rope has a pressed eye with thimble.

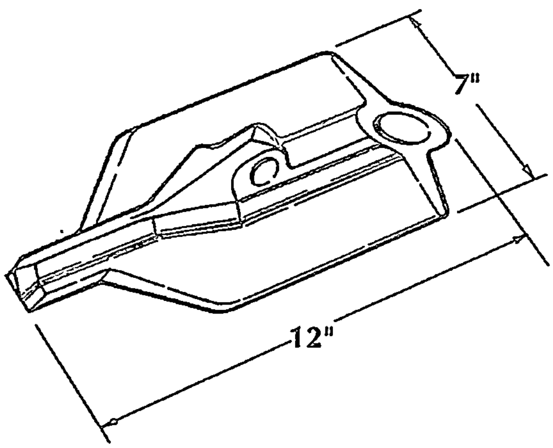


Figure 3. Manta Ray MR-1 anchor.

Soil Toggle Anchor

Two sizes of soil toggle anchors are available (fig. 4). The smaller of the two is designed for less than 1 inch wire rope straps and the larger is designed for 1 inch or greater straps.

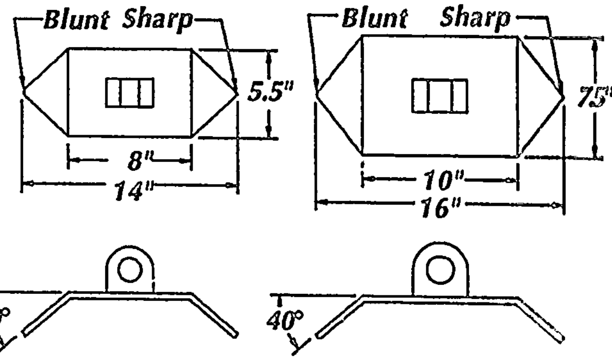


Figure 4. Small and large soil toggle anchors.

INSTALLATION EQUIPMENT

Impact Hammers

Three types of impact hammers can be used for driving Arrowhead and Manta Ray MR-1 anchors: Hydraulic, pneumatic, and gasoline. Hydraulic hammers require a power unit that can deliver a flow of 8 gallons per minute at a pressure of 2,000 pounds per square inch. Construction equipment (such as hydraulic backhoes, excavators, and yarders used for logging) typically have hydraulic systems meeting these requirements. However, unless the equipment can travel over steep and uneven terrain, anchor installations will typically be confined to a 200-foot radius from where the power unit is parked. Portable hydraulic power units that can be carried into remote areas are available that meet requirements for providing power to impact hammers. Pneumatic hammers require an air supply of at least 100 cubic feet per minute.

The hammers needed to drive anchors weigh between 60 and 90 pounds. The lighter weight hammer is used to drive the anchor in loose soils or when an augered pilot hole is used. A 90-pound hammer may be needed in dense or rocky soils if a pilot hole is not used. Some pneumatic hammers can drill pilot holes with a rock bit while also blowing out the cuttings.

Gasoline-powered hammers, such as the Swedish-made Pionjar, require no external power supply and are portable. They weigh approximately 60 pounds and exert an impact force as well as a rotational force on the drive rod. Because of the light weight of this hammer, it works best in loose soils or with pilot holes.

Drive Rods

Drive rods (sometimes called drive gads) transmit the reciprocating force from the impact hammer to the anchor. Most hydraulic and pneumatic hammers require a rod 1.125 or 1.25 inches in diameter. Some smaller hammers and the gasoline hammers use a rod 0.875 inch in diameter. The end of the rod that is inserted into the anchor needs to be machined for a tight clearance. If the clearance is too small, however, the anchor may become seized on the rod during installation. With the use of arrowhead anchors the rod should also be machined so that the end of the rod does not touch the bottom of the socket in the anchor. This allows the driving force to be transmitted through the collar of the rod, avoiding the problem of flaring the rod end which would cause it to bind inside the anchor.

Drive rods can be obtained in 2.5-, 4.0-, and 5.5-foot fixed lengths. Rods are also available which are designed so that multiple 2.5-foot sections may be coupled together. The threaded sections can be lubricated with an all-purpose grease so they separate easily after use. A disadvantage of using fixed-length rods is the depth an anchor is driven to is limited by the length of the rods. Also, if a 5.5-foot rod is used to start the driving operation, the operator will be required to hold the hammer about 6 feet above the ground. This may require standing on something to gain a safe working elevation. If the rods are shorter and additional sections can be added as the anchor is driven, the operator is usually working with the hammer below shoulder height, which is easier and safer.

Augering Equipment

Many gasoline- and hydraulic-powered portable augers can auger holes 2 to 8 inches in diameter. Auger extension flights can be obtained in several lengths and diameters to suit various conditions. Carbide tips are recommended for most forest soils. Manufacturer's specifications on installation equipment are in appendix 3.

ANCHOR INSTALLATION

Anchors

The installation procedures differ with the type of soil and anchor.

For small anchors (such as a 2-inch Arrowhead) in soft soils, the anchor is driven into the ground with a drive rod and a sledge hammer or with a driving device similar to that used for steel fence posts. The drive rod is inserted into the hole at the top of the anchor and is driven at the desired angle until it cannot be driven further or the desired depth is reached. The rod is removed, and then the anchor must be "set" or "keyed" by pulling on the anchor strap. You should be able to detect an increase in the resistance to the pull on the strap when the anchor begins to set. Experience will assist in developing a feel for the set point for a particular soil/anchor combination.

For the larger Arrowheads (6-inch size or larger) and Manta Ray MR-1's, a hydraulic, pneumatic, or gasoline driven impact hammer is needed to install the anchor. The installation procedure is the same as for the drive rod and sledge hammer, except that the hammer is placed on the drive rod before the rod is inserted into the anchor.

In stiff soils, such as dense clays, a pilot hole can be augered before the anchor is driven. With a Manta Ray MR-1 anchor, for example, a 4-inch pilot hole is augered at least 6 inches deeper than the design depth. This leaves an area at the bottom of the hole for loose soil to accumulate. After the hole is augered, the anchor is driven by using the pilot hole as a guide. Because the Manta Ray MR-1 anchor is 7 inches wide, 3 inches of its width is driven through the undisturbed soil. Once the anchor is at the desired depth, the rod is pulled out and the hole is filled with soil and tamped and the anchor must be set.

The additional time and equipment required to auger a pilot hole before the anchor is driven is offset by several advantages. With fixed length drive rods, retrieving the rod after the anchor is driven becomes difficult if a pilot hole is not used. The friction of the soil on the rod is enough to require a mechanical pulling device for retrieval. The time needed to drive an anchor by using a pilot hole is less than without a pilot hole. If an obstacle is encountered during the augering process, the auger can be pulled up and moved to a new hole site. However, if an obstacle is first encountered when the anchor is driven, it would be very difficult to retrieve the anchor to move it to another location, and the anchor could become damaged.

In rocky soils, it may be easier to make a pilot hole using a rock bit and impact hammer. In soft soils and at shallow depths, driving a pointed rod into the soil may be adequate for a pilot hole.

Both the Arrowhead anchor and the Manta Ray MR-1 anchor are installed by being driven into the ground. The soil toggle anchor is installed by dropping it down an augered hole. The smaller soil toggle requires a hole 6 inches in diameter, and the larger model requires a hole 8 inches in diameter. The soil toggle has a wing on each end, one blunt and the other sharp (fig. 4). *The anchor is placed blunt end down in the hole.* This allows the anchor to slide down the hole without catching on a root or other obstacle. The hole is then filled and tamped. As the anchor is set, the pointed wing at the top will dig into the side of the hole and cause the anchor to rotate to its load-holding position.

The minimum depth of installation for the anchor types should be 3 feet for the 2- or 4-inch arrowhead anchors, 4 feet for the larger arrowhead anchors, 5 feet for the Manta Ray MR-1 and small soil toggle anchor, or 8 feet for the large soil toggle anchor. If these depths cannot be reached, the installer should move a few feet and try to attain the proper depth. The production anchors should not be installed at a depth less than that at which the feasibility tests are conducted. In stiff soils all anchors should be installed with the strap facing away from the direction of pull (fig. 5).

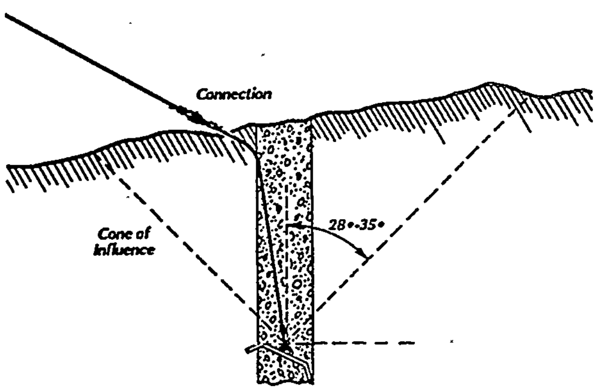
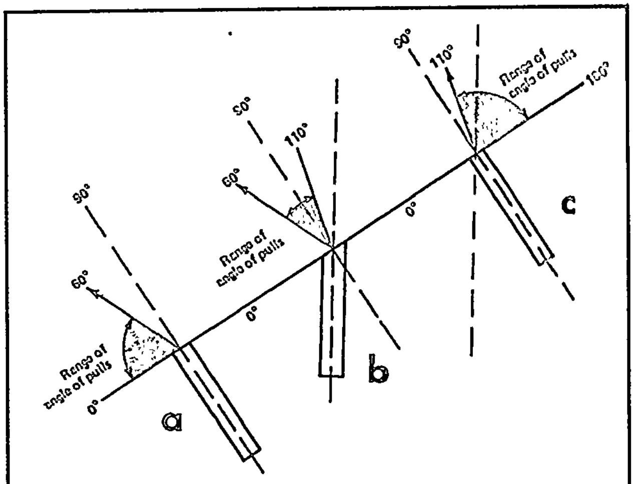


Figure 5. Orientation of anchor in stiff soils.

The angle of installation should be decided after the direction of pull relative to the slope of the ground is determined. In general, for upslope and downslope pulls, the anchor should be installed perpendicular to the ground surface. As the angle of pull nears perpendicular to the ground, the anchor should be installed vertically. The objective is to avoid having the direction of pull in line with the direction of installation and to maximize the distance of undisturbed soil between the installed anchor and the ground surface in the direction of pull (refer to fig. 6). It is recommended that a trench be dug along the direction of pull so that the attachment cable tends to dig into the side of the installation hole and pulls the anchor towards undisturbed soil.



a. Downhill pull—Install anchor perpendicular to ground. For all ground slopes.

b. Downhill pull—uphill pull. Install anchor vertical. Range of pull angle is 60° on downhill side of perpendicular to 110° on uphill side. This is also true for very steep slopes.

c. Uphill pull—Install anchor perpendicular to ground. For all ground slopes.

Figure 6. Angle of installation relative to ground slope.

Rigging and Bridling

In most cases, more than one anchor will be needed to obtain the holding capacity required to restrain the skyline or guyline. Multiple anchors will have to be bridled into an anchorage. The individual anchors in a bridled anchorage must be installed far enough apart so that they do not bear on the same soil mass. Different types of bridling systems will be discussed in the "Anchor Design" section that follows.

Safety

Although tipping-plate anchors are fairly easy to install using the procedures outlined above, the work is sometimes physically demanding, requires some preparation before going to the field and attention to safety while in the field. The following suggestions will reduce injuries and help to reduce the cost of anchor installation:

- It is important that the blocks of a nonrigid bridle system be kept clean and free of dirt. Small amounts of dirt or other debris jammed between the wire rope and the sheave can cause unequal tension across the block and more tension on one anchor than the other.
- Wear personal protective gear when installing anchors. Earplugs should be worn when impact hammers are in use. Goggles and other types of eye and face protection should be worn at all times because of the chance of injury from flying particles.
- Use proper methods for lifting the auger from the hole or lifting the hammer onto the drive rod to prevent back injuries.
- Read instruction manuals before using equipment and test all equipment before taking it to the field to ensure that it is in good working condition.
- Inform each crew member of the procedures and discuss any hazardous conditions.

ANCHOR DESIGN

The general procedure for planning anchor installations has seven steps:

1. Review logging system requirements
2. Site investigation
3 Select anchor and installation equipment
4. Conduct pull tests
5. Estimate number of anchors
6. Design the anchorage
7. Estimate costs.

1. Review Logging System Requirements

The first step is to review the sale design to determine the logging equipment that will be used. The breaking strength of the wire rope and the desired anchor locations for the guylines or tailholds should be determined. Determine a design load equal to or greater than the maximum force expected to be exerted on the planned anchorages. Lacking better information, use the breaking strength of the wire rope being anchored. This introduces some margin of safety in the case where static loads in the cables are kept to one-third of the breaking strength or less. The values used for the breaking strength of wire rope are published by wire rope manufacturers.

2. Site Investigation

For a particular anchor design, the primary variables influencing its holding capacity are depth of installation, soil strength, and moisture content of the soil.

Before the type and number of anchors are selected, the site conditions must be assessed. This is done by walking the site to estimate potential locations for anchor installations and to determine the characteristics of the soil at these locations. It should be determined whether a hole can be augered with the portable augering equipment. This will determine to a large extent what type of anchor to use. Other factors that should be assessed are the likely seasonal variation in soil moisture and the likelihood of encountering obstacles during the anchor installation.

Augering equipment may be used to drill several exploratory holes as deeply as possible at the proposed site. These holes should be marked so that they can be found later. The date, a detailed site description, soil description, and equipment used for exploration should be recorded in a drill log.

As more experience is gained, a correlation may be developed between holding capacity and soil conditions for particular depths of installation by classifying the soil according to the Unified Soil Classification System (American Society for Testing Materials 1988a) performing the standard penetration (American Society for Testing Materials 1988b) or other strength tests, and determining the soil moisture content.

3. Select Anchor and Installation Equipment

After the initial investigation of the site, table 2 can be used to make a preliminary selection of anchor type to use in conducting feasibility tests. This preliminary selection will depend on the results of the initial site investigation and the logging system requirements.

Table 2. Preliminary selection of anchor type.

Soil Condition	Diameter of Wire Rope (inches)	Anchor type and procedure
Soil is loose enough to drive a rod directly to the desired depth, and uncased hole collapses	5/8 or greater	Manta Ray MR-1; no pilot hole
	Less than 5/8	Arrowhead; no pilot hole
Can auger hole 8 inches in diameter	1 or greater	Large soil toggle; auger 8-inch hole
Can auger hole 6 inches in diameter	Less than 1	Small soil toggle; auger 6-inch hole
	Less than 7/8	Manta Ray MR-1; 4-inch pilot hole
Can auger hole 4 inches in diameter	5/8 or greater	Manta Ray MR-1; 4-inch pilot hole
	Less than 5/8	Arrowhead; 2-inch pilot hole
Can drill hole 2 inches in diameter (not solid rock)	5/8 or greater	Manta Ray MR-1; 2-inch pilot hole
	Less than 5/8	Arrowhead; 2-inch pilot hole

If the above conditions cannot be met the soil is not suitable for tipping-plate earth anchors.

If during a site investigation, for example, cobbles too large for an auger to bring to the surface are found (but a hole 2 inches in diameter can be drilled), then a Manta Ray MR-1 or Arrowhead anchor would be selected. If the wire rope diameter is 5/8 inch or larger, the preliminary anchor selection would be the Manta Ray MR-1. If the the wire rope diameter is less than 5/8 inch, then both the Manta Ray MR-1 and Arrowhead could be tested to determine which will provide the greatest holding capacity with the fewest anchors.

The equipment chosen for installing the anchor will depend on the anchor selected and the difficulty of access to the site. Use table 3 as a guide to the recommended installation equipment. Table 11 in appendix 3 gives a more detailed list of the recommended equipment.

Table 3. Installation equipment and access guide.

Anchor	Recommended Installation Equipment	Portability[a]
Large soil toggle	Hydraulic Little Beaver with 8-inch auger	Can be mounted on sled or trail machine for remote access
Small soil toggle	Hydraulic or gas Little Beaver with 6-inch auger	Can be mounted on sled or trail machine for remote access
Manta Ray MR-1:		
Augered pilot hole	Gas Little Beaver with 4-inch auger plus gas, hydraulic or pneumatic driving hammer	Can be mounted on sled or trail machine; for remote access use portable HPU with hydraulic hammer, or gas hammer such as Pionjar
Drilled pilot hole	Hydraulic, pneumatic, or gas drill with 2-inch diameter rock bit; gas, hydraulic, or pneumatic driving hammer (some hydraulic and gas hammers will drill and drive)	Portable gas hammer, such as Pionjar, can drill and drive and can be backpacked; portable HPU can be used with hydraulic hammer and drill; pneumatic equipment is not portable
No pilot hole	Hydraulic, pneumatic or gas hammer	Same as Manta Ray MR-1—drilled pilot hole
Arrowhead:		
Augered pilot hole	Same as Manta Ray MR-1 —augered pilot hole except a 2-inch diameter auger would be used	
Drilled pilot hole	Same as Manta Ray MR-1 —drilled pilot hole	
No pilot hole	Same as Manta Ray MR-1 —no pilot hole	

[a]Helicopter access is possible for all installation equipment.

4. Conduct Pull Tests

Data from a limited number of pull tests (Copstead 1988), are shown in appendix 2. Because the tests were done in only a few soil types, and rigorous soil investigations were not always done, the results should be used for preliminary selection only and not for detailed designs. The holding capacity of an anchor in a specific soil type and location should be determined by onsite feasibility tests. Conducting feasibility tests will also uncover any installation problems that could affect installation costs, or affect holding capacity of the installed anchors.

Test anchors should be installed under conditions identical to those expected for the production anchor installation and pulled to failure. All pullout tests should be conducted under identical conditions so that variation in the results is attributable only to random effects of the test.

The procedure for conducting pull tests starts with the installation of anchors according to procedures described earlier. The anchor testing equipment is attached to each anchor. The anchor is then pulled to failure or to a load that is sufficient to withstand the expected operating loads. The anchor testing equipment consists of a hydraulic cylinder and equipment to activate it (usually a hydraulic power unit), instruments for measuring loads, and the rigging needed to connect the cylinder to the anchor strap on one end and to a fixed reaction point on the other end. A sample set of test equipment is shown in figure 7. Refer to appendix 3 for specifications.

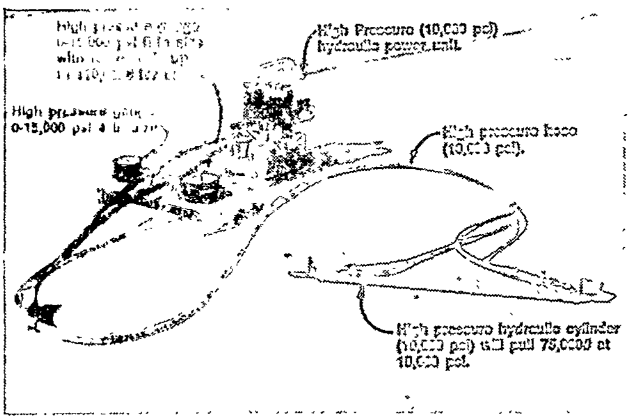


Figure 7. Example of one type of pull test equipment.

The minimum instrumentation system required for conducting the feasibility tests is a calibrated pressure gauge connected to the high-pressure side of the hydraulic cylinder. For safety reasons, the gauge should be located near the controls for the hydraulic power unit. The pressure-gauge/hydraulic-cylinder system should be calibrated prior to the feasibility tests over the range of loads expected by using a load measuring device of known accuracy and precision. The pressure indicated on the gauge may depend on the temperature of the hydraulic oil in the system as well as on the pulling force.

Instrumentation systems are available which measure force directly with a mechanical gauge, such as a Dillon dynamometer, or with a strain gauge load cell and electronic indicator. In this case, the force transducer is linked directly between the hydraulic cylinder and the rest of the rigging. A system that includes a peak force indicator or that samples and records the force continuously will allow easy interpretation of test results.

Caution: Load ratings for the test rigging should be equal to or greater than the maximum load the equipment can produce and greater than the rated breaking strength of the strap attached to the anchor. Test equipment should not be operated at loads greater than the rated breaking strength of the anchor strap.

The procedure for the pull tests begins with connecting one end of the cylinder to a solid anchor such as a tree or a stump, and the other end to a length of chain which is attached to the test anchor. If a tree is used for an anchor, the cylinder may be attached with a nylon strap to protect the tree from being girdled during the pull test. The chain which is connected between the cylinder and the test anchor must be at least as long as the anchor strap. The rigging usually will have to be repeatedly tensioned and the cylinder restroked, because the movement of the anchor will usually exceed the stroke of the hydraulic cylinder before its failure load is reached.

Record the maximum load reading (or pressure reading, if a calibrated pressure gauge is used).

Develop a load displacement curve to provide an indication of the movement of a production anchor. Place a small amount of tension in the line and mark the beginning location of the eye at the end of the anchor strap using a stake in the ground as a reference point. With each restroking of the cylinder, note the load and the distance traveled by the eye. An example of plotted results is shown in figure 8. ***Caution: Do not approach the rigging while it is under tension.***

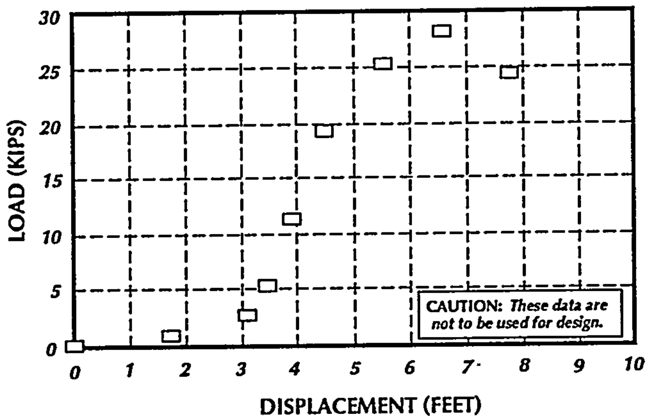


Figure 8. Plotted example of load displacement data.

The number of pull tests to be conducted will be determined by the variability of the results obtained, however, the results from a minimum of three tests will be required to use the method outlined in this guide.

5. Estimate Number of Anchors

First calculate the sample mean and standard deviation of the pull test results, then calculate two ratios:

(1) $$\frac{Fp}{X} = \frac{\text{Design load for anchorage}}{\text{Sample mean of pullout test results}}$$

(2) $$\frac{S}{X} = \frac{\text{Sample standard deviation of test results}}{\text{Sample mean of pullout test results}}$$

Using the chart of figure 9, find the number of anchors by locating the intersection of the value for Fp/X (along the vertical axis) and S/X (along the horizontal axis). The lines extending from the left side of the chart to the right and sloping downward demarcate zones corresponding to the number of anchors. If the intersection of the ratios falls on a line, then the estimated number of anchors is given in the zone above the line. This chart has been calculated assuming five tests were done (charts for other numbers of tests are in appendix 1). ***Caution: The chart for the actual number of pull tests done must be used.***

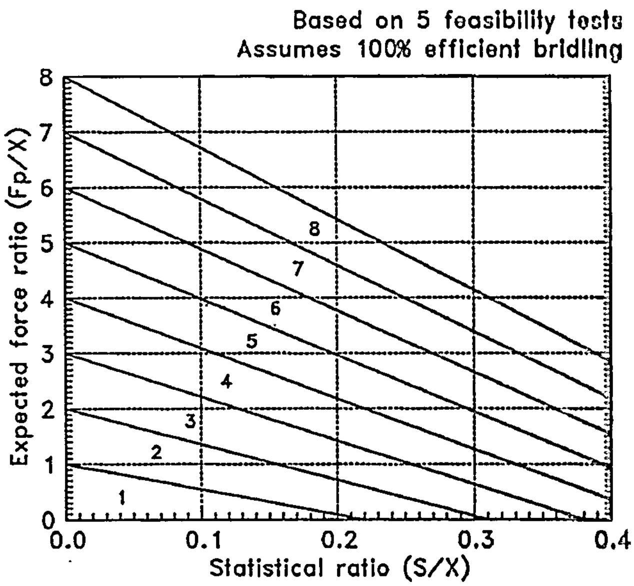


Figure 9. Number of anchors based on the ratio of expected force, Fp, to mean pullout force, X, and on the ratio of sample standard deviation, S, to mean pullout force for 5 feasibility tests [See appendix 1 for additional charts]

Additional pull tests will more accurately measure the variability of results at a site and, with the use of the appropriate chart, may lead to a design requiring fewer anchors in the final installation.

6. Design the Anchorage

Designing an anchorage means determining how many individual anchors need to be bridled together to stabilize the system, how deep and at what angle they are installed, how far apart they should be, and how they are bridled. This design is based mainly on the results of the pull tests and the engineering judgement and experience of the designer.

The initial estimate obtained from step 5 assumes that a bridle design is 100 percent efficient. In fact, the holding capacity of a group of anchors is not usually equal to the holding capacity of one anchor multiplied by the number of anchors in the group (Kovacs and Yokel 1979).

Two factors affecting the capacity of an anchorage are the degree to which loads are shared among the individual anchors of the cluster and the degree to which individual anchors in an anchorage act on separate soil masses. If loads are not adequately shared among clustered anchors, then one anchor may reach its maximum load capability before the others, and the maximum holding capacity of the entire anchorage will be some fraction of the capacity of a 100-percent-efficient anchorage. Because the load capacity of a soil anchor depends partially on the soil mass mobilized, two anchors sharing the same soil mass will have less ultimate capacity than if they operated on separate soil masses.

How loads are shared among clustered anchors is affected by soil characteristics, the depth of the anchor installation, the geometry of the anchor installation relative to the direction of pull, and the design of the bridle. Anchors installed in soft, highly disturbed soils—in general, soils having a large capacity to be compressed—will have greater potential for equalizing loads among several anchors in a cluster.

Figure 10 depicts the results of tests on Arrowhead anchors that were performed by Foster-Miller, Inc., Waltham, MA, in 1985-86. The graph shows that the mean pullout force for single-anchor installations was 9,400 pounds; however, when more than one anchor was installed in a bridled cluster, each additional anchor added only 4,100 pounds of pullout capacity. These anchors were installed 5 feet deep, and the anchors of each cluster were within 5 feet of each other. All the anchors in a cluster were clearly acting on a common soil mass, which undoubtedly contributed to the poor efficiency of the installation.

The anchors were also bridled using a rigid (non-load-sharing) bridle. This means that the anchor straps had a fixed unstretched length. In such an arrangement, any differences in pretension among the straps could have led to one anchor reaching its ultimate pullout force before the others resulting in an ultimate pullout force for the anchorage that was less than the sum of the ultimate pullout forces for the individual anchors.

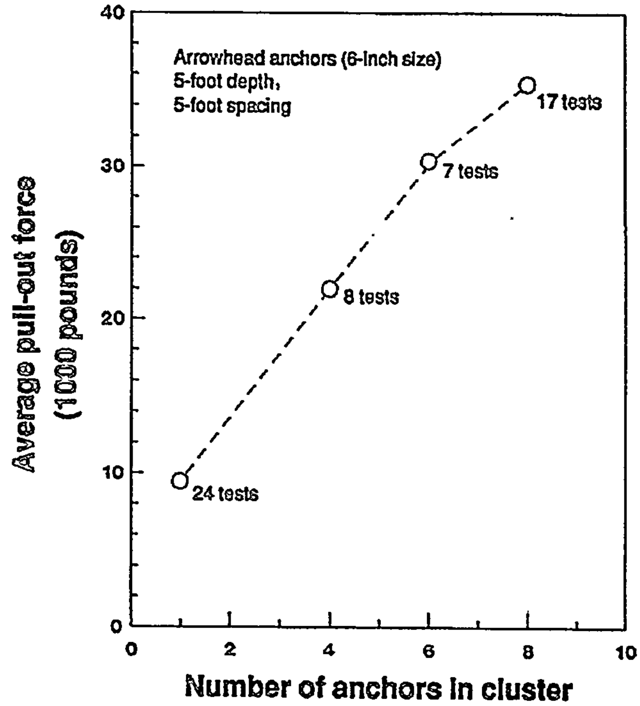


Figure 10. Cluster pullout capacity vs the number of anchors in a cluster [Tests were performed by Foster-Miller, Inc.—Unpublished data on file with: R.L. Copstead, USDA Forest Service Forestry Sciences Laboratory, Pacific Northwest Research Station, 4043 Roosevelt Way, NE, Seattle, WA 98105]

Anchors must be installed far enough apart so that they do not bear on the same soil mass. To ensure this, a zone of influence is defined around each anchor. This zone of influence is at the intersection of the ground surface with a cone extending up from the anchor. In *granular soils*, the angle of the cone is nearly equal to the angle of internal friction, which for most conditions is less than 45 degrees (table 4). Therefore, a conservative approach to determining the zone of influence at the ground surface is to assume that for granular soils, the zone extends to a distance equal to the depth of installation around the anchor.

Table 4. Soil parameter correlations for granular soils.

Parameter	Very loose	Loose	Medium dense	Dense	Very dense
	Compactness				
SPT[a] N-values[b]	0-4	4-10	10-30	30-50	>50
Relative density (percent)	<15	15-35	35-65	65-85	85-100
Angle of internal friction (degrees):					
Moist[c] sand	28	28-30	30-3	36-41	>41
Saturated[d] sand	26	26-28	28-34	34-38	>38
Moist silt	24	24-28	28-30	30-35	>35
Saturated silt	12	12-14	14-16	16-18	>18
Unit weight (pounds per cubic foot):					
Moist sand	100	100	120	125	130
Saturated sand	55	60	65	70	75
Moist silt	100	110	115	120	125
Saturated silt	50	55	60	65	70

[a]SPT = standard penetration test.
[b]N-value = blows per foot from the SPT.
[c]Moist denotes conditions above the groundwater table.
[d]Saturated denotes conditions below the groundwater table.
Source: Foster-Miller, Inc. 1987.

If, for example, the anchor is installed 5 feet deep, the soil within a radius of 5 feet from the hole will have an influence on its holding capacity, and the anchors would not influence each other if they were at least 10 feet apart. For *cohesive soils,* the the angle of the zone of influence ranges from 28 to 35 degrees (fig. 11). An estimate of the distance between anchors would be determined by multiplying a factor of 1.4 times the depth of installation (2 x tan35°=1.4).

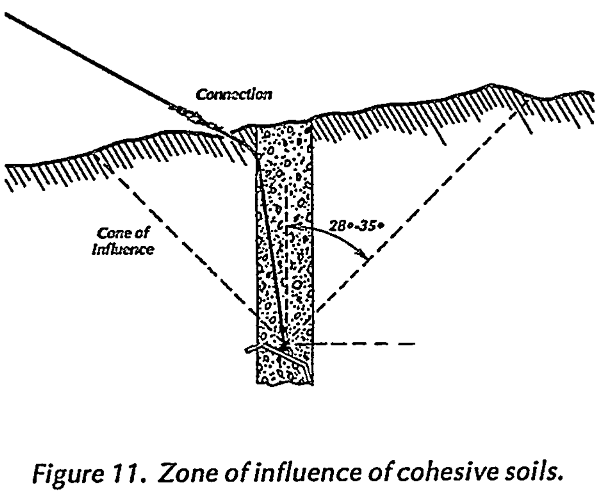


Figure 11. Zone of influence of cohesive soils.

Making an allowance for bridle systems where loads might not be shared evenly among component anchors is not simple. The problem is complicated by the different displacements of individual anchors under load, which can result from differences in installed depth, soil conditions, rigging details, backfilling technique, etc. Bridle performance is more critical in stiff soils where little displacement occurs before anchor, rigging, or soil failure occurs.

Bridling systems are either rigid or nonrigid. Rigid systems are not necessarily load equalizing because the initial unstretched length of each tieback line is fixed (fig. 12). The nonrigid type uses blocks to equalize the tensions in the tieback lines from each anchor (fig. 13). Thus, each anchor is required to hold its share of the load. An example of the nonrigid type is the "parachute" bridle system (Foster-Miller, Inc. 1984).

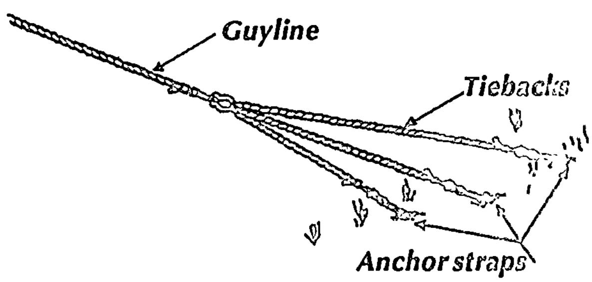


Figure 12. Example of a rigid bridle.

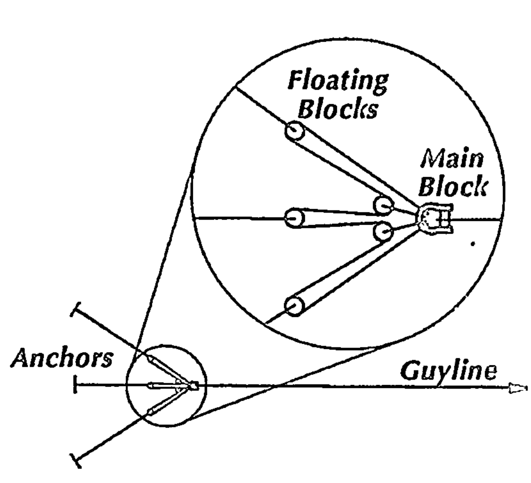


Figure 13. Example of a nonrigid bridle.

Further analysis of rigid and non-rigid bridle design concepts has shown that the installation geometry, bridle design, and the relative strengths of individual anchors in an anchorage can have a significant effect on the overall capacity of an anchorage (Gonsior, et.al., 1989). Installation geometry is estimated to be at least as important as the bridling method. Two extremes in installation geometry were analyzed and are shown in figure 14. In a colinear installation (fig. 14a) the resultant force, the anchors, the bridle point and the tower (or tailhold) are all on a line. In a spread installation (fig. 14b) the resultant force on the anchorage is applied perpendicular to the row of anchors.

Results of analysis for rigid bridles illustrates the effect of geometry on the predicted ultimate pullout capacity (Gonsior, et.al., 1989). It was assumed that five anchors with identical force-deflection characteristics were bridled. If the installation geometry was perfect (i.e., according to fig. 14), the computed ultimate pullout capacity for the spread configuration was only 2 percent less than for the colinear. However, if the tower was located on an azimuth 6 degrees off from "perfect," the capacity for the spread configuration was 10 percent less, while there was virtually no effect on the capacity of the colinear. If the bridle point was offset slightly (4 percent of the distance from the anchors to the tower) from the centerline of the configuration, the spread arrangement capacity was reduced 28 percent, while there was no reduction for the colinear arrangement. The effect of neglecting to evenly distribute the tensions to all anchors of a rigidly bridled anchorage will be similar.

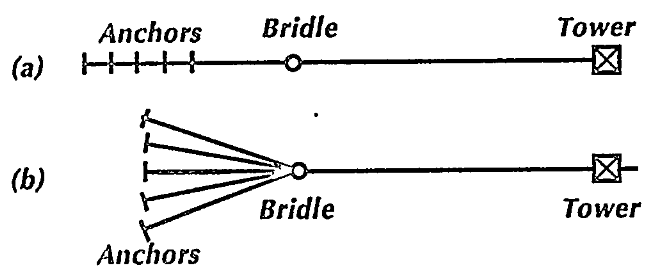


Figure 14. (a) Colinear and (b) spread multiple anchor bridling configurations.

If one anchor in the rigidly bridled system fails, the system will often adjust and may hold the load long enough for operations to be shut down safely. On the other hand, with a nonrigid bridling system, if one anchor fails, the entire system can fail because of the large resulting deflection. The safety margin of the nonrigidly bridled anchor system cannot exceed the safety margin of the weakest anchor in the system. The advantages and disadvantages of the two bridle types are summarized in table 5.

Table 5. Advantages and disadvantages of bridle designs.

Bridle Design	Advantages	Disadvantages
Rigid	Any number of anchors can be rigged	May not share loads equally among anchors
	If one anchor or tieback line fails, the other anchors will take up the load with a minimum of bridle movement	May be difficult to initially equalize tensions in tie backs
Nonrigid	Excellent load sharing among anchors (important in stiff soils)	If one anchor or tieback fails, the entire bridled system may fail
	Easier to rig than rigid bridle, because tensions will automatically equalize	Requires more rigging hardware. Ultimate strength is reached when the weakest anchor in the anchorage fails

In the rigid bridle system, the tieback lines should be the same diameter as the anchor strap. Since for a rigid bridle the length of the tie-back lines must be individually adjusted, the free end is threaded through the eye of the anchor strap, pulled tight with a hand-operated ratcheting winch and clamped using three or four wire rope clamps, or as directed by logging safety code.

The method for estimating how many individual anchors are needed to withstand the design load is illustrated in example 1. *The results obtained from the equations and charts in this guide only serve as a basis for the designer to determine the actual number of anchors to be bridled together for a specific operation.* The designer must weigh numerous considerations before deciding on the actual number of anchors to use, including but not limited to the bridling method, the depth of anchor installation, anticipated changes in soil moisture, the desired life expectancy of the anchorage, the frequency the logger is likely to visually check anchorages, etc.

Example 1
Estimation of anchors to withstand design load.

Feasibility tests have been done at a site where earth anchors will probably have to be used. The tests gave the following pullout forces in pounds:

34,300; 35,800; 33,600; 34,900; and 36,000.

How many anchors should be installed for each production anchorage if the rated breaking strength of the guyline to be anchored is 192,000 pounds?

Solution:
Choose a design load for the anchorage equal to the rated breaking strength or 192,000 pounds. The sample mean and standard deviation are 34,920 and 1,008 pounds, respectively. We then calculate the two ratios:

$$Fp/X = 192{,}000/34{,}920 = 5.50$$

and

$$S/X = 1{,}008/34{,}920 = 0.03$$

Because five tests were done, we use the chart for N=5 (fig. 9) and read that six anchors are needed, assuming 100-percent bridling efficiency. Knowing that the location of the individual anchors will be spread somewhat and that the tower may not be located exactly where we assume it will be, we add one more anchor for a total of seven.

Large differences in the test results will cause the number of anchors required to be higher.

During pull testing of the test anchor, loads and displacement of the anchor were measured and recorded before the cylinder was re-stroked. Figure 8 shows the pull test data and an example plot of a load-displacement curve. Each anchor tested at the site should have its load-displacement curve plotted on the same graph so the curves can be compared and a rough estimation be made as to how far the production anchors may move, before failure of the anchorage is impending.

The following procedure serves only as a rough estimate of how far an anchorage will move before failure is pending. Experienced judgement should be exercised when estimating distances that anchors may move before failing. Calculate the standard deviation of the displacements at maximum load for the feasibility tests. From the graph, measure the displacement distance for each anchor at maximum load. Calculate the mean displacement which is the sum of all the displacements divided by the number of anchors tested. Calculate the sample standard deviation of these displacements:

$$\text{sdev} = \sqrt{\frac{\text{sum of the } x^2 - N X^2}{N - 1}}$$

where:

N is the number of anchors tested
x is the displacement at maximum load for each test anchor
X is the mean of the displacements.

The mean displacement minus two standard deviations could serve as a warning for impending failure, or:

$$\text{Warning distance} = X - 2(\text{sdev})$$

Example 2
Calculation of displacement to warn of impending failure.

The five anchors tested in example 1 had displacements in feet at their maximum loads of:

2.5; 2.8; 1.9; 3.1; and 2.4.

How far can the production anchors move before failure is impending?

Solution:
Calculate the mean of the displacements,

$$(2.5 + 2.8 + 1.9 + 3.1 + 2.4)/5 = 2.54 \text{ ft}$$

Calculate the standard deviation,

$$sdev = \sqrt{\frac{(2.5^2 + 2.8^2 + 1.9^2 + 3.1^2 + 2.4^2) - 5(2.54)^2}{5 - 1}}$$

$$= \sqrt{\frac{33.07 - 5(6.45)}{5 - 1}} = 0.45.$$

The distance that the production anchors could move before failure is impending would then be:

$$2.54 - 2(0.45) = 1.64 \text{ ft.}$$

After the production anchors are installed, the bridle system attached, and a small amount of tension placed in the lines to remove any slack, a stake is placed in the ground at the location of the eye at the end of the guyline. If during the logging operation, the eye has moved the distance calculated using the procedure described above, or as in the example, 1.64 feet, then the logging operation should be stopped. The anchorage should then be tested by pulling on it with a known load that is equal to the design load, or the anchorage should be abandoned.

Caution: ***There are two situations where use of this procedure can give a warning distance that is either too conservative or one that is very close to the actual failure distance:***

1. If there is a large variation in the displacements of the test anchors, the distance calculated may be too conservative and the production anchorage may not be close to impending failure

2. If the variation in the displacement distances is very small; i.e., all of the distances are the same or nearly the same, the calculated warning distance by the above method will be very close to, or the same as the distance that the test anchors reached their maximum load, thus leaving no margin of safety.

In either case, the procedures and results of the feasibility tests should be reviewed and the load-displacement curves inspected, looking for test anomalies or any indication that the tests were conducted in ground with differing engineering properties. After review, professional judgement should be used to estimate a movement distance that will give suitable warning of impending failure.

7. Estimate Costs

An example of estimating costs for installing an anchorage follows.

Example 3
Estimating costs

Develop a cost estimate for installing Manta Ray MR-1 anchors for a site requiring three tailholds. At one tailhold, three anchors will be needed; the other two tailholds require four anchors each. For this estimate assume the following prices:

- Crew consists of two people at $20 per hour including fringe benefits.
- Cost of owning and operating a pickup is $0.50 per mile.
- Average travel distance to sale area is 100 miles.
- It takes 3 hours to travel and move in equipment to first anchor point.
- It takes 15 minutes to stake out anchor locations within each anchorage.
- It takes 2 minutes to auger a pilot hole and 5 minutes to drive an anchor.
- It takes 10 minutes to move to the next anchor hole and 30 minutes to move to next anchorage.
- Installation equipment rental rate is $9 per hour.
- Anchors with straps cost $100 each.

Calculate costs of moving equipment to first anchor point and move out:

Travel: 100 miles x $0.50 per mile	=	$50.00
Labor: 3 hours x $20.00 per hour	=	$60.00
Equipment: 3 hours x $9.00 per hour	=	$27.00
Total move-in cost:		$137.00
Total move-in/ move-out costs: 2 x $137.00	=	$274.00

Calculate total installation time:

Three anchorages requiring stake out: 3 x 15 min = 45 min			
Auger hole:	2 min		
Drive anchor:	5 min		
	7 min x 11 anchors	=	77 min
Move between individual anchors:			
	8 moves x 10 min	=	80 min
Move between anchorages:			
	2 moves x 30 min	=	60 min
			262 min

Calculate installation costs:

Labor:		
(262 min/60 min per hour)		
x $20.00 per hour	=	$87.33
Equipment:		
(262 min/60 min per hour)		
x $9.00 per hour	=	$39.30
Anchors:		
11 anchors		
x $100.00 per anchor	=	$1,100.00
Total installation cost:		$1,226.63
Total costs = $274 + $1,226.63	=	$1,500.63

NOTE: *No cost allowance was made for this installation potentially requiring more than 1 day.*

LITERATURE CITED

American Society for Testing and Materials. 1988. Designation D 2487-85: test method for classification of soils for engineering purposes. In: 1988 Annual book of ASTM standards; Philadelphia: American Society for Testing and Materials. Vol. 4.08.

American Society for Testing and Materials. 1988. Designation D 1586-84: standard method for penetration test and split-barrel sampling of soils. In: 1988 Annual book of ASTM standards; Philadelphia: American Society for Testing and Materials: 216-219. Vol. 4.08.

Copstead, Ronald L. 1988. *Results of tests on earth anchors for cable logging systems.* In: International mountain logging and Pacific Northwest skyline symposium: Proceedings; 1988 December 12-16; Portland, OR. [Place of publication unknown]:[Publisher unknown]. 42-48. Sponsored by: Department of Forest Engineering, College of Forestry, Oregon State University; International Union of Forest Research Organizations, Mountain Logging Section.

Foster-Miller, Inc. 1984. *Engineering tradeoff analysis report for SEAS conceptual designs.* Rep. FSS-8266-R-016. [Location of publisher unknown]:[Publisher unknown]. Prepared for: U.S. Department of Agriculture Forest Service. Contract 53-91S8-2-94. 250 p.

Foster-Miller, Inc. 1986. *Substitute earth anchoring system (SEAS) bridle test report.* Rep. FSS-8266-R-027. [Location of publisher unknown]:[Publisher unknown]. Prepared for: U.S. Department of Agriculture Forest Service. Contract 53-91S8-2-94. 38 p.

Gonsior, Michael J.; Copstead, Ronald L.; McGaughey, Robert J. 1989. *Analysis of multiple anchor bridling alternatives.* In: Implementing techniques for successful operations: 12th annual Council on Forest Engineering meeting; 1989 August 27-30; Coeur D'Alene, ID. Corvallis, OR: Council on Forest Engineering: 41-46.

Johnson, N. L., and Welch, B. L. 1940. *Applications of the non-central t-distribution.* Biometrika. March: 362-389.

Kovacs, W. D.; Yokel, F.Y. 1979. *Soil and rock anchors for mobile homes—a state-of-the-art report.* National Bureau of Standards Building Science Series 107. Washington, D.C.: U.S. Department of Commerce. 164 p.

Wallis, W. A. 1947. *Use of variables in acceptance inspection for percent defective.* In: Selected techniques of statistical analysis for scientific and industrial research and production and management engineering. 1st ed. New York: McGraw-Hill. 7-93.

ADDITIONAL REFERENCES

A.B. Chance Co. 1977. *Encyclopedia of anchoring.* Bulletin 4-7706. [Location of publisher unknown]: [Publisher unknown]. 58 p. Available from A. B. Chance Co., 210 N. Allen St., Centralia, MO 65240.

Foster-Miller, Inc. 1987. *Substitute earth anchoring system (SEAS) anchor selection—preliminary evaluation.* Rep. FSS-8266-R-047. [Location of publisher unknown]:[Publisher unknown]. Prepared for: U.S. Department of Agriculture Forest Service. Contract 53-91S8-2-94. 139 p.

Hanna, Thomas, H. 1982. *Foundations in tension—ground anchors.* Clausthal, Germany: Trans Tech Publications. 573 p.

Kovacs, Austin; Blouin, S.; McKelvy, B.; Colligan, H. 1975. *On the theory of ground anchors.* Tech. Rep. 258. Hanover, NH: Cold Regions Research and Engineering Laboratory, U.S. Army Corps of Engineers. 77 p.

Obradovich, John N.; Dulin, Robert O. 1982. *A study of available anchor systems and development of concepts suitable for application to meet cable-logging and/or assault vehicle egress requirements.* Rep. R 0300.011-2. Fort Belvoir, VA: U.S. Army Mobility Equipment Research and Development Command. 2 vol.

U.S. Department of Agriculture, Forest Service, San Dimas Equipment Development Center. 1978. *Substitute anchor systems —bibliographies and abstracts of reports and lists of patents.* Proj. Rec. 7824 1201 for ED&T project no.2640. San Dimas, CA. 56 p.

APPENDIX 1

Charts For Estimating Number of Anchors

The charts on the following pages (figs. 15 - 20) were constructed according to the following equation:

$$\frac{Fp}{x} \geq m - k\sqrt{m}\left(\frac{s}{x}\right)$$

where:

Fp = Expected load.

x = Average pull-out force for the feasibility tests.

m = Number of anchors.

k = Function of the probability level, confidence coefficient, and the number of feasibility tests done and is obtained following the method of Wallis (Wallis 1947), and Johnson and Welch (Johnson and Welch 1940). Also includes a factor to convert the sample standard deviation to an unbiased estimator of standard deviation.

s = Sample standard deviation of the pull-out force for the feasibility tests. It is calculated using n - 1 in the denominator.

The charts are calculated using a probability level of 0.95 and a confidence coefficient of 0.95. This means that there is a 95 percent chance that 95 percent of the bridled anchorages (consisting of anchors tested under the same conditions as the feasibility tests and combined with a 100 percent efficient bridling system) will have pull-out forces equal to, or greater than the expected force. Values of k used for the charts are as follows:

n	k
3	9.455
4	5.827
5	4.548
6	3.901
7	3.511
8	3.250

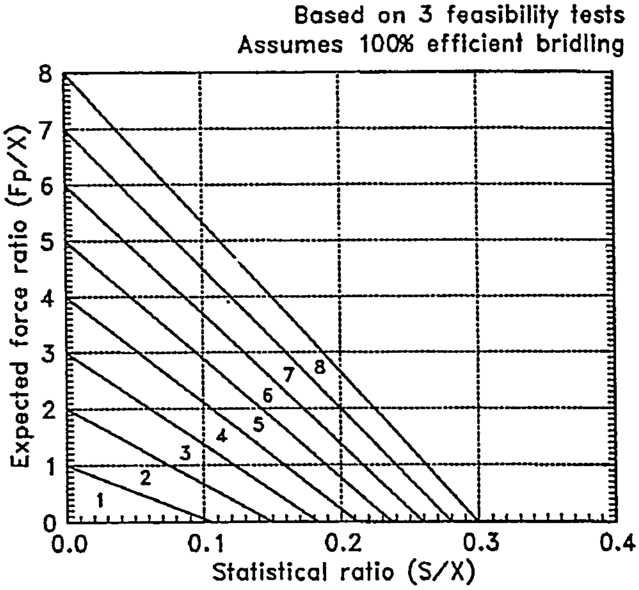


Figure 15. Number of anchors to install based on the ratio of expected force, Fp, to mean pullout force, X, and on the ratio of sample standard deviation, S, to mean pullout force for three feasibility tests.

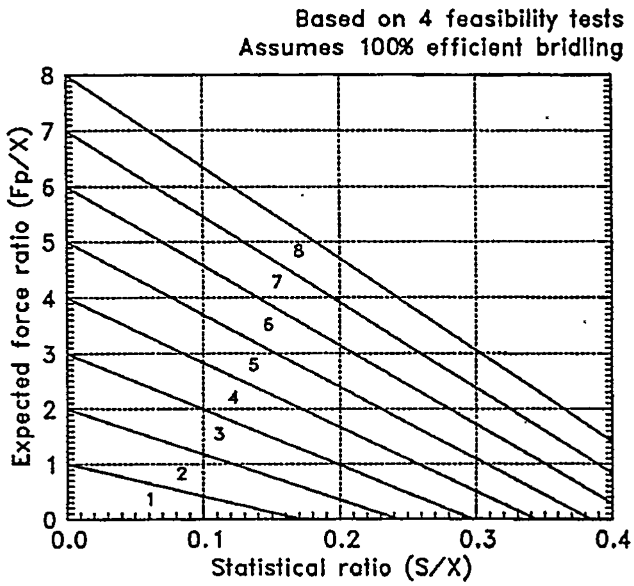


Figure 16. Number of anchors to install based on the ratio of expected force, Fp, to mean pullout force, X, and on the ratio of sample standard deviation, S, to mean pullout force for four feasibility tests.

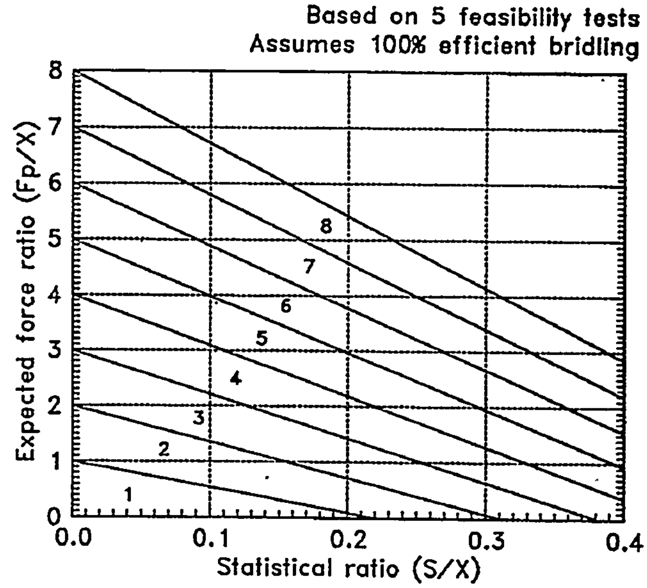


Figure 17. Number of anchors to install based on the ratio of expected force, Fp, to mean pullout force, X, and on the ratio of sample standard deviation, S, to mean pullout force for five feasibility tests.

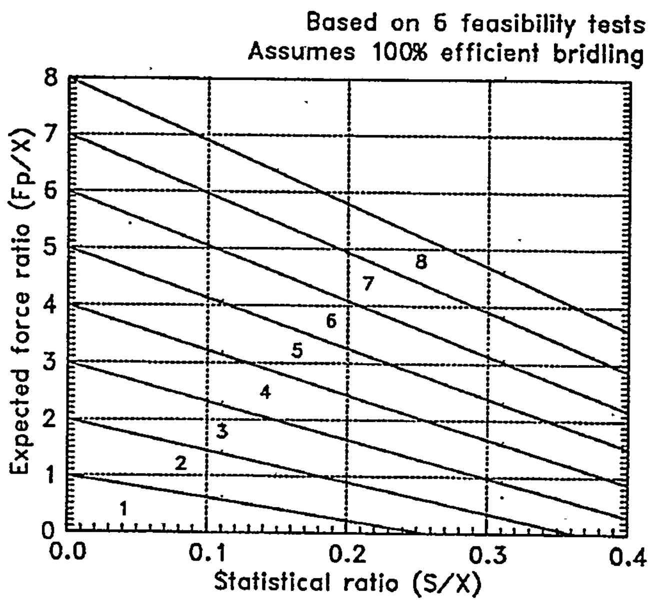


Figure 18. Number of anchors to install based on the ratio of expected force, Fp, to mean pullout force, X, and on the ratio of sample standard deviation, S, to mean pullout force for six feasibility tests.

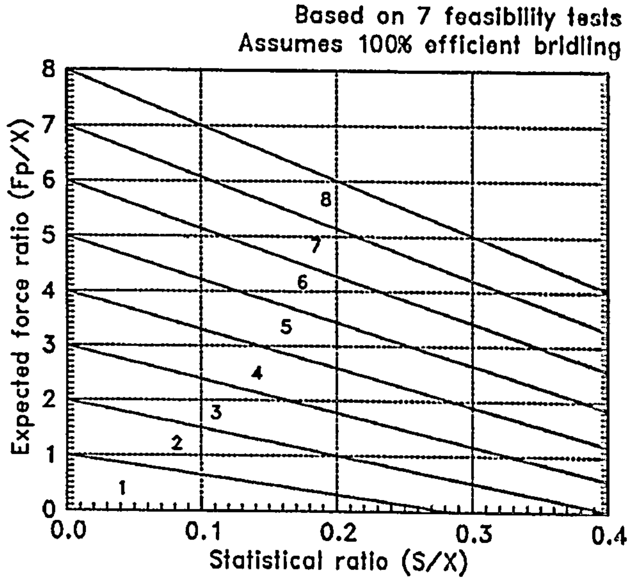


Figure 19. Number of anchors to install based on the ratio of expected force, Fp, to mean pullout force, X, and on the ratio of sample standard deviation, S, to mean pullout force for seven feasibility tests.

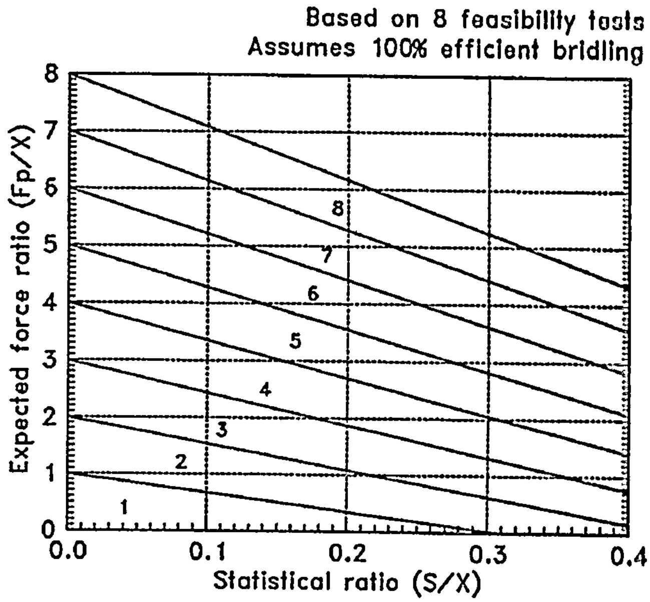


Figure 20. Number of anchors to install based on the ratio of expected force, Fp, to mean pullout force, X, and on the ratio of sample standard deviation, S, to mean pullout force for eight feasibility tests.

APPENDIX 2

Measured Anchor Pullout Forces

Tables 6 and 7 show results of tests of three types of tipping plates for anchoring in earth (Copstead 1988). The tests were done at similar installations at several locations in California, Oregon, and Washington. All anchors were 5-feet deep.

Table 6. Description of anchor test locations.

Site	Description
Rigdon demonstration	Willamette NF, Oregon. Silty sand with rock fragment sand duff, USCS group SM. Soil extends to a depth of approximately 2 feet. Below this to a depth of 5 feet is weathered rock of pyroclastic origin. Standard penetra tion test (American Society for Testing and Materials 1988) N-values were 76 blows/foot at a depth of 4.5 feet and 100 blows/foot or greater at 5 feet.
Rigdon landing	Willamette NF, Oregon. The same as Rigdon demonstration, except that the soil extends to only a 1-foot depth and the SPT N-values were 85 blows/foot at 4-foot depth and 100 blows/foot or greater at 6 feet.
Powder Creek	Willamette NF, Oregon. Silty sand, USCS group SM. N-values were 12 blows/foot at a depth of 5 feet.
San Antonio	San Bernardino Mountains, California. USCS group SM. No strength measurements.
San Dimas	San Dimas, California. Medium dense silty sand or clayey sand, USCS group SM or SC, AASHTO classification A-4(o). No strength measure ments.
Sylmar	Angeles NF, California. Medium dense silty sand, USCS group SM, AASHTO classification A-2-4. No strength measurements.
Tujunga	Angeles NF, California. Loose clayey sand, USCS group SC, AASHTO classification A-2-6(o). No strength measurements.
Wildwood	Angeles NF, California. Loose gravelly sand, USCS group SW to SM, AASHTO classification A-1-b. No strength measurements.
Muddy River	Gifford Pinchot NF, Washington. Analysis not available. Probably a loose clayey sand to a depth of approximately 9 feet. Below 9 feet to a depth of at least 13 feet is weathered rock probably of pyroclastic origin.
Coeur d'Alene	Idaho Panhandle NF, Idaho. Analysis not available. Probably a loose cobbly sand mixed with layers of highly fractured rock. Joint spacing is 1 to 3 inches.

Table 7. Pullout forces, in thousands of pounds, for anchors installed to 5-foot depth.

Site	Anchor	Number of tests	Pull-out force: Range	Pull-out force: Sample standard deviation	Pull-out force: Mean
Rigdon demo	Manta Ray MR-1	8	14.0-27.5	4.53	19.0
Rigdon demo[a]	Manta Ray MR-1	6	18.6-32.2	4.81	24.6
Rigdon landing	Manta Ray MR-1	4	13.7-20.3	2.80	16.5
Powder Creek	Manta Ray MR-1	6	4.7-13.4	3.00	9.5
San Antonio	Arrowhead	5	13.8-18.9	2.03	17.3
	Manta Ray MR-1	2	9.1-11.3	1.56	10.2
	Soil Toggle[b]	2	9.6-14.6	3.54	12.1
	Soil Toggle[c]	2	13.2-15.8	1.84	14.5
San Dimas	Arrowhead	10	5.3-17.5	4.39	12.8
	Manta Ray MR-1	6	21.9-42.1	7.35	36.3
	Soil Toggle[b]	3	27.4-50.0	11.5	37.5
	Soil Toggle[c]	3	20.3-49.1	14.4	34.1
Sylmar	Arrowhead	3	7.3-19.3	6.87	15.2
	Manta Ray MR-1	2	34.3-35.9	1.13	35.1
Tujunga	Arrowhead	5	8.4-20.2	4.67	13.1
	Manta Ray MR-1	1	17.3	—	17.3
Wildwood	Arrowhead	4	9.2-14.4	2.14	12.0
	Manta Ray MR-1	3	15.1-16.9	1.04	16.3
Muddy River[a,d]	Soil Toggle[c]	4	43.5-52.0	3.5	48.3
Coeur d'Alene[a]	Manta Ray MR-1	4	15.0-32.5[e]	7.86[e]	21.1[e]

[a]The pull direction for these tests was 70 degrees or more away from the axis of installation.
[b]Anchor bearing area was 59 square inches.
[c]Anchor bearing area was 94 square inches.
[d]Anchors were installed 13 to 15 feet deep.
[e]Installation depth was 7 feet for the test resulting in 32,500 pound pull-out force. The mean pull-out force for the three installations at 6 feet or shallower was 17,300 with sample standard deviation of 2,520 pounds.

APPENDIX 3
Specifications of Anchors and Installation Equipment

Tables 8, 9, and 10 give specifications for Arrowhead, Manta Ray MR-1 and soil toggle tipping-plate anchors.

Typical equipment required to install earth anchors for cable logging anchoring are shown in table 11.

Table 8. Arrowhead anchor specifications.

Item	Specification
Size:	6 or 8 inches
Bearing area:	18 or 32 square inches
Ultimate capacity:	18 kips (has held the breaking strength of 5/16-inch wire rope)
Holding capacity:	8 to 12 kips in granular soils
Minimum depth:	4 feet
Installation method:	Drill or drive a pilot hole; drive anchor
Cost (est.):	$25
Manufacturer:	Laconia Malleable Iron Co., Laconia, NH

Table 9. Manta Ray MR-1 anchor specifications.

Item	Specification
Size:	7 by 12 inches
Bearing area:	70 square inches
Ultimate capacity:	41.2 kips (breaking strength of 5/8-inch wire rope) 58.8 kips (breaking strength of 3/4-inch wire rope)
Holding capacity:	19 kips in sand or saturated clay 23 kips in silty sand 41 kips in dense clay
Minimum depth:	5 feet
Installation method:	Auger a pilot hole 4 inches in diameter; drive anchor
Cost (est.)	$130 w/8-foot strap; $50 w/o strap
Manufacturer:	Foresight Products, Inc. 6430 E. 49th Drive Commerce City, CO 80022 800-325-5360

Table 10. Soil toggle anchor specifications.

	Specification	
Item	Large	Small
Size:	7-1/2 by 16 inches	5-1/2 by 14 inches
Bearing area:	94 square inches	59 square inches
Ultimate capacity:	103.4 kips (1-inch wire rope) 79.6 kips (7/8-inch wire rope)	58.8 kips (3/4-inch wire rope) 41.2 kips (5/8-inch wire rope)
Holding capacity:	55 kips installed to 6 foot depth	55 kips installed to 6 foot depth
Minimum depth:	6-7 feet	5 feet
Installation method:	Auger hole 8 inches in diameter, drop anchor, and backfill	Auger hole 6 inches in diameter,drop anchor, and backfill
Cost (est.):	$225	$160
Manufacturer:	Foresight Products, Inc. 6430 E. 49th Drive Commerce City, CO 80022 800-325-5360	

Table 11. Installation equipment needed for various tipping-plate anchors.

Equipment needed	Type of anchor: Arrowhead or Manta Ray MR-1 w/o pilot hole	Arrowhead with 3-inch pilot hole	Manta Ray MR-1 with 4-inch pilot hole	Arrowhead or Manta Ray MR-1 w/ pilot hole in fractured rock	5-inch soil toggle	7-inch soil toggle
Gas auger (for example, 7 horsepower Little Beaver)		X[a]	X		X	
Gas auger (for example, 11 horsepower Little Beaver with hydraulic drive)						X
3-1/2 inch diameter auger flight, 42 inches long, with carbide blade	X					
4-inch diameter auger flight, 42 inches long, with carbide bit		X				
6-inch diameter auger flight, 42 inches long, with carbide bit					X	
8-inch diameter auger flight, 42 inches long, with carbide bit						X
Additional auger flights, each 42 inches long		X	X		X	X
Auger extension tube, 42 inches long		O[b]	O		X	X
Tamping rod for use during backfilling			X		X	X
Shovel			X		X	X
Tee handle for lifting auger flights from hole		X		X	X	
Slotted holder for adding and removing auger flights		O		X	X	
Drive hammer (gas, hydraulic, or pneumatic)	X	X	X	X		
Drive rod for Arrowhead or Manta Ray MR-1	X	X	X	X		
Drive hammer with drilling capability				X		
Drill steel, with bits, in 2, 4, 6, and 8 foot lengths				X		

[a]Equipment is required.
[b]Equipment is optional.

Pionjar Gas-powered Impact Hammers

We have used two models of gasoline powered impact hammers for installing earth anchors. The Pionjar model 120 is a combined rock drill and impact hammer. The operator can switch from drilling to breaking (pounding) by turning a lever. As an impact hammer, the unit is comparable to medium size pneumatic hammers and drills. The Pionjar model 130 is the same as the Pionjar model 120 except that it does not have the rotation mechanism and thus has fewer moving parts and is lighter weight.

Both the Pionjar model 120 and 130 have:

- Handles of vibration-absorbing material to suppress high-frequency vibrations
- An adjustable choke and throttle control
- An air filter that will allow operation in-dusty environments
- A power take-off for attaching accessories (for example a drill steel grinder or a winch)

Some specifications for these hammers are given in table 12.

Table 12. Specifications for Pionjar gasoline-powered impact hammers.

Engine:	
Displacement	11.3 cubic inches
Strokes	2,600 to 2,800 rpm
Carbureto	Floatless (manual needle valve)
Ignition system	Thyrister-type, breakerless
Fuel tank volume	0.33 gallon
Fuel mixture	1:12 (8%) two-cycle motor oil straight
Fuel consumption	Approx. 0.4 gallon per hour
Dimensions and weights:	
Tool chuck	7/8 by 4-1/4 inches for both models
Weight	57 pounds (model 120), 53 pounds (model 130)
Length	29 inches (model 120), 27 inches (model 130)
Performance limitations (model 120):	
Drill steel rotation	Approx. 250 revolutions per minute
Max drilling depth	20 feet with 1-inch bit
Max drilling angle to horiz.	45 degrees
Drilling rate in granite	10-12 inches/minute with 1.3-inch bit
Manufacturer	Berema, Inc., Norwalk, CT 06856

Little Beaver Gas-powered Earth Drills

Two models of Little Beaver earth drills have been used for installing earth anchors. The Little Beaver model 7 is a mechanical earth drilling system that includes power plant, power take-off, and adaptors for using a variety of augers. The 11 horsepower hydraulically driven model was used with a handle designed for two operators and should be used for augering 6- or 8-inch diameter holes.

Both models are designed with a 7-foot long "torque tube" that minimizes the torque felt by the operator while augering holes. Some other features are:

- Reversible blades on augers
- A reversing valve on the hydraulic model so that the power unit can be used to help free a stuck auger
- A 10:1 (20:1 available) gear reduction transmission causes the auger to rotate at an easily controllable rate
- Semi-pneumatic, 8-inch diameter wheels
- A snap-on adaptor for augers ranging from 1-1/2 to 16 inches in diameter

The weight of the model 7 (doesn't include torque tube or fuel) is 130 pounds, while the corresponding weight of the hydraulically driven unit is 172 pounds.

The manufacturer of these earth drills is Little Beaver, Inc., Livingston, Texas.