Research and Analysis for
Manufactured Housing Foundations

Reports:

2a: Preliminary Review of Protocol and Related Literature

2b: Search and Review of State Requirements

2c: Verification of Applied Engineering Principles and
Sound Engineering Judgement

Prepared for

U.S. Department of Housing and Urban Development
Washington, DC

Prepared by

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U.S. Department of Housing and Urban Development
INTERIM REPORT

Report Date:	**1-31-2006**
Description:	**Research and Analysis for Manufactured Housing Foundations**
Report Scope:	**Task 2a – Preliminary Review of Protocol and Related Literature**
Contact:	**William Zoeller, Senior Associate Steven Winter Associates, Inc., Norwalk, CT wzoeller@swinter.com**

I. OVERVIEW OF TASK REQUIREMENTS

A preliminary review of the MHCC draft protocol was accomplished along with related literature with the hopes of identifying key issues which shall prove to be imperative in development of ground anchor and testing protocols. There appear to be few "outside" precedents against which to measure the MHCC protocol. Therefore, the only available precedent is the credible independent analysis of a neutral party in consideration of past industry practice represented by housing manufacturers, anchor producers, design professionals, and general or professional experience.

To validate this work a review of related literature in the following categories were conducted:

- Foundation Installation Guides
- Earthquake Related
- Comparative Performance Criteria
- Performance Evaluations & Recommendations
- Test Reports on Conventional Ground Anchor Systems
- Test Reports on Alternative Anchorage Systems

The review of related literature was catalogued and summarized highlighting the significant points and data that will provide insight to future tasks. This summary can be found in Section II.

II. SUMMARY OF FINDINGS

Foundation Installation Guides

Permanent Foundations Guide for Manufactured Housing, U.S. Dept. of Housing and Urban Development, Washington, DC. September 1996.

> *Design criteria and prescriptive design solutions for permanent foundations. Gives definition of permanent foundations, but without explicit limits on deformation/slip. Excludes conventional strap and ground anchor systems.*

Steven Winter Assoc. Inc. Building Systems Consult Norwalk CT, "Manufactured Home Installation Training Manual," HUD Report April 1999

Intent of report is to support the industry's efforts to improve the reliability of conventional HUD-Code home set-ups, using concrete block piers and ground anchors tie-downs. Alternative foundations are also described.

Earthquake Related

How to Make Your Wyoming Home More Earthquake Resistant, Wyoming State Geologic Survey, Information Pamphlet #5, 2001 (http://www.wsgs.uwyo.edu/hazards/IP-5.pdf)

Gives overview of basic DIY earthquake mitigation recommendations; refers to work by others including SWA guide, EQE guide, WJE testing report, list anchorage systems approved for use in California, etc.

WJE Associates, (June 22, 1995) "Guidance for Supports of Manufactured Housing and other Relocatable Structures for Idaho Bureau of Disaster Services" prepared for FEMA Under the National Earthquake Technical Assistance Contract, WJE Associates, Inc., Northbrook, IL.

Objective was to provide cost-effective solution for withstanding wind loads of 70 miles per hour and seismic shaking based on the Modified Mercalli Intensity (MMI) Scale VIII

Yokel, F.Y., Marshall, R.D (1995). "Recommended Performance-Based Criteria for the Design of Manufactured Home Foundation Systems to Resist Wind and Seismic Loads." Prepared for HUD, NISTIR 5664 National Institute of Standard and Technology, Gaithersburg,, MD.

This report examines manufactured home support and anchoring systems and the degree to which tornadic wind speeds should influence their design.

Comparative Performance Criteria

Survey of Existing Performance Requirements in Codes and Standards for Light-Frame Construction, FPL 26, USDA, Forest Products Laboratory, Madison, WI. January 1980.

Gives background on performance criteria required for design of various systems of a home. Most relevant is performance criteria (design resistance and deflection) of shear wall systems (e.g., 0.6 inch deflection at 50% of ultimate load or design load if safety factor of 2 is used).

Nierlich, H. and Bruce, D.A. A Review of the Post-Tensioning Institute's Revised Recommendations for Pre-stressed Rock and Soil Anchors, web document, date?

Relates to criteria for retaining wall anchorage devices.

British Standards Institution. (1989). "Ground Anchorages." BS8081. BSI, London, England.

Document is not in possession.

Draft European Standard. (1994). "Execution of Special Geotechnical Work: Ground Anchors." European Committee for Standardization, Central Secretariat: Rue de Stassart 35, B-1050, Brussels, Belguim.

Document is not in possession.

Performance Evaluations & Recommendations

Mays, T.W., 2005. "Permanent Foundations vs. Traditional Soil Anchors: Using example calculations to illustrate relative performance of manufactured housing foundations in hurricane zones," Coastal Disasters 2005, American Society of Civil Engineers, Reston, VA.

Reviews findings of past similar studies by NIST, etc. Does analysis of foundation performance to show recommended anchor designs, evaluates performance of existing anchor design criteria and recommends improved performance criteria.

Marshall, R.D., "Manufactured Homes – Probability of Failure and the Need for Better Windstorm Protection Through Improved Anchoring Systems," NISTIR 5370, National Institute of Standards and Technology, Gaithersburg, MD. November 1994.

Review previous test data from Yokel et al. (1982) and trends in test data vs. soil type, etc. Applies data to conduct performance analysis (reliability study) of ground anchorages using statistics from test data and wind hazard probability functions. Recommends improved performance criteria. Document needs more careful review for relevance to this project.

Marshall, R.D. and Yokel, F.Y., "Recommended Performance-Based Criteria for the Design of Manufactured Home Foundation Systems to Resist Wind and Seismic Loads," NISTIR 5664, National Institute of Standards and Technology, Gaithersburg, MD. August 1995.

Recommends a performance-based design approach for anchorage. Document needs more careful review for relevance to this project.

Waldrip, T.G. Mobile Home Anchoring Systems and Related Construction Institute for Disaster Research Report, TTU, Lubbock, TX June 1976

Report not in possession.

Vann, P.W. and McDonald, J.R. (1978). "An Engineering Analysis: Mobile Homes in Windstorms." Report prepared for Disaster Preparedness Staff, National Weather Service, NOAA, Silver Spring, Maryland. Institute for Disaster Research, Texas Tech University, Lubbock, TX, 145 pp.

The report provides detailed engineering analysis of the various aspects of mobile home behavior in windstorms. Recommendations are made based on findings. One recommendation states the use of tie-downs should be made mandatory for all mobile homes.

Yokel, F.Y., Yancey, C.W.C. and Mullen, C.L. (1981). "A Study of Reaction Forces on Mobile Home Foundations Caused by Wind and Flood Loads." NBS Building Science Series 132, National Bureau of Standards, Washington, DC, 74 pp.

This report studies does a comparison between wind loads and anchoring requirements in the ANSI 119.3 (NFPA 501A). Conclusions is that diagonal ties are instrumental in resisting wind forces while vertical ties are more effective than diagonal ties when it comes to flood forces.

Kovacs, W.D. and Yokel, F.Y. (1979). "Soil and Rock Anchors for Mobile Homes – A state of the art Report." NBS Building Science Series 107, National Bureau of Standards, Washington, DC, 147 pp.

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

Yokel, F.Y., Chung, R.M., and Yancey, C.W., "NBS Studies of Mobile Home Foundations," NBSIR 81-2238, NBS, US DOC, Washington DC March 1981

Two papers discuss the results of test on soil anchors used to secure mobile homes and of an analytical study of wind and floor loads on soil anchors.
<u>Performance of Soil Anchors for Mobile Homes</u> concludes that anchors could perform adequately if installation techniques included pre-loading to 1.20 times the design load.
<u>Wind and Flood Loads on Soil Anchors</u> suggest that anchoring systems must be designed to resist substantial horizontal load component.

Marshall, R. D., "The Measurement of Wind Forces Upon a Full Scale Mobile Home" NBSIR 77-1289, National Bureau of Standards, Washington, DC September, 1977.

Report not in possession.

HUD USER's Southwest Research Institute Development and Correlations of Mobile Home Stiffness Field Test
Methodology Report 55

Report not in possession (relevance to foundation anchor systems unknown).

<u>Test Reports (Conventional Ground Anchor Systems)</u>

Guidelines for Anchor System Design: Technical Support Document, Manufactured Housing Research Alliance, New York, NY. January 7, 2000.

Document includes tests performed by Froehling & Robertson Inc. for MHRA following "Ground Anchor Test Protocol" developed by MHI and MHRA. Document is under review.

Tie Down Engineering, Inc. Ground Anchor Independent Testing Results (www.tiedown.com)

Provides summary of ultimate strength, working load, and soil class for various anchors performed by Atec Associates and Gallet & Associates. Reported data does not indicate variability in results. Test criteria such as deflection limit and safety factors are not presented.

Pearson, J.E., Meinheit, D.F. and Longinow, A. (Nov 1996). "Wind Protection Tie-Downs for Manufactured Homes." ASCE Practice Periodical on Structural Design and Construction, 126 pp.

This paper reviews existing standards and discusses the behavior of soil anchors subjected to axial and shear loads.

Pearson, J.E., Meinheit, D.F. and Longinow, A. (1991). "Testing of Soil Anchors and Strapping." Report No. WJE 901798, prepared for U.S. Dept. of Housing and Urban Development, WJE Associates, Inc., Northbrook, IL, 67 pp.

The report provided findings on soil anchor testing. Research provides observations on tied downs systems and *detailed testing results. Lab test were done on strapping at 4725 pounds, the same as our overloading criteria found in state requirements. Document maybe helpful as we develop our own testing criteria.*

Pearson, J.E., Meinheit, D.F., and Longinow, A., "Full-Scale Laboratory Testing of Manufactured Housing Lateral Load Restraint Devices." for U.S. Department of Housing and Urban Development, Wiss Janney Elstner Assoc. Inc. report Sept. 1993. (HUD 006360)

This report conduct tests on auger anchors for manufactured homes to evaluate ultimate strength and failure mode. Conclusion show anchor capacity to be lower than required HUD standards for wind loads. Anchor system resistance is limited by the size of the stabilizer plate; passive resistance of soil; and size and depth of anchor shaft and auger. Report also provides extensive findings on the effect of varying soil types and comparison of other foundation types for manufactured homes.

Pearson, J.E., Meinheit, D.F., and Longinow, A., "Laboratory Testing of Soil Anchors" for HUD, WJE Assoc. Report January 1995 (HUD 006546)

This report provides data on the capacity of four foot auger anchors that maybe used to set guidelines for tying down manufactured housing located in seismic regions and/or regions of high wind intensity. This report recommends an allowable working load of based on a maximum horizontal displacement of four inches should be 1000 lbs for anchor with stabilizer plates and 600 lbs for anchors without stabilizer plates. A maximum 3 inches horizontal deflection is also recommended. Stabilizer plates tested in laboratory did not provide definitive results to quantify its use, however it is still recommended because more positive results were found in other testing. In addition it recommends that analytic studies be done to determine the effectiveness of vertical ties on the stability of MH unit when subject to wind and seismic loads.

Yokel, F.Y., Chung, R.M., Rankin, F.A. and Yancey, C.W.C. (1982). "Load-Displacement Characteristics of Shallow Soil Anchors." NBS Building Science Series 142, National Bureau of Standards, Washington, DC, 147 pp.

Report conducted test on soil anchors including single helix, double helix and swivel anchors on various soil anchors. Parameters for testing included direction of installation, direction of loading, anchor depth, size of anchor plate, and cyclic load effects. Recommendations include that minimum load capacity requirement for anchors be waived; that all anchors be preloaded to 1.25 times design load; and that one anchor per mobile home, or three anchors per site if soil conditions are uniform, be preloaded to 1.5 times the design load.

FEMA 85 (draft) Manufactured Housing in Flood Zones….

Document contains chapter on ground anchor design and reports/summarizes data from FEMA sponsored tests of 60 anchors in sandy soil (saturated and dry). Test data needs to be obtained from David Low (FEMA consultant), 804-749-3700. Document addresses "permanent foundations" but doesn't define in terms of performance. State approval agencies are listed in Appendix.

American Industrial Testing, Anchor Testing Data Sheet

Summarizes numerous test on anchors at with different criteria's.

The Proposed MHRA Test Protocol for Soil Anchors

This paper studies the effectiveness of the helix soil anchoring system. Their belief is there is no credible evidence that this system will work and is set out to prove its theses.

<u>Test Reports (Alternative Anchorage Systems</u>)

Wiss, Janney, Elstner Associates, Inc., 1998, Full scale testing of the "Vector Dynamics" manufactured housing foundation system for Tie Down Engineering, Inc., Atlanta, Georgia: Wiss, Janney, Elstner Associates, Inc., Report WJE No. 971061, Northbrook, Illinois, 189 p.

Report not in possession.

U.S. Department of Housing and Urban Development
INTERIM REPORT

Report Date:	**1-20-2006**
Description:	**Research and Analysis for Manufactured Housing Foundations**
Report Scope:	**Task 2b – Search and Review of State Requirements**
Contact:	**William Zoeller, Senior Associate** **Steven Winter Associates, Inc., Norwalk, CT** **wzoeller@swinter.com**

I. OVERVIEW OF TASK REQUIREMENTS

As part of their responsibility for regulating the installation of manufactured homes, individual states have the authority to regulate ground anchor assemblies. Under this task, Steven Winter Associates, Inc. (SWA) compiled and analyzed these state regulations, including ground anchor performance requirements, angle of installation, failure criteria and testing methods. The work completed in this subtask will be used to support our review of the proposed Ground Anchor Testing Protocol developed by MHCC (Task 2).

Regulations were identified by conducting online research on federal and state government websites and websites addressing manufactured housing, and by contacting state agencies with jurisdiction over applicable regulations.

The information collected and conclusions drawn are summarized in Section II. Sections III and IV contain a listing of Federal regulations and common industry standards, and a detailed matrix of regulations for each state.

II. SUMMARY OF FINDINGS

Code of Federal Regulations and Common Industry Standards
In conducting the research, SWA found within the state regulations multiple references to several codes and industry standards. These are:

24 CFR 3280 2004 - 2005	**Manufactured Home Construction and Safety Standards** (HUD Code) Code of Federal Regulations
NFPA 501 2005	**Standard for Manufactured Housing** National Fire Protection Association
IRC AE 2003	**Manufactured Housing Used as Dwellings** International Residential Code, Appendix E

ANSI A119.1	**Standard for Mobile Homes**
2000 (canceled)	American National Standards Institute

ANSI A225.1	**Manufactured Housing Installations**
1994	American National Standards Institute
(superseded by NFPA 501a)	

A comparison of the requirements found in these documents is listed in Section III.

State Regulations
Working Loads. The HUD code requires a minimum of 3,150 pounds. Based on our research, it is evident that the majority of U.S. states defer to manufacturer's installation instructions in determining requirements for ground anchor assemblies. The contents of these instructions are regulated by the HUD Code (See section III).

In lieu of manufacturer's instructions, typical working load requirements must meet the HUD Code minimum; there is no state working load requirement that is lower than the HUD Code. Florida, Louisiana, Mississippi, Tennessee and Texas are the only states that have adopted minimum standards for working loads that are higher than the HUD Code.

Alternate installation designs are typically allowed, if designed by a Professional Engineer, and/or installed by a Certified Installer.

Overload. Typical allowable overload requirements meet the HUD Code requirement of 50%. Note: in some states the overload is referred to as the "ultimate load".

Failure Criteria. The HUD Code does not quantify failure criteria. The majority of states either defer to the HUD Code's loosely defined "without failure of either the anchoring equipment of the attachment point" requirement, or do not address this issue. State regulations, if specified, typically limit anchor movement to no more than 2 inches of vertical uplift, with an allowable 3 inches of side deflection.

Testing Standards. The HUD Code requires testing in accordance with ASTM Standard Specification D3953-91, *Standard Specification for Strapping, Flat Steel and Seals*. The majority of states do not specify an alternate testing standard.

Installation Angle. The HUD Code does not specify allowable angle of installation, neither do the majority of states. A range of installation angles specified is between 30 and 50 degrees.

	Working Loads	Overload	Failure Criteria	Testing Standards	Angle	Details	Section
24 CFR 3280 (HUD Code)	Equal to or exceeding 3150 pounds	50% (4725 pounds)	Without failure of either the anchoring equipment or the attachment point on the manufactured home.	Test in accordance with procedures in ASTM Standard Specification D3953-91, Standard Specification for Strapping, Flat Steel and Seals.	(not specified)	For anchoring systems, the instructions shall indicate: (i) The minimum anchor capacity required; (ii) That anchors should be certified by a professional engineer, architect, or a nationally recognized testing laboratory as to their resistance, based on the maximum angle of diagonal tie and/or vertical tie loading (see paragraph (c)(3) of this section) and angle of anchor installation, and type of soil in which the anchor is to be installed; (iii) That ground anchors should be embedded below the frost line and be at least 12 inches above the water table; and (iv) That ground anchors should be installed to their full depth, and stabilizer plates should be installed to provide added resistance to overturning or sliding forces. (v) That anchoring equipment should be certified by a registered professional engineer or architect to resist these specified forces in accordance with testing procedures in ASTM Standard Specification D3953–91, Standard Specification for Strapping, Flat Steel and Seals.	3280.306
NFPA 501	Equal to or exceeding 3150 pounds	50% (4725 pounds)	Without failure of either the anchoring equipment or the attachment point on the manufactured home.	Test in accordance with procedures in ASTM Standard Specification D3953, Standard Specification for Strapping, Flat Steel and Seals.	(not specified)	For anchoring systems, the instructions shall indicate the following: (1) Minimum anchor capacity required. (2) Anchors shall be certified by a professional engineer, architect, or a nationally recognized testing laboratory as to their resistance, based on the maximum angle of diagonal tie and/or vertical tie loading and angle of anchor installation, and type of soil in which the anchor is to be installed. (3) Ground anchors shall be embedded below the frost line and be at least 12 inches (305 mm) above the water table. (4) Ground anchors shall be installed to their full depth, and stabilizer plates should be installed to provide added resistance to overturning or sliding forces. (5) Anchoring equipment shall be certified by a registered professional engineer or architect to resist these specified forces in accordance with testing procedures in ASTM Standard Specification D3953, Standard Specification for Strapping, Flat Steel and Seals.	6.6.2
IRC Appendix E	At least equal to 3150 pounds in the direction of the tie	50% (4725 pounds)	Failure shall be considered to have occurred when the anchor moves more than 2 inches (51 mm) at a load of 4,725 pounds (21 kN) in the direct of the tie installation.	(not specified)	Those ground anchors which are designed to be installed so that loads on the anchor are other than direct withdrawal shall be designed and installed to resist an applied design load of 3,150 pounds (14 kN) at 40 to 50 degrees from vertical or within the angle limitations specifed by the home manufacturer without displacing the tie end of the anhcor more than 4 inches horizontally.		AE604

State	Working Loads (lbs)	Overload	Failure Criteria	Testing Standards	Angle	Details	Code/Resource	Section
Alabama Alabama Manufactured Housing Commission http://www.amhc.state.al.us/Application.htm	**4725**		Anchor displacement limited to 3 inches horizontally and 2 inches vertically at 4725 pound load.	Reference is made to applicable ASTM standards but none are specificically cited. Test report shall "detail the applied load at 10 second intervals and 500 lb. increments. The test report shall identify the vertical and horizontal displacements at each increment and describe the mode and location of failure."		The installation shall comply with the manufacturer instructions (including the anchor manufacturer) or comply with the minimum standards developed by the commission. If no instructions available, then follow commission's rules or provide a PE design. Specific details for piers and anchors are provided in the rules.	Acts 1975 No. 1144, p 2247, Acts 1991, No 91-642, p. 1213 requires the Alabama Manufacturers Housing Commission to establish rules consistent with ANSI A 119.1/NFPA 501B. The Commission has an extensive set of rules that are not online (2006 edition of Rules and Regulations of the Alabama manufactured housing commission).	(1) **Acts 1975 No. 1144**, p.2247, (2) **Acts 1991 No. 91-642**, p.1213
Alaska						Alaska does not appear to have any regulations at the state leve for installation of MHs. Fire marshall's office was not aware of any regulations or rules but noted that some local juristictions do have applicable requirements.		
Arizona Department of Building and Fire Safety Rules and Regulations	**3150**	**50%**				**C.** Materials: An installer or contractor shall **1.** Use materials that comply with the standards incorporated in R4-34-102: Uniform Building Code, Uniform Mechanical Code, Uniform Plumbing Code, National Electrical Code, and HUD standards (24 CFR 3280); and **2.** Test metal supports to ensure they can withstand 15,000 pounds of downward pressure under 24 CFR 3280.401.	(1) **Arizona Revised Statutes** Title 41, Chapter 16, Articles 1, 2, 3, 4, and 5 Rules and Regulations A.A.C. R4-34-101 – R4-34-1001	(1) **R4-34-101-1001** - Accessory Structures and Ground Anchoring
Arkansas Arkansas manufactured Home Commission http://sos.state.ar.us/ar_rules/rule_proposed/066.00.05-002P.pdf						Not regulated by state. The commission accepts listed equipment installed in accordance with manufacturer instructions or plans stamped by a PE.	None (only rules to date cover modular).	
California Department of Housing and Community Development, manufactured housing section http://www.hcd.ca.gov/codes/mp/articles/MP_Article_7.pdf	A working load for the tiedown assembly shall be established from the test results, which shall be two-thirds (2/3) of the amount of resistance the tiedown assembly endured without failure.		(a) Ground Anchor, uplift limited to 2 inches, side deflection to 3" (b) or, a failure that threatens the integrity of the tiedown assembly (causes it to break or wear). Regulation are not very exact on this last item. A component is classified as a failure when the tie stretches more than 2" or fractures or Yields.	No reference to a consensus or third part test standard. The tiedown assembly shall be tested by applying an increasing test load while the anchor is installed in accordance with the manufacturer's recommendations. The test shall be performed in Type 5 soil, alternatively called 1000 pound soil.		(a) A ground anchor component designed for the connection of multiple ties and the means for the attachment of the ties shall be capable of resisting, without failure, the combined working load of the maximum number of ties that can be attached to the anchor. (b) Listed tiedown assemblies subject to wind load based on calculation using either the design load for the MH or 15 psf, whichever is greater. Assembly is subject to tests and working load is determined as 2/3 of load at failure.	(1) **Title 25 Housing and Community Development** - Mobile Home parks and Installations Requirements	(1) **Article 7**, section 1320 to 1336.
Colorado State housing Board if the State of Colorado	**3150**	**50%**			Install at 45 degrees from vertical		(1) **ANSI A225.1** – 1994. (2) Amendment to ANSI A225.1 **- Manufactured Housing Installations** – Resolution 38, Nov 23, 2003 (3) **Permanent Foundations Guide for Manufactured Housing** (HUD-7584)	(2) **Resolution 38**, p 17 Amendments Manufactured Home Installations
Connecticut							(1) **HUD Regulations**	

State	Working Loads (lbs)	Overload	Failure Criteria	Testing Standards	Angle	Details	Code/Resource	Section
Delaware Manufactured Home Installations Board to be established January 2006 under Department of Professions and Licensing. www.delcode.state.de.us/title24/c044/index.htm#TopOfPage						Not directly addressed. Delaware regulations on installation go into effect in January 2006. It appears that the board to be established will develop specific requirements. Code currently requires installation by certified installer in accordance with manufacturer's instructions, ANSI 225.1-1994, or PE design, in that order.	(1) **Title 24 of Delaware Code**, Jan 2006 (2) **ANSI 225.1**-1994	**(1) Chapter 44 -** Manufactured Home Installation, **Subchapter I, II, III**
Florida Department of Highway Safety and Motor Vehicles Division of Motor Vehicles	**4000**	**50%**	Withstand overload **Soil 4B Failure** – 2 inches uplift or 3" side deflection	For type4(b) soil, requires 6000 pounds in vertical direction and 4725 in 45 degree horizontal direction.	Testing load applied at 45 degrees from horizontal	All anchors, piers and tie-down components used in the installation of a mobile/manufactured home or park trailer shall be tested, listed and approved by the Florida Department of Highway Safety and Motor Vehicles, Bureau of Mobile Home and Recreational Vehicle Construction. If tests are conducted out of the State of Florida, the anchor or component manufacturer shall pay the expenses (per diem and travel) incurred by this out-of-state travel. Installation of such anchors, piers and tie-down components shall be in accordance with the manufacturer's instructions used during the testing procedure.	(1) **Rules of Department of Highway Safety and Motor Vehicles Division of Motor Vehicles**	(1) **Chapter 15C-1** - General
Georgia Office of Commissioner of Insurance	**3150**	**50%**	without failure of either the anchoring equipment or the attached point of the MH				(1) **Rules and Regulations for Manufactured Homes**, 1996	(1) **Appendix A**
Hawaii							(1) **HUD Regulations**	
Idaho Division of Building Safety	**3150**	**50%**	without failure of either the anchoring equipment or the attached point of the MH				(1) **Idaho Manufactured Installation Standard**-37987	
Illinois Department of Public Health http://ilsos.net/departments/index/register/register_volume29_issue46.pdf	**3150**	**50%**	Anchor limited to 2" movement in vertical direction, for other than direct withdrawal anchors, 3" in vertical direction with 4725. Tie materials must resist 3150 pounds with no more than 2% elongation and 4725 pounds before failure.	No reference standards cited. Tiedown must be tested a minimum of three times while installed in accordance with manufacturers instructions.	Testing load applied at 45 degrees from horizontal	Piers or other support required over footings to cover dead and live loads. Soil must have 2000 psf bearing capacity for footings.	(1) **Illinois Register: Rules of Government Agencies,** November 14, 2005	(1) **Subpart D** - Requirements for the installation of manufactured homes sections 870.90 through 870.220
Indiana							(1) **HUD Regulations**	
Iowa Iowa State Building Code Bureau http://www.dps.state.ia.us/fm/building/index.htm						All installations must comply with manufacturer instructions, PE design, or State Building Code, in that order (must follow manufacturers instructions unless unavailable)	(1) **State of Iowa Building Code**	(1) **Chapter 16,** rule 661
Kansas **Kansas Housing Resources Corporation** **http://www.kshousingcorp.org**						No standards yet established.Kansas Housing Resources Corporation was given the responsibility of promulgating standards for installation in SB-4, signed by the governor in April 2005. Corporation is waiting for final HUD rule before taking any action.	(1) **Kansas Manufacturer Housing Act**, April 2005 (Authority to develop standards found in SB 4)	(1) **KSA 58-4201 - 58-4227** (new sections covered by SB 4 are not online as of December 21, 2005)
Kentucky							(1) **HUD Regulations**	

State	Working Loads (lbs)	Overload	Failure Criteria	Testing Standards	Angle	Details	Code/Resource	Section
Louisiana Louisiana Manufactured Housing Commission http://www.geocities.com/thelmhc/LAMfdHsgLaw.htm	**4725**		Not specified for anchor systems. Piers can not deflect more than 3/8 inch under design loads.	Testing required only reference is to and "meet industry standards." No specifics offered.		Specific details for anchor roof ties, piers and footings are invoked if no manufacturer instructions available.	(1) **Louisiana Revised Statutes,** 2004	(1) **Title 51, Chapter 2, Part XIV-B** - Minimum Standards for Installation of Manufactured Homes
Maine							(1) **HUD Regulations**	
Maryland Department of Housing and Community Development http://lhi5.umbc.edu/dhcd2/ma						Maryland requires MH to be installed in accordance with the manufacturer's instructions. If none, then the local enforcement agency (presumably the local building official?) shall approve the installation.	(1) **Annotated Code of Maryland, Title 05 Department of Housing and Community Development,** December 9, 2005	(1) **Subtitle 02** - Building and Material Codes, **Chapter 04** - Industrialized Buildings and Mobile Homes
Massachusetts							(1) **HUD Regulations**	
Michigan							(1) **HUD Regulations**	
Minnesota MN Building Codes and Standards Division www.doli.state.mn.us/bc_manufactured_laws_rules.html	**3150**	**50%**	**(a)** 2" between tie and anchor in vertical direction at 4725 pounds when tie installed as per manufacturer instructions **(b)** For other than direct withdrawal ties, 4" at 3150 pounds at 45 degree installation angle.	Nothing specific beyond load requirements.	45 degree installation angle	Footings must carry 85 psf. Minimum 2000 psf soil capacity assumed.	(1) **Manufactured Structures Laws and Rules, Office of Revisor of Statutes**, October 27, 2003	(1) **Minnesota Rules, Chapter 1350**, sections 1350.2600 through 1350.3300.
Mississippi State Fire Marshall	**4750**		4750 pounds of pull in vertical and horizontal direction without failure.	Standard Method of Test for manufactured Home Anchors, Part A & B; described in the Federal manufactured Home Construction and Safety Standards, 24 CFR Section 3280.401	Diagonal Tie no less than 30 degrees from vertical		1) **Rules and Regulations for the Uniform Standard Code for Factory Built Home Law Regulation MH-4,** June 7, 1999 2) **HUD Regulations -** Manufactured Home Construction and Safety Standards, 1995	(1) **Chapter IV** p.10 **Table 1** - Soil Classification p.14
Missouri Department of Economic Development, Public Service Commission in Office of Secretary of State. http://www.moga.mo.gov/STATUTES/C700.HTM and http://www.sos.mo.gov/adrules/csr/current/4csr/4csr.asp#4-240	**3150**	**50%**	**(a)** If head of anchor moves more than 2" in vertical direction at 4725 pounds when tie installed as per manufacturer instructions. **(b)** For other than direct withdrawal ties, 3" at 40 to 50 degree installation angle.	In accordance with the anchor manufacturer instructions.	40 to 50 degree installation angle	Too many details to show here. See links to the rules.	(1) **Rules of Department of Economic Development, Code of State Regulations**, Dec 31, 2001	(1) **Division 240, Chapter 124** - Manufactured Home Tie-down Systems
Montana							**(1) HUD Regulations**	
Nebraska							**(1) HUD Regulations**	
Nevada http://leg.state.nv.us/NRS/NRS-489.html						Nevada does not appear to have any specific regulations except that they adopt the Uniform Building Code for manufactured structures. But they do carryout inspection of installations.	(1) **Uniform Building Code for Manufactured Structures**	

State	Working Loads (lbs)	Overload	Failure Criteria	Testing Standards	Angle	Details	Code/Resource	Section
New Hampshire							(1) **HUD Regulations**	
New Jersey Department of Professional and Financial Regulations						Design of foundation system must be done by NJ licensed PE and based on the manufacturer's installation instructions.	(1) **Uniform Construction Code**	(1) T**itle 5:** Residential Site Improvement Standards
New Mexico Regulations and Licensing Department, Manufactured Housing Division www.rld.state.nm.us/mhd/Rules%20&%20Law/rules-and-law.htm						Not specifically addressed. All installations must follow manufacturer instructions. Division may approve alternative methods if by PE or HUD-approved DAPIA engineer.	(1) **New Mexico Administrative Code**, 2002	(1) **TITLE 14**: Housing and Construction, **Chapter 12** Manufactured housing, Part 2
New York NYS Department of State Codes Division	3150	50%	Failure shall be considered to have occurred when the anchor moves more than 2 inches at a load of 4725 lbs.		40 - 50 degrees	IRC 2003	(1) **An Installation Guide for the Code Enforcement Official**: Mobile/Manufactured Homes (2) **NYS Fire Prevention and Building Code** (3) IRC 2003 (4) RS 68 NCSBCS/ANSI	
North Carolina							(1) **HUD Regulations**	
North Dakota Division of Community Services, ND Dept. of Commerce www.nd.gov/dcs/assistance/mobile/						No existing rules for installation or anchors. Rules to be developed and in place by July 2006 or when HUD rule is final. Currently rely on manufacturers instructions.	To be developed by July 2006.	
Ohio Ohio Manufactured Homes Commission and Department of Health www.omhc.ohio.gov/index.htm www.odh.ohio.gov/rules/final/f3701-27.aspx						Ohio statute requires commission to establish rules consistent with HUD's and no less stringent or allows the use of the manufacturer's "standards" if deemed equal. They do not list specific rules but do have the HUD proposed Rule on their website. Rules are being developed for statewide application. Only existing rules are for inside parks, which are administered by the Department of Health. DOH rules for parks require tiedowns and other installations components to be in accordance with manufacturer's instructions or ANSI 1987	(1) **Ohio Administrative Code** (2) **Ohio Revised Code** (3) **HUD** (4) **ANSI 1987**	(1) **Chapter 4781** (2) **Section 3781.184, Section 3701-27-08.2** address DOH tie down/installation in parks.
Oklahoma							(1) **HUD Regulations**	
Oregon Building Codes Division www.bcd.oregon.gov/programs/mdprogram/md_2002mds.html	3150	50%		Test according to ASTM D-3953-1997 using wind Zone 1. with a 1.5 Safety factor.		Too many options to describe. See specific details in code.	(1) **2002 Oregon manufactured dwelling and park specialty code**	(1) **Chapter 3**
Pennsylvania						Must comply with manufacturer instructions.	(1) **Act 158** of 2004	(1) **Section 6**
Rhode Island Department of www.							(1) **International Residential Code** 2003: One and Two Family Dwelling Code (As RI SBC - 2)	

State	Working Loads (lbs)	Overload	Failure Criteria	Testing Standards	Angle	Details	Code/Resource	Section
South Carolina South Carolina Manufactured Housing Board www.llr.state.sc.us/POL/ManufacturedHousing/mhbstat.htm	**3150**	**50%**				Systems(anchor systems) have to be installed in accordance with manufacturers instructions or designed by PE if for unusual installation. Other foundation systems must meet the Standard Building code requirements.	(1) **Uniform Standards Code for Manufactured Housing** (2) **South Carolina Manufactured Housing Board Regulations,** May 1990	(1) **Chapter 29** (2) **19-425.39** through end of document (Manufactured Housing Board regulations)
South Dakota Fire Marshals Office							**Department of Commerce and Regulations** (1) **Standards for Installation of Manufactured Homes and Construction**, December 16, 1996 (2) **Manufacture's Installation Instructions**	(1) **Chapter 20:01:12** – Installation of Manufactured Homes (2) **Chapter 20:01:12:02** – Standard for new Manufactured Homes
Tennessee Department of Commerce and Insurance, Division of Fire Prevention http://tennessee.gov/sos/rules/0780/0780-02/0780-02-05.pdf	**4725**		Connection between tie and anchor limited to 2" vertical movement when installed in accordance with manufacturer's instructions. If other than direct withdrawal, then movement limited to 4" in horizontal direction.	Tests have to be by a recognized independent lab but no requirements cited except the loads and failure criteria.			(1) **Rules of the Division of Fire Prevention**, revised May 2004 (2) **ANSI A225.1**-1994 as alternative for installation.	(1) **Chapter 0780-2-5** Installation of Manufactured Homes
Texas Texas Dept. of Housing and community Affairs http://www.tdhca.state.tx.us/mh/docs/rules.pdf	**4725**					Too many details to show here. See link to actual text for details.	(1) **Manufactured Housing Rules,** December 11, 2005 (2) **Manufacturer Instructions**	(1) **Subchapter D**
Utah							(1) **HUD Regulations**	
Vermont Department of Housing and Community Affairs http://www.dhca.state.vt.us/Housing/mhs.htm						Vermont does not regulate installation of manufactured housing.	Not applicable (NA).	Not applicable (NA).
Virginia Department of Housing and Community Development www.dhcd.virginia.gov/BFR/Documents/Virginia%20Construction%20Code.pdf						Install in accordance with manufacturer's instructions	(1) **The Virginia Construction Code**, effective November 16, 2005 (2) **ANSI A225.1**-1994 (3) **IRC**	(1) **Section 419** - Site Work for Manufactured Homes and Industrialized Housing (3) **Appendix E**

State	Working Loads (lbs)	Overload	Failure Criteria	Testing Standards	Angle	Details	Code/Resource	Section
Washington Department of Community, Trade and Economic Development www://apps.leg.wa.gov/wac/default.aspx?cite=296-150M&full=true	**3150**	**50%**	without failure of either the anchoring equipment or the attached point of the MH				(1) **ANSI A225.1** – 1994. (2) Exception to ANSI A225.1 - **Chapter 296-150M WAC: Manufactured Homes**, May 24, 2005 (3) Professional Engineer or Architect	2) **Chapter 296-150M 0600 WAC,** p.20
West Virginia Manufactured housing West Virginia Division of Labor www.labor.state.wv.us	**3150**	**50%**	without failure of either the anchoring equipment or the attached point of the MH				(1) **ANSI A225.1**	
Wisconsin Department of Commerce, safety and Buildings Division http://folio.legis.state.wi.us/cgi-bin/om_isapi.dll?clientID=42725882&infobase=code.nfo&jump=ch.%20Comm%2027	.					Contains some prescriptive requirements for piers and footing sizes. Wisconsin is still working on installation rules for manufactured housing. Final rules will be posted to the following webpage: http://commerce.wi.gov/SB/SB-CodeDevelopment.html#95 Currently there is only a "statement of scope" on that page under Comm 27 and Comm 20.	**(1) Wisconsin Code**	(1) **Chapter 27** - Manufactured Housing - Comm 27.001 through Comm 27.35
Wyoming							(1) **HUD Regulations**	

U.S. Department of Housing and Urban Development
INTERIM REPORT

Report Date:	July 13, 2006
Description:	Research and Analysis for Manufactured Housing Foundations
Report Scope:	**Task 2c – Verification of Applied Engineering Principles and Sound Engineering Judgment**
Contact:	William Zoeller, Senior Associate Steven Winter Associates, Inc., Norwalk, CT wzoeller@swinter.com

I. OVERVIEW OF TASK REQUIREMENTS

Two key objectives define the purpose of Task 2c and this interim report:

1. Review literature to identify significant work related to content of the proposed Ground Anchor Assembly Test Protocol (GAATP), and
2. Use relevant technical information, engineering principles, and professional judgment to make recommendations in regard to the GAATP.

Activities to achieve these objectives, as detailed in the project work plan, are represented in this interim report. The report is organized as follows:

I. Overview of Task Requirements
II. Executive Summary
III. Detailed Review and Analysis of the Proposed GAATP
IV. References

APPENDIX A – Detailed Review of Selected Literature
APPENDIX B – Recommended Revisions to GAATP
APPENDIX C – Preliminary Analysis of Reliability Benchmarks and Safety Factors for the GAATP

Scope

This interim report focuses on information related to the structural resistance of conventional ground anchors used for manufactured home installations, including topics such as test methods, soil classification approaches, variability in anchor performance, safety margins, and other relevant matters. However, structural performance and overall reliability of that performance also depends on the manner of determining and applying structural loads in the regulated design process. Because of this implication, potential uncertainties and systematic biases in design loads should not be ignored. Therefore, this related issue is given some consideration in this report.

Literature Review

The literature reviewed for this task is listed at the end of this interim report (see References). A detailed review of selected literature is found in Appendix A. The literature addresses a broad range of topics related to ground anchors including, but not limited to:

- soil characterization methods,
- prediction of anchor strength based on soil mechanics/properties,
- use of soil index tests to correlate to anchor performance for anchor selection purposes (e.g., soil test probe (STP) or standard penetrometer test (SPT)),
- variation in anchor strength and stiffness within a given site, within laboratory controlled soil conditions, and between sites with different soil types and characteristics,
- variation of anchor strength in relation to in-situ moisture content of soil,
- effects of loading direction and anchor installation angle to load-deflection behavior,
- methods of improving anchor stiffness or deflection performance (e.g., pre-tensioning of straps, use of stabilizers, etc.),
- effects of loading rate on anchor deflection and strength,
- effects of static vs. cyclic loading behavior,
- methods of conducting anchor tests,
- test rigging and instrumentation for conducting anchor tests and recording data,
- significance of “deep anchor” vs. “shallow anchor” behavior (based on d/b ratio of anchor depth to anchor plate or helix diameter),
- installation factors affecting anchor performance (e.g., torsional yielding or fracture of anchor shafts, weld failure at anchor head to shaft or shaft to auger during installation, refusal due to dense soil layers or sub-surface obstruction, etc.),
- practices to address installation difficulties (e.g., pre-drilling holes to approximately one-half depth of anchor with compaction of backfill in anchor hole after installation),
- comparison of installed anchor test results of various anchor sizes/types relative to prescriptive working load requirements in the Manufactured Home Construction and Safety Standards or “HUD Code” (MHCSS, 1994),
- testing of anchor hardware (strapping and anchors) in conditions where anchor and strap loads were not limited by soil failure (e.g., controlled test of hardware in laboratory),
- methods of characterizing anchor design values based on deflection limitations or safety factoring of ultimate strength to account for variability in strength (e.g., performance based design vs. testing to prescribed load values without regard to variability in performance),
- group load effects on anchor spacing and pull-out strength efficiency,
- concerns with corrosion on long-term strength of anchors and strapping,
- method of determining anchorage loads using wind load provisions and a basic rigid-body mechanical model of the housing unit and anchorage system, and
- Safety factors typically applied in foundation and ground anchorage designs.

II. EXECUTIVE SUMMARY

This report includes an extensive literature review, evaluation of the GAATP, and analysis of reliability of anchor performance. The major findings and recommendations from this report are listed below in two categories: (1) a summary of general findings and recommendations for HUD to consider and (2) specific recommendations for the GAATP task force to consider toward improvement of the GAATP. The reader is encouraged to refer to detailed information, explanations, and technical references contained in this report for justification and additional study as needed.

Conclusions & Recommendations for HUD

Overall, the GAATP represents a significant and valuable achievement in regard to establishing a "nationally recognized testing protocol" for qualification of the resistance capability of ground anchors. The draft GAATP should be revised and improved to address multiple concerns ranging from editorial to technical impacts that affect the usability of the protocol, clarity of requirements, repeatability of results, measurements, and application of the results to establish anchor design values (see separate list below for the GAATP task force). Finally, the findings of this report have several implications in regard to the originally conceived anchor test plan for Task 2d, *Validation of Testing Protocol*. Therefore, these implications should be carefully considered and the anchor test plan should be re-evaluated to better address needs related to assessing and improving the GAATP. Some topical studies for the anchor testing plan are suggested in the report.

The following list of general findings and recommendations is intended to identify important implications of this report for HUD's consideration.

1. The **failure criteria** (anchor deflection limits) provided in Section 9.0 of the GAATP are considered to be technically sound and a general improvement over past practice in regard to providing for reliable performance of ground anchors for manufactured home installation.
2. The **soil classification methodology** is the most ambiguous part of the proposed GAATP (Section 4.0), particularly in terms of potential impacts on anchor performance and reliability (see Item #3 below).
3. An initial evaluation of anchorage system reliability in Appendix C of the report indicates that the GAATP's **safety factor** of 1.5 is generally inadequate unless anchor design values are determined using the GAATP at individual end-use sites. Therefore, improvements to safety factors have been recommended and coordinated with improved soil classification strategies for the GAATP (see Appendix B).
4. It is recommended that **prescriptive load values** for anchor qualification testing be considered as optional load value targets and that actual tested anchor performance be permitted to establish anchor ultimate load values from which anchor design (working) resistance values are determined by application of a safety factor. Fully implementing this approach, which is already partially recognized in the MMHIS and GAATP, will create greater opportunities for anchorage system innovation, avoid exclusion of existing ground anchor products, and have no negative impact on reliability of an anchor performance because reliability is solely dependent on other factors (see Item #3 above).
5. Several coordinating changes to the HUD Code and the MMHIS provisions have been recommended in relation to treatment of **wind and earthquake loads**. The specific changes discussed in this report would promote more risk-consistent and cost-effective anchorage system designs. From the standpoint of safety and affordability, they should be considered to be at least as important as any of the recommendations in this report regarding the GAATP.

Recommendations for the GAATP Task Force

The following list identifies editorial and technical concerns in various parts of the draft GAATP and provides recommendations to address those concerns for careful consideration by HUD and the GAATP Task Force. The items are summarized below for reason of convenience. But, the issues involved may require a more detailed review of this report to fully understand or appreciate the implications. The reader is also referred to Appendices B and C for additional information and conceptual revisions to Sections 4.0, 9.0, and 10.0 of the GAATP.

1. *Section 3.0:* The definition for **deflection limits** should be better coordinated with the dual usage of deflections in Section 9.0 and 10.0. For example, in Section 9.1.1 of the GAATP the deflection limits are used as a structural safety limit state to define ultimate anchor load resistance. In Section 9.1.2, however, a different deflection limit is used as a serviceability limit state (e.g., allowable deflection at design load conditions).

2. *Section 4.0:* Several recommendations pertain to methods of **soil identification and characterization** (see example revisions to this section of the GAATP in Appendix B).
    a. The provision appears to allow only visual/mechanical soil particle size assessment for Class 1-4 soils for the purpose of characterizing test sites as well as end-use sites for the purpose of anchor selection. It permits an additional soil test (e.g., Soil Torque Probe) to be done to distinguish between Class 4A or 4B soil. Yet, the Soil Torque Probe test method described in Appendix A of the GAATP suggests that this method of soil characterization must be used on all sites. The latter is a preferable approach as it would tend to reduce uncertainty in the basis of tested anchor values as well as selection of anchors based on similarity of end-use site characteristics.
    b. Direction on how to use the Soil Torque Probe test method to characterize a site is needed to ensure consistent use and consistent correlation to anchor performance. Based on reviewed literature and data, direct withdrawal resistance of anchors is best correlated to Soil Torque Probe tests taken just above the anchor helix depth or for an average for the depth of soil above the helix. For anchors that are laterally loaded and use stabilizer plates, performance is usually dictated more by surface soil conditions to a depth no greater than the stabilizer plate (a hand-held pocket penetrometer or the Dynamic Cone Penetrometer as described below may be preferred for measurements at the soil surface or very shallow depths, e.g., up to 12 inches). In addition, the number of soil tests should be specified and whether or not those tests should be averaged to characterize a test site or end-use site.
    c. The Standard Penetrometer Test (blow count) method should be eliminated from the GAATP. The reviewed literature and data clearly indicates its lack of repeatability and reliability for predicting anchor performance at soil depths of less than about 10 feet. In substitute, use of a smaller and more economical Dynamic Cone Penetrometer (blow count) test method should be considered pending additional data to confirm its ability to overcome the problems associated with the Standard Penetrometer Test method.
    d. Use of the ASTM D2487 and D2488 standards for soil classification should be treated as optional or removed in their entirety (assuming the recommendation in Item ‘a.’ above is implemented). The reviewed literature warns against use of visual soil classification methods (e.g., per Unified Soil Classification System) as the sole means of predicting anchor performance. In addition, a complete particle size analysis of the soil does little to improve prediction of anchor

performance. In substitute, soils should be more simply and cost-effectively assessed as being predominantly cohesive (relying on cohesion for shear resistance in a moist state) or non-cohesive (relying on friction for shear resistance). Within these two broad soil categories, anchor test values should be associated with soil index test values (e.g., Soil Torque Probe) for each test site. Then, these same soil test methods should be used to select anchors for end-use sites based on similarity (e.g., equal or better torque probe value for either non-cohesive or cohesive soils as appropriate for the site).

e. For reasons stated above in Item ‘d.’, anchors should be separately tested in cohesive soils and non-cohesive soils and results used independently (with separate correlations based on soil test such as Soil Torque Probe) to selected anchors for sites with similar soil conditions. The GAATP currently requires that anchor only be tested in non-cohesive soils; however, it is unclear whether or not results from test sites with non-cohesive soils can be used for anchor selection at end-use sites with cohesive soils even though that is understood to be the intent. The uncertainties in soil test methods differ for these two soil types and the difference in densities of soil can result in conditions where an anchor in a cohesive soil performs less favorably than a non-cohesive soil and vice-versa.

f. At a minimum, soil moisture conditions at a test site (to be associated with a particular anchor test value) should be assessed and documented. Soil moisture can have a positive or negative effect on anchor performance, soil index test values (e.g., torque value or blow count), and prediction of anchor performance using soil index test values. This concern may be greater for cohesive soils than for non-cohesive soils. The assessment should consider a simple methodology that would categorize the soil as being dry, damp, moist, or wet/saturated based.

3. *Section 5.0:* Several recommendations pertain to the **field testing apparatus**.
   a. Section 5.1.1 should be moved to Section 4.0 as it pertains to test site soil characterization.
   b. Additional description of acceptable test rigs should be provided (e.g., it is common to include a generic illustrations of acceptable test set-ups in similar test standards)
   c. Additional guidance should be include to avoid interference and repeatability problems (e.g., test rig reactions on the ground within the cone of influence of the anchor being test)
   d. Guidance should be provided in regard to how the angle of pull is to be maintained during the displacement of the anchor relative to the test rig or that the angle of pull at the beginning and end of the test be recorded (the final angle being the angle associated with the anchor test value).
   e. Based on similar test applications (e.g., foundation load tests), a measurement tolerance of ±5 percent for load and ±0.1 inch for length should be considered acceptable for the GAATP (current tolerance is 1 percent).
   f. Load rate requirements should be moved to this section as they relate to test rigging, equipment, and operational criteria. Current load rates specified in Section 8 of the GAATP are controlled by way of a minimum test duration of 2 minutes. However, this duration will not account for relaxation (creep) in soil response. Based on prior recommendations from the literature, a load rate of no more than 600 lbs/min or 0.3 in/min should be used to avoid a non-conservative bias in anchor load measurement. Alternatively, the minimum test duration should be changed to 8 minutes under constantly increasing load.

4. *Section 6.0:* At least one example of a suitable means of obtaining a **random sample of anchor specimens** should be described. However, the requirement for a random sample is only relevant to the degree that the GAATP is also intending to serve as a “single point in time” sample of anchor manufacturing quality control. Normally, such objectives (if considered important to the GAATP) are addressed through periodic random sampling and test verification.

5. Section 7.0: This section (**Test Requirements**) includes several topics that are stated elsewhere (e.g., site soil classification, test apparatus, etc.) and should be moved to the front of the GAATP and adapted to serve as an “application guide” or roadmap for use of the standard.

6. Section 8.0: Several comments apply this section (**Field Testing**):
    a. Sections 8.1 through 8.3 appear redundant or would be better placed elsewhere (e.g., move list of test site information to reporting requirements in Section 11.0).
    b. Section 8.4 should be deleted and any new information (e.g., required number of tests) moved to Section 9.0. The section requires a minimum of six tests and that the anchor pass all six tests. However, this requirement and others in Section 8.4 really pertain to or are redundant with the failure criteria stated in Section 9.0. See later comments on Section 9.0 regarding required number of tests.
    c. If the above comments are implemented, Section 8.6 will appropriately serve as the enabling language for Section 8.1 and it should be renumbered as Section 8.1.
    d. Sections 8.7 through 8.9 effectively limit the application of the GAATP to three very specific anchor configurations and installation practices. It is recommended that a final section be included to allow for variations from these configurations provided that the variations are fully documented in the test report and in the manufacturer’s installation instructions.
    e. How should installation variations such as pre-boring of anchors (where necessary due to refusal) be considered? Commentary or a note in the GAATP should be provided to give “non-mandatory” guidance on this issue.
    f. Is the required 500 lb pretension loading consistent with field practice? (e.g., is pre-tension load measured during installation of anchors at end-use sites such that a minimum 500 lb value is reliably achieved?) If not, then the resulting pre-load at the test site should reflect variation in pre-load as a result of the installation practice (e.g., pull anchor or tighten strap until anchor is in contact with stabilizer plate and then record this load as part of the test record). Commentary or a note in the GAATP should be provided to give “non-mandatory” guidance in regard to replicating pre-tensioning practice used during installation and possible variation in actual pretension load. Two means of providing pre-tensioning in anchor certification tests as well as at an end-use site through coordinated installation practices are possible: force controlled pretensioning or displacement controlled pretensioning. Each as advantages and disadvantages. But, the main issue is that the pretensioning technique used for anchor qualification testing and design value derivation per the GAATP needs to be coordinated with field installation practice to ensure that a similar level of pretensioning is achieved in the field.

7. Section 9.0: The requirement to **test to prescriptive ultimate load values** should be eliminated or retained only as an option. This approach is already partially recognized in the GAATP Section 8.5 and in the Model Installation Standards. Such a change will have no effect on anchor reliability because reliability is determined by provisions in

Section 10.0 (e.g., safety margin). This improvement will promote innovation and avoid exclusion of existing anchorage solutions. In coordination with previous comments for Section 8.4 and next for Section 10.0, the number of test repetitions required to define the "lower-bound" estimate of an anchor's ultimate load value can be reduced from 6 to 5 if the safety factors recommended next are implemented.

8. *Section 10.0*: The **safety factor** of 1.5 is in need of improvement to better coordinate with different levels of uncertainty associated with different soil classification or anchor verification strategies. The safety factor associated with each strategy should also consistently meet a performance objective (target reliability) that ensures that the ground anchors are no more likely of failure than the metal straps used to attach the housing unit to the anchors. Based on the reliability analysis in Appendix C of this report, the soil classification methods of Section 4.0 and the safety factor of Section 10.0 of the GAATP should be modified as shown in Appendix B of this report. This approach (or something very similar) is the only rational means to ensure that the GAATP will provide reliable anchor design values consistent with the objectives and intent of the HUD Code.

III. DETAILED REVIEW AND ANALYSIS OF THE PROPOSED GAATP

GAATP Documentation

As a separate consideration from the technical focus of this report, one of the current drawbacks of the GAATP is the lack of a commentary to document references, substantiating data, and implications of various decisions on technical and practical elements of the GAATP. Thus, any independent review must begin with an undefined basis for the provisions that are presently in the GAATP. While this does not imply that problems exist, it does cause some difficulty in deciphering the exact technical rationale and judgment used to justify various important considerations in the draft GAATP.

As an example of a documentation concern, no information is given in support of the ability of the proposed soil classification method to relate field test site data (e.g., anchor design values) to end-use applications at other sites. The uncertainty involved in such correlations can be very large as indicated in the reviewed literature. This uncertainty affects anchor performance and should be explicitly documented in regard to how the GAATP effectively addresses this concern in establishing anchor design values and in achieving the level of reliability of anchor performance implied by the HUD Code.

– Recommendation

- A commentary to the GAATP should be developed to document the basis of various parts of the GAATP, including references, key data and judgments as appropriate.

Evaluation of the Draft GAATP

This section provides a review of the draft GAATP (August 12, 2005 version). It includes a mix of technical discussions and recommendations as well as some editorial suggestions for improved clarity. In all, the GAATP may viewed as a major technical advancement toward the qualification of ground anchors to meet the intent of the HUD Code for windstorm protection related to support and anchoring systems (MHCSS, 1994; refer to Section 3280.306). Some of the more significant recommendations related to soil classification (Section 4.0), failure criteria

(Section 9.0), and design values (Section 10.0) are shown as revisions to the GAATP in Appendix B.

Section 3.0: Definitions

The definitions for allowable deflection limits, load resistance design value, and ultimate load definition are stated as follows in Section 3.0 of the GAATP:

> Allowable Deflection Limits – criteria establishing the maximum amount of bending of a material, assembly or component under load.
>
> Load Resistance Design Value – the rated load capacity (working anchor load) in pounds of the ground anchor.
>
> $\text{Ultimate}_{\text{anchor}}$ Load – the lower of either the highest load achieved during an individual test prior to failure due to exceeding displacement limits, or, the load at failure of the anchoring equipment or its attachment point to the testing apparatus.

– Recommendations

- *Some clarification of the above mentioned definitions should be considered to avoid confusion.* The use of the term "allowable" when defining deflection limits may create some confusion because they are used for different purposes in the GAATP. First, the displacement limits of 2 inches in vertical and 3 inches in horizontal movement are associated with defining the ultimate anchor load in Section 9.0 Failure Criteria. Thus, the deflection limits in this context imply that they are to be considered as a structural safety limit state, not as a serviceability or allowable deflection limit state in the traditional use of the term in engineering design standards. On the other hand, one of the deflection limits (e.g., 2 inches in any direction at the design load) is used as a traditional or allowable deflection as a serviceability limit. While these requirements in Section 9.0 of the GAATP appear reasonable, the definitions do not necessarily clearly convey the above intent. Finally, the issue with allowable deflection is not necessarily with "bending" but rather anchor head displacement. Therefore, the definition for allowable deflection limits should be changed to read: "… criteria establishing the maximum amount of anchor head displacement resulting from material bending, soil deformation, or other causes due to the applied anchor loading."

Section 4.0: Soil Identification & Characteristics

In Section 4.1.1 of the GAATP, test site soils are permitted to be described in accordance with the table in Section 3285.202(a)(3) of the MMHIS. However, this is not stated as a requirement. Instead, Section 4.2.1 requires that all soils be classified in regard to particle size composition (Unified Soil Classification System) using ASTM D2487 (mechanical analysis of particle size composition) or ASTM D 2488 (visual analysis of particle size composition). Next, Section 4.2.1 suggests that ASTM D1586 Standard Penetration Test (SPT) blow count and Soil Test Probe (STP) torque values may be conducted to differentiate between a Class 4A and 4B soil classification (two of the six soil classifications listed in the table in Section 3285.201 of the MMHIS). However, the commentary provided on the STP (torque value) soil test method at the end of the draft GAATP suggests that the STP (torque value) soil test is a common means of classifying soils for ground anchor selection and "must be used to determine soil classification for the selection of ground anchor assemblies approved using this standardized test method [i.e., the GAATP]." Finally, Section 4.3 addresses the types of soils in which anchors are required to be qualified in accordance with the GAATP. Section 4.3.1 requires that all anchors be tested and qualified for use in non-cohesive soil. Section 4.3.2 permits (but does not require) anchors to be qualified for use in cohesive soils.

– Recommendations

- *Section 4.1.1 – Clarification is needed as to why general description of soil is "permitted" and not required to be determined in accordance with the table in 3285.202(a)(3) of the MMHIS.* Is the intention to allow other classification systems to be used in accordance with manufacture-specific data or other sources?

- *Section 4.2.1* -- For soil classes 1-3, it appears that no other classification than particle size of the soil (per ASTM D2487 and D2488) is required in accordance with Section 4.2.1.1. In addition, the ASTM D1586 SPT (blow count) soil test in Section 4.2.1.2 and the STP (torque value) soil test is not required, but "may" be used to differentiate between soil classes 4A and 4B. If the STP (torque value) soil test is not conducted, the table in Section 3285.202(a)(3) of the MMHIS requires that soil class 4B be assumed (see footnote 2 of the referenced table). However, this direction appears to be in conflict with commentary provided on the STP (torque value) soil test method at the end of the GAATP. The commentary suggests that the STP (torque value) soil test must be used in all cases. Furthermore, if a Class 4 soil is assumed to be Class 4B at the test site (for lack of doing a STP (torque value) soil test for the site) but the test site is actually a Class 4A site, then this could result in a non-conservative bias in any end-use site which is similarly classified (as Class 4 without doing an STP (torque value) soil test) but which is actually a Class 4B site. In this hypothetical case, an anchor rated on the basis of a "true" Class 4A site could be used on a site which is a "true" Class 4B site.

  The requirement to use the STP (torque value) soil test on all sites (test sites and end-use sites) appears reasonable and advisable. This intent should be clarified in the GAATP. In general, literature reviewed in Appendix A of this interim report warns against relying on visual soil characterization to select ground anchors because it provides little or no value in prediction of anchor performance (Kovacs and Yokel, 1979; Chance, 2000; etc.). This would also include classifications per ASTM D2487 or D2488 that do not address important factors such as in-situ soil relative density or consistency.

  The usefulness of a complete soil classification in compliance with ASTM D2487 and D2488 (Unified Soil Classification System) is questionable in regard reliability of performance for reasons stated above. *It is recommended that the requirement to perform a complete soil particle size evaluation and classification in accordance with ASTM D2487 or D2488 be replaced with a means of grossly classifying soils into two basic categories: cohesive and non-cohesive. This should economize soil classification requirements. The best means of differentiating these basic soil types for the purpose of anchorage selection and correlation to STP (torque value) soil test may not exactly coincide with the cohesive and non-cohesive soils as defined in ASTM D2487 and D2488 which was created primarily for the purpose of establishing a unified method of soil classification, not a particular application such as correlating soil index tests to ground anchor performance. Therefore, an appropriate and simplified means of visually and manually classifying a soil as cohesive or non-cohesive should be considered for the GAATP based on the degree to which cohesion or friction properties of the soil govern anchor resistance. Such a method could be based on a simplified field assessment of plasticity and dry strength in accordance with ASTM D2488 (visual-manual procedure) for the unified soil classification system. For example, if a dried ½" diameter ball of soil requires considerable finger pressure to break or crumble, then it should be considered* *as a cohesive soil. Alternatively (or additionally), the ability to roll the soil into a 1/8" diameter thread when moistened can be used to classify a soil as cohesive. This approach should be described directly in the GAATP.*

The reviewed literature and available data indicate that a general correlation of anchor performance with STP (torque value) does exist and that the only important distinguishing factor may be in regard to whether the soil is broadly classified as cohesive or non-cohesive as this condition tends to affect STP (torque value) soil test correlations to anchor performance and the uncertainty of those correlations (Kovacs and Yokel, 1979; Yokel et al., 1982; Chance, 2000; Pearson et al., 1996). In fact, reviewed manufacturer anchorage design and selection information revealed some cases where different anchor design value charts using STP torque values were differentiated on the basis of soils being classified as cohesive or non-cohesive (e.g., Chance, 2000).

In addition, it would appear to be redundant and potentially counter-productive to allow the SPT (blow count) soil test method in lieu of the STP (torque value) soil test method. The ASTM D1586 SPT (blow count) soil test method is considerably more expensive to perform than the STP (torque value) soil test method, has repeatability problems when used at shallow soil depths (e.g., less than 10 feet), and provides very unreliable prediction of anchor performance (Kovacs and Yokel, 1979; Yokel et al., 1982; Pearson et al., 1996). *As a potentially better alternative, the Dynamic Cone Penetrometer (DCP) soil test method, which is essentially a scaled-down version of the SPT test method, should be considered in lieu of the more expensive and cumbersome SPT test method.* Because of its reduced size and hammer weight, it may also resolve some of the repeatability concerns with the STP (blow count) method when used at soil depths of less than about 10 feet. However, there is insufficient data to confirm this belief. The DCP soil test method was particularly designed for shallow soil exploration (e.g., less than 10 feet depth) and has become increasingly popular as an inexpensive shallow sub-soil exploration tool.

The GAATP does not provide any guidance in regard to depth of soil at which any of the prescribed soil classification methods are to be performed. For anchors used in direct withdrawal applications (coaxial or in-line loading), soil characterization should occur at or just above the anchor depth. Some guidelines and studies suggest that proper use of the STP (torque value) method requires an average of readings for a distance of several feet immediately above the anchor depth or for the entire depth of the anchor from the ground surface (the latter applying to relatively shallow anchors) (Yokel et al., 1982; Chance 2000). This type of guidance in use of the STP (torque value) soil test method appears important to repeatability of soil classification methods used at field test sites for purpose of anchor qualification testing as well as at end-use sites for purpose of anchor selection.

In addition, anchors that resist horizontal load (stabilizer plate method) may depend substantially on the soil properties at the surface of the soil in relation to passive soil resistance against horizontal movement of the stabilizer plate. Thus, soil classification requirements at the soil surface or shallow depths relevant to stabilizer plates should be considered. This concern would also need to be coordinated with the manner in which manufacturers commonly represent anchor design values for anchor selection purposes. It would seem to render soil classification almost irrelevant if anchor performance is governed by a stabilizer plate and passive soil resistance at the soil surface, but soil classification is based on the soil conditions at the anchor depth. Again, clarification and additional consideration may be required in this regard, particularly as it may affect tested vs. end-use anchor performance through the GAATP's proposed soil classification approach.

As an additional concern, soil moisture may have a large effect in tested anchor performance. In some cases, the affect of a saturated soil condition has been found to improved anchor direct withdrawal performance in one sandy soil condition (FEMA, 2004). This is consistent with the understanding that the shear strength of non-cohesive soils is primarily the result of friction between particles of soil. For anchors with stabilizer plates at the same site, soil saturation was found to reduce anchor performance. In clay soils, the effects of increasing moisture content would tend to decrease anchor performance after the moisture content at plastic limit is exceeded. Thus, soil moisture conditions at a cohesive soil test site are important to acknowledge and report. In addition, it would be important to ensure that the cohesive soil is at or near a representative or "probable maximum" moisture content. Testing a clay soil in a dry condition and selecting anchors for an end-use site based on a dry condition would not necessarily reflect actual performance and would likely overstate actual performance under seasonally varying soil moisture contents. Therefore, it may be necessary to require moistening of soils for testing purposes or the conduct of tests during the "wet season." For sandy soil sites, it may be advisable to require testing in dry to moderate moisture conditions as well as saturated conditions as the impact on anchor performance seen in test data can vary from expected moisture effects.

For reasons stated above, a basic means of assessing soil moisture (at the surface and at anchor depth) should be considered for the purpose of at least defining whether the soil is dry, damp, wet, or saturated. One approach is included in ASTM D 2488 and should be enhanced (especially for the purpose of documenting anchor tests or soil index tests in cohesive soils). It is noted that the HUD Code and the MMHIS require that anchors be placed at least 1-foot above the water table, so some form of soil moisture assessment is already implied. Additional consideration is required in regard to how soil moisture conditions of a particular site should potentially affect anchor field testing requirements (e.g., site selection or preparation) and anchor selection requirements based on end-use site moisture conditions and correlation to soil classification tests such as the STP (torque value) soil test.

- *Section 4.3 – Anchors should be tested and certified in whatever soil type they will be permitted for use (cohesive or non-cohesive). Within these two soil types, anchor selection would then depend on a soil classification, preferably by STP (torque value) soil test. The DCP soil test method should also be permitted subject to additional study to confirm its ability to predict anchor performance in cohesive and non-cohesive sites over a range of density and moisture conditions.* Currently the GAATP requires that all anchors be tested in non-cohesive soils which could be interpreted to limit the qualified anchor's use to sites with only non-cohesive soils. The qualification of anchors in cohesive soil sites is considered optional. However, it is presumable that sites with cohesive soils are as common as those with non-cohesive soils.

Section 5.0: Field Testing Apparatus

In Section 5.1.1, the GAATP specifies that the anchor design value is established on the basis of the soil characteristics determined in Section 4.0.

– Recommendation

- *Section 5.1.1 – The topic of this section is not actually related to the test apparatus per se. Thus, the requirement to characterize a soil for the test site should be incorporated as a statement in Section 4.0 where requirements for soil characterization are addressed.*

In Section 5.1.2 and 5.1.3, the GAATP requires a test apparatus capable of applying a minimum 10,000 lb force and that instrumentation be calibrated to a tolerance of 1 percent. ASTM E4 and E74 are referenced for verification methods for test instrumentation and equipment. These two provisions are the extent of guidance on field testing apparatus found in the GAATP.

– Recommendations

- *Test Apparatus Requirements – Guidance should be given to ensure that a constant angle of pull is maintained during the test or that the angle of pull when the ultimate load is reached be recorded as the loading angle associated with the test specimen results.* In typical standards for similar testing applications, the topic of test rigging is generally given much greater consideration, especially since different configurations of test rigging may be employed by different agencies or individuals. Therefore, it is common to provide one or more generic illustrations of acceptable test rigging. Also, guidance is usually provided to ensure that the test rigging does not alter or interfere with the specimen being tested so that the data is repeatable and representative of actual end use conditions. In reviewing examples of ground anchor test rigging in the literature (Chance, 2000; MHRA, 2000; Yokel et al., 1982; Pearson et al., 1991), it appears that some of the test methods employed may actually introduce reaction loads on the soils within the "cone of influence" of the anchor. This could alter test results by introducing a non-conservative bias. In addition, as an anchor deflects laterally, the angle of pull on the anchor may change, further altering the response of the anchor relative to actual conditions that should dictate a constant angle of pull. This concern is particularly important to tests that involve diagonal loading because, as the anchor deflects, the angle of pull may become steeper. As the angle of pull becomes steeper, the anchor reaction depends more on its vertical load resistance capability which is generally a stiffer response mode. Therefore, this condition also could alter test results by introducing a non-conservative bias. However, in terms of design values this should have little impact with the currently proposed allowable deflection limits which limit maximum horizontal movement to 3 inches. But, it would be appropriate to place a tolerance limit on the angle of pull at the start of the test (being the prescribed loading angle) and that which occurs at the maximum deflection limits. This will serve to constrain the test rigging geometry such that the angle of pull will not change considerably during the test up to the allowable deflection limits.

- *Load Measurement – A minimum requirement for accuracy of load measurement for the GAATP should consider a maximum 5% tolerance, and perhaps even as high as 10%.* Given the variability in ground anchor performance, a maximum 1 percent tolerance for accuracy of load measurements may be considered excessive (i.e., precisely measuring something that has an imprecise failure limit state and significant variability in performance at that limit state is not necessarily beneficial). Other similar test standards, such as ASTM D3689 and D3966 for pile tension and lateral load testing, permit as much as a 10 percent level of accuracy in lateral load measurement. However, for tension testing a maximum 5% tolerance in load measurement accuracy is required. The level of precision and accuracy of testing equipment can affect the cost of test equipment as well as reliability of test equipment.

- *Length/Deflection Measurement – Given the variability in ground anchor performance, a maximum 0.1 inch level of precision in length measurement appears reasonable and should be considered for the GAATP.* Currently, the level of accuracy and precision in deflection or length measurements is not defined. Again, similar tests standards provide some precedents to consider. A length measurement precision of 0.01 inch to 0.1 inch is used for test methods for pile tension and lateral load testing (e.g., ASTM D3689 and D3966).

- *Load Rate – The GAATP should consider specifying a maximum load rate of 600 lbs/minute and/or a maximum displacement rate of 0.3 inches/minute for a number of reasons. Alternatively, the minimum duration of test to ultimate load should be increased to 8 minutes (e.g., 4,725 lbs / 600 lbs/min = 7.9 minutes).* The GAATP addresses identical loading rate requirements repeatedly in Sections 8.7.2, 8.8.2, and 8.9.2. Also, the required load rate affects the test apparatus capability which is directly related to the content of Section 5.0. In addition, the current load rate criterion in the GAATP is such that "the ultimate$_{anchor}$ load is reached in not less than 2 minutes from the start of the test." This requirement should be reconsidered for a number of reasons.

  First, the NBS 142 report (Yokel et al., 1982) found that the load rate should not exceed 600 lbs/minute to properly account for creep effects on tested anchor performance (see Appendix A). In terms of displacement-controlled testing, which may also be an appropriate means of controlling rate and is used in other similar test methods (e.g., ASTM D3689), a maximum displacement rate of about 0.3 inches/minute corresponds with the NBS 142 report recommendation of a 600 lbs/minute maximum load rate. Second, the load rate specified in the GAATP (by way of a minimum 2 minute time limit on the test) may result in load rates that exceed the 600 lbs/minute recommendation by as much as a factor of 4. Thus, the tested stiffness and ultimate load capacity of the anchor would tend to not account for potential creep effects and overstate the anchor's actual performance under actual loading conditions in end-use. In addition, controlling load rate by a minimum 2-minute test duration would result in a different load rates for anchors tested to the prescribed ultimate load value (e.g., 4,725 lbs) relative to anchors that are tested and approved for lower load values as permitted in Section 8.5 of the GAATP and in the proposed MMHIS (MMHIS, 2005; refer to Section 3285.402(a)(1) and relevant footnotes to Tables 1, 2, and 3). It is noted that using anchors with lower tested load values would not affect a change in reliability of the anchors because the same failure criteria and safety margins would apply. Instead, an anchor with a lower tested design load value would simply require that more anchors be used for a given application to provide equivalent performance to that of fewer anchors with a higher tested design load value.

<u>Section 6.0: Test Specimens</u>

This section of the GAATP provides a list of anchor specification information that must be provided to the evaluation agency. It also requires that the anchorage devices used as test specimens be randomly selected by the certifying entity.

– Recommendations

- *Random Selection of Anchors* – The above requirements are reasonable and consistent with accepted practice for similar testing and material performance standards. However, the requirement for random selection of anchors is somewhat vague. *The GAATP should include at least one example of an acceptable means of obtaining a random selection of* *anchors for qualification testing.* However, the necessity of a truly "random" sample of anchors may only be important to the extent that the next comment is considered important.

- *Testing of Mechanical Strength of Anchors* – While soil failure is generally the controlling failure mode for ground anchors (based on literature reviewed for this report), the requirement to randomly select anchors for field testing implies that variation in anchor manufacturing quality is important. However, manufacturers are not required to provide qualification test data on the mechanical strength of anchors. It is optional in the GAATP. Furthermore, there is no standard test method to determine the mechanical properties of the anchors that do not involve actual soil failure modes. One test program (Pearson, 1991) investigated the mechanical performance of a number of ground anchor products. Laboratory tests of ground anchors in constrained soil conditions resulted in average maximum loads (direct tension only) ranging from 5,471 lbs to 17,471 lbs depending on the anchor type or manufacturer. The lowest single test value from all 43 tests was 3,450 lbs. The average COV for all products tested was 11%. These tests indicate that the tested anchor products (as sampled for the referenced test program) have capacity well above that which would otherwise occur with inclusion of soil failure modes representative of actual end-use applications. In addition, the failure criteria in Section 9 of the GAATP include a statement regarding breakage of the anchor device. Therefore, it appears that the GAATP also serves as a means to qualify the anchor mechanical performance as one of the failure modes considered. It also assumes that significant variation in anchor manufacturing quality over time will not occur such that periodic production sampling and manufacturing quality control measures should be required. However, the practice of quality assurance and verification is common to many building products.

  No specific recommendation is given in this regard because it is unclear that manufacturing quality control and variation in mechanical properties of anchors is a concern that is not adequately addressed in the GAATP. The above discussion is provided simply to ensure that this topic has been adequately considered.

<u>Section 7.0: Test Requirements</u>

This section appears to restate requirements given elsewhere, including site soil classification and requirements for the test apparatus.

– Comment on Format and Content

- This section may be more appropriately located at the beginning of the GAATP and expanded to serve as an overall application guide to the use of the provisions of the GAATP. It would be useful to also explain how the test results are to be used for the purpose of anchor design and selection based on end-use site soil conditions, including the intended means of characterizing soils at any given end-use site and how this end-use site soil characterization is to be used in the selection of an anchor tested in accordance with the GAATP at a field site of similar soil classification.

<u>Section 8.0: Field Testing</u>

Sections 8.l through 8.3 address characterization and reporting of test site soil conditions, connection of test apparatus to the ground anchor assembly, and general anchor certification requirements.

– Comment on Format and Content

- It appears that Sections 8.1 through 8.3 contain information redundant to other parts of the GAATP or that would be better located in other parts (e.g., place list of required test site information under reporting requirements of Section 11.0). In addition, the list of site data should also include soil moisture content at the ground surface as well as at the depth of the anchor auger as these factors tend to affect test results. Section 8.2 includes a requirement that the connection of the test apparatus to the anchor head should be representative of actual loading conditions (e.g., use of strap and slotted bolt). This requirement is reasonable, but should be located under previous Section 5.0 because the subject relates directly to the test apparatus and rigging. Section 8.3 deals with the scope and intended application of the standard and should be deleted because it appears to be redundant with Section 1.3 and does not specifically relate to the field test methodology and requirements addressed in Section 8.0.

Section 8.4 requires a minimum of six tests to an ultimate load in the direction of pull of 4,725 lbs (3,150 lbs x 1.5 factor of safety). It requires that the anchor product samples pass all six tests. This section also repeats the failure criteria for deflection as stated in Section 9.0.

– Comment on Format and Content

- With the exception of the number of tests required and that all test repetitions must pass the failure criteria, the remaining information in this section is redundant with the failure criteria and design value requirements of Section 9.0 and 10.0. It also does not completely state all of the failure criteria listed in Section 9.0. Therefore, the section should simply state the number of test required and that all tests must pass the failure criteria stated in Section 9.0. The remaining text related to test load values and failure criteria should be deleted from this section. Finally, it is realized that the number of tests required (and the requirement that all specimens must pass each test) essentially establishes a statistical lower-bound estimate of the $\text{ultimate}_{\text{anchor}}$ load. Therefore, the number of tests is really related to how the failure criteria are defined or determined for a given anchor and, therefore, the entire Section 8.4 should be moved to Section 9.0. The requirement (i.e., a minimum of six tests and all specimens required to pass the failure criteria) appears to be a reasonable and simple approach at reliably establishing anchor design values at the test site. However, this topic is revisited later in this report in regard to its relationship to the overall reliability or uncertainty of anchor performance at end-use sites and the intended anchor performance objectives in the HUD Code.

Section 8.5 essentially creates a performance specification allowing "special purpose" anchors to be tested to different performance limits than specified in the GAATP.

– Recommendation

- *Section 8.5* - This section provides a performance basis for qualification of anchor devices, but limits it only to special applications. The proposed MMHIS permits any anchor device to be tested and qualified with design values that are less than those prescribed in the installation standards, HUD Code, and the GAATP (i.e., the 4,725 lbs ultimate load and 3,150 lbs design working load values). The failure criteria as defined in Section 9 of the GAATP and the safety factoring as required in Section 10 of the GAATP can effectively allow all anchors to be qualified based on their actual tested performance rather than to prescribed load values. *Because a performance-based anchor qualification method will allow product innovation as well as alternate design solutions with equivalent performance, it is recommended that the intent and application* *of this section be expanded to include the entire scope of the GAATP*. It is realized that there is some practical value in testing anchors to a prescribed load condition for the sake of having uniform installation requirements (e.g., one anchor installation spacing table can addresses all applications because it is based on only one possible anchor design load value). But, it is a relatively simple matter to base anchor designs on actual anchor performance rather than on prescribed working and ultimate load values. Manufacturers can address these concerns on their approved plans.

In taking full advantage of a performance-based anchor qualification approach, it may be necessary to give a prescriptive minimum limit to acceptable anchor design values (or spacing of anchors) to prevent anchors from being spaced too closely, resulting in loss of anchor efficiency due to group action effects (e.g., overlapping cones of influence in the soil surrounding the anchors). In addition, it may be necessary to clarify that anchor spacing may be controlled by the design working load value of the strapping material should anchors be qualified for a design load greater than 3,150 lbs. But, in such situations a stronger strapping material could be used to allow wider anchor spacing for ground anchors with qualified design values that exceed 3,150 lbs. Consequently, it may be necessary to place a prescriptive limit on the maximum anchor spacing based on limitations in the ability of the housing unit and its structural system to transmit loads to the anchorage points and to maintain some minimum level of anchorage redundancy. However, these concerns are all design concerns in the use of qualified anchor design values and not necessarily considerations that should be addressed in the GAATP. Therefore, they should be addressed in a commentary to the GAATP to ensure its proper use and interpretation when a performance-based anchor qualification approach is used. The need for a commentary to the GAATP was addressed earlier in this interim report.

In Section 8.6, the various sections that apply to three different anchor installation methods are described and referenced.

– Comment on Format and Content

- If the previous comments are accepted in regard to organization of the GAATP and moving Sections 8.1 through 8.5 to other locations in the GAATP, this section would appropriately serve as the initial or enabling language for proceeding requirements in Section 8.0 related to anchor installation requirements for field testing.

Three anchor installation approaches for field testing purposes are described in Sections 8.7 through 8.9.

– Recommendations

- These sections effectively limit the application of the GAATP to three typical installation configurations. However, there may be installations that use different configurations (e.g., different loading angles or anchor installation angles) which can provide acceptable alternative solutions. Is it the intention to limit application of the GAATP strictly to the detail installation configurations described in these sections? If not, a section should be added that allows different installation and anchor configuration details (e.g., load angles, distance of stabilizer plate from the anchor shaft prior to pre-loading, anchor installation angle, etc.) provided the intent of the GAATP is met and the configuration and installation details are reported as required in Section 11.0 of the GAATP and included in manufacturer installation instructions as appropriate. In addition, it is not uncommon to encounter conditions where the anchor may meet refusal and pre-boring of the anchor may be required. Is this practice excluded from anchors evaluated by the GAATP? Either way, such practice should be addressed as either being permissible or not permissible. This latter concern may also be more suitably addressed in a commentary (see earlier section on GAATP documentation).

Section 8.7 (Ground Anchor Assembly/Stabilizer Plate Method) – The approach for installing a test specimen representing a ground anchor and stabilizer plate assembly is described. However, there are some observations worth further consideration. First, the stabilizer plate is required to be installed three inches from the anchor shaft prior to pre-tensioning. But, other literature (such as the MHRA Guidelines for Anchor System Design, 2000) are based on the stabilizer plate being spaced 2 inches from the anchor shaft during installation. At least one manufacturer installation guide recommends that stabilizer plates be "nested against" the anchor shaft when installed prior to completely driving the anchor into the ground. These practices result in different stiffness or pre-tensioning conditions of the anchor assembly. *Is it the intention of the GAATP to establish a single installation practice for anchors with stabilizer plates? If so, an explicit statement regarding inclusion of this practice in manufacturer installation literature should be required. Alternatively, different installation methods should be permitted as described in the general comment above. Finally, the maximum pre-tension load value (i.e., 500 lbs) should be reconsidered to require that the tension load be sufficient to cause the anchor shaft to contact the stabilizer plate and that this load be recorded. In field practice, pretension load will not necessarily be monitored, but it could be expected that the installer would pre-tension the anchor to the point of causing the shaft to contact with the stabilizer plate, irregardless of the tension load actually required to cause contact between the anchor shaft and stabilizer plate.*

- *Section 8.8 and 8.9 (In-line Anchor Configurations)* – Similar concerns apply to Sections 8.8 and 8.9 as mentioned above for Section 8.7. For example, it may be more realistic in terms of field practice to require that the strap pretension be based on a number of turns of the slotted bolt after slack is removed from the strap. However, if pretension load is commonly measured and controlled during field installation (or if it is specifically required in the installation instructions), then it may be reasonable to require a 500-lb pretension load. The intent expressed here is to have the test method replicate the uncertainties associated with the installation practice actually used in the field, particularly in regard to the amount of pre-tension.

  It would also be appropriate, as mentioned above for Section 5.0, to place a tolerance limit on the angle of pull at the start of the test (being the prescribed loading angle) and that which occurs at the maximum deflection limits. This will serve to constrain the test rigging geometry such that the angle of pull will not change considerably during the test up to the allowable deflection limits.

  Load Rate – In each of Sections 8.7 through 8.9, a subsection (.2) is devoted to the load rate for testing. For recommendations on load rate, refer to previous review of Section 5.0 of the GAATP above.

<u>Section 9.0: Failure Criteria</u>

Section 9.0 of the GAATP states the following failure criteria:

.1 When the anchor head, or its attachment point, displaces 2 inches in the vertical direction or 3 inches in the horizontal direction from its pretensioned measurement position prior to holding a total of 4,725 lbs (including any pretension load).

.2 When the anchor head, or its attachment point, displaces 2 inches in any direction from its pretensioned measurement position prior to holding a total of 3,150 lbs (including any pretension load).

.3 When breakage of any component of the ground anchor shaft occurs prior to reaching a total load of 4,725 lbs.

– Comments on Format and Content

- These criteria represent significant improvements relative to past practice which has either required no deflection limitation or which has allowed up to 4 inches of lateral deflection. This section also represents an improvement in that the stated deflection limits in subsections (.1) and (.3) above are clearly interpreted as structural safety limits states to which a safety factor is applied in accordance with Section 10 of the GAATP. This practice will remove ambiguity as to the interpretation of deflection limits, safety margins, and anchor design values. Furthermore, a 2 inch maximum deflection limit is applied to movement in any direction at a load equivalent to the design load value (currently prescribed as 3,150 lbs). This criterion will ensure that lateral and/or uplift load at a design load event will not exceed 2 inches. In the context of design load conditions, the 2-inch deflection criterion in subsection (.2) appears to represent a serviceability deflection limit state. This criterion also appears reasonable and reflects and improvement relative to past experience as well as past practice for anchorage of manufactured homes. In past accepted practice for various types of foundation anchors, including piles and helical anchors, deflection limits for evaluating tested performance have varied widely from as little as 1 inch to as large as 6 inches (ASTM D3689; ASTM D3966; Chance, 2000; Perko and Rupiper, 2000). Therefore, from the perspective of prior precedents, there appears to be little reason to question the integrity of the proposed deflection limits in the GAATP.

– Recommendation

- *Performance-Based Approach* – As previously discussed in comments on Section 8.5 of the GAATP, it seems unnecessary to require the use prescriptive load values (e.g., 4,725 lbs ultimate and 3,150 lbs design), particularly when the intended safety margin is explicitly provided for in Section 10 of the GAATP. Thus, equivalent anchor performance, regardless of the actual ultimate load and design load achieved, is adequately addressed by a performance-based approach for ground anchors that already exists in the GAATP and the proposed MMHIS (see prior comments in on Section 8.5). *Therefore, it is recommended as an accepted and common engineering practice that the prescriptive load values of 4,725 lbs (ultimate) and 3,150 lbs (design) be removed from the failure criteria descriptions of the GAATP. Instead, these prescriptive load values should be stated as an optional goal that would allow prescriptive anchor installation requirements in the MMHIS to be used without modifying the prescribed anchor spacing requirements based on an assumed 3,150 lb anchor design value (see Tables 1, 2, and 3 in the MMHIS). If the prescriptive load values are removed or treated as optional target loads, the reference to "a total load of 3,150 lbs" in subsection (.2) should be changed to read "the load resistance design value (working anchor load) determined in accordance with Section 10.0 by applying the required safety factor to ultimate$_{anchor}$ load as limited by failure modes described in 9.1.1 and 9.1.3."*

The use of a performance-based qualification approach will prevent viable or existing anchorage systems and innovative solutions from being unnecessarily excluded from use.

For example, recent testing of one manufacturer following the 30 degree anchor pull test (Section 8.7 of the GAATP) indicated that several currently used anchors failed with use of the proposed failure criteria in Section 9.0 of the GAATP (American Industrial Testing, 2005; unpublished manufacturer test data). Using a performance-based approach as described above would allow these anchors to be used while ensuring equivalent reliability and performance through use of the required failure criteria and safety margin. The only impact would be that a design value of less than 3,150 lbs would be determined which would require a closer anchor spacing to achieve a consistent level of reliability. Thus, total exclusion of these viable anchorage options would be avoided.

Section 10.0: Establishment of Load Resistance Design Value or Anchor Working Load

This section requires that the $\text{ultimate}_{\text{anchor}}$ load as defined by failure modes described in Section 9.1.1 and 9.1.3 be divided by a safety factor of 1.5. It also requires that field tests be performed in "the weakest soil that the ground anchor is being qualified for use." It also requires the load resistance design value to be reported in the ground anchor listing or certification for each installation method considered (i.e., per Section 8.7 through 8.9).

– Comments on Format and Content

- The use of a 1.5 safety factor has been a common and long-standing interpretation of the HUD Code provisions for ground anchors. However, this interpretation does not necessarily provide for ground anchor performance that is actually equivalent to the performance of metal strapping material upon which this safety margin and prescribed load values in the HUD Code and MMHIS are based. This concern exists because ground anchor failure modes result in a much larger variability of performance than that of metal straps. This understanding is clearly confirmed in the literature (MHRA, 2000; Pearson et al., 1996; Yokel et al. 1982; Mays 2005; Kovacs and Yokel, 1979; FEMA, 2004; Pearson et al., 1991). Unfortunately, the HUD Code is silent on the manner of reconciling differences in variability of metal strap and ground anchor performance toward ensuring that a consistent level of reliability is achieved for these inter-dependent components of the ground anchorage system or the manufactured home structural system as a whole.

  At a most fundamental level of applying engineering reliability concepts, two products (such as metal strapping and ground anchors) that are each integral to a structural system (e.g., foundation) can only have a similar reliability if the safety factors used to define design values for each product account for differences in variability of performance. Thus, the product with the higher variability in performance should require a larger safety margin and vice-versa. For ground anchors, the level of variability depends on the manner of qualifying and selecting anchors based on soil characterization. Thus, a more rigorous soil characterization (assuming improved correlation to anchor performance) would tend to cause a lower variability in anchor performance in end-use and justify a lower the safety margin. Conversely, a less rigorous soil characterization (such as visual soil assessment or particle size assessment without soil testing) would tend to result in a higher anchor performance variability in end-use and require a larger safety margin in a relative sense.

  In the end, a determination regarding acceptable reliability and related safety margins to achieve that level of reliability is ultimately a political decision (e.g., "how much safety is enough?"). But, such decisions should be guided by a reasonable technical understanding of the potential implications (including what is known and not known) as well as judgment and experience in past successful practice. To assist in decisions regarding ground anchor reliability and safety margins to ensure reliability consistent with the metal strapping used to attach the housing unit to the anchor, a reliability study has been conducted as a part of this report (see Appendix C).

– Recommendations

- The following safety factors are recommended for Section 10.0 of the GAATP (see also Appendices B and C for analysis and recommended revisions to the GAATP):

Recommended Safety Factor (applied to lowest ultimate value in 5 test reps)[1]	**Soil Classification Approach Used for Selection of Anchors at End-Use Sites**	**Estimated Variability in Anchor Performance (COV)[2]**
1.5	Anchors tested per GAATP at end-use site (no soil classification required)	0.20 (or 20%)
2.0	Anchors selected on basis of correlating soil index test at end-use site to similar value at anchor qualification test sites (e.g., Soil Torque Probe values)	0.35 (or 35%)
4.0	Anchors selected only on basis of visual or mechanical assessment of soil particle size distribution (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 if 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.

The safety factors recommended above are reasonably consistent with accepted engineering practice for foundation design as discussed in the next section of this report. They are also based on using the minimum tested value for anchor performance from a total of 5 test repetitions. Using the lowest value from 6 test repetitions as currently required in the GAATP would only slightly reduce the above safety margins (see Appendix C). Should the estimated variability (COV) of anchor performance be considered high or low for any of the above considered soil classification strategies (based on future data or a different analysis of existing data), then the recommended safety factors can be readily adjusted to reflect the new information following the approach used in Appendix C. The important feature in the above table is that the safety margins reflect different levels of variability in end-use performance (based on different levels of rigor in soil classification or anchor performance verification) in a way that maintains a consistent level of reliability. Furthermore, the level of reliability (probability of failure) used to establish the above safety factors will ensure that ground anchors or no more likely of failure than the straps that attach them to the manufactured home (see Appendix C).

Finally, there appears to be no need to modify metal strap values to account for potential biases in nominal vs. actual design value (as found in tests by Pearson et al., 1991) because the safety factor of 1.5 used for straps, in combination with the relatively low variability of metal strap performance, adequately addresses this concern (see Appendix C).

Discussion on Safety Margins and Reliability of Ground Anchor Performance

Safety margins for design of foundations, including soil retaining structures, commonly vary from a low of 1.5 to more than 5 depending on the application, potential consequences, confidence in knowing soil conditions, and the level of risk aversion of the individual engineer or owner. Furthermore, magnitude of a safety margin to be employed is dependent on the manner of defining the characteristic resistance value (e.g., ultimate load value) to which a safety factor is applied. For example, safety margins of 2 to 3 are commonly used with the average ultimate strength of wood frame shear walls to determine a design value for these systems. For metal strapping, safety margins of 1.5 or 2 for building design applications are standardized and depend on whether the safety margins are applied to yield strength or ultimate breaking strength, respectively (refer to the North American Specification for the Design of Cold Formed Steel Structural Members, AISI/COS/NASPEC 2001). However, the variability in structural properties of these types of structural systems and materials is much less than ground anchors (COV of 2% to 5% in comparison to a typical COV of 20% for anchors within a single test site to 40% or more for ground anchors selected on the basis of correlation of anchor performance at a test site to an end-use site on the basis of typical soil classification methods). Therefore, one might conclude that the higher variability of ground anchors would require the use of a much higher safety margin than 1.5 to establish ground anchor design values that provide a level of structural reliability consistent with that of the systems or components the anchor is intended to restrain.

The $\text{ultimate}_{\text{anchor}}$ load value to which the safety margin is applied in the GAATP is not an average value because it represents a value that does not exceed the specified failure mode limits in all of six required tests at a given field site. Thus, the $\text{ultimate}_{\text{anchor}}$ load value in the GAATP represents a lower-bound estimate of the actual average $\text{ultimate}_{\text{anchor}}$ load value associated with the specified failure mode deflection limits for a given field test site soil condition. Because the safety margin is applied to a lower-bound estimate of the ultimate load (and not the average ultimate load), this would tend to reduce the magnitude of the safety margin needed to provide acceptable performance. However, this lower-bound estimate of the $\text{ultimate}_{\text{anchor}}$ load value must also be tempered with an understanding that the variability of anchor performance at the field test site does not capture all of the variability that will exist in actual end-use applications, particularly when anchors are selected on the basis of uncertain correlations through test site and end-use site soil classification. The inter-relationship of all of these factors requires a more careful analysis based on available data related to variability in anchor performance. Such an analysis, at least in preliminary form, has been provided in Appendix C of this report. The analysis makes use of existing test data found in the literature (e.g., Pearson et al., 1991; Yokel, et al., 1982; MHRA, 2000; FEMA, 2004; Kovacs and Yokel, 1979; etc.).

Discussion on Design Loads in Relation to Overall Anchorage System Reliability

It is also important to at least mention that the overall reliability of an anchorage system design also depends on the means of determining design loads. Based on the manner of establishing loads for anchor system design, additional uncertainties and biases may be introduced that affect the relative reliability of manufactured home anchorage systems. Some examples follow.

The HUD Code does not address seismic loads. Seismic or cyclic loads were addressed in one reviewed study (Pearson et al., 1993; Marshall and Yokel, 1995), but guidance regarding an appropriate seismic response modifier for foundation anchor system design was not adequately addressed. The literature reveals that seismic loads are often determined using a seismic response modifier, R, that is applicable to light frame shear wall systems. This entails an R-factor of roughly 6 depending on the building code version used. However, conventional anchorage systems for manufactured homes use metal tension straps which are more closely related to and R factor of 4 in accordance with modern building code provisions for wall systems braced with metal tension straps (refer to ASCE 7-05 for example). Thus, a non-conservative load bias of as much as 50 percent or more can be introduced in the application of anchorage system designs purely based on the selection of seismic response modifier used for an anchorage system design, regardless of how anchor design values are established.

In regard to wind loads, the HUD Code assumes that all sites are subject to wind loads associated with an open site exposure condition (Exposure C per ASCE 7). Given that most buildings are located in more obstructed wind exposures, and may often be further protected by shielding effects that are not accounted for in the ASCE 7 or HUD Code wind provisions, a conservative bias in wind load of 1.4 or much more will likely exist for most manufactured home installations. This bias will tend to improve the actual reliability of anchorage systems in a broad scale considering all manufactured home installations. It is noted that site-built residential construction in accordance with the International Residential Code is permitted to be assumed by default to exist in a suburban wind exposure (Exposure B). In part, this allowance is intended to offset a conservative bias in wind load and in the surface roughness characterization used in ASCE 7 for exposure B (e.g., the surface roughness value used to determine wind load exposure coefficients for exposure B in ASCE 7 are conservatively defined and are not consistent with the physical description of a site exposure B condition as used in ASCE 7; refer to the commentary of ASCE 7-05 for additional detail). It is understood that site exposure conditions are not necessarily known for manufactured homes, because the final destination of the structure is often not known. Therefore, it is prudent to use a conservative representation of wind exposure in the HUD Code. But, the site exposure condition will be known and the effects of exposure on design wind load magnitude could be considered at the time of installation of anchorage systems.

There are other wind load considerations, however, which tend to produce a non-conservative bias on anchorage system loads. For example, the HUD Code permits the entire dead load to be used to resist or offset the uplift and overturning effects of the prescribed design wind loads. This creates a situation where, at the design wind load, the uplift value may be at or near zero. Yet, at an ultimate wind load event (which is not directly checked in the allowable stress design format, but which is a design intent expressed through the use of safety factors and nominal load and resistance values) the dead load would likely be offset such that a net uplift force exists. It is for this reason that modern wind loading standards, such as ASCE 7, require that the dead load be reduced by a load factor of less than one (e.g., 0.6 or 2/3rds depending on the edition of the ASCE 7 standard) when dead load is used to offset design wind load in an allowable stress design format. This ensures intended performance is provided for loading conditions that exceed the nominal design load up to the implied ultimate load condition.

In an ideal situation, biases should be minimized or eliminated in the treatment of structural loads and resistance. In reality, they cannot be completely eliminated so judgment is required to achieve a reasonable design outcome and minimize any systematic biases that could inadvertently impact reliability of actual anchor system's performance or its cost-effectiveness. To some degree, these considerations may directly or indirectly affect decisions in regard to the GAATP and its manner of establishing ground anchor design values for use with the HUD Code design load provisions.

– Recommendations

- *Based on the above discussion, it is recommended that HUD consider updating the wind load provisions of the HUD Code such that they are treated consistently across all wind zones based on an updated map of wind zones found in ASCE 7-98 and later editions of* *that standard.* This update should consider a pending or forthcoming revision of the wind map such that the latest improvements in wind risk modeling are incorporated in the update. In regard to anchor system design, this would eliminate the use of an additional 1.5 load factor for anchor design used only in Wind Zone I of the current HUD Code. It would also represent, in a more risk-consistent and efficient manner, exposure C (open terrain) wind loads to be used for manufactured homes throughout the United States. In addition, it should be possible to consider the effects of site wind exposure on required ground anchor spacings in the MMHIS which are based on wind exposure category C wind loads. This allowance would require a visual assessment of site exposure at the time of installation (when the site is known). The anchor spacing would then be selected from the MMHIS tables, modified relative to the actual anchor's rated working load value relative to the 3,150 lb value prescribed in the HUD Code and MMHIS, and then adjusted to account for effect of site exposure on wind load (if the site is not in an open wind exposure condition). This process can be easily tabulated as shown in suggested revisions to the GAATP in Appendix C. This approach will promote more economical and risk-consistent anchor installations across the United States.

- *In addition to the above recommendations for addressing wind loads, the HUD Code should be updated to include specific provisions regarding earthquake loads. The provisions should include a simplified approach to determining earthquake loads as recommended in the literature (Marshall and Yokel, 1995; HUD, 2000; HUD, 2001).* For example, a simple equation for determining earthquake loads for one-story buildings using modern earthquake design provisions is as follows (HUD, 2000; ASCE, 2005):

$$V = [0.9\, S_S/R]\, W$$

where,
V = seismic design shear load,
S_S = mapped ground motion hazard (short period spectral response acceleration),
R = seismic response modifier to account for ability to safely dissipate energy through ductile damage behavior, and
W = weight of supported portion of the structure (mass tributary to the component or system under consideration).

For manufactured homes, two seismic response modifiers must be considered: one for the unit itself (light frame construction) and one for the foundation/anchorage system. Relevant values for R for various relevant building systems are as follows (ASCE, 2005; refer to Table 12.2-1):

- Light-framed walls sheathed with wood structural panels, R = 6.5
- Light-framed walls with other types of shear panels, R = 2
- Light-framed walls using flat strap bracing, R = 4

The above R factors account for the ability to reduce the actual seismic load to account for the seismic response capability of the building system. It does not account for the actual forces that the building system will experience in components such as connections or the foundation anchor system. For this reason, overstrength factors are used to determine design forces in components that must transmit forces into and out of the main seismic force resisting systems associated with the R value selection (ASCE, 2005; refer to Table 12.2-1). Thus, the actual force in the ground anchor, calculated using the simplified equation above and the seismic response modifier appropriate to the housing unit's structural system, should be multiplied by an overstrength factor. For light-framed walls with wood structural panels, the overstrength factor is 3. Assuming an R factor of 6.5 (for light frame systems in general) and an overstrength factor of 3, the effective R factor for anchor system design would be 2.2 (= 6.5 / 3). However, this value of R for anchor system design appears conservative because flat strap systems used in walls are permitted to use an R of 4 (see above). Therefore, for seismic design of conventional ground anchor systems, an R of 4 is recommended until such a time that a study is conducted to better quantify a value for R appropriate for design of manufactured home foundation/anchorage systems.

In addition to wind and seismic loading, ground anchors securing homes placed in Special Flood Hazard Areas (SFHA) can be exposed to flood forces. Although, it would be most appropriate to not locate homes in a SFHA, it is recommended that for these conditions, loads be determined from Chapter 5 of ASCE 7-98 (or later) for the site where the home will be placed.

Implications for Planned Anchor Testing (Task 2d)

The findings of this report are considered important to the objectives of planned testing of anchors in accordance with Task 2d of this contract. Thus, the anchor test plan as originally proposed should be re-evaluated in view of the findings in this interim report.

One topic that should be considered for study in Task 2d testing is the issue of variability in prediction of anchor performance relative to different methods of soil classification used to correlate test site anchor performance with an end-use site anchor selection. This topic is important because it has a significant impact on anchorage system reliability. As such, it impacts the magnitude of safety margin required to consistently maintain and acceptable level of reliability. These issues were addressed in previous sections of this report and analyzed in Appendix C based on current knowledge, data, and judgments regarding the meaning of that data (e.g., magnitude of variability associated with various soil classification and anchor selection strategies). Thus, additional testing could provide some greater insight into the appropriate level of uncertainty to assign to different soil classification strategies. But, any significant improvement in knowledge of uncertainties (relative to current knowledge) would require an extensive test plan covering many different sites with varying soil conditions. Such a test plan is beyond the scope of the originally planned effort for Task 2d.

Based on the above discussion, the Task 2d test plan may be best aimed at some very specific topics related to various findings and recommendations related to the GAATP. Such topics might include:

- an investigation of test rigging implications on anchor test results (e.g., controlling angle of pull),
- an application of a performance-based approach to establishing anchor performance and design values,
- additional exploration of load rate effects,
- additional exploration on moisture effects, and
- other topics yet to be decided.

V. REFERENCES

American Industrial Testing. 2005. Unpublished Anchor Testing Data Sheets (7 different tests of Oliver Technologies auger-type anchors w/ stabilizer plates, including 30 deg angle pull), dated 3/15/2005 through 6/28/2005, fax from Lon Larson (Oliver) to HUD.

ASCE. 1988. Minimum Design Loads for Buildings and Other Structures. American Society of Civil Engineers. New York, NY.

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

ASTM D3689-90. 2004. Standard Test Method for Individual Piles Under Static Axial Tensile Load, Annual Book of ASTM Standards, Vol. 4.08, American Society of Testing and Materials, West Conshohocken, PA.

ASTM D3966-90. 2004. Standard Test Method for Individual Piles Under Lateral Load, Annual Book of ASTM Standards, Vol. 4.08, American Society of Testing and Materials, West Conshohocken, PA.

Chance. 2000. The Chance Encyclopedia of Anchoring, Centralia, MO. 2000 http://www.hubbellpowersystems.com

FEMA. 2004. Ground Anchor Testing – unpublished summary of testing performed for update of FEMA 85, presented to MHCC Ground Anchor Testing Protocol Task Group, July 2004.

FEMA. 2005. Manufactured Homes in Flood Areas (FEMA 85), Second Edition, August 2005 (DRAFT)

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

HUD. 1996. Permanent Foundations Guide for Manufactured Housing, U.S. Dept. of Housing and Urban Development, Washington, DC. September 1996.

HUD. 2000. Residential Structural Design Guide. 2000 Edition. U.S. Department of Housing and Urban Development, Washington, DC.

HUD. 2001. Structural Design Loads for One- and Two-Family Dwellings. U.S. Department of Housing and Urban Development, Washington, DC.

HUD. 2002. Guide to Foundation and Support Systems for Manufactured Homes, HUD, MHRA, MHI, 2002.

ICC-ES, Helical Pier Foundation Systems, Evaluation Report #5110 (ER-5110) for Hubbell Corporation / A.B. Chance Co., Centralia, Missouri, www.icc-es.org

Kovacs, W.D. and Yokel, F.Y. 1979. "Soil and Rock Anchors for Mobile Homes – A state of the art Report." NBS Building Science Series 107, National Bureau of Standards, Washington, DC, 147 pp.

Marshall, R.D. 1994.“Manufactured Homes – Probability of Failure and the Need for Better Windstorm Protection Through Improved Anchoring Systems,” NISTIR 5370, National Institute of Standards and Technology, Gaithersburg, MD. November 1994.

Marshall, R.D. and Yokel, F.Y. 1995. “Recommended Performance-Based Criteria for the Design of Manufactured Home Foundation Systems to Resist Wind and Seismic Loads,” NISTIR 5664, National Institute of Standards and Technology, Gaithersburg, MD. August 1995.

Mays, T.W. 2005. “Permanent Foundations vs. Traditional Soil Anchors: Using example calculations to illustrate relative performance of manufactured housing foundations in hurricane zones,” Coastal Disasters 2005, American Society of Civil Engineers, Reston, VA.

MHCSS. 1994. Manufactured Home Construction and Safety Standards (24 CFR Part 3280) 4-1-04 Edition

MHRA. 2000. Guidelines for Anchor System Design: Technical Support Document, Manufactured Housing Research Alliance, New York, NY. January 7, 2000.

MMHIS. 2005. Model Manufactured Home Installation Standards (24 CFR Part 3280 and 3285), proposed rule published in Federal Register, Vol. 70, No. 79, Tuesday, April 26, 2005. pp21498-21559.

Nierlich, H. and Bruce, D.A. A Review of the Post-Tensioning Institute’s Revised Recommendations for Pre-stressed Rock and Soil Anchors, internet document

Pearson, J.E., Meinheit, D.F. and Longinow, A. 1991. “Testing of Soil Anchors and Strapping.” Report No. WJE 901798, prepared for U.S. Dept. of Housing and Urban Development, WJE Associates, Inc., Northbrook, IL, 67 pp.

Pearson, J.E., Meinheit, D.F., and Longinow, A. 1993.“Full-Scale Laboratory Testing of Manufactured Housing Lateral Load Restraint Devices.” for U.S. Department of Housing and Urban Development, Wiss Janney Elstner Assoc. Inc. report Sept. 1993. (HUD 006360)

Pearson, J.E., Longinow, A., and Meinheit, D.F. 1996. “Wind Protection Tie-Downs for Manufactured Homes,” Practice Periodical on Structural Design and Construction, American Society of Civil Engineers, Reston, VA. November 1996. pp126-140

Perko, H.A. and Rupiper, S.T., Helix Pier Engineering Handbook 2000. Ingal Precision Foundations, Inc. 2000.

Progressive Engineering, Inc. 1989. “Ground Anchor Test Procedure for Manufactured Homes,” PEI Standard No. 89-5, Progressive Engineering, Inc., Goshen, Indiana. December 1989.

SWA. 1999. “Manufactured Home Installation Training Manual,” HUD Report, Steven Winter Assoc. Inc., Norwalk, CT. April 1999.

SWA. 2006. Task 2b – Search and Review of State Requirements, Interim Report, prepared by Steven Winter Associates for U.S. Department of Housing and Urban Development, Washington, DC. January 20, 2006.

Tie Down Engineering. 2003. Manufactured Housing Anchor Installation Information, Tie Down Engineering, Atlanta, GA.

Tie Down Engineering, Inc. (date unknown). Ground Anchor Independent Testing Results. (www.tiedown.com)

USDA-FPL. 1980. Survey of Existing Performance Requirements in Codes and Standards for Light-Frame Construction, FPL 26, USDA, Forest Products Laboratory, Madison, WI. January 1980.

WJE. 1995. Guidance for Supports of Manufactured Housing and other Relocatable Structures for Idaho Bureau of Disaster Services, prepared for Federal Emergency Management Agency by Wiss, Janney, Elstner Associates, Inc., Northbrook, Illinois. June 22, 1995.

WSGS. 2001. How to Make Your Wyoming Home More Earthquake Resistant, Wyoming State Geologic Survey, Information Pamphlet #5, 2001 (http://www.wsgs.uwyo.edu/hazards/IP-5.pdf)

Yokel, F.Y., Chung, R.M., and Yancey, C.W. 1981."NBS Studies of Mobile Home Foundations," NBSIR 81-2238, NBS, US DOC, Washington, DC. March 1981.

Yokel, F.Y., Chung, R.M., Rankin, F.A. and Yancey, C.W.C. 1982. "Load-Displacement Characteristics of Shallow Soil Anchors." NBS Building Science Series 142, National Bureau of Standards, Washington, DC, 147 pp.

Yokel, F.Y., Yancey, C.W.C. and Mullen, C.L. 1981. "A Study of Reaction Forces on Mobile Home Foundations Caused by Wind and Flood Loads." NBS Building Science Series 132, National Bureau of Standards, Washington, DC, 74 pp.

APPENDIX A – DETAILED REVIEW OF SELECTED LITERATURE

Review of Regulatory Requirements

- *HUD Code (or MHCSS), Revised 2004 (Part 3280.306 Windstorm protection)*

Foremost, the HUD Code requires that each manufactured home be provided with an anchoring/support or foundation system that will resist overturning and lateral movement (sliding) at the imposed design loads. In Wind Zone I, the HUD Code requires a 1.5 safety factor to be applied to prescribed wind pressures for the purpose of anchorage system design only. This factor is presumed to account for the fact that the pressures used for Wind Zone I are considerably less than 50-year design wind loads represented in ASCE 7-88 in the interior of the United States and with the assumption of an Exposure C (open terrain) wind exposure condition. In Wind Zone II and III, this factor is not applied because the pressures are based on the ASCE 7-88 provisions. Furthermore, the HUD Code allows the full dead load of the structure to be used to resist wind loading effects, whereas the ASCE 7 requires that only a portion of the dead load be considered, particularly in an allowable design stress format, to account for the difference in offsetting load effects that occur at the ultimate load level (which is really the event of concern in design).

The anchoring system is required to be designed by a registered professional engineer. However, the manufacturer is not required to supply the anchoring equipment, but must make provision within the design of the unit for anchorage equipment to be installed. The manufacturer is also required to provide installation instructions specifying the location and required capacity of stabilizing devices for at least one acceptable anchoring system. The ground anchors themselves are required to be certified by a professional engineer, architect, or a nationally recognized testing laboratory as to their resistance. The resistance is required to be based on the maximum angle of the diagonal and/or vertical tie loading, and angle of anchor installation, and type of soil in which the anchor is to be installed. However, for anchors resisting lateral load, the lowest angle of the diagonal strap may actually have the greater effect on lateral movement of an anchor. Thus, anchors should be tested for the actual intended angle of the diagonal strap.

Ground anchors are required to be installed to their full depth, embedded below the frost line, and located at least 12 inches above the water table. Stabilizer plates are not required, but are recommended for added resistance to overturning and sliding forces. Flat steel strapping is required to comply with ASTM D3953 and tension forces represented therein. Straps are required to be spaced evenly along the length of a manufactured home to resist the design wind loads specified in the HUD Code. They are also required to be located not more than 2 feet from the ends of the unit. Where vertical and diagonal ties are co-located, they may be fastened to a single ground anchor, provided the anchor is capable of carrying both loads simultaneously. In Wind Zone I, only diagonal ties are required. In Wind Zones II and III, vertical ties are required at each diagonal tie location. Tie straps are also required to be protected from sharp edges.

Finally, anchoring equipment (ground anchors) are required to be capable of resisting an allowable working load of at least 3,150 lbs and a 50 percent overload value of 4,725 lbs without failure of the anchoring equipment. This last requirement is subject to interpretation because it is referring to the equipment (e.g., mechanical capacity of the strapping material and anchor and their inter-connections). However, these load requirements are generally interpreted as being applied also to defining anchor minimum pullout capacities in the soil, at least for the purpose of developing prescriptive anchor spacing tables for installation guidelines. Unfortunately, this criterion is an incomplete expression of the intended performance objective because is does not define how variability in in-situ ground anchor performance is to be treated to provide an equivalent performance (i.e., comparable failure probability) of the mechanical hardware (e.g., strapping and/or anchors). Ultimately, a complete and well-defined performance objective statement must be created for ground anchors as this will affect the manner of ground anchor qualification testing as well as design applications to ensure that the installed ground anchor is not the “weak link” of the anchorage system. Coupled with this concern is the need to distinguish deflection limits states that relate to serviceability and structural safety depending on the magnitude of deflection and the associated consequences. These performance objectives would clarify the vague performance language in the HUD Code (Section 3280.306(a)) and confusion related to anchor qualification testing and design value characterizations relative to failure limit states such as ultimate strength or excessive deflection and deflection limits related to serviceability concerns at design working load conditions.

- *Model Manufactured Home Installation Standards (proposed rule for 24 CFR Parts 3280 and 3285 as published in Federal Register, Vol. 70, No. 79, Tuesday, April 26, 2005)*

This review focuses only on the portions of the proposed installation standards that relate to ground anchorage. In Section 3285.202, three options are provided for soil classification: (1) soil tests by accepted engineering practice, (2) use of applicable soil records, or (3) or soil type identification in accordance with a table for soil classification. The table includes six soil classes with descriptions in accordance with ASTM D2487 and D2488 following the Unified Soil Classification System (USCS). Based on this table and its related text, it appears that presumed allowable pressure values, ASTM D1586 blow counts, and STP torque values are given and “must be used.” However, it is unclear how they are to be used, particularly in regard to ground anchor qualification testing and selection. The following question explains the concern: are soil torque probe test required to be conducted at the installation site to aid in proper ground anchor selection or can the tabulated torque probe values be used purely on the basis of a visual soil classification of the installation site per ASTM D2487 or D2488? The answer to this question has implications in regard to variability and reliability of anchor performance at the point of installation. For special site conditions (e.g., peat, organic clays, or non-compacted fill), the soil classification and bearing value must be determined by a registered professional.

In Subpart E – Anchorage Against Wind, requirements for ground anchor installations are set forth. Ground anchors are required to resist a minimum total load capacity of 4,725 lbs and a working load capacity of 3,150 lbs. Based on the prescribed minimum working load of 3,150 lbs, tables are provided to select anchor spacing requirements for various configurations and wind zones. However, reduced anchor capacities are permitted provided the strap spacing is reduced to compensate for the lower anchor capacity. This is essentially a performance based provision and follows earlier recommendations made by NBS (or NIST) for ground anchors. It is not stated, but implied that these reduced capacity anchors will be provided with a similar margin of safety between working load and overload. The anchors are required to be selected to meet the required minimum capacity based on a site soil classification as discussed above. The selected anchors are required to be certified for the applicable soil class represented at the installation site. As in the HUD Code, the resistance capability of ground anchors is required to be determined by a registered professional or nationally recognized third party testing agency in accordance with a nationally recognized testing protocol. It is the latter requirement, a nationally recognized testing protocol, that the GAATP is intended to fulfill.

It is yet unclear as to whether the required “minimum capacity” for any anchor is to represent an average performance, some lower bound statistical estimate, or some value that is consistently met in some specified number of test repetitions at a given site. It is also unclear as to how this “minimum capacity” is to be met at the installed site with respect to the uncertainties involved with selecting anchors on the basis of different methods of soil classification and their correlation to tested anchor performance. This again speaks to the need for a carefully described performance objective that establishes a fixed target for anchor performance and establishment of anchor design values. A reasonable performance objective would be to require that, considering anchor variability, the design and ultimate values (whether less than or equivalent to the current prescriptive load values) reflect a lower bound performance characteristics of the anchors in final installed conditions. In other words, there should be a low likelihood that the ground anchor would withdraw from the soil or deflect beyond a specified structural limit state. The design value associated with this structural limit state should then be established at a level of reliability consistent with the metal strapping such that the anchors are no more likely to fail than the strapping material at the loading event that produces stresses at the nominal design value for the respective devices or materials.

- *State Regulations for Ground Anchors*

The requirements for and variation in anchor qualification testing and performance criteria for most states were addressed in a previous interim report completed under Task 2b. In summary, state requirements represent a mixed conglomeration of performance and prescriptive requirements that are generally consistent with the HUD-Code requirements and prior editions of installation guidelines. It is felt that the GAATP has the potential to bring needed uniformity to state regulations related to ground anchorage for manufactured housing.

<u>HUD Ground Anchor Testing (late-1970s through mid-1990s)</u>

HUD has commissioned a number of studies on conventional ground anchors, including testing and analysis of ground anchor performance. These studies span from the late 1970s through the mid-1990s. Several of these studies have already been summarized in by Pearson et al., 1996. They are again summarized and evaluated for this interim report as follows:

- *NBS 107 Report (Kovacs and Yokel, 1979)*

The NBS 107 report constitutes a state-of-the-art review of knowledge regarding soil and rock anchors for manufactured homes in the late 1970’s. It did not involve testing of anchors to generate new data. Relevant information is summarized and evaluated (see italicized text) as follows:

1. The practice of assigning pull-out capacities of anchors on the basis of visual descriptions of soil types is “potentially misleading and unsafe” (i.e., high variability is not accounted for in the establishment of design values for anchors or prediction of performance within a given soil type at various locations). The report recommends eliminating visual soil classification ambiguities by requiring that pull-out capacity be related directly to index soil test results for a given site (e.g., SPT blow count, STP torque value, or anchor installation torque). *In more recent studies, others have also used the Dynamic Cone Penetrometer (DCP) which is essentially a smaller-scale version of the SPT soil test apparatus.*
2. Correlation between soil index tests (e.g., SPT or STP) and anchor pull-out capacity is poor. They only crudely improve predicted anchor behavior with limited reduction in variability of actual vs. predicted performance at a given site. *However, this finding is revised in a later study which finds that a reasonable correlation, albeit with substantial uncertainty, is found with the soil test probe measurements. Other more recent studies*

have concluded poor correlation for a select group of sites. But, these soil test methods are commonly used by anchor manufacturers to characterize test site soils and as an aid in anchor selection for end-use sites where anchor tests are not performed.

3. Soils can change properties seasonally and this source of variability in tested vs. actual performance should be addressed. Also, degree of soil saturation will affect the correlations of anchor performance to soil property by way of soil index tests.
4. There is a complete lack of information on cyclic (dynamic loading) effects on anchor capacity. *(This issue was addressed in a later study)*. Reviewed literature suggests a capacity reduction factor of 0.5 to 0.8 depending on soil type, consistency or relative density, and moisture condition. Other studies recommend that a factor of safety of 5 be applied to determine allowable displacements when cyclic loading is involved. A thunderstorm gust front may produce as many as 300 cycles of load whereas a hurricane may develop over 5000 loading cycles.
5. There is an overall lack of data for complete load-displacement behavior in order to establish ultimate loads as well as displacement characteristics in specific soil conditions. Most load test reports only list soil class as determined visually. A test program is needed to establish appropriate correlations and the variability inherent to such correlations anchor performance to various soil classification methods. *(Such a test program at least initiated in a later follow-up study).*
6. There is a need for a standard test method to provide a uniform means of obtaining and reporting anchor test data. *(The draft GAATP represents a recent effort to address this concern, but not to the extent of addressing #5 above).*
7. While manufactured home anchorages typically use a safety factor of 1.5, other anchorage design approaches investigated in the literature recommend a minimum safety factor of 2 when a reliable soil classification is available (e.g., measure of soil shear strength on each site) and a minimum safety factor of 3 or more where uncertainties in soil classification exist. These recommendations were for deep anchor conditions with D/B equal to or greater than 5 or 6 (D= anchor depth and B = anchor diameter).
8. Group effects do no appear to reduce anchor efficiency (group capacity based on sum of individual anchor capacity) when anchor spacing is approximately 4 diameters or more in clay and sand soils. However, this finding appears to be applicable only to "deep" anchors (e.g., D/B >>5) and shallow anchors are general spaced wider (based on depth of anchor, not diameter) on the basis of avoiding overlap of "cones of influence".

It should be noted that the above findings were based primarily on co-axially loaded ground anchor tests without any lateral load applied at the head of the anchor. With very limited data, a coefficient of variation of roughly 40% seems to represent uncertainty in the correlation of anchor pull-out strength based on soil torque probe torque values. As a point of relevant comparison, this level of variation seems similar to that for direct withdrawal of nails from wood when using a simple correlation based on density of wood in accordance with accepted design standards. Such connections with high variability in strength generally have a safety margin of 4 or more relative to the average ultimate withdrawal capacity (or a safety factor of roughly 2 to 2.5 relative to a lower-bound, e.g., 5th percentile, estimate of ultimate capacity).

At the time of the above study (late 1970s), NIST reported only one reference dealing with the effects of non-coaxial pull-out behavior. The maximum capacity developed in the referenced tests was only 145 lbs (presumably related to an undefined lateral deflection limit state). This finding evidences potential concerns related to manufactured home ground anchors when installed to resist combined uplift and lateral loads, a condition that represents a common installation practice.

- *NBS 142 Report (Yokel et al., 1982)*

In response to the findings of the previous NBS 107 report, a study was commissioned by HUD to investigate the load-displacement characteristics of shallow soil anchors. More than 200 ground anchor tests were conducted on three sites: a silty site, a sandy site, and a clay site. Of primary interest are the tests conducted with conventional 6-inch single helix and 4-inch double helix anchors. The effects of several parameters were investigated including direction of anchor installation, direction of loading, anchor depth, size of anchor, cyclic loading, and effect of pre-loading on anchor stiffness. The report's findings are summarized and evaluated (see italicized text) as follows:

1. The anchor types tested *(without stabilizer plates or pre-loading)*, failed to deliver anchor performance required in current standards. Conversely, when anchors are adequately pre-loaded their performance far exceeds standard requirements for displacement limits (e.g., 2" vertical and 4" lateral).
2. To achieve adequate stiffness a preloading practice was recommended (e.g., preload anchors to 1.25 times the design working load). *Evidently, the use of stabilizer plates was not considered at this time as a possible solution in combination with a lesser degree of pre-tensioning (see later studies).*
3. To ensure adequate and reliable performance a few anchors per site should be preloaded to 1.5 times design load (i.e., the ultimate load). *Evidently, this recommendation was intended to give a high level of confidence that the minimal safety margin of 1.5 is actually achieved at the installation site – not on the basis of soil classification methods which result in greater uncertainty and the need for a larger safety margin.*
4. Coupled with the previous two recommendations, it was suggested that the minimum prescribed loading requirements (e.g., working load of 3,150 lbs and overload of 4,725 lbs) be eliminated in favor of determining the number of anchors required in accordance with the anchor performance as determined above at each installation site and with use of a 1.5 safety margin on the basis of site-tested anchor performance. *The concept of a performance-based anchor testing and design methodology is still quite valid and is recommended again in later reports. However, a more practical and less costly means of achieving this approach may be to assign a suitable safety margin based on variability in anchor performance as a result of using soil property correlations. The above recommendation for on-site proof testing may prove valuable if it can be extended to multiple applications at a given manufactured housing development and it results in the use of a lower safety margin due to greater confidence in anchor performance.*
5. Cyclic loading does not appear to alter the "virgin" load displacement characteristics of anchors unless "a great number of cycles of load close to the load capacity are applied." *This finding suggests that cyclic loading may not be as significant of a concern as originally anticipated (at least for the soil conditions and cyclic loading conditions investigated).*
6. Coaxially loaded inclined anchors have smaller load capacities *(due to less penetration depth)* than coaxially loaded vertical anchors, but their initial stiffness is similar. *The use of coaxially loaded inclined anchors is recommended in later work for the FEMA 85 project to address stiffness concerns in providing resistance to lateral loads*.
7. Vertical anchors subject to inclined loads have higher load capacities than coaxially loaded vertical anchors, but their initial stiffness is much less than that of coaxially loaded anchors. *Stabilizer plates were not used and, as a result, a high degree of preloading was recommended to provide adequate stiffness to this common installation configuration with inclined loads; without pre-loading or adequately sized stabilizer plates, lateral deflections required to attain working load values were commonly well above 4 inches and often greater than 1 foot.*
8. Helix anchors experience bending of the helix in all loading modes and bending of the shaft in non-coaxial loading. The anchor hardware tended to have adequate capacity but was vulnerable in the weld between the shaft and the helix, particularly for non-coaxial loadings *where maximum tension forces tended to exceed 6,000 lbs*.
9. A loading rate of no greater than 600 lb/minute was considered adequate to account for creep effects that would otherwise alter measured stiffness. *Based on the data for this load rate*

recommendation, a displacement rate of approximately 0.3 in/min should not be exceeded. The approach of displacement-controlled test operation may provide better control of tests and is commonly used in other similar test applications.

10. Correlations between soil torque probe measurements and anchor strength (or stiffness) in coaxial loading was found to exist. The uncertainties observed are discussed below.

For identical anchors tested at a given test site, the coefficient of variation in ultimate pull-out load was typically about 20% or less and not more than 40%. An approximate coefficient of variation in anchor strength at ultimate capacity and for load at a 2-inch vertical deflection (coaxial loading) is about 30% to 40% relative to STP torque values. When using only visual soil classification as the basis for anchor qualification and selection, actual anchor performance would tend to have much greater variation, but this practice not investigated.

- *Soil Anchor and Strapping Study (Pearson et al., 1991)*

Wiss, Janney, and Elstner Associates, Inc. conducted laboratory ground anchor tests in a constrained soil to determine hardware performance of several manufacturer's products. In addition, field tests were done on a sandy soil site. In the field tests, all anchors were installed at a 15 degree angle and loaded at a 45 degree angle. On several tests, 12" wide by 10" deep stabilizer plates (7 ga steel) were also tested to explore effects on lateral load resistance and stiffness. Tested anchors typically had 6-inch diameter augers, but a few anchors with 5-inch and 4-inch diameter augers were also included. Finally, tests were performed on 1-1/4" x 20g metal straps from several different suppliers to quantify the performance attributes of metal strapping used to tie manufactured housing units to ground anchors.

Key findings and recommendations are summarized as follows:

1. Laboratory tests of ground anchors in constrained soil conditions resulted in average maximum loads (direct tension only) ranging from 5,471 lbs to 17,471 lbs depending on the anchor type or manufacturer. The lowest single test value from all 43 tests was 3,450 lbs. The average COV for all products tested was 11% with values ranging from 4% to 19% within each product tested (see Table 1 in Pearson, 1991). Sample sizes within each product type ranged from 4 to 5.
2. Field tests were conducted at a sandy site (SPT blow count of 12 to 17 at a depth of 3.5 feet) and most anchors experienced installation difficulties such as refusal or failure of hardware during installation. Anchor shafts tended to show signs of torsional yielding.
3. Phase I field tests were done without stabilizer plates and anchors experienced excessive horizontal deflection without reaching required design or working load values. *This finding is similar to previous studies; see NBS 107 and NBS 142 reports.*
4. In Phase II field tests with stabilizer plates, peak lateral loads were generally higher, but loads at a 4-inch horizontal deflection were commonly less than 25% of the required ultimate load of 4,725 lbs. Of the 21 tests with stabilizer plates and anchors correctly installed to full-depth, none met the required ultimate load and stiffness. At a 4-inch horizontal displacement, the average load for anchors with stabilizer plates was 1,029 lbs and without stabilizer plates it was 558 lbs. The COV was 76% for anchors with stabilizer plates and 50% for those without in regard to load at 4-inch horizontal displacement *(although values of half this much are determined with exclusion of a couple data points that may be considered as outliers)*. In regard to peak load achieved, the average peak load (at 45 degree angle of pull) was 2,833 lbs for anchors with stabilizer plates and 2,103 lbs for anchors without stabilizer plates. The COV of the peak load values was 35% and 53%, respectively.

5. Laboratory tests of metal strapping material were conducted in accordance with ASTM D3953. In several cases (3 of 5 strap products tested), ductility (elongation) requirements were not met. In these same cases, the minimum ultimate load of 4,725 lbs also was not met. The average ultimate load for each product tested ranged from 4,068 lbs to 5,630 lbs with a COV of 2.5% in the largest-sized single group (sample of 5). For all strapping products tested the average ultimate load value was 4,804 lbs and the COV was 15% (see Table 5 of referenced report; sample size varied from 3 to 5 for each of five tested products).

It is interesting to note that the Cold-Formed Steel Design Specification (AISI/COS/NASPEC 2001) requires a safety factor of 2.0 to be used when steel strapping design is based on ultimate (post-yield) capacity rather than yield strength of the steel. The 1.5 overload margin in the ASTM D3953 standard relative to ultimate (post-yield) capacity of strapping may not have been intended to apply to building design applications because that standard addresses packaging and shipping applications. A safety margin of 2.0 for metal strapping with an ultimate (post-yield) capacity of 4,725 lbs would result in a design working load of 2,365 lbs in lieu of 3,150 lbs. Such a safety factor may also better account for stress concentrations that occur in actual installations and which have been found to reduce strap capacity by as much as 20 percent relative to carefully prepared laboratory coupon tests.

- *Full-scale Laboratory Testing (Pearson et al., 1993)*

Using a simulated 14-ft wide manufactured housing unit, five different ground anchor restraint systems were investigated by a total of 9 tests using monotonic and load-reversal (cyclic) loading histories. The purpose of the study was to investigate wind and seismic loading conditions. Tests 2, 3, 5, and 7 are of greatest interest here because they used conventional anchors and straps.

A large bin of homogenous, compacted sandy soil was used in a laboratory for the purpose of simulating ground conditions. The sand density in the test bed was such that anchors had to be installed in 12-inch diameter by 24-inch deep pre-drilled holes, backfilled and compacted. The anchors were 48-inches in length. Stabilizer plates were used with ground anchors when ground anchors were required in the test plan (in particular Tests 2, 3, 5, and 7).

Anchorages and supports investigated included metal piers only, block piers only, combination of piers and straps with anchors, and a couple of proprietary earthquake resistant bracing systems (ERBS). When anchors were used they were either 4-inch or 6-inch diameter augers and, in all cases, were installed at a 15 degree angle with strapping at a 45 degree angle attaching to the simulated chassis/frame. Strapping was pre-loaded by tightening the slotted bolt at the anchor head until the strap "began pulling the soil anchor from its original position." There was one anchor and strap for each loading direction (one anchor loaded at a time).

Loads were applied only in a horizontal direction to the simulated manufactured housing unit frame. The frame was placed on four piers and, when required by the test plan, one anchor and strap was provided for each load direction. Combinations of horizontal load with vertical load (e.g., wind uplift) were not considered.

The relevant findings are summarized as follows:

1. For Test #1 (monotonic load, unanchored frame on metal jack stands), the peak horizontal load achieved on the test frame was 1,000 lbs with observed rotation of the jack stands.

2. For Test #2 (monotonic load, anchored frame on unanchored jack stands), the peak horizontal load achieved was 1,800 lbs at a test frame deflection of about 2 inches. Thus, the inclusion of anchorage (ground anchor, stabilizer plate, and diagonal strap) improved load capacity by about 800 lbs relative to Test #1.
3. For Test #3 (load reversal, anchored frame on unanchored jack stands), the maximum load in each load direction was 1800 lbs and 2,236 lbs (maximum load occurred at a horizontal frame displacement of 2.4 inches).
4. Test #4 was similar to Test #1 (no anchors or strapping) except jack stands were clamped to the chassis. Performance was similar to Test #1.
5. Test #4A (reverse cyclic) was similar to Test #4 (no anchors or strapping), but under reverse cyclic loading very little energy dissipation capability was observed due to rocking of jack stands that were clapped to the chassis.
6. Test #5 was similar to Test #2 except the jack stands were clamped to the chassis and results were similar to Test #2.
7. Tests #6 and #8 were ERBS systems and are not relevant to this review.
8. Test #7 (load reversal, anchored chassis, concrete block piers) was intended for comparison to similar Test #3 (with metal jack stands) and it was found that the maximum load in each direction was 1,500 lbs and 2,300 lbs. It was also found that slipping of the chassis on the concrete piers and wood blocking/shims provided a greater amount of energy dissipation than the rocking mechanism found with metal jack stands.

In general, the inclusion of anchorage (ground anchor, stabilizer plate, and diagonal strapping) provided additional capacity and stiffness over unanchored systems. However, none of the tests resulted in lateral resistance as required by the HUD code working load values for anchors. The average maximum horizontal resistance of the test frame supported on metal or concrete block piers with restraint provided by an anchor and strap for each load direction was about 1850 lbs at a 1.6-inch horizontal deflection of the test frame. Without anchors or strapping, the average resistance was 1,230 lbs at a 1.1-inch horizontal deflection of the test frame. Thus, the anchors and straps provided only an additional 620 lbs of lateral resistance on average and slightly improved the drift capability (e.g., ability to retain resistance with continued deflection of the test frame). In addition, slack developed in the strapping under cyclic loading (due to cumulative soil deformation around anchors and stabilizer plates). This occurrence would tend to alter the foundation's seismic response characteristics during an earthquake event.

In terms of earthquake design, these findings raise an implication as to the appropriate seismic response modifier, R, to use for the purpose of determining lateral loads for conventional ground anchor systems. In the reviewed report, an R-factor of 6.0 was assumed on the basis of the structural system of the unit (e.g., wood frame shear walls). But, the foundation is of an entirely different construction and should use a different R-factor. For example, in the ASCE 7-05 standard, a comparative bracing system would be light-framed walls with flat strap bracing which has an R of 4. Another comparable construction system would be ordinary steel concentrically braced frames which are required to use an R of 3.25. Using an R of 3.25 would result in a seismic design load greater by a factor of 1.8 in comparison to the use of an R of 6.

<u>Recent Ground Anchor Testing (2000 to present)</u>

- *Guidelines for Anchor System Design: Technical Support Document (MHRA, 2000)*

In this study, MHRA developed ground anchor design values based on testing of ground anchors at six selected locations in the southeastern U.S. The sites had sandy soils with soil classes ranging from 2 to 4(b); however, soil classes 4(a) and 4(b) were most common. The goal of the study was to develop ground anchor design values which could be used without relying on any form of site soil classification and without necessarily meeting the HUD-Code prescribed working load and overload values of 3,150 lbs and 4,725 lbs, respectively. Soil Test Probe (STP) and Dynamic Cone Penetrometer (DCP) soil tests were used to help classify the soils at the test sites. Anchors of 30-inch to 60-inch lengths with 12-inch to 17-inch wide stabilizer plates were used. Anchors were installed at a 15 degree angle and loaded at a 40 degree angle. The tests were based on a pre-tensioning practice whereby stabilizer plates were installed 2 inches from the anchor shaft and then the anchor strap is tightened until the anchor makes contact with the stabilizer plate plus an additional ½" of anchor movement against the plate. This provided a modest degree of pre-tensioning in the installation methodology employed.

Key findings are summarized and evaluated (see italicized text) as follows:

1. For most tested anchors, the maximum test load value was controlled by a 3-inch horizontal displacement criterion. However, a 2-inch vertical displacement criterion controlled for some anchors. These displacements were considered to be serviceability limit states. *Structural limit states, including safety margins were not explicitly addressed.*
2. Design values were based on essentially an average performance for the displacement criterion used. *In other words, roughly half of the tested anchors exceeded the specified displacement limits. In addition, tests were not continued through failure of the anchor at higher displacement levels to determine an actual safety margin relative to ultimate capacity or some higher displacement limit that would effectively result in failure of the foundation (e.g., toppling off of piers). Also, for anchors that were controlled by 2-inch vertical displacement safety margins may have been less than 1.5 because these types of anchors tend to have less vertical displacement capability leading up to pullout failure, particular in sandy soils (this concern is based a review of load-deflection behavior of similar anchors in previous test reports).*
3. The COV of anchor test load at the specified displacement limits ranged from 30% to 40% at the test sites as a whole. *For illustration purposes, using anchor design values representing one standard deviation below the mean (rather than the mean value) would reduce the recommended design values to a range of 1,300 lbs to 2,000 lbs instead of 2,000 lbs to 3,150 lbs. Without considering safety margins or testing to a specified failure limit state, such a practice would seem advisable.*
4. Anchor working load values of 2,000 lbs to 3,150 lbs (varying by wind zone , anchor length, and stabilizer plate size) were recommended based on the stated serviceability limits and essentially average loads recorded at those limits. *The wind zone doesn't necessary govern the establishment of anchor design values, but anchors in Wind Zones II and III are limited to a minimum 4-foot length whereas shorter anchors may be used in Wind Zone I.* Charts for anchor spacing based on these values were also developed based on an assumed Class 4 soil.
5. It was suggested that the tests as a whole cast doubt on the ability of Soil Torque Probe torque values to predict the holding capacity of soil. *In part, this observation may be because laterally loaded anchors with stabilizer plates are governed by soil properties and passive resistance of the soil at the soil surface and not at anchor depth.*

Given the manner of defining the ultimate performance as an average value, the variability of anchor performance at the test sites, and the additional variability due to not requiring a soil classification at end-use sites, the adequacy of using averages of a serviceability limited design value without consideration of actual safety margin to structural safety limits states is not a typical accepted engineering practice. In typical design practice, a minimum safety margin is established on the basis of ultimate performance or a limit state that is associated with failure. Then, a serviceability limit state may require that a lower design value be used. The approach taken in this report does not appear to satisfy the performance objectives implied by the HUD-Code to “resist overturning and lateral movement (sliding) of the manufactured home as imposed by the respective design loads” (Section 3280.306(a)). However, this observation depends on whether the 3 inches of displacement at a design load condition (not ultimate load) may be considered as a non-structural or serviceability limit state without incipient or consequential structural damage. Based on field experience this amount of displacement appears to be more reflective of incipient structural damage rather than a serviceability limit state that might merely require adjustments after a design event. For clarification, the concern here is not with meeting the prescriptive working load values (which has little to do with actual performance unless designs are based on those values), but in meeting the implied performance objectives of the HUD-Code. Therefore, this performance objective needs to be explicitly and more carefully defined and justified as it affects the manner of interpreting anchorage test data and establishing design values for anchorage systems.

- *Anchor Tests for FEMA 85 Update (FEMA, 2004; unpublished presentation by David Lowe)*

In the interest of providing “statistically-valid” ground anchor design values for use in an updated of FEMA 85, 120 anchors from 5 manufacturers were tested near Kissimmee, FL in dry sand and wet sand conditions. The soils were classified as 4(a) by STP and DCP tests. The anchors were installed vertically and loaded coaxially, installed at 45 degrees and loaded coaxially, and installed at 15 degrees and loaded at 45 degrees with 17-inch and 24-inch while using stabilizer plates. The anchors and stabilizer plates were installed to match “common” manufacturer instructions. Some of the major differences from the MHRA, 2000 study included testing to ultimate capacity as well as statistical analysis of the test results to derive design stiffness values for anchors from which design values at a given displacement could be determined. Anchor stiffness values were based on a lower 10^{th} percentile estimate of the stiffness at a 90% confidence level based on 12 repetitions for each test condition. Design stiffness was then determined by applying a safety factor of 1.05 to that value based on a judgment that “the soils at the site were relatively weak” and presumed to represent an uncommonly poor site condition. However, this judgment suggests that on sites with similar weak soils the design values will have a much lower safety margin than those with stronger soils. This approach was taken to allow anchorage design stiffness values to apply to all sites without regard to variation in soil characteristics that affect anchor holding strength and stiffness.

For coaxially loaded anchors, mean anchor stiffness values ranged from 2,345 lbs/in to 3,800 lbs/in for the dry site condition and 4,112 lbs/in to 5,506 lbs/in for the wet site condition. For these same conditions, the statistically-determined design stiffness values ranged from 1,009 lbs/in to 1,199 lbs/in and 1,311 lbs/in to 1,819 lbs/in, respectively for dry and wet site conditions. Corresponding design load values are determined by multiplying these stiffness values by 3 inches. Evidently, a 3-inch rather than a 2-inch maximum vertical deflection limit is specified for co-axially loaded anchors for purpose of determining design values based on a lower-bound estimate of anchor stiffness. For coaxially loaded anchors, stiffness and design load values tended to be higher on the wet site than the dry site. Safety margins achieved by determining design values according to the above approach, relative to mean ultimate pullout capacity, were not explicitly evaluated and discussed.

For the anchors with stabilizer plates and loaded non-coaxially, the stiffness tended to be slightly lower on the wet site in comparison to the dry site condition. In addition, the stiffness values were much lower. For anchors used with 17 inch stabilizer plates, mean stiffness values ranged from 1,094 lbs/in to 1,475 lbs/in with statistically-determined design values ranging from 675 lbs/in to 873 lbs/in. Again, design load values are determined by multiplying the anchor design stiffness values by a specified maximum 3-inch horizontal displacement. Evidently, vertical displacement did not control any of the tests as was found in the MHRA, 2000 study for a number of anchor specimens tested at six different sites. This difference in the occurrence of vertical and horizontal deflection limit states in diagonal loading tests could be related to differences in soil conditions, differences in test rigging or methodology, or a number of other factors. One possible concern with test rigging is the degree to which the angle of the pull load changes during the course of the test. If the test load angle becomes steeper during the course of the test due to movement of the anchor head relative to test rigging, then the anchor would tend to increasingly resist the load by vertical reaction rather than a lateral reaction which is less stiff. While this is speculation, it is a matter of concern that should be addressed in any standard test methodology and could affect repeatability of tests from various plausible test rigging approaches.

The methodology of using a lower-bound estimate of anchor stiffness provides some greater assurance that a maximum displacement limit of 3-inches will not be exceed at design load conditions than was achieved in the MHRA, 2000 study. However, it also is somewhat non-conventional in that a safety margin relative to a defined structural safety limit state is still not explicitly considered, except by way of a statistical lower-bound estimate of anchor stiffness. In reviewing the above data, it would appear that the statistical approach creates a central safety margin (relative to mean stiffness) of more than 1.5. However, it is still not clear if this results in a level of performance that is consistent with the reliability of metal strapping materials used to attach the structure to the anchors or some other explicitly defined reliability target consistent with the intent of the HUD-Code. Again, the inconsistency in treatment of anchor design values gives evidence of need for an explicit and well-defined description of the performance objective for ground anchors.

<u>Ground Anchor Performance Evaluations and Related Studies</u>

The following studies are primarily aimed at making recommendations for anchor system design and qualification, in some cases based on findings from previous test-based studies.

- *NBS 132 (Yokel et al., 1981)*

In this study, commissioned by HUD, forces acting on the foundations of manufactured homes due to wind and flood loads were analyzed and presented in chart form for various foundation and housing unit configurations. Wind loads were based on the HUD Code as well as recommendations by NBS. The study concluded the following:

1. Diagonal ties are instrumental in resisting wind loads, unless piers are designed to resist the horizontal wind load component. Diagonal ties using a near-tie connection can be used alone (without vertical ties) to resist both wind uplift and lateral forces.
2. The prescriptive anchorage provisions in the NFPA installation standard provide adequate resistance to the wind loads stipulated in the Standard, if the anchors can provide the resistance required of the straps.

- *NISTIR 5370 (Marshall, 1994)*

This study investigated HUD-Code wind loads relative to ASCE 7 wind loads in regard to relative differences in probability of failure of manufactured housing units. It was found that (prior to the 1994 update of the HUD-Code) manufactured housing units had a probability of failure 5 to 10 times that stipulated by the ASCE 7 provisions. More importantly, the report addressed load capacity, performance issues, and criteria related to anchoring systems. Relevant findings are summarized as follows:

1. The report reviewed current MHCSS (HUD-Code) provisions for windstorm protection which simply required an allowable working load of 3,150 lbs for anchoring components and 50 percent overload (4,725 lbs) without failure of the anchoring equipment. *These requirements are unchanged at the present*.
2. The report reviewed ANSI A225.1-1982 (Manufactured Home Installations) and recognized the additionally required soil anchor displacement limits. The displacement-based failure criteria included a defined failure as occurring when a 2-inch vertical displacement is exceeded at a load equal to or less than the prescribed overload value (4,725 lbs). For anchors installed to resist loads other than direct withdrawal, the horizontal displacement of the anchor head is required not to exceed 4 inches when a working load (3,150 lbs) is applied at 45 degrees from the horizontal. The same standard also stated that "anchors designed for connections of multiple ties shall be capable of resisting the combined working load and overload consistent with the intent expressed herein." But, it was recognized that this statement could result in varying interpretations, particularly since the intent is confused by having different load conditions for different displacement failure criteria. The report also noted that the displacement criteria had been removed from a more recent update of the installation standard. But, neither version provided any commentary on the original intent of the displacement limitations or the justification for their deletion.
3. The study also recognizes that anchors are assumed to provide a prescribed safe working load of 3,150 lbs which is implicit to the analysis of prescriptive installation requirements of ANSI A225.1 in regard to spacing of soil anchors and metal strapping.
4. Based on a review of test data on metal strapping by Pearson, 1991, the report concludes that a 0.8 reduction factor in strap ultimate capacity (4,725 lbs x 0.8 = 3,800lbs) was necessary to account for actual in-service ultimate strength. This was also intended to account for variation between different products (COV = 0.16) verses that which is seen within a given product lot (COV = 0.02 or less).
5. Based on a review of test data by Pearson, 1991 on the mechanical strength of anchors, it was concluded that anchors generally exceeded the ultimate strength of strapping and would not control performance of the foundation anchor system. The anchors were broadly grouped and characterized as having a mean ultimate strength of 8,650 lbs with a COV of 0.23. While damage to anchors during installation was a recognized factor that may reduce actual in-service capacity, no strength reduction factor was proposed due to lack of data.
6. Based on a review of test data by Pearson, 1991 on pull-out and lateral capacity of anchors, the report determined load and displacement characteristics for anchors with and without stabilizer plates. Discounting a couple of outlier data points, which would result in a doubling of variation in the test data, the COV of anchors with stabilizer plates for load at 4 inch displacement still approached 41%. The COV of maximum load was 22%. It was suggested that this large variability at the limiting horizontal displacement needed to be accounted for when assigning an allowable working load or resistance factor.
7. To resolve what was termed as "abysmal" performance of non-coaxially loaded ground anchors, even with the use of stabilizer plates, the report recommended using the preloading methodology given over 10 years prior by Yokel et al., 1982.
8. Based on the above findings, a recommended design approach and installation procedure was presented whereby strap spacing was based on a use of a 3,800 lb tie strap ultimate capacity and a design wind load factored by 1.5 (providing the 50% overload required by

the HUD Code). From that point, the strap spacing was determined and anchors were installed under the pre-loading scheme proposed to ensure adequate anchor stiffness and strength. If anchors failed during pre-loading or were found to be of less capacity than the strapping, then the strap spacing would be controlled by the anchor strength and not the strap.

- *NISTIR 5664 (Marshall and Yokel, 1995)*

This study dismisses the need to consider tornadic wind speeds in manufactured home design, restates some of the previous information regarding wind loading and anchor testing, and investigates earthquake loading conditions. A simplified earthquake load equation was suggested, but in recognition that the assumed seismic response modifier, R, may result in higher loads. An R of 6 to 8 was investigated based on current code requirements for light-frame shear walls. Based on other studies, such a large seismic response reduction for energy dissipation does not appear appropriate for conventional anchor and diagonal strap foundation restraints (refer to WJE, 1993). In addition, several different foundation anchorage methods were investigated because it was concluded that conventional auger-type anchors and straps were inadequate, even with pre-loading or improved lateral stiffness by other means, for wind zones greater than 100 mph (fastest-mile) due to overlapping cones of influence when anchors are spaced to closely. Finally, a performance based design criteria was proposed for manufactured home support and anchoring systems for reasons including: (1) expectations for anchor performance in the HUD-Code and ANSI A225.1-94 exceed the level of resistance that traditional anchoring systems can provide, (2) the various state provisions regarding anchor performance represent a disjointed mix of prescriptive and performance-based criteria, and (3) the current requirements for anchorage potentially exclude innovative systems that could be expected to performance adequately. The recommended anchor performance criteria and installation practices are similar to those given in prior reports by NBS, namely that the anchors be pre-loaded to the near the working load value used as a basis for design. Again, this practice was recommended as a means to confirm reliable anchor performance (or actual anchor performance) at the end use site and to also provide adequate anchor stiffness. However, the practice adds substantial cost to foundation installations. Therefore, preferred industry practice has focused on using stabilizer plates and a modest pre-tensioning installation procedure.

- *Mays (2005)*

This paper evaluates manufactured housing foundations and also concludes that the required working and ultimate load values of 3,150 and 4,725 lbs, respectively, are “simply unattainable on any reliable basis.” The author further states that “extensive test data has continually shown the unpredictability and typical poor performance of these systems in contrast to required federal standards and basic engineering practice.” The basis for these conclusions include many of the reports reviewed in this study covering the 1979 through 2000 time period. Finally, the report addresses recommendations for foundation performance criteria. It mentions typical safety factors of 3 to 6 for soils subjected to upward loading in comparison to the 1.5 overload factor required by the HUD-Code. The report suggests that most manufactured home installations have an actual anchorage safety factor of less than 0.5. However, it is unclear as to whether this determination is made in regard to a failure limit state (e.g., peak load capacity of anchors) or a drift limits state (e.g., 3 inch or 4 inch deflection limit for horizontal load or 2 inch for vertical load).

<u>Anchor Design & Practice Manuals</u>

- *Chance Encyclopedia of Anchoring (2004)*

This document includes ground anchor testing, design, and selection data from decades of experience with helix type ground anchors. The document primarily addresses industrial applications and deep anchor situations. However, the information is relevant to smaller-scale applications such as manufactured housing foundation anchorage. The document discusses the importance of differences in basic soil type (cohesive vs. non-cohesive) as well as knowing the consistency and layering of soil which may affect performance depending on the depth or positioning of the anchor helix. The document asserts that "successful, trouble-free anchoring demands the careful evaluation of local soil conditions and anchor types…. without proper soil/anchor planning, maximum anchor performance can never be assured." The document also mentions the importance of soil moisture content and water table level, suggesting that a high water table can reduce helix capacity by as much as 50 percent in granular soil. While this finding may be related to a unique set of data, it is in conflict with findings in the FEMA 85 anchor test study whereby wet sand conditions resulted in greater anchor pullout values than did dry sand conditions.

In using the Soil Test Probe (STP) as an aid in determining anchor capacity, it is recommended that the probe is installed in to the earth to the planned anchor depth. Average readings for 3 feet above the anchor and excluding the reading at the anchor is the basis of soil classification. From this statement, it appears that the method of using the STP is important in properly classifying a soil in relation to predicting anchor performance. The document also recommends the additional use of installation torque indicators to "predict with relative accuracy the holding capacity of the installed anchor." The correlations between installing torque and anchor performance are reported to have been based on "thousands of tests throughout the United States and in every conceivable soil condition." Again, this information appears to be limited to deep anchor applications where the soil failure region is entirely below the ground surface.

In regard to anchor creep and deflection, the document suggests that the holding capacity of a coaxially loaded anchor is the load at 4-inches creep or the maximum load before the creep totals 4 to 6 inches. However for shallow anchors under vertical coaxial loading, failure may occur well before this amount of deflection as determined in other test reports reviewed herein. For non-coaxially loaded shallow anchors, maximum loads are commonly achieved at much greater than 4 inches of deflection (with or without stabilizer plates).

The Chance encyclopedia also addresses the practice of testing anchors. It suggests that screw anchors may be spaced as close as 3 to 5 feet apart (again for deep anchor applications). It also mentions that careful soil classification is critical to associating soil class or torque probe values to tested anchor performance. The following test procedure guidelines are noted:

a) When evaluating anchor types, install three or more at each test site.
b) Install the anchor as close as possible, usually within 3 to 5 feet of adjacent anchor.
c) Drive each anchor at a constant rate of rotation.
d) Weaving affects torque and bearing strength, hold weaving to a minimum.
e) Employ the same driving angle.
f) Install each anchor specimen to the same depth.
g) Make a complete record of each measurable step during the test. Include all data that has a direct relationship to the testing cycle.
h) Significant differences in installation torque should be recorded for each anchor type where driving torque is to be credited to anchor design.
i) Remember, variance in down pressures and rotational speed influence driving effort (installation torque) as well as helix stress.

For tension testing, guidance suggests use of a scale affixed to the anchor shaft that can be read with a transit to record deflection. Each test is to be conducted with coaxial load (direct pull-out) and at a constant load rate. Failure to control load rate is considered to negate the test due to effects of load rate on anchor performance (i.e., higher load rate results in increased apparent anchor resistance). It is suggested that load be applied in steps with a waiting time of 3 to 5 minutes at the end of each load step to monitor creep. The load steps should never be greater than 25 percent of the anticipated ultimate pullout load of the anchor. Smaller steps will give greater accuracy of test results. The test should be discontinued when the cumulative creep exceeds 4 inches. Multiple tests are required to average local soil variance.

- *Helix Pier Engineering Handbook 2000*

This handbook provides engineering and design guidance for helix piers. Methods of estimating bearing and pullout capacity are discussed, including "cylindrical shear", "individual bearing", and "installation torque" methods. It further claims that installation torque methods yield "more consistent results", but recommends that all three methods be considered and the results "weighed against the reliability of the input data." A factor of safety of 2 is recognized as a typical practice for bearing and pullout capacity (presumably where load tests have been conducted at the end-use site). Anchor capacity prediction charts are provided for two categories of soils (cohesive and non-cohesive) by way of SPT blow count. In addition field testing recommendations and an example test rig is shown. The test recommendations are similar to those reported in the Chance encyclopedia. However, a maximum test displacement of 1 inch is recommended rather than 4 inches as suggested by others.

<u>Comparative Test Standards and Methods</u>

- *ASTM D3689 – 90 (Reapproved 1995) Standard Test Method for Individual Piles Under Static Axial Tensile Load*

This standard is written purely as a test method and does not address interpretation or analysis of test results, including definition of performance criteria or safety factors. Instead, this standard requires that a "qualified geotechnical engineer should interpret the test results for predicting pile performance and capacity." Furthermore, the term "failure" is defined by a "rapid progressive movement of the pile… in the direction of loading under a constant or decreasing load." Thus, failure is not associated with test load at a specific deflection limit of 1", 3", or 4" to 6" as found in other documents related to ground anchors. Instead it is related to the ultimate pullout capacity. The variation in interpretation of deflection limits for performance evaluation of ground anchors indicates a significant divergence in accepted engineering practice. In part, this lack of consistency may be because the required performance depends on many factors related to any specific application.

The ASTM D3689 also requires that the reaction piles (or reaction forces from the test rigging) be separated by distance from the actual test specimen to remove any influence of the test rigging from altering the performance of the test specimen and its influence on surrounding soil. An accuracy of applied loads of 5% is required. If greater accuracy is required, the standard recommends use of load cells or equivalent devices with a 2% accuracy. However, a load measurement accuracy of 10% is permitted in lateral pile tests when loads are applied by pulling action rather than pushing (refer to ASTM D3966). ASTM D3966 also references a method to conduct combined lateral and uplift load testing and, in recognition of rigging difficulties, suggests using a crane equipped with a line load indicator to conduct the test. A minimum deflection scale precision of 0.01 inch is also required. But, lateral movements are required to be measured at a 0.1 inch precision. Several different test rig configurations are discussed and illustrated. In addition, a recommendation is made for application in cohesive soils to allow for 3 to 30 day waiting period after test pile installation to allow dissipation of any excess pore water pressure generated by the pile (anchor) installation. A maximum test load of 200 percent of the anticipated design load is recommended and it is further recommended that piles be tested to failure. According to the Timber Pile Design and Construction Manual (2002), safety factors of 2 to 4 are considered typical for pile bearing design with the lower values being used where in-situ pile load tests are performed. An uplift loading rate resulting in a displacement rate of 0.02 to 0.04 in/min is suggested. An optional "quick load test method" is also presented which requires application of load in 10 to 15% increments of the proposed design load with a constant time interval in between increments of 2-1/2 minutes. The load increments are to be applied until continuous jacking is required to maintain the test load or the capacity of the loading equipment is reached, whichever occurs first. The full load is to be removed from the test pile after a 5-minute interval. Measurements of time, load, and pile movement are to be taken immediately before and after each load interval. An extensive list of reporting requirements is also provided.

- *Progressive Engineering, Inc. 1989. "Ground Anchor Test Procedure for Manufactured Homes," PEI Standard 89-5, Progressive Engineering, Inc., Goshen, Indiana. December 1989.*

This non-consensus test protocol includes many features necessary for complete a ground anchor qualification testing protocol. For example, it addressed detailed requirements for test rigging including illustrations of an acceptable test apparatus. In addition, includes the common features of displacement limits and measurement tolerances. While specific requirements do not always agree with the related recommendations in this report or the content of draft GAATP, it has many features that could be useful to the GAATP as a model for a nationally accepted test protocol.

APPENDIX B – RECOMMENDED SOIL CLASSIFICATION, ANCHOR FAILURE CRITERIA, AND DESIGN RESISTANCE VALUE DETERMINATION

Based on the findings of this report, recommended revisions to Sections 4.0, 9.0, and 10.0 are presented in this appendix as concepts for further consideration and refinement. Revisions reflecting various other findings and recommendations in the main body of this report are not included.

<u>Section 4.0: Soil Classification</u>

The soil classification approach described below is considered as a preliminary procedure and should be subject to additional consideration, perhaps also explored in the planned Task 2d field testing. However, to thoroughly validate any soil classification approach would require a significant amount of testing and this concern was recognized by NIST in some of its earliest studies on this matter. But, a reasonable framework is needed upon which future testing can be used to eventually build a large database of anchor test data, compare to the soil testing/classification methodology, and then make refinements over time to improve the soil classification methodology. This framework and any future improvements should reasonably balance trade-offs in complexity, accuracy, and practicality in a way that is coordinated with impacts to the reliability of anchor performance or safety margins used to ensure an intended level of performance in end-use. Therefore, it is important to have a sound framework for soil classification in a way that is coordinated with safety margins used in the GAATP.

Soil classification concept for anchor qualification testing as well as for purposes of selecting anchors at end-use sites through correlation to soil classification tests is described below for two different anchor applications. This concept (or something similar) is intended as a revision or replacement of Section 4.0 in the GAATP.

SUGGESTED SOIL CLASSIFICATION METHOD FOR ANCHOR PULL-OUT PREDICTION

1. Determine whether soil is grossly classified as cohesive (clay) or non-cohesive (silt/sand/gravel) – *This categorization defines the basic soil differences that result in fundamental difference in anchor performance and related index tests to correlate to anchor performance. It also places less emphasis on a complete soil particle size analysis per ASTM D2487 or D2488. Instead only the plasticity or strength assessments in ASTM D2488 (visual-manual) soil classification method would be required.*
2. For cohesive soils, correlate anchor values directly to Soil Test Probe readings (torque) or Dynamic Cone Penetrometer readings (blow count) with an adjustment to account for at least three levels of soil moisture (dry, moist, saturated). Alternatively, anchor tests and soil index tests should be done when the cohesive soil is at its "probable maximum" moisture content.
3. For non-cohesive soils, correlate anchor values directly to Dynamic Cone Penetrometer (blow count) or soil test probe (torque). Moisture content at time of anchor tests or soil index tests should be recorded. Dry to moist soil conditions should be preferred for anchor testing in non-cohesive soils.
4. Soil classification as described above should be based on soil located in the lower third of the anchor depth.

SUGGESTED ADDITIONAL SOIL CLASSIFICATION FOR NON-COAXIAL LOADED GROUND ANCHORS WITH STABLIZER PLATES

1. Same as #1 above.
2. Use pocket penetrometer or Dynamic Cone Penetrometer to correlate soil resistance property to anchor/stabilizer lateral load resistance or stiffness.
3. The soil property measurement should be taken at the mid-point of the stabilizer plate's installed depth, but not greater than 6 inches below the soil surface at finish grade.

REQUIRED NUMBER OF SOIL TESTS AT A TEST SITE

At a test site where a minimum of six anchors shall be tested, the soil shall be sampled in a least three locations covering the extent of the anchor test layout on the site. The value used shall represent the average of the three or more soil samples; however, variance in soil index test results shall be included in the test report. A sample constitutes a soil index test as described above as well as a characterization of the soil as cohesive or non-cohesive as also described above (methodology to be determined). The samples shall be taken at depths as described above. An assessment of moisture content shall also be made as described above.

REQUIRED NUMBER OF SOIL TESTS AT AN END-USE SITE

A minimum of three soil tests/samples as described above shall be used to characterize an end use site of one lot up to and including the area of six adjacent lots. For larger sites or numbers of lots, the minimum number of soil tests/samples shall be one test per 6 lots, but not less than three total. Soil index test results shall be averaged for the purpose of selecting an appropriate anchor and/or stabilizer plate combination.

QUALIFICATIONS

The soil tests as described above shall be conducted by a qualified person. For anchor qualification tests, the soils shall be tested by the agency conducting the soil anchor tests. For end-use installations, the required soil assessment and index tests for anchor selection purposes shall be performed by a person trained to conduct such tests. The intent of this approach is to allow an appropriately trained installer to perform this activity at an end-use site. The same person would then use the data or report the data such that an anchor selection can be made for the site or sites.

Failure Criteria (Section 9.0) & Design Values (Section 10.0)

9.0 FAILURE CRITERIA

.1 Failure Modes:

.1 Ultimate load (including any pretension) shall be determined at the point when the anchor head, or its attachment point, displaces 2 inches in the vertical direction or 3 inches in the horizontal direction from its pretensioned measurement position ~~prior to holding a total load of 4,725 pounds (including any pretension load).~~
.2 When the anchor head, or its attachment point, displaces 2 inches in any direction from its pretensioned measurement position prior to holding a total load (including pretension load) equivalent to the ultimate load defined above divided by the appropriate safety factor from Section 10.0. ~~of 3150 pounds (including any pretension load).~~
.3 When breakage of any component of the ground anchor shaft occurs prior to reaching the load associated with the deflection limit states described in 9.1.1 above. ~~a total load of 4,725 pounds.~~

(COMMENTARY: Items .1 and .3 above are related to structural safety limit states and thus define an ultimate load for the anchor. Item .2 is a serviceability limit state to control deflection at design load level.)

10.0 USE OF ULTIMATE ANCHOR LOADS TO ESTABLISH THE LOAD RESISTANCE DESIGN VALUE (WORKING ANCHOR LOAD)

.1 The load resistance design value (working anchor load) shall be the lowest ultimate anchor load determined by testing (5 repetitions minimum), divided by ~~the 1.5~~ a factor of safety determined in accordance with Table 10.1.
.2 ~~A field test shall be performed in the weakest soil that the ground anchor is being qualified for use.~~ Anchors shall be selected for end use sites on the basis of an anchor's load resistance design value for a field test site with an equal or lesser soil strength (higher site class number) as determined by soil test probe torque reading, Dynamic Cone Penetrometer reading, or visual soil classification in accordance with Section 4.0. The load resistance design value, for each installation method, shall be stated in the ground anchor assembly listing or certification.
.3 Anchor spacing determined using the load resistance design value shall not be less than 1.5 times the depth of the anchor when the anchor depth to helix diameter ratio (d/b) is less than 5. When the anchor d/b ratio is greater than 5, anchor spacing shall not be less than 5 anchor helix diameters.

TABLE 10.1
Anchor Safety Factor based on Soil Classification Method used for Anchor Qualification Testing and Anchor Selection at End-use Sites

Recommended Safety Factor (applied to lowest ultimate value in 5 test reps)[1]	Soil Classification Approach Used for Selection of Anchors at End-Use Sites	Estimated Variability in Anchor Performance (COV)[2]
1.5	Anchors tested per GAATP at end-use site (no soil classification required)	0.20 (or 20%)
2.0	Anchors selected on basis of correlating soil index test at end-use site to similar value at anchor qualification test sites (e.g., Soil Torque Probe values)	0.35 (or 35%)
4.0	Anchors selected only on basis of visual or mechanical assessment of soil particle size distribution (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 if 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.

APPENDIX C – Preliminary Analysis of Reliability Benchmarks and Safety Factors for the GAATP

The following reliability analysis is intended to represent a crude, but practical means to evaluate and recommend safety factors to be used in the GAATP. The purpose and approach for this analysis was adequately described in the main body of this report. The step-wise approach used in this analysis explains the rationale in sufficient detail to allow the reader to re-create or improve upon the procedure.

The following reliability analysis assumes normality (normal distribution) for anchor performance data at deflection limits states similar to those contemplated in the GAATP. The assumption of normality appears consistent with the available anchor test data reviewed for this report. Only in a few cases did the data demonstrate a slight skew that might indicate that a log-normal distribution could be considered plausible. However, there is insufficient data to make a rigorous conclusion using common goodness of fit tests for any particular statistical distribution. Therefore, it is accepted practice (barring any conflicting observation) to make the assumption that the data is normally distributed.

The following statistical analysis resources were used in this study:

Ang, A. H-S. and Tang, W.H. 1975. Probability Concepts in Engineering Planning and Design, Vol. 1, Basic Principles, John Wiley & Sons, New York, NY.

Ott, L. 1988. An Introduction to Statistical Methods and Data Analysis. Third Edition. PWS-Kent Publishing Co., Boston, MA.

STEP 1: Determine a target reliability (probability of failure) for anchor performance

In accordance with the HUD Code (Section 3280.306) and principles of structural integrity in Chapter 1 of the ASCE 7 standard for design loads, the intended performance objective for ground anchors may be stated as follows:

> *A ground anchor shall be no more likely of failure at a given applied load level (up to the average ultimate load capacity) than would be expected for the metal straps which connect the ground anchor to the manufactured housing unit.*

For the purpose of this study, a reliability target or benchmark (fulfilling the above objective) shall be based on the probability of failure of the metal strapping at a design load event (e.g., what is the probability that the strap will break when it is loaded to its design load value?). This reliability target, stated in terms of a probability of failure, is determined as follows.

Based on test data on metal strap performance (Pearson et al., 1991), the following data characterizes the variability of metal strap ultimate (tensile) breaking strength, the bias in the assumed ultimate breaking strength (e.g., 4,725 lbs), and the safety factor intended for design purposes by the HUD Code.

- Nominal Ultimate (Tensile) Strength, T_{ult} = 4,725 lbs
  (based on HUD Code and ASTM D3953)
- Actual Average Ultimate (Tensile) Strength, T_{ult} = 4,318 lbs
  (n = 18 for all 5 products per Pearson et al., 1991)
- Estimated Correction Factor (Bias) in Ultimate Value (actual/nominal) = 4,318/4,725 = 0.91
- COV (within 1 product) = 3% (n = 5)
- COV (all 5 products) = 16% (n = 18)

- Safety Factor = 1.5 (assuming no bias)
- Corrected Safety Factor = 1.5 x 0.91 = 1.37 (corrected for bias in nominal relative to actual ultimate strength)
- Strap Design (Tensile) Strength, T_{des} = [Nominal Ultimate (Tensile) Strength] / Safety Factor or Corrected Safety Factor

The design value for the strap can be related to the Z-value (normal distribution) and then the Z-value can be related to a probability (single tail area of the normal probability distribution) as follows.

$$T_{des} = T_{avg,ult} - Z \times (\text{std dev})$$

Because the COV = (std dev) / $T_{avg,ult}$, the equation can be re-written as follows:

$$T_{des} = T_{avg,ult} - Z \times (COV) \times T_{avg,ult}$$

However, the ratio of T_{des} / $T_{avg,ult}$ is simply the inverse of the safety factor with the correction factor as mentioned previously to account for bias in the actual ultimate value relative to the nominal value used for design purposes. Therefore, substituting this ratio and solving the above equation for 'Z' gives the following:

$$Z = \{1 - [1/(SF \times C_{bias})]\}/COV$$

where SF = Safety Factor and C_{bias} = correction factor described above

Finally, three different scenarios are considered using the above equation to determine a target reliability (probability of failure) assuming the occurrence of a design load event (e.g., strap loaded to its design tensile value).

Case #1: Actual Strap Reliability Basis with Bias (SF = 1.5, C_{bias} = 0.9, COV = 16%)

Z = 1.69
Pf = 0.0455 (area in tail of normal distribution ~ probability of failure at design load)

Case #2: Actual Strap Reliability Basis without Bias (SF = 1.5, C_{bias} = 1.0, COV = 16%)

Z = 2.06
Pf = 0.0197

Case #3: Intended Strap Reliability without Bias (SF = 1.5, C_{bias} = 1.0, COV = 3%)

Z = 11.1
Pf = 0.0000… (effectively zero probability of failure)

Based on the above analyses, a reasonable estimate for the reliability of metal straps (for use as a target reliability for evaluation of ground anchor safety factors) ranges from about 0.02 to 0.05. These values represent a probability of failure given the condition that the strap is loaded to its design capacity (e.g., probability of failure given the design event occurs). This range of reliability corresponds to a 1% to 3% probability of structural failure in a 50 year period which is generally consistent with collapse prevention goals for earthquake design (e.g., probability of experiencing a load greater than or equal to the 50-year recurrence interval design load over a 50 year period is 0.64; therefore, multiplying this probability by the prior target probabilities of failure for anchors at the design load level gives 1% and 3%, respectively). But, it results in a slightly lower level of reliability (higher probability of failure) than normally considered for wind design in engineering standards such as ASCE 7 (e.g., 0.62% probability of structural failure in a 50 year period). However, this deviation seems acceptable when the potential conservative biases in the HUD Code's wind loads are considered (see discussion in main body of report regarding wind exposure and effect on wind load). The "intended strap reliability", calculated above as approaching zero by assuming no bias and assuming only variation associated with a given "point in time" sample from a single strap supplier, gives an impractical target value for reliability (too stringent and inconsistent with normal design practice). This finding also indicates that there should be little need to modify the nominal strap design value (e.g., 3150 lbs) to account for the non-conservative bias found in the strap testing by Pearson et al., 1991. In other words, the safety factor of 1.5 used with the strap's nominal ultimate value of 4,725 lbs is adequate to address the 0.91 bias factor represented in the test data without adversely impacting the reliability of strap designs.

> <u>Conclusion for Step 1:</u> *Target reliability for ground anchors should be based on a probability of failure at design load of no greater than 0.05 to fulfill the intended performance objective for foundation anchorage systems as represented by the reliability of metal strapping used to attach a manufactured home to the ground anchors.*

STEP 2: Determine the Probability Percentile of the Ultimate Anchor Load Corresponding to Use of the Lowest Ultimate Load Resistance from Six Test Repetitions

It should be assumed that the lowest ultimate value obtained by testing per the GAATP for any given anchor qualification effort would, on average, represent a mean estimate of this lower bound ultimate strength value. In other words, in a series of independent qualification efforts (using lowest tested ultimate strength from six repetitions in each case) about half of the outcomes would result in a higher estimate of the lower bound ultimate strength and the other half would be lower. With this assumption and forgoing any clear need to have a greater level of confidence in estimating the lower bound ultimate strength, the probability percentile associated with using the lowest of six test repetitions is determined as follows using the binomial theorem in the following form:

$$P_a = 1 - (1 - P_f)^{1/n}$$

where

P_f = probability of that the actual lowest anchor ultimate load value in a given series of six tests is lower than that which may be determined from many such tests scenarios (e.g., Pf is assumed to be 0.5 for reasons described above).
P_a = probability that any one anchor would have a tested value less than the lowest value recorded in a series of six test repetitions.
n = the number of trials or test repetitions

Substituting 6 for n and 0.5 for P_f, the equation is solved as follows:

$$P_a = 1 - (1 - 0.5)^{1/6} = 0.10 \text{ or } 10\%$$

Therefore, the use of the lowest value in a series of 6 tests would, on average, represent a 10-percentile probability estimate of an anchor's ultimate strength, but only within the bounds of the specific field test site conditions.

STEP 3: Estimate variability of anchor performance at test site and at end-use sites based on manner of classifying soil for purpose of anchor selection

Based on the available test data on ground anchors (see references for and Appendix A of the main report), the variability in anchor performance corresponding to different methods of soil classification at end-use sites for the purpose of anchor selection can be roughly characterized as follows:

- Case #1: Anchors tested per GAATP at a give test site or end-use site – COV = 0.2
- Case #2: Anchors selected at end-use site based on soil test correlations – COV = 0.35
- Case #3: Anchors selected at end-use site based on visual soil classification – COV = 0.5

STEP 4: Assess Reliability of Current Safety Factor and Soil Classification Approaches used in the GAATP

Following an approach similar to that used in Step 1, the lower 10-percentile of the normal distribution (10% chance of a lower ultimate value in any single anchor) is associated with a normal Z-value of 1.28. This corresponds with the GAATP's ultimate anchor load value as determined by the lowest value of six tests at a given test site (see Step 2). As estimated in STEP 3, the COV of individual anchor tests at a given site is 0.20. Thus, the ratio of $T_{10\%}$ to $T_{avg,ult}$ is determined as follows:

$$T_{10\%} / T_{avg,ult} = 1 – Z \text{ x COV} = 1 – (1.28)(0.2) = 0.744$$

This corresponds to a central safety factor of 1/0.744 = 1.34 represented by comparing the lowest ultimate load test of 6 tests to the average of the same 6 tests. But, the design value is further determined by use of a safety factor of 1.5 applied to the $T_{10\%}$ which is the ultimate anchor load value per the GAATP. Therefore,

$$T_{des} = T_{10\%/}1.5 = (0.744/1.5) \text{ x } T_{avg,ult} = 0.496\ T_{avg,ult}$$

In essence, the use of a safety factor of 1.5 applied to $T_{10\%}$ as required in the GAATP based on using the lowest value from 6 test repetitions results in a central safety margin (relative to $T_{avg,ult}$) of 1/0.496 = 2.0. However, this safety margin is relative to the amount of variability only at the original test site and does not include the additional variability introduced at end-use sites due to the manner of selecting anchors using either soil test methods or visual soil classification. The greater total variability (COV) that results in end-use of the anchor is accounted for as follows:

$$T_{des} = T_{avg,ult} – Z\ (COV)\ (T_{avg,ult})$$

$$0.496\ T_{avg,ult} = T_{avg,ult} – Z\ (COV)\ (T_{avg,ult})$$

$$Z = 0.504 / (COV)$$

For the different estimated values of COV for the different soil classification cases represented in Step 3, the normal Z-value and the associated probability of failure when an anchor is loaded to its design value determined in accordance with the GAATP is as follows (using the above equation and tables of single tail areas for the normal distribution):

Case #1: Anchors tested per GAATP at a given end-use site – COV = 0.20

$Z = 2.52$

Pf = 0.0059

Case #2: Anchors selected at end-use site based on soil test correlations – COV = 0.35

Z = 1.44
Pf = 0.0749

Case #3: Anchors selected at end-use site based on visual soil classification – COV = 0.5

Z = 1.01
Pf = 0.1562

As can be seen in the above cases, the probability of failure is greater than the target probability of failure of 0.05 from Step 1 in all but the first case (anchor tested per the GAATP at the end-use site). In effect, this finding suggests that the safety factor of 1.5 as used in the GAATP is only adequate (or slightly conservative) when the anchors are essentially qualified (or at least proof tested) at each end-use site. However, only a small increase in the safety margin used in the GAATP would be needed to select anchors at end-use sites using soil test correlations such as the Soil Torque Probe (Case #2 above). A much larger safety margin is needed when anchors are selected at end-use sites on the basis of using visual soil classification methods (Case #3) to correlate to tested anchor values at a similar visually classified test site. In this context, "visual soil classification" would include any classification approach that relies solely on an assessment of soil particle size distribution such as the Unified Soil Classification System (i.e., ASTM D2487 and D2488).

STEP 5: Determine Safety Factor Required to Meet Target Reliability from Step 1

To achieve a consistent target probability of failure, Pf, of 0.05 (for the given condition of a design load event) a normal Z-value of 1.65 is required in each of the soil classification cases evaluated in Step 4. This allows the required safety factor (which is applied to the $T_{10\%}$ value as determined from the GAATP based on the use of the lowest ultimate anchor load value from 6 test repetitions) to be determined for each of the above cases. The calculation is done as follows by treating the safety factor as the independent variable in the prior equations because the Z-value is known based on the desired value of Pf = 0.05:

$$T_{des} = T_{10\%}/SF = (0.744/SF) \times T_{avg,\,ult}$$

$$T_{des} = T_{avg,ult} – Z\ (COV)\ (T_{avg,ult})$$

Substituting the first equation into the second, the following expression for the SF is derived:

$$SF = 0.744 / [1 – Z\ (COV)]$$

Safety factors recommended for use in the GAATP to provide reliability consistent with the performance objective as stated in Step 1 while accounting for variability associated with three different soil classification methods for anchor selection at end-use sites are determined using the above equation as follows:

Case #1: Anchors tested per GAATP at a given end-use site – COV = 0.20

SF = 0.744 / [1 – 1.65(0.2)] = 1.1

Case #2: Anchors selected at end-use site based on soil test correlations – COV = 0.35

SF = 0.744 / [1 – 1.65(0.35)] = 1.8

Case #3: Anchors selected at end-use site based on visual soil classification – COV = 0.5

SF = 0.744 / [1 – 1.65 (0.5)] = 4.3

It can be seen that in Case #1 a safety margin of 1.1 instead of 1.5 may be used (e.g., the anchor design value is determined by use of the lowest ultimate value of 6 tests at the end use site divided by 1.1). For larger manufactured housing developments, this approach could result in a significant advantage to on-site anchor qualification testing that would apply to the entire development. Similarly, when anchors are selected at an end-use site on the basis of soil test correlations (e.g., comparison of Soil Torque Probe values at the end-use site with a similar anchor qualification test site), the use of a 1.5 safety factor as required by the GAATP is slightly non-conservative and a safety factor of 1.8 may be adequate. Finally, when visual soil classification is used as the basis for anchor selection without the use of a soil index test correlations, the safety factor of 1.5 appears grossly inadequate and should be increased to approximately 4.0.

CONCLUSIONS & RECOMMENDATIONS

Based on the above preliminary analyses of reliability, it is clearly necessary to consider different safety factors that apply to different levels of uncertainty in predicting or correlating anchor performance at end use sites. These different uncertainties are primarily associated with different levels of rigor in soil classification or proof testing used for the purpose of anchor selections and design at an end-use site.

First, it may prove more economical and practical to reduce the number of test repetitions required in the GAATP to 5 instead of 6. The lowest ultimate anchor load value for the required repetitions should still be used. Second, safety factors to be applied to the lowest ultimate value from 5 test repetitions should be as follows for three different soil classification approaches:

Recommended Safety Factor (applied to lowest ultimate value in 5 test reps)[1]	Soil Classification Approach Used for Selection of Anchors at End-Use Sites	Estimated Variability in Anchor Performance (COV)[2]
1.5	Anchors tested per GAATP at end-use site (no soil classification required)	0.20 (or 20%)
2.0	Anchors selected on basis of correlating soil index test at end-use site to similar value at anchor qualification test sites (e.g., Soil Torque Probe values)	0.35 (or 35%)
4.0	Anchors selected only on basis of visual or mechanical assessment of soil particle size Distribution (e.g., Unified Soil Classification System)	0.50 (or 50%)

Table Notes:

3. 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 if different soil classification approaches.
4. 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.

The safety factors recommended above are reasonably consistent with accepted engineering practice for foundation design as discussed in this Appendix, in the main body of this report, and in the literature reviewed for this report (see Appendix A and References). Should the estimated variability (COV) of anchor performance be considered high or low for any of the above considered soil classification strategies (based on future data or a different analysis of existing data), then the recommended safety factors can be readily adjusted to reflect the new information following the approach used in this study.

Finally, there appears to be no need to modify strap values to account for potential biases in nominal vs. actual design value (as found in tests by Pearson et al., 1991) because the safety factor of 1.5 used for straps, in combination with the relatively low variability of metal strap performance, adequately addresses this concern.