Research and Analysis for Manufactured Housing Foundations: Ground Anchor Verification Testing

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APPENDICES

1.0 Introduction

The performance of conventional ground anchor assemblies is critical to the overall quality and structural integrity of manufactured housing installations. Consequently, a draft Ground Anchor Assembly Test Protocol (GAATP) [1] has been developed to fulfill the role of a "nationally recognized testing protocol" as required in the Model Manufactured Home Installation Standards: Final Rule (24 CFR Part 3285, Section 3285.402(a)) [2]. Therefore, it is important that this test protocol is practical and that it produces reliable and repeatable data characterizing the structural performance of ground anchors.

This report provides an assessment of the proposed GAATP based on actual implementation of the test protocol with a variety of conventional ground anchor assemblies, test configurations, and site soil conditions. In addition, a new test rig was developed in compliance with the GAATP rig requirements and implemented in this study to facilitate an efficient and repeatable method of ground anchor testing.

This report should be considered together with an extensive review of literature, findings based on the literature, and recommendations provided in an earlier Task 2c report [3]. Many of the findings in this present study confirm or build upon findings and recommendations made in the Task 2c report.

2.0 Test Program

2.1 Anchor Test Plan

The original study plan for this task was intended to provide a total of 36 ground anchor tests at three sites in the MD-DC-VA region. However, as the study progressed, testing activities were added to address various needs or interests. In addition, one test site was changed to a location near Clyo, Georgia. As a result, a total of 74 conventional ground anchor assemblies were tested as shown in Table 2.1 using the ground anchor test rig developed for this project. An additional 30 duplicate tests were conducted in Georgia using one manufacturer's existing test rig for comparative testing purposes. These duplicate tests are included only in Section 5.5 and are not intermingled with data elsewhere in this report. Overall, a total of 104 tests were performed. The anchor materials used in the tests are described in Table 2.2. The three test sites are shown in Figures 2.1 through 2.3.

TABLE 2.1
Study Matrix

Test Site	Anchor Test Configuration	Ground Anchor ID[1]	Stabilizer Plate ID	No. of Anchors Tested (n)	Reference Data (Tables & Figures)
Site #1 Davidsonville, MD	90deg in-line	MM4636(3/4)	n/a	6	Table 6, Fig 1a
	30deg angle	MM4636(3/4)	MM12	6	Table 8, Fig 3a
	30deg angle	MM4636(3/4)	MM12	6	Table 8, Fig 3b
Site #2 Clyo, Georgia	90deg in-line	MM4636(3/4)	n/a	6[2]	Table 6, Fig1c
	90deg in-line	MM650(3/4)	n/a	6[2]	Table 7, Fig 2
	30deg angle	MM4636(3/4)	MM12	6[2]	Table 8, Fig 3d
	30deg angle	MM650(3/4)	MM17	6[2]	Table 9, Fig 4
	45deg angle	MM650(3/4)	MM17	6[2]	Table 10, Fig 5
Site #3 Cambridge, MD	90deg in-line	MM4636(3/4)	n/a	6	Table 6, Fig1b
	30deg angle	MM4636(3/4)	MM12	6	Table 8, Fig 3c
	45deg angle	TD648(3/4)	TD17 & MM17	6	Table 11, Fig 6
Exploratory Tests at Site #2	90deg in-line	HP860(3/4)	n/a	2	Table 12, Fig 7
	45deg angle	HP860(3/4)	TD17	4	Table 13, Fig 8
	45deg in-line	TD648(5/8)	n/a	2	Table 14, Fig 9

Table Notes:

1. Ground anchor identifications (ID) are used for purposes of this report only and do not necessarily reflect manufacturer product identifications. See Table 2.2.
2. These 30 tests at the Georgia site were also repeated using one manufacturer's existing test rig (see Section 5.5).

TABLE 2.2
Description of Anchor Materials

Ground Anchor or Stabilizer ID	Product Description
Ground Anchors	
MM4636(3/4)	Minuteman Products, Inc. (Model 4636-DH ¾; Mark MMA-52) – 36" long anchor with double 6" and 4" discs, double connection head, and ¾" diameter shaft. Distance from bottom of head to center of 6" disc = 24"(30" to center of 4" disc)
MM650(3/4)	Minuteman Products, Inc. (Model 650-DH ¾; Mark MMA-4) – 50" long anchor with single 6" disc, double connection head, and ¾" diameter shaft. Distance from bottom of head to center of 6" disc = 45"
TD648(3/4)	Tie Down Engineering, Inc. (Model MI2H3/4; Part #59094) – 48" long galvanized anchor with single 6"disc, double connection head, and ¾" diameter shaft. Distance from bottom of head to center of 6" disc = 45"
TD648(5/8)	Tie Down Engineering, Inc. (Model MI2H5/8; Part #59081) – 48" long galvanized anchor with single 6"disc, double connection head, and 5/8" diameter shaft. Distance from bottom of head to center of 6" disc = 45"
HP860(3/4)	Home Pride, Inc. (Model HP8) – 60" long galvanized anchor with single 8" disc, double connection head, and ¾" diameter shaft. Distance from bottom of head to center of 8" disc = 56.6"
Stabilizer Plates	
MM12	Minuteman Products Inc. (Mark MMA-SD2A) – 11.75" wide painted stabilizer plate, ~0.119" thick steel, 1" lip, 8.25" vertical edge length, 11.5" height from top to tip (~0.8 ft^2 surface area)
MM17	Minuteman Products Inc. (Mark MMA-SD2) – 18" wide galvanized stabilizer plate, ~0.110" thick steel, 5/8" Lip, 7.5" vertical edge length, 13.5" height from top to tip (~1.3 ft^2)
TD17	Tie Down Engineering, Inc. (Part #59286) – 17.5" wide galvanized stabilizer plate, ~0.099" thick steel, with 5/8" lip, 7.5" vertical edge length, and 13.5" height from top to tip (~1.3 ft^2 surface area)

Figure 2.1. View of Davidsonville, MD test site

Figure 2.2. View of Cambridge, MD test site

Figure 2.3. View of Clyo, GA test site

2.2 Site Soil Characterization Plan

The GAATP does not provide guidelines on how to conduct a site soil characterization study. Such guidelines should include instruction on the number of tests or borings, depth of test relative to anchor depth, etc. For this study, two soil borings were conducted: one at the beginning and one at the end of testing at each site. The borings were located at opposite corners of the anchor layout grid (test area). Soil tests were also conducted at the two Maryland sites several months prior to actual anchor testing and during a period of extreme drought.

At or next to each of the two soil borings at each test site, the following soil data was collected:

1. ***Unified Soil Classification (visual per ASTM D2488)*** – including qualitative moisture assessment and density assessment (generally at soil depths of 12” and 36”)
2. ***Unified Soil Classification (mechanical per ASTM D2487)*** – generally at soil depths of 12” and 36”, but also other depths at some sites
3. ***Soil Moisture Content per ASTM D2216*** – generally at soil depths of 12” and 36”, but also other depths at some sites
4. ***Soil Torque Probe*** **(torque value)** – torque reading taken adjacent to soil borings at depths of 12” and 36”, plus other depths for some sites depending on anchor sizes
5. ***Dynamic Cone Penetrometer*** **(Durham Model S-200)** – blow count (blows per 1-3/4” penetration) taken adjacent to soil borings at depths of 12” and 36”, plus other depths for some sites depending on anchor sizes. DCP blow count is roughly equivalent to blows per foot (standard “N” resistance) using the Standard Penetrometer Test per ASTM D1586.
6. ***Pocket-Type Soil Penetrometer (Humbolt H4200)*** – soil “bearing value” (tons/ft^2) taken at soil surface and at 6” depth adjacent to soil borings. Readings can be considered to represent the ultimate bearing capacity of the soil and should be divided by a suitable safety factor. The purpose herein is to determine if the readings help explain variation in lateral resistance of anchor stabilizer plates.

The HUD Code and the GAATP recognize the Unified Soil Classification (USC) method, Torque Probe (TP), and Standard Penetrometer Test (SPT) as means of selecting anchors or qualifying anchor design values (see Table below). The HUD Code does not explicitly recognize the use of the more portable Dynamic Cone Penetrometer (DCP) as a substitute for the SPT (but neither does it prohibit its use as substitute). It also only seems to recognize use of a pocket-type or hand-held penetrometer (HP) for purpose of determining soil bearing values to specify bearing pads, not for ground anchor specification (although this interpretation may be questionable).

Use of these soil test methods and the degree of correlation (or lack of correlation) with anchor performance is a critical concern in accounting for major sources of variability in anchor performance that affect reliability of manufactured housing foundation anchorage. This issue receives some special attention in this report and also in the prior Task 2c report [3].

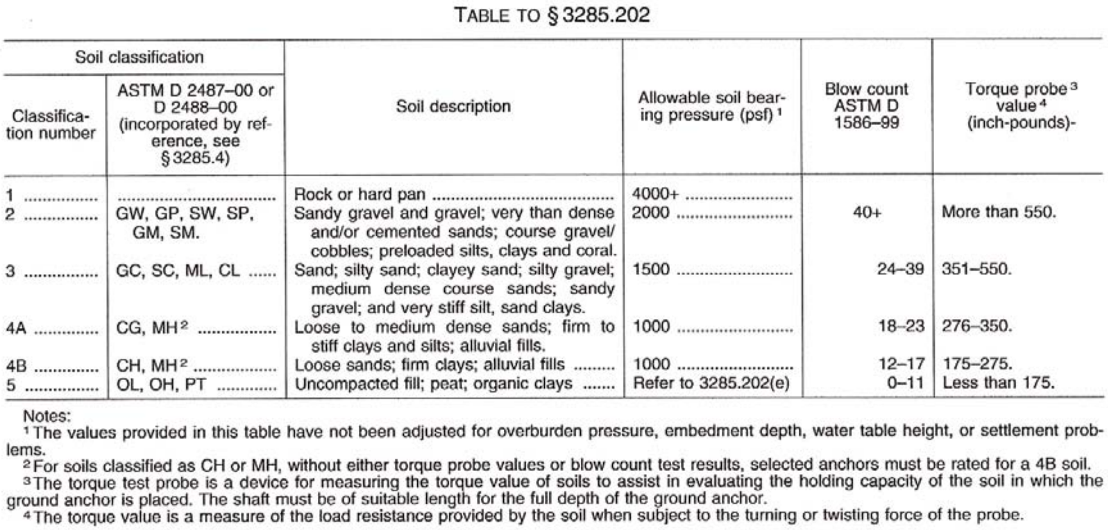


TABLE TO § 3285.202

Soil classification		Soil description	Allowable soil bearing pressure (psf) [1]	Blow count ASTM D 1586–99	Torque probe [3] value [4] (inch-pounds)-
Classification number	ASTM D 2487–00 or D 2488–00 (incorporated by reference, see § 3285.4)				
1		Rock or hard pan	4000+		
2	GW, GP, SW, SP, GM, SM.	Sandy gravel and gravel; very than dense and/or cemented sands; course gravel/cobbles; preloaded silts, clays and coral.	2000	40+	More than 550.
3	GC, SC, ML, CL	Sand; silty sand; clayey sand; silty gravel; medium dense course sands; sandy gravel; and very stiff silt, sand clays.	1500	24–39	351–550.
4A	CG, MH [2]	Loose to medium dense sands; firm to stiff clays and silts; alluvial fills.	1000	18–23	276–350.
4B	CH, MH [2]	Loose sands; firm clays; alluvial fills	1000	12–17	175–275.
5	OL, OH, PT	Uncompacted fill; peat; organic clays	Refer to 3285.202(e)	0–11	Less than 175.

Notes:

[1] The values provided in this table have not been adjusted for overburden pressure, embedment depth, water table height, or settlement problems.

[2] For soils classified as CH or MH, without either torque probe values or blow count test results, selected anchors must be rated for a 4B soil.

[3] The torque test probe is a device for measuring the torque value of soils to assist in evaluating the holding capacity of the soil in which the ground anchor is placed. The shaft must be of suitable length for the full depth of the ground anchor.

[4] The torque value is a measure of the load resistance provided by the soil when subject to the turning or twisting force of the probe.

NOTE: Table extracted from HUD Code [2].

2.3 Ground Anchor Test Apparatus, Equipment, and Operation

A complete listing of tools and equipment required in conducting the tests reported herein is found in Appendix A. This section summarizes the key components and operational features of the test rig.

Test Rig – A schematic of the test rig developed for this study is shown in Figures 2.4 and 2.5. The test rig has a rated load capacity of 20,000 lbs using a screw jack actuator with 14 inches of throw in forward and reverse directions. The screw jack displacement is controlled by a DC motor controller with adjustments allowing for displacement rates ranging continuously from 0 to 3.6 inches per minute (see Figure 2.6). A tension force may be applied by the actuator from either end of the screw and in forward (up) and reverse (down) directions. The test stand weight is 600 lbs (400 lbs stand + 200 lbs screw jack, gearbox, and controller). The footing pads on each test stand leg are 6”x6” steel plates such that, if no other footing block is used, the total area of the four steel footing pads is 1 ft^2. Thus, by adding the weight of the test rig to the maximum vertical force component applied to tested anchor devices, the bearing pressure applied to the soil can be easily determined as a “proof test” of soil bearing capacity. The legs of the test stand are

5-feet apart, allowing for vertical anchor pull tests with minimal interaction with any typical anchor's "cone of influence".

The stand was fabricated using bolted joints to facilitate transportation and shipping (with the screw jack assembly removed and separately stored). Assembly requires about 1 hour. The test stand was transported in a pick-up truck in the assembled condition to each site to minimize assembly time. Once located on site, it was moved manually by skidding on the ground. At the completion of testing the screw jack was removed and the test stand was tilted against and then pushed or pulled into the pick-up truck bed (requiring two to three men or a come-along if done by one person) and securely tied in place.

Based on operation and experience gained during the course of this project, a maximum of 36 anchors could be tested by three people in one day under ideal conditions (including anchor placement and removal) with a total of about 12 set-ups of the test rig (each set-up comprising two angle pull anchor tests and one 90 deg axial pull test). However, at any new site, several hours may be spent determining the best location for a test area and conducting preliminary soil tests. Therefore, a reasonable maximum level of daily productivity might be considered 9 set-ups of the test rig (18 angle pull tests plus 9 axial pull tests).

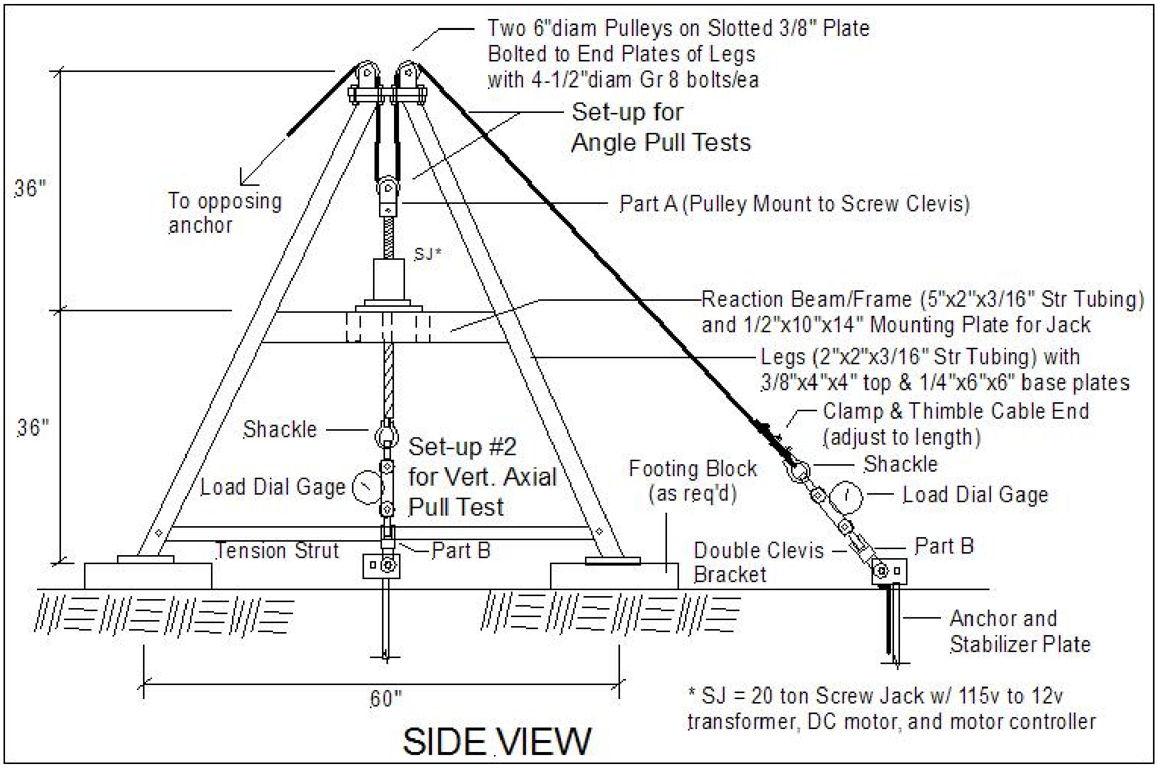


Figure 2.4. Side view of anchor pull test stand and rigging for angle pull and vertical (90^o) in-line withdrawal test set-ups.

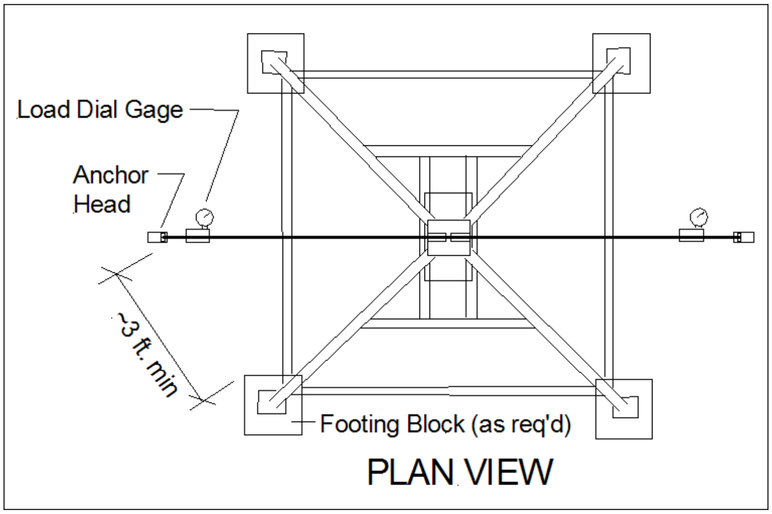


Figure 2.5. Plan view of test stand

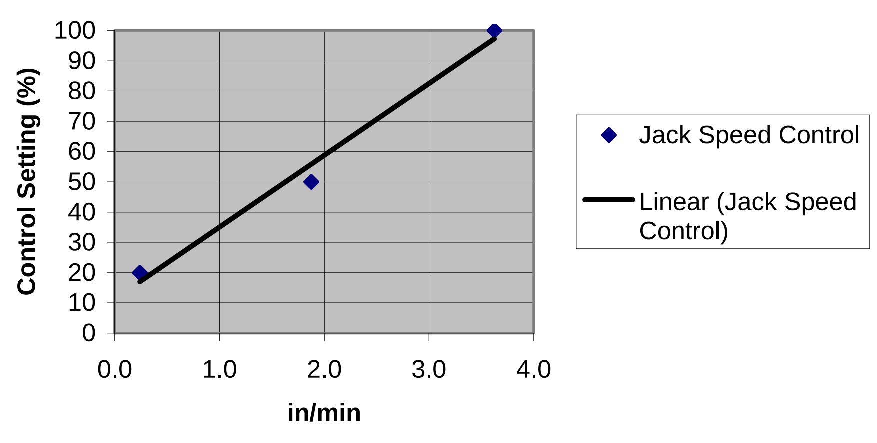


Figure 2.6. Displacement rate control of screw jack actuator.

90deg In-Line (Axial) Pull Test Set-up – The test rig is centered over one anchor and the pulleys at the head are aligned with the two anchors to be tested in the angle pull configuration (see below). The anchor is attached directly to the screw jack actuator as shown in Figures 2.4 and 2.7. Load and deflection measurement set-up (isolated from movement of the test stand) is also shown in Figure 2.7.

Angle Pull Test Set-up – The test rig is capable of testing anchors at angles ranging from about 60 degrees to less than 30 degrees from ground surface plane and with anchors in-line (axial) or at an angle to the applied load. Two methods of conducting angle pull tests are possible. In the single anchor angle pull arrangement, a test anchor and a “dead-man” anchor are used. The dead-man anchor is for reaction purposes only and the test anchor is monitored for load and displacement. In the dual anchor angle pull set-up, identical anchors are used and both are monitored for load and displacement. In this manner, the six anchor tests required by the GAATP can be conducted in three set-ups (also including an anchor test in the vertical pull configuration at each set-up). For reason of efficiency and similarity in result, the dual anchor angle pull set-up was used for most angle pull tests in this study. The angle pull test set-up is shown in Figures 2.4 and 2.8. The load and deflection measurement technique for angle pull tests is shown in Figure 2.9.

Figure 2.7. 90 degree in-line (axial) pull test set-up.

Figure 2.8. Angle pull test set-up

(NOTE: Anchors are being tested as an in-line angle pull installation so the horizontal ruler used for deflection measurement is set-up to the inside of the anchors to avoid potential ground surface disturbance caused by the anchor)

Figure 2.9. Deflection measurement technique for angle pull tests.

(NOTE: Anchor being tested is a not in-line with the angle of pull so a stabilizer plate is used and the horizontal ruler for measuring anchor deflection is set-up to the outside of the anchor)

2.4 Anchor Lay-out and Installation Procedure

Anchor Lay-out – Based on the test plan for each site (Table 2.1), anchors were laid-out in a grid with three "columns" or lines of anchors spaced 5-feet apart in each line. The middle column of anchors was used for 90 degree in-line (axial) pull tests. The outer two columns of anchors were for angle pull tests and these anchors were located a distance from the middle anchor to achieved the desired angle of pull. To facilitate anchor layout for angle pull tests, the chart in Figure 2.10 was developed based on the geometry of the test rig. Anchors were sequenced and grouped according to angle of pull to limit adjustments to the cable length during the course of testing at each site. In general, only one adjustment to cable length was needed at each site (i.e., to switch from 30 degree to 45 degree angle pull test groups). This approach allowed three anchors to be tested from each test rig set-up (i.e., 90deg in-line pull from center column of anchors followed by a dual anchor angle pull test of the outer two anchors).

Horizontal Distance from Center of Test Rig to Center of Hole in Anchor Head (FEET)

Angle	Radians	Footing Block Thickness (in) [distance test rig base is raised above grade]				
		0	1.5	3	4.5	6
30	0.524	10.90	11.11	11.33	11.55	11.76
40	0.698	7.68	7.83	7.98	8.13	8.27
45	0.785	6.54	6.67	6.79	6.92	7.04

Figure 2.10. Anchor head distance from center of test rig for angle pull tests.

Anchor Installation – All anchors were installed using an electric driver provided by the anchor manufacturer. At the first site (Davidsonville, MD) anchors were installed with the bottom of the head at or no more than about 1” above the ground surface. For angle pull tests, the top of stabilizer plates were driven to ground surface. For all other sites, the installation practice was modified slightly to drive anchors to no more than about ½ inch above the top of the stabilizer plate and stabilizer plates where driven flush with the ground or as much as 1” below the ground surface. This practice was discussed and agreed upon with manufacturers participating at the Georgia site. It is believed that this practice will result in more consistent and repeatable anchor test results. It may also tend to increase anchor performance slightly, but the magnitude of effect was not investigated in this testing program. The effect is probably small in comparison to other factors. When stabilizer plates were required for angle pull tests, they were installed approximately 3 inches in front of the anchor shaft as required by the GAATP. For angle pull tests, anchors were driven at a 10 degree angle leaning away from the direction of pull. For the one dual anchor in-line angle pull test conducted at the Georgia site, the two anchors were installed with shaft in-line with the angle of pull (45 degrees to ground surface) without stabilizer plates.

2.5 Anchor Testing and Data Collection Procedure

Data Collection – Data collection sheets were developed to facilitate manual load and displacement readings (see Appendix B). The first sheet was used to document general information and site-related data. A blank copy of the second sheet was used for each individual anchor test (or two anchors for dual anchor angle pull tests).

Anchor Set-Loading (angle pull tests only) – At the Davidsonville site, anchors were pre-tensioned as required by the GAATP (see below) and then the test initiated. In some cases, this approach did not result in the anchor shafts being seated snuggly against the stabilizer plates at the beginning of the test. As a result, some of these tests exhibited noticeable “slack” in the early stages of the load deflection plots. At the Georgia site, this concern with the GAATP procedure was discussed with participating anchor manufacturers. It was agreed that the anchors should be set against the stabilizer plates by applying a “set load” of as much as 1,000 lbs and, if necessary, tapping the head of the anchor to aid its movement through the soil. This practice was adopted for all tests at the Georgia and Cambridge, MD test sites. This approach had a significant effect on improving repeatability of test results even though it may serve to increase the Ultimate Anchor Load (when controlled by deflection limits) by as much as 10 percent (approximate). This topic will be discussed later and, in consideration of actual field installation practices, may warrant an additional “installation quality factor” being included with the safety factor for determination of anchor design values (see Section 5.2).

Anchor Pre-Tension – All anchors were tested with deflections zeroed at a maximum 500 lb initial load at the start of a test. If a greater “set load” had been applied (see above) for angle pull tests only, then the load was completely released after setting the anchor against the stabilizer plate. Next, the maximum 500 lb pre-tension load was applied, deflection measurements zeroed, and the test started. In a few cases (angle pull tests only), the pretension load was as low as 450 lbs at the start of testing. However, this small variation in pre-tension load for angle pull tests (especially after having “set” the anchor) appeared to have little effect on the repeatability and consistency of results.

Displacement Rate – An actuator displacement rate of 0.5 inches per minute was applied to all tests, with only a few exceptions where a 0.6 inches per minute rate was applied for angle pull tests at the Davidsonville site. This displacement rate was selected as a compromise between the 600 lb/min load rate recommended by others [see Reference 3] and the 2-minute minimum test duration required by the GAATP. As a result, most anchors reached deflection limit states at about a 4- to 6-minute duration. However, in a few 90 degree axial pull tests at the Davidsonville site, a strength limit state (ultimate anchor load) was reached in less than 2 inch vertical displacement at a test time of barely over 2 minutes. Without knowing the stiffness of an anchor in a given ground condition or assembly configuration, it is difficult to know what load rate to use to satisfy the 2 minute minimum duration required by the GAATP. This is primarily a concern with in-line anchor pull tests which tend to be much stiffer in response than angle pull tests where anchor shafts are not in-line with the direction of pull force and stabilizer plates are used to react the horizontal force component.

It is well known that fast load or displacement rates have an effect of increasing anchor resistance [3]. Thus, it is recommended that a maximum displacement rate be specified in the GAATP. Most anchors tested in this study had very repeatable and consistent results with an actuator load rate of about 0.5 inches/min resulting in anchor displacement rates typically between 0.3 inches/min to 0.6 inches/min. This load rate also facilitated accurate visual/manual readings of load and displacement during the course of a test. A much faster load rate would cause difficulties in reliable data collection and potentially cause some anchors to reach a strength limit state prior to the required minimum 2-minute duration. It would also tend to increase anchor resistance by not accounting for soil creep effects. A much slower displacement rate is also not advisable for reason of productivity, although a slightly more conservative (lesser) anchor value might result due to increased allowance for soil creep effects.

3.0 Results

3.1 Soil Characterization Data

Unified Soil Classification of Test Sites

Soils laboratory results for the three test sites are summarized in Table 3.1. The ASTM D2487 classifications are based on the *Unified Soil Classification* method and relate only to particle size and cohesive properties of the soils. They do not include information on the consistency (i.e., firmness) of the soil in-situ. Yet, these methods are recognized in the HUD Code [2] and the proposed GAATP [1] as a sole means of assigning a soil class for anchor qualification testing and specification purposes. The assigned HUD Code soil classes based on *Unified Soil Classification* are also shown in Table 3.1.

TABLE 3.1
Unified Soil Classifications (USC) for Test Sites
with Assigned HUD Soil Class

	Davidsonville, MD		Clyo, GA			Cambridge, MD	
	12” depth	36” depth	12” depth	36” depth	54” depth	12” depth	36” depth
USC (ASTM D2487)	ML	ML	SP	SP	SC	ML	ML
Gravel %	0	0	0	0	6.8%	0	0
Sand %	26.0%	32.0%	88.7%	79.6%	66.8%	2.6%	15.3%
Silt %	44.5%	38.0%	6.5%	5.8%	8.9%	75.4%	58.7%
Clay %	29.5%	30.0%	4.8%	8.7%	17.5%	22.0%	26.0%
LL	34.0%	38.0%	-	-	-	28.0%	30.0%
PI	11.0%	15.0%	-	-	-	NP	13.0%
USC (ASTM D2488)	ML/CL	ML/CL	SP-SM	SP-SM	SP-SC	ML	ML/CL
HUD-Code Soil Class (based on USC only)	Class 3	Class 3	Class 2	Class 2	Class 3	Class 3	Class 3

Torque Probe (TP) Results for Test Sites

In-situ Torque Probe test results for the three sites are shown in Table 3.2. Torque Probe measurements are recognized in the HUD Code [2] and the proposed GAATP [1] as a means of assigning a soil class for anchor qualification testing and specification purposes. They are also commonly used for ground anchor design purposes in other applications [3]. The assigned HUD Code soil classes based on Torque Probe results are also shown in Table 3.2.

TABLE 3.2
Torque Probe (TP) Readings (in-lbs) for Test Sites
with Assigned HUD Soil Class in Parenthesis

Depth Below Surface[1]	Davidsonville, MD Site			Cambridge, MD Site			Georgia Site	
	Prelim.[2] (8/1/07)	Boring 1 (11/14/07)	Boring 2 (11/16/07)	Prelim.[2] (8/2/07)	Boring 1 (12/18/07)	Boring 2 (12/18/07)	Boring 1 (12/4/07)	Boring 2 (12/5/07)
12”	240 (4B)	80 (5)	75 (5)	425 (3)	80 (5)	80 (5)	190 (4B)	150 (5)
24”				-	125	200		

					(5)	(4B)		
36”	240 (4B)	105 (5)	95 (5)	340 (4A)	250 (4B)	425 (3)	130 (5)	150 (5)
48”				180 (4B)	275 (4B)	300 (4A)	-	225* (4B)

1. Depth below surface as measured from tip of torque probe.

2. Preliminary site visits at Davidsonville, MD and Cambridge, MD sites occurred during a period of extreme drought with soil at very low moisture content.

*Torque wrench used for measurements in this table was compared to a calibrated torque wrench and found to read low by 20 in-lbs at 225 in-lb reading (approximately 9% low bias). Thus, readings in this table may be adjusted upward by about 9%. This also signals another potential source of uncertainty introduced in the use of the Torque Probe without a calibrated torque wrench as is common practice.

Dynamic Cone Penetrometer (DCP) Results for Test Sites

In-situ Dynamic Cone Penetrometer (DCP) test results for the three sites are shown in Table 3.3. DCP measurements are not directly recognized in the HUD Code [2] or the proposed GAATP [1] as a means of assigning a soil class for anchor qualification testing and specification purposes. They are based instead on the Standard Penetrometer Test (SPT) in accordance with ASTM D1586-99. However, the DCP test method is similar, more portable, and less costly. DCP measurements when reported as “blows per 1-3/4 inch penetration” can be substituted directly for “blows/ft” readings from the STP test method. The DCP test method is commonly used for shallow soil investigations (i.e., 10 feet or less in depth) for a variety of geotechnical applications and, in this context, may be superior to use of the SPT method [3]. The assigned HUD Code soil classes based on DCP results are also shown in Table 3.3.

Hand Penetrometer (HP) Results for Test Sites

Pocket or hand penetrometer (Humbolt Model 4200) test results for the three sites are shown in Table 3.4. HP measurements are recognized in the HUD Code [2] as a means of determining soil class, but not for the purpose of ground anchorage applications in the proposed GAATP [1]. Therefore, HP measurements were included in this study for two purposes: (1) to explore a simple means of determining in-situ consistency (e.g., firmness) of surface soils at the sites, and (2) exploring possible correlations with performance of stabilizer plates which depend on soil properties near the ground surface.

TABLE 3.3
Dynamic Cone Penetrometer (DCP) Readings (blows per 1-3/4” penetration)[1] with HUD Soil Class in Parenthesis

Depth Below Surface	Davidsonville, MD Site			Cambridge, MD Site			Georgia Site	
	Prelim.[2] (8/1/07)	Boring 1 (11/14/07)	Boring 2 (11/16/07)	Prelim.[2] (8/2/07)	Boring 1 (12/18/07)	Boring 2 (12/18/07)	Boring 1 (12/4/07)	Boring 2 (12/5/07)
12”	18 (4A)	7 (5)	6 (5)	39* (3)	4.5 (5)	6 (5)	8 (5)	5 (5)
36”	12 (4B)	6 (5)	-	9 (5)	12 (4B)	15 (4B)	6 (5)	5 (5)
48”				-	7 (5)	9 (5)	-	8 (5)
54”							-	33 (3)

* Reading taken at approximately 6” depth.

1. Blows per 1-3/4” penetration with DCP test can be taken as equivalent to blows per foot (“N- value”) with ASTM D1586 Standard Penetrometer Test.
2. Preliminary site visits at Davidsonville, MD and Cambridge, MD sites occurred during a period of extreme drought with soil at very low moisture content.

TABLE 3.4
Hand Penetrometer (HP) Readings (tons/ft^2) for Test Sites

Depth Below Surface	Davidsonville, MD Site			Cambridge, MD Site			Georgia Site	
	Prelim.[2] (8/1/07)	Boring 1 (11/14/07)	Boring 2 (11/16/07)	Prelim.[2] (8/2/07)	Boring 1 (12/18/07)	Boring 2 (12/18/07)	Boring 1 (12/4/07)	Boring 2 (12/5/07)
~1”	4.5+	2.6	0.7	-	1.2	1.0	2.5	-
6”	4.5+	1.2	1.0	4.5+	1.5	1.75	3.5	3.5

1. A rainy day occurred between Boring 1 and Boring 2 at Davidsonville, MD site.
2. Preliminary site visits at Davidsonville, MD and Cambridge, MD sites occurred during a period of extreme drought with soil at very low moisture content.

Soil Moisture Content for Test Sites

Moisture content measurements per ASTM D2216 are shown in Table 3.5. The pronounced difference in moisture content between the preliminary soil tests and soil tests made at the time of anchor testing (Borings 1 and 2) are due to a drought during the time of the preliminary measurements at the Davidsonville and Cambridge, MD test sites. This difference in moisture content had dramatic effect on the soil index test data (Tables 2, 3, and 4) at a 12” depth with a much decreased effect at 36” depth. This observation is due to antecedent moisture conditions (e.g., drought or rainfall) having a greater effect on the upper “active zone” of the soil profile. The effect of soil moisture condition on assignment of HUD-Code soil class for anchor qualification or specification purposes will be discussed later.

TABLE 3.5
Soil Moisture Content by Weight (% dry basis)

Depth Below Surface	Davidsonville, MD Site			Cambridge, MD Site			Georgia Site	
	Prelim. (8/1/07)	Boring 1 (11/14/07)	Boring 2 (11/16/07)	Prelim. (8/2/07)	Boring 1 (12/18/07)	Boring 2 (12/18/07)	Boring 1 (12/4/07)	Boring 2 (12/5/07)
12”	15.6%	27.4%	29.8%	8.3%	24.2%	25.5%	5.1%	5.1%
36”	18.2%	24.1%	27.2%	20.2%	19.2%	18.9%	11.5%	7.1%
48”				-	20.5%	-	-	17.0%
54”							-	17.0%

1. A rainy day occurred between Boring 1 and Boring 2 at Davidsonville, MD site.

2. Preliminary site visits at Davidsonville, MD and Cambridge, MD sites was during period of extended (record) drought with soil at very low moisture content.

Summary of HUD Soil Class Predictions by Soil Characterization Methods

The variation in HUD Soil Class assigned to each site by various soil classification (index test) methods is summarized in the table below for soil data taken at a 36 inch depth. The TP and DCP index tests appear to give the most reliable readings in comparison to tested anchor performance addressed later. Also, the DCP method appears to yield a slightly more consistent HUD soil class assignment for different measurements taken within a given site.

Comparison of HUD Soil Class Assignments by Soil Characterization Method

Site	USC	TP	DCP	HP[1]
Cambridge, MD	3	3 to 4B	4B/5	1 to 3
Davidsonville, MD	3	4B/5	4B/5	1 to 4B
Clyo, GA	2	5	5	2

[1] The HP correlations where based on allowable soil bearing pressure in Table 3285.202 of the HUD Code and comparing to HP measurements at 6” depth (Table 3.4) divided by a safety factor of 2.0.

3.2 Anchor Performance Data

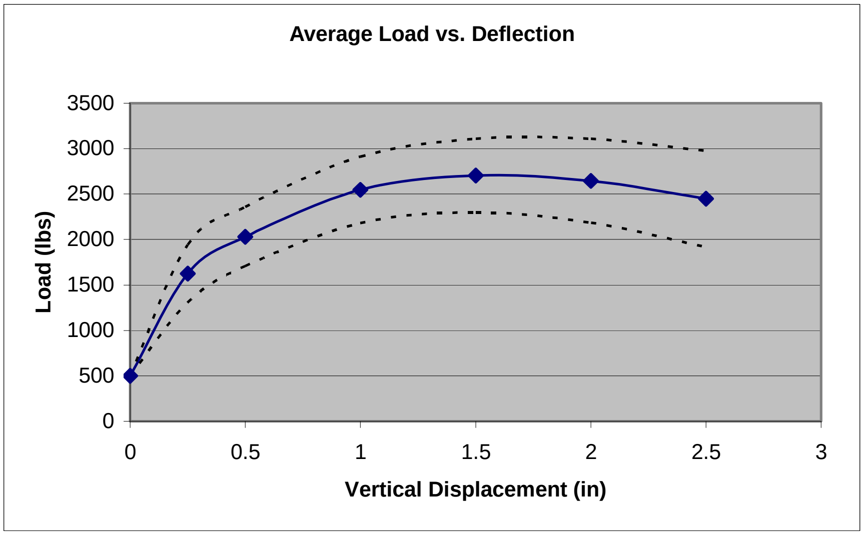
90 degree In-Line (Axial) Withdrawal Tests

Results for 90 degree in-line (axial) withdrawal tests are shown in Tables 3.6 and 3.7 and Figures 3.1 and 3.2. Anchor response was clearly non-linear for the entire load-displacement history. This observation applies to all anchor assembly configurations tested in this study (some more than others). These results are evaluated and discussed later in Sections 4.0 and 5.0. These results do not include data from comparison tests using a manufacturer’s unique test rig (refer to Section 5.5).

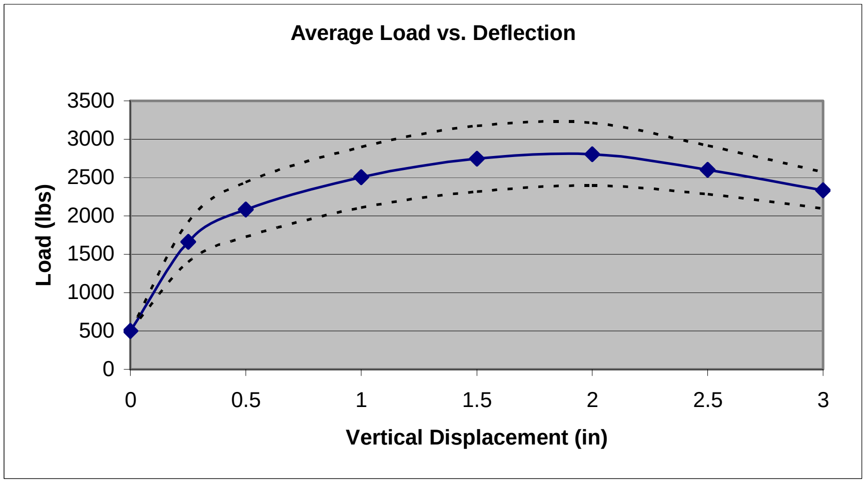
TABLE 3.6
90 Degree Axial Withdrawal Tests (n=6) at Three Sites Using Minuteman 36-inch Anchors with ¾” Shaft and 4”/6” Double Disc (MM4636)

Test Site	Vertical Displacement (inches)	Average Load (lbs)	Standard Deviation (lbs)	Coeff. of Variation
Davidsonville, MD • USC – ML w/30% clay • TP – 90-105 in-lbs • DCP – 6 blows/1.75 in HUD Soil Class 5 based on TP and DCP at 36” depth Figure 3.1(a)	0	500	n/a	n/a
	0.25	1625	316	0.19
	0.5	2031	325	0.16
	1	2546	366	0.14
	1.5	2704	406	0.15
	2	2647	463	0.17
	2.5	2447	529	0.22
	Failure Mode: Shear cone failure of soil (~32 inch diameter at surface) Ultimate Test Load: 2743 lbs (Std. Dev. = 377 lbs; COV = 0.14) Avg. Vert. Displ. at UTL: 1.65 in (Std. Dev. = 0.34 in; COV = 0.21) Ult. Anchor Load (≤2” displ): 2743 lbs (SD = 377 lbs; COV = 0.14) Avg. Vert. Displ. at UAL: 1.63 in (SD = 0.34 in; COV = 0.21) Lowest UAL (≤2” displ): 2205 lbs Avg. Vert. Displ. at LUAL: 0.78 in (SD = 0.62 in; COV = 0.80) Working Anchor Load: **1470 lbs** (LUAL / 1.5) Avg. Vert. Displ. at WAL: **0.25 in** (Std. Dev. = 0.11 in; COV = 0.42)			
Cambridge, MD • USC – ML w/26% clay • TP – 250-425 in-lbs • DCP – 12-15 blows/1.75in HUD Soil Class 4B based on DCP (and lower TP value) at 36” depth Figure 3.1(b)	0	500	n/a	n/a
	0.25	1661	259	0.16
	0.5	2083	353	0.17
	1	2504	394	0.16
	1.5	2746	427	0.16
	2	2804	407	0.15
	2.5	2600	315	0.12
	3	2333	238	0.10
	Failure Mode: Shear plug withdrawal from anchor hole (n=6) Ultimate Test Load: 2838 lbs (Std. Dev. = 413 lbs; COV = 0.15) Avg. Vert. Displ. at UTL: 1.94 in (Std. Dev. = 0.37 in; COV = 0.19) Ult. Anchor Load (≤2” displ): 2829 lbs (SD = 419 lbs; COV = 0.15) Avg. Vert. Displ. at UAL: 1.81 in (SD = 0.19 in; COV = 0.10) Lowest UAL (≤2” displ): 2300 lbs Avg. Vert. Displ. at LUAL: 0.95 in (SD = 0.64 in; COV = 0.67) Working Anchor Load: **1533 lbs** (LUAL / 1.5) Avg. Vert. Displ. at WAL: **0.25 in** (Std. Dev. = 0.10 in; COV = 0.40)			
Georgia • USC – SM • TP – 130-150 in-lbs • DCP – 5-6 blows/1.75in HUD Soil Class 5 based on TP and DCP at 36” depth Figure 3.1(c)	0	500	n/a	n/a
	0.25	1358	354	0.26
	0.5	1738	322	0.19
	1	2017	256	0.13
	1.5	1946	197	0.10
	2	1842	191	0.10
	2.5	1719	103	0.06
	Failure Mode: Shear plug withdrawal (n=2); faint shear cone 12-24” diam (n=4) Ultimate Test Load: 2054 lbs (Std. Dev. = 238 lbs; COV = 0.12) Avg. Vert. Displ. at UTL: 0.96 in (Std. Dev. = 0.29 in; COV = 0.30) Ult. Anchor Load (≤2” displ): 2054 lbs (SD = 238 lbs; COV = 0.12) Avg. Vert. Displ. at UAL: 0.96 in (SD = 0.29 in; COV = 0.30) Lowest UAL (≤2” displ): 1825 lbs Avg. Vert. Displ. at LUAL: 0.66 in (SD = 0.38 in; COV = 0.57)			

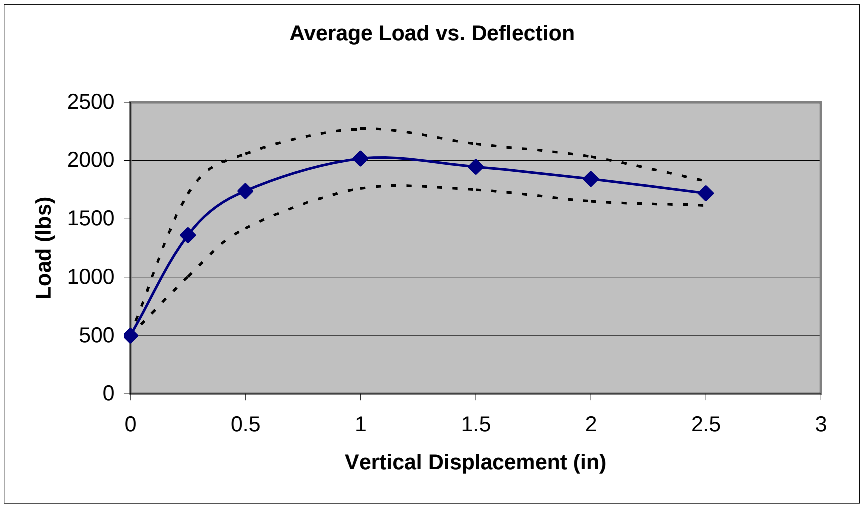
	Working Anchor Load: **1217 lbs** (LUAL / 1.5) Avg. Vert. Displ. at WAL: **0.25 in** (Std. Dev. = 0.11 in; COV = 0.43)



(a) Davidsonville, MD Site



(b) Cambridge, MD Site



(c) Georgia Site

Figure 3.1. Average Load (n=6) vs. Vertical Displacement for 90° Axial Withdrawal Tests Using Minuteman 36-inch Anchors with ¾" Shaft and 4"/6" Double Disc (MM4636)

[Note: Smoothed curves drawn through actual data points from Table 6; dotted lines represent +/- 1 standard deviation]

TABLE 3.7
90 Degree Axial Withdrawal Tests (n=6) at Georgia Site Using Minuteman 50-inch Anchors with ¾" Shaft and 6" Single Disc (MM650)

Test Site	Vertical Displacement (inches)	Average Load (lbs)	Standard Deviation (lbs)	Coeff. of Variation
Georgia • USC – SM • TP – 225 in-lbs • DCP – 8 blows/1.75in HUD Soil Class 5 based on DCP at 48" depth (4B based on TP) Figure 3.2	0	500	n/a	n/a
	0.25	863	38	0.04
	0.5	1208	96	0.08
	1	1725	172	0.10
	1.5	2058	213	0.10
	2	2325	237	0.10
	2.5	2525	244	0.10
	3	2713	255	0.09
	Failure Mode: No failure observed at ground surface Ultimate Test Load: 3700 lbs (maximum at test termination) Avg. Vert. Displ. at UTL: ~8 in (maximum achieved) Ult. Anchor Load (≤2" displ): 2325 lbs (SD = 237 lbs; COV = 0.10) Avg. Vert. Displ. at UAL: 2.0 in (UAL based on load at 2" displ) Lowest UAL (≤2" displ): 1950 lbs Avg. Vert. Displ. at LUAL: 1.36 in (SD = 0.35 in; COV = 0.26) Working Anchor Load: **1300 lbs** (LUAL / 1.5) Avg. Vert. Displ. at WAL: **0.58 in** (Std. Dev. = 0.10 in; COV = 0.16)			

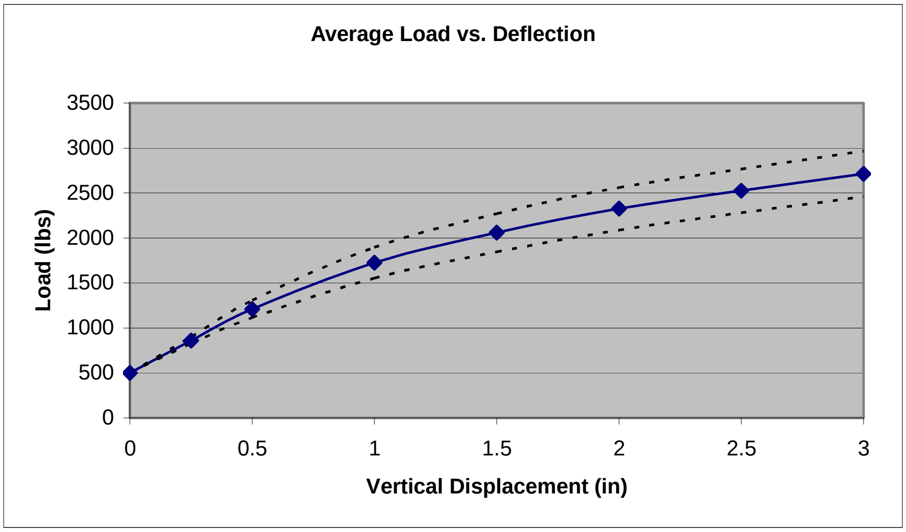


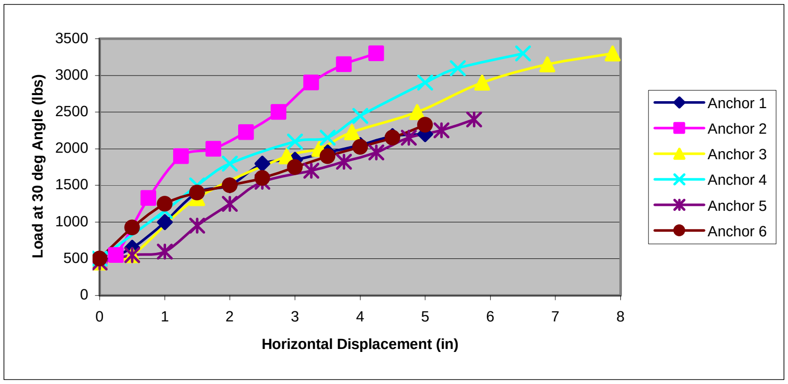
Figure 3.2. Average Load vs. Deflection Plot for 90 Degree Axial Withdrawal Tests (n=6) at Georgia Site Using Minuteman 50-inch Anchors with ¾” Shaft and 6” Single Disc (MM650)

30degree Angle Pull Tests

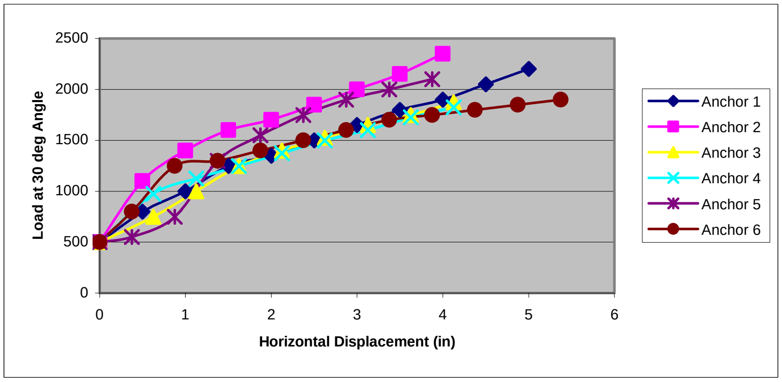
Results for 30 degree angle pull tests are shown in Tables 3.8 and 3.9 and Figures 3.3 and 3.4. These results are analyzed and discussed later in Sections 4.0 and 5.0. These results do not include data from comparison tests using a manufacturer’s unique test rig (refer to Section 5.5).

TABLE 3.8
30 Degree Angle Pull Tests (n=6) at Three Sites Using Minuteman 36-inch Anchors with ¾” Shaft and 4”/6” Double Disc and 12” Stabilizer Plates (MM4636+MM12)

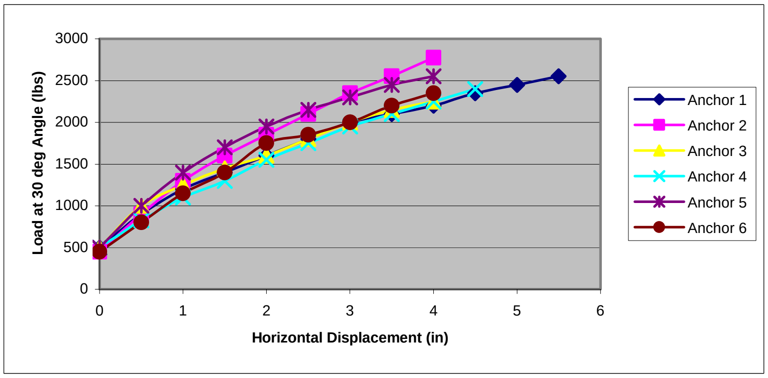
Site Information	Performance Criteria	Average	Std Dev	COV	Lowest of n=6
Davidsonville, MD (Dual Anchor Pull) • USC – ML w/30% clay • TP – 90-105 in-lbs • DCP – 6 blows/1.75 in HUD Soil Class 5 based on TP and DCP at 36” depth HP – 1.0-1.2 tons/ft^2 (6”) DCP – 6-7 blows (12”) TP – 75-80 in-lbs (12”) Figure 3.3(a)	Max load at ≤ 3” horiz displ	1854	154	0.08	1650
	Max load at ≤ 2” vert displ	n/a	n/a	n/a	n/a
	Max load at ≤ 2” total displ	1531	178	0.12	1250
	Ultimate Anchor Load = **1650 lbs** Avg. horiz displ = 2.37 in (SD = 0.43 in; COV = 0.18) Avg. vert displ = 0.12 in (SD = 0.09 in; COV = 0.76)				
	Working Anchor Load = **1100 lbs** (UAL / 1.5) Avg. horiz displ = 1.08 in (SD = 0.39 in; COV = 0.36) Avg. vert displ = 0.06 in (SD = 0.12 in; COV = 1.95)				
Davidsonville, MD (Single Anchor Pull) • USC – ML w/30% clay • TP – 90-105 in-lbs • DCP – 6 blows/1.75 in HUD Soil Class 5 based on TP and DCP at 36” depth HP – 1.0-1.2 tons/ft^2 (6”) DCP – 6-7 blows (12”) TP – 75-80 in-lbs (12”) Figure 3.3(b)	Max load at ≤ 3” horiz displ	1733	181	0.10	1575
	Max load at ≤ 2” vert displ	n/a	n/a	n/a	n/a
	Max load at ≤ 2” total displ	1461	151	0.10	1340
	Ultimate Anchor Load = **1575 lbs** Avg. horiz displ = 2.45 in (SD = 0.62 in; COV = 0.25) Avg. vert displ = 0.21 in (SD = 0.16 in; COV = 0.73)				
	Working Anchor Load = **1050 lbs** (UAL / 1.5) Avg. horiz displ = 0.91 in (SD = 0.31 in; COV = 0.34) Avg. vert displ = 0.06 in (SD = 0.08 in; COV = 1.20)				
Cambridge, MD • USC – ML w/26% clay • TP – 250-425 in-lbs • DCP – 12-15 blows/1.75in HUD Soil Class 4B based on DCP (and lower TP value) at 36” depth HP – 1.5-1.75 tons/ft^2 (6”) DCP – 4.5-6 blows (12”) TP – 80 in-lbs (12”) Figure 3.3(c)	Max load at ≤ 3” horiz displ	2100	176	0.08	1950
	Max load at ≤ 2” vert displ	n/a	n/a	n/a	n/a
	Max load at ≤ 2” total displ	1711	160	0.09	1545
	Ultimate Anchor Load = **1950 lbs** Avg. horiz displ = 2.63 in (SD = 0.42 in; COV = 0.16) Avg. vert displ = 0.31 in (SD = 0.13 in; COV = 0.42)				
	Working Anchor Load = **1300 lbs** (UAL / 1.5) Avg. horiz displ = 1.18 in (SD = 0.22 in; COV = 0.19) Avg. vert displ = 0.12 in (SD = 0.05 in; COV = 0.39)				
Georgia • USC – SM • TP – 130-150 in-lbs • DCP – 5-6 blows/1.75in HUD Soil Class 5 based on TP and DCP at 36” depth HP – 3.5 tons/ft^2 (6”) DCP – 5-8 blows (12”) TP – 150-190 in-lbs (12”) Figure 3.3(d)	Max load at ≤ 3” horiz displ	2225	122	0.06	2100
	Max load at ≤ 2” vert displ	n/a	n/a	n/a	n/a
	Max load at ≤ 2” total displ	2074	120	0.06	1947
	Ultimate Anchor Load = **2100 lbs** Avg. horiz displ = 2.06 in (SD = 0.49 in; COV = 0.24) Avg. vert displ = 0.56 in (SD = 0.13 in; COV = 0.24)				
	Working Anchor Load = **1400 lbs** (UAL / 1.5) Avg. horiz displ = 0.78 in (SD = 0.13 in; COV = 0.16) Avg. vert displ = 0.12 in (SD = 0.04 in; COV = 0.35)				



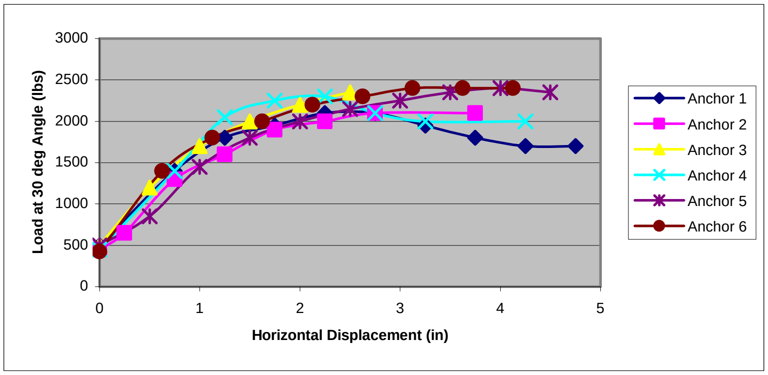
(a) Davidsonville, MD Site (Dual Anchor Pull Set-up)



(b) Davidsonville, MD Site (Single Anchor Pull Set-up)



(c) Cambridge, MD Site (Dual Anchor Pull Set-up)



(d) Georgia Site (Dual Anchor Pull Set-up)

Figure 3.3. Load at 30 degree angle vs. horizontal displacement for Minuteman 36-inch Anchors with ¾" Shaft and 4"/6" Double Disc and 12" Stabilizer Plates (MM4636+MM12)

TABLE 3.9
30 Degree Angle Pull Tests (n=6) at Georgia Site Using Minuteman 50-inch Anchors with ¾" Shaft and 6" Single Disc and 17" Stabilizer Plates (MM650+MM17)

Site Information	Performance Criteria	Average	Std Dev	COV	Lowest of n=6
Georgia • USC – SM • TP – 225 in-lbs • DCP – 8 blows/1.75in HUD Soil Class 5 based on DCP (4B based on TP) at 48" depth HP – 3.5 tons/ft^2 (6") DCP – 5-8 blows (12") TP – 150-190 in-lbs (12") Figure 3.4	Max load at ≤ 3" horiz displ	2659	314	0.12	2175
	Max load at ≤ 2" vert displ	n/a	n/a	n/a	n/a
	Max load at ≤ 2" total displ	2212	301	0.14	1725
	Ultimate Anchor Load = **2175 lbs** Avg. horiz displ = 1.86 in (SD = 0.63 in; COV = 0.34) Avg. vert displ = 0.72 in (SD = 0.29 in; COV = 0.40)				
	Working Anchor Load = **1450 lbs** (UAL / 1.5) Avg. horiz displ = 0.78 in (SD = 0.30 in; COV = 0.38) Avg. vert displ = 0.23 in (SD = 0.12 in; COV = 0.52)				

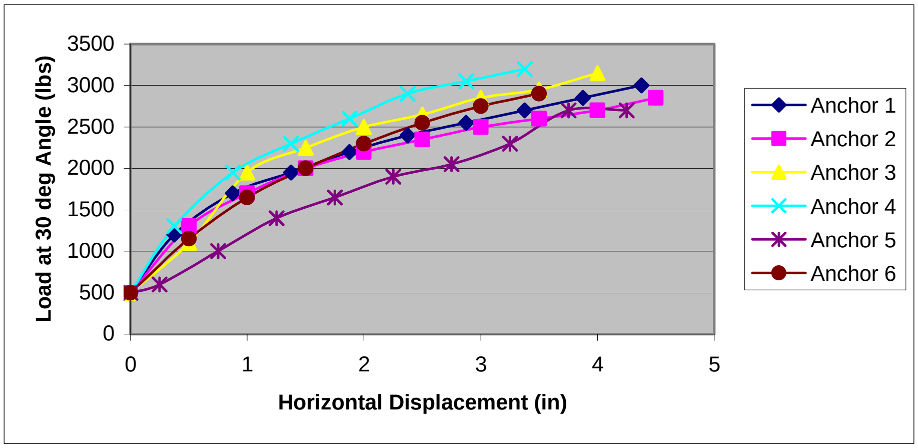


Figure 3.4. Load at 30 degree angle vs. horizontal displacement for 30 Degree Angle Pull Tests (n=6) at Georgia Site Using Minuteman 50-inch Anchors with ¾" Shaft and 6" Single Disc and 17" Stabilizer Plates (MM650+MM17)

45degree Angle Pull Tests

Results for 45 degree angle pull tests are shown in Tables 3.10 and 3.11 and Figures 3.5 and 3.6. These results are analyzed and discussed later in Sections 4.0 and 5.0. These results do not include data from comparison tests using a manufacturer's unique test rig (refer to Section 5.5).

TABLE 3.10
45 Degree Dual Anchor Angle Pull Tests (n=6) at Georgia Site
Using Minuteman 50-inch Anchors
with ¾" Shaft and 6" Single Disc and 17" Stabilizer Plates (MM650+MM17)

Site Information	**Performance Criteria**	**Average**	**Std Dev**	**COV**	**Lowest of n=6**
Georgia • USC – SM • TP – 225 in-lbs • DCP – 8 blows/1.75in HUD Soil Class 5 based on DCP (4B based on TP) at 48" depth HP – 3.5 tons/ft^2 (6") DCP – 5-8 blows (12") TP – 150-190 in-lbs (12") Figure 3.5	Max load at ≤ 3" horiz displ	3202	188	0.06	2913
	Max load at ≤ 2" vert displ	3180 (n=5)	121	0.04	2913
	Max load at ≤ 2" total displ	2577	102	0.04	2448
	Ultimate Anchor Load = **2913 lbs** Avg. horiz displ = 2.27 in (SD = 0.39 in; COV = 0.17) Avg. vert displ = 1.51 in (SD = 0.20 in; COV = 0.13)				
	Working Anchor Load = **1942 lbs** (UAL / 1.5) Avg. horiz displ = 0.84 in (SD = 0.10 in; COV = 0.12) Avg. vert displ = 0.55 in (SD = 0.16 in; COV = 0.30)				

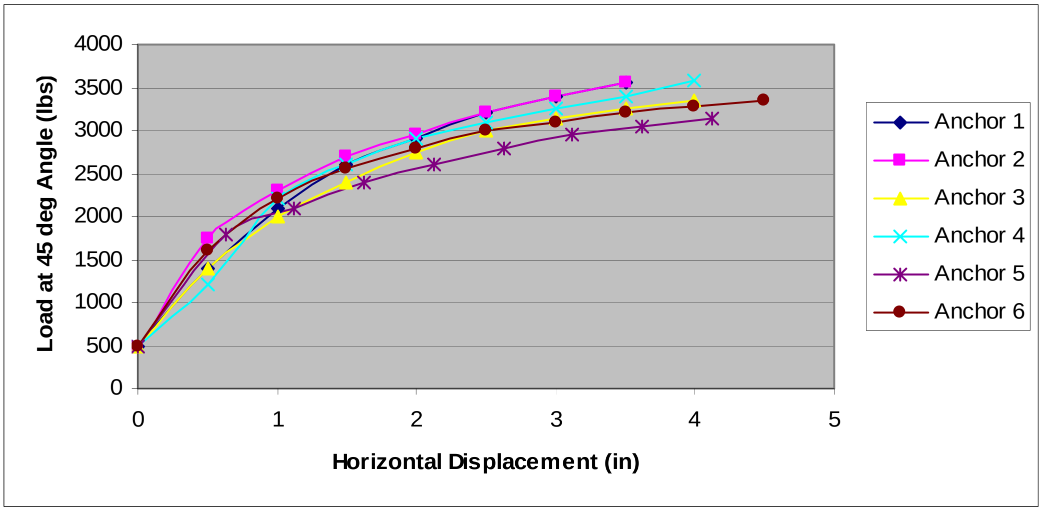


Figure 3.5. Load at 45 degree angle vs. horizontal displacement for 45 Degree Dual Anchor Angle Pull Tests (n=6) at Georgia Site Using Minuteman 50-inch Anchors with ¾" Shaft and 6" Single Disc and 17" Stabilizer Plates (MM650+MM17)
[Note: Load on Anchor #2 was at 52 deg; all other anchors were 47-48 deg]

TABLE 3.11
45 Degree Dual Anchor Angle Pull Tests (n=6) at Cambridge, MD Site Using Tie-Down Engr 48-inch Galv. Anchors with 5/8” Shaft and 6” Single Disc and 17” Stabilizer Plates (TD648+TD/MM17)

Site Information	Performance Criteria	Average	Std Dev	COV	Lowest of n=6
Cambridge, MD • USC – ML w/26% clay • TP – 275-300 in-lbs • DCP – 7-9 blows/1.75in	Max load at ≤ 3” horiz displ	3361	258	0.08	3000
	Max load at ≤ 2” vert displ	n/a	n/a	n/a	n/a
	Max load at ≤ 2” total displ	2735	115	0.04	2568
HUD Soil Class 5 based on DCP (4B/5 based on TP) at 48” depth	Ultimate Anchor Load = **3000 lbs** Avg. horiz displ = 2.42 in (SD = 0.34 in; COV = 0.14) Avg. vert displ = 0.50 in (SD = 0.18 in; COV = 0.35)				
HP – 1.5-1.75 tons/ft^2 (6”) DCP – 4.5-6 blows (12”) TP – 80 in-lbs (12”) Figure 3.6	Working Anchor Load = **2000 lbs** (UAL / 1.5) Avg. horiz displ = 1.13 in (SD = 0.16 in; COV = 0.14) Avg. vert displ = 0.22 in (SD = 0.09 in; COV = 0.39)				

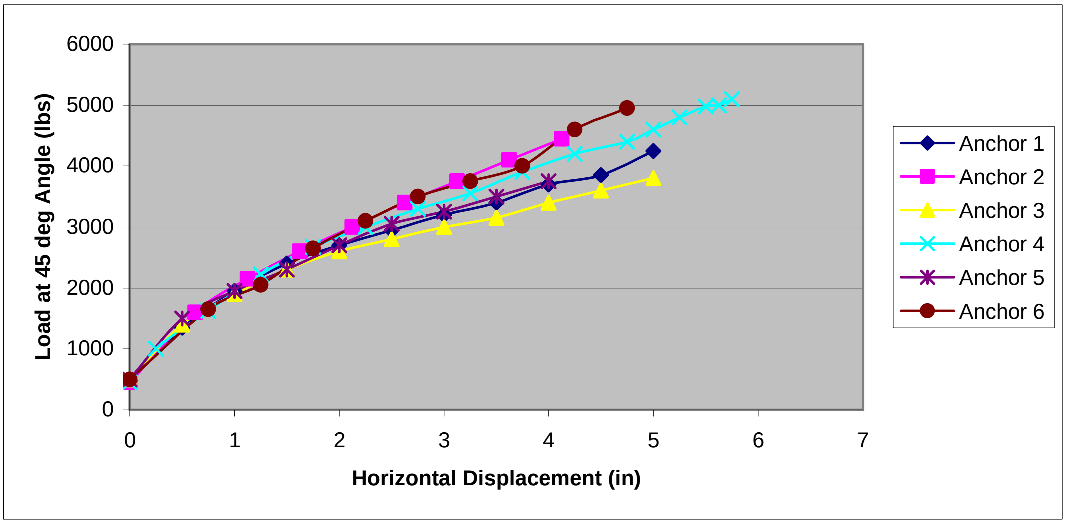


Figure 3.6. Load at 45 degree angle vs. horizontal displacement for 45 Degree Dual Anchor Angle Pull Tests (n=6) at Georgia Site Using Tie-Down Engr 48-inch Galv. Anchors with 5/8” Shaft and 6” Single Disc and 17” Stabilizer Plates (TD648+TD/MM17)

[Note: Anchors 5 and 6 used MM17 stabilizer plates]

3.3 Exploratory Anchor Test Data

Exploratory tests of various ground anchors and configurations were conducted without meeting the requirement for n=6 test repetitions required by the GAATP. These tests were included at the Georgia test site for the following reasons:

- investigate 90 degree in-line (axial) withdrawal of a larger anchor (Table 3.12 and Figure 3.7),
- investigate 45 degree angle pull performance with a larger anchor (Table 3.13 and Figure 3.8), and
- investigate 45 degree in-line (axial) pull performance of an anchor also tested at 45 degree in an angle pull configuration with stabilizer plates (Table 3.14 and Figure 3.9).

The results for these exploratory tests are analyzed and discussed later in Sections 4.0 and 5.0. These results do not include data from comparison tests using a manufacturer's unique test rig (refer to Section 5.5).

TABLE 3.12
90 Degree Axial Withdrawal Test (n=1) at Georgia Site
Using Home Pride 60-inch Anchors with 8" Disc and ¾" Shaft (HP860)

Vertical Displacement (inches)	Average Load (lbs)	
0	500	ONLY ONE TEST CONDUCTED VARIABILITY IS UNKNOWN[1] See Figure 3.7 DCP – 33 blows/1.75" (54" depth) HUD Soil Class 3 at 54" depth
0.5	3150	
1	4275	
1.5	5000	
2	**5525**	
2.5	5875	
3	6150	
3.5	6300	
?	6550	
Failure Mode:	No failure at ground surface observed.	
Ultimate Anchor Load (≤2" displ):	**5,525 lbs** (NOT BASED ON n=6 TESTS !)	
Vert. Displ. at UAL:	**2 inches**	
Working Anchor Load:	**3,683 lbs** (NOT BASED ON n=6 TESTS !)	
Vert. Displ. at WAL:	**0.74 inches** (by interpolation)	

Table Note:

1. One additional anchor was tested with load applied to hole in anchor head that was not aligned with the anchor shaft. Due to prying action caused by the eccentric load on the anchor head, the anchor head-to-shaft weld connection failed at a load of 3275 lbs at an anchor head vertical displacement of 1.25 inches.

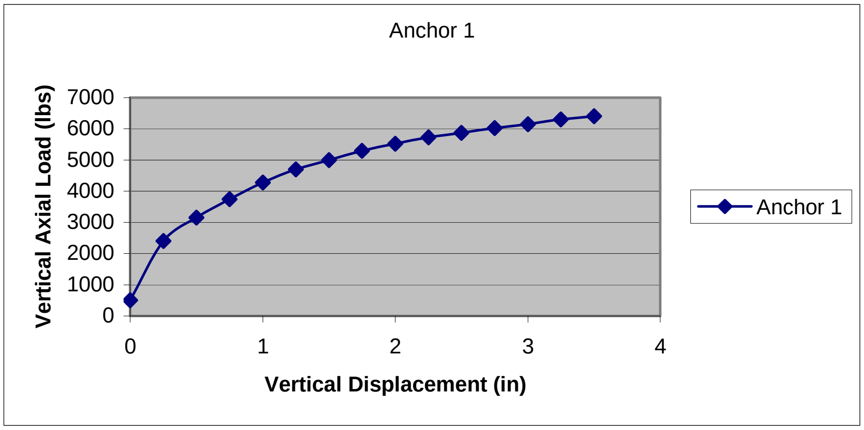


Figure 3.7. 90 Degree Axial Withdrawal Test (n=1) at Georgia Site
Using Home Pride 60-inch Anchors with 8” Disc and ¾” Shaft (Model HP860)

TABLE 3.13
45 Degree Dual Anchor Angle Pull Tests (n=4) at Georgia Site Using Home Pride 60” x 8” Single Disc Anchors with ¾” shaft and 17” Stabilizer Plates (HP860+TD17)

Site Information	Performance Criteria	Average	Std Dev	COV	Lowest of n=4
Georgia • USC – SM • TP – 225 in-lbs (48”) • DCP – 8 (48”); 33 (54”) blows/1.75in HUD Soil Class 5 based on DCP (4B based on TP) at 48” depth; Class 3 based on DCP at 54” HP – 3.5 tons/ft^2 (6”) DCP – 5-8 blows (12”) TP – 150-190 in-lbs (12”) Figure 3.8	Max load at ≤ 3” horiz displ	3691	476	0.13	3250
	Max load at ≤ 2” vert displ	n/a	n/a	n/a	n/a
	Max load at ≤ 2” total displ	2975	214	0.07	2729
	Ultimate Anchor Load = **3250 lbs** Avg. horiz displ = 2.45 in (SD = 0.43 in; COV = 0.18) Avg. vert displ = 0.45 in (SD = 0.10 in; COV = 0.23)				
	Working Anchor Load = **2167 lbs** (UAL / 1.5) Avg. horiz displ = 1.16 in (SD = 0.06 in; COV = 0.05) Avg. vert displ = 0.17 in (SD = 0.05 in; COV = 0.31)				

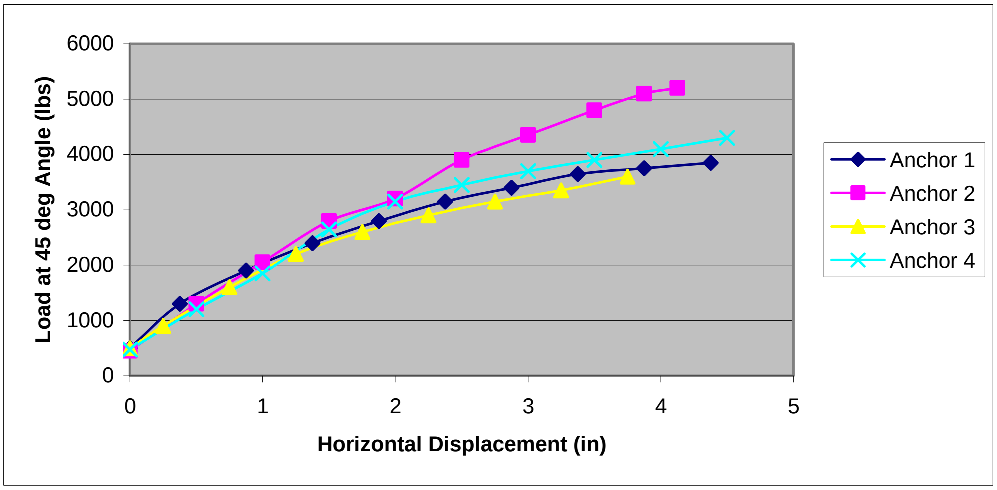


Figure 3.8. Load at 45 degree angle vs. horizontal displacement for 45 Degree Dual Anchor Angle Pull Tests (n=4) at Georgia Site Using Home Pride 60” x 8” Single Disc Anchors with ¾” shaft and 17” Stabilizer Plates (HP860+TD17)

TABLE 3.14
45 Degree Dual Anchor Axial Pull Tests (n=2) at Georgia Site Using Tie Down Engr 48” x 6” Single Disc Anchors with ¾” Shaft (TD648)

Site Information	**Performance Criteria**	**Average**	**Std Dev**	**COV**	**Lowest of n=2**
Georgia • USC – SM • TP – 130-150 in-lbs • DCP – 5-6 blows/1.75in HUD Soil Class 5 based on TP and DCP at 36” depth	Max load at ≤ 3” horiz displ	n/a	ONLY TWO TESTS CONDUCTED VARIABILITY UNKNOWN		n/a
	Max load at ≤ 2” vert displ	2649			2630
	Max load at ≤ 2” total displ	2395			2292
	Ultimate Anchor Load = **2630 lbs** (based lowest of n=2 tests) Avg. horiz displ = 1.56 in Avg. vert displ = 1.93 in				
Figure 3.9	Working Anchor Load = **1753 lbs** (UAL / 1.5) (based on lowest of n=2 tests) Avg. horiz displ = 0.64 in Avg. vert displ = 0.84 in				

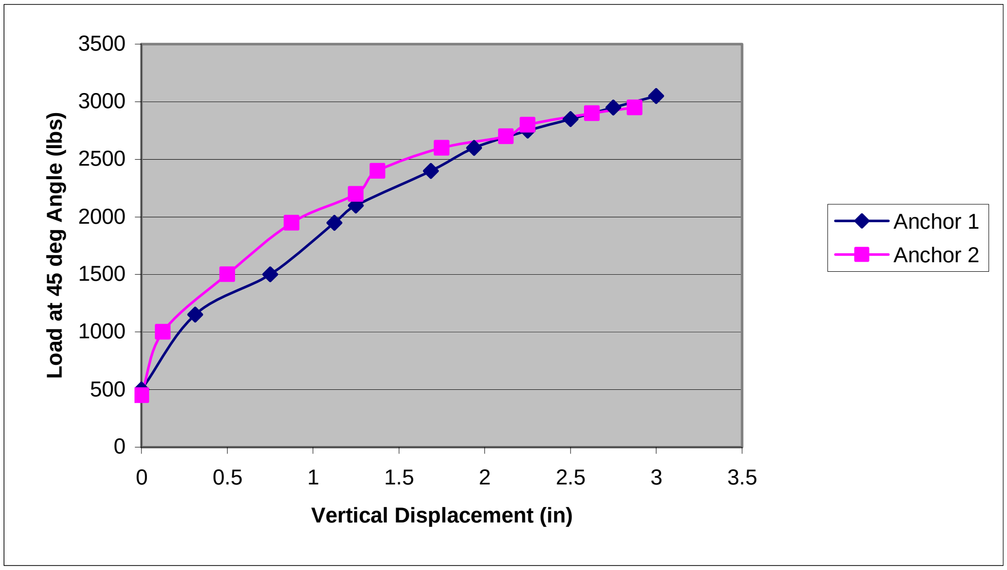


Figure 3.9. Load at 45 degree angle vs. vertical displacement for 45 Degree Dual Anchor Axial Pull Tests (n=2) at Georgia Site Using Tie Down Engr 48” x 6” Single Disc Anchors with ¾” Shaft (TD648)

[Note: Anchors reached 2” vertical displacement prior to 3” horizontal displacement]

4.0 Analysis

4.1 Relationships between Soil Index Test Methods

Based on soil index tests results (Tables 3.2 through 3.4), relationships between the three soil index test methods are explored in Figures 4.1 through 4.3. While insufficient data is available to confirm these relationships with a reasonable level of confidence, trends are apparent. These trends may be useful when using one method to characterize a site when anchor performance is characterized by another soil index test method. A primary example is the use of the DCP test method to characterize a site and then select an anchor which has performance qualified on the basis of the TP method. For reasons discussed later, the DCP method appears to hold promise as a preferred method of site characterization because of its decreased variability in result at a given site.

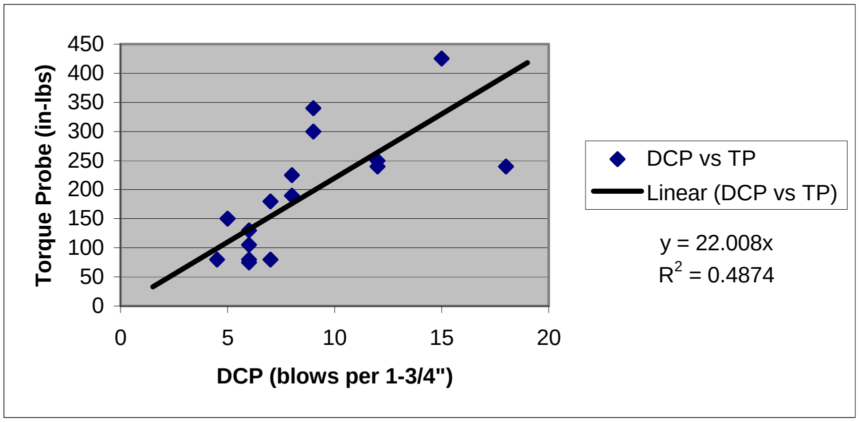


Figure 4.1. Relationship between Dynamic Cone Penetrometer and Torque Probe measurements for all three test sites and depths up to 4 feet.

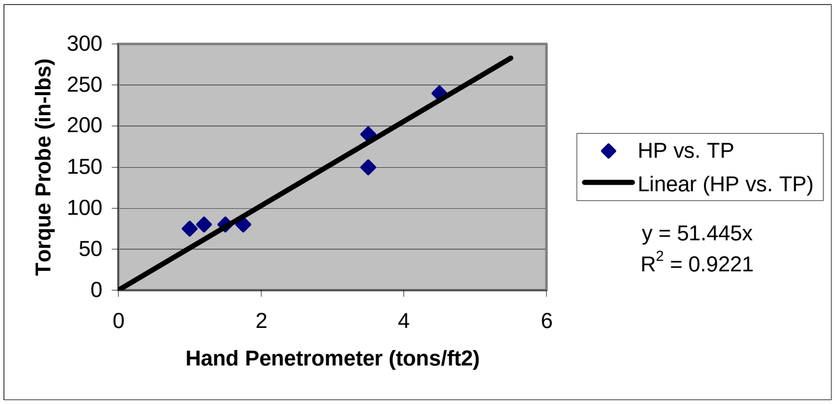


Figure 4.2. Relationship between Hand Penetrometer (Humbolt Model 4200) and Torque Probe measurements at a depth of 6 to 12 inches below soil surface for all three test sites.

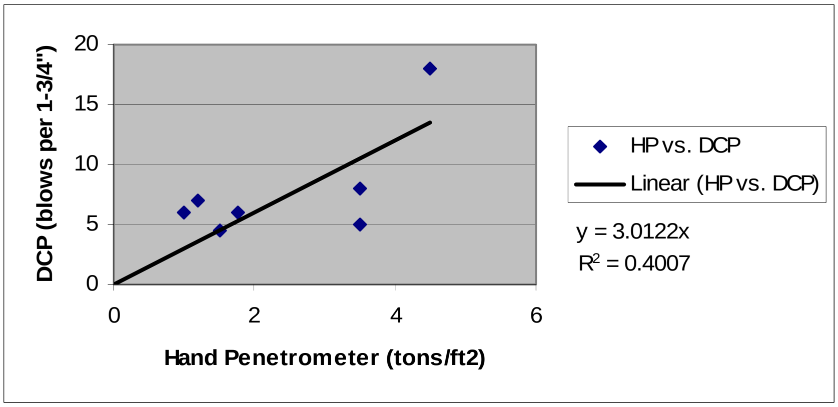


Figure 4.3. Relationship between Hand Penetrometer (Humbolt Model 4200) and Dynamic Cone Penetrometer at depth of 6 to 12 inches below soil surface for all three test sites.

4.2 Correlation of Soil Index Tests to Anchor Performance

Angle Pull Tests (Ground Anchor and Stabilizer Plate Lateral Resistance) – In this analysis, the horizontal force component of the average Ultimate Anchor Load (at 3” horizontal displacement) from Tables 3.8, 3.9, 3.10, 3.11, and 3.13 is used to determine a “uniform lateral soil pressure” value acting on the surface area of the stabilizer plate for each test group at all three test sites (see Table 2.2 for stabilizer plate surface area). This normalized data is then compared to the average soil index test data taken at the soil surface (6” to 12” depth) for the three sites (refer to Tables 3.2 through 3.4). The goal is to explore the potential existence of a useful correlation between soil index test methods and lateral resistance of the ground anchor and stabilizer plate assembly. If such a correlation exists, then it would be feasible to estimate ground anchor assembly lateral performance from soil index tests of a given site or to determine an appropriate stabilizer plate size to achieve a desired level of performance. This capability would also compliment the anchor design methodology described in the next analysis topic in Section 4.3 (“Design Method”).

Data shown in Figures 4.4 and 4.5 from this test program indicate that use of HP and TP soil index test methods provide a very poor correlation to lateral resistance of ground anchor assemblies for the limited range of soil surface conditions encountered at the three test sites. This finding agrees with literature reviewed in the Task 2c report [3]. However, the DCP measurements (Figure 4.6) at or near the soil surface do not have nearly the same scatter and this soil test method appears to give a more consistent and tightly grouped reading at each of the three test sites which agrees with the similar anchor assembly performance observed across the three sites. Thus, an average uniform lateral pressure of 2000 psf (COV = 0.12) acting on the stabilizer plate surface area can be related to DCP blow counts ranging from 5 to 7 blows per 1-3/4” at 12-inch depth for the three sites.

Given that the anchor lateral resistance must be at or near zero for a DCP reading of zero (barring any effect of the root network from vegetative ground cover), a linear fit is provided in Figure 4.6 as a hypothesis for relating ground anchor lateral performance to DCP blow count. Additional testing at sites with lesser and greater DCP blow counts at the ground surface (6” to 12” depth) should be conducted to verify and extend this relationship to DCP blow counts greater than 8 blows per 1-3/4” up to as much as 24 blows per 1-3/4” or more (e.g. Class 3 sites per HUD Code). However, as shown previously, soil index tests at the ground surface appear to be very sensitive to soil moisture content as influenced by antecedent rainfall (at least for cohesive or nearly cohesive soils such as the silt and clayey silt soils found at the Maryland sites). Therefore, the relationship shown in Figure 4.6 should be considered together with data on soil moisture at 12-inch depth shown in Table 3.5. The soil moisture condition associated with Figure 4.6 can be generally described as being “normally moist” (neither dry, nor saturated).

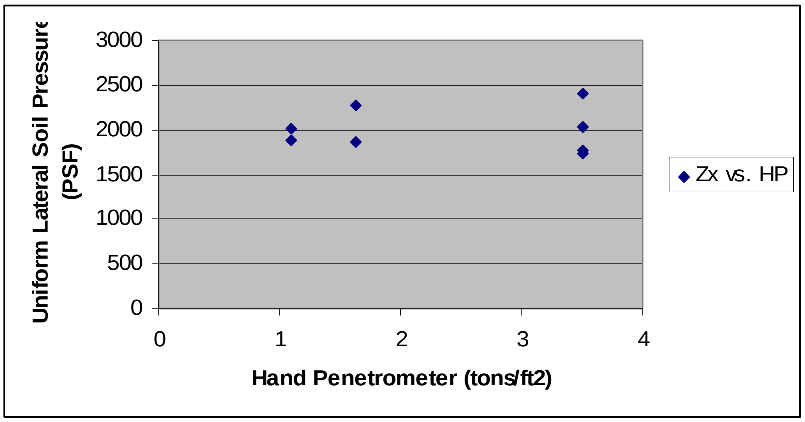


Figure 4.4. Scatter plot of Hand Penetrometer (Humbolt Model 4200) readings at 6" depth vs. lateral soil pressure acting on stabilizer plate based on assumed uniform pressure distribution over surface area of plate reacting horizontal component of angle pull force at anchor head.

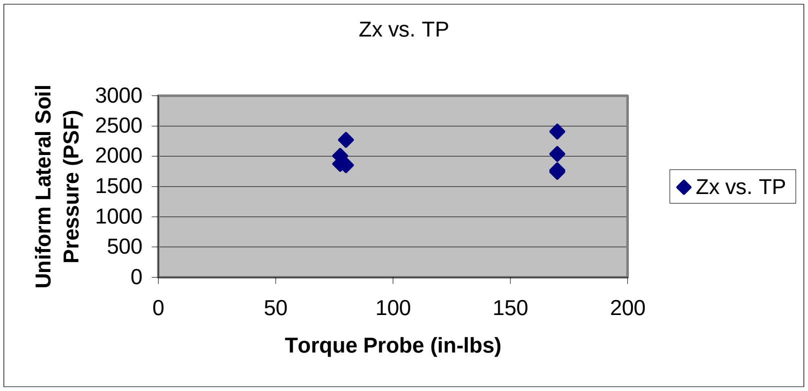


Figure 4.5. Scatter plot of Torque Probe readings at 12" depth vs. lateral soil pressure acting on stabilizer plate based on assumed uniform pressure distribution over surface area of plate reacting horizontal component of angle pull force at anchor head.

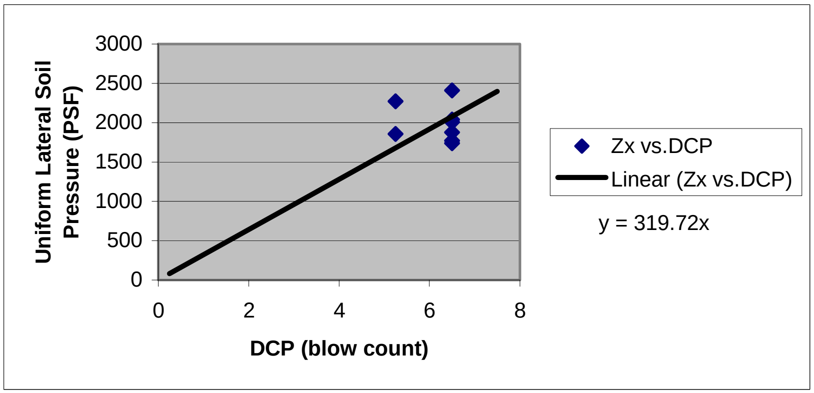


Figure 4.6. Scatter plot of DCP blow count at 12" depth vs. lateral soil pressure acting on stabilizer plate based on uniform pressure distribution over surface area of plate reacting horizontal component of angle pull force at anchor head.

In-Line (Axial) Pull Tests – In review of limited data on 90deg in-line vertical pull anchor configurations, the Torque Probe results exhibited a generally poor or inconclusive relationship to anchor vertical withdrawal performance (i.e., average Ultimate Anchor Load). However, the limited data does suggest the possibility of a non-linear trend of increasing anchor performance with increasing DCP value. This trend is illustrated in Figure 4.7, but warrants additional testing under a wider range of site conditions and DCP readings to confirm.

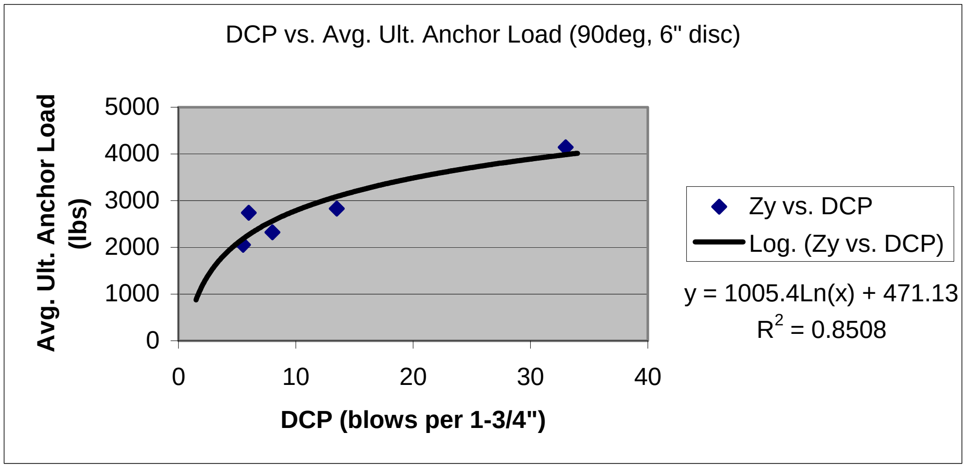


Figure 4.7. Illustration of a possible trend between DCP blow count and anchor 90 degree vertical withdrawal performance of 6” disc anchors (average Ultimate Anchor Load).

4.3 Design Method for Use of Anchor Performance Data

It is reasonable to believe that data from anchors tested in 90 degree axial loading and at 30 degree angle pull loading configurations can be used to determine anchor performance for any angle of pull ranging from 30 degrees to 90 degrees. This concept can be explored using data from Tables 3.7, 3.9, and 3.10 where the same anchor configuration was tested in 90 deg axial pull and at 30 degrees and 45 degrees for angle pull configurations. The approach uses simple engineering mechanics (force vectors and components) and is demonstrated as follows:

- From Table 3.7, the average[1] Ultimate Anchor Load value was found to be 2,325 lbs for 90 degree axial withdrawal (i.e., y-direction value for the anchor, P_y = 2,325 lbs)

- From Table 3.9, the average[1] Ultimate Anchor Load value was found to be 2,659 lbs for 30 degree angle pull. This corresponds to a horizontal force (x-direction) component of P_x = (2,659 lbs) x cos(30) = 2,303 lbs.

- The above two data representing the average performance capability (average[1] Ultimate Anchor Load) of the anchor in the horizontal and vertical directions of resistance can be used to predict anchor performance for a 45 degree angle pull as follows:

Predicted Average Ultimate[1]
Anchor Load at 45 deg = min [P_y/sin(45), P_x/cos(45)]

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[1] The average anchor performance is used in the context of determining an average trend in predicting anchor performance as would be appropriate for developing a calculation procedure as described in Section 4.3. However, for the purpose of qualifying anchor strength per the GAATP, the lowest value of n=6 tests is required.

= min [2325 lbs/sin(45), 2303 lbs/cos(45)]
= min [3162 lbs, 3257 lbs]
= 3,162 lbs

The tested average[1] Ultimate Anchor Load (Table 3.10) was 3,180 lbs which is within 22 lbs (less than 1%) of the prediction! While this single prediction is insufficient to draw any grand conclusions, it does demonstrate the feasibility of using two bounding test configurations to provide a means of accurately designing anchors in a multitude of intermediate configurations without having to test each of those configurations. An expanded effort should be considered to further evaluate and improve upon this concept because of its economic advantages in reducing cost of anchor qualification testing while extending its applications.

It should be noted that the above example purposefully used the average Ultimate Anchor Load value, not the lowest Ultimate Anchor Load value from each test group as required by the GAATP for the purpose of determining a lower-bound test value for establishing Working Anchor Loads (e.g., lowest Ultimate Anchor Load determined from n=6 tests divided by a safety factor). Therefore, when considering the above suggested design approach (based on average trends) for actual anchor design, the anchor value used should be the Working Anchor Load as determined from the GAATP.

5.0 Discussion

5.1 Impact of Soil Characterization Uncertainty

Several significant issues were confirmed in this study and relate to concerns with soil characterization methods used in the HUD Code [2] and the GAATP [1] for the purpose of ground anchor qualification testing and specification at end use sites. These are summarized as follows:

Unified Soil Classification (USC) – The test data from this study show that the USC method is a very poor indicator of ground anchor performance. In fact, it appears not to be related to ground anchor performance at any of the test sites. Warnings against the use of USC to specify ground anchors or qualify anchor test data was found in the literature [3]. In this study, all three test sites would be classified as ‘Class 3’ soils (if not ‘Class 2’ in one case) in accordance with the HUD Code soil classes based on USC soil classifications (see Table 3.1). However, the anchor test results and other soil index test methods clearly indicate Class 4B or 5 soils in most cases at the time of anchor testing at each of the three sites (see Tables 3.2 and 3.3). Thus, use of the USC method as the sole means of qualifying anchor tests and specifying anchors introduces significant uncertainty in predicting anchor performance rather than reducing it. For example, consider an anchor qualification test site with Class 4 soils on the basis of USC soil classification, but the in-situ condition of the soil is such that it is actually a Class 3 in terms of anchor performance. Next, consider an end-use site that is also classified as Class 4 on the basis of USC soil classification, but the in-situ density of the soil is such that it is actually a Class 5 site. On the basis of this soil classification scheme, each site is considered as a ‘Class 4’ soil. The anchor selection process then results in an anchor with a design value associated with a true

‘Class 3’ soil being used on a site with a true ‘Class 5’ soil. This describes the current situation in the HUD Code and GAATP and perhaps reflects common practice. This condition was observed in this project where true Class 4B or 5 sites were characterized as Class 2 or 3 as a result of using the USC method.

Thus, it is reasonable to conclude that current anchor usage on the basis of USC soil class alone easily results in uncertainty in anchor performance reflective of two soil classes as defined in the HUD code and GAATP. It is for this reason that a higher safety factor was recommended in Appendix C of the Task 2c report (see also Table 5.2 in Section 5.2) to provide reliable anchor performance when anchors are selected using only the USC method to characterize soil. In this case, the larger variability in anchor performance at end use sites introduced by the use of USC method to select an anchor is offset by a larger safety factor which is “tuned” to result in the same reliability that would be achieved by testing on the actual end use site and determining anchor design values with a much lower safety factor due to a significant reduction in the anchor’s performance variability at end use sites.

Because of the impact and lack of benefit in reducing variability in ground anchor performance, it would be far better to discontinue use of the USC classification method as a means of qualifying ground anchor data or selecting anchors for design purposes. However, it may be beneficial in a very limited and simplified form for the purpose of categorizing soils as cohesive or non-cohesive which could improve correlation to anchor performance when using DCP and TP soil index test methods, particularly since the performance of anchors and results of soil index tests in cohesive soils are very dependent on moisture conditions. As other soil index test methods discussed below demonstrate, it is far more important to know the in-situ strength of the soil than its particle size distribution for the purpose of ground anchorage design.

Torque Probe Method – Using torque probe readings to determine ground anchor lateral performance was shown to be as poor as relying on the USC method described above. While insufficient data was produced in this study to draw conclusions about the ability of the torque probe to predict anchor withdrawal performance, other data in the literature suggests that a correlation does exist, albeit with modest uncertainty [3]. Depending on soil moisture content, it can also result in a factor of 3 to 5 difference in torque readings taken at different times of the year for the same site (see Table 3.2). Thus, errors in soil classification in the magnitude of two HUD Code soil classes can result with the torque probe simply due to the soil moisture level at the time the test was conducted at a given site. This is a greater concern with readings taken in the very active zone of the soil (e.g., upper two to three feet). These issues need to be resolved before the torque probe can be used to significantly reduce uncertainties in shallow-depth anchor performance. It is for this reason that a modest level of variability in anchor performance was used to evaluate an appropriate safety factor for anchor design in Appendix C of the Task 2c report, even when a soil torque probe test is used to qualify an anchor design value and end-use site for purposes of anchor specification (see Table 5.2). This study further confirms the use of a modestly increased safety factor (1.8 instead of 1.5) when soil torque probe is used to characterize a test site for purposes of anchor design value qualification and an end-use site for anchor specification. However, a 1.5 safety factor appears suitable when limited only to anchors that have a helix placed deeper than the seasonally “active layer” of the soil (i.e., greater than about 3-feet deep) and when Ultimate Anchor Load is limited by deflection (i.e., no failure prior to reaching maximum deflection criteria in the GAATP).

Dynamic Cone Penetrometer (DCP) – Using the DCP method does not resolve the issue with variation in soil index test reading vs. moisture content as was also discussed above with the Torque Probe method. However, the DCP does provide a more consistent basis of soil characterization as shown in Table 3.3 for the three test sites under soil moisture conditions that occurred at the time of testing. It also showed potential for predicting anchor lateral performance (see Figure 4.6) whereas the torque probe did not (see Figure 4.5). Its potential to predict anchor withdrawal performance also seems promising (see Figure 4.7) and perhaps is at least as good as the Torque Probe in this regard. Furthermore, the variation in DCP blow count at each site seems to align much more closely with the level of variability observed in anchor tests at each site. However, much more data is needed to confirm these trends. Even so, the greater stability of DCP readings at the various sites in comparison to the torque probe and the ability to correlate DCP readings and Torque Probe readings (see Figure 3.10) suggests that it can be used in place of the torque probe with at least equivalent if not improved correlation to actual ground anchor performance.

Hand Penetrometer (HP) – The hand penetrometer provided little indication that it could be used to reliably predict ground anchor performance (lateral or withdrawal). However, its readings did seem to agree reasonably well with soil bearing pressures produced by the test rig (see Section 5.7 below).

5.2 Implications of Using Lowest Anchor Value with n=6 Tests

Assuming normality of the data, using the lowest value from n=6 tests should result in a test statistic that approximates the 10th-percentile of the data on average (see Task 2c Report, Appendix C). The lower-tail cumulative probability (or percentile or fractile) represented by the lowest tested Ultimate Anchor Load in each test series is shown in Table 5.1. It is noteworthy that the average of this value is 0.11 which is consistent with expectation. However, the actual probability was nearly twice this amount in two test series in Table 3.8. The lowest probability observed in three tests groups was 0.06 which was not quite one-half the expected probability. While some variability in defining a lower bound anchor performance value is introduced, using the lowest test value seems to be an adequate practice, especially given that any series of tests only includes 6 repetitions and variability due to other factors is not considered (e.g., site-to-site variability, anchor installation variability, etc.).

TABLE 5.1
Lower-tail Normal Probability of Lowest Anchor Ultimate Load and Anchor Working Load

Reference Data Table	Lower-Tail Probability of Lowest Anchor Ultimate Load	Lower-Tail Probability of Anchor Working Load (Safety Factor = 1.5)	Lower-Tail Probability of Anchor Working Load (Safety Factor = 1.1)
Table 3.6			
Davidsonville	0.08	0.00037	0.025
Cambridge	0.10	0.00099	0.039
Georgia	0.17	0.00022	0.048

Table 3.7 (Georgia)	0.06	0.000007	0.010
Table 3.8			
Davidsonville1	0.09	0.0000005	0.011
Davidsonville2	0.19	0.000084	0.049
Cambridge	0.20	0.000003	0.032
Georgia	0.15	0.000000…	0.005
Table 3.9 (Georgia)	0.06	0.00006	0.015
Table 3.10 (Georgia)	0.06	0.000000…	0.002
Table 3.11 (Cambridge)	0.08	0.00000007	0.007
Average:	0.11	0.00016	0.030
Range (+/- 1 std dev):	0.05 to 0.16	0.0… to 0.0005	0.003 to 0.057

The lower-tail cumulative probability associated with the Working Anchor Load (derived by dividing the lowest Ultimate Anchor Load in n=6 tests by a safety factor of 1.5) varied much more widely as shown in Table 5.1. However, on average the lower-tail normal probability of the Anchor Working Load value was 0.00016 with a safety factor of 1.5 applied to the lowest Ultimate Anchor Load. Thus, on average and in theory, about 16/100,000 anchors might be expected to fail at loads equal to or less than the Working Anchor Load, which is fairly conservative. Consequently, the use of a safety factor of 1.1 applied to the lowest Ultimate Anchor Load from n=6 tests results in a lower-tail normal probability of 0.030 on average and no greater than about 0.057 within one standard deviation of the average. Interestingly, this finding is consistent with the reliability analysis and safety factor recommendations in Appendix C of the Task 2c report [3]. The reliability analysis was based on achieving a probability of failure (exceedance of strength or deflection limit state) at the Anchor Working Load which is consistent with the reliability of the steel anchor straps. Thus, a target reliability for the Working Anchor Load (design value) was found to be 0.05.

T*his test program shows that for anchors qualified at a particular site and used on that site (e.g., testing done following the GAATP at an end-use site), a safety factor of 1.1 applied to the lowest Ultimate Anchor Load from n=6 tests results in an Working Anchor Load with an adequate level of reliability.* However, when test results at one site are used to select anchors for use at another site on the basis of correlation of soil index tests, additional sources of variability are introduced and the safety factors must be increased to account for this effect in the process of specifying anchors when the anchors are not tested at the end-use site. In summary, this test program confirms the safety factor recommendations from Appendix C of the Task 2c report (see Table 5.2 below). In addition, the recommended safety factors implicitly account for the “installation quality factor” discussed previously (see Section 2.5) by use of a higher-bound variability of anchor performance (COV) in comparison to variability observed in this study and in the literature [3].

TABLE 5.2
Recommended Anchor Safety Factors based on Soil Classification Method used for Anchor Qualification Testing and Anchor Selection at End-use Sites

Recommended Safety Factor (applied to lowest ultimate anchor load in 6 test reps)[1]	Soil Classification Approach Used for Selection of Anchors at End-Use Sites	Estimated Variability in Anchor Performance (COV)[2]
1.1	Anchors tested per GAATP at end-use site (no soil classification required)	0.20 (or 20%)
1.8(3)	Anchors selected on basis of correlating soil index test at end-use site to similar value at	0.35 (or 35%)

	anchor qualification test sites (e.g., DCP or TP values)	
4.3	Anchors selected only on basis of correlating soil particle size distribution at end use site to select anchor design value based on qualification testing at a similar site (e.g., Unified Soil Classification System)	0.50 (or 50%)

Table Notes:

1. Safety factors represent a consistent level of anchor performance, similar to that achieved by metal strapping used to attach the anchors to the manufactured home, based on differences in anchor performance variability at end-use sites as a result of different soil classification approaches.
2. COV = coefficient of variation; a measure of variability determined by dividing the standard deviation by the average of the data. As COV increases, it represents a larger dispersion (scatter) of the data about the mean or average of the data.
3. For anchors placed greater than 3 feet in depth measured to the lowest anchor helix, a safety factor of 1.5 may be used provided Ultimate Anchor Load is limited by deflection and resistance continues to increase up to the maximum deflection criteria.

In addition to the probability implications discussed above, using the lowest anchor value to define anchor performance for design purposes also has some implications on stiffness or deflection performance of the anchors. Because the least stiff anchor is used to establish the Ultimate Anchor Load based on a 2" vertical or 3" horizontal displacement limit per the GAATP, the average displacement when multiple anchors are used in parallel to resist load will always be less than the displacement limit. For example, Table 3.7 shows that the average vertical displacement of the anchor head at the lowest Ultimate Test Load (which is the Ultimate Anchor Load) was 1.36 inches. Furthermore, the vertical displacement at the Working Anchor Load was 0.58 inches. Similarly, for Table 3.8 (Davidsonville Site, Dual Anchor Pull), the horizontal displacement of the anchor establishing the Ultimate Anchor Load was 3 inches, but the average displacement of all anchors (n=6) at the Ultimate Anchor Load was 2.37 inches. The average horizontal displacement at the Working Anchor Load was 1.08 inches. This effect is also apparent when the Ultimate Anchor Load is defined by strength rather than stiffness as in Table 3.6 and Figure 3.1 where all anchors reach their peak capacity prior to experiencing the deflection limits established by the GAATP.

When anchors are used in a parallel system where anchors may be caused to displace uniformly, the deflection when the Working Anchor Load is achieved on average for all anchors sharing the load will be less than the GAATP's deflection limits. This should be considered a serviceability benefit of using the lowest performing anchor of n=6 tests. However, it can also be used as a basis for some latitude in defining appropriate safety factors for anchors that provide increasing resistance beyond the required deflection limits. For example, this rationale could be used along with judgment to justify using a safety factor 1.5 for anchors that exhibit increasing or sustained load carrying capability past their peak capacity, whereas anchors that fail in a more abrupt fashion prior to reaching deflection limits would be assigned a safety factor of 1.8. This approach would provide some incentive to place anchors deeper in the soil with a rational and justified reward for improving the post-Ultimate Anchor Load performance of anchors (i.e., see footnote 3 in Table 5.2 above). This practice will also benefit performance of anchorage systems that rely on load sharing between individual anchors that have different (variable) stiffness characteristics.

Finally, the use of the lowest Ultimate Anchor Load value to determine anchor performance for design purposes can result in one anomalously low performing anchor in the test set having a disproportionate effect on the anchor evaluation; however, it may also help to account for sources of variability not accounted for in the small sample size at a single site. These sources of variability may include factors related to anchor installation, soil moisture effects, or localized ground variations. However, the use of the lowest Ultimate Anchor Load from n=6 tests does a reasonable job of estimating the 10th-percentile anchor ultimate load value. It also avoids problems of using a statistical approach to determine lower bound performance without knowing the actual distributional form which can result in very erroneous estimates of lower-bound anchor performance, particularly when attempting to gain a perceived high level of confidence in a lower bound estimate with limited test data (e.g., 90% confidence estimate of the lower 10th percentile of anchor performance). Therefore, from the viewpoint of simplicity and practicality, using the lowest anchor value from n=6 tests as required in the GAATP is quite reasonable.

5.3 Performance vs. Prescriptive Anchor Load Targets

Of all sites and anchors tested in the 90 degree axial load configuration, only one of the 90 degree axial load anchors (Table 3.12) actually satisfied the HUD Code's prescriptive performance target of 4,725 lbs (Ultimate Anchor Load at 2" vertical displacement). This was a single exploratory test using a large anchor (HP860). Similarly, none of the angle pull tests met the prescriptive anchor performance targets of 4,725 lbs (Ultimate Anchor Load at ≤3" horizontal displacement or ≤2" vertical displacement) or 3,150 lbs (Working Anchor Load at ≤2" total displacement).

- From the standpoint of site soil conditions (Class 4B or Class 5 soils in most cases), the anchors as a whole provided useable and consistent performance in the broader context of a performance-based design approach. For example, the anchors tested for 90 degree axial withdrawal in Table 3.6 provided a performance-based Working Anchor Load of at least 1,217 lbs (which was the lowest Working Anchor Load value observed of any of the 90 degree axial load tests at all three sites). Bearing in mind that the MM4636 anchor's 6" disc was only 24 inches below ground surface in a loose sandy soil or moist clayey silt soil, this level of performance is somewhat amazing. Furthermore, the average vertical displacement of these anchors at their Working Anchor Load values was found to be 0.25 inches. Well below the HUD Code's prescriptive displacement limits. Thus, with proper design, these anchors can provide performance that, in terms of stiffness, exceeds the HUD Code requirements. Proper design would dictate that these anchor be spaced more closely than anchors designed assuming a prescribed Working Anchor Load of 3,150 lbs. For example, if a design based on a 3,150 lbs Working Anchor Load required a 10-foot anchor spacing, an anchor with a Working Anchor Load of 1,217 lbs would require a spacing of about 4 feet on center (i.e., 1,217 lbs / 3,150 lbs = 0.4 and 0.4 x 10 feet = 4 feet). Similar performance-based applications of all the anchors tested can be made and will result in anchor performance that exceeds the intent of the HUD Code when tested as in this study and in accordance with the GAATP. However, the distance between adjacent anchors should be prescriptively limited to approximately the lesser of 1.5 times the anchor helix depth or 9 times the anchor helix diameter. This limitation is needed to avoid overlapping "cone of influence" in the soil resisting anchor forces which would reduce anchor performance (i.e., a group action effect such as experienced in pile foundations and other similar engineering applications).

5.4 Single Anchor vs. Dual Anchor Angle Pull Tests

At the Davidsonville, MD site, angle pull tests were done using a single anchor set-up (where a stronger anchor is used as a dead-man and only the "test anchor" is monitored) and also a dual anchor set-up (both anchors are "test anchors" and both are monitored). The results of these comparative tests were shown in Table 3.8. The resulting Working Anchor Load determined from six anchors tested with each set-up was within 50 lbs of each other (or +/- 2 percent from the mean of both anchor groups). The average Ultimate Anchor Loads were within 3 percent of each other for the two anchor groups. Thus, it can be concluded that the two test set-ups for angle pull testing produce consistent results. Because load is applied to two anchors just as it would be applied to a single anchor by any other test rig, there is no reason to expect a difference. The only source of difference in result may occur when one anchor in a dual anchor test is significantly less stiff than the other. Then the displacement of the actuator will cause mainly the less stiff anchor to move and at a higher displacement rate than would have otherwise occurred. However, at the displacement rates observed in this study (0.3 to 0.6 inches/min), this concern appears to have a negligible impact on consistency and repeatability of test results.

5.5 Test Rig Comparison Tests

As mentioned, duplicate anchor tests were done at the Georgia site (see Table 2.1) using a manufacturer's existing test rig (see Figure 5.1 below). The results of these tests using an alternate test rig are reported in this section only and are not intermingled with other test results reported elsewhere in this report. The rig is a simple lever arm mechanism that allows load form a vehicle-mounted winch to be directed at angles ranging from "almost vertical" to 30 degrees or less. The major differences in this test rig were related to: (1) lack of load or displacement rate control resulting in pulses of anchor movement, (2) lack of a stable reaction anchorage such that when load was paused to allow for relaxation after a pulse of movement the reaction "creeps" as well as the soil at the test anchor, and (3) the foot of the lever arm mechanism appeared to be located within the "cone of influence" of the anchor, mainly for vertical withdrawal tests and anchors greater than 3-feet in depth. In contrast, the test rig developed for this test program provided very even displacement control and solid support for stable anchorage load and deflection readings. The feet of the test stand were also spread wide enough such that up to 5-foot long anchors may be tested without concern with affecting the "cone of influence" of test anchors.

Despite the above contrasts between the test rigs and some difficulty in consistently recording data for the lever arm test rig (mainly associated with the lack of constant load rate or displacement rate control), the results for the two test rigs were reasonably similar and are compared in Table 5.3. The test procedure used with the lever arm test rig (not necessarily the rig itself) tended to produce higher anchor values than the "project rig" used in this study, especially when comparing to "instantaneous" readings after advancing an anchor at a momentarily high displacement rate due to "pulsing" the winch used as an actuator. These "instantaneous" loads were generally about 400 lbs (or 20 percent) higher in terms of the lowest Ultimate Anchor Loads reported. However, the "sustained" load from the lever-arm test rig was very similar to that of the test rig used in this study when comparing lowest Ultimate Anchor Loads (generally within +/- 200 lbs or +/- 10%).

It was reported that it is common practice to read the Ultimate Anchor Load as an “instantaneous” load rather than a sustained load or one arrived at through constant and moderate displacement rate. This practice should be avoided for reason of lack of accounting for creep effects and introduction of a dynamic response which both serve to artificially increase the anchor resistance. It also creates uncertainty in making accurate visual readings of load and manual measurements of anchor displacement. The lever arm test rig, procedure, and repeatability of results could be significantly improved by incorporating a speed control (e.g., DC motor controller) on the electric winch used as the actuator. Outside of this one significant and easily remedied concern, the simplicity of the lever arm test rig and its ability to test a variety of anchor configurations is commendable.

While the above comparative tests generally confirm that significantly different test rigs can produce similar results, it also demonstrates the importance of maintaining a constant and smooth load application to facilitate repeatable test results and avoid variable load rate effects that may bias anchor performance by as much as 20 percent (compared to an evenly and slowly applied loading). Thus, the importance of requirements in the GAATP to apply a constantly increasing load is confirmed. The only thing the GAATP lacks in this regard is a guideline on the range of acceptable displacement rates. Based on testing conducted for this study, a maximum displacement rate of about 0.6 inches per minute is recommended for reasons given previously and also given in the literature [3].

Figure 5.1. Lever Arm Test Rig (Tie Down Engineering, Inc.)

TABLE 5.3
Comparison of Test Rig Results at Georgia Site

Anchor Test	Anchor Assembly	Project Test Rig		Lever Arm Test Rig[1]			
		~0.5”/min displ. rate		Instantaneous		1-2min Sustained	
		Avg Ult	Lowest Ult	Avg Ult	Lowest Ult	Avg Ult.	Lowest Ult.
90 deg Axial Pull	MM4636	2054 lbs	1825 lbs	2438 lbs	2200 lbs	2067 lbs	1900 lbs
	MM650	2325 lbs	1950 lbs	2904 lbs	2500 lbs	2456 lbs	2096 lbs
30 deg Angle Pull	MM4636+MM12	2225 lbs	2100 lbs	2550 lbs	--	2190 lbs	1919 lbs
	MM650+TD17	2659 lbs	2175 lbs	3271 lbs	2857 lbs	3000 lbs	2575 lbs

Table Note:

1. Some data were missing from the data sheets for the lever arm test rig such that not all data reported in this section of table are based on a n=6 sample size.

5.6 GAATP Test Procedure Clarifications & Modifications

Based on the various tests and experience gained from this field testing and GAATP verification exercise, several areas of improvement to the GAATP were identified:

- *Test Duration and Displacement Rate* – The requirement for a minimum 2 minute test duration is vague and subject to varied interpretation. It should be clarified that this duration reflects the time from start to the point at which the anchor reaches one of the prescribed strength or displacement limit states (i.e., “failure criteria”). Furthermore, the clarity of the GAATP and repeatability of tests may be improved by specifying a recommended maximum displacement rate of 0.6 inches per minute.
- *Anchor Pre-tension Practice* – The GAATP should be modified to allow a load as great as 1,000 lbs to set the anchor shaft to stabilizer plate for angle pull test configurations. This may also include light tapping of the anchor head to help it move snuggly against the stabilizer plate. After “setting” the anchor, the set load should be released and then the maximum 500 lb pre-tension load applied and deflection readings zeroed at the start of the test. While this may improve anchor performance and exceed normal installation practice, it will greatly improve the repeatability of anchor test results from the GAATP test procedure. As mentioned, the affect of installation quality at actual end-use sites can be accounted for in the safety factor as was done for the safety factors recommended in Table 5.2.
- *Anchor Installation Practice* – The GAATP should be clarified in regard to anchor and stabilizer plate installation practice. The bottom of anchor heads should be driven flush with the ground surface or no more than 1” below the ground surface. Stabilizer plates should be driven flush with the ground surface or no more than 1” below the ground surface. The gap between the anchor head and stabilizer plate should not be more than ¾”.
- *Deflection and Load Measurement* – The precision of deflection measurements should be changed to allow for plus or minus 1/16-inch precision. Similarly load measurements should be changed to allow +/- 5% precision in load readings (e.g., +/- 50 lbs at 1,000 lb load). A greater level of precision would unnecessarily prevent simple manual measurements and would also exceed a level of precision commensurate with all uncertainties involved in actual ground anchor performance not accounted for in the GAATP or better accounted for in the selection of appropriate safety factors.
- *Soil Characterization* – There are many uncertainties with regard to how a particular site’s soils are to be characterized (which soil index test method to be used, what depth to test, how many borings and at what locations, etc.). In addition there are many uncertainties associated with any given soil characterization test or method. These were discussed earlier and will not be repeated here. Several clarifications and improvements are needed in this area of the GAATP as well as the HUD Code. One worth mentioning again is that the Unified Soil Classification System should not be used as a means to characterize site soils for the purpose of anchor qualification testing or specification at an end-use site. In addition, the Dynamic Cone Penetrometer (DCP) method should be favored over use of the Standard Penetration Test (SPT) currently recognized in the HUD Code and GAATP for reasons given herein and in the literature [3].

- *Safety Factors* – For reasons given in this report (see Section 5.2) and in the Task 2c report [3], safety factors should be revised to encourage the benefits of doing anchor qualifications tests at end-use sites (resulting in a lower safety factor of 1.1 applied with the GAATP failure criteria) and appropriately account for variability when visual or particle size soil characterization is used for ground anchor specification at an end-use site (resulting in a safety factor of 4). A safety factor of 1.8 is adequate for situations where anchors are tested or selected on the basis of site characterizations using the DCP or TP soil index test methods, assuming reasonably "normal" soil moisture conditions are present at the time of soil characterization. As mentioned, a safety factor of 1.5 appears adequate for anchors that extend below the seasonally active layer of soil and that do not fail abruptly prior to reaching maximum deflection limits required in the GAATP. The seasonal active layer of the soil is the depth of soil at the surface that changes properties (i.e., moisture content and related structural properties) with seasonal changes in climate.
- *Data Collection and Processing* – The GAATP appears adequate in this area. However, in this test program it was often necessary to interpolate between data points. Given the shape of load displacement curves this should always result in a conservative intermediate data point between those that are actually recorded. However, the GAATP does not clearly indicate that interpolation between data points is an acceptable practice.
- *Test Rig* – The GAATP should provide greater guidance on test rig operational and functional features that are important to repeatability of tests. For example, the test rig should be constructed such that the angle of pull during an angle-pull anchor test does not change by more than +/- 2 degrees from the targeted angle of pull (see Figure 3.5 for an indication of the effect of variation in angle of pull on stiffness and strength of anchor performance). In addition, specific guidance should be provided in regard to allowable proximity of reaction supports to the "cone of influence" of a tested anchor. It is recommended that the ground reaction(s) applied through the test stand should not be placed any closer to the anchor head than the lesser of 5 times the anchor helix diameter or 2/3rds of the depth below ground to the upper-most helix on the anchor shaft.
- *Other Items* – Several other items were also identified in the Task 2c report as a part of this overall project [3]. The reader is referred to that report for additional considerations and recommendations related to improving the GAATP.

5.7 Use of Test Rig for Soil Bearing Pressure Verification

As mentioned, the four 6"x6" steel footing pads on the legs of the test stand provide a total of 1 square foot of bearing area for the test rig to react the test rig weight and applied forces to tested ground anchorage devices. Thus, by adding the weight of the test rig (approximately 600 lbs) to the vertical component of the force applied to the anchor(s), the applied soil bearing pressure can be determined. Additional footing blocks were applied only rarely to level the test rig, so most of the tests conducted in this study may also be used as a "proof test" of the surface bearing capacity of soils at the three test sites. In no case were soil bearing "failures" observed; however, slight depressions (e.g., usually no more than ~1/2") were observable at the footing pad locations after testing in some cases. This settlement of the test rig probably accounted for most of the variation in displacement rate applied to the tested anchors discussed earlier. Examples of the maximum bearing pressures caused by the test rig reaction at each site are as follows:

- Davidsonville, MD Site (Table 3.6) [2743 lbs + 600 lbs]/1ft^2 = 3,343 psf
- Cambridge, MD Site (Figure 3.6) [2sin(45)(5,100 lbs) + 600 lbs]/1ft^2 = 7,812 psf
- Clyo, GA Site (Figure 3.8) [2sin(45)(5,200 lbs) + 600 lbs]/1ft^2 = 7,954 psf

It is interesting to compare this data with the Hand Penetrometer (HP) and Dynamic Cone Penetrometer (DCP) data at the depths of 6” to 12” below the soil surface, especially for the Cambridge, MD and Clyo, GA sites (see Tables 3.3 and 3.4). Thus, a DCP blow count of 8 may correspond to roughly 8,000 psf of ultimate soil bearing capacity based on the Georgia site for a short test duration. Similarly, the hand penetrometer reading of 3.5 tons/ft^2 at the Georgia site seems to agree well with this data. But, the reading of 1.5 tons/ft^2 at the Cambridge site is conservative by more than a factor of 2, perhaps due to the more plastic and moist condition of the soil at the time of testing that affected the HP reading due to its small tip (1/4” diameter, 0.05 in^2 bearing area). Use of a larger adapter foot (1” diameter, 0.78 in^2 bearing area) on the hand penetrometer may have resulted in better agreement.

5.8 Miscellaneous Topics

The GAATP is silent on the effect of time span between anchor installation and anchor testing. This is an area where little data exists to guide an appropriate decision. All testing done in this project was within one to 1-1/2 days from the time of anchor installation. This may have resulted in some failure modes (e.g., anchor hole or core withdrawal in 90 deg axial withdrawal tests) which might not have occurred with a longer time between anchor installation and testing. However, it is unclear what affect, if any, this may have had on the recorded anchor performance. This topic deserves further research as time effects will likely affect tested anchor performance. No recommendation for the GAATP is made at this time.

It is also interesting to consider that ground cover (e.g., vegetative root mass) may have a natural “geo-grid” effect on soil behavior that affects anchor performance, particularly in weaker soils. There is no known data addressing this issue. However, it is an issue that may deserve future study. No recommendation for the GAATP is made at this time.

As found in this study, soil moisture content appears to have a dramatic effect on soil index testing and, thus, anchor performance (mainly for fine grained soils with cohesive or nearly cohesive (plastic) behavior). The GAATP is silent on this issue but should include at least some guidance on suitable soil moisture conditions for testing purposes or soil characterization purposes. For example, it should be stated that soil tests and ground anchor tests should be performed under soil moisture conditions that are considered typical to the local climate and geology (e.g. moist, but neither dry nor saturated). More work is needed on this issue to provide better guidance on this important issue, especially for shallow laterally loaded anchor assemblies.

6.0 Conclusions

The following conclusions are based on the findings of this study:

1. The test rig developed for this test program performed efficiently and reliably and produced repeatable and very consistent anchor performance results (refer to Sections 2.3 and 3.0).
2. Various improvements to GAATP test procedures, employed in this study, improved repeatability and practicality of ground anchor testing (refer to Section 5.6).
3. The basic failure criteria and use of the lowest performing anchor in a series of 6 test repetitions results in a reasonably reliable Working Anchor Load consistent with safety factors as analyzed and variability as predicted in Appendix C of the Task 2c report and verified in this study (refer to Section 5.2).
4. Safety factors recommended in Table 5.2 should be employed in the GAATP to ensure reliable and adequate anchor performance in accordance with varying levels of uncertainty with different soil characterization methods (refer to Sections 5.1 and 5.2).
5. It is possible to correlate soil index tests methods such that ground anchor selections can be made using either the Torque Probe or the Dynamic Cone Penetrometer (refer to Section 4.1).
6. The hand-held penetrometer and Torque Probe were not as consistent in characterizing site soils and did not provide the level of correlation to anchor performance observed with the Dynamic Cone Penetrometer method. A relationship to predict the lateral resistance of stabilizer plates using the DCP method appears feasible with further study (refer to Section 4.2). The use of HP and TP soil index test methods provided a very poor correlation to lateral resistance of ground anchor assemblies for the limit range of soil surface conditions encountered at the three test sites.
7. Using Unified Soil Classification of soils provided no apparent relationship to anchor performance and gave misleading HUD Code soil classes for the three sites (too high by as much as 3 soil classes compared to TP and DCP results).
8. It appears very feasible to design ground anchors for a variety of applications and angles of pull by characterizing anchor horizontal and vertical force resistance in two bounding configurations (e.g., 90 degree axial withdrawal and 30 degree angle pull) (refer to Section 4.3)
9. With similar load application procedures (e.g., controlled displacement rate), a variety of test rigs should be able to achieve consistent and repeatable results (refer to Section 5.5).
10. Anchor performance is influenced by load or displacement rate and can result in anchor values as much as 20 percent higher in comparison to tests conducted at a moderate and evenly controlled rate of displacement (e.g., maximum 0.5 to 0.6 inches per minute) (refer to Section 2.5 and 5.5).
11. Anchor installation, “setting”, and pre-tensioning procedures have an important influence on the repeatability and consistency of anchor test results (refer to Sections 2.4 and 2.5 and data in Section 3.0).
12. Soil index tests are significantly altered by “point-in-time” soil moisture conditions such that a given site may be characterized as Class 3 at one time and Class 5 at another, depending on depth of measurement and antecedent rainfall conditions, particularly for sites with fine-grained, plastic soils. This significant source of variability in classifying soils can result in

overly conservative or non-conservative errors in anchor specification at end use sites (refer to Section 5.1).

13. Only one anchor satisfied the HUD Code's and GAATP's prescriptive Ultimate Anchor Load and Working Anchor Load requirements. However, all anchors performed with reasonable consistency and can be safely used provided design values are established using performance requirements as implied by the GAATP's failure criteria (provided the prescriptive load values are wavered when a performance-based design approach is used to determine anchor spacing and size). In this approach, however, a prescriptive limit on the minimum spacing of anchors is needed to avoid reduction of anchor performance due to an overlapping "cone of influence" in the soil (Refer to Section 5.3).
14. The test rig used in this study can be used effectively to provide "proof load" tests of soil bearing capacity in addition to testing of ground anchorage devices (refer to Section 5.7).

7.0 Recommendations

The following recommendations are based on the findings of this study:

1. Several important clarifications and improvements to the GAATP should be considered in view of the recommendations made in Section 5.6 of this report and also in the Task 2c report [3].
2. Additional testing work should be conducted at a wider range of site soil conditions to improve the anchor design methodologies and soil index test correlations found to have merit in this study (refer to Section 4.0).
3. Soil moisture effects on anchor performance and soil index tests, and the ability to relate the two should be conducted on cohesive and non-cohesive sites to establish guidelines that better account for and control variability in anchor performance or anchor specification (via end use soil characterization) due to time-varying soil moisture effects.

One additional item worth mentioning as a recommendation for future consideration is related to the bigger picture of achieving affordability and safety in foundation anchorage of manufactured homes through extended use of performance-based design principles. The GAATP can serve this purpose in terms of accurately defining anchor resistance or strength under properly characterized ground conditions (or on a site-specific anchor testing basis). However, the overall efficiency of performance-based design also relies on the accurate determination of probabilistic design loads. Thus, it is important to consider the value of conducting a site assessment of wind exposure for the purpose of characterizing a site-specific design wind load (just as a site's soil may be characterized for the purpose of determining an anchor's rated strength value). Wind loads in the HUD Code are purposefully and conservatively based on open wind exposure to ensure that manufactured units have adequate strength irrespective of the final site location and wind exposure condition. However, at some time prior to actual installation, the site is known and an assessment of wind exposure could be conducted to make a final determination of anchorage requirements (e.g., anchor spacing or anchor size). This design activity can be particularly cost-effective for development sites with many units. It can also be done safely and reliably provided the assessment is done by a qualified professional. Such an assessment can result in wind load reductions of 30 percent or more which could reduce anchor installation costs substantially and offset the additional engineering cost of executing a performance-based design approach [4,5]. This practice may be especially helpful in arriving at practical and safe anchorage designs given that the tests conducted in this study using the GAATP indicate that many typical anchors in typical soil conditions may not provide the standard 3,150 lb working load traditionally required by the HUD Code.

8.0 References

[1] GAATP. 2005. *Ground Anchor Assembly Test Protocol* (Draft), Manufactured Housing Consensus Committee Installation Subcommittee, August 12, 2005.

[2] MMHIS. 2007. *Model Manufactured Home Installation Standards: Final Rule* (24 CFR Part 3285), published in Federal Register on October 19, 2007. (Effective October 20, 2008)

[3] *Task 2c – Verification of Applied Engineering Principles and Sound Engineering Judgment*, Interim Report, prepared by Steven Winter Associates for U.S. Department of Housing and Urban Development, Washington, DC. July 13, 2006. (HUD Contract No. C-CHI-00830)

[4] ASCE. 2006. *Residential Building Loads, Review and roadmap for future progress*. J. H. Crandell, T.M. Kenney, and D.V. Rosowsky (Eds.), American Society of Civil Engineers, Reston, VA.

[5] ASCE. 2005. *Minimum Design Loads for Buildings and Other Structures*. American Society of Civil Engineers, Reston, VA.

APPENDIX A

Test Rig Components and Equipment

- Test Stand (steel frame, pulleys, and screw jack mounting bracket)
- 10 ton Screw Jack (Nook Industries, Actionjac Model 10-MSJ with 20:1 gear, DC Drive Motor, and Controller)
- 115v AC generator and power cords
- 3/8” wire rope (50’), clevises (2), and misc. hardware for attachment to anchors and load gauges
- 8,000 lb Dial Load Gauges (2) (Dillon Mechanical Dynamometer, 50-lb increments)

Soil Testing/Characterization Equipment & Supplies

- Soil Torque Probe and torque wrench
- Dynamic Cone Penetrometer and Soil Auger (Duram Model S-200)
- Hand-held Penetrometer (Humbolt Model H4200)
- Soil Sample Baggies (heavy-duty Zip-lock freezer bags)

Anchor Installation Equipment

- 115v Electric Anchor Driver and Brackets (also used to drive torque probe into ground)
- 6 lb Sledge Hammer and wood block (to drive stabilizer plates into ground)
- Post hole digger (to remove anchors or dig holes to ½ anchor depth where anchors meet refusal)
- Tamping/digging bar (to compact holes when anchor installation requires pre-digging)

Miscellaneous Equipment & Materials to Set-up and Operate Test Rig

- Stop Watch (measure test duration and individual reading times)
- Wood blocks/shims (to level test rig legs on uneven ground)
- Concrete Form Stakes (4) (to set up angle pull displacement measurement)
- 4-foot metal rulers (2) (to set up angle pull displacement measurement)
- 2” C-clamps (4) for attaching 4-foot ruler to concrete form stakes
- 12” adjustable carpenters square (2) (for anchor head deflection measurement)
- 1”x1”x6-foot metal angle and two stakes (for 90 deg axial pull deflection measurement)
- Permanent marker (labeling soil sample baggies, etc.)
- Ground marker paint & flags (for site set-up and anchor locations)
- String line (for site anchor layout and horizontal alignment of 4-foot rulers with a horizontal plain defined by the base of test rig for angle pull deflection measurement)
- Tape measures (100’ and 25’)
- Shovel & small spade
- Mechanics tool box (wrenches, etc.)

APPENDIX B

Sample Test Data Collection Sheet

Date:____________________________

Location: ____

____

Technician(s): ____

Weather Conditions/Temperature:_____________________________________

Soil Characterization:

- Soil Moisture Content:_________________________(sample for test lab)*
- ASTM D2487 (USC Classification): _____________(sample for test lab)*
- ASTM D2488 (Visual/Manual):_________________(on site classification)*
- Soil Torque Probe Reading:______________________(on site measurement)*
- DCP reading (blows/1-3/4” penetration):___________(on site measurement)*
- Hand Penetrometer (surface & 6” depth):___________(on site measurement)

* take soil samples and readings at 12” and at anchor depth (36” or 48”)

Anchor Manufacturer:________________________________

Anchor Size & Model No.:____________________________

Stabilizer Plate Size & Model No.:_____________________

Test/Anchor/Site Sketch:

Comments:

Anchor Load-Deflection Test Data Record

Test Configuration: Angle of Pull (deg):

Load Rate:________________ (25% typical; 35% max)
Anchor Set Load:_______________lbs (1,000 lbs max) – as required to set anchor shaft to stabilizer plate
Pretension Load: _______________lbs (500 lbs typical) – as required at start of test
Start Time: 0:00 (after set load and then pre-tension) End Time:___________

ANCHOR ID:______________________________

Reading No.	ANCHOR A			ANCHOR B (dual anchor test only)			Reading Time (m:ss)	
	Load (lbs)	Vert. Disp. (in)	Horiz. Disp. (in)	Load (lbs)	Vert. Disp. (in)	Horiz. Disp. (in)		
1								
2								
3								
4								
5								
6								
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COMMENTS: