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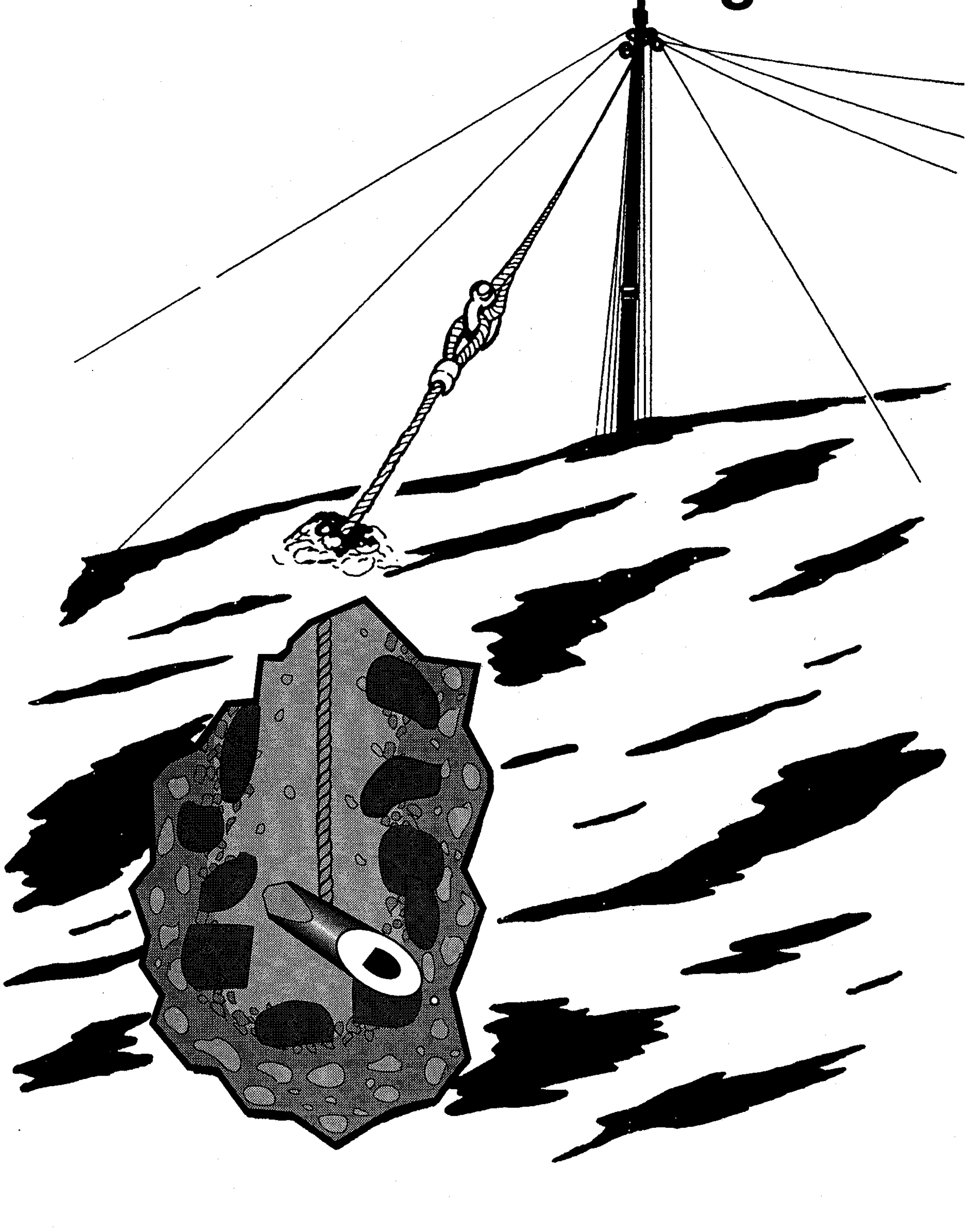
ROCKY SOILS SUPPLEMENT to An Earth Anchor System: Installation and Design Guide



FORWARD

This publication is a result of the Rocky Soils Project at the San Dimas Technology and Development Center.

This project was initiated by the Forest Product Sales Technology Committee. This group meets yearly to discuss field needs in the area of forest product sales, ranging from the initial sale layout to the transport of products. Work is prioritized and future projects are developed to address needs which appear to be multi-regional in scope.

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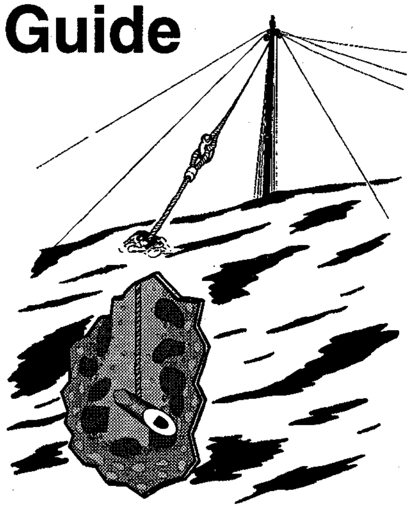

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BACKGROUND

Forest Service logging engineers recognized the need for substitute anchors for cable yarding systems long ago, and the San Dimas Technology and Development Center (SDTDC) has been developing anchoring techniques for over a decade. Tipping-plate anchors were developed for use where soil depth and conditions are adequate. Rockbolt anchors have been successfully tested for logging applications. Although these anchor designs address most sites, many difficult situations remain. Often, rock is present in the soil such that it prevents the use of standard tipping-plate earth anchors, but the rock is not massive enough to allow the use of rockbolts.

This report documents the design and testing of anchors, and associated installation equipment, in rocky soils. This work was accomplished by members of the Biological and Agricultural Engineering Department of the University of California—Davis under a cooperative agreement with the Forest Service.

This document is the latest of many outputs from the effort to find alternatives for anchoring cable-yarding machines. The reader is encouraged to refer to *An Earth Anchor System: Installation and Design Guide* (August 1993, Spcl. Rep. 9324 1804—SDTDC) for further information on a complete system for anchoring guylines and skylines for cable yarding equipment. It presents three types of tipping-plate anchors and installation equipment and methods specific to each type.

Procedures for estimating the number of anchors to install are included in the cited Special Report, along with guidelines for installing the anchors so they will withstand the expected forces imposed on them in this application. Appendices provide charts for estimating the number of anchors to install, give results of tests that were conducted, and specifications for anchors and installation equipment.

A video tape presentation that covers the use of anchors and associated installation equipment is also available. Inquiries regarding obtaining copies of the outputs, or about further development of anchor technology, should be directed to:

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SUMMARY

This project addressed the problem of inadequate anchors on rocky soils for guylines and tailholds of cable logging equipment. A substitute tipping anchor was developed that was estimated to have a breaking strength of 80 to 90 kips if fabricated of cast iron or mild steel. When installed and properly backfilled to depths of 8 to 9 ft in a gravelly clay loam soil overlaying metavolcanic greenstone, the anchors had pullout capacities averaging 70 kips (95 percent confidence interval of 64 to 76 kips). Capacities closer to the breaking strength of the anchor would be expected in rockier soils.

Installation equipment—consisting of a commercially available pneumatic rotary-percussion drill, accessories and a custom lightweight support frame—was also developed. The equipment is powered by a 185 standard cfm compressor. The components can be hand-carried to off-road anchoring sites located within 200 ft of the compressor. This distance is limited by pressure losses in the air hose connecting the compressor and drill. Installation times per anchor—including preparing the equipment, drilling a pilot hole, and driving the anchor—averaged 70 min for a crew of two relatively inexperienced people.

INTRODUCTION

The problem of finding adequate stump anchors for cable logging systems has become more common as the size of the average tree has decreased. Crawler tractors and deadman anchors have been commonly been used in logging where adequate stumps were not available; however, these anchors require the use of heavy equipment, which may not be feasible at many potential anchor locations. Tipping-plate anchors have been developed for situations where soil depth and conditions are adequate (Copstead and Studier, 1993), and rockbolts and grouted anchors have been successfully tested for use in rock (Miyata et al., 1985; Schroeder and Swanston, 1992). This study addressed rocky soil situations; i.e., where rock was present in the soil to the extent that it prevented standard installation of tipping-plate anchors, yet was not massive enough to allow the use of rock anchors.

Trials conducted during 1991 indicated the potential for using small pneumatic tools for installing tipping plate anchors in rocky soils (Hartsough et al., 1992). Load testing of several anchors showed that pulls in the range of 50 to 100 kips could be resisted by anchors with relatively small (i.e., 50 sq in or less) projected areas, if the anchors were driven to depths of 7+ ft. The keys for successful installation were the use of (1) A pilot hole having a diameter nearly as large as the maximum cross section dimension of the anchor, (2) adequate airflow to clear cuttings from the hole during drilling, and (3) extreme care to prevent sticking of the drill bit when using a hand-held drill.

The 1991 trials exposed two areas for improvement—installation equipment and anchor design. We used a 55-lb jackhammer with a 3-in bit to drill some of the pilot holes. Actual drilling and driving time per anchor totaled approximately 1 hour and was exhausting work, requiring experience and finesse to avoid problems. Drilling was highly stressful because of the vibration of the drill and the frequent lifting required to change or add sections of steel, clear the hole, and remove stuck bits. Crawler drills were used to produce other holes. While this equipment drilled quickly and reliably, it may not be possible to reach installation locations with these drills. Therefore, a piece of equipment that required less effort than a hand-held jackhammer, and was more portable than a crawler drill, was needed.

A commercially available anchor (Model MR-2, Foresight Products, Commerce City, Colorado) with cross-section dimensions of 3.5- by 3.5-in failed at a load of 70 kips in field testing, and at 29 kips in laboratory tests under worst case loading geometry. A custom anchor with a 4.5- by 5-in cross-section resisted a load of 95 kips without failure in the field, and was anticipated to have a strength of at least 100 kips in worst case loading. The custom anchor was too large to install in a 3-in hole.

This project had two objectives: (1) Develop a small support and lift frame for a pneumatic drill and (2) develop an anchor with a maximum cross-section dimension of 3 in, a length of approximately 14 in, as large a projected area as possible and a physical strength of at least 70 kips.

APPROACH

Installation Equipment

We aimed to meet the following specifications: The apparatus would utilize an 80-lb jackhammer drill, operate on slopes of up to 75 percent, and drill approximately perpendicular to the soil surface. The device should be easily broken down into hand-transportable sections, each to weigh 60 lb or less (with the exception of the drill itself which weighed 80 lb), and be powered by a 185 standard cfm compressor located on a nearby road. We hoped to limit the time to install an anchor to 1 hour or less, including time to setup and dismantle the installation equipment.

A lightweight steel frame (fig. 1) was designed and built, with an air cylinder to raise the drill to an adequate height to change or add sections of steel. The cylinder also provided thrust on the drill. Spikes on the base of the frame and four tiedown straps at the top maintained the orientation of the drill during operation. A locking pivot allowed the operator to swing the drill away from the hole when changing longer steels or when clearing the hole with the blowpipe. An air manifold was mounted on the frame, with control valves for the drill, lift cylinder, and auxiliary blowpipe. An in-line oiler was mounted in the air line to the drill.

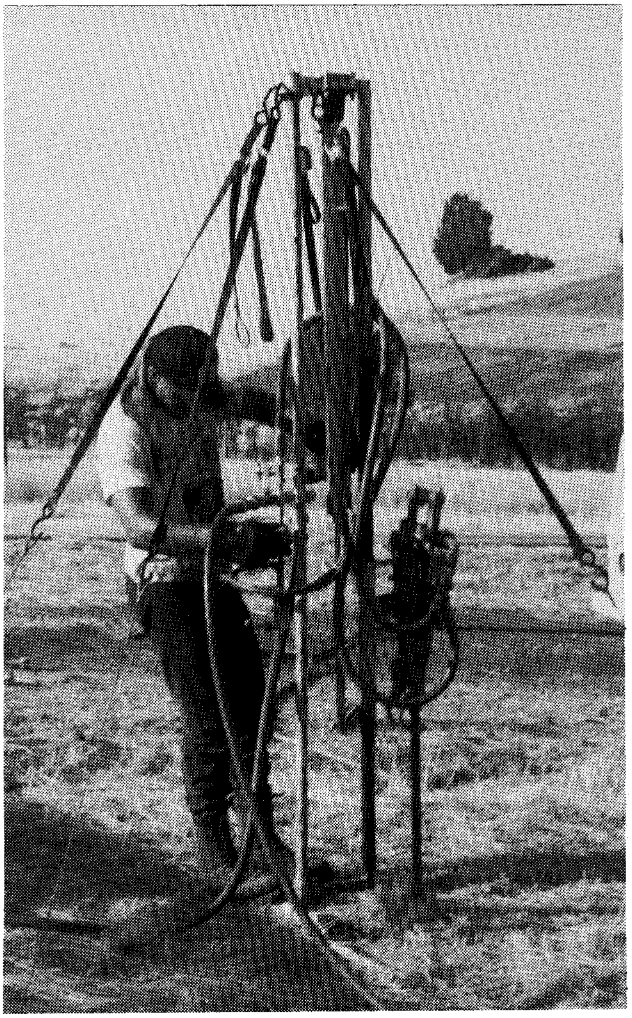


Figure 1. Installation equipment.

After preliminary tests and minor modifications, we tested the drill at the University of California (U.C.) Sierra Foothill Research Center, east of Marysville, California. The Argonaut series soil at the test site consisted of gravelly loam and clay loam in the top 3 to 5 ft, overlaying and developed from basic metavolcanic greenstones. The soil was dry in the surface 2 ft, and moisture content was estimated at less than 10 percent at depth in most holes. Surface slope ranged from 2 to 5 percent. Thirty test anchors were installed at the site. We attempted to drill each hole to a depth of 9.5 ft, and drive each anchor to a midpoint depth of 8.5 ft. (We tried driving a few anchors farther than this.) For each anchor we recorded the time required to setup and tear down the installation equipment, drilling time and depth, and driving time and depth. "D" thread drill steels of 2- through 10-ft length were used, with bits of 3-in diameter. A Foresight Products "Stinger" drive gad and two extensions were used to drive the anchors.

Anchor Design

The majority of the anchor design work was carried out by Visser (1992). We initially wanted to obtain as strong an anchor as possible given the size constraints. The ANSYS finite element program (Swanson Analysis Systems, 1989) was used to compare discrete design alternatives and to help optimize the design. Prototypes were fabricated and pulled to failure under simulated worst-case loading in a Tinius Olsen testing machine. In rocky soils, worst case conditions would occur when the fully deployed anchor was lodged against a rock at either end, resulting in two point reaction loads—spaced nearly the full span of the anchor. Because of local crushing of the rock, the loads would be distributed over a small area. Assuming the area to be circular, and using compressive strength for granite, a relatively hard rock (Beer and Johnston, 1981), we determined that the equivalent point loading would occur at no less than approximately 1 in from the end of the anchor, giving a free span of 12 in for a 14-in anchor.

After settling on a basic design, ten anchors were built, installed, and tested at the Sierra Foothill Research Center. Problems with installation prompted us to revise the design. We fabricated and tested ten additional anchors. Some anchors were used twice to give a total of 30 data points. Installation locations for most of the anchors were laid out in two concentric semicircles at 25 and 33 ft from a pulling fixture which was 4-ft tall, giving initial pull angles of 9 and 7 degrees above the plane of the soil surface. Minimum spacing between anchors along the semicircles was 6 ft.

Most anchors were pull tested with a four-part block and tackle; three parts were connected to the pulling fixture and the fourth to a Caterpillar D6 tractor, which was driven forward to increase the load. Load and displacement of the above-ground end of the anchor cable were sensed with an instrumented pin load cell (Strainsert Model CP-FB

07523) and a string potentiometer, respectively. (We checked the manufacturer's scale factor by testing the pin load cell in a Tinius Olsen testing machine at U.C.—Davis, and found it gave results within 2 percent of the actual applied load.) Both sensors were connected to a Campbell Scientific CR10 datalogger, which recorded the information at 1-sec intervals (for most tests).

RESULTS

Anchor Design

Finite element analysis was used to compare the relative peak stresses that would occur in four discrete anchor designs: A commercially available Foresight MR2 and three anchors produced from round stock, including "one-hole," "two-hole," and "internal-hole" designs (fig. 2). The MR2 had a maximum cross-section dimension of 3.5 in; the other three were limited to 3 in in diameter. We used equal simulated loads on all anchors and assumed elastic deformation.

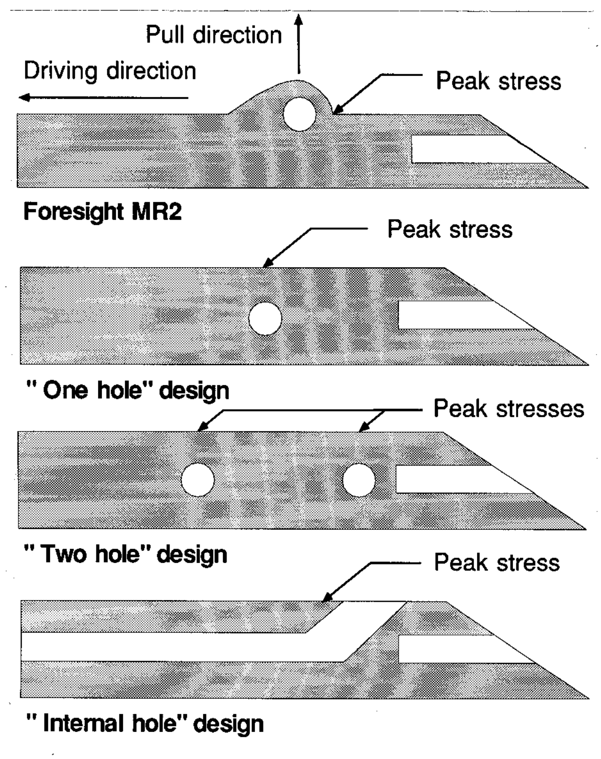


Figure 2. Approximate cross-sections of anchors used in finite element analysis showing locations of simulated peak stresses.

Two options were considered for the "two-hole" design. One length of cable can be doubled and each end connected to one of the eyes in the anchor. After installation, the loop in the cable would be placed through an equalizer block so that each part would see equal load. The alternative would use two cables of equal length, one attached to each eye. These would be shackled to the loading line (guyline or skyline) at the surface. The second configuration would almost ensure that the anchor would fully key, but would require that each of the cables be of equal strength as the loading line.

Since the MR2 anchor failed at a load of 29 kips, we were hoping to reduce the simulated peak stresses in a new design by a factor of approximately three—assuming that the anchor material had properties similar to those of the 60-40-18 ductile cast iron, of which the MR2 was made. Simulation of the MR2 indicated a peak stress at the base of the eye, as would be expected because of the shape transition. Peak stresses for all other designs occurred at the surfaces near the eyes or exit point for the cable. Relative maximum stresses for the four designs are listed in table 1. They indicated that any of the new designs would meet the specified strength requirement.

Table 1. Simulated peak stresses in the various anchor designs.

Design	Relative Peak Stress
MR2	100
"One-hole"	18
"Two-hole"	
Equal loads on each cable	11
All load on one cable	15
"Internal-hole"	25

To minimize stress, the eye in the "one-hole" design was not offset from the centerline of the anchor. We expected that cutting the back end of the anchor at an angle and backfilling the hole would cause the anchor to key, eliminating the need for an offset to produce a turning moment. Even though the "two-hole" anchor had the lowest stress, we did not pursue it because we anticipated problems when driving an anchor with two cables with pressed eyes into a small hole. Reducing the cross-section of the anchor to provide relief for the cables would significantly reduce its strength.

We fabricated prototypes of the "one-hole" and "internal-hole" designs and tested them in the laboratory. The "internal-hole" design was first fitted with a 7/8-, then a 1-in cable. We estimated the ratio R of the bending diameter of the rope to the rope diameter at 2.3 and 2.0 respectively for the two cables. The cable was pushed through the anchor and a nubbin pressed on the end protruding from the nose of the anchor. The advantage of this design is that only a single piece of cable exits from the side of the anchor, thus minimizing the cross section of material being driven into the hole.

Various versions of the "one-hole" design were fabricated from 4140 HRA steel round. A loop, or grommet, of 3/4-in rope was fitted to each anchor. Design A had a uniform round exterior and a drilled eye (fig. 3). The ratio R was estimated at 1.0. Modifications following laboratory and field testing resulted in Designs B and C. Both had the sides cut down on the rear half to provide relief for the cable during installation, and a milled stepped eye that increased the ratio R to 1.5. Design C was 2 in longer than Designs A and B, so that the deployed area would be the same as for Design A; C and B were identical in all other respects.

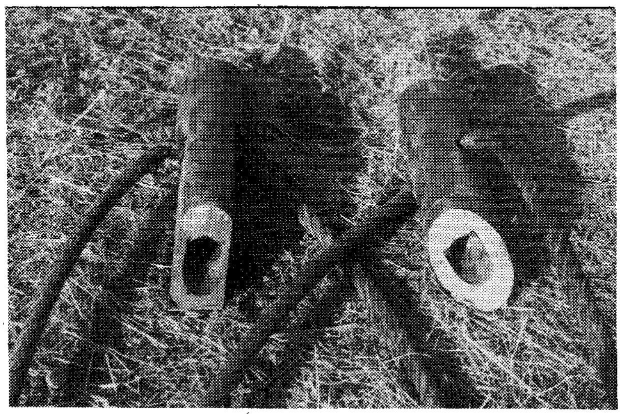


Figure 3. Variations of the "one-hole" anchor; Designs C (left) and A (right).

Ignoring the effects of bending radius, the breaking strength of two parts of 3/4-in rope is greater than one of 1-in rope attached to the anchor with an eye. We did not think it feasible to drive an anchor which had an eye on a 1-in rope into a 3-in hole in rocky soil, therefore we chose the 3/4-in loop. The top end of the loop would be attached to the loading line with a block.

Actual and calculated ultimate capacity results for the cables and anchors are displayed in table 2. Capacities for the cables as bent through the anchors were calculated by using a strength efficiency relationship (Macwhyte Wire Rope Co., 1984):

$$\text{Strength efficiency, } \% = 100 - 50/R^{0.5} \quad \text{for } R < 6$$

Table 2. Ultimate load capacity results for cables and anchors in laboratory tests, and calculated capacities for cables.

Design	Breaking loads, kips	Published wire rope breaking strength, kips*	Estimated R value	Calculated rope strength as bent, kips
"One-hole" (Design A)				
Cable	58, 72	118	1.0	59
Anchor	182, 187			
"One-hole" (Design B)				
Cable	67, 72	118	1.5	70
Anchor	152, 154			
"Internal-hole"				
7/8" cable	68	80	2.3	54
1" cable	67	103	2.0	67
Anchor	(not tested to failure)			

** EIPS IWRC. Source: Macwhyte Wire Rope Co., 1984.*

he weakest link in all cases was the wire rope rather than the anchor, with failures occurring first at the outer strands of the ropes at the bends where they exited the anchors. The small bending radii resulted in large losses in strength efficiency for the wire ropes. After the ropes broke, we loaded the Design A and B anchor bodies to failure in a fixture which approximated the load imposed by a cable. The breaking loads for Designs A and B were approximately 20 percent higher than those calculated from the inelastic design approach assuming that all fibers in the limiting cross section have reached the published ultimate tensile stress for 4140 HRA steel. The additional capacity may have been due to strain hardening and/or a higher than published strength for the batch of steel used. We chose to pursue the "one-hole" design because the theoretical and observed cable breaking loads for Design B slightly exceeded those for the "internal-hole" anchor.

We used all three variations of the "one-hole" design during the field tests. As expected, none of the anchors broke during the field tests. Of the 30 cases, soil failure occurred in 23, cable failure in five and a pressed duplex sleeve gave way in one (table 3). One anchor could not be pulled completely to failure because it was located too close to the pulling frame.

Table 3. Anchor pull test results.

Anchor type	Anchor number	Depth, feet	Max Pull, kips	Displacement at max pull, ft	Failure mode
A	1	8.5	55	N/A	did not fail
A	2	8.5	59	4.4	cable
A	3	8.5	46	5.1	soil
A	4	8.5	81	5.0	cable
A	5	8.5	48	3.9	soil
A	6	8.5	75	4.6	cable
A	7	9	37	6.0	soil
A	8	9	64	4.8	soil
A	9	6	46	3.5	soil
A	20	8.5	90	5.7	cable
A*	21	8.5	65	5.2	soil
A*	23	6	38	2.9	soil
B	12	8.5	51	5.1	soil
B	14	8.5	55	4.0	soil
B	15	8.5	53	3.0	soil
B	16	8.5	60	4.1	soil
B*	24	8.5	88	4.8	sleeve
B*	25	8.5	65	3.9	soil
B*	28	8.5	78	4.8	cable
C	10	4	24	2.0	soil
C	11	8.5	46	3.9	soil
C	13	8	58	4.9	soil
C	17	7	42	2.5	soil
C	18	9	64	4.1	soil
C	19	8.5	47	4.4	soil
C*	22	8.5	68	5.1	soil
C*	26	8.5	63	3.3	soil
C*	27	8.5	64	4.5	soil
C*	29	8.5	59	3.4	soil
C*	30	8.5	64	3.1	soil

** Reinstalled anchors.*

Maximum loads versus depth for the three designs are plotted in figure 4. For the 26 anchors driven to depths of 8 to 9 ft, the average peak pull was 62 kips. The average for the four shallower anchors (mean depth of 6 ft) was significantly less, at 38 kips. There was no significant difference in pulls between the three design variations, although Design C had a slightly lower average (table 4). We suspected that the longer Design C might not key as readily as the others and, therefore, might have less pull capacity.

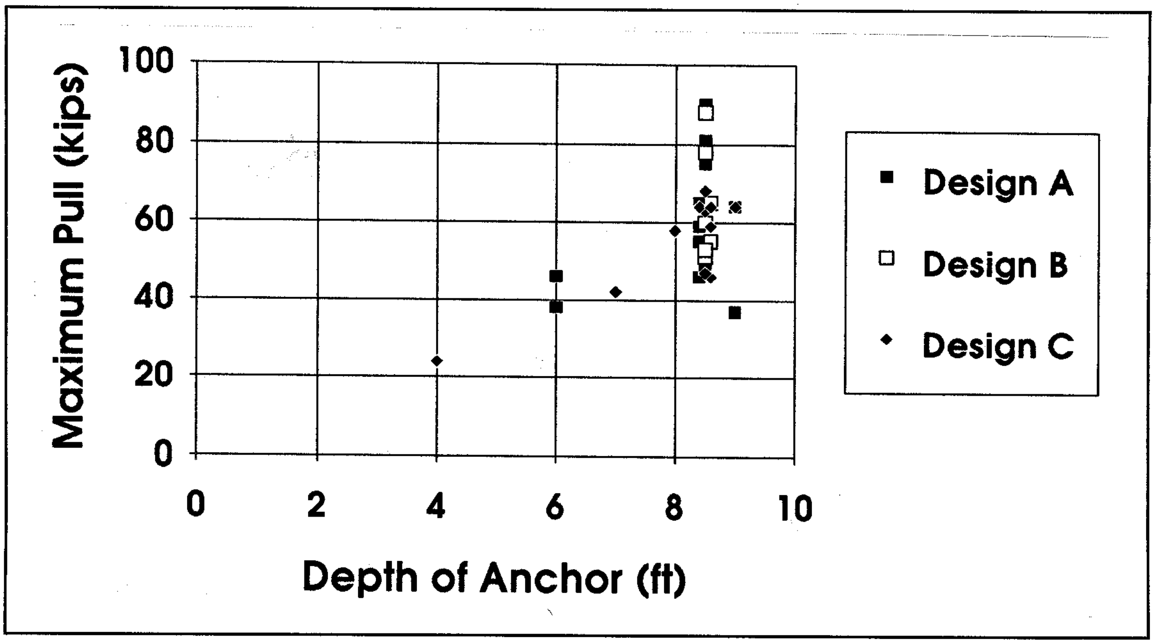


Figure 4. Maximum pull versus anchor depth.

Table 4. Maximum pulls for anchors installed to 8-ft (min.) depth.

Group	*Mean*	*Max. Pull, kips* *Std. dev.*	*95% C.I.*	*Number of observations*
Design A	62	16	52 - 72	10
Design B	64	13	54 - 74	7
Design C	59	8	54 - 64	9
All three designs	62	13	57 - 67	26
Last 10 anchors	70	10	64 - 76	10

We had intended to backfill each anchor hole and tamp the fill in lifts. Due to a misunderstanding some holes were not thoroughly tamped. We did use the intended method for the last ten holes where anchors were driven to 8 ft or more; average peak pull for these was 70 kips, significantly higher than the overall average.

Two soil failure mechanisms were probably active during our tests. At depth, as the loads increased to the peak values, a "deep seated or punching type failure" probably occurred (Hausmann, 1990). In this mode the anchor compresses the soil, increasing the resistance. As the anchor is pulled up, the soil eventually fails abruptly along a conical surface and load resistance drops (fig. 5). Visual observations of surface heaving as resistance diminished and of the smooth wall of the exit hole at depth (along a different trajectory than the drilled hole) tended to support the failure mechanism hypothesis. We should note that the soil had less rock than we had expected. Failure in rockier soil may be different.

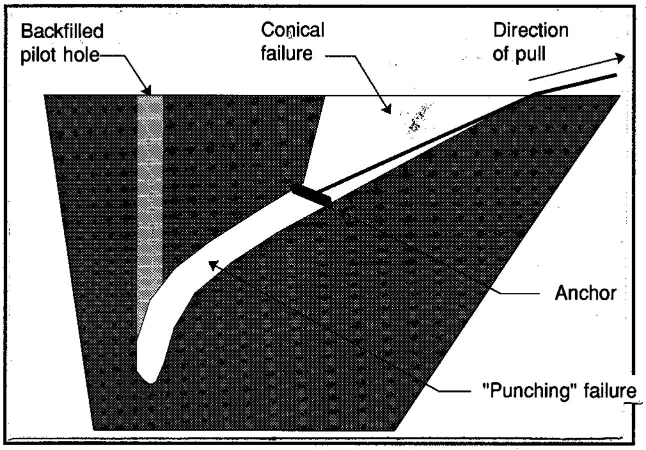


Figure 5. Probable mechanisms of soil failure.

The pull capacities obtained in our tests were considerably higher than those expected from some earlier results (Obradovich and Dulin, 1982) from which equations were developed for rectangular anchors. Predicted requirements for anchor area at 10-ft depth in dense clay-gravel soil are shown in table 5, for 50- and 100-kip capacities. Our anchors had surface areas of 30 to 38 sq in; for those driven to 8 ft or more the minimum capacity was 37 kips and the average was 62 kips.

Table 5. Predicted minimum anchor plate area requirements at 10-ft depth. (Source: Obradovich and Dulin, 1982)

	Anchor area required (in2) for anchor capacity of:	
Soil condition	***50 kips***	***100 kips***
Dry	15	330
Wet	600	1300

Obradovich and Dulin's results also indicated a four-fold reduction in capacity when non-rocky soil becomes saturated; this effect is important to consider when designing anchors for wet sites, but may be less important on rocky sites.

When compared with the results from the laboratory, the six field tests where we failed cables or a sleeve provided a measure of the contribution of soil-cable friction (table 6). Capacities in the field were an average of 18 percent higher than those in the laboratory.

Table 6. Cable failure loads in laboratory and field tests.

Anchor	Mean failure load, kips		Number of Observations	
Design	***Laboratory***	***Field***	***Laboratory***	***Field***
A	65	76	2	4
B	70	83	2	2

Figure 6 shows the horizontal displacement of the upper end of the anchor cable versus the maximum pull, for anchors driven to 8+ ft. There was no significant difference between the mean displacements for the three anchor designs.

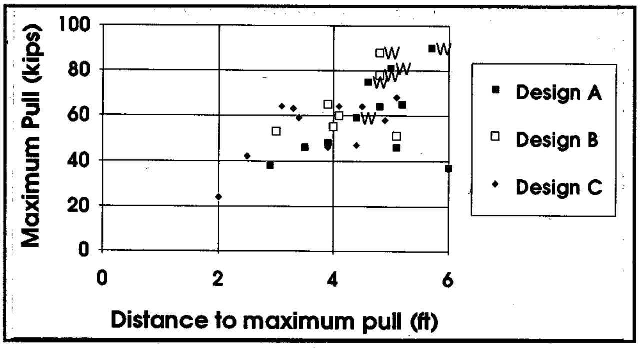


Figure 6. Maximum pull versus displacement to maximum pull. ("W" indicates a failure of the wire rope or sleeve.)

Installation Equipment and Method

Drawings of the tested drill frame are included in the appendix. The weight of the frame with all attached components, less the 80-lb drill, was 95 lb. This exceeded the goal of 60 lb, but the dimensions of the frame made it easy for two people to carry. With the exceptions of the drill and frame, each of the required pieces of equipment weighed 20 lb or less. We estimate that two people would have to make three or four trips to carry all the equipment to an installation site. The equipment needed for installation includes the following (descriptions of most components are also included in the appendix):

185-cfm compressor

Air hose—up to 100' of 3/4" hose can be used, but pressure drop may reduce drill performance; 1" hose is recommended for distances between 50' and 200'.

Drill frame

Stakes—four required, 8" long x 3" wide wing with attachment ring

Adjustable tiedown straps—four required, 10' long

Blowpipe (12' long x 1/2" pipe) equipped with 15' of 3/4" air hose

80-lb drill with 1" x 4-1/4" chuck

Drill steel—1" x 4-1/4" x "D" thread hollow, in lengths of 2' through 10' in 2' increments (spare steels are handy in case one is shanked while drilling)

Drill bits—3" diameter "D" thread, one dirt bit for the 2' steel and four rock bits for the longer steels are recommended; extra dirt and rock bits are useful if a bit is lost due to a shanked steel

Striker bar—1" x 4-1/4" x 1.25" rope thread

Drive gad—Foresight Products "Stinger" drive gad with 1.25" rope thread

Drive steel extensions—two 32" long x 1.25" rope thread

Collars—two 1.25" rope thread

Mirror to direct light into drill holes when diagnosing problems

Anchors with cables

The recommended installation procedure is as follows:

1. Install the four stakes in an X-pattern centered on the desired drilling location. Setup the drill frame, attach the tiedown straps, pound the frame base into the soil; then pull the straps tight. Do not readjust the frame alignment after drilling has begun, as this tends to bind the drill steel. The drill frame does not have to be aligned vertically or perpendicular to the soil. Attach the drill to the frame and ensure that the drill axis is parallel to the slide tube axis; misalignment will cause the drill steel to bind as drilling progresses. Grease the frame slider, squirt some oil onto the drill's air inlet, and fill the in-line oiler. Oiler orifices can be easily clogged by dirt, so make sure the cap and area around it are clean before removing and replacing the cap. (An oiler located at the compressor can have a larger reservoir and is less prone to contamination; however, a second dry air line might have to be run from the compressor to the blowpipe.) Connect the hoses between the frame, drill, and blowpipe. Make sure that all air valves are in the off position. Connect the air hose between the drill frame and compressor. Start and warm-up the compressor according to the manufacturer's directions. Ensure that the oiler is working: while the hose to the drill is depressurized, disconnect it, and point at a sheet of cardboard. Turn on the air; the air spray should leave visible oily residue on the cardboard.

2. Before drilling the first hole, grease the five drill bits and thread them onto the steels. The bits can then remain on the steels indefinitely.

3. Mount the 2-ft steel in the drill chuck. Clear the ground surface of any loose rock and then begin to drill. Use 20 to 40 psi of down pressure on the frame cylinder for drilling in rock; less in softer material if the drill is progressing too fast. If necessary, stop drilling and wet the collar at the top of the hole to help stabilize any ravely material. Use care to prevent material from falling in on top of the drill bit; e.g., when inserting or removing the steel or blowpipe. Alternate full drilling and full blowing through the steel until the drill reaches the bottom stop on the frame, then apply lifting pressure to lift the steel from the hole. Stop rotating the bit before it reaches the top of the hole; this keeps the bit from knocking loose material from the collar into the hole. Remove the steel from the chuck, then clear the hole with the blowpipe. Blow through the drill to remove any dirt from inside the chuck.

4. Insert the 4-ft steel in the hole and mount in the chuck. Drill an additional 6 to 12 in, alternating drilling and blowing with the drill. Then clear cuttings from above the bit with the blowpipe. Continue drilling to the bottom of the stroke for the 4-ft steel, then clear above the bit with the blowpipe—it is extremely important to fully clear cuttings from above the bit before lifting the steel, especially in clayey material. At times it may require two or three

thrusts of the blowpipe to complete the task. It is usually possible to hear and feel when the end of the blowpipe contacts the bit. (The blowpipe could also be marked at 2-ft intervals lined up with a reference mark on the drill to indicate when the pipe has reached the depths of the bits.) Then slowly raise the drill and steel to the top of the stroke while rotating with the drill to ream the hole. Remove the steel from the hole and clear any remaining cuttings from the hole with the blowpipe. Blow through the drill to clear the chuck.

5. Repeat step 4 with the 6- through 10-ft steels. Several problems may be encountered while drilling:

a. *Stuck bit:* It's much better to drill carefully and avoid sticking the bit. Bits can stick if the drill progresses too fast so that the hole has a spiral rather than cylindrical bore, if material falls in on top of the bit, if cuttings are not cleared with the blowpipe before lifting the steel, or if the hole is not straight. Holes which start to deviate from the initial drill path should be abandoned. To clear a stuck bit, use the mirror to light the hole and try to identify the problem. If small material is visible above the bit, use the blowpipe to remove it. If clay has been compacted into a collar, the blowpipe should be thrust down all around the steel to break and remove the collar. If, after removing all material that the airstream will carry, larger rocks are visible, the rotating drill can be run up and down to force the rock into the side of the bore.

b. *Drill won't cut any deeper:* The air holes in the bit may be clogged, also indicated when blowing through the drill will not bring any material to the surface. This can happen when drilling in soil rather than rock; it is best to use dirt bits here. Also check to see if the end of the air tube in the drill chuck has been broken. Clear the bit by drilling into rock if possible.

c. *Drill will impact but not rotate the steel, seems weak:* The drill has probably overheated due to a lack of lubrication, causing the pawl springs to deform and/or break. Replace the pawl springs (and the pawls if they are too pitted), and make sure the oiler is working.

6. After the hole is drilled to the desired depth, insert the anchor into the hole. The duplex sleeve on the cable should be positioned approximately 1 ft from the aboveground end of the grommet, so it does not interfere with the drive steel. Grease the drive gad, striker bar, extensions, and couplers. Insert the drive gad, collar, and striker bar in the anchor and chuck. Drive the anchor until the drill reaches the bottom stop on the frame.

7. Carefully lift the drill off of the striker bar *without lifting the drive gad*—it can be difficult to reinsert the gad into the anchor. Remove the striker bar, add an extension and collar, replace the striker bar, and lower the drill back onto the bar. Continue driving until the drill reaches the lower stop.

8. Repeat step 7 with the second extension. This will drive the anchor to approximately 8.5 ft, near the maximum obtainable in a 9.5-ft hole. Then raise the drill to the upper stop to lift the drive gad from the anchor, remove the striker bar from the drill, swing the drill away from the hole, and manually lift the drive gad and extensions from the hole.

Installation Times

Drilling with the frame was successful; of 33 holes (including a few for reaction anchors), all but one were drilled to the specified depth of 10 ft. The one exception was aborted at 8 ft because the hole did not drill straight and the bit began to jam against the side of the bore. Driving was almost as successful. Of the 30 test anchors, 26 were driven to within 0.5 ft of the specified 8.5-ft depth. Two of the failures were of Design A, where the cables exiting from the anchors extended beyond the 3-in dimension. We suspected that in these two cases the cables were driven against rocks on the peripheries of the bores and would not penetrate any further. This was the impetus for relieving the back halves of anchor Designs B and C. In two other cases driving was arrested when the drive gad bound; we also noticed several other cases when the drill had difficulty turning the gad soon after the duplex sleeve on the loop of cable entered the hole. We then found that the combined dimensions of the sleeve, drive gad, and cable did exceed the 3-in bore of the hole and, therefore, could explain the binding. To solve the binding problem, we installed the last several anchors with the sleeve near the top of the loop; all of these anchors drove very easily.

Preparation (setup and takedown), drilling and driving times are shown in table 7. The mean total time per anchor was 71 min, slightly longer than our goal of 1 hr. We noticed very little learning curve reduction in time over the period of the study; the running average total time decreased by only 4 min or so. Our preparation time involved move distances of only 10 to 100 ft; most of the preparation time was spent erecting the frame and attaching and readying the drill.

Table 7. Installation times and depths.

Element	Mean	Std.dev.	Min	Max	N
Preparation, min	14.3	4.7	9	24	27
Drill, min	44.1	14.6	26	79	29
Drive, min	12.6	8.2	4	36	27
Drill depth, feet	9.9	0.3	8	10	33
Drive depth, feet	8.2	0.8	4	9	30

While the time definitions used in the 1991 tests (Hartsough et al., 1992) were somewhat different than in the present study, table 8 shows our estimates of the times required, including moving the equipment 100 ft from roadside to the anchor location, to install a single anchor.

Table 8. Estimated anchor installation times for the tested pieces of equipment.

Equipment	Total time per anchor, min
Jackhammer	60
Drill and frame	70
Crawler drill	15

Time for the hand-held jackhammer is estimated to be less than observed with the new drill and frame, due to shorter preparation time. The time difference should be viewed in the context of the trials—the driller who carried out the 1991 work had many years of experience with pneumatic drills, while the 1992 crew had drilled only three holes with the installation equipment prior to beginning the tests (although one member had observed the previous year's operations). We would argue for the use of the new equipment, because it allowed a relatively inexperienced crew to install anchors with little physical labor and to reach the desired drilling and driving depths more frequently than the experienced driller using the jackhammer drill.

CONCLUSIONS AND RECOMMENDATIONS

The installation equipment worked well in its tested configuration. Using this equipment, a crew of two should be able to install an anchor in little over 1 hr, and with relatively little physical effort. The following recommended changes to the tested drill frame have already been included in the drawings:

The horizontal base was shortened by 1 ft and the pegs cut to 4 in. We originally tried 2-in pegs, but they were too short to hold the base securely while drilling. We then tested 6-in pegs; they were longer than necessary.

The lift cylinder was inverted (rod end up) to give more lifting force. With the rod end down, we found that the down force was more than needed and lift force was sometimes inadequate. With the cylinder rod end up, the two-position (raise/lower) valve for the lift cylinder should be replaced with a three-position (raise/stop/lower) valve so that the drill can be held in a position other than full up or down when needed.

Ruggedly-built valves should be used to control the cylinder, drill, and blowpipe. We had problems with handles loosening and handle threads failing.

In most cases the anchor capacity was limited by soil strength. Higher capacities could be achieved by expanding the plan area of the anchor, but this would mean increasing the length if the 3-in diameter is a firm constraint. As noted earlier, we are concerned that longer anchors may not key as readily; they would also require slightly deeper holes if they were to be driven to the same depths. Capacities should be higher in soils with more rock than at our test site. Where soil strength is adequate, the wire rope is the weak link. In theory, a perfect semicircular bend which kept the exterior of the 3/4-in rope within the 3-in envelope would have an R value of 2.0, and give a strength of approximately 77 kips (or 90 kips if soil-cable friction is included). A loop of larger diameter cable does not appear feasible because it might bind with the drive rod couplings in the three inch hole.

Our recommended design for the anchor is shown in figure 7. It includes the following improvements on Design B:

The nose is cut down and the eye offset slightly to improve keying performance.

Only the upper back quarter of the anchor is relieved for the cable. This increases the surface area to nearly the 38 sq in of Design A. The anchors should have strengths equivalent to that of the as-bent cable, if fabricated of 1020 CD steel or 60-40-18 ductile cast iron (table 9).

Table 9. Estimated strengths of recommended-design anchors.

Material	Material strength, ksi* Tensile	Yield	Estimated anchor breaking strength, kips
60-40-18 cast iron	70	52	80
1020 CD steel	78	66	90
4140 HRA steel	90	63	110

* From Deutschman et al., 1975.

These tests involved only one soil type. Soil strength is highly variable; therefore, these results can't be used for predictions on other sites. We recommend proof testing any anchor to half of the capacity of the limiting link (in this case, the anticipated strength of the wire rope loop as reduced to account for bending), and keeping applied load to one-third or less of this capacity.

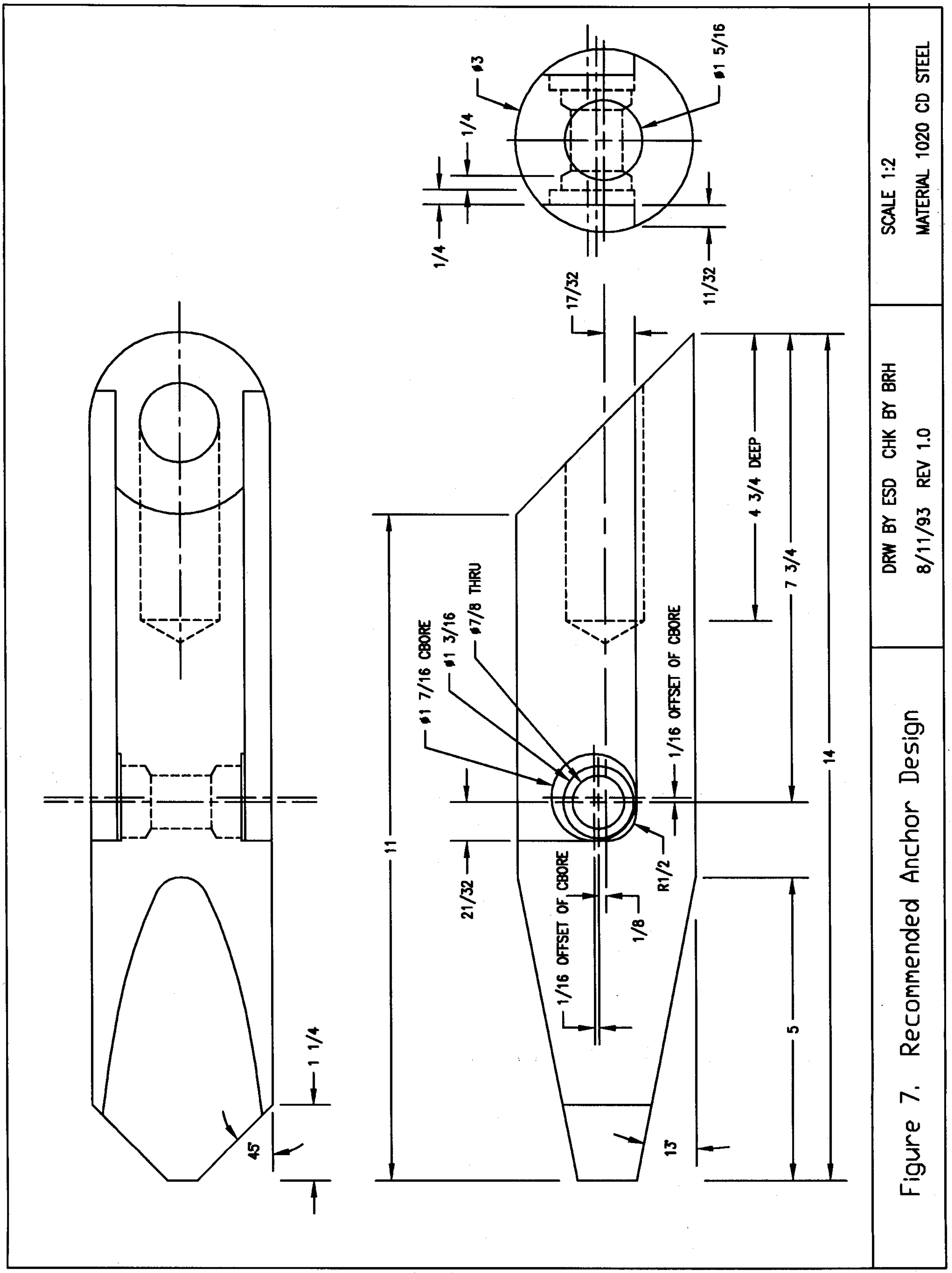


Figure 7. Recommended anchor design.

REFERENCES

Beer, F. and E. Johnson. 1981. *Mechanics of Materials.* McGraw-Hill, New York.

Copstead, R.L., D.D. Studier, et al. 1993. *An earth anchor system: installation and design guide.* USDA Forest Service Technology & Development Program Spcl Rpt 9324 1804—SDTDC. San Dimas, CA.

Deutschman, A.D., W.J. Michels and C.E. Wilson. 1975. *Machine design: theory and practice.* Macmillan, New York.

Hartsough, B.R., E. Drews, J.A. Miles, J.J. Mehlschau, B. Vannucci, R.L. Copstead, R.J. Simonson and D.D. Studier. 1992. *Preliminary experiences with cable logging anchors for rocky soils.* ASAE Transactions 35(6):1995-1999.

Hausmann, M.R. 1990. *Engineering principles of ground modifications.* McGraw-Hill, New York.

Macwhyte Wire Rope Co. 1984. *Macwhyte wire rope catalog G-18.* Kenosha, WI.

Miyata, E.S., T.L. Ortman and P.J. Clemens. 1985. *Reliability of rockbolt anchorages for forestry applications.* IN: *Proceedings, Improving Mountain Logging Planning, Techniques and Hardware.* Vancouver, BC. May 8-11. pp. 97-100.

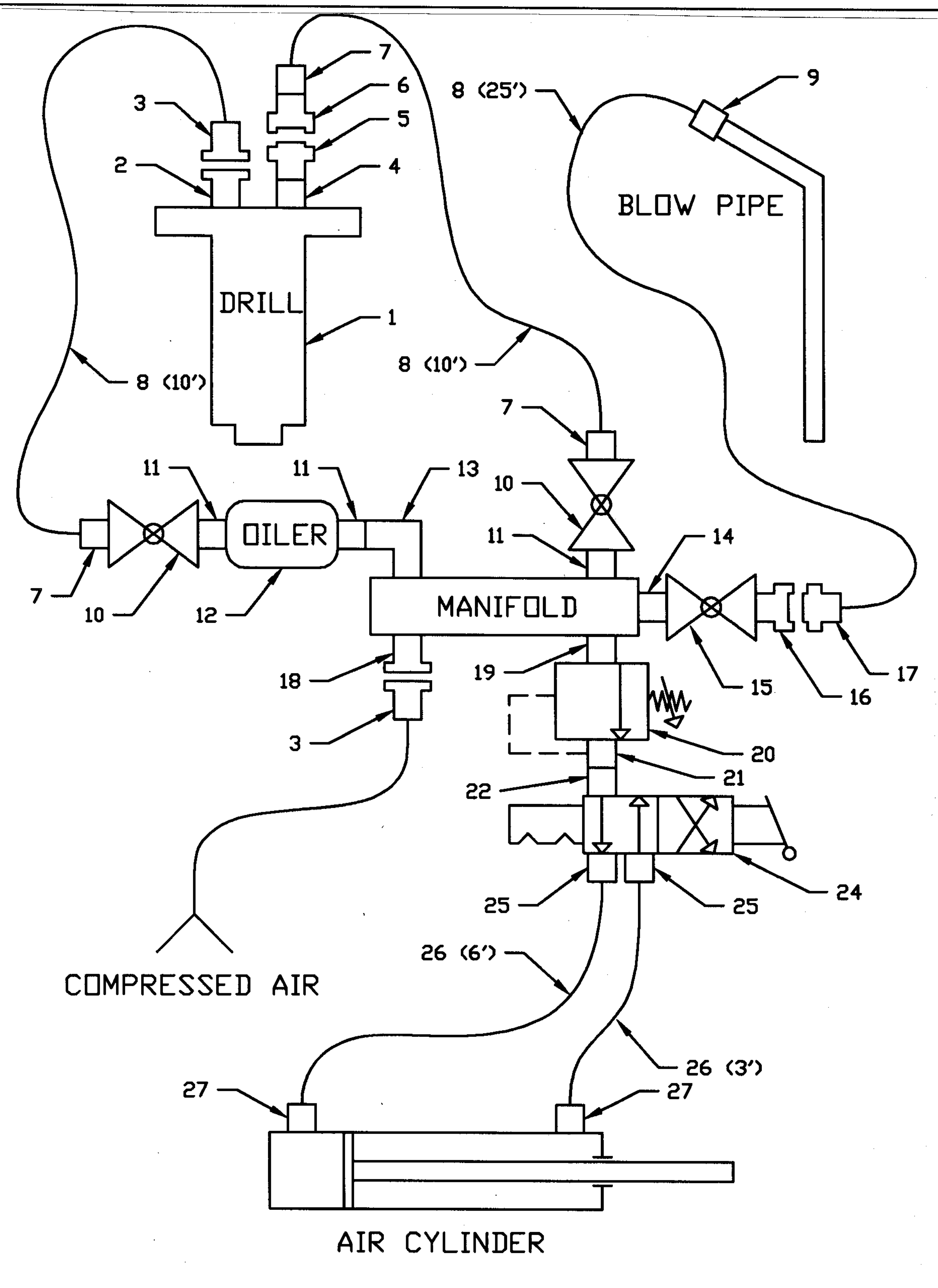
Obradovich, J.N. and R.O. Dulin. 1982. *A study of available anchor systems and development of concepts suitable for application to meet cable logging and/or assault vehicle egress requirements.* VSE Corporation. Alexandria, VA.

Schroeder, W.L. and D.N. Swanston. 1992. *Installation and use of epoxy-grouted rock anchors for skyline logging in southeast Alaska.* USDA Forest Service Pacific Northwest Research Station General Technical Report PNW-GTR-297. Portland, OR.

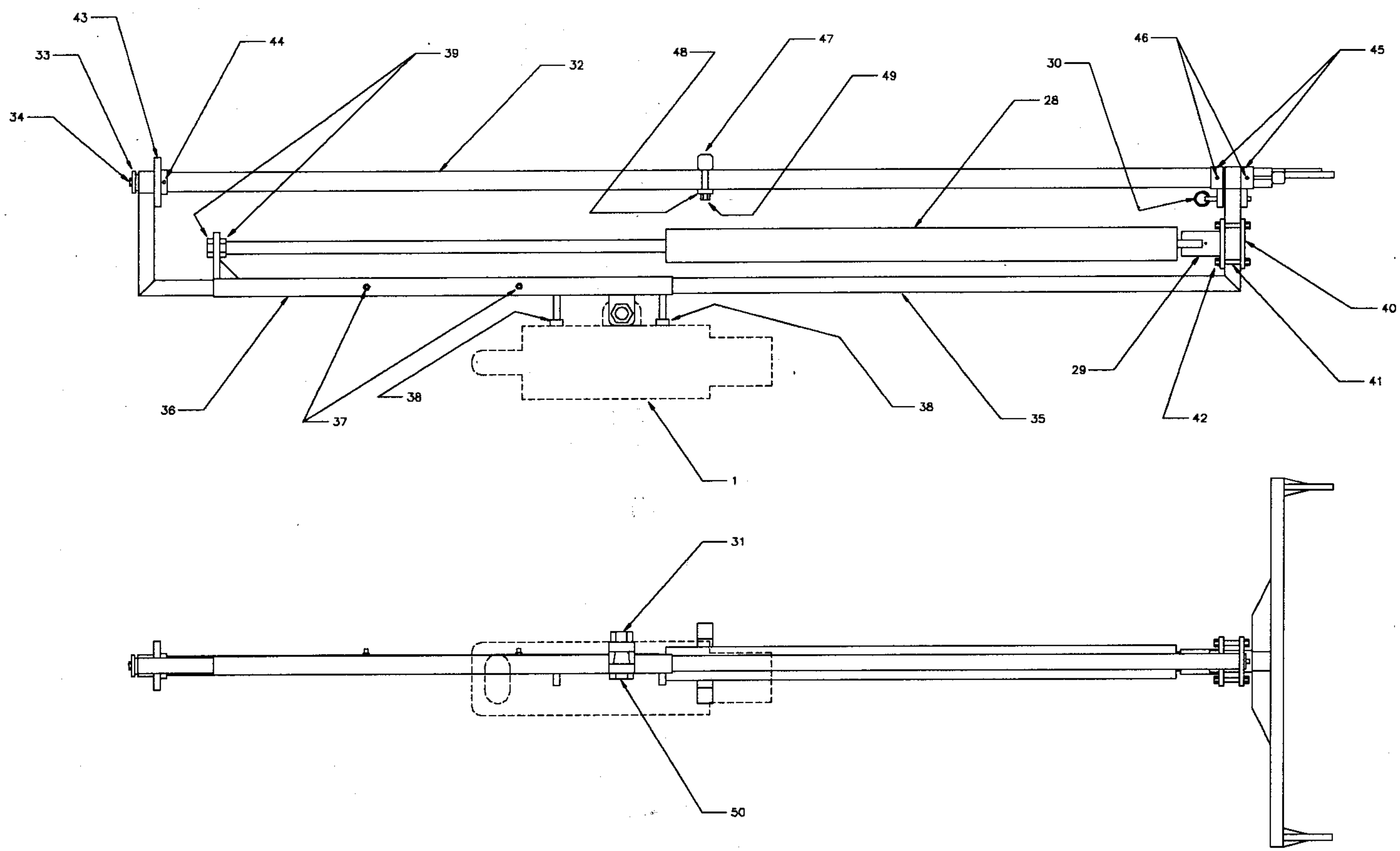
Swanson Analysis Systems, Inc. 1989. *ANSYS Version 4.4a.* Houston, PA.

Visser, R.J.M. 1992. *Improved artificial cable logging anchors for rocky soil conditions.* Masters of Engineering Report, Biological and Agricultural Engineering Department, University of California, Davis.

APPENDIX—Drill Support Frame Drawings and Parts List



Pneumatic Circuit for Anchor Installation Equipment



NO.	REQ.	PART DESCRIPTION	DRW NO.
1	1	DRILL	
28	1	CYLINDER	
29	1	CLEVIS	
30	1	QUICK RELEASE PIN	
31	1	1"-14 HEX NUT	
32	1	DRILL STAND	DE-D002
33	1	END DISK	DE-D002
34	1	1/4" X 3/4" NC BOLT	
35	1	SWING ARM	DE-D003
36	1	DRILL SLIDER	DE-D003
37	2	GREASE FITTING	
38	2	RUBBER PAD	
39	2	1" HEX NUT	
40	1	CLEVIS MOUNTING PLATE	DE-D007
41	4	3/8" X 2 3/4" NC BOLT	
42	4	3/8 NC HEX NUT	
43	1	GUYLINE RING	DE-D005
44	1	1/4" X 2" ROLL PIN	
45	2	POSITIONING COLLAR	DE-D006
46	2	1/4" X 1 3/4" ROLL PIN	
47	1	MANIFOLD	DE-D008
48	1	MANIFOLD BRACKET	DE-D008
49	2	1/2" NC HEX NUT	
50	1	DRILL MOUNTING BOLT	DE-D004

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DRILLING EQUIPMENT ASSEMBLY	DRW BY ESD	CHK BY BRH	SCALE 1 : 5
DRAWING # DE-A001	REV. 1.0	8/26/93	

Part	Item	Supplier	Addit. Part No.	Price ea
1	80 lb feed leg rock drill w/ 1" x 4 1/4" chuck	Harper Air Tool	8301	$2,700.00
2	Coupling, Dixon fitting x 3/4" female pipe	TMC	A-RUF-3	$4.95
3	Coupling, Dixon fitting x 3/4" hose barb	TMC	A-RHE-75M	$5.40
4	Reducing coupling, 3/8" x 1/2" pipe thread, steel	California Hose & Fittings	3/8 x 1/2 GG-S	$4.71
5	Parker quick coupling nipple x 1/2" male pipe	California Hose & Fittings	BH2F	$3.91
6	Parker quick coupling x 3/4" female pipe	California Hose & Fittings	B37G	$12.36
7	Push-loc fitting, 3/4" male pipe x 3/4" hose barb	California Hose & Fittings	30182-12-12	$3.23
8	3/4" pneumatic hose, per foot	California Hose & Fittings	801-12-BLU	$2.11
9	Push-loc fitting, 1/2" female pipe x 3/4" hose barb	California Hose & Fittings	30182-8-12B	$3.23
10	Bronze butterfly valve w/ 3/4" female pipe threads	McMaster-Carr	9798K82	$9.58
11	3/4" pipe thread nipple			
12	In-line oiler, 3.7 oz.	TMC	NEW2L	$65.50
13	3/4" pipe street elbow			
14	1/2" pipe thread nipple			
15	Ball valve w/ 1/2" female pipe threads			
16	Parker quick coupling x 1/2" male pipe	California Hose & Fittings	B36	$12.36
17	Parker quick coupling nipple x 3/4" hose barb	California Hose & Fittings	H5F-G	$4.35
18	Coupling, Dixon fitting x 3/4" male pipe	TMC	ME-75	$5.95
19	3/8" pipe thread nipple			
20	NGN ROB-300-RGMA regulator and gage	Bay Pneumatic		$33.85
21	Reducing bushing, 3/8" x 1/4" pipe thread, steel	California Hose & Fittings	3/8 X 1/4 PTR-S	$0.90
22	1/4" pipe thread nipple			
24	Allenair V-400-H valve w/ offset 1/4" pipe ports	Bay Pneumatic		$147.00
	Suggested three position replacement for 24:			
	Norgren K81DA00-KC0-KL3 valve	Bay Pneumatic		$56.00
25	Push-loc fitting, 1/4" male pipe x 3/8" hose barb	California Hose & Fittings	30182-4-6	$1.03
26	3/8" pneumatic hose, per foot	California Hose & Fittings	801-6-BLU	$1.07
27	Push-loc fitting, 3/8" male pipe x 3/8" hose barb	California Hose & Fittings	30182-6-6	$1.63
28	Allenair A 2 1/2" x 38"-OS-RC cylinder	Bay Pneumatic		$296.75
29	Allenair 339 clevis and pin	Bay Pneumatic		$21.25
30	1"-14 steel hex nut, grade 8	McMaster-Carr	94896A038	$1.15
31	Quick release pin	McMaster-Carr	98320A743	$4.58
	spare pawl	Harper Air Tool	83016	$9.00
	spare pawl plunger	Harper Air Tool	83017	$10.00

Part	Item	Supplier	Addit. Part No.	Price ea
	spare pawl spring	Harper Air Tool	83018	$0.50
	spare water tube	Harper Air Tool	83030	$18.00
	1" x 4 1/4" x 125R x 5/16" striker bar	Brunner & Lay	P04B120	$58.99
	2' x 1" x 4 1/4" D thread carbon hollow drill steel	TMC	STLE23024D	$71.35
	4' x 1" x 4 1/4" D thread carbon hollow drill steel	TMC	STLE23048D	$92.95
	6' x 1" x 4 1/4" D thread carbon hollow drill steel	TMC	STLE23072D	$113.75
	8' x 1" x 4 1/4" D thread carbon hollow drill steel	TMC	STLE23096D	$142.55
	10' x 1" x 4 1/4" D thread carbon hollow drill steel	TMC	STLE230120D	$152.45
	3" D thread rock bit	TMC	STLE3008MD	$116.25
	Stinger drive gad w/ radius tip	Foresight	SG-3	$130.53
	Drive extension	Foresight	SG-2	$114.40
	1.25 rope thread collars C125BB3	Ingersoll-Rand	50896349	$22.89
	Drill thread lubricant, 5 lb pail	Ingersoll-Rand	51378639	$38.85
	Drill oil, 1 gallon	Ingersoll-Rand	51389948	$18.00
	20' circumference 3/4" 6 x 19 IPS IWRC grommet	Sacramento Wire Rope		$75.00
	Bay Pneumatic, 440 Convention Way, Redwood City, CA 94063-1407 (415) 365-1444			
	Brunner & Lay, Inc., 2425 East 37th St., Los Angeles, CA 90058			
	California Hose & Fittings, etc., 4015 Seaport Blvd., W. Sacramento, CA 95691 (916) 372-3888			
	Foresight Products Inc., 6430 East 49th Drive, Commerce City, CO 80022 (303) 286-8955			
	Harper Air Tool Manufacturing Co., P.O. Box 58344, Los Angeles, CA 90058 (213) 589-8171			
	Ingersoll-Rand Equipment Sales, 1851 Bell Avenue, Sacramento, CA 95838 (916) 641-1994			
	McMaster-Carr Supply Company, Santa Fe Springs, CA (310) 695-2449			
	Sacramento Wire Rope & Supply, 2445 Front St., W. Sacramento, CA 95691 (916) 372-2864			
	TMC Industrial Power Tool, 6014 Egret Court, Benecia, CA 94510 (707) 746-7762			