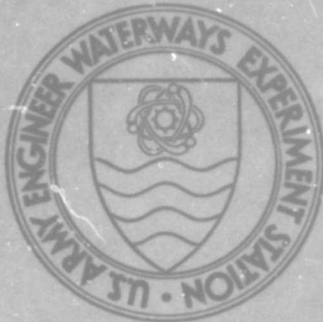


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TECHNICAL REPORT 3-71-10

# EVALUATION OF ANCHORS USED TO SECURE MEMBRANE SURFACINGS

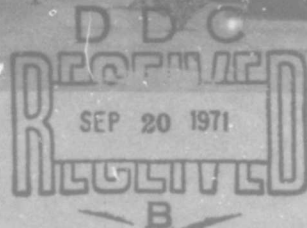
by

R. H. Grau



July 1971

Sponsored by U. S. Army Materiel Command



Conducted by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

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13. ABSTRACT A review of two previously published reports concerning the evaluation of anchors was made to determine the feasibility of using any of the anchors tested to secure membrane surfacings. Tests reported herein were conducted to evaluate and compare the performances of various anchors driven into a lean clay subgrade. Holding strengths of the various anchors were determined in four types of soil subgrades. Performances of the anchors were compared with the performance of the guy anchor, which is a standard item. The literature review and test results indicated that the heads of the guy anchors were either broken from the reinforcing bars or bent when the anchors were driven to a depth of 24 in.; disk-type anchors were easily driven into the soil subgrade; two-legged, threaded guy, and threaded disk-type anchors were damaged when they were driven into the clay subgrade; arrowhead anchors had the greatest holding strengths; guy and arrowhead anchors developed adequate holding strengths in sand, silt, and fat and lean clay subgrades; disk-type and two-legged anchors produced adequate holding strengths in the silt, fat clay, and lean clay subgrades; anchors developed the greatest holding strengths when extracted at a 60-deg angle with the surfaces of the subgrades; anchors described in the literature review were not feasible for use in securing membrane surfacing. Based on the results of the tests reported herein, it is concluded that the disk-type anchors are satisfactory for securing membrane surfacing.			

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by

R. H. Grau



July 1971

Sponsored by U. S. Army Materiel Command

Project No. IG664717D556, Task 02

Conducted by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS

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## FOREWORD

This report describes an investigation that was conducted under the sponsorship of the Ground Mobility Office, Directorate of Development, Headquarters, U. S. Army Materiel Command (AMC), under Project No. 1G664717D566, "Prefabricated Surfacing and Dust Control," Task 02, "Prefabricated Membrane Development." The investigation was conducted during the period November 1966-June 1967 at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi.

Engineers of the Soils Division, WES, who were actively engaged in the planning, analyzing, and reporting phases of this investigation were Messrs. W. J. Turnbull, A. A. Maxwell, W. L. McInnis, S. G. Tucker, R. H. Grau, and T. W. Vollar. This report was prepared by Mr. Grau.

Directors of the WES during the conduct of this investigation and preparation of this report were COL John R. Oswalt, Jr., CF, COL Levi A. Brown, CF, and COL Ernest D. Peixotto, CE. Technical Directors were Mr. J. B. Tiffany and Mr. F. R. Brown.

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## CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
inches	2.54	centimeters
feet	0.3048	meters
pounds	0.45359237	kilograms
pounds per cubic foot	16.0185	kilograms per cubic meter

## SUMMARY

Tests were conducted to evaluate and compare the performances of various anchors driven into a lean clay subgrade. The performances of the anchors were compared with the performance of the guy anchor, which is a standard item furnished in T17 membrane surfacing sets. Tests were also conducted to determine the holding strengths of anchors used to secure neoprene-coated nylon membrane placed on soil subgrades to waterproof and dustproof airfields, helicopter pads, and roadways. A review of two previously published reports concerning the evaluation of anchors was made to determine if it would be feasible to use any of the anchors tested to secure membrane surfacings.

The test results and literature review indicated the following:

- a. The heads of the guy anchors were either broken from the reinforcing bars or bent to such a degree that they would not fit flush with the surface of the subgrade when the anchors were driven to a depth of 24 in.
- b. Disk-type anchors were easily driven vertically into the soil subgrades, and their heads were flush with the surfaces of the subgrades when the anchors were driven to a depth of 12 in.
- c. Two-legged, threaded guy, and threaded disk-type anchors were damaged beyond use when they were driven into the lean clay (CL) subgrade.
- d. Arrowhead anchors had greater holding strengths in all subgrades tested than did the guy, disk-type, or two-legged anchors.
- e. The holding strengths of the guy and arrowhead anchors were adequate in sand (SP, nonplastic), silt (ML), fat clay (CH), and lean clay (CL).
- f. The disk-type and two-legged anchors produced adequate holding strengths in silt, fat clay, and lean clay, but not in sand.
- g. The average holding strengths of the anchors were greater when the anchors were extracted at a 60-deg angle with the surfaces of the subgrades than when the anchors were removed vertically.
- h. The anchors described in the literature review were not feasible for use in securing membrane surfacing.

Based on the results of the tests reported herein, it is concluded that the disk-type anchors are satisfactory for securing membrane surfacing on assault runways.

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# EVALUATION OF ANCHORS USED TO SECURE MEMBRANE SURFACINGS

## PART I: INTRODUCTION

### BACKGROUND

1. During the period July 1965-November 1966, integrated engineering and service tests were conducted at Ft. Campbell, Ky., to determine whether T17 and WX18 membrane surfacings would be suitable for surfacing assault runways. The T17 membrane was designed to withstand sustained aircraft operations of the OV-1 Mohawk and CV-2 Caribou and limited operations of the C-130 Hercules; the WX18 membrane was designed to withstand sustained operations of C-130 aircraft. The performances of accessories required for emplacing the membrane surfacings were also evaluated.

2. Results of the integrated engineering and service tests of the T17 and WX18 membranes indicated that the guy anchors, which were used to secure each section of membrane surfacing to the soil subgrade, were difficult to drive vertically into the subgrade (photograph 1) and that the heads of the anchors were damaged or broken from the reinforcing bars (photograph 2) when the anchors were driven into the subgrade with sledgehammers. The damaged anchor heads did not fit flush with the surface of the membrane when the anchors were driven into the soil subgrade for the full depth of 24 in.\* The damaged anchors punctured the membrane and were considered hazards to aircraft operations. The investigation reported herein was conducted to evaluate various anchors used to hold the membrane surfacing in place during assault-type aircraft operations. Improved field performance was the main objective of designing these test anchors, but it was kept in mind during testing that it would also be advantageous if the anchors required less cubage for packaging and shipping purposes.

### PURPOSE AND SCOPE OF INVESTIGATION

#### Purpose

3. The purpose of this investigation was to evaluate various anchors in an effort to select one that could be successfully installed and that would anchor membranes used to surface assault runways. The specific objectives were as follows:

- a. Review published reports and determine if existing anchors could be used for securing membrane surfacing.
- b. Evaluate the ability of various experimental anchors to withstand the force required to drive the anchors into soil subgrades with sledgehammers.
- c. Determine the holding strengths of various experimental anchors in four types of soil subgrades.
- d. Compare weight and cubage of experimental anchors for packaging purposes.

#### Scope

4. The investigation included a literature search and field tests. Experimental earth anchors

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\* A table of factors for converting British units of measurement to metric units is presented on page ix.

and the guy anchor were studied during the field tests, which included visual observations during anchor driving operations, measurement of the force required to extract the anchors from subgrade soils, and measurement of weights and sizes of the anchors.

## PART II: LITERATURE REVIEW

5. The initial effort in this investigation was a search of current literature. Two reports<sup>1,2</sup> that concerned investigations of various anchors were prepared by the Atlantic Research Corporation and published by the U. S. Naval Air Materiel Center, Philadelphia, Pa. These reports were reviewed to determine if it would be feasible to use any of the anchors described therein to secure membrane surfacing. Both reports were submitted to fulfill a contract with the Naval Air Materiel Center for the design and development of an improved anchoring system for use in the Navy's Short Airfields for Tactical Support (SATS) program. A SATS runway is surfaced with landing mat, and a metal rail is provided within the surfaced area so aircraft can take off by means of a catapult system. Arresting gear equipment is also an integral part of SATS and is used to provide a means of stopping aircraft during landing operations. The primary goal of the contract study was to reduce the time required to install anchors used to secure the catapult and arresting gear systems that are located on SATS installations. A brief summary of each report is presented in the following paragraphs.

### ANCHOR STUDY REPORT

6. The purpose of this investigation was to study the state-of-the-art of earth anchors. All information contained in the report was obtained through a literature search. Theories of soil mechanics, dynamic loading, soil stabilization, and earth penetration were explored to obtain a working knowledge of the best available methods for advancing designs of earth anchors.

7. The final analysis of the literature search indicated that a great variety of anchors was available commercially that might be used on SATS installations. These anchors fell into the categories of ground plate, arrowhead, conical, screw type, expanding, deadman, stake type, and rock anchors. The report indicated that the arrowhead anchor best met the stated requirements. Also, it was recommended that studies be conducted to improve the design of the arrowhead anchor to make it easier to remove from the soil subgrade and that field tests be conducted on the eight types of anchors that appeared feasible for use.

### EQUIPMENT ANCHORS PRELIMINARY DESIGN REPORT

8. This report concerned the evaluation of various earth anchors to be used to secure catapults, landing mat, and arresting gear systems for SATS runways. Included in the report are preliminary design drawings, stress analyses, and cost estimates of the anchors. Eight basic types of anchors were tested to determine their holding strengths when driven into the weakest soil anticipated in the installation of SATS runways. The soil was classified as a Class 6 soil (soft plastic clay, loose coarse sand, clayey silt, and compacted fine sand) as defined by the A. B. Chance Soil Classification System.\*

9. Of the eight types of anchors tested, three that were considered feasible for the intended purpose were the single drive plate anchor, the split drive plate anchor, and the double-fluked stake

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\* A. B. Chance Company, Anchor Catalog, Section 4.

anchor. It was determined that in Class 6 soil, these anchors had holding strengths in excess of the required 13,500 lb. The remaining five types of anchors that were tested were rejected because they did not develop the holding strengths that were required and/or because a considerable length of time was required to place them in the soil. The drive plate and stake anchors were emplaced in the subgrade by means of a mechanical apparatus that was mounted on the rear of a tractor. Special tools were required to excavate holes for the emplacement of the other anchors.

#### **DISCUSSION OF REVIEWS**

10. The anchors that were evaluated by the Atlantic Research Corporation were designed to develop far greater holding strengths than are required for securing membrane surfacing. The minimum holding strength criterion for SATS anchors is approximately 13,500 lb in Class 6 soil, whereas the minimum holding strength required to secure membrane surfacing is 200 to 300 lb. The time required to emplace the test anchors was excessive when compared with the time required to drive the anchors that are now used to secure membrane surfacing.

### PART III: DESCRIPTIONS OF ANCHORS TESTED

11. The anchors evaluated during the field investigation are described in the following paragraphs. All anchors except the arrowhead anchor were driven into the subgrades with a sledgehammer. The arrowhead anchor was driven with a manual impact tool.

#### GUY ANCHOR

12. The guy anchor was designed and constructed at the U. S. Army Engineer Waterways Experiment Station (WES) and weighed approximately 6-1/2 lb. It was fabricated by welding a 12-in.-diam, 11-gage, hot-rolled steel plate\* to a 2-ft-long, 3/4-in.-diam, No. 6 reinforcing bar.\*\* The end of the reinforcing bar to be driven into the soil subgrade was cut at a 30-deg angle to provide a point. A slot 3/4 in. wide and 5 in. long was cut in the head of each anchor so that a cable connected to the reinforcing rod when the anchor was to be extracted from the soil could be positioned at a 90- or 60-deg angle with the surface of the subgrade. The guy anchor is shown in fig. 1. Since this anchor had been used previously during service tests,<sup>5</sup> its performance was compared with that of other anchors evaluated during this study.

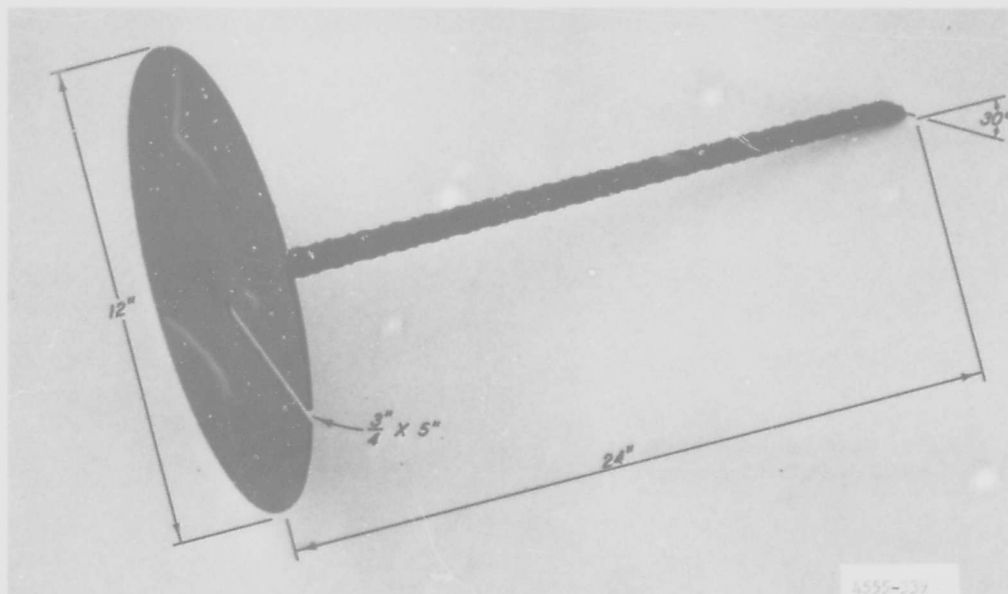


Fig. 1. Guy anchor

\* Conforming to ASTM Standard Specification A-36-67<sup>3</sup> for structural steel.

\*\* Conforming to ASTM Standard Specification A-15-66<sup>4</sup> for billet-steel bars for concrete reinforcement (deformed bars).

## DISK-TYPE ANCHOR

13. This anchor was designed and constructed at the WES and weighed approximately 3 lb. It was fabricated by welding an 8-in.-diam, 11-gage, hot-rolled steel plate\* to a 1-ft-long, 3/4-in.-diam, No. 6 reinforcing bar.\*\* The 8-in.-diam plate was formed so that the inner 6-in. diameter of the plate would provide a 7/16-in. crown and the remaining 1-in.-wide band would be flat. The 1-in.-wide flat band was designed to provide a bearing surface to hold membrane in place. A pyramid-shaped point was provided at one end of the reinforcing bar by cutting a 20-deg bevel on four sides of the rod. A slot 3/4 in. wide and 3 in. long was cut in the head of each anchor so that a cable connected to the reinforcing rod when the anchor was to be extracted from the soil could be positioned at a 90- or 60-deg angle with the surface of the subgrade. The disk-type anchor shown in fig. 2 was evaluated during the anchor driving tests, and the slotted disk-type anchor shown in fig. 3 was evaluated during the anchor holding-strength tests.

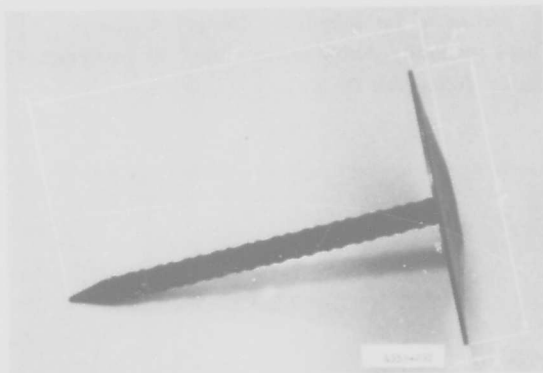


Fig. 2. Disk-type anchor

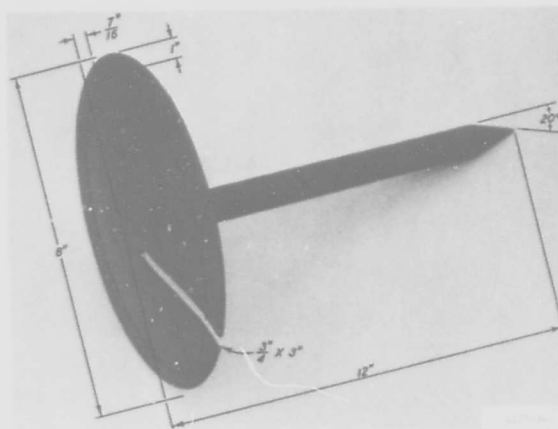


Fig. 3. Slotted disk-type anchor evaluated during holding-strength tests

\* Conforming to ASTM Standard Specification A-36-67<sup>3</sup> for structural steel.  
\*\* Conforming to ASTM Standard Specification A-15-66<sup>4</sup> for billet-steel bars for concrete reinforcement (deformed bars).

## TWO-LEGGED ANCHOR

14. The design for the two-legged anchor was submitted to the WES by Defense Construction Supply Center (DCSC), Columbus, Ohio, as an employee suggestion. The anchor was constructed at the WES and weighed approximately 3-3/4 lb. It was fabricated from a 12-in.-diam, 11-gage, hot-rolled steel plate.\* The anchor was fabricated by pressing the 12-in.-diam plate to provide a 1/4-in. crown in the plate. The crowned part of the plate was 11 in. in diameter, and the remaining 1/2-in.-wide strip located around the outside edge of the plate was flat. The 1/2-in.-wide flat band provided a bearing ring to hold membrane in place. Two parallel legs, 1-1/2 in. wide and 9 in. long, were cut out of the steel plate. The legs were cut on both sides but only on one end so they would remain attached to the plate. The free ends of the legs were cut at approximately 40-deg angles to provide points. To add strength, the center of each leg was crowned 1/4 in. for the length of the leg. The two-legged anchor is shown in fig. 4.

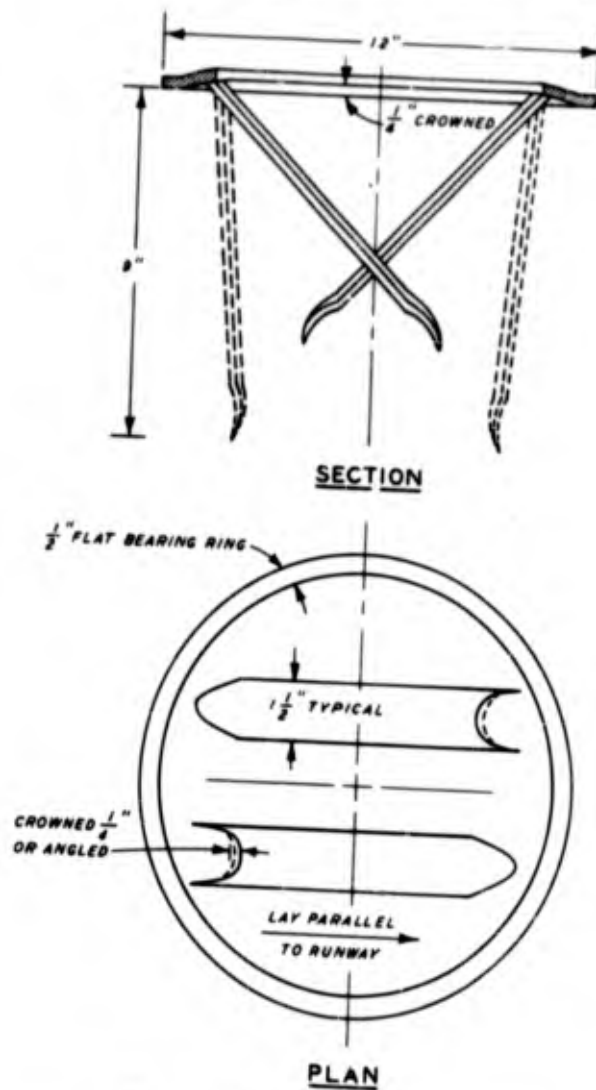


Fig. 4. Two-legged anchor

\* Conforming to ASTM Standard Specification A-36-67<sup>3</sup> for structural steel.

## ARROWHEAD ANCHOR

15. Four-in. arrowhead anchors were procured commercially for use with 8-in.-diam bearing plates fabricated at the WES. The anchor consisted of a 4-in. stamped iron arrowhead; a 36-in.-long, 3/16-in.-diam cable assembly; a 3/16-in. strand vise; a collar; and an 8-in.-diam, 11-gage, hot-rolled steel plate.\* Each anchor weighed approximately 2-1/2 lb. The 8-in.-diam plate was pressed so the inner 6-in. diam of the plate would provide a 7/16-in. crown, and the remaining 1-in.-wide band would be flat. The 1-in.-wide flat band provided a bearing surface to hold membrane in place. A 3/4-in.-diam hole was drilled in the center of the plate so the strand vise could be inserted. A slot 3/4 in. wide and 3 in. long was cut in the head of each anchor so that a cable used when the anchor was to be extracted from the soil could be positioned at either a 90- or 60-deg angle with the surface of the subgrade. The arrowhead anchor is shown in fig. 5.

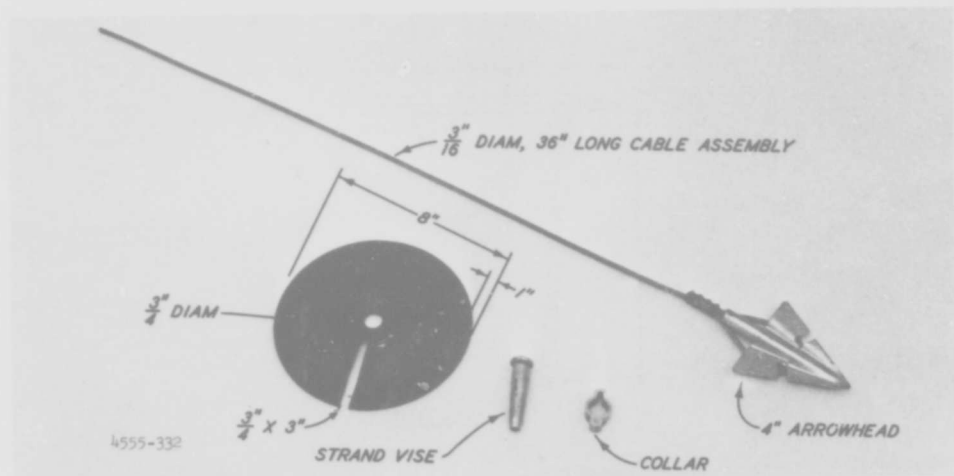


Fig. 5. Arrowhead anchor

## THREADED GUY ANCHOR

16. The design for this anchor was also submitted to the WES as a DCSC employee suggestion. The anchor was constructed at the WES and weighed approximately 7 lb. The anchor was essentially the same as the guy anchor (paragraph 12), with the exception that the No. 6 reinforcing bar was threaded at one end, and a threaded steel collar was welded to the head of the anchor. One end of the bar was threaded for a length of 1 in. with 1/2-in.-diam threads. Approximately 6 in. from the threaded end of the bar, a 1/8-in.-deep flat area was cut on two sides of the bar so the bar could be held with a wrench. The steel collar consisted of a 1-1/4-in.-diam rod that was 1-1/2 in. long. Threads 1/2 in. in diameter were cut for a depth of 1 in. into the center of the collar. The anchor was assembled by threading the reinforcing bar into the collar. A threaded guy anchor and a guy anchor are shown in fig. 6.

\* Conforming to ASTM Standard Specification A-36-67<sup>3</sup> for structural steel.

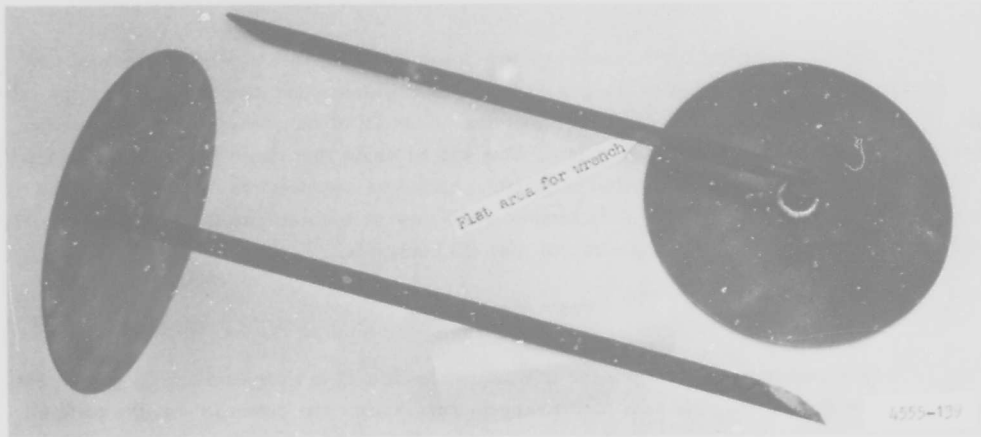


Fig. 6. Threaded guy anchor (top) and guy anchor (bottom)

#### THREADED DISK-TYPE ANCHOR

17. This anchor was designed and constructed at the WES and weighed approximately 5 lb. It was fabricated by welding a 1-1/8-in.-diam steel collar that was 1-1/2 in. long to a flat 8-in.-diam, 11-gage, hot-rolled steel plate.\* Threads 1/2 in. in diameter were cut for a depth of 1 in. into the center of the collar. A 1-ft-long, 1-1/8-in.-diam No. 9 reinforcing bar<sup>5</sup> was threaded so that it could be connected to the plate. One end of the reinforcing bar was threaded for a length of 1 in. with 1/2-in.-diam threads, and the other end was cut at a 30-deg angle to provide a point. A threaded disk-type anchor and guy anchor are shown in fig. 7.

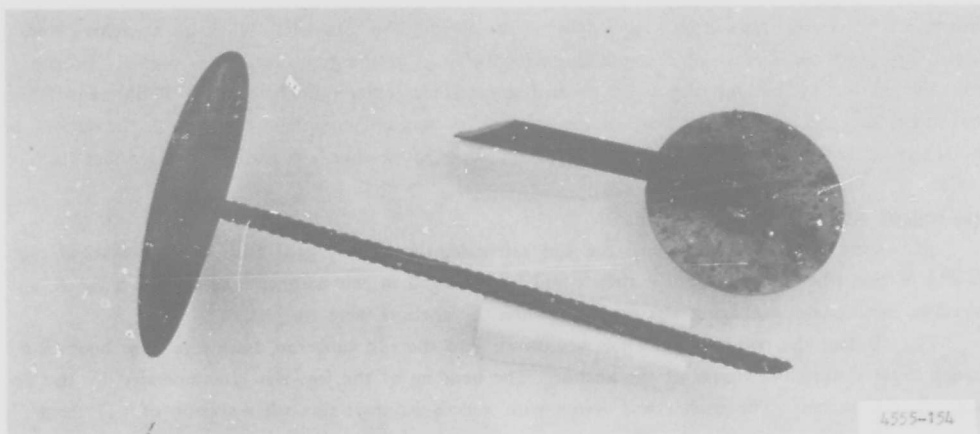


Fig. 7. Threaded disk-type anchor (top) and guy anchor (bottom)

\* Conforming to ASTM Standard Specification A-36-67<sup>3</sup> for structural steel.

## PART IV: ANCHOR DRIVING TESTS

18. Anchor driving tests were conducted to compare the disk-type, two-legged, threaded guy, and threaded disk-type anchors with the guy anchor. These anchors were designed to reduce the cubage required when packaging the anchors for shipment. Since all of the anchors were either smaller than the guy anchor or could be disassembled, there was no doubt that they would require less space for packaging than would the guy anchor. Therefore, tests were conducted to determine if the anchors could withstand blows from a sledgehammer when they were driven into the soil subgrade. The anchors were driven into a well compacted lean clay (CL) subgrade.

### TEST PROCEDURE

19. Each anchor was driven into the soil subgrade with a 12-lb sledgehammer. A guy anchor was driven into the soil subgrade each time an experimental anchor was driven so that the performance of the experimental anchor could be compared with that of the guy anchor. As the anchors were driven to various depths into the subgrade, photographs were made to record the performance of each anchor.

### TEST RESULTS

#### Disk-Type Anchor

20. The disk-type and guy anchors were driven with a sledgehammer into the same soil subgrade. Due to the difference in length of the two anchors, the disk-type anchor was driven to a depth of 12 in., and the guy anchor was driven to a depth of 24 in. Photograph 3 shows both anchors after they had been driven approximately 2 in. into the subgrade, and photograph 4 shows the same two anchors after they had been driven to depths of 6 and 12 in., respectively. At the 12-in. depth, the guy anchor began to diverge from its initial vertical position, but the disk-type anchor remained vertical after it had been driven halfway into the subgrade. When both anchors were driven flush with the surface of the soil subgrade, the head of the guy anchor was partially broken from the reinforcing bar, but the disk-type anchor remained intact (photograph 5). Photograph 5 shows that the periphery of the head of the guy anchor was not completely flush with the surface of the subgrade, but the periphery of the head of the disk-type anchor was flush with the subgrade.

#### Two-Legged Anchor

21. Prior to being driven into the soil subgrade, three two-legged anchors were stacked one on top of the other to determine if they could be packaged in this manner. As shown in fig. 8, an excellent method for packaging was provided when the anchors were stacked.

22. Before the two-legged anchor was driven into the soil subgrade, both legs were bent to a 20-deg angle toward the center of the anchor. The bending of the legs was recommended by the designer of the anchor. The anchor was driven with a sledgehammer through a section of T17 membrane into the lean clay subgrade. Care was exercised when the anchor was being driven to ensure that the sledgehammer hit the anchor head directly over each leg. Both legs of the anchor remained straight, and no apparent damage occurred when the anchor was driven a distance of 1 in. into the soil subgrade (photograph 6). One leg began to show signs of bending (photograph 7) after the



Fig. 8. Two-legged anchors stacked for packaging

anchor had been driven to a depth of 4-1/2 in. When the anchor was driven flush with the surface of the membrane surfacing, additional bending of the leg occurred, as shown in photograph 8. After the anchor had been driven into the soil subgrade, it was extracted and examined for damage. Photograph 9 illustrates the damage that occurred to the anchor legs when driven to a depth of 9 in. into the soil subgrade.

23. After the tests described in paragraph 22 had been completed, an anchor with the legs straightened to a vertical position was driven with a sledgehammer into the soil subgrade to a depth of 2 in. without damage to the anchor, as shown in photograph 10. When the anchor was driven to a depth of 5 in., the legs began to bend, and tears occurred where the legs joined the anchor head (photograph 11). When the anchor was driven to a depth of 9 in., the legs were bent toward the periphery of the anchor head (photograph 12), and this prevented the anchor head from fitting flush with the membrane surfacing.

#### Threaded Guy Anchor

24. This anchor was assembled by screwing the 2-ft-long reinforcing bar into the steel collar that was welded to the head of the anchor. The threaded guy anchor and the guy anchor were driven with a sledgehammer into the soil subgrade so their performances could be compared. Photographs 13 and 14, respectively, illustrate the threaded guy anchor and the guy anchor after they had been driven to a depth of 6 in. into the soil subgrade. The reinforcing bar of the threaded guy anchor began to bend, but the reinforcing bar of the guy anchor did not. The bend in the reinforcing bar of the threaded anchor was also evident after the anchor had been driven to a depth of 18 in. (photograph 15). The bend in the reinforcing bar occurred where it had been ground flat on two sides for wrench placement. No bend occurred in the guy anchor's reinforcing bar, but the head had been bent slightly to one side (photograph 16). When the threaded guy anchor was driven to a depth of 24 in., making the head flush with the surface, the head broke loose from the steel collar that connected it to the reinforcing bar (photograph 17). The head of the guy anchor was not broken from the reinforcing bar when the anchor was driven to a depth of 24 in., but considerable edge curl occurred about the periphery of the steel plate head (photograph 18).

#### **Threaded Disk-Type Anchor**

25. Due to the difference in length of the reinforcing bars, the threaded disk-type anchor and guy anchor were driven with a sledgehammer into the soil subgrade to depths of 12 and 24 in., respectively. Photograph 19 shows both anchors after they had been driven through a section of membrane surfacing into the soil subgrade to a depth of 6 in. At the 6-in. depth, no damage had occurred to either anchor. When the anchors were driven 12 in. into the subgrade (see photograph 20), the reinforcing bar of the threaded disk-type anchor was broken; however, the guy anchor was not damaged. The reinforcing bar of the threaded disk-type anchor broke where the cross-sectional area of the bar had been reduced when the bar was threaded. The guy anchor incurred no damage when driven flush with the membrane surfacing.

### **SUMMARY OF RESULTS**

#### **Guy Anchor**

26. The guy anchor deviated from its vertical position as it was driven into the soil subgrade. When the guy anchor was driven into the subgrade to the full depth of 24 in., the head was bent and considerable edge curl of the steel plate head occurred. Approximately one guy anchor head out of three was partially broken from its shaft when the anchors were driven to a depth of 24 in.

#### **Disk-Type Anchor**

27. The disk-type anchor was driven vertically into the lean clay subgrade without difficulty. When the disk-type anchor was driven into the soil subgrade to the full depth of 12 in., the entire periphery of the anchor head was flush with the surface of the subgrade.

#### **Two-Legged Anchor**

28. Initial bending of the legs of the anchors occurred when the anchors were driven to depths of 4 to 5 in. into the subgrade. When the anchors were driven into the subgrade to the full depth of 9 in., the legs bent excessively and were torn from the head of the anchor. The anchor heads were not flush with the membrane surfacing after driving had been completed. No appreciable differences in the performance of the anchor were observed when the legs of the anchors were positioned at a 20-deg angle or in a vertical position in relation to the head of the anchor. The two-legged anchors can be stacked easily for packaging.

#### **Threaded Guy Anchor**

29. Initial bending of the 2-ft-long reinforcing bar occurred when the anchor was driven into the subgrade to a depth of 6 in. Bending occurred in the reinforcing bar where it had been ground flat on two sides for a wrench fitting, approximately 6 in. from the threaded end. The head of the anchor was broken from the steel collar when the anchor was driven into the subgrade to the full depth of 24 in.

#### **Threaded Disk-Type Anchor**

30. When the threaded disk-type anchor was driven into the soil subgrade to a depth of 6 in., no damage occurred. The threaded end of the reinforcing bar was broken from the bar when the anchor was driven into the subgrade to the full depth of 12 in.

## PART V: ANCHOR HOLDING-STRENGTH TESTS

31. Tests were conducted to determine the holding strengths of the guy, disk-type, two-legged, and arrowhead anchors when used to secure membrane surfacing. Since the membrane surfacing designed to withstand C-130 aircraft will develop tear strength of 200 lb/in., it is feasible to use an anchor that develops a minimum holding strength of approximately 200 lb. Three anchors of each type were driven into four types of soil subgrades: an in situ silt (ML), a nonplastic compacted sand (SP), a fat clay (CH), and a lean clay (CL). The sand and clay subgrades were located in soil test sections that had been used previously for vehicle traffic tests. Classification and gradation data for the four soils are shown in plates 1-4. The bearing strength, moisture content, and density determinations for each type of soil are presented in table 1.

### TEST EQUIPMENT AND PROCEDURE

32. Before the anchors were driven into the subgrade, a 4-ft-long, 3/8-in.-diam cable sling, which had eyes spliced into each end, was attached to each anchor so the anchor could be removed from the subgrade.

33. The arrowhead anchors (fig. 5) with 3/8-in.-diam. cable assemblies attached were driven to a depth of 2 ft into the soil subgrade with a manual impact tool, as shown in photograph 21. After the anchor had been driven into the subgrade, the cable assembly was threaded through a hole in the steel bearing plate, and a cable vise was then attached to the cable. The vise was pulled down tight on the cable so the bearing plate would be flush with the surface of the subgrade. No problems were encountered when the arrowhead anchors were driven into the subgrades with the manual impact tool.

34. The guy, disk-type, and two-legged anchors were driven into the subgrade with a sledgehammer. Photograph 22 shows a guy anchor being driven into the subgrade. The guy and disk-type anchors were driven easily into the soil subgrades with a sledgehammer, but a problem was encountered when the two-legged anchors were driven into the soil subgrades with a sledgehammer. When the legs of the anchors were positioned inward or outward from a perpendicular position relative to the head of the anchor, the legs were bent inward toward the head of the anchor or away from the head of the anchor as it was driven into the soil subgrade. The legs of the anchor also crumpled as the anchor was being driven into the subgrade. When this occurred, the anchor could not be driven the full depth of the legs, thus causing a decrease in the holding strength of the anchor. Tests also revealed that the anchor legs were bent and crumpled rather easily when the head of the sledgehammer did not strike the anchor exactly on the area where the legs joined the head.

35. A mobile crane, shown in fig. 9, was used to remove each anchor from the soil subgrade. The crane was positioned over the anchors so that the anchors were removed vertically or at a 60-deg angle with the surface of the soil. The force required to pull each anchor from the subgrades was measured by a 2000-lb-capacity electric dynamometer attached between the snatch block of the crane and the cable sling that was attached to the anchor (see fig. 9). An electric recorder was used to record the data on oscillograms. The maximum force required to remove each anchor is given in table 1.



Fig. 9. Mobile crane used to remove anchors from the soil subgrade

### TEST RESULTS

36. Pertinent soils data on each subgrade at the time the anchors were extracted are also given in table 1 along with the maximum forces required to remove the guy anchors vertically and at a 60-deg angle with the surface of the subgrade.

#### Guy Anchors

37. The 3/4-in.-diam reinforcing rods of the anchors were threaded through the eyes of the cable slings; then three anchors were driven flush with the surface in each of the four subgrades. Care was exercised to ensure that the cable slings were placed through the slots in the anchor bearing plates before the anchors were driven. The dynamometer, which was attached to the snatch block of the mobile crane, was then connected to an eye of one of the cable slings, and force was applied to the cable with the mobile crane. The anchors were pulled vertically or at an angle of 60 deg with the subgrade surface and were extracted with a slow steady pull until completely removed from the subgrade.

38. *Sand subgrade.* Oscillograms of the pulling force required to remove the anchors from the sand subgrade showed that the force increased abruptly until initial movement of the anchors occurred; then the magnitude of force that had been required to cause movement remained approximately constant until one-half of the anchor rod had been withdrawn from the subgrade. Thereafter, the force decreased irregularly until the anchors had been removed completely. Respective

maximum holding strengths of 170 and 199 lb were obtained when the anchors were removed vertically and when they were removed at an angle of 60 deg with the surface of the subgrade.

39. *Silt subgrade.* The pulling force required to remove the guy anchors from silt increased rapidly as the anchors were being extracted a distance of 8 to 10 in. from the subgrade; then the force decreased gradually as the remaining lengths of the anchor rods were removed from the subgrade. Maximum holding strengths for anchors removed vertically and at an angle of 60 deg with the surface of the subgrade were 339 and 358 lb, respectively.

40. *Fat and lean clay subgrades.* The magnitudes of the pulling force increased rapidly until approximately one-third of the anchor rod lengths had been extracted from the subgrades. Then the pulling force decreased irregularly until the anchors were completely removed. Maximum holding strengths for anchors removed vertically and at an angle of 60 deg with the surface of the fat clay subgrade were 505 and 611 lb, respectively; anchors removed from the lean clay subgrade developed maximum holding strengths of 447 and 611 lb, respectively.

#### **Disk-Type Anchors**

41. The reinforcing rods, which were welded to the concave metal plates, were threaded through the eyes of the cable slings before the anchors were driven into the subgrade. The anchors were driven approximately 10 in. into the subgrade, the cable slings were placed through the slots that were cut in the concave metal plates, and then the anchors were driven flush with the surface of the subgrade. The loose end of the cable sling was attached to the dynamometer, which was connected to the snatch block of the mobile crane. The anchors were pulled vertically or at an angle of 60 deg with the subgrade surface and were extracted with a slow steady force until completely removed from the subgrade. The forces required to remove the anchors from the subgrade were recorded by the electric recorder onto the oscillograms.

42. *Sand subgrade.* The oscillograms indicated that the force required to pull the anchors from the subgrade increased gradually until approximately one-third of the anchor rod had been removed from the subgrade; this pulling force remained constant while another one-third of the anchor rod was removed from the subgrade. After removal of approximately two-thirds of the anchor rod from the subgrade, the pulling force decreased gradually until the rod was extracted completely. Maximum holding strengths for anchors removed vertically and at an angle of 60 deg with the surface of the compacted sand subgrade were 36 and 54 lb, respectively.

43. *Silt subgrade.* The pulling force increased steadily until approximately one-half of the anchor rod had been pulled from the subgrade; then the pulling force decreased at approximately the same rate at which it had increased when initial movements of the anchors occurred. Maximum forces required to pull the anchors vertically and at a 60-deg angle with the surface of the subgrade were 188 and 212 lb, respectively.

44. *Fat and lean clay subgrades.* Oscillograms showed that the force increased rapidly until one-half of the lengths of the anchor rods had been withdrawn. The pulling force decreased rapidly when the remaining lengths of the anchor rods were removed from the subgrade. Maximum holding strengths for anchors removed vertically and at an angle of 60 deg with the surface of the fat clay subgrade were 230 and 334 lb, respectively; anchors removed from the lean clay subgrade developed maximum holding strengths of 259 and 376 lb, respectively.

### Two-Legged Anchors

45. The anchors were driven vertically into the subgrade by alternately driving one leg and then the other with a sledgehammer. The cable slings were threaded through the two precut slots in the tops of the anchors before the anchors were driven flush with the surface of the soil subgrade. Each sling was positioned at the center of the anchor so that equal force was exerted on each leg as it was removed from the subgrade. Oscillograms recorded the pulling force required to extract the anchors from the subgrade with the mobile crane.

46. *Sand subgrade.* The pulling force increased steadily until anchors were approximately one-half removed from the subgrade. Then the pulling force decreased gradually until the anchors were withdrawn completely from the subgrade. A maximum force of 19 lb was required when the anchors were removed vertically, and a maximum force of 26 lb was required when they were removed at an angle of 60 deg with the surface of the subgrade.

47. *Silt subgrade.* The oscillograms indicated that the pulling force increased rapidly until movement of the anchors occurred. Then the force decreased at an irregular rate until the anchors were completely removed from the subgrade. Maximum holding strengths for anchors extracted vertically and at an angle of 60 deg with the surface of the soil subgrade were 161 and 259 lb, respectively.

48. *Fat and lean clay subgrades.* The pulling force required to remove the anchors increased abruptly when anchors were removed approximately 4 in. from the subgrades. Then the pulling forces decreased irregularly until the anchors had been removed completely from the subgrades. Maximum holding strengths of anchors removed vertically and at a 60-deg angle with the surface of the fat clay subgrade were 294 and 388 lb, respectively; anchors removed from the lean clay subgrade developed maximum holding strengths of 274 and 282 lb, respectively.

### Arrowhead Anchors

49. These anchors were driven 24 in. into the subgrade with a manual impact tool, as shown in photograph 21. The cable assembly of each anchor was threaded through an eye of the cable sling before the bearing plate and cable vise were connected to the cable assembly. After the bearing plate had been positioned flush with the surface of the subgrade and the cable vise had been locked in place, the cable sling was inserted into the slot, which had been precut in the bearing plate, so that the anchor could be removed vertically or at a 60-deg angle with the surface of the subgrade. All anchors were removed from the subgrade with the mobile crane shown in fig. 9. As force was exerted to withdraw the anchor, the arrowhead moved until it was oriented at an angle of 90 deg with the line of applied force. This feature increased the anchor's resistance to removal.

50. *Sand subgrade.* Oscillograms of the pulling force required to remove the anchors from the subgrade indicated that the pulling force increased gradually until the arrowhead anchors were positioned in the subgrade at an angle of approximately 90 deg with the line of applied force. Once the anchors were thus positioned in the subgrade, the pulling force increased at an accelerated rate until approximately 18 in. of the cable assembly had been withdrawn from the subgrade. Then the pulling force decreased rapidly until complete removal of the anchors from the subgrade. Maximum holding strengths for anchors removed vertically and at an angle of 60 deg with the surface of the subgrade were 589 and 626 lb, respectively.

51. *Silt subgrade.* Pulling force increased gradually until the arrowhead anchors were

oriented in the subgrade at an angle of approximately 90 deg with the line of applied force. Then the pulling force increased rapidly until approximately 18 in. of the cable assemblies had been withdrawn from the subgrade. Pulling forces decreased rapidly when 6 in. of the cable assemblies remained beneath the surface of the subgrade. Maximum holding strengths for anchors removed vertically and at an angle of 60 deg with the surface of the subgrade were 1011 and 1199 lb, respectively.

52. *Fat and lean clay subgrades.* The oscillograms showed that the pulling force required to remove the anchors increased gradually until the arrowhead anchors were positioned in the subgrade at an angle of approximately 90 deg with the direction of the pulling force. Then the magnitude of the pulling force increased rapidly until approximately 20 in. of the cable assemblies had been extracted from the subgrade. The pulling force decreased abruptly as the last 4 in. of the cable assemblies were removed from the subgrade. Maximum holding strengths of anchors removed vertically and at an angle of 60 deg with the surface of the fat clay subgrade were 705 and 729 lb, respectively; anchors removed from the lean clay subgrade developed maximum holding strengths of 1057 and 1551 lb, respectively.

### SUMMARY OF RESULTS

53. The results of the anchor holding-strength tests are summarized in the following tabulation:

Anchor Type	Direction of Pull	Maximum Holding Strength in Indicated Subgrade, lb			
		Sand	Silt	Fat Clay	Lean Clay
Guy	Vertical	170	339	505	447
	60 deg	199	358	611	611
Disk	Vertical	36	188	230	259
	60 deg	54	212	334	376
Two-legged	Vertical	19	161	294	274
	60 deg	26	259	388	282
Arrowhead	Vertical	589	1011	705	1057
	60 deg	626	1199	729	1551

## PART VI: DISCUSSION OF RESULTS

### ANCHOR DRIVING TESTS

#### **Guy Anchor**

54. Since the performance of the guy anchor was compared with those of the four experimental test anchors, sufficient data were obtained to determine that the design of the guy anchor is not adequate for present requirements. The anchor was originally designed for use in a loose sand subgrade; therefore, a 2-ft-long reinforcing bar was required to provide an adequate holding strength. At the present time, assault runways are generally surfaced with a clay backfill of adequate soil bearing strength to withstand C-130 wheel loads. Since the assault runways are surfaced with a clay backfill, the guy anchors were driven into a clay subgrade. When the anchors were driven to a depth of 24 in. into the subgrade, the heads of the anchors were either broken from the reinforcing bars or were damaged so severely that they would not fit flush with the surface of the subgrade. Tests also indicated that the anchors could not be driven vertically into a clay subgrade. The point of the anchor, which was formed by shearing the reinforcing bar at an angle of 30 deg, caused the anchor to enter the soil subgrade at an irregular angle, and the anchor would not remain in a vertical position while being driven into the subgrade.

#### **Disk-Type Anchor**

55. This anchor was easily driven vertically into the soil subgrade with a sledgehammer. As the anchor was driven into the subgrade, it did not stray from the vertical because of the shape of the point. The pointed end of the reinforcing bar was beveled on all four sides. When the anchor was driven into the soil subgrade to a depth of 12 in., the periphery of the head was flush with the surface of the subgrade. No damage occurred to the anchor head or reinforcing bar when the anchor was driven into the soil subgrade to a depth of 12 in.

#### **Two-Legged Anchor**

56. As the two-legged anchors were driven into the soil subgrades, the anchor legs were bent. Bending of the legs grew progressively more severe as the anchors were driven deeper into the subgrade. The legs of several anchors were torn from the heads while the anchors were being driven into the subgrade. Anchor heads did not fit flush with the surface of the subgrade after the anchors had been driven to the full depth of 9 in. The performance of the anchors was relatively the same whether the anchor legs were prepositioned at a 20-deg angle or at a vertical position relative to the heads of the anchors. The poor performances of the anchors can be attributed to the design of the anchor and to the thin gage of steel used in the construction of the anchors. However, it is believed that very little difference in the performance of the anchor would have been achieved had the anchor been constructed from a heavier gage steel nor would a savings in weight be realized. The anchors could be stacked one on top of the other for compact packaging purposes.

#### **Threaded Guy Anchor**

57. The reinforcing bars of the threaded guy anchors began to bend when the anchors were driven to a depth of 6 in. into the soil subgrade. After initial bending of a reinforcing bar

occurred at a depth of 6 in., no additional bending was observed as the anchor was driven to a depth of 24 in. The bar bent approximately 6 in. from its threaded end where the bar had been ground flat on two sides for a wrench fitting. The reinforcing bar bent at this location because its cross-sectional area had been decreased when it was ground flat on two sides. When the anchor was driven into the subgrade to a depth of 24 in., the anchor head was broken from the steel collar that had been welded to the bottom side of the anchor head. The performance of this anchor indicates that it could not be driven satisfactorily into a compacted soil subgrade without excessive damage to the anchor head and reinforcing bar.

#### **Threaded Disk-Type Anchor**

58. This anchor was not damaged when it was driven into the soil subgrade to a depth of 6 in.; however, the threaded end of the reinforcing bar was broken when the anchor was driven to a depth of 12 in. Damage occurred to the threaded end of the bar because the cross-sectional area of the bar had been reduced when the threads were cut on the end of the bar. The anchor head was not damaged when the anchor was driven into the subgrade. Although the design of the anchor made it compact for packaging, the performance of the anchor indicated that it would not be adequate when driven into a compacted soil subgrade.

### **ANCHOR HOLDING-STRENGTH TESTS**

#### **Guy Anchor**

59. Average vertical holding strengths of the anchor in the different subgrades were as follows: 466 lb in a fat clay subgrade, 399 lb in a lean clay subgrade, 313 lb in a silt subgrade, and 154 lb in a compacted sand subgrade. When the anchors were pulled at an angle of 60 deg with the surfaces of the subgrades, the average holding strengths increased 12, 41, 2, and 17 percent in the fat clay, lean clay, silt, and compacted sand, respectively. The test results indicated that once installed, the guy anchor will provide an adequate means for anchoring membrane surfacing in the four types of soil subgrades used during this investigation.

#### **Disk-Type Anchor**

60. The holding strengths of these anchors were less than those of the guy anchors. In the sand subgrade, the average holding strength developed by the disk-type anchors was approximately 19 to 25 percent of the average holding strengths developed by the guy anchors. In the silt subgrade, the holding strength of the disk-type anchors was approximately 50 to 53 percent of that of the guy anchors. In the fat and lean clay subgrades, the respective average holding strengths of the disk-type anchors were approximately 46 to 56 percent and 63 percent of the holding strength of the guy anchors. Based on the results of these tests, it is believed that the disk-type anchor will develop adequate holding strength in silt, fat clay, and lean clay subgrades. The anchors will provide a limited means for anchoring membrane in a compacted sand subgrade.

#### **Two-Legged Anchor**

61. The holding strength of the two-legged anchors was also considerably less than that of the guy anchors. The average holding strength of the two-legged anchors in the sand subgrade was approximately 10 to 13 percent of the holding strength of the guy anchors. In the silt subgrade,

the holding strength was approximately 47 to 59 percent of that of the guy anchors. In the fat clay subgrade, the holding strength was approximately 61 to 62 percent of that of the guy anchors; in the lean clay subgrade, the holding strength of the anchors was approximately 40 to 56 percent of that of the guy anchors. The two-legged anchors produced sufficient holding strengths in the silt, fat clay, and lean clay subgrades to anchor membrane surfacing, but the anchors produced inadequate holding strength for anchoring membrane surfacing in the compacted sand subgrade.

#### **Arrowhead Anchor**

62. These anchors produced the highest holding strengths of all anchors tested. In the sand subgrade, the average holding strength of the arrowhead anchors was approximately 3.5 to 3.7 times greater than the average holding strength of the guy anchors. The holding strengths of the arrowhead anchors in the silt subgrade were approximately 2.5 to 3.5 times that of the guy anchors. In the fat clay subgrade, the holding strengths of the arrowhead anchors were approximately 1.3 to 1.4 times greater than that of the guy anchors; in the lean clay subgrade, the holding strengths of the anchors were approximately 2.3 to 2.5 times that of the guy anchors. The arrowhead anchors provided adequate holding strengths in each of the four types of soil subgrades.

## PART VII: CONCLUSIONS AND RECOMMENDATIONS

### CONCLUSIONS

63. Based on the results of this investigation, the following conclusions are believed to be warranted:
- a. None of the anchors evaluated by the Atlantic Research Corporation are considered feasible for use in securing membrane surfacing.
  - b. Guy anchors, two-legged anchors, threaded guy anchors, and threaded disk-type anchors are not satisfactory because they cannot withstand the force required to drive them into the subgrade.
  - c. Arrowhead anchors develop holding strengths in excess of that specified to secure membrane surfacing. A special emplacement tool is required to drive the anchors into the subgrade.
  - d. Disk-type anchors can withstand the required driving force and develop adequate holding strength in silt, fat clay, and lean clay but not in compacted sand. Disk-type anchors are considered satisfactory for securing membrane surfacing on assault runways.

### RECOMMENDATIONS FOR FUTURE DEVELOPMENT

64. The specific objectives of further development and investigation of anchors used to restrain membrane surfacing should be to:
- a. Determine by field tests the ability of anchors evaluated during this investigation to restrain membrane used to surface airfields, helicopter pads, and roadways.
  - b. Evaluate the holding strengths and driving capabilities of new and improved anchors.
  - c. Evaluate improved systems for anchoring membrane surfacing.
  - d. Design and evaluate anchors that can be packaged compactly.

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Table 1

Properties of Subgrade Soils and Holding Strengths of Anchors

Sand Test Section, Compacted Sand (SP, Nonplastic) Subgrade					Silt Test Section, In-Place Silt (ML) Subgrade					Clay Test Section, Clay (CH, Fat Clay) Subgrade					Clay Test Section, Clay (Cl, Lean Clay) Subgrade														
Depth in.	Moisture Content		Density pcf	CBR	Maximum Force Required To Remove Anchor lb	Anchor Type	Angle at Which Anchor Was Removed from Sub-grade, deg	Test No.	Anchor Type	Maximum Force Required To Remove Anchor lb	Angle at Which Anchor Was Removed from Sub-grade, deg	Test No.	Anchor Type	Moisture Content % Dry Weight	Density pcf	CBR	Depth in.	Moisture Content % Dry Weight	Density pcf	CBR	Test No.	Anchor Type	Maximum Force Required To Remove Anchor lb	Angle at Which Anchor Was Removed from Sub-grade, deg	Test No.	Anchor Type	Moisture Content % Dry Weight	Density pcf	CBR
	0	5.1																											
6	13.8	103.6	10.0	129			26		295		26		97.5	7.6	6.3	6	17.3	104.8	16.0	74		447		50		23.6	98.5	6.3	
12	15.0	104.7	18.0	170			27		339		27		94.8	6.0	7.0	6	20.6	100.4	18.6	75		423		51		22.4	100.4	7.0	
18	17.0	100.9	10.0	29	Disk	90	28	Disk	180	90	28	Disk	95.7	7.0	8.0	12	23.2	96.7	8.0	76	Disk	213	90	52	Disk	23.1	96.7	8.0	
24	*	*	4.3	36			29		188		29		93.7	7.0	10.3	18	23.7	97.7	12.3	77		230		53		23.1	97.7	10.3	
				22			30		130		30					24	21.8			78		198		54		21.5			
				19	Two-legged	90	31	Two-legged	141	90	31	Two-legged									79	Two-legged	294	90	55	Two-legged			
				18			32		161		32										80		282		56				
				12			33		141		33										81		290		57				
				589	Arrowhead	90	34	Arrowhead	788	90	34	Arrowhead									82	Arrowhead	626	90	58	Arrowhead			
				517			35		577		35										83		705		59				
				558			36		1011		36										84		626		60				
				161	Guy	60	37	Guy	297	60	37	Guy									85	Guy	485	60	61	Guy			
				199			38		358		38										86		611		62				
				182			39		304		39										87		470		63				
				54	Disk	60	40	Disk	165	60	40	Disk									88	Disk	302	60	64	Disk			
				47			41		212		41										89		334		65				
				36			42		188		42										90		250		66				
				26	Two-legged	60	43	Two-legged	215	60	43	Two-legged									91	Two-legged	388	60	67	Two-legged			
				21			44		259		44										92		302		68				
				24			45		141		45										93		349		69				
				619	Arrowhead	60	46	Arrowhead	1160	60	46	Arrowhead									94	Arrowhead	729	60	70	Arrowhead			
				621			47		1199		47										95		679		71				
				626			48		1002		48										96		576		72				

\* No moisture or density samples were obtained because the soil was saturated with water.

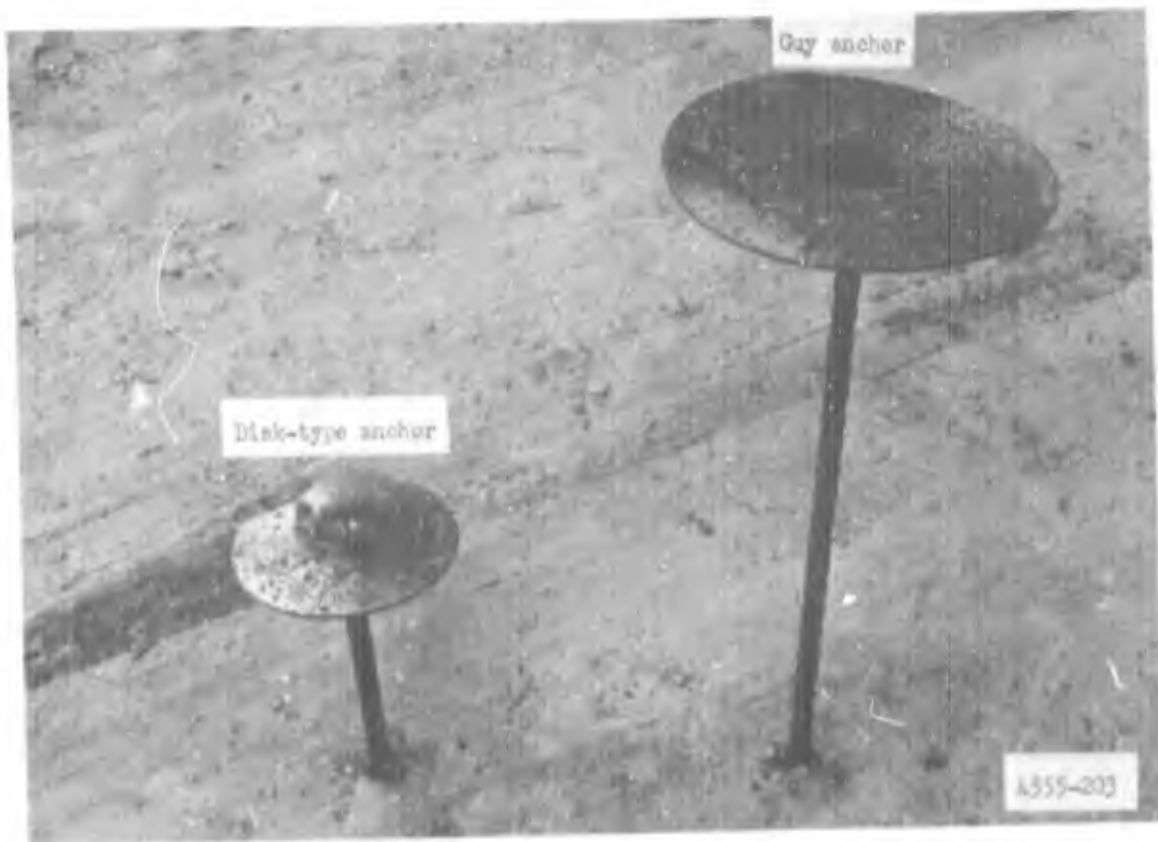
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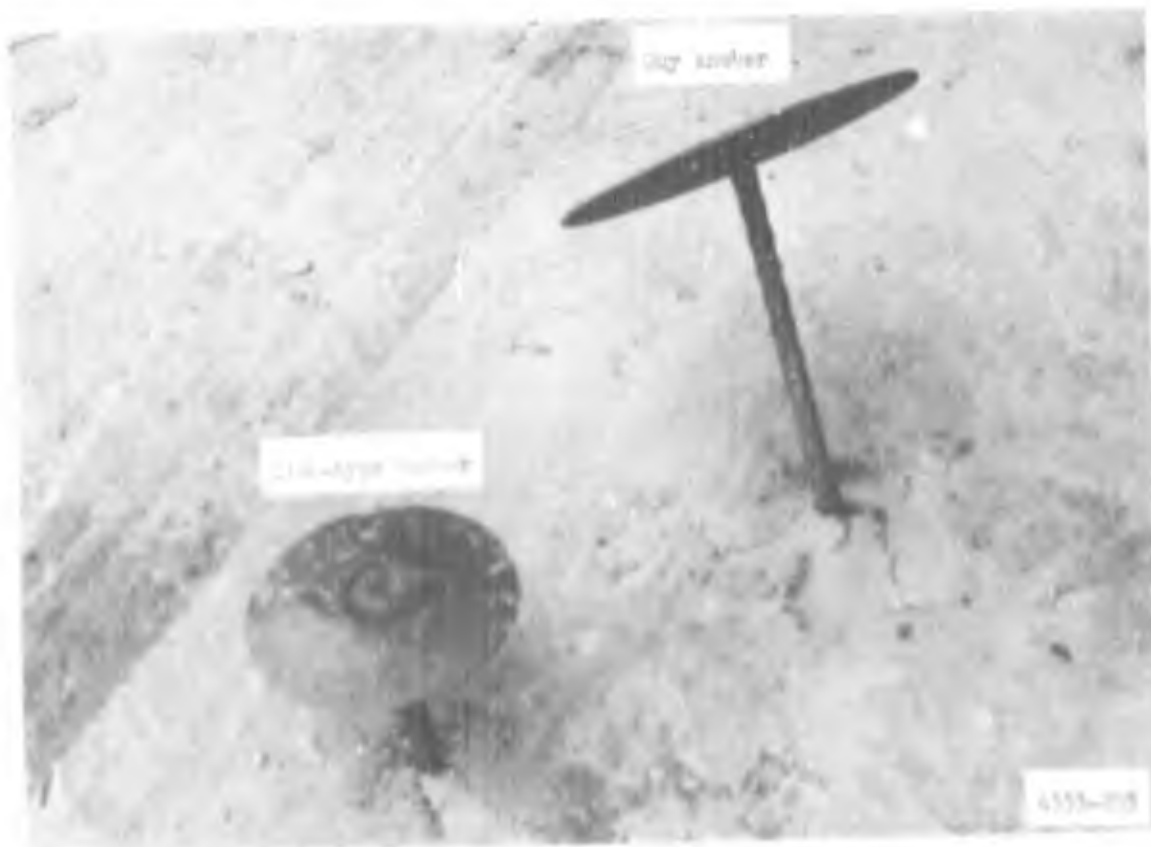
Photograph 1. Guy anchors driven into soil subgrade with sledgehammers



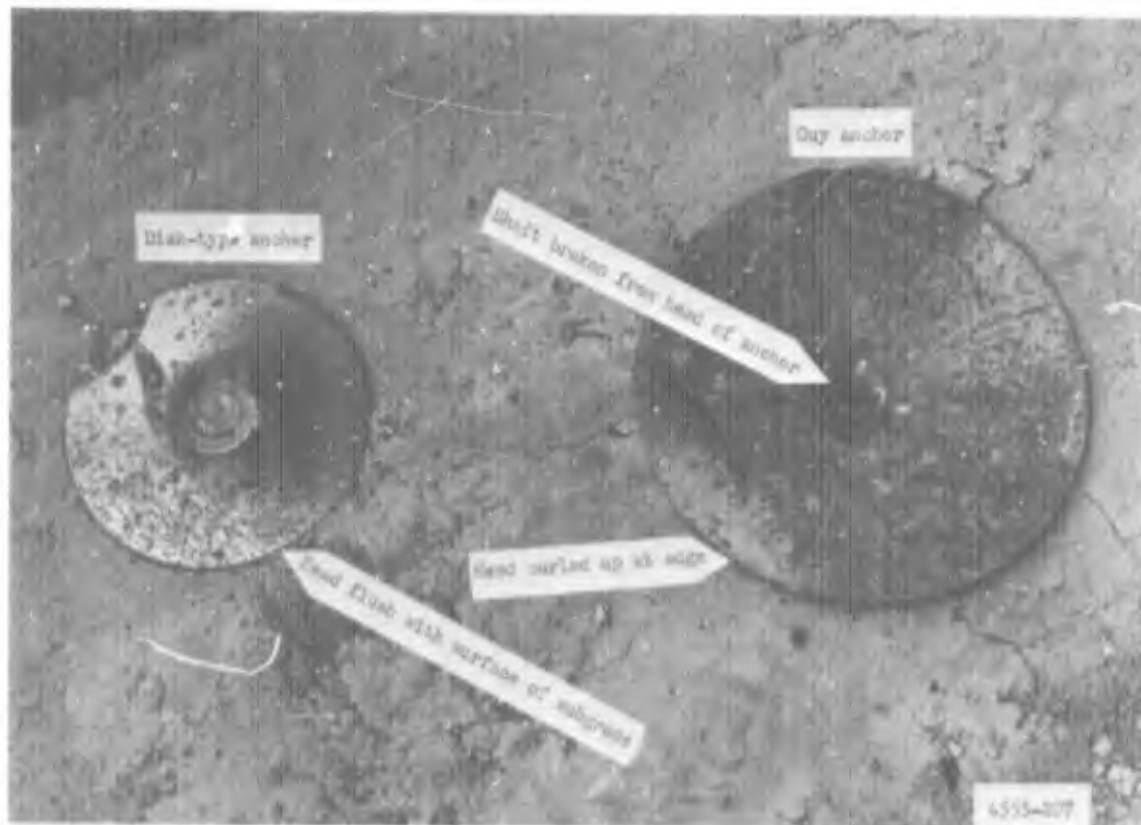
Photograph 2. Head of guy anchor broken from reinforcing bar



Photograph 3. Disk-type and guy anchors driven approximately 2 in. into the soil subgrade



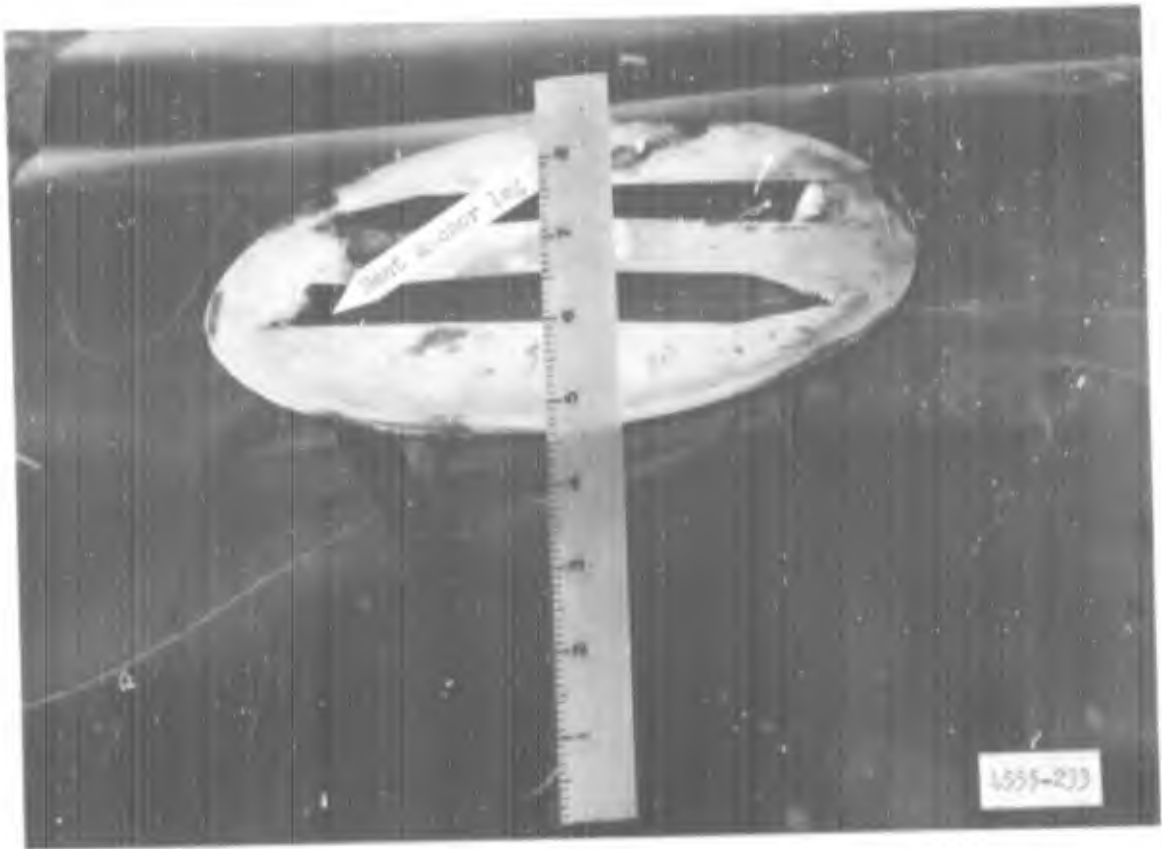
Photograph 4. Disk-type and guy anchors driven into the soil subgrade to depths of 6 and 12 in., respectively



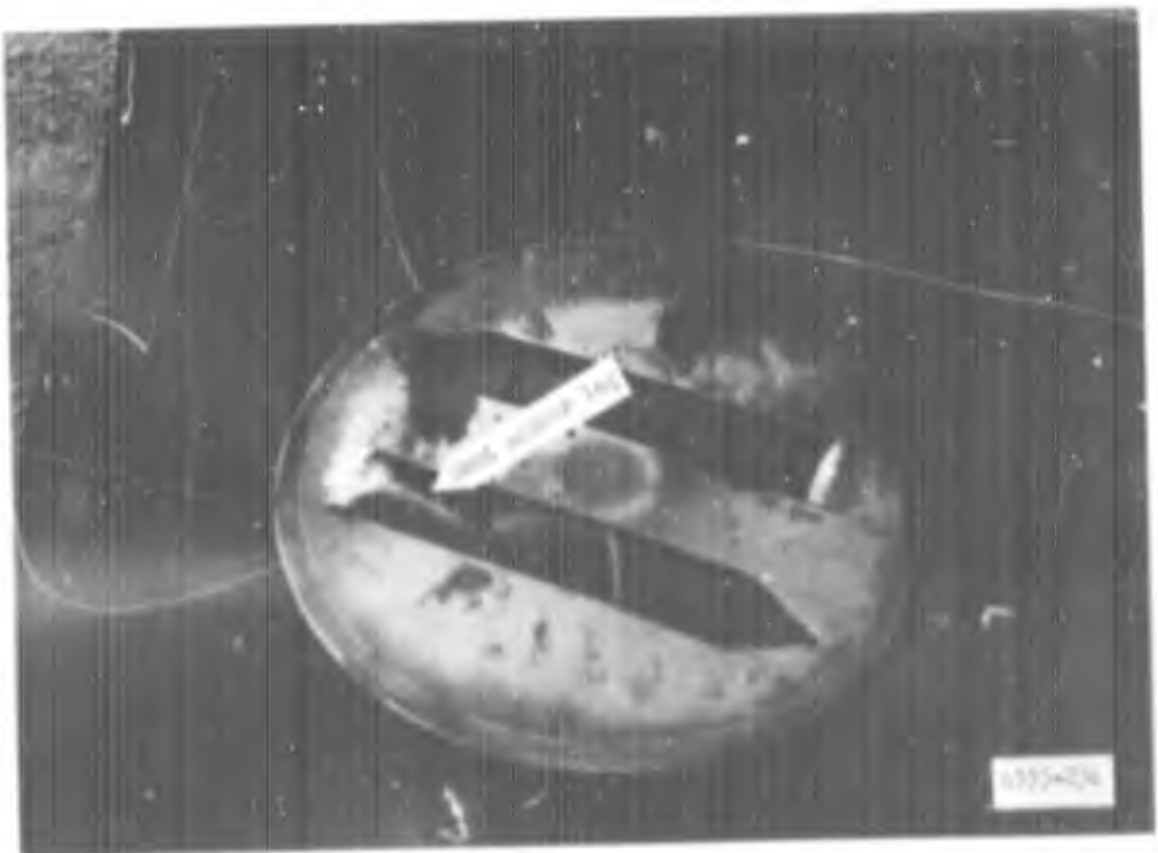
Photograph 5. Disk-type and guy anchors driven flush with the surface of the soil subgrade



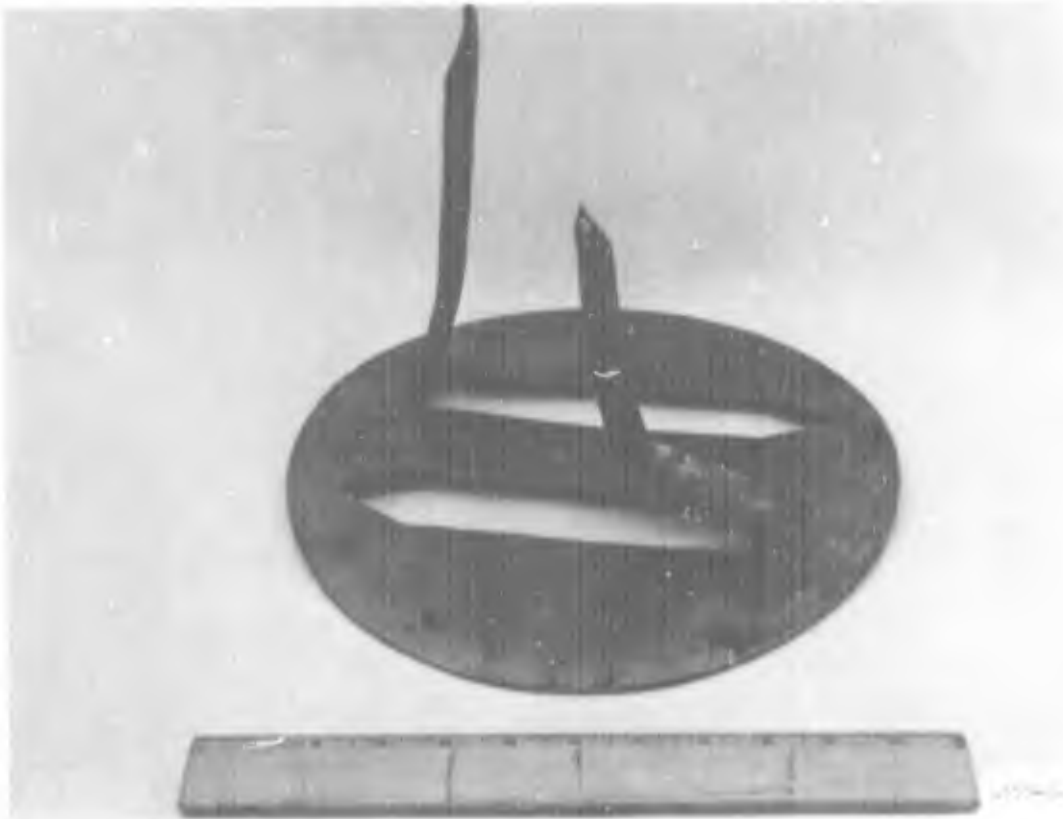
Photograph 6. Two-legged anchor driven through membrane surfacing into the soil subgrade to a depth of 1 in.



Photograph 7. Two-legged anchor driven through membrane surfacing and into the soil subgrade to a depth of 4-1/2 in.



Photograph 8. Two-legged anchor driven flush with the surface of the membrane



Photograph 9. Damage to the anchor legs that was caused when the two-legged anchor was driven into the soil subgrade to a depth of 9 in.



Photograph 10. Legs of two-legged anchor straightened to a vertical position and driven through membrane into the soil subgrade to a depth of 2 in.



Photograph 11. Two-legged anchor with straightened legs driven through membrane into the soil subgrade to a depth of 3 in.



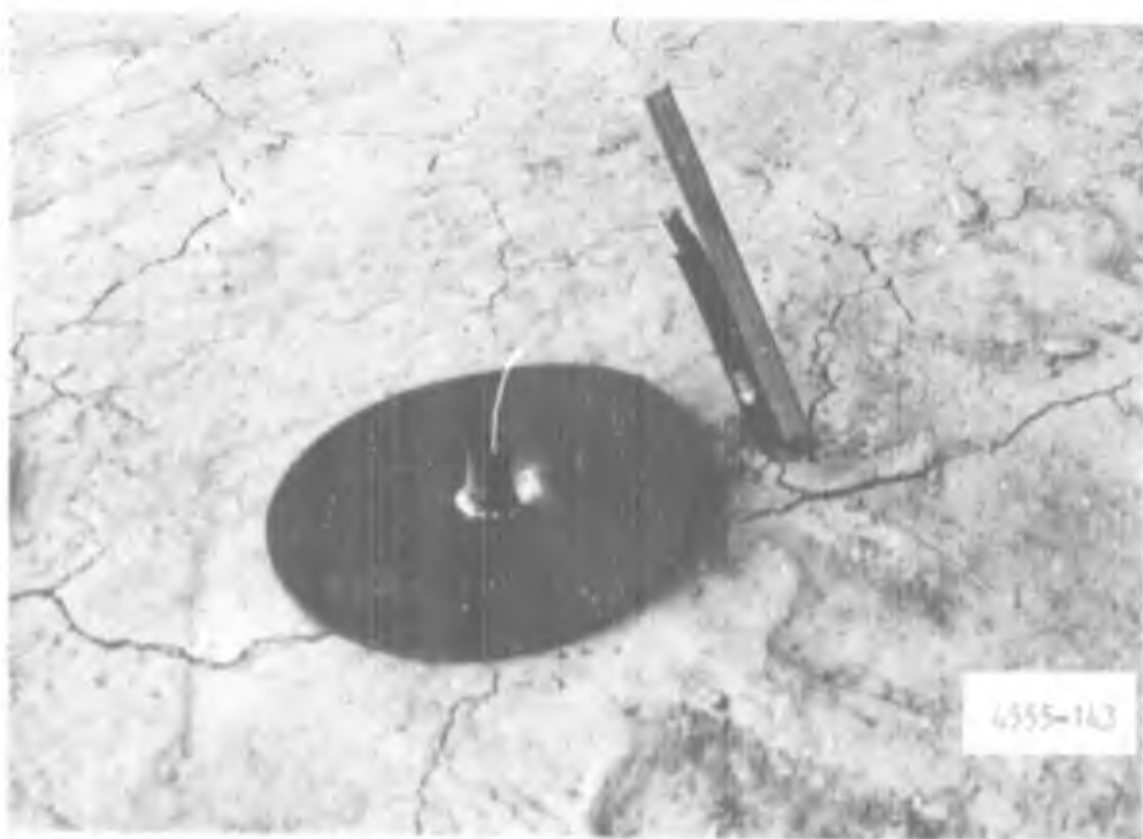
Photograph 12. Anchor with straightened legs driven through membrane into the soil subgrade to a depth of 9 in.



Photograph 13. Threaded guy anchor driven into the soil subgrade to a depth of 6 in.



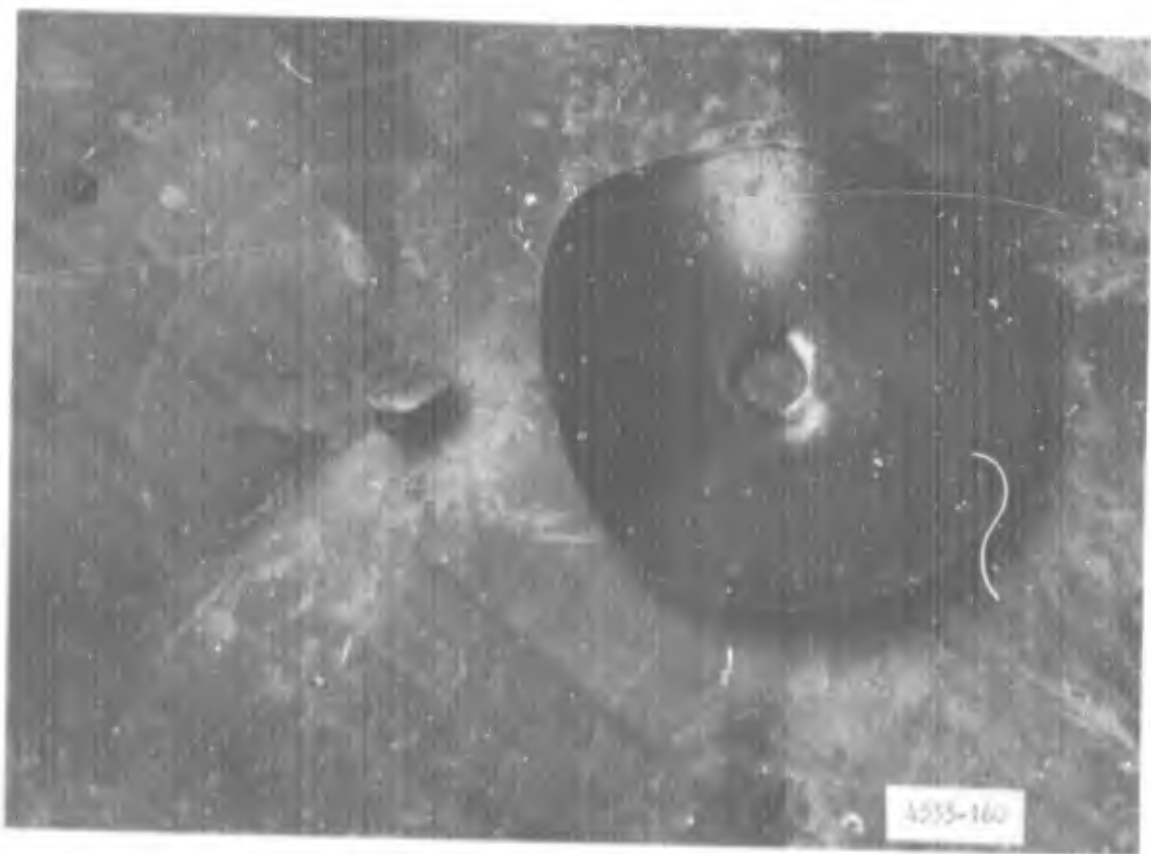
Photograph 14. Guy anchor driven into the soil subgrade to a depth of 6 in.



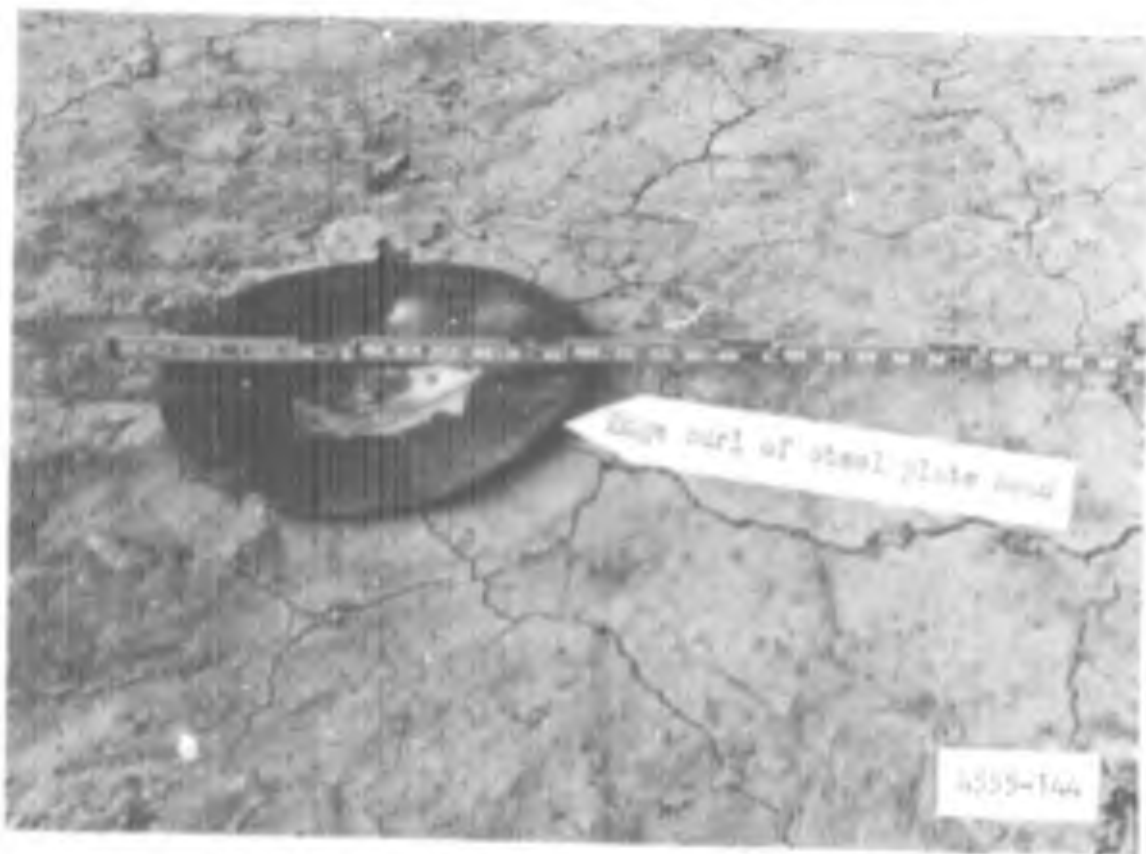
Photograph 15. Threaded guy anchor driven into the soil subgrade to a depth of 18 in.



Photograph 16. Guy anchor driven into the soil subgrade to a depth of 18 in.



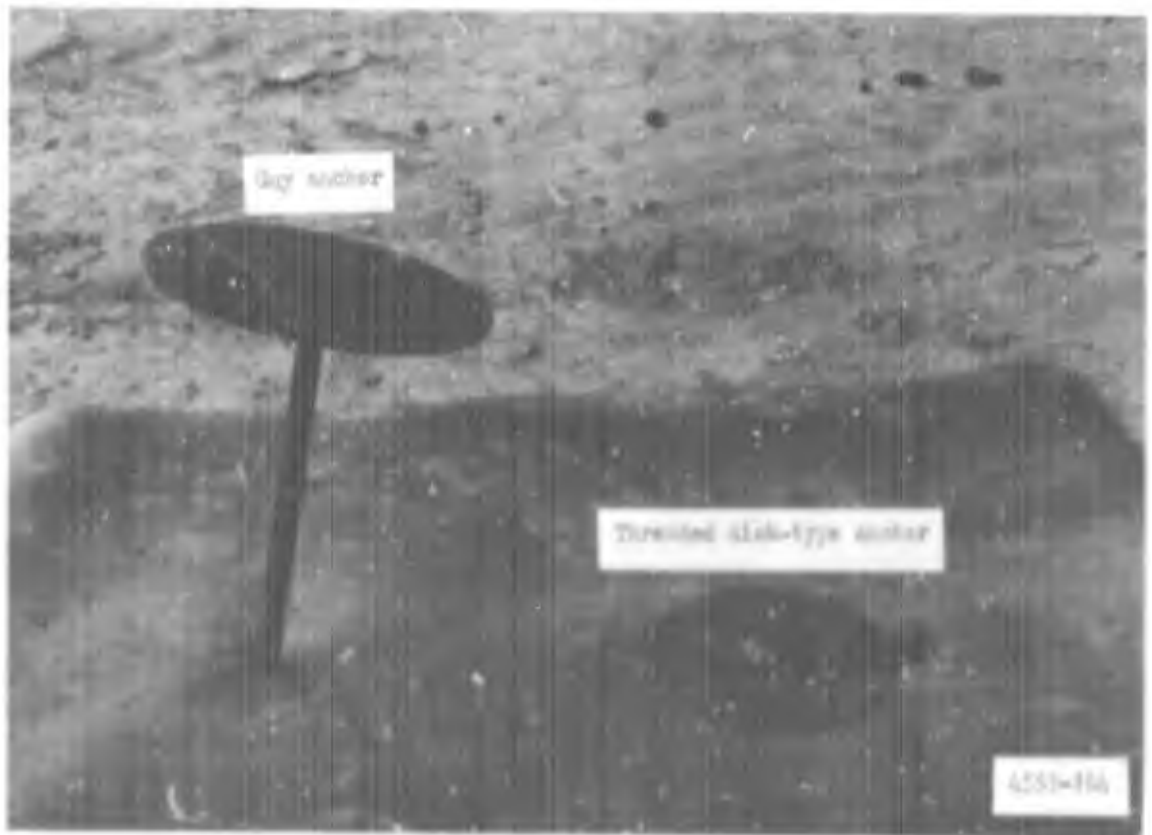
Photograph 17. Head broken from the steel collar after the threaded guy anchor had been driven to a depth of 24 in.



Photograph 18. Condition of guy anchor after being driven to a depth of 24 in.



Photograph 19. Guy anchor and threaded disk-type anchor after they had been driven through membrane surfacing into the soil subgrade to a depth of 6 in.



Photograph 20. Guy anchor and threaded disk-type anchor after they had been driven to a depth of 12 in.

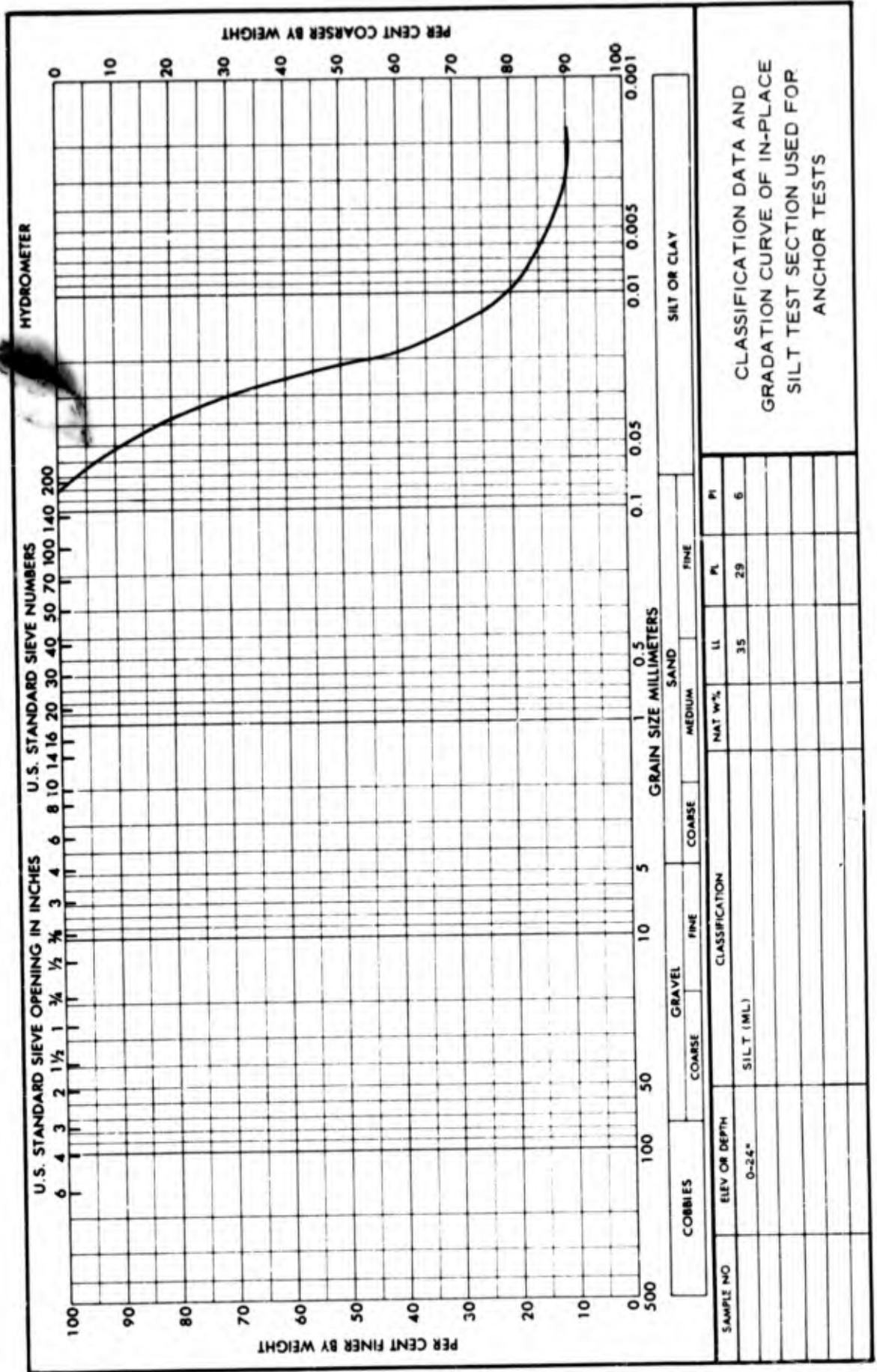


Photograph 21. Driving arrowhead anchor into subgrade with manual impact tool

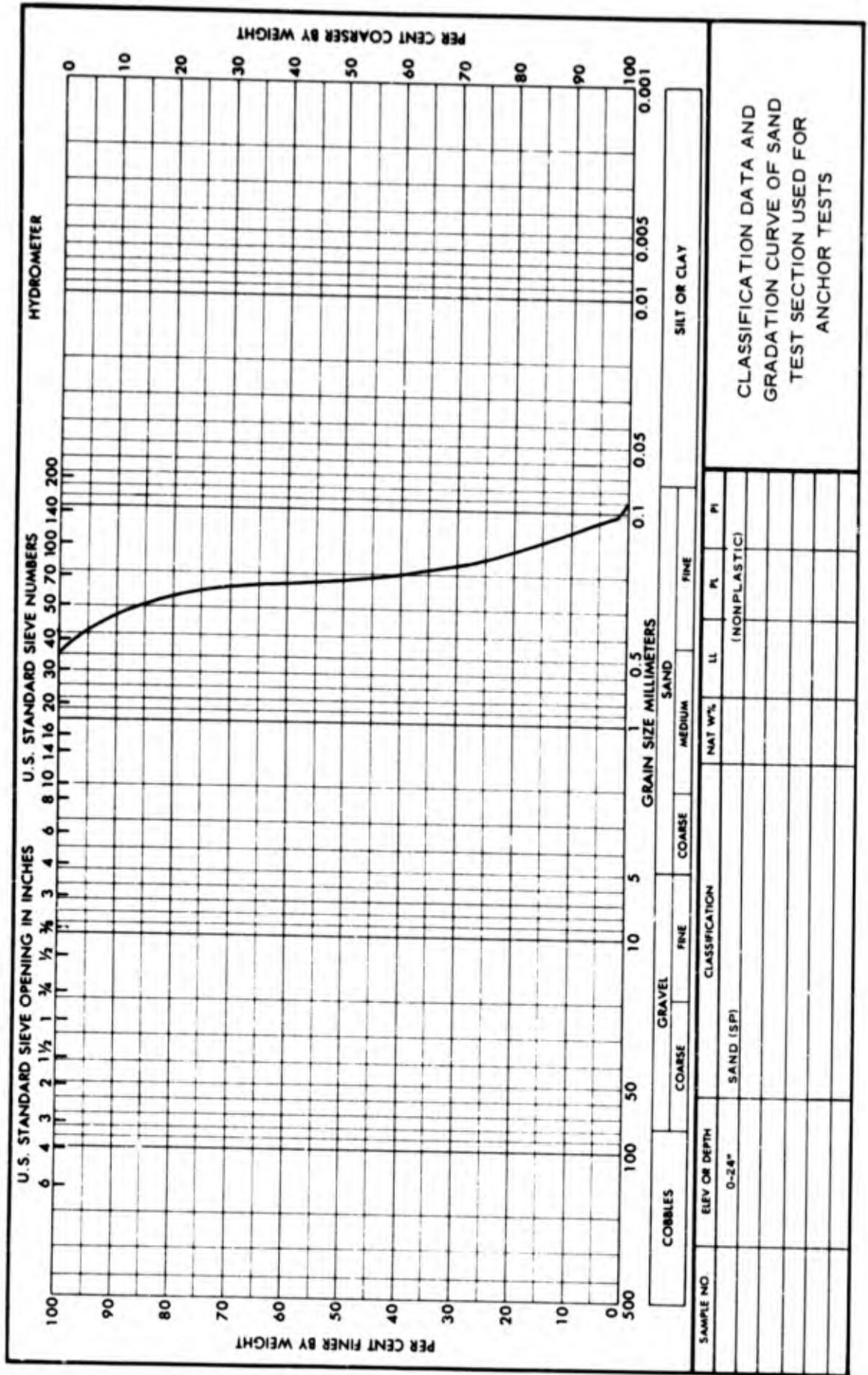


Photograph 22. Driving guy anchor into subgrade with sledgehammer

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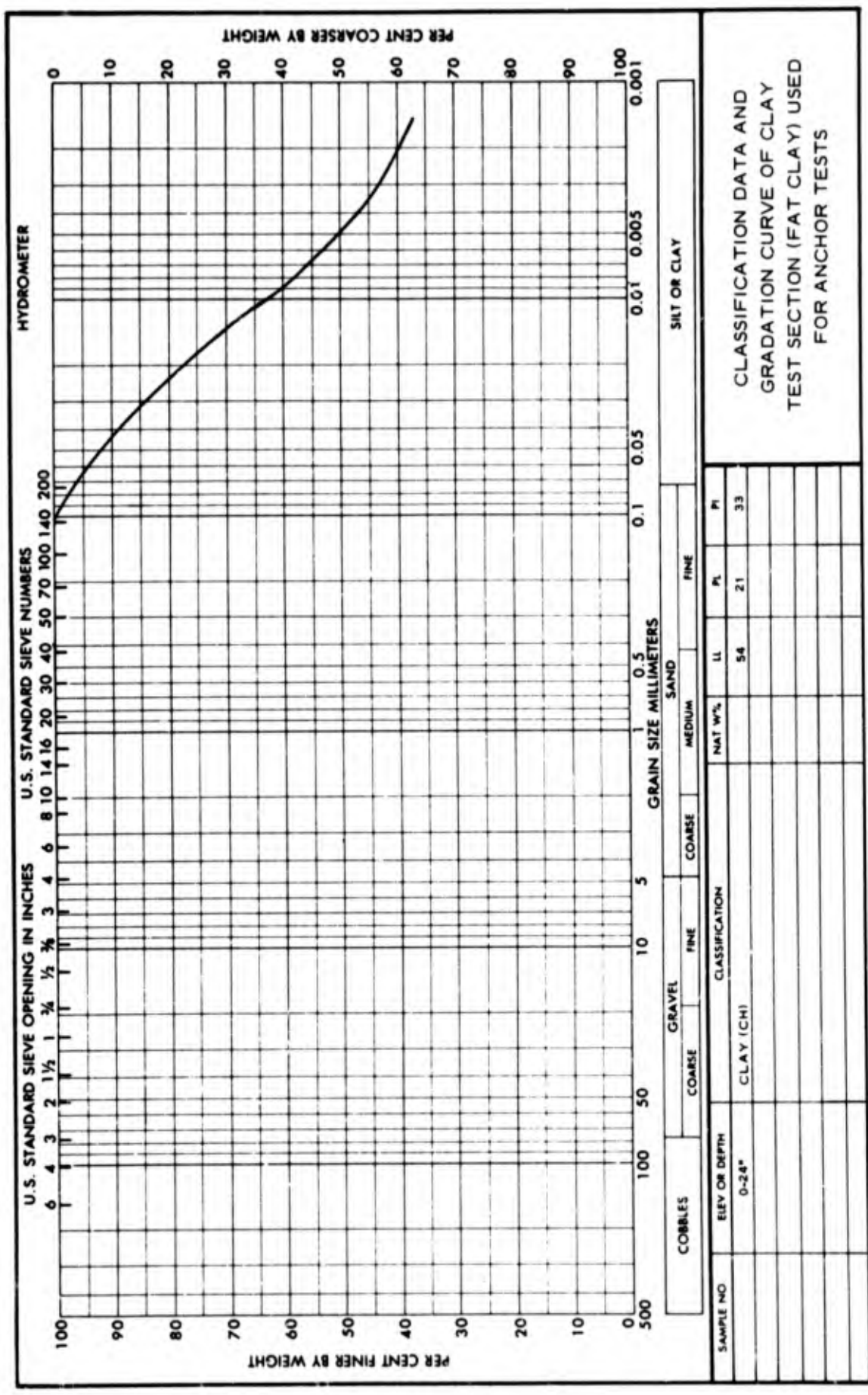


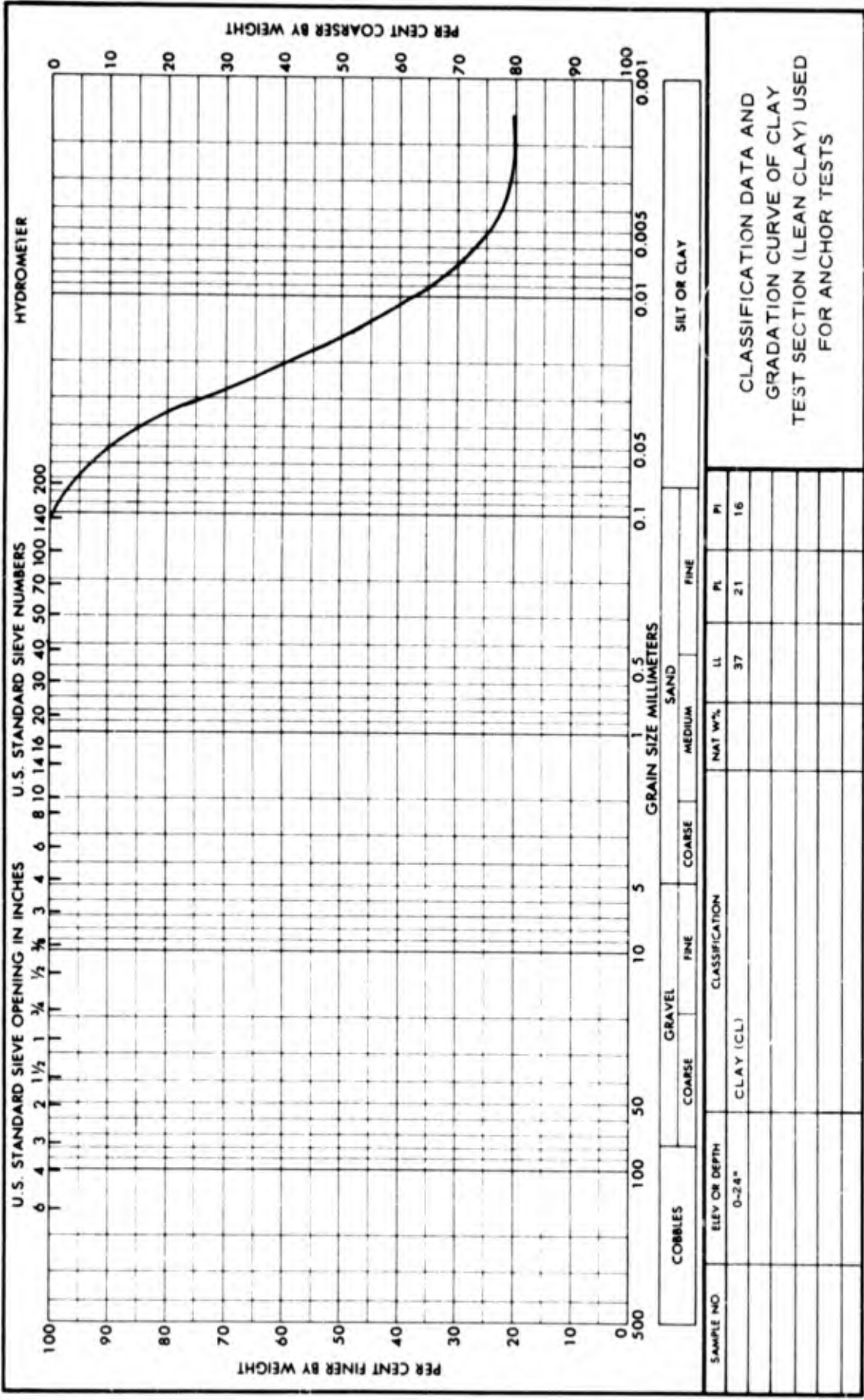
CLASSIFICATION DATA AND  
 GRADATION CURVE OF IN-PLACE  
 SILT TEST SECTION USED FOR  
 ANCHOR TESTS



CLASSIFICATION DATA AND  
 GRADATION CURVE OF SAND  
 TEST SECTION USED FOR  
 ANCHOR TESTS

PLATE 2





CLASSIFICATION DATA AND  
 GRADATION CURVE OF CLAY  
 TEST SECTION (LEAN CLAY) USED  
 FOR ANCHOR TESTS