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EVALUATION OF ANCHOR SYSTEMS THROUGH FULL SCALE PULLOUT TESTING

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Biography

Mr. Jay Sprague, a Certified Professional in Erosion and Sediment Control, is the Laboratory Director of TRI Environmental's Denver Downs Research Facility in Anderson, SC. Mr. Sprague has been integrally involved with implementing large-scale test methods, including the construction and maintenance of the state-of-the-art facilities that make TRI the only independent commercial laboratory offering a wide array of performance testing capabilities. Mr. Sprague is a member of the IECA Southeast Chapter Board, as the South Carolina state representative. In addition, Mr. Sprague has authored or co-authored multiple peer reviewed technical papers, and was awarded the "Most Distinguished Technical Paper" award for his paper, "Evaluating Floating Surface Skimmers" in 2015, by the International Erosion Control Association.

Mr. Joel Sprague is a long-time member of the senior technical staff of TRI/Environmental, Austin, TX, specializing in research, development, and application of geosynthetics, plastic pipe, and erosion and sediment control technologies. He is a registered professional engineer in North and South Carolina, and Georgia. Mr. Sprague has authored numerous technical papers on his research. He received ASTM's 2003 Award for Outstanding Article on the Practice of Geotechnical Testing for his paper titled, "Development of RECP Performance Test Methods". Also, Mr. Sprague was awarded IECA's Most Distinguished Technical Paper Award 2007 for his paper titled "Slope Erosion Testing – Identifying "Critical" Parameters".

Abstract

This paper discusses the testing methodology and results of a research program that evaluated the pullout resistance of several commonly used turf reinforcement mat (TRM) anchoring systems. The testing was full-scale and used soils with known mechanical properties. The results provide quantitative performance differences based on the design, size, and embedment depth of the chosen anchor(s). The paper describes the design, construction, and use of the test apparatus; details the performance characteristics of the anchor systems evaluated; recommends further research; and encourages the adoption of a standardized full scale anchor system pull out test for the evaluation of anchor systems designed to be used in turf reinforcement matting installations.

Keywords: erosion control, performance testing, High Performance Turf Reinforcement Matting, HPTRM, anchor system, full-scale testing

1 INTRODUCTION

Anchor systems are a vital portion of any erosion control program tasked with negating the effects of erosive forces on disturbed soils. Anchor systems are typically deployed in situations where a rolled erosion control product (RECP) is to be used as the primary erosion control measure. As more RECPs, especially high performance turf reinforcement matting (HPTRM), are being designed and specified to be used as systems in place of traditional “hard armor” for high erosion risk scenarios, anchor systems have been designed that can provide the pullout strength necessary to hold the HPTRM systems in place under “worst case” conditions. However, there is no standardized test method used to determine the true “apples to apples” pullout capabilities of the different anchor system designs. This technical paper aims to accomplish the following goals:

- Provide the reader with a background of anchor system use in HPTRM applications;
- Discuss the findings of full scale research that has been completed evaluating the pull out strength of different anchor system designs;
- Propose a standardized test methodology for the evaluation of anchor pullout strength based on the full scale simulation discussed herein and;
- Encourage the use of further study to determine actual pull out performance of anchor systems in different scenarios.

2 BACKGROUND

The evolution of permanent erosion control technologies has led to a significant concentration on high performance, manufactured products that can be used to mitigate erosion and sediment loss in high risk scenarios. This evolution has included the production and distribution of synthetic woven rolled erosion control products that provide end users with quantitatively “high end” material properties, including very high tensile strength, UV resistance, thickness, and mass. Generally, these high performance synthetic woven products are referred to in the product category of “HPTRM” or “High Performance Turf Reinforcement Matting”. Turf reinforcement matting products (TRM), and more specifically, high performance turf reinforcement matting (HPTRM) products are designed to be used in high flow, high erosion risk scenarios, and provide “root reinforcement” to the underlying root structure once the fundamental goal of establishing grass is achieved. Because these HPTRM products are designed to be used in high flow, high erosion risk scenarios, the ability of the HPTRM to remain intimately contacted to the soil surface during a high flow event is of the utmost importance. If the HPTRM loses contact with the soil surface because of floatation or tractive shear forces, seed migration and soil erosion can occur beneath the mat undermining the fundamental goal of rolled erosion control products; that is, to encourage seed germination and vegetation establishment on a construction site, thus enhancing development of the root structure and holding soil in place permanently.

Traditionally, rolled erosion control products and other geosynthetics have been anchored to the soil surface with “U” shaped sod staples in varying lengths, crown gaps, and gauge thicknesses. These sod staples were initially designed to hold sod in place in areas that are rarely under the effect of erosive forces, such as home or commercial lawns, and become redundant once the root structure of the sod establishes. However, sod staples have traditionally been used throughout the industry as the essential technique for anchoring RECPs, including HPTRMs, to the soil surface. As the industry has pivoted to a focus on the use of alternatives to traditional “hard armor”, such as riprap, an increasing number of HPTRM systems have been introduced. Yet, there is a gap between the rapid adoption of HPTRM products and the relative slow adoption of anchor systems specifically designed to act as part of the HPTRM system.

Because the combination of vegetation establishment and soil protection is the design criteria for HPTRM products and both vegetation establishment and soil protection are dependent upon intimate soil contact by the HPTRM, there must be assurance of intimate soil contact over the entire disturbed area under protection of the HPTRM. As such, manufacturers have brought to market a wide range of innovative anchoring devices designed to be used specifically with HPTRM materials. These Mechanical Soil Anchoring (MSA) systems are designed to provide a stronger mechanical anchor point or points by which to ensure intimate contact between the HPTRM and the soil surface across the protected area, under the designed high flow, high erosion risk scenarios. As shown in Figure 1, these anchor systems come in many shapes, sizes, and designs, including; washer pins, deeply embedded anchors with strap or cable connectors anchored to the surface with a ratcheting plate, wood stakes, pins with proprietary designs, and many other variants. All of these examples come in different sizes, gauges, and strengths designed to provide graduated pull out strength performance when installed. However, there is currently no standardized test used to determine the actual pull out characteristics of each of these individual anchor types, sizes, and designs. Most available data on MSA systems are empirical or theoretical interpretations, derived from field trials, project-specific proof testing, or mathematical theory. Design professionals are, therefore, unable to quantitatively determine which MSA systems should be used for specific HPTRM scenarios. In addition, without data representing a range of soil types and anchorage conditions, MSA system selection must be made without accounting for any potential change in anchor system behavior based on soil type, embedment depth, or installation technique.

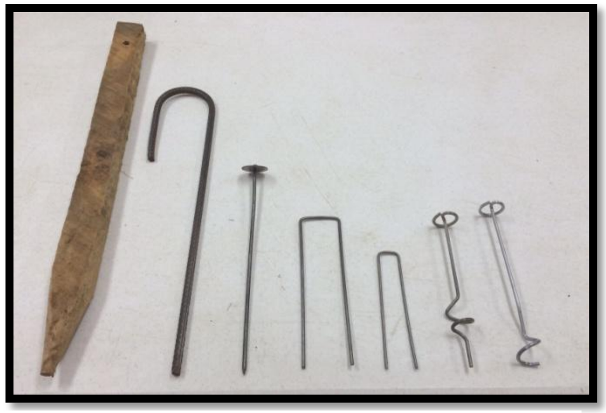

Figure 1 – Anchor Designs Tested

3 FULL SCALE ANCHOR PULLOUT TESTING

To answer the question, “How much pullout resistance can I expect from this anchor?”, a full scale anchor pull out test apparatus was constructed in an effort to create a replicable, accessible, full scale pull out test. As shown in Figures 2 and 3 the test apparatus consisted, in its most basic form, of a concrete “box” filled with compacted soil, steel support beams, and a pulley system. The concrete tank, a re-imagined topless septic tank, allowed for a rigid, confinable area where soil could be verifiably compacted, and anchor installation and testing could be performed. The dimensions of the concrete tank were 262 cm (8.6 ft) L x 127 cm (4.2 ft) W x 79 cm (2.6 ft) D. The steel beams of the apparatus acted as supports for clip on points for the pulley system, and provided the ability to conduct a pullout test of individual anchors without any physical contact with the soil surface, as would occur if, say, a tri-pod and wench system were used to create the pull out force. The soil in question was a Sandy Clay Loam per the USDA soil classification (USCS Clayey Sand (SC) per ASTM D2487) with a plasticity index of 14 per ASTM D4318, maximum dry density of 1749.2 kg/m^3 (109.2 pcf) per ASTM D698, and an optimum moisture content of 17% per ASTM D698. The density of the soil after placement and compaction was determined to be 88.3% of standard proctor density via the drive cylinder method per ASTM D2937. Once soil placement, compaction, and verification were completed, the apparatus was fully assembled.

Figure 2 – Test Apparatus (End View)

Figure 3 – Test Apparatus (3/4 View)

After the apparatus was fully assembled, the anchors to be tested were installed. The anchors tested varied greatly in design and installation technique: from rebar j-hooks and washer pins that were to be driven into the soil with a hammer, to proprietary anchor products that required specialized drill bits for installation. Once the anchors were installed, a custom plate (Figure 4) was placed under the head of the anchor (if necessary to facilitate vertical pullout), and the pulley system was attached to the anchor or plate. The pulley was a double pulley block and tackle system that allowed for a 2:1 advantage from the load applied on one end of the system to the load imparted on the anchor. This advantage allowed for evaluation of higher strength anchor products without the need for very high loads, expedited test time, and alleviated safety concerns associated with large hanging loads. At the other end of the pulley system from the anchor was a vessel for adding load, connected to the pulley system by a calibrated load cell (Dillon "ED junior"). The vessel was either one or two five gallon buckets. As shown in Figure 5, these buckets would be slowly filled with water, so that the anchor being tested would feel a gradual and dynamic load application, allowing for measurements to be made regarding both load and anchor pullout distance, in inches. As the load was applied to the anchor, measurements of pullout distance from the soil surface as shown in Figure 6 and the associated applied load would be recorded at ½", 1", and complete anchor pullout. The theoretical justification for taking pullout measurements at different levels of displacement is simple: there is currently no standard definition for pullout. One is left to interpret if pullout refers to the point at which an anchor initially moves from its "as installed" position, or on the other extreme, if pullout is defined by a complete removal of the anchor from the soil, or if it is somewhere in between. This procedure was repeated on all anchors tested in this program. The program discussed herein consisted of pullout testing via the method described above on the following generically identified anchors:

Figure 4 – Anchor and Plate Assembly

Figure 5 – Load Application with Load Cell Visible

- TA1 (Proprietary Anchor)
- TA2 (Proprietary Anchor)
- Rebar J-Hook 18"
- Rebar J-Hook 24"
- Washer Pin 12"
- Washer Pin 18"
- Washer Pin 24"
- 1.5" x 1.5" Wooden Post
- EA 10" (Proprietary Anchor)
- 8" x 1" x 8" – 8 Ga. Staple
- 6" x 1" x 6" – 11 Ga. Staple

These anchors were chosen to represent a cross section of "commodity" and proprietary anchor styles used on construction sites to anchor HPTRM materials. The majority of the anchors tested via the method described above did not experience incremental pullout at 1/2" and 1", and instead would experience full pullout or full anchor removal from the soil. In these cases, only the load at full anchor removal could be recorded. The load and displacement was recorded and tabulated in Microsoft Excel (Figure 7) and used to create the graphical representation shown in Figure 8. The data seems to show a clear hierarchy of anchor system performance. Calculated pullout strength of the tested anchors ranged from 10 – 320 lbs. This range represents the large difference in performance between product designs, and, arguably, also represents a quantifiable difference in performance of products of the same design, but different sizes.

Figure 6 – Pullout Measurement

TA-1	1/2"	86.0
	1"	114.4
	P/O	163.2
TA-2	1/2"	59.0
	1"	80.4
	P/O	132.0
J-Hook 18"	P/O	33.8
J-Hook 24"	P/O	40.8
Washer Pins 12"	P/O	22.4
Washer Pins 18"	P/O	13.6
Washer Pins 24"	P/O	23.2
1.5" x 1.5" Wood	P/O	153
AE - 10"	P/O	312
8x1x8 - 8 Ga. Sod	P/O	48
6x1x6 - 11 Ga. Sod	P/O	20

Figure 7 – Anchor Pullout Data

The testing program described herein seems to have objectively demonstrated clear, quantifiable performance differences between anchor systems of different designs and sizes. One anomaly did occur during the testing; the pullout strength of the washer pin design anchors did not increase with an increase in anchor size or embedment depth, as occurred with other anchor systems designs that were tested at different sizes and embedment depths. This anomaly could be attributed to the fact the only 10 replicate pullout tests were completed on each anchor design and size, and could potentially be reconciled with further study. As previously discussed, these results are only representative of anchor system performance in the particular soil type and compaction conditions used for this test program, and therefore are limited in scope. However, initial results seem to provide justification for further investigation of anchor performance using a full scale "standardized" testing procedure. In addition, the results of this test method seem to pass the "common sense" test of providing definable performance differences based on product design and size, therefore, at least preliminarily, providing validation for the test method, test apparatus construction, and data interpretation methodology utilized in this test program.

4. STANDARDIZATION AND FURTHER STUDY

Based on the promising results of the test program described above, there appears to be a benefit to having a fully defined, standardized approach for the evaluation of anchor systems used in HPTRM and other applications. The test program described herein provides a starting point for defining the test apparatus design and construction, test methodology, data collection and interpretation, and reporting. However, several important aspects of the test methodology should be more fully defined in any future standardized test for evaluating anchor system pullout performance. The following items should receive further consideration and definition:

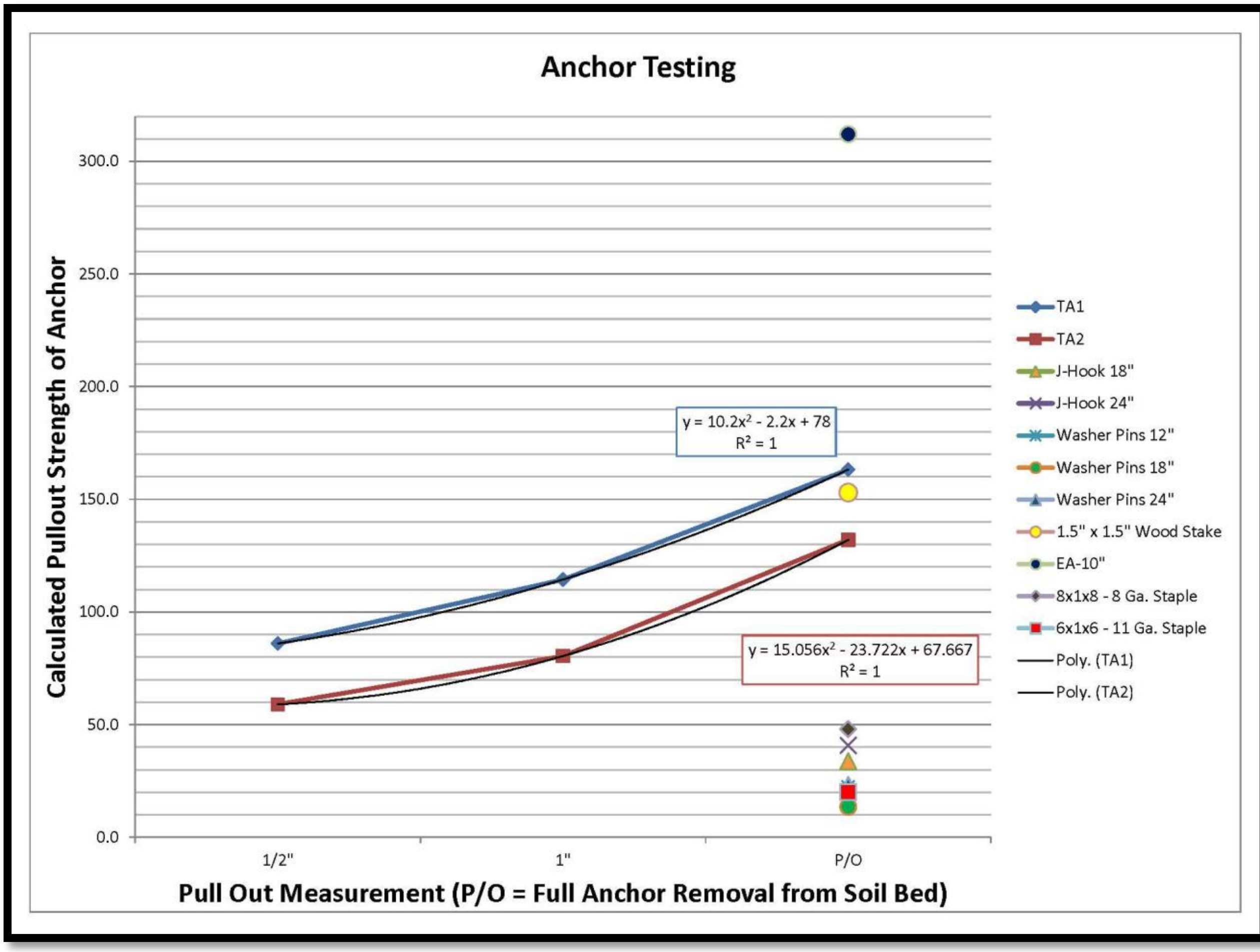

Figure 8 – Pullout Data Plotted to Show Hierarchy of Performance

- Soil type
- Number of different soil types
- Compaction
- Number of compaction conditions to be evaluated or correlation between compaction level and anchor system performance.
- Number of replicate pullout tests to be performed on each anchor in each soil type.
- Definition of connection between anchor and pulley system. (This test program used a custom “pullout plate”, but this plate was only used to ensure a vertical pullout direction. Not all anchors were evaluated using the plate.)
- Definition of installation technique to be used.
- Significance of use – How does the pullout strength of an individual anchor translate to anchor system selection and anchor frequency based on expected field conditions?
- Precision and bias of test method

Surely there are other items that need further definition in the development of any future standardized test method, but the items above are the immediately noticeable uncertainties that remain unanswered by the test program described herein. Many of these uncertainties can reasonably be expected to be answered through further study. A replication of the test program described above, but using two or three different soil types could potentially answer the question of anchor performance changes between soil types, and also potentially provide a mathematical correlation between anchor performance and soil type based on mechanical soil properties. Compaction or number of compaction conditions seems a more arbitrary definition, but could be defined by industry. This test program used 10 pullout test replicates per anchor design and size, but could accommodate any number of replicate tests needed to accurately develop a standard deviation for the subsequent results, thus helping to answer the questions associated with precision and bias. Effect of different connections between the anchor and pulley system could be determined with further study, and the reliable connection type could be defined. Significance of use is more difficult to define, as the anchor strength necessary for any given project is dependent upon the expected conditions, however, this definition will be important in ensuring end user adoption of data produced from the test method.

The current state and direction of the erosion and sediment control industry has identified a tangible need and a unique opportunity for the development of a standardized test method for the evaluation of anchor system pullout performance. The testing described herein is not fully adequate for the development of a standardized test method. However, the results of the test program justify the pursuit of a standardized test using this test program as a prototype, and provide the basis for further study to investigate the uncertainties of the test program as a standardized test method is developed.

5. CONCLUSIONS

The use of High Performance Turf Reinforcement Matting (HPTRM) materials has lead to a need for anchor systems that can provide the appropriate mechanical soil anchorage under high erosion risk scenarios. As such, manufacturers have developed proprietary anchor designs that theoretically provide the necessary pullout strength and performance. However, there is currently no standardized test method available to determine, quantifiably, the pullout strength and performance of these Mechanical Soil Anchor (MSA) systems. The test program described herein was designed to provide a relevant full scale performance test of anchor pullout strength under defined, documented, and replicable conditions. The results of the test program seem promising. Further, the results provide justification for further study, and development of a standardized test method based on the program and methodology discussed in this paper.