Bio-Engineering for Land Stabilization

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16. Abstract

As part of the Ohio Department of Transportation's (ODOT's) ongoing effort to solve engineering problems for the Ohio transportation system through research, The Ohio State University has undertaken a study entitled "Bioengineering for Land Stabilization" under the direction of Professor Patrick J. Fox and Professor Emeritus T. H. Wu.

A large number of slopes and embankments throughout Ohio are experiencing shallow slope failures and/or erosion problems. The aim of this study is to identify bioengineering methods to address ODOT's slope stabilization needs in response to these occurrences. Bioengineering is an ecologically, and often economically, attractive alternative to conventional slope stabilization techniques. The objectives of this research are: 1) to identify important factors that control success or failure of bioengineering methods, 2) to develop installation techniques and designs for successful application of bioengineering methods, and 3) to provide thorough documentation to aid in the development of future design guides for bioengineering work for ODOT.

Three field installations were conducted and monitored at demonstration sites located in Muskingum, Logan and Union Counties. Results indicate that biostabilization methods can be effective for the stabilization of shallow (less than 3 – 4 ft.) slides if vegetation can be established. Establishment of vegetation is dependent on local soil and climate conditions, especially during the first growing season after installation. The use of instrumentation (tensiometers, piezometers) can be effective in predicting vegetation survivability. Side-by-side panel comparisons indicated that varying installation techniques do not affect the survivability of live willow poles. The cost of bioengineering stabilization, if properly planned and implemented, is expected to be approximately 25% less than that of conventional methods.

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ABSTRACT

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Chapter 1 INTRODUCTION

Bioengineering for land stabilization is an ecologically, and often economically, attractive alternative to conventional slope stabilization techniques. Typically, conventional stabilization methods for highway embankments include slope flattening, cutting and benching, retaining walls, and revetments. The application of these methods is expensive and requires extensive construction activity to implement them. Soil bioengineering is an alternative technique that utilizes vegetation, alone or in conjunction with mechanical elements, to provide slope stabilization and/or arrest erosion. It should be noted, however, that in general, bioengineering methods are limited to mitigating shallow erosion or landslides and are inappropriate for controlling deep-seated slope failures due the limited depth of plant growth.

Throughout Ohio, there are thousands of highway slopes and embankments that are experiencing slope stability issues. Most of these locations are primarily experiencing shallow slope failures and/or erosion problems. These failures usually begin as shallow mass movements or local erosion in the forms of sloughing and small gullies along the slope face. While these are initially small maintenance issues, it is difficult and impractical to continually repair them as the problem is generally recurring. Typically, these sites are left to continue eroding and/or sloughing until they become a danger to the stability of the roadway (i.e. the failure has propagated up the slope to the roadway and started to expose the guardrail and/or sub-base). It is at this point that conventional stabilization methods are implemented to mitigate the failure and restore the slope to a safe condition.

The focus of this investigation is to ascertain the feasibility and effectiveness of implementing bioengineering stabilization to remediate areas that have begun to experience shallow sliding. This will be achieved by installing vegetation, specifically willow cuttings, in slopes that are showing instability. Shear strength of the soil mass will be enhanced both mechanically and hydrologically through the presence of the cuttings, the root network of the vegetation, and by moisture reduction in the near-surface soils. While this application will not be suitable for all cases of shallow failures, it is hoped that it will be a cost effective approach to mitigating these issues for many sites. The objectives of this research are: 1) to identify important factors that control success or failure of bioengineering methods, 2) to develop installation techniques and designs for successful application of bioengineering methods, and 3) to provide thorough documentation to develop design guides for future work in bioengineering for the Ohio Department of Transportation (ODOT).

In support of this research, three demonstration sites have been selected near central Ohio for implementation of the proposed bioengineering technique. It is believed that a thorough evaluation of these sites should provide an accurate assessment of bioengineering remediation methods and their potential application to supplementary candidate sites. The first demonstration site is a fill embankment located along I-70, outside of the village of New Concord, about 70 miles east of Columbus on the west bound entrance ramp of the I-70/SR-83 interchange in Muskingum County, Ohio. Shallow sliding and erosion has been a major problem along this stretch of the interstate

and these embankments have seen several conventional remedial repairs during their design life, including a full undercut to incorporate new drainage systems. The second demonstration site is a cut slope drainage channel located along US-33 approximately 15 miles northwest of Marysville within the infield of the interchange of eastbound US-33 and SR-347 (Loop Ramp "B") in Logan County, Ohio. The drainage channel directs flow from areas northwest of the site down to the Darby Creek Watershed. Current sliding and erosion of the slopes are adversely affecting the outflow to this area through the deposition and transportation of silts and clays along the streambed. The final demonstration site is a fill embankment located just outside of Marysville off of the westbound entrance ramp of the US-33/SR-36,4 interchange in Union County, Ohio. Shallow sliding immediately adjacent to an overpass was repaired using conventional techniques described in Chapter 6. As a direct comparison of bioengineering and conventional methods, bioengineering techniques were implemented in sections adjacent to the conventional remediation areas.

To date, all three of the field demonstration sites have been installed and are currently being monitored. Construction at the Muskingum County demonstration site, carried out by Ohio State University (OSU) personnel, took place during the late spring/early summer of 2005, and included the installation of live poles and brushlayers to arrest shallow movement. Construction at the remaining two sites was carried out by a local contractor during March 2007, and included the installation of live poles at both sites, as well as slope grading and construction of a toe berm at the Logan County site.

Extensive monitoring of instrumentation and vegetation at all three sites has been an ongoing process from the time of their selection to the present. Instrumentation including tensiometers, piezometers, shallow monitoring wells, gypsum moisture blocks, and slope inclinometers have been installed and monitored at all three sites to obtain soil-moisture and displacement activity both prior and subsequent to construction. Survival rates of vegetation have also been closely monitored to establish factors that lead to successful/unsuccessful establishment of the cuttings within the slope. Subsurface investigations in support of this research have been conducted at both the Muskingum County and Logan County demonstration sites which have produced standard penetration sounding and undisturbed soil samples. Laboratory tests including triaxial shear, direct shear, consolidation, Atterberg limits, soil-moisture characteristic, and soil nutrient have been conducted to establish the properties and composition of the soil at each site.

This report is divided into 7 chapters and presents the efforts undertaken to date for the ODOT funded research project, Bio-Engineering for Land Stabilization. This chapter provides an introduction to the research project. Chapter 2 contains a comprehensive literature review of historical bioengineering case studies, a brief overview of the general stabilizing effects provided by bioengineering methods, and an in-depth look at the impact of the soil-moisture regime on the establishment and growth of willow cuttings. General project considerations which are not specific to the individual demonstration sites are described in Chapter 3. The three field demonstration sites at Muskingum, Logan and Union Counties are reported in Chapters 4, 5, and 6, respectively. Finally, Chapter 7 presents conclusions for the research effort to date, as well as future work and recommendations for this research project.

Chapter 2 RESEARCH OBJECTIVES

The original proposal contained the following statement with regard to research objectives:

> The primary objective of the proposed research is to evaluate the applicability of various bioengineering methods to the Ohio Department of Transportation's (ODOT's) land stabilization needs. Application to three types of problems– cut slopes, embankment slopes, and stream banks– will be investigated. More specific objectives are: 1) to identify important factors that control success or failure of bioengineering methods, 2) to develop installation techniques and designs for successful application of bioengineering methods, and 3) to provide thorough documentation to guide future work in bioengineering for ODOT.

Due to difficulty in locating a suitable stream bank field demonstration site, the project team and project liaisons agreed that the demonstration sites would consist of one cut slope and two embankment slopes.

Chapter 3 LITERATURE REVIEW

3.1 INTRODUCTION

Historically, soil bioengineering is not a new concept. Records indicate that bioengineering stabilization was being utilized in China as early as the first century B.C. for dike repairs (Finney 1993). Today, with the popular appeal for "green" engineering increasing, there has been a large amount of research conducted on the success of differing bioengineering techniques in climates throughout the world as well as quantifying the effectiveness of bio-stabilization. The bulk of research in the field of soil bioengineering stabilization has been focused primarily in areas throughout Europe and Asia. However, as the need for cost efficient and environmentally friendly techniques are becoming paramount in the United States, research into bioengineering and other "green" technologies is increasing in the United States.

While bioengineering designs have been largely successful worldwide, it must be recognized that these methods need to be evaluated in representative regions prior to large scale implementation. Vegetation and designs specific to tropical locations, such as Malaysia, most likely will not be appropriate for implementation in Ohio. Therefore, climate, soil-moisture condition, and composition of soil must be carefully considered in the selection of plant species for bioengineering remediation sites. Due to the dramatic fluctuations in seasonal climate in Ohio, plant species that should be considered for use in bioengineering designs should be hardy and able to withstand these effects, as well as be locally available and plentiful. As such, two plant species will be utilized as part of the designs implemented in the current investigation. These will primarily be willows with a percentage of poplars for comparison of the effect of differing vegetation at the Muskingum County demonstration site.

The following sections give detailed overviews of bioengineering designs, including the implementation of live poles and brushlayers. Recommendations for the proper collection, storage and environmental considerations of vegetation are also outlined. Bioengineering case studies from the United Kingdom using similar methods of stabilization are also presented. A brief overview of these sites will be presented along with installation procedures and evaluation of the sites subsequent to construction. An overview of stabilizing effects from bioengineering, specifically live staking, is also presented. Quantification and detailed calculations relating to slope stability for the current research are presented in subsequent chapters. Lastly, an evaluation of the effects of the soil-moisture regime on willow species is also presented at the end of this chapter.

3.2 SOIL BIOENGINEERING DESIGNS

Soil bioengineering design methods range from installations that merely resist erosion to systems which provide slope stabilizing reinforcement and drainage through the strategic establishment of vegetation. Some examples of the numerous established techniques are live staking, live poles, fascines, brushlayers, vegetated geogrids, branchpacking, vegetated crib walls, live slope grating, wattle fences, furrow planting,

and vegetated gabions. Comprehensive guides and design details for these methods can be found in Gray and Leiser (1982), Gray and Sotir (1996), and Schiechtl and Stern (1996). Table 2.1, summarizes some of the more common soil bioengineering systems, and, specifically, their construction and functions.

Sections 3.2.1 and 3.2.2 present in greater detail the bioengineering design schemes incorporated into the demonstration sites for this project, which include live poles and brushlayers. Guidelines for the installation and establishment of soil bioengineering projects are discussed in Schiechtl (1980), Gray and Leiser (1982), Coppin and Richards (1990), Gray and Sotir (1996), and Schiechtl and Stern (1996). The use of erosion control projects in conjunction with soil bioengineering techniques has been documented as well (Szymoniak et al. 1984; Di Pietro and Brunet 2002).

Although different hardwood species have been used successfully in bioengineered projects, the literature indicates that willow species are generally the most robust for live pole and brushlayer installations (Gray and Sotir 1996; Eubanks and Meadows 2002). Willow species in general possess good to excellent ability to root from cuttings. Additionally, they establish quickly, and are, in general, tolerant to flooding, salt, and deposition (Gray and Sotir 1996).

3.2.1 Live Poles

Live pole planting is the installation of hardwood cuttings (i.e., poles) into a slope. A typical live pole installation could be one to two inch diameter willow cuttings, five to six feet long, and placed perpendicularly into a slope on a grid pattern with spacing of two to three feet (see Figure 3.1). Live poles have the ability to stabilize relatively steep slopes which are subject to shallow sliding and has been used successfully to stabilize highway slopes (Barker 2004; Steele et al. 2004). The live poles provide immediate mechanical stabilization similar to micropiles or soil nails. Over time, root development will provide additional mechanical reinforcement by binding the soil mass together, as well as providing the hydrological benefits of reducing soil moisture, increasing evapotranspiration, and inducing negative pore pressures (Barker 2004).

3.2.2 Brushlayer

Live brushlayering is the placing of layers of live branches into a slope. Figure 3.2 shows a schematic brushlayer installation of a cut slope. Brushlayer designs use soft hardwood (e.g., willow, alder, and dogwood) branches which can extend into the slope as much as twelve feet in some applications (Gray and Sotir 1996). This stabilization technique is applicable for the impediment of shallow sliding and provides erosion protection. Erosion protection is achieved by intercepting and reducing the velocity of runoff water which transports or erodes soil sediments. Brushlayers can be constructed entirely of vegetative material or the design can incorporate natural or synthetic reinforcement. Typical natural reinforcement may include coir fabric and synthetic reinforcement may be achieved with geogrids.

Table 3.1: Summary of bioengineering systems (after Gray and Leiser 1982).

Name	Construction	Primary function(s)
1. Live stakes	Sticks are cut from rootable plant stock and tamped directly into the ground.	Live plants reduce erosion and remove water by evapotranspiration. Plant roots reinforce soil.
2. Live poles	Poles are cut from rootable plant stock and inserted into premade holes.	Same as 1.
3. Live faccine (wattling)	Sticks of live plant material are bound together and placed in a trench. They are tied to the ground by stakes.	Same as 1.
4. Brush mattress	Live branches are placed close together on the surface to form a mattress.	Same as 1. In addition, it provides immediate protection against erosion.
5. Brushlayer branchpacking	Live branches are placed in trenches or between layers of compacted fill.	Same as 1.
6. Vegetated geogrid	Live branches are placed in layers between compacted soil wrapped in geogrid.	The geogrid provides immediate stability. The plants serve the same functions as in 1.
7. Rooted plants	Rooted plants grown in a nursery or in the wild are planted.	Same as 1. In addition, roots provide buttressing.

3.3 Vegetation

Vegetation selection is an essential aspect of bioengineering design. The use of native versus exotic species and plant availability are important considerations. Soft hardwood species like willow, cottonwood, poplar, and dogwood have been used successfully for bioengineering construction throughout the United States (Gray and Sotir 1992; Gray and Sotir 1995; Lewis et al. 2001; WSDOT 2003) with willow being the species of choice for the majority of applications. Gray and Sotir (1996) outline the location, availability, habitat value, size/form, root type, and rooting ability from cuttings for suitable soil bioengineering plant species, as well as plant tolerance to deposition,

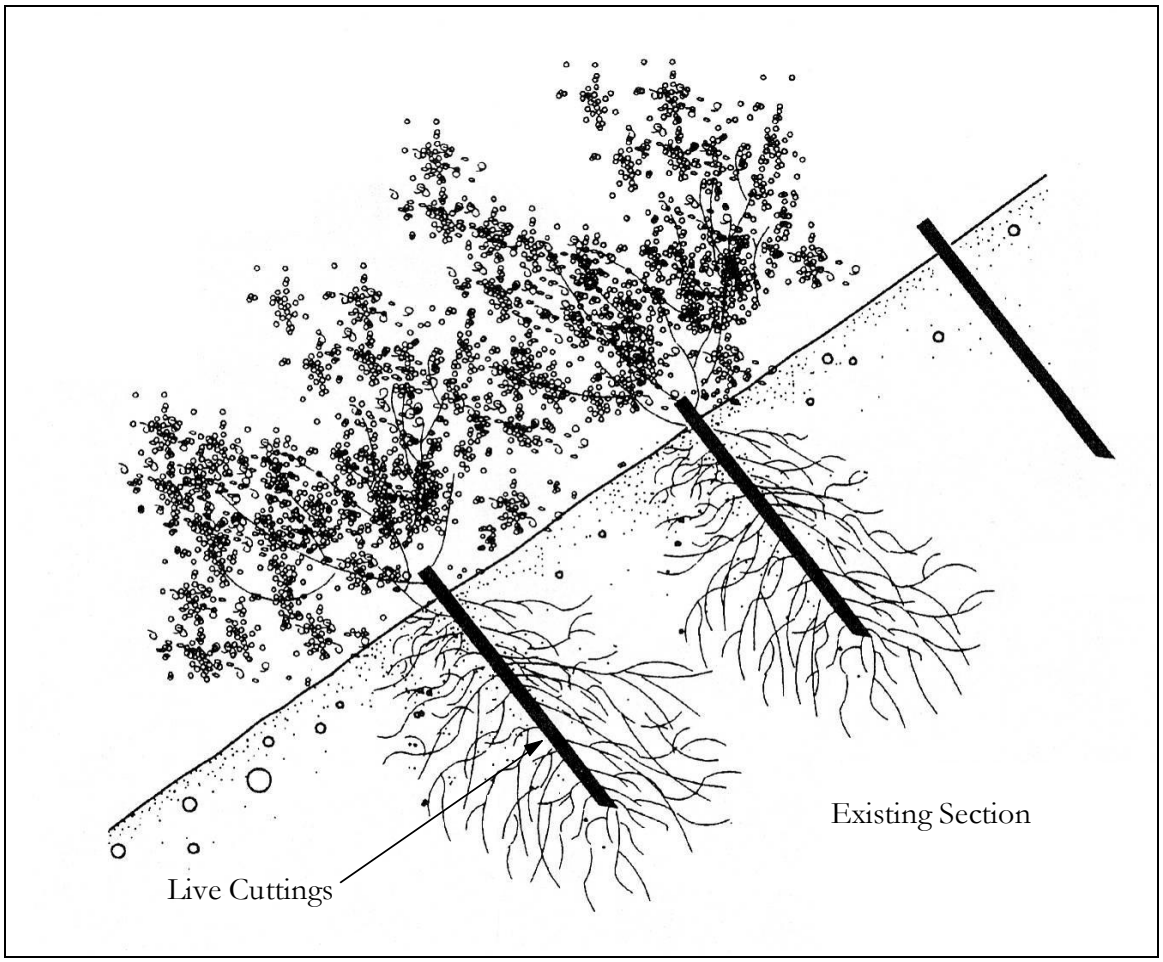


Figure 3.1: Schematic diagram of an established live pole installation (Gray and Sotir 1996).

flooding, drought, and salt. These tables are useful as they provide a guide for the selection of bioengineering plant material. Additionally, one should consider the use of native material before introducing exotic plant species because native varieties are typically better acclimated to localized climate and environment (Gray and Sotir 1996). However, a case can be made for choosing introduced species in some instances where aesthetics or availability may be of concern (Gray and Leiser 1982).

Because the success of a bioengineering project relies on the propagation of the chosen vegetation, careful attention must be placed on environmental factors like climate and soil vitality when choosing the vegetation for a bioengineered project and a carefully monitored maintenance schedule should be followed to hedge off any potentially detrimental occurrences. The vegetation used in this project was limited to hardwood species. For this reason little or no reference has been made to various other types of plants, shrubs, grains, grasses and turfs, which are often employed for various erosion and stability ventures. The interested reader is referred to Coppin and Richards (1990) and Gray and Sotir (1996) for guidelines on the use of these other flora. Additionally, the focus of the literature presented herein has been on upland slope stabilization because of

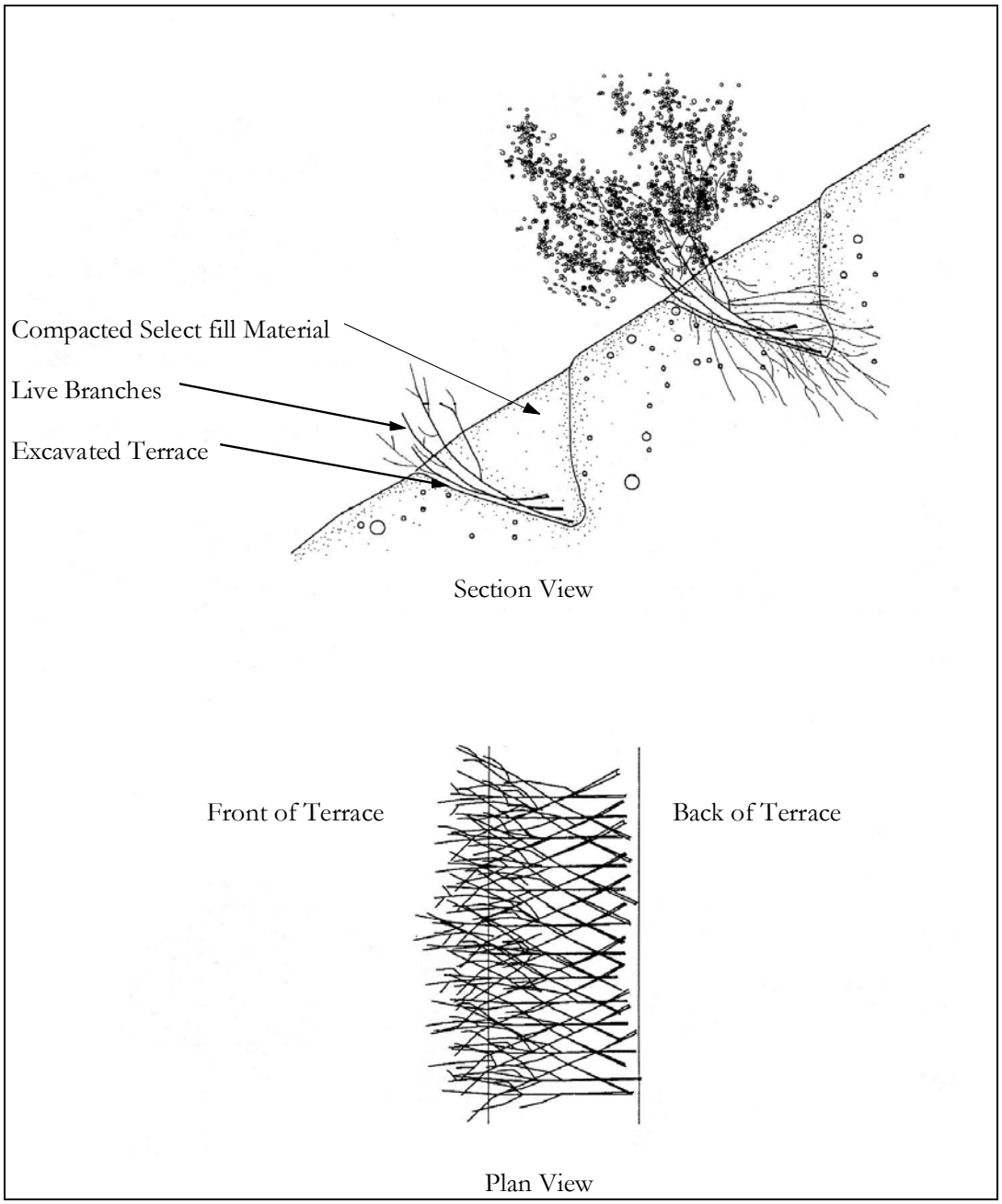


Figure 3.2: Schematic diagram of an established, growing *cut slope* brushlayer installation showing alternating layers of live cut brush placed on narrow benches or terraces excavated in the slope (Gray and Sotir 1996).

the relevance to the project demonstration sites and little has been discussed on stream bank slopes, riparian slopes, and wetland slopes. Thorough treatments on non-upland soil bioengineering and biotechnical stabilization can be found in Schiechtl and Stern (1997), Fotherby et al. (1998), and Eubanks and Meadows (2002).

3.3.1 Collection

Soft hardwood cuttings (willow and poplar), which are used in many bioengineering applications, must be harvested and installed in their dormancy. The dormant period is generally during the winter after a hard frost has occurred and before budding. Hardwood cuttings are generally harvested using conventional tree trimming tools like pruners, loppers, tree saws, chain saws, and brush saws. Additionally, cuttings should be taken 8 to 10 inches above the ground surface so that the host plants can regenerate (Gray and Sotir 1996).

3.3.2 Storage

In some instances, the harvest of vegetation and installation times may not coincide; therefore, it may be necessary to store the cuttings for some period. Refrigerated storage, such as commercial cooler/freezer, refrigerated truck, or barn with suitable conditions, offers a solution for allowing delayed, late spring, planting. Another alternative for storage is "heeling in" where the cuttings are temporarily planted in loose soil during the dormant season and then dug up and moved to the permanent installation site later (Rowe 2005). Research into the effects of temperature, moisture, and duration of storage on hardwood cuttings has been conducted by Cram and Lindquist (1983) and Volk et al. (2004). The consensus is that the optimal environment for the refrigerated storage of hardwood cuttings is 34°F and 90% humidity (Gray and Sotir 1996).

3.3.3 Environmental Considerations

Soil pH and nutrient and metal concentrations should be within acceptable limits as indicated through soil nutrient and pH testing of representative soils from the project site. In some cases it may be necessary to fertilize or otherwise treat the soil to promote favorable growing conditions (Gray and Sotir 1996). Soil texture has been reported by Schaff et al. (2003) to be the dominate factor in determining black willow cutting growth, health, and survivability with coarse-grained soils (sands) being the most conducive. The tolerance of riparian willow and cottonwood species to water table decline has been studied by Amlin and Rood (2002) and their findings suggest that a gradual water table decline tends to promote shoot and root growth and, conversely, a rapid decline induces mortality with willow being the more vulnerable of the two genera. One must also be aware of site microclimate conditions, for example, areas susceptible to drought or heavy rainfall uncharacteristic of the surrounding area's climate. Also, the aspect or slope facing direction is an environmental consideration which must not be overlooked. Slopes receive substantially less sunlight on north facing slopes in the northern hemisphere than south facing slopes. The amount of sunlight can have an effect on the stability of an earthen slope by influencing both plant survivability and the near surface groundwater regime.

Pre-planting soaking has been shown to be beneficial for the survival of hardwood cuttings and Schaff et al. (2002) recommends a ten day pre-planting soaking for black willow cuttings. Gray and Sotir (1996) state that live cuttings must be protected from drying up and should be heeled into moist soil or kept in water prior to planting.

3.4 SELECT CASE HISTORIES

This section presents select case histories that utilized bioengineering stabilization design schemes for remediation of shallow landslides. Several bioengineering slope stabilization techniques and methods are outlined in Gray and Sotir (1996), including: live staking, live fascines, brushlayering, vegetated geogrids, branchpacking, vegetated crib walls, and live slope grating. Case studies are available that discuss each of these stabilization techniques in detail. However, the selection of case histories presented henceforth will include only those that have direct relevance to the current investigation. It should also be noted that selection was also limited to studies of bioengineering in upland areas primarily along highway embankments. Studies that encompass stream and riparian slope remediation are not covered as in-situ moisture conditions and soil-root interaction mechanisms are largely dissimilar.

3.4.1 United Kingdom Live Willow Pole Trials (1997-2002)

This study utilized live willow poles to stabilize highway slopes at several sites throughout the United Kingdom (UK). Shallow slope failures along engineered highway embankments are a widespread problem throughout the UK and the world. While initially these failures are not critical, they typically become a costly maintenance problem in time and can lead to larger failures if not corrected. To alleviate these issues, bioengineering stabilization schemes using live willow poles were implemented at five select sites in an effort to determine the effectiveness and feasibility of bioengineering methods in the UK. The designs incorporated the use of live willow poles staked into the slope face to a depth that would adequately increase the shear strength of the entire slope to an acceptable factor of safety. Instantaneous stabilizing effects are provided by the willow poles themselves acting as a form of soil nail, and long-term stability is provided primarily by the root-growth reinforcing the soil mass and introducing an additional apparent cohesion to the soil. Reduction in soil moisture content and positive pore pressures through the removal of water by the vegetation is also a long-term stabilizing effect, but is difficult to quantify as the relationship is heavily influenced by the local soil and climate conditions of the remediated area and also by the type of vegetation used.

3.4.1.1 United Kingdom Live Willow Pole Trial - Iwade (1997)

The initial trial investigation of the use of live willow poles in a bioengineering stabilization scheme in the United Kingdom was at the A294 demonstration site in Iwade, UK. The site is a cut slope consisting typically of Woolwhich Beds Clay with discontinuous thin seams of sand overlying the Woolwhich Beds Sand. The slope has an inclination of approximately 3:1 (H:V) and is generally SE facing. Near the ends of the site, the Thanet Sands were encountered at depths near 1.0 m (3.3 ft.) within the stabilizing zone. Counterfort drains were installed in the slope along with other drainage measures at the crest of the slope to control drainage problems. All information presented in this section is based on the unpublished project report PR/CE/133/97 by Barker (1997), the primary project consultant.

To augment the drainage controls at the site, a total of 500 willow poles were installed in various areas along the slope during May 1996. As seen in the site layout illustrated in Figure 3.3, the site was split into 16 different panels, including three control panels that were not reinforced so a direct measure of the stabilizing effects could be observed. Seven installation techniques were employed to determine the effects, if any, of various installation techniques on the establishment of the vegetation, and also, in part, due to difficulties encountered during construction. These techniques are outlined below.

1. 90 mm diameter auger to lm depth then 75 mm diameter auger to 1.25 m depth and the pole driven to refusal;
2. 100 mm diameter auger to 1.25 m depth, the pole driven and extracted, then 75 mm diameter auger to 1.75 m depth and pole driven to refusal;
3. 90 mm diameter auger to lm depth, 75 mm diameter auger to 1.25 m depth, lubricated with water and pole driven to refusal;
4. 75 mm diameter auger to l m depth and pole driven to refusal;
5. 100 mm diameter auger to l m depth and pole driven to refusal;
6. 120 mm diameter auger to l m depth and pole driven to refusal;
7. 90 mm diameter auger to l m depth and pole driven to refusal.

Despite the large variation and labor intensive nature of the installation, an average of 50-70 poles were installed per day. Two species of willow were installed at the site. The first, and most abundant, was the *salix fragilis* harvested from various stream banks, and the second was the *salix viminalis* that had been farm raised and was generally smaller in diameter. Prior to installation, the poles were kept covered and moist. After pole installation, each hole was backfilled with topsoil and capped using cuttings from the augering process. To protect the poles from competing vegetation and animals, either solid or open-mesh tree guards were installed around each pole. Pole tops were wired to prevent splitting due to desiccation. Figure 3.4 shows a picture of live poles after they have established and grown.

Site monitoring was conducted during the fall of 1996 and during the spring of 1997. During site visits, survival rates were determined, soil samples were obtained and both root growth and stem growth were observed in detail on select specimens. Survival was determined for each willow pole and was based on whether it was living, had grown and experienced a subsequent die-back, or had never experienced any growth. Initial survival at the site during early summer, just after installation, indicated promising results with 95% of the vegetation showing signs of growth. However, the survival rate fell off dramatically to 17% by August of 1996 due to a large amount of die-back. The final recorded survival rate was at 15% in May 1997. In reviewing the results, it was noted that, while the final survival rate was extremely low, nearly 70% of the vegetation had experienced growth with subsequent die-back. Several site-specific factors were speculated to have influenced the poor survival and will be discussed later in this section.

As previously mentioned, several living poles were examined in detail during the spring of 1997. The soil around these poles was excavated to observe root growth. Extensive root growth was observed in this region (depth of approximately 0.5 m (1.6 ft.)), with all roots consisting of very fine rootlets. Window sampling was also conducted near each of these willows to determine moisture content of the soil over the depth of the reinforced zone and also to determine the extent of deep rooting of the vegetation. This

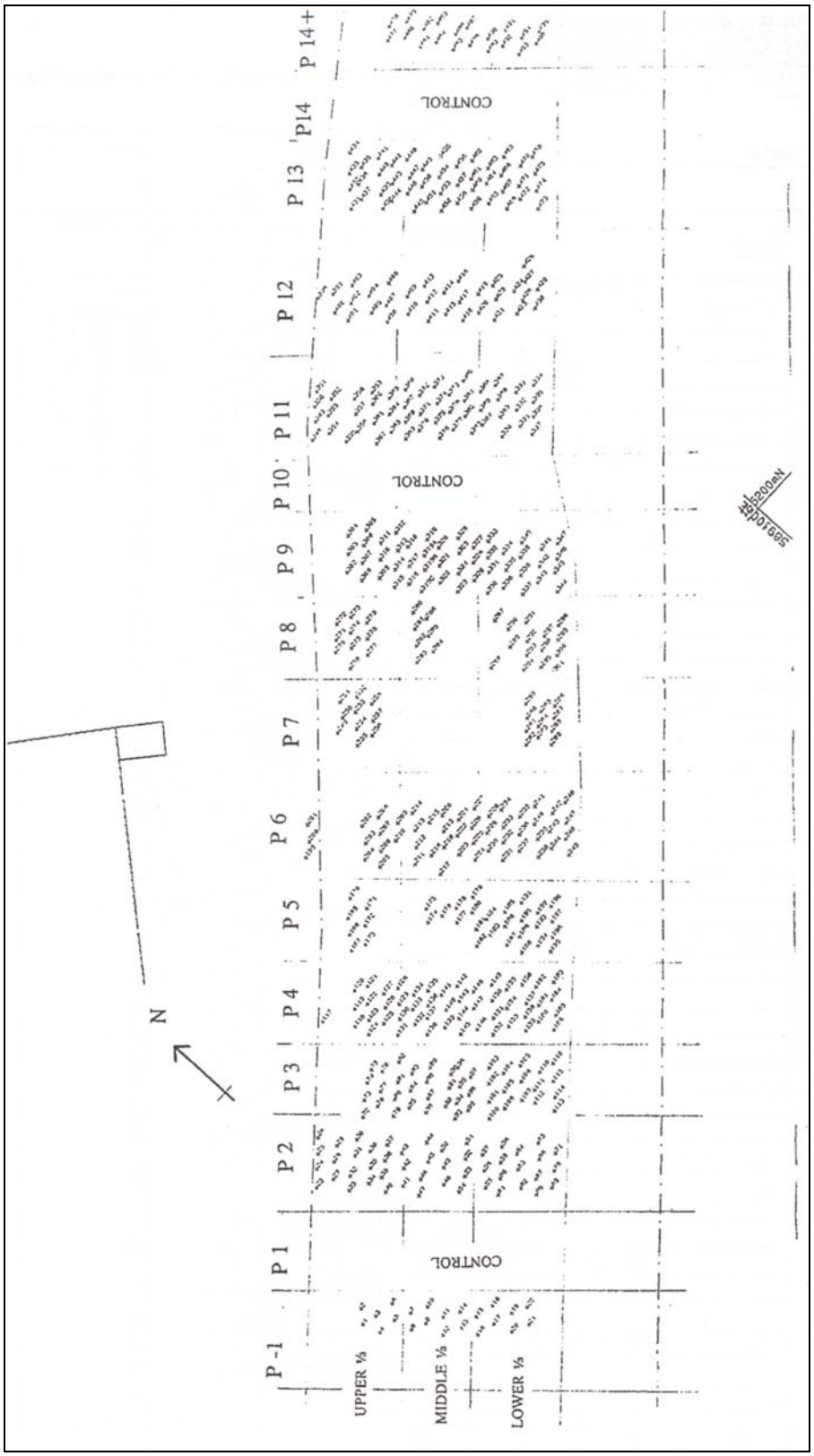


Figure 3.3: Site plan layout for the A294 demonstration site at Iwade, U.K. (Barker 1997).

Figure 3.4: Established vegetation for the A294 demonstration site at Iwade, UK (Barker 1997).

was achieved by analyzing samples at 250 mm (10 in.) intervals obtained from continuous undisturbed sampling to a depth of 1.5 m (5 ft.). Only one pole showed definitive signs of rooting to a depth of approximately 1.15 m (3.8 ft.). No clear correlation could be made as to the effect of the vegetation on soil moisture content. However, it was noted that lower moisture contents were measured near live poles at the near surface compared to measurements at dead poles and in the control sections. Due to the fact that these measurements were not all recorded on the same day, and also due to the presence of the counterfort drains, it was determined that these data were inconclusive.

Despite the fact that overall survival was exceptionally low, the Iwade trial was not considered a complete failure. Several site-specific factors may have heavily influenced the high mortality rate observed. Some of the primary factors that contributed to the high mortality rate were the time of the installation and deviation from proper installation procedure. The optimum period to install willow cuttings is during the dormant season, typically from the beginning of November to the end of March, before spring growth initiates. Installation at the Iwade site occurred during May, well after the optimum installation period. It was noted that some of the pole stock delivered to the site was not optimal for this type of installation, with some poles dried out upon arrival while others dried out on site prior to installation. This was partially due to difficulties with installation procedures. When a particular pole could not be installed to the desired

depth, it was left in the open hole exposed to the elements, occasionally for days at a time, which led to high desiccation rates during that period from strong breezes and hot weather until the installation was complete.

Local soil and climate conditions also played a large role in the high mortality rate observed at the site. Generally, willows thrive in areas where soil moisture is readily available. It was noted that small isolated areas of high survival occurred where the slope was wettest. Several factors were identified that may have led to unusually dry conditions within the slope after the installation was complete. Water supply that typically would be available to the slope may have been limited through the presence of the counterfort drains within the slope and a crest drain that intercepts surface runoff. This combined with the fact that there was a long dry spell prior to and subsequent to installation greatly reduced the amount of water available to the vegetation within the slope. It was noted in the report that the first several growing seasons were among the wettest during the winter and driest during the summer on record for the last 250 years. This may have affected survival statistics until the year-on-year effects became less influential. It was also noted during the spring 1997 site visits, that there was no precipitation from early March until April, and during April there were two hard, late frosts. While survival was already low at this time, this may have adversely affected the live vegetation.

While the Iwade demonstration site was considered a failure with respect to vegetation establishment and survival, it has helped engineers identify problems with installation technique and other site conditions that could be considered and resolved in future installations. The criteria for successful growth based on high observed survival percentages at this site indicated a minimum pole diameter of 30 mm (1.2 in.) and a minimum installation depth of 1.5 m (5 ft.) for engineering practicality. Installation method 2, listed previously, had the highest survival rate of all installation techniques employed. Small localized areas of growth were observed at the lower and middle thirds of the slope as the water levels within the slope tends to curve down behind the crest, and at location along the slope at panel 3 where it was wettest. A comprehensive outline for installing and maintaining similar installations was drafted by David Barker and is available in TRL Report TRL619 as an Appendix titled "Advice note: Installation of live willow poles for stabilising highway slopes".

3.4.1.2 United Kingdom Live Willow Pole Trials (2000-2002)

After the largely unsuccessful installation at the A294 Iwade site, engineers evaluated the issues that may have hindered the establishment of vegetation and came up with a new transportation and installation procedure that addressed the issues discussed in the previous section. Four new sites were selected throughout the UK in which new installations were performed in early 2000 and early 2001. Site selection criteria varied such that sites were representative of common types of embankment fill as well as geometry and slope face orientation. The following sections present an overview and evaluation of the demonstration sites, including the location and conditions of each embankment, along with design schemes and installation techniques employed for each installation. Survival statistics and in-situ soil-moisture conditions were closely monitored and recorded at each site. A comparison of these results with observations

from current installations in Ohio, presented in this report, will be included in Chapter 7. All information presented in this section is based on the TRL (Transport Research Laboratory) Report TRL619 by Steel et al. (2004).

Demonstration Site Descriptions

The first demonstration site was a cut slope close to the junction of the A10 and the A1170 link road at Hoddesdon. Consisting typically of Boulder Clay overlying a deposit of London Clay, the embankment has a slope inclination of approximately 3H:1V, a slope height of approximately 5 to 6 m (16 to 20 ft.), and is generally WNW facing. Preliminary surveys of the site and surrounding area indicated that several areas along the slopes had a number of significant shallow slips.

The second demonstration site was a fill embankment along the M1 motorway at Toddington. The embankment was constructed in 1959 of locally available Gault Clay, primarily comprised of firm brown and gray mottled silty clay, founded on cohesive glacial till overlying Gault Clay to a depth of about 20 m (65 ft.). The geometry of the slope was recorded to have an inclination of approximately 2H:1V, a slope height of approximately 6 to 7 m (20 to 24 ft.), and is generally SW facing. The initial site investigation reported that shallow slips had been observed in several areas in recent years.

The third demonstration site was a cut slope along the A5 at Milton Keynes near the junction with A422. Consisting typically of dark gray Oxford Clay, the embankment has a slope inclination of approximately 4H:1V, a slope height of approximately 10 m (33 ft.), and is generally SSW facing. Shallow translational slides were observed along the upper half of the slope length within and in close proximity of the trial site.

The fourth demonstration site was a fill embankment along the M23 at Gatwick near the Gatwick interchange. The embankment was constructed in 1972 of Weald Clay, and the geometry of the slope was recorded to have inclination of approximately 2H:1V, a slope height of approximately 3.5 m (11 ft.), and is generally W facing. A pond is present at the toe of the slope.

Installation Procedures

Installation of live poles at the Hoddesdon, Toddington, and Milton Keynes demonstration sites was carried out in the early months of 2000. Table 3.2 gives an overview of the general site conditions, as well as installation dates and the number of live poles planted at each site. As seen from the table, the first three sites had relatively small amounts of live poles installed. This section gives an overview of the harvesting and installation procedure used at each site.

All species of vegetation were of the willow family and consisted of *Salix alba* (white willow), *Salix dasyclados*, and *Salix spaethii*. All poles were to have diameters between 65 and 90 mm (2.5 to 3.5 in.) at the butt end and 40 to 60 mm (1.5 to 2.3 in.) at the tip end. It is believed that cuttings with smaller in diameters may adversely affect the growth and establishment of the vegetation due to a smaller biomass that sustains them until establishment. Harvesting and installation of live poles was to occur during the dormant period (between the beginning of November and the end of March) before

Table 3.2: Demonstration site descriptions and details.

Demonstration Site	Soil Type	Slope Type	Slope Inclination (H:V)	Slope Height (m)	Slope Face Orientation	Installation Date	Number of Poles Installed[1]
A10 Hoddesdon	Boulder Clay overlying London Clay	Cut	3:1	5 to 6	WNW	January, 2000	67
M1 Toddington	Gault Clay	Fill	2:1	6 to 7	SW	February, 2000	126
A5 Milton Keynes	Oxford Clay	Cut	4:1	10	SSW	March, 2000	72
M23 Gatwick	Weald Clay	Fill	2:1	3.5	W	February, 2001	635

[1] – Mycorrhizal treatment was applied to 211 poles at the M23 Gatwick demonstration site.

growth and establishment of the vegetation due to a smaller biomass that sustains them until establishment. Harvesting and installation of live poles was to occur during the dormant period (between the beginning of November and the end of March) before sprouting of buds started in early spring. Once harvested, the cuttings were then wrapped in Hessian cloth and stored in cold storage until required for installation.

Holes were formed at the first three sites using a two-man hydraulically powered auger. This was preferred over large-scale mechanically driven systems as the size of installations was sufficiently small enough that manual augers were more cost efficient. However, due to the large scale of the installation at the Gatwick site, a 13 ton excavator was utilized with a boom mounted auger attachment so that all holes could be drilled mechanically with minimal disturbance to the slope. All holes were advanced using a continuous flight auger to a depth of approximately 1.9 m (6.25 ft.) with a diameter of 85 mm (3.35 in.). Holes were formed nearly vertically at the first three demonstration sites as this was the easiest way to advance the manual two-man auger, and all holes were formed normal to the slope face at the Gatwick site. Each site had holes drilled on staggered grid using 0.75 m (2.5 ft.) on-center (OC) spacing across slope and 1 m (3.25 ft.) OC spacing down slope.

Poles were removed in small bundles from cold storage just prior to installation and were wrapped in wet Hessian cloth and covered with a tarp during transportation to the site. Once on site, the poles were stored underwater in tanks and covered with a tarp to protect them from UV and wind damage. After holes were formed, poles were removed from the storage tank and dimension measurements of each were recorded. The butt end of each pole was then sharpened to a point, and any nodules or protrusions along the pole length that could hinder the installation were removed or filed down. Two turns of galvanized fencing wire were placed around to top of the pole to prevent splitting caused by tamping during installation.

Once pole preparation was complete, the poles were inserted into the pre-augered holes butt end first and driven to refusal using a fencing hammer. Each hole was then backfilled using topsoil and tamping to ensure that all void space was filled. A clay cap

consisting of cuttings recovered from the augering process was compacted into place around the base of the exposed portion of the pole to seal the hole at the ground surface. The upper portion of the exposed pole was then cut to an angle of approximately 60° and two turns of galvanized fencing wire was placed below the angled cut to prevent splitting of the pole from desiccation. A 500 mm (1.65 ft.) square woven weed prevention mat was placed and secured around the base of each pole to minimize the competition with other vegetation (grass and weeds). Vented tree guards were also installed around each pole to prevent damage by pests such as rabbits and deer. Figure 3.5 shows a picture of live poles after they have established and grown.

Figure 3.5: Established vegetation at the Hoddesdon demonstration site (Steele et al. 2004).

The addition of mycorrhizal fungi, a technique for potentially increasing the survival rate if installed with live willow poles, was also applied to a select amount of poles at the M23 Gatwick site. Mycorrhizal fungi is described as a symbiont which occurs in most biomes on earth and is a fundamental reason for plant growth and development, and is primarily responsible for nutrient transfer from soil to plant. Nutrients are captured by the network of mycelium (branching filaments of fungi) present throughout the upper soil horizons, linking plants in natural ecosystems. The addition of mycorrhizal fungi during the installation process assists in the creation of this mutually beneficial network. The addition of mycorrhizal fungi was accomplished using two products: Terravital G, a gel-like slurry, and Terravital D, a dry formulation. The

Terravital G slurry was applied to the tapered end of the pole, completely covering the exposed cut. After the pole was driven into the hole, the dry Terravital D was poured into the open hole. As this mix was dry, it adhered to the length of the wetted pole rather fall to the bottom. The remaining installation procedure for these poles was completed as described above.

Post-Construction Monitoring

At the completion of construction, each site was instrumented to monitor soil-moisture content and rooting of the vegetation as an aid in assessing the effects of the vegetation in the reinforced areas of the slopes. A control section was identified at each demonstration site and was instrumented similarly to the remediated sections so that the effects of vegetation on soil-moisture interaction could be identified and quantified. Tensiometers were installed to monitor soil suctionss within the rooting zone, and standpipe piezometers were installed to monitor static groundwater levels. Root development of the vegetation was monitored in-situ through the use of mini-rhizotron access tubes.

There are several principal stabilizing effects that live vegetation provides when used as slope reinforcement. Hydrologically, stabilization is augmented by reductions in soil-moisture content through evapotranspiration after vegetation has been established. This results in an increase in matric suction (negative pore-water pressure) within the vadose zone from the rooting of the plants as water is drawn from the soil. Typically, there is also a decrease in the local static groundwater level. As such, tensiometers were installed to depths of 0.5, 0.75, 1.0, and 1.5 m (1.6, 2.5, 3.3, and 5 ft.) to assess soil suctions over the reinforced depth, and standpipe piezometers were installed to depths of approximately 2.0 to 2.5 m (6.5 to 8 ft.) to assess groundwater fluctuations within the reinforced zone.

The primary stabilizing mechanism of this bioengineering technique is provided through the establishment and interaction of the root systems of the vegetation with the soil and neighboring poles. Over time, after the vegetation has been established, the root systems of each individual pole will spread and intertwine with neighboring poles to create one large network of reinforcement that will last indefinitely. To this end, it was apparent that monitoring root growth and depth was a key factor in determining the effectiveness of this stabilization method. This was accomplished using a non-destructive method of observation. A clear access tube was augered approximately 1.5 m (5 ft.) into the soil within the reinforced zone, and a camera system, called a mini-rhizotron system, would be lowered into the access tube to observe any root growth that was occurring within the soil in close proximity to it. Figure 3.6 through Figure 3.9, presented in the following pages, show the layouts of the each site, including vegetation and instrumentation locations.

The final phase of site monitoring included recording survival rates of vegetation at each site for initial and long term time frames, and gathering local climate data for all four sites. Survival rates were based on a rating system that determined the health of each plant as to whether it was thriving or unlikely to survive. The climate data that was presented in the report included rainfall, sunshine and temperature normals and values that were recorded locally subsequent to installation.

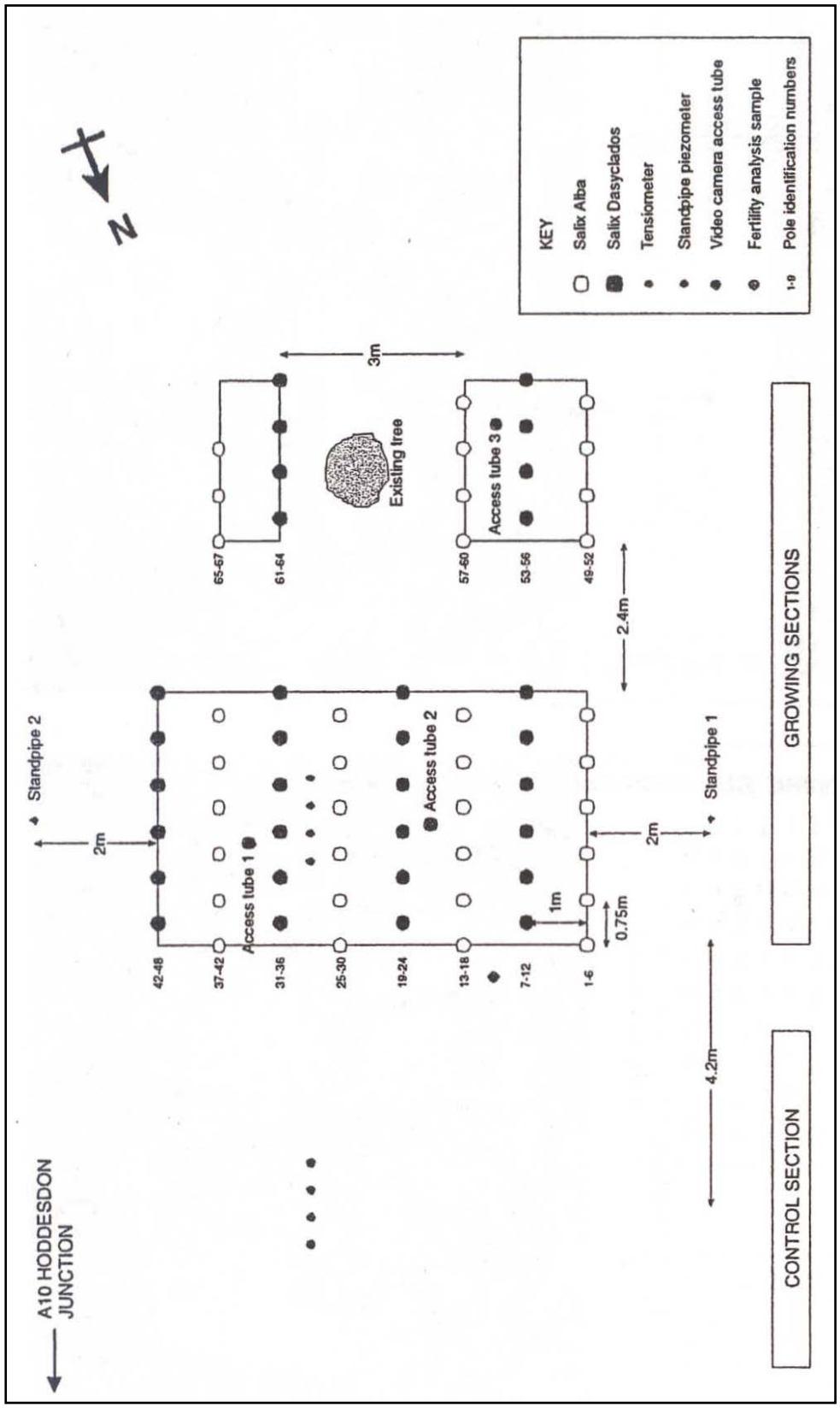


Figure 3.6: Site plan layout for the Hoddesdon demonstration site (Steele et al. 2004).

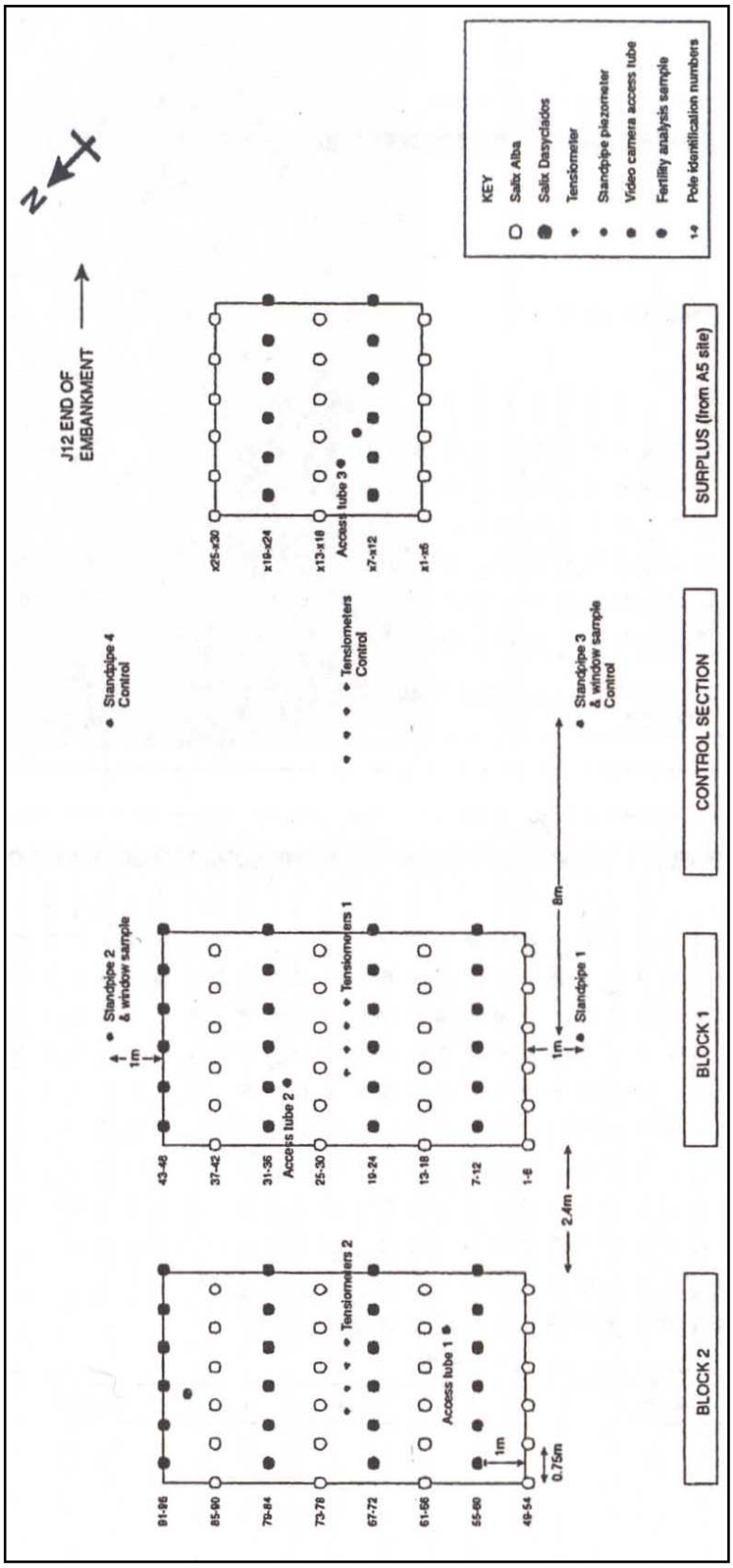


Figure 3.7: Site plan layout for the Toddington demonstration site (Steele et al. 2004).

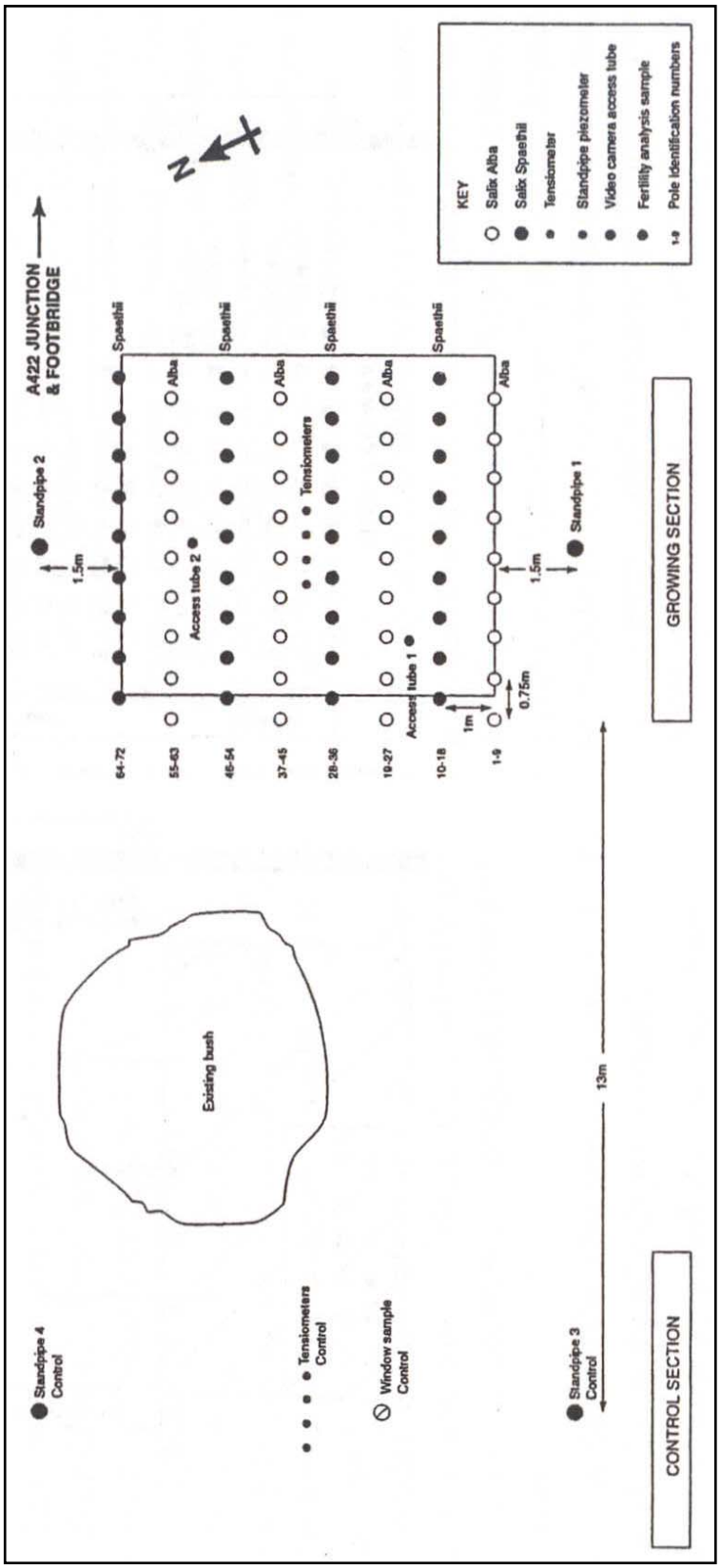


Figure 3.8: Site plan layout for the Milton Keynes demonstration site (Steele et al. 2004).

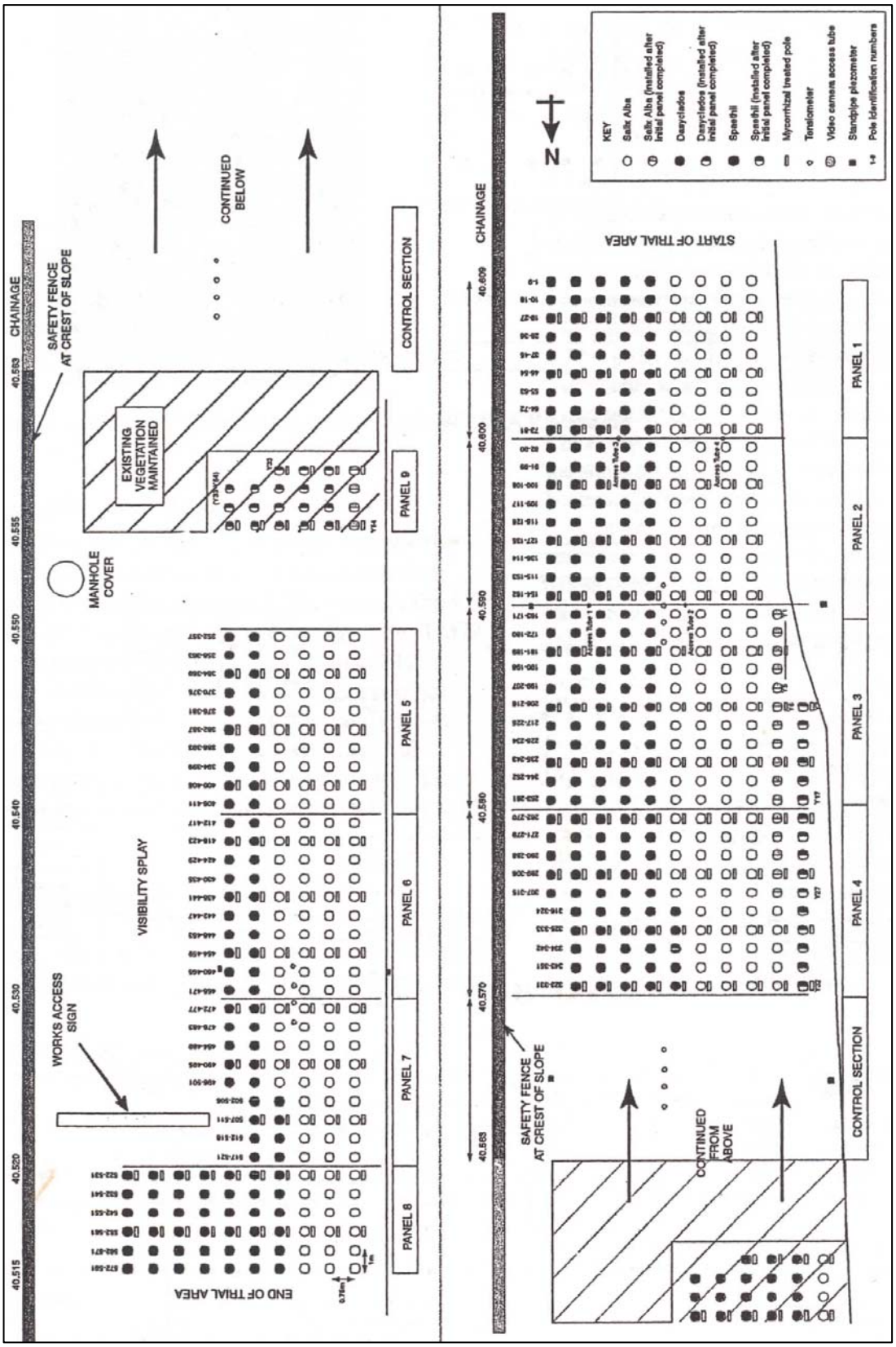


Figure 3.9: Site plan layout for the Gatwick demonstration site (Steele et al. 2004).

Results and Statistics

Extensive amounts of climate and vegetation data was presented in the TRL619 Report. These will be referenced in the concluding chapter of this report as a baseline for comparison with data from the current investigation. A brief overview of the results will be presented in this section, including ranges of climate and survival data, as well as the impact of the bioengineering reinforcement on stability of the slopes.

Rainfall at the initial three demonstration sites, Hoddesdon, Toddington, and Milton Keynes over the trial period was approximately 9% above the 30 year normal (established for 1971 – 2000) for the area. The first three years after installation saw rainfall from slightly above average in 2002 to about 30% above average during 2001. The final monitoring year, 2003, was considerably drier than previous years with rainfall approximately 20% lower than normal. Hours of sunlight, recorded monthly for these sites, were about average for the first three years and were slightly above average during 2003. Generally, the mean monthly maximum and minimal temperatures rarely fell below average and were slightly higher than normal for the bulk of the trial period.

Rainfall at the final demonstration site, Gatwick, was approximately 16% above the 30 year normal over the trial period. Rainfall was about 20 to 45% above average for the first two years after installation. Rainfall for the final monitoring year, 2003, was well above average during the beginning months of the year and became considerably less during the spring and summer growing seasons, falling to approximately 20 to 25% lower than normal. Hours of sunlight, recorded monthly for this site, were about average for the first three years and were slightly above average during 2003. Generally, the mean monthly minimal temperatures rarely fell below average and the mean maximum temperatures were slightly lower than normal during the spring and summer seasons and slightly higher than normal during the fall and winter seasons.

Survival statistics presented in the report were based on a ranking system that determined the vitality of the vegetation based solely on visual inspection. The ranking system used five ratings, one being a healthy vibrant specimen and five being a failed (dead) specimen. Vegetation was considered to have survived if it achieved a ranking of one, two or three. Initial vegetation survival rates at all three of the initial demonstration sites were 100% for all species planted. Overall survival of vegetation remained high at the Hoddesdon and Milton Keynes sites with final survival rates of 91 and 90%, respectively, being recorded in 2003. Survival at the Toddington site fell considerably by the end of the trial period to 65%. Initial survival at the Gatwick site was observed to be about 96% and fell slightly to 94% by 2003. The mycorrhizal treatment seemed to have negligible effect on the establishment of vegetation. It should also be noted that, while all species of vegetation installed were from the willow family, there were three different species of willow used at the trial sites. Two of the species, *Salix alba* and *Salix spaethii*, had nearly full survival, while most of the mortalities were from the *Salix dasyclados* specie. This indicates that the type of vegetation used may have a large impact on project success.

Moisture conditions at the Hoddesdon, Milton Keynes and Gatwick demonstration sites showed greater suction recorded from tensiometers at depths of approximately 1.0 to 1.5 m (3.3 to 5 ft.) in reinforced areas when compared with data obtained from the control sections. The significant increase in soil suction in the

reinforced zones occurred earlier in the year (about May) and decreased later in the year, thus suggesting that more moisture is being removed from the soil by the root system of the vegetation. This increase in moisture depletion from the soil during the warm seasons also suggests that more water would need to be introduced during the wet seasons to soften the soil to the point where an unstable condition is produced. Static water levels fluctuated seasonally, with higher groundwater levels recorded within the slope during the winter months and lower levels during the late summer months. No clear differentiation was established between levels observed in the reinforced areas and control areas.

Roots were observed growing immediately adjacent to access tubes using the mini-rhizotron camera system at depths up to 1.5 m (5 ft.). However, more extensive observations were made by exhuming select poles from each site and carefully exposing the root structures. Exhumation of poles from the Hoddesdon, Milton Keynes and Gatwick demonstration sites showed significant rooting of all specimens removed. Roots were exposed to depths ranging from 1.0 to 1.5 m (3.3 to 5 ft.) along the length of the poles. Radial rooting of the plants into the stiff surrounding clays was extensive with root lengths measuring in excess of 600 mm (2 ft.).

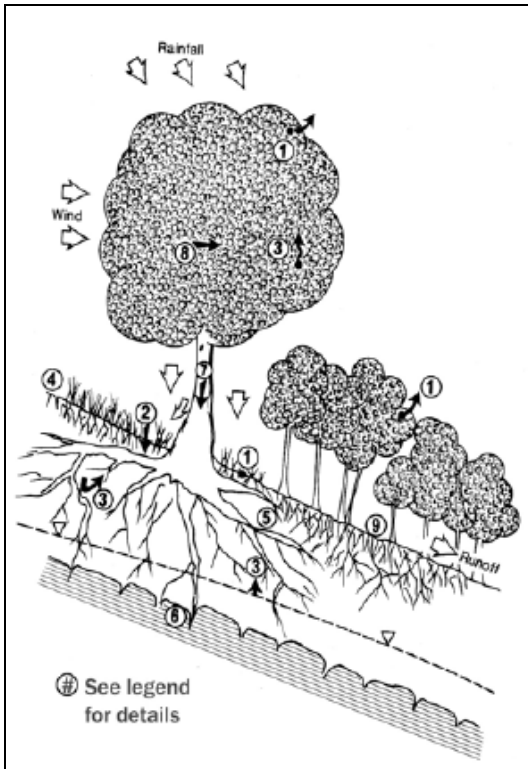
Back-analysis of stabilization after the establishment of vegetation indicated that the factor-of-safety against sliding increased due to two effects. The factor-of-safety increased due to the doweling effects of the cuttings immediately after installation. Subsequent increases in the factor-of- safety resulted from root reinforcement and were due to an increase in root area ratio as the plants become established and grow. It was also determined that the factor-of-safety would increase due to an increase in soil suction as water is absorbed through the roots. However, as this is a seasonal effect, the increase in soil suction would not necessarily be a conservative application for slope stabilization.

An overview of the output productivity and cost of the installations was provided in the report. Using the manual installation methods described for the initial three sites, a production level of about 80 to 100 fully installed poles per week was possible. The cost per pole installed ranged from £69 to £87 ($110 to $140) depending on the soil conditions encountered. Using the mechanical installation method described for the Gatwick site, a production level of about 300 fully installed poles per week was possible. The cost per pole installed was approximately £50 ($80). The cost of construction was approximately 35% less, per pole installed, using mechanical installation techniques compared to manual techniques.

3.5 GENERAL STABILIZING EFFECTS OF BIOENGINEERING TECHNIQUES

As research in the field of bioengineering has become quite extensive, many sources cite beneficial and adverse influences that live vegetation contributes to overall slope stability. The primary factors that appear to beneficially influence stabilization are presented and summarized by Greenway (1987) and Gray and Sotir (1996) as: 1) root reinforcement, 2) anchoring, buttressing and arching, 3) soil-moisture depletion, and 4) surcharge loading effects. The primary factors that appear to adversely influence stabilization are also presented and summarized by Greenway (1987) and Gray and Sotir (1996) as: 1) increased infiltration capacity through rooting of vegetation and depletion of soil-moisture, 2) surcharge loading, and 3) wind loading effects.

This section provides a summary of the beneficial and possible adverse effects that vegetation can have on slope stability. A schematic diagram of these effects is presented by Greenway (1987) and is illustrated in Figure 3.10. Quantitative assessment of these effects within slope stability analyses for the current investigation will be covered in subsequent chapters.



Hydrological Mechanisms	*Influence*
1. Foliage intercepts rainfall, causing absorptive and evaporative losses that reduce rainfall available for infiltration.	Beneficial
2. Roots and stems increase the roughness of ground surface and permeability of the soil, leading to increased infiltration capacity.	Adverse
3. Roots extract moisture from the soil which is lost to the atmosphere via transpiration, leading to lower pore-water pressures.	Beneficial
4. Depletion of soil moisture may accentuate desiccation cracking in the soil, resulting in higher infiltration capacity.	Adverse
Mechanical Mechanisms	
5. Roots reinforce the soil, increasing shear strength.	Beneficial
6. Tree roots may anchor into firm strata, providing support to the upslope soil mantle through buttressing and arching.	Beneficial
7. Weight of trees surcharges the slope, increasing normal and downhill force components.	Adverse/ beneficial
8. Vegetation exposed to wind transmits dynamic forces into slope.	Adverse
9. Roots bind soil particles at the ground surface, reducing susceptibility to erosion.	Beneficial

Figure 3.10: Slope-vegetation interactions influencing stability (Greenway 1987).

Roots mechanically reinforce a soil by transfer of shear stress in the soil to tensile resistance in the roots (Gray and Sotir 1996). As vegetation establishes and grows, the root system spreads out radially and tends to grow downward where, typically, higher soil-moisture and vital nutrients are present. In the case of live staking, as employed in the current investigation, the root systems of adjacent cuttings intertwine as each plant grows, creating a large interconnected network of roots. To be effective, the root system of the vegetation (live poles in this case) must extend to depths that penetrate into stable soil below the shear surface. As the shear stress along the assumed failure surface approaches the shear strength of the soil mass, sliding begins to occur. Once vegetation has been established with an extensive root system, a percentage the shear stress imparted in the soil is transferred to the roots crossing the shear plane through the tensile resistance of the individual root fibers. This effect is included in traditional slope stability analyses through an additional equivalent soil shear strength, Δs , which is calculated using the perpendicular root reinforcement model as,

$$\Delta s = T_R \left(\frac{A_R}{A} \right) (\sin\theta + \cos\theta \tan\phi) \tag{3.1}$$

where: Δs = shear strength increase
T_R = mean tensile strength of roots
A_R = total cross-sectional area of roots crossing shear plane
A = total cross-sectional area of shear plane
θ = angle of shear distortion in the shear zone
ϕ = angle of internal friction of the soil

Figure 3.11 is a schematic representation of the perpendicular root reinforcement model. An average value of 1.15 – 1.20 is suggested for the term $(\sin\theta + \cos\theta \tan\phi)$ in Eq. 2.1 based on typical values of θ and ϕ encountered in field conditions (Barker 1986; Wu et al. 1979). The term $\left(\frac{A_R}{A} \right)$ is the root area ratio, which is the fraction of soil cross-section occupied by roots. Figure 3.12 provides an illustration. Wu (2007) suggests that values of $\left(\frac{A_R}{A} \right)$ range from 0.002 to 0.3% for various types of vegetation based on data provided in case studies. Steele et al. (2004) suggests a maximum value of 2% for root area ratio.

Anchored and embedded stems can act as buttress piles or arch abutments to counteract downslope shear forces (Gray and Sotir 1996). A schematic representation of this mode, illustrated below as Figure 3.13, is presented by Greenway (1987). In this case, additional shear strength is gained when taproots or sinker roots anchor themselves in stable soil below the sliding mass. As the vegetation establishes further, a root cylinder, comprising of the taproot and other radial root offshoots, is defined based on the mean radial root length from the center of the tree. When vegetation is placed at adequate spacing throughout the slope face, these root cylinders can provide buttressing and arching support as demonstrated in Figure 3.14.

For the case of live staking, poles are embedded in the slope to depths that anchor the poles into stable soil below the sliding mass. Immediate stabilization is provided by the shear resistance of the poles. This effect is included in traditional slope stability analyses through an additional equivalent increase in soil shear strength as determined by the limiting soil resistance calculated for three common types of failure modes (Wu 2009). In the first failure mode, called the "flow mode", the limiting soil resistance is developed in the zone above the slip surface and the soil flows around the pole. In the second failure mode, the cutting is analyzed as a laterally loaded pile. Broms (1964) presents a simple analysis method for this case. In this case, the pole is either analyzed as a "short pile", where failure occurs in the soil below the slip surface and the pole is pushed through the stable soil; or it is analyzed as a "long pile", where failure occurs in the cutting by bending. The third failure mode is shear failure of the cutting at the slip

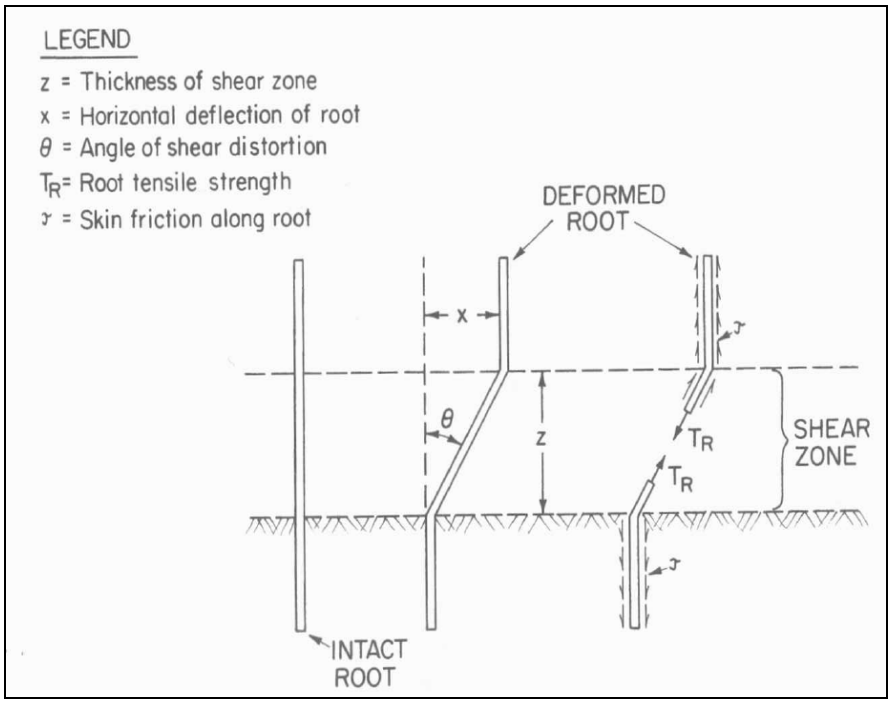


Figure 3.11: Schematic representation of perpendicular root reinforcement model (Gray and Sotir, 1996).

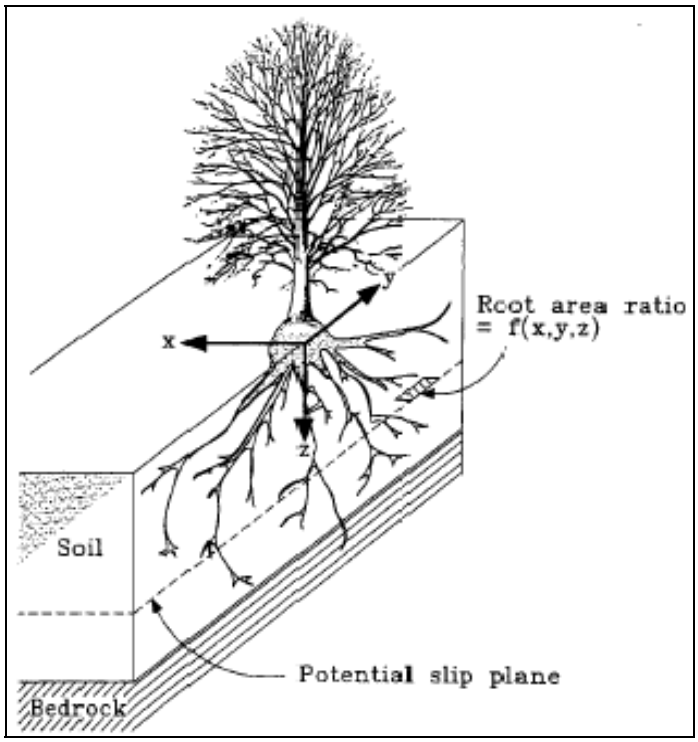


Figure 3.12: Schematic representation of root area ratio (Gray and Sotir, 1996).

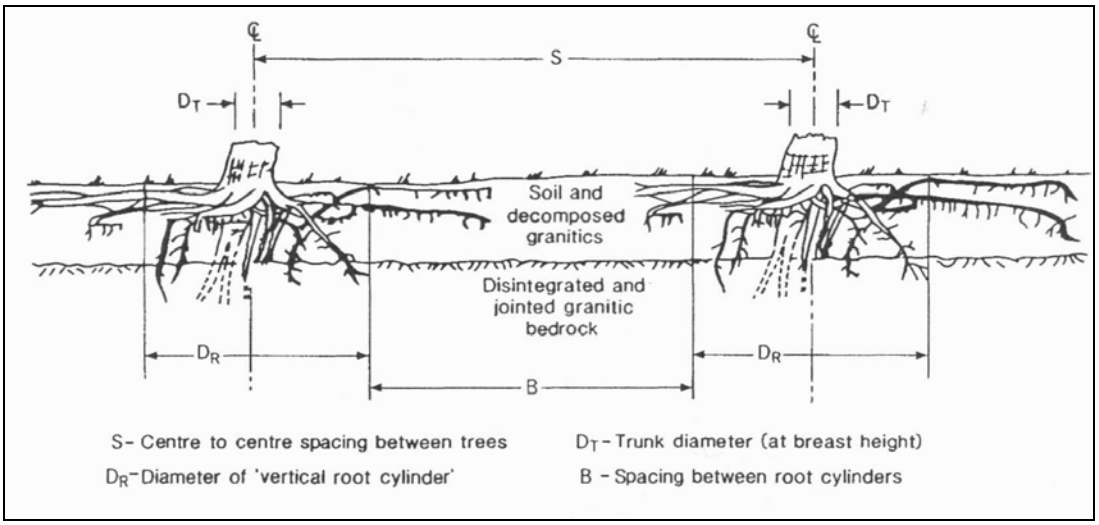


Figure 3.13: Schematic representation of cuttings acting as buttress piles (Greenway 1987).

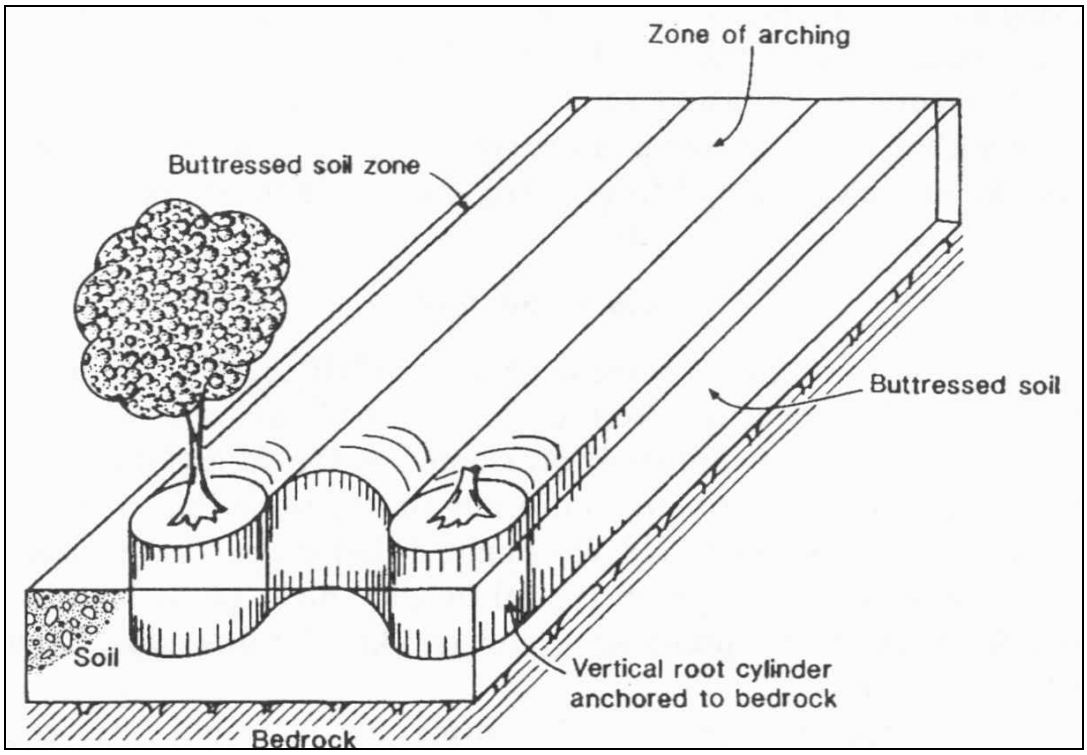


Figure 3.14: Schematic representation of cuttings providing buttressing and arching effects (Greenway 1987).

surface such as presented by Steele et al. (2004). Detailed analyses for these failure modes are presented in Chapter 3.

Evapotranspiration and interception in the foliage can limit buildup of positive pore waster pressure (Gray and Sotir 1996). On slopes, vegetation requirements for water are met by the extraction of soil-moisture through the roots. This lowers the moisture content within the root zone, and may generally alter the distribution of soil-moisture (and pore-water pressures) beyond the root zone (Greenway 1987). Figure 3.15 shows the distribution of observed reductions in soil-moisture near a poplar tree in a study conducted by Biddle (1983) (Greenway 1987). These reductions in soil-moisture content impact the pore pressure within the slope in two ways. First, static groundwater levels tend to lower as the vegetation establishes itself and grows. Second, matrix suctions in unsaturated soils tend to increase as the root structure develops and expands. Additionally, Greenway (1987) notes that there can be beneficial effects from increased interception from vegetation leading to lower quantities of precipitation available for infiltration. On the other hand, there can be adverse effects through an increase in infiltration capacity due to higher permeability of the soil from rooting and possible increased desiccation cracking from depletion of soil-moisture.

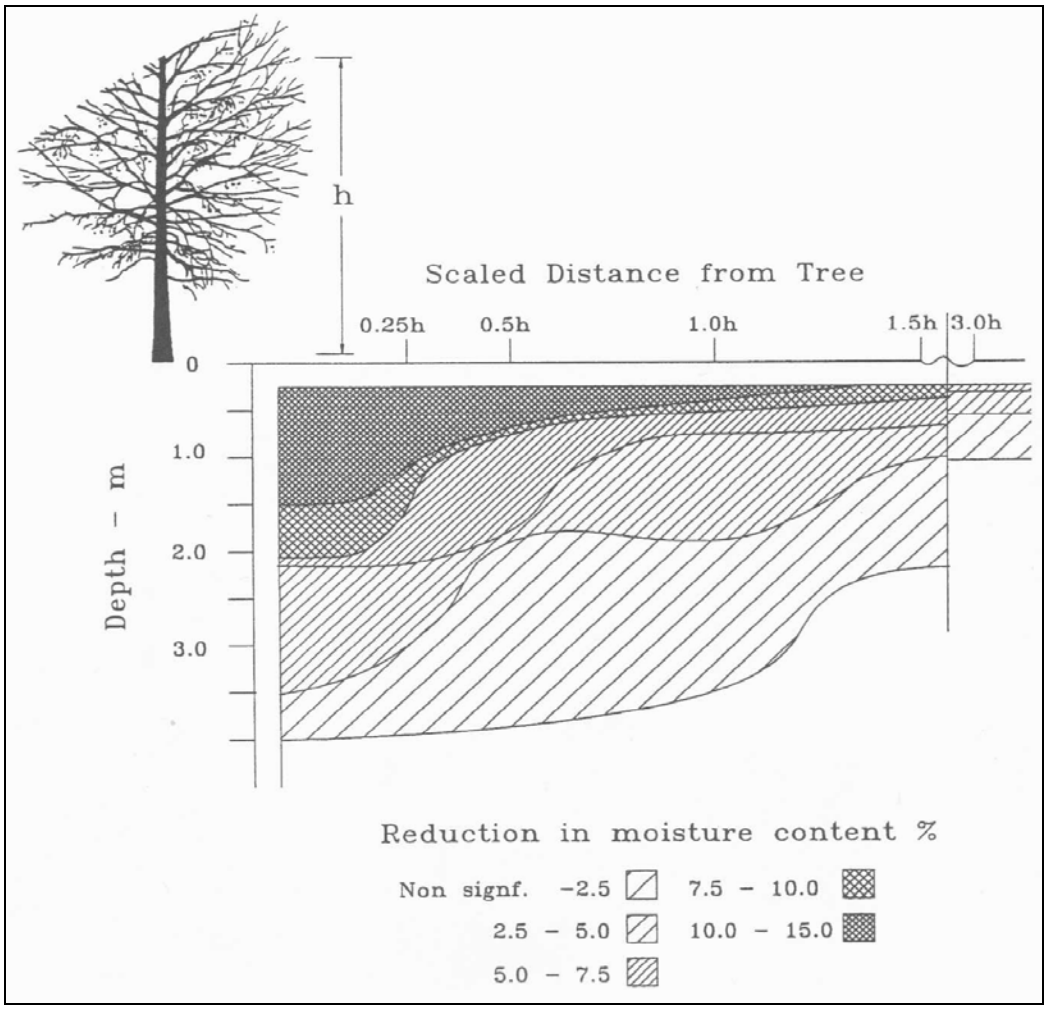


Figure 3.15: Distribution of observed reductions in soil-moisture near a poplar tree in a study conducted by Biddle (1983) (Gray and Sotir, 1996).

While these effects can greatly influence the increase in shear strength available by lowering overall pore pressures within the slope, these effects are difficult to predict with accuracy. Factors such as the plant species, soil composition, soil-moisture characteristics, local climate, and stabilization technique are just a few of the factors that need to be evaluated in order to evaluate these effects. Furthermore, seasonal fluctuations in groundwater levels, and consequently in soil-moisture of the entire soil mass, are severe in areas such as Ohio. Observations of static groundwater levels in near-surface soils (upper 5 ft. of the slope) can show fluctuations from nearly saturated conditions during the winter months to dry conditions during the late summer months.

Weight of vegetation can, in certain instances, increase stability through increased normal stress on the failure surface (Gray and Sotir 1996). A surcharge on a slope increases both the normal and shear force components acting on a potential shear surface (Greenway 1987). When applied to a basic infinite slope solution, as shown in Eq. 3.2 (Steele et al. 2004), a surcharge has a net stabilizing influence when the slope inclination angle, β, is less than the angle of internal friction, ϕ'.

$$FS = \frac{\left(c' + c_R^{'}\right)L + \left[\left(W + S_W\right)\cos\beta - uL\right]\tan\phi'}{\left(W + S_W\right)\sin\beta + D} \tag{3.2}$$

where: c' = effective cohesion of the soil
ϕ' = effective angle of internal friction of the soil
W = weight of sliding soil mass
u = pore water pressure at failure surface
L = length of failure surface
β = slope inclination angle
$c_R^{'}$ = increase in cohesion due to root reinforcement
S_W = weight of surcharge from vegetation
D = downslope wind force on trees

Greenway (1987) presented an evaluation of the shear stress generated by wind on vegetation from tests conducted in wind tunnels on a simulated forest canopy. Eq. 2.2 accounts for wind effects by resolving the load into a single force acting in the direction of the sliding mass.

3.6 EFFECTS OF SOIL-MOISTURE ON WILLOW SURVIVAL

Several studies have been conducted on the effects of soil-moisture regimes on the establishment and survival of willow species, particularly, black willow (*Salix nigra*). Some of these studies included installation and monitoring full scale demonstration sites along stream embankments (Pezeshki et al. 1998b; Schaff et al. 2003), while others took a more controlled approach by conducting greenhouse studies under varying, controlled

growing conditions (Pezeshki et al. 1998a). The primary focus of this section will be on the controlled greenhouse investigation presented by Pezeshki et al. (1998a).

Data from investigations conducted on willow propagation suggest that site-specific characteristics, such as soil texture, hydrology, and oxidation-reduction potential are critical factors effecting the establishment and survival of the vegetation (Schaff et al. 2003). In this study, soil texture was held constant by providing a thoroughly blended, controlled soil mixture consisting of two parts washed sand and one part Sharkey Clay Series from the floodplain of the Mississippi River in Dyer County, Tennessee. Five scenarios of varying soil-moisture conditions were investigated to observe the effects of hydrology on the establishment and survival of the vegetation. These scenarios included: 1) a control (C), 2) an intermittently flooded (IF), 3) a partially flooded (PF), 4) a continuously flooded (CF), and 5) a drought (D) soil-moisture condition. A total of eight (8) poles for each scenario were monitored over 92 days for oxidation-reduction potential (Eh), pH, physical health, root porosity, gas exchange, water relations, leaf area, chlorophyll concentration, and biomass.

Black willow poles were harvested and trimmed such that each pole was approximately 3.8 cm (1.5 in.) in diameter at the base and 1.83 m (6 ft.) in length. Prior to planting the poles were kept in cold storage for four days. PVC pots, 1.2 m (3.94 ft.) long and 10.2 cm (4 in.) in diameter, were filled with mixed field soil. Holes were drilled along the side and bottom of the pots to allow control of water within the soil. Plants were installed to a depth of 1.17 m (3.8 ft.), leaving 0.66 m (2.15 ft.) exposed above the soil surface. The soil moisture in the control treatment was maintained close to field capacity so that the vegetation was subjected to well-watered and well-drained conditions. The intermittently flooded treatment represented a fluctuating groundwater level (GWL) that was subject to a fully flooded condition (GWL 5 cm (2 in.) above soil surface) for two weeks, and then drained to a partially flooded condition (GWL 60 cm (24 in.) below soil surface) for two weeks. The partially flooded treatment maintained a GWL at 45 cm (18 in.) below the soil surface, and the continuously flooded treatment maintained a GWL at 5 cm (2 in.) above the soil surface. The drought treatment represented field drought conditions imposed by periodically withholding water. To allow establishment of the vegetation, this treatment was not initiated until day 20 of the study. It should be noted that the drought treatment simulates a mild to moderate drought condition, and that actual field drought conditions could be more severe than what is investigated in this study.

Soil measurements indicated that the pH of the soil throughout the test ranged from 7.16 to 7.22. The oxidation-reduction potential (Eh) was observed to be high (aerated) for the control. It was also observed in treatments experiencing flooding conditions that the Eh remained low (reduced) in sections that were submerged below the groundwater level. This adversely effects the root production at the depths where low Eh was recorded.

Physical health observations showed that halfway through the investigation, approximately 63% of the poles in the drought treatment were stressed. Stress was indicated by the presence of yellowish or brownish leaves, death of branch tips, or leaf senescence (i.e., the process in which the leaves change color). At the end of the study, all (100%) of the posts in the drought, and half (50%) of the posts in the continuously

flooded treatments were stressed. There was a 25% mortality rate in the drought treatment. Stress was not observed for any of the posts in the remaining treatments.

Stomatal conductance (gas exchange) and net photosynthesis was highest in the control and lowest in the drought treatment. Intermittently and partially flooded treatments exhibited levels slightly lower than those observed in the control, while the continuously flooded treatment fell somewhere between those and the drought treatment measurements. Predawn water potentials, which provide an estimate of plant-water status and soil moisture availability, were more negative in the drought and continuously flooded treatments than those measured in the control and partially flooded treatments. This indicates that the posts under drought and continuously flooded treatments experienced greater internal water deficits that, in turn, induced water stress in the poles. There was no clear pattern observed for root porosity or chlorophyll concentration for the treatments.

Overall biomass was significantly lower in the drought and continuously flooded treatments in comparison to observed biomass in the remaining treatments. Biomass was significantly lower in the drought treatment compared to the continuously flooded treatment. Roots were observed over the entire length of the control and drought treatment specimens. There was a large concentration of roots within the upper 15 cm (6 in) for the intermittently and continuously flooded treatments. A large spike in root development that corresponded to the elevation of the GWL was observed in the partially flooded treatment. Low root biomass was observed in treatments subject to flooding at depths where constant standing water and low Eh conditions were present. Overall root biomass was low for the drought and continuously flooded treatments. It was determined that continuously flooded and drought conditions imparted adverse effects on both root initiation and elongation.

In conclusion, areas subject to continuously flooded and drought conditions should be avoided when considering a bioengineering mitigation solution. Low leaf water potentials in the drought treatment compared to control observations imparted water stress on the specimens that disrupted many of the metabolic activities, such as photosynthesis, and thus interfered with normal plant growth and development. It is clear from this investigation that the soil-moisture regime plays a large and crucial role in the successful propagation of willow species, and should be one of the primary considerations during preliminary assessments of candidate sites for bioengineering stabilization.

3.7 NEED FOR CURRENT RESEARCH

Currently, there is an insufficient amount of research into bioengineering slope stabilization methods within Ohio to support its use as a reliable method of remediation. Successful slope remediation in the UK trial, using live willow staking to arrest shallow landslides, has shown that bioengineering methods can be an attractive alternative to conventional methods. As such, three demonstration sites, briefly overviewed in Chapter 1 and presented in detail in the following chapters, were selected near central Ohio for research in the implementation of bioengineering remediation, specifically live staking. Each site was thoroughly instrumented and monitored for climate conditions, soil-moisture conditions, and slope displacements both prior and subsequent to construction.

Detailed calculations specific to each site will be presented to evaluate the effectiveness of the remediation. Post-construction data including survival rates and slope displacements will be evaluated to determine the feasibility of vegetation establishment and growth in Ohio climates, and to assess the potential to arrest of shallow failures. The following chapters will address these issues for each demonstration site, and conclusions regarding the current investigation will be presented in the concluding chapter.

Chapter 4 GENERAL PROJECT INFORMATION

4.1 INTRODUCTION

This chapter presents general information and procedures typical to research activities for this project. Included are site exploration methods, laboratory testing techniques, site instrumentation and monitoring, slope stability analysis and design, vegetation sources, climate data collection and events, and pile verification methods.

4.2 SITE EXPLORATION METHODS

Field exploration was conducted at each demonstration site to determine subsurface conditions. Methods included drilling and sampling and excavation of temporary (shallow) test pits using hand tools. Drilling logs were obtained from the Ohio Department of Transportation (ODOT) central office for each boring conducted at all three demonstration sites. Subsurface profiles (location and extents of geologic units) were determined from notes on these logs and from soil classifications.

4.2.1 Drilling and Sampling

Drilling and sampling was conducted at both the Logan County (US-33/SR-347) and Muskingum County (I-70/SR-83) demonstration sites under the supervision of OSU and ODOT personnel during 2005, prior to construction. Additional borings were conducted during January and February of 2009 at both demonstration sites. The additional borings conducted in Muskingum County were in support of a proposed Phase II biotechnical stabilization installation at a newly developed slide approximately ¼-mile west of the current installation. Due to the close proximity, it was determined that samples collected and tested from this location would provide reasonable soil parameters for use in analysis for the original Muskingum County demonstration site.

All borings conducted at the Muskingum County site, and half the borings at the Logan County site, were advanced using a truck mounted drill rig owned and operated by ODOT. Due to rough terrain, the remaining borings conducted at Logan County were advanced using a track mounted drill rig owned and operated by FMSM Engineers and Ohio Testbor, Inc. Two borings conducted during 2009 at the Muskingum County site were advanced using a new track-mounted rig owned and operated by ODOT.

The soil borings were advanced using 3.75 in. hollow stem augers (HSA). Standard penetration tests (SPT) were conducted using a 140 lb. hammer falling 30 in. to drive a 2 in. O.D. split barrel sampler for 18 inches. Soil samples obtained from the SPT sampling were visually identified in the field, preserved in plastic jars, and classified at the ODOT laboratory. Relatively undisturbed soil samples were obtained using Shelby tubes and preserved with paraffin/petroleum jelly seals. Boring logs from this subsurface investigation program were prepared by ODOT.

4.2.2 Temporary (Shallow) Test Pits

Temporary test pits were excavated at all three demonstration sites using hand tools (shovels and pick-axes) to depths of approximately 1.5 to 3 ft. Shallow samples, both disturbed and relatively undisturbed, were recovered from these locations and tested for various properties at OSU laboratories. Disturbed samples were recovered using shovels and pick-axes, and material was stored in buckets and kept sealed until tested. Relatively undisturbed samples were obtained by pressing thin-walled samplers (typically soup cans) into the soil at the bottom of the test pits. The tubes were preserved with paraffin/petroleum jelly seals.

4.3 LABORATORY TESTING TECHNIQUES

Laboratory testing was conducted at the OSU Soil Mechanics Laboratory and the ODOT Geotechnical Laboratory on soil samples recovered from subsurface investigations. Laboratory tests consisting of moisture content determinations, Atterberg limits, consolidation, triaxial (CD and CU) shear, unconfined compression, direct shear, Torvane in-situ vane shear, and soil-moisture characteristic relationship (variance of moisture content over a range of matric suction [negative pore pressure] conditions) were conducted on undisturbed samples obtained from site investigation activities. The tests were performed in general accordance with standard test methods of the American Society for Testing and Materials (ASTM) or other applicable procedures. Soil nutrient testing was conducted by Calmar laboratories of Westerville, Ohio. Flexure testing on willow poles extracted from the Muskingum County and Logan County demonstration sites was also conducted to verify engineering properties of representative vegetation installed at the site.

4.3.1 Flexure Testing

Mechanical properties of the vegetation, such as tensile strength, σ_t, and Young's Modulus, E, were evaluated in the lab by conducting flexure tests on green (live pole that has not dried out prior to test) and dry (dead pole that has been dried out prior to test) poles recovered from vertical pullout tests (see Section 4.8.1 for information about vertical pullout test). Results from testing were compared with data obtained from the USDA Wood Handbook (1987) for the black willow species. Mechanical properties determined from laboratory testing were in general agreement with published values. As such, laboratory determined mechanical properties were used in all stability analyses. Results from these tests are provided in their respective chapters.

4.4 INSTRUMENTATION AND MONITORING

Instrumentation and site monitoring is a key issue on this project as it is the only basis for determining the feasibility and success of bioengineering stabilization in central Ohio. Field monitoring programs focused on groundwater conditions, displacement

conditions, and survival rate of vegetation. Groundwater data was collected using tensiometers, piezometers, monitoring wells, and gypsum blocks. Slope movement data was obtained using shallow and deep inclinometers. This data is used to define the baseline site conditions for use in design and also provide data and information for documenting the performance of the various stabilization methods.

4.4.1 Tensiometers

Soil suction measurements at each demonstration site were obtained through the use of Jet Fill Tensiometers manufactured by the Soilmoisture Equipment Corp. of Santa Barbara, California. Each tensiometer consists of a plastic tube (body) with a high air entry ceramic porous tip at the base, a pressure gauge near the top that remains above the ground surface, and a cup that injects water and removes air that accumulates at the top of the body that caps off the unit. The installation, operating procedures, and schematics are outlined by the manufacturer (Soilmoisture Equip. Corp. 2725 operating instructions, Aug 1997).

It should be noted that the ability of tensiometers to function correctly are limited to the mechanical properties of water. Soil suction measurements are limited to pore-water pressures of 13 psi (90 kPa) due to the possibility of cavitation. Also, temperatures at or below freezing may damage the instrument as water in the tube or gauge expands during the freezing process. Due to this temperature sensitivity, tensiometers were typically installed in late-April/early-May and monitored regularly until late-October/early-November. Additionally, the suction measured was corrected for the elevation head from the standing column of water between the porous tip and the gauge. This correction results in a more negative water pressure being measured than that recorded by the measuring device (Fredlund and Rahardjo 1993). Figure 4.1 and Equations 4.1 through 4.4 demonstrate that the correction is computed by setting the total head at the gauge elevation equal to the total head at the elevation of the porous tip of the tensiometer and solving for the soil suction at the tip of the instrument.

$$H_1 = z_1 + \frac{u_1}{\gamma_w} \tag{4.1}$$

$$H_2 = z_2 + \frac{u_2}{\gamma_w} \tag{4.2}$$

$$z_1 + \frac{u_1}{\gamma_w} = z_2 + \frac{u_2}{\gamma_w} \tag{4.3}$$

$$u_2 = u_1 + (z_1 - z_2)\gamma_w \tag{4.4}$$

where: H = total head at respective point
z = elevation head at respective point
u = soil suction at respective point
γ_w = unit weight of water

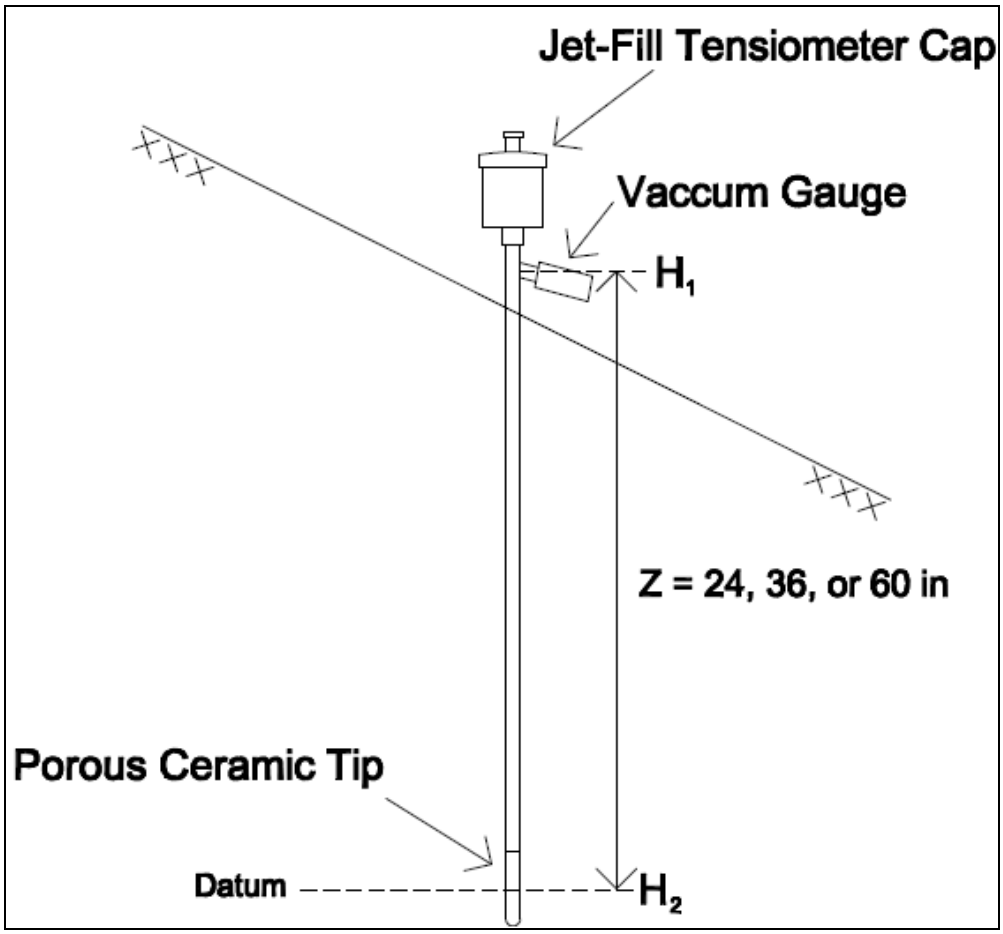


Figure 4.1: Schematic setup of an installed tensiometer.

4.4.2 Gypsum Moisture Blocks (G-Blocks)

In addition to tensiometers, gypsum moisture blocks (G-Blocks) manufactured by the Soilmoisture Equipment Corp. of Santa Barbara, California, were also used to monitor soil suction and in-situ water content in the near-surface regime. Soil suction values were indirectly measured through correlations to the electronic resistance (meter reading) measured across each G-Block using G-Block Relationships provide by the manufacturer (Soilmoisture Equip. Corp. 5201F1 operating instructions, Jan. 2000). In addition to soil suction values, laboratory tests have been conducted on representative samples from the Muskingum and Logan County demonstration sites to produce charts for determining the water content based on the electronic resistance (meter reading) measured across each G-Block. Figure 4.2 shows the results for the Muskingum County red clay and Logan County brown till typically found in the near-surface soil of those sites as well as the Soilmoisture Corp. calibration for Yolo Clay Loam and Olympic Clay. For the current investigation, all data reported will be based on correlations with laboratory generated curves from samples obtained from the current demonstration sites. Soilmoisture Corp. calibrations are shown to verify that OSU laboratory curves are reliable.

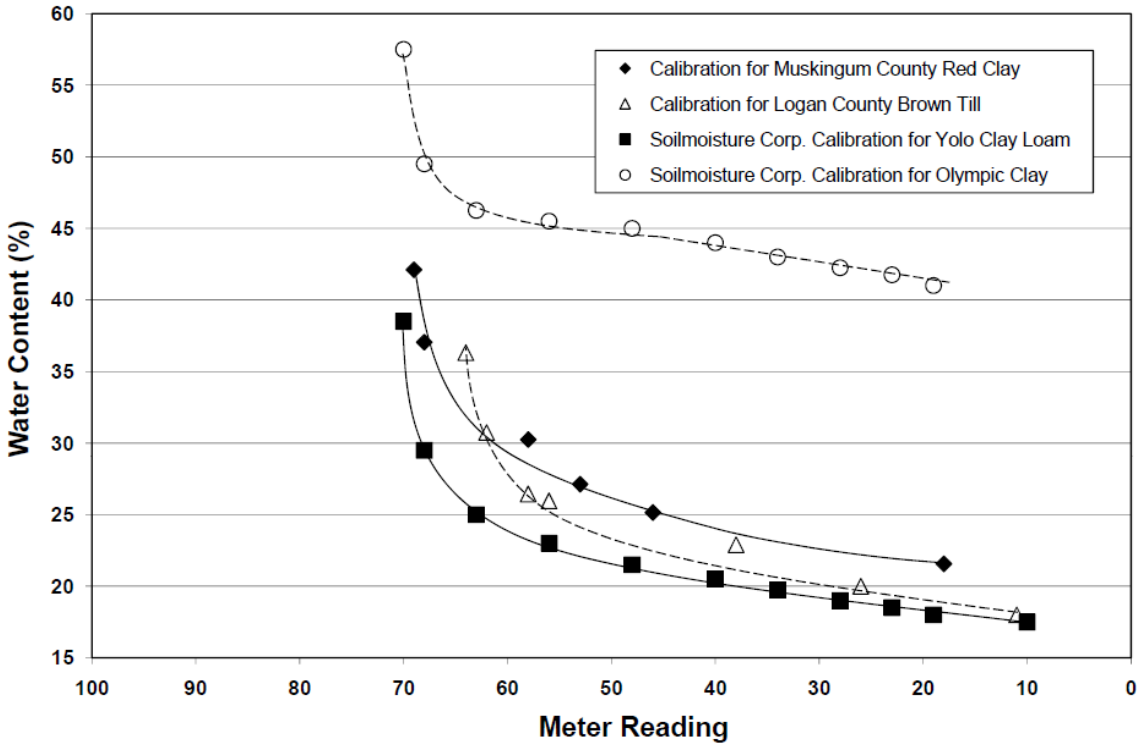


Figure 4.2: Gypsum moisture block (G-Block) water content calibration results for soil water content.

4.4.2.1 Tensiometer and Gypsum Block Reliability

As mentioned in the previous sections, tensiometers and gypsum blocks have been installed at all three demonstration sites to monitor the near-surface moisture regime. These values are important in determining the effects from the vegetation on the soil-moisture condition within remediated areas. Tensiometers and G-Blocks both measure soil suction within the slope as described in their respective sections. It is imperative that the data obtained from these instruments be compared to assess reliability of the recorded values. Figure 4.3 shows a plot of data recorded from several stations at the Muskingum County site selected for a direct comparison of soil suction values as determined by both tensiometers and gypsum blocks. Each station contains tensiometers and gypsum blocks at 24 and 36 in. depths, and each instrument was read at the same time to insure moisture conditions were identical.

Data presented in Figure 4.3 indicate that there is no correlation between soil suction values measured by tensiometers and gypsum blocks at these stations. The dashed line in Figure 4.3 represents the expected correlation trend if the instruments were functioning identically. This also indicates that there is a decrease in the reliability of these measurements due to the fact that no correlation between the measured values could be established.

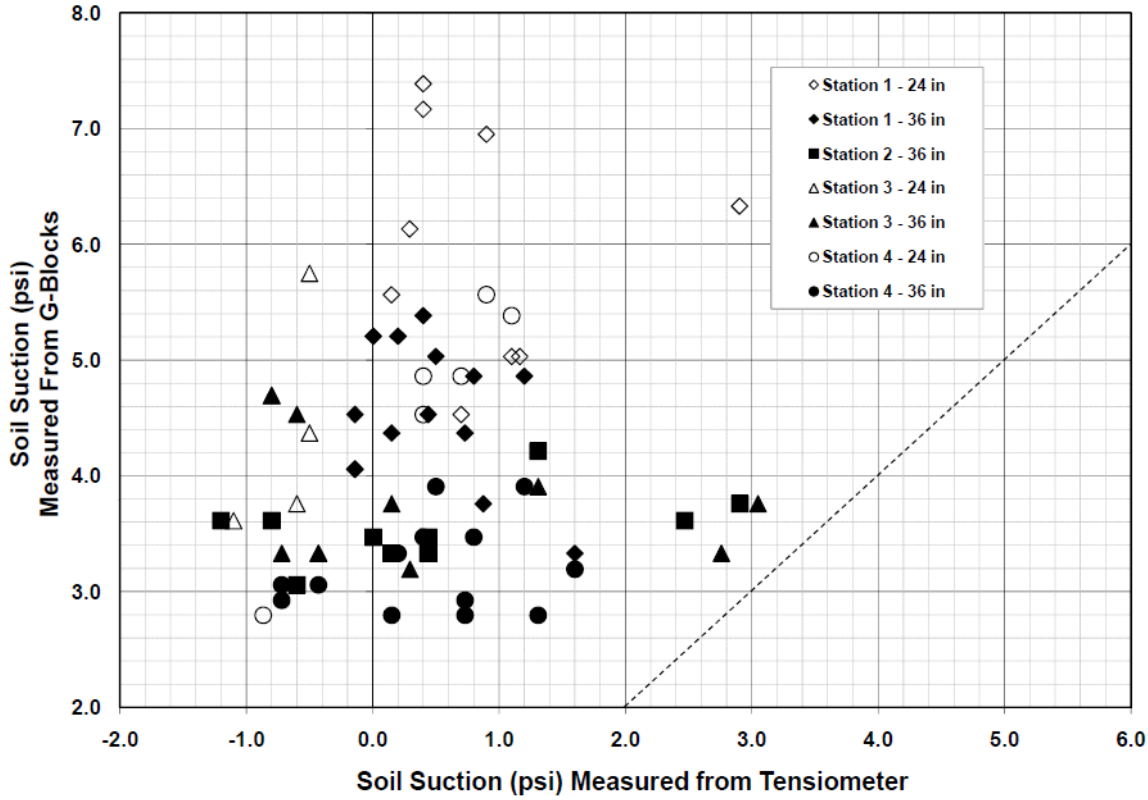


Figure 4.3: Plot of soil suction values as obtained by G-Blocks and tensiometers.

4.4.3 Piezometers and Monitoring Wells

Piezometers and monitoring wells were installed at each demonstration site to directly measure groundwater piezometric head within the slopes. Deep piezometers were installed in borings conducted by ODOT personnel during site exploration to monitor the depth of the local groundwater table. Installation methods are illustrated schematically in the drilling logs for each demonstration site and are available in Appendices A-C. Shallow (4.5 ft.) monitoring wells were installed by OSU personnel using a hand auger and PVC piping with a flexible non-degradable mesh screen taped to one end to prevent infiltration and plugging from fine particles. These were installed throughout the slope face to identify the presence of any local shallow (perched) groundwater tables at each demonstration site.

4.4.4 Shallow Inclinometers

Near-surface slope movements were measured using copper shallow inclinometers (CSI). CSI's consist of a thin walled copper tube that is installed in a pre-augered hole to a depth of about 5 ft. The installation technique is simple: each copper rod is straightened prior to installation; a 4.5 to 5 ft. hole is drilled vertically into the slope using a gas-powered hand auger; the rod is placed vertically in the center of the

hole and backfilled with sand; and the last four in. is capped off using granular bentonite to prevent water from pooling in the hole.

While deep inclinometer systems, such as ones produced by Slope Indicator described in the previous section, can provide displacement over time, CSI's only provide one measurement. This is done by the careful exhumation of the CSI when an appropriate amount of time has passed. Exhumation of several CSI's from each demonstration site was conducted by OSU personnel. The process is very labor intensive. Using hand tools, such as pick axes and shovels, a hole is dug adjacent to the side of the CSI so as not to disturb it during the excavation process; when the hole reaches the depth of the CSI, the soil and sand immediately adjacent to it is gently scraped away until the entire profile of the CSI is exposed; the CSI can then be gently removed from the hole in the deformed condition and thus indicates depth and magnitude of slope displacements. Near-surface slope displacements can be directly measured from the CSI by measuring the displacement of the tube at the ground surface elevation. Site specific data is presented in detail in the following chapters.

It is important to realize that in some cases sliding may have occurred deep enough, or displacement propagated downslope far enough, that the base of the CSI could not remain fixed in its original position. Thus, actual displacements may be larger than values measured from the instrument. This has been noted where appropriate.

4.4.5 Deep Inclinometers

Deep inclinometers were installed in select boreholes by ODOT personnel during site exploration at the Muskingum and Logan County demonstration sites to monitor deep seated slope movements. The inclinometer system, manufactured by Slope Indicator, is comprised of PVC inclinometer casing, an inclinometer probe and control cable, and an inclinometer readout unit. The system permits the measurement of the rate, depth, and magnitude of slope movements. This data can then be used for identifying and quantifying movement of failure surfaces within an unstable slope.

The casings were installed to depths where negligible movement is assumed to occur, which is also the reference point for the survey. From there, readings were collected at 1–ft. increments to the top and incremental movements relative to the reference point are determined. Cumulative and incremental displacement plots were generated for each deep inclinometer using data collected from each inclinometer survey. A graph of cumulative displacement shows how subsurface movement relates to movement at the surface (Slope Indicator, 2004). An incremental displacement graph shows displacements at discrete depths where a growing "spike" indicates movement (Slope Indicator, 2004).

Information produced from inclinometer surveys is useful for determining the geometry and extent of a slide and deciding the appropriate design and remediation measures. For this project, initial movements were recorded and quantified so that a design could be determined for the remediation of a deep-seated failure at the Logan County demonstration site. Long term performance of the mitigated slope will be determined by comparing before and after construction slope movements. Site specific data is presented in detail in Chapter 5.

4.5 SLOPE STABILITY ANALYSIS

As part of this research project, OSU personnel submitted design recommendations, as well as drawings and specifications used in the plans for the Muskingum, Logan, and Union County demonstration sites, to ODOT for review and bid process. Two slope stability analysis approaches have been completed as part of the design process for this project; infinite slope and circular slip. The following sections will present details pertaining to these methods of stability analysis. Specific design details and recommendations for the Muskingum, Logan, and Union County sites are discussed in their respective chapters.

4.5.1 Infinite Slope Stability Analysis

The infinite slope stability analysis has been utilized for determining the stability for shallow, transitional sliding at the demonstration sites. This method is suitable for slopes where the slip surface is assumed to be parallel to the ground surface and the depth to length ratio of the sliding mass is small. The geometry of the infinite slope simplifies the analysis to that of a vertical element where the horizontal forces acting on the element's sides are assumed to be equal and opposite, as well as collinear, and the overall end effects in the sliding mass can be ignored. Because this approach is fundamentally a mechanics problem, one may incorporate nearly every conceivable force which may act on a slope, including seepage direction as well as uniform slope surcharges. The infinite slope stability analysis uses a force equilibrium approach, where a factor of safety is predicted by determining the ratio shear strength to shear stress acting on the failure plane.

Moisture and groundwater conditions are a major factor that must be considered in an infinite slope stability analysis as seepage forces are one of the major destabilizing forces present in the system. An infinite slope stability analysis is presented in Gray and Sotir (1996) where the effects of vegetation and seepage can be evaluated. In the method outlined below, the factor of safety is determined using the infinite slope analysis for the case where seepage and seepage direction, apparent reinforcement cohesion, and no uniform vertical surcharge are present. Figure 4.4 shows a schematic diagram of an infinite slope scenario. Equations 4.5 – 4.8 are used to evaluate the factor of safety based on force equilibrium and the geometry of the system.

$$FS = A\left[\frac{\tan(\phi)}{\tan(\beta)}\right] + B\left[\frac{c + c_R}{\gamma H}\right] \tag{4.5}$$

$$A = 1 - \frac{r_u}{\cos^2(\beta)} \tag{4.6}$$

$$B = \frac{1}{\cos^2(\beta)\tan(\beta)} \tag{4.7}$$

$$r_u = \left(\frac{\gamma_w}{\gamma}\right)\left(\frac{1}{(1+\tan(\beta)\tan(\theta))}\right) \tag{4.8}$$

where:
- β = slope angle of natural ground surface
- ϕ = angle of internal friction of the soil
- c = soil cohesion
- c_R = apparent reinforcement cohesion
- γ = soil density
- γ_w = density of water
- θ = seepage angle (with respect to horizontal)
- H = vertical thickness (or depth) of sliding surface

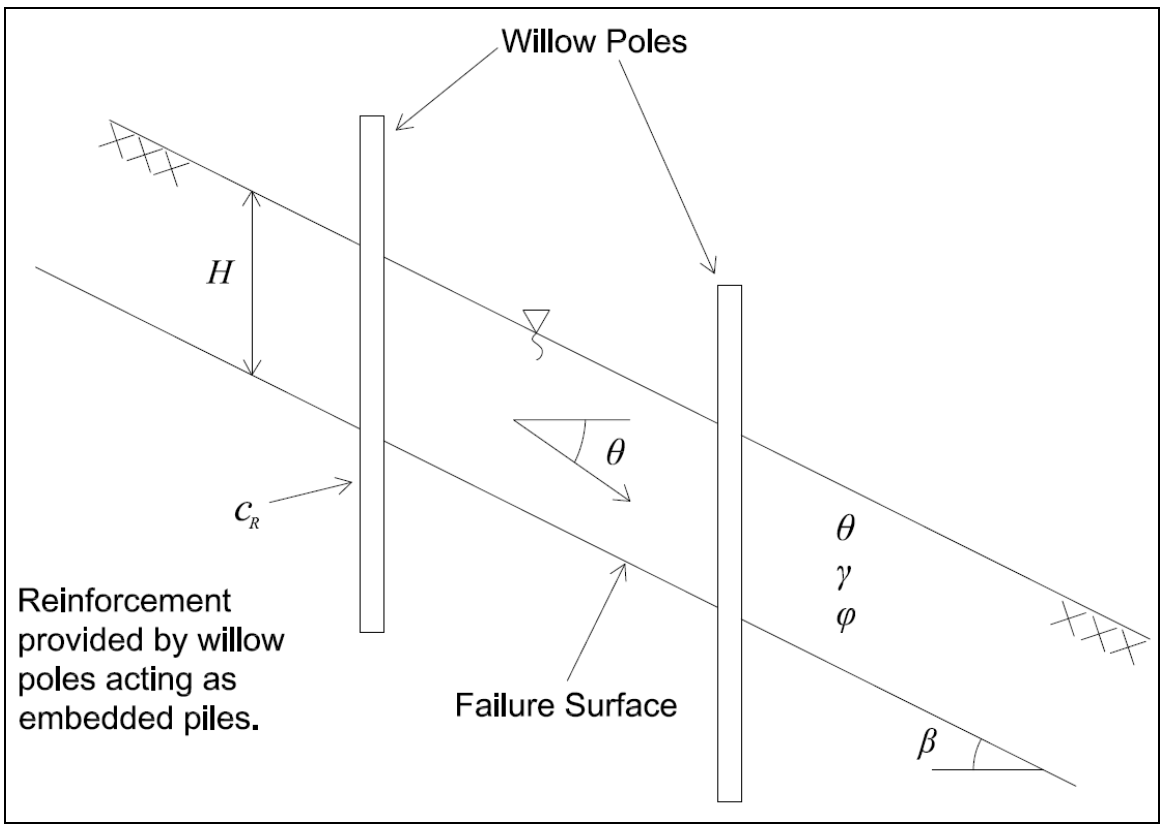


Figure 4.4: Schematic diagram of infinite slope with seepage and reinforcement cohesion.

The apparent reinforcement cohesion term, c_R, accounts for additional strength provided by vegetation reinforcement. Further information on determining the reinforcement cohesion is presented in the following section. Seepage conditions can be identified and quantified using the proper instrumentation. Values of moisture content and pore pressure/soil suction at various depths within a slope can be accurately measured with instruments such as tensiometers, piezometers, and porous blocks. The

seepage direction, θ, can be determined by identifying pore pressure/soil suction gradients using readings from several instrumentation stations throughout the slope. Site specific analyses for the Muskingum and Logan County sites are discussed in their respective chapters.

4.5.1.1 Evaluation of Reinforcement Cohesion

Chapter 2 presented several reinforcement factors that enhance slope stability, including root reinforcement, anchoring (pile) reinforcement, and reduction in soil-moisture. These factors can be incorporated into traditional slope stability analyses by representing them as apparent increases in soil shear strength as shown in Equations 3.9 and 3.10.

$$\tau_f = \left(c' + c_R\right) + \left(\sigma_n^{'} + \Delta u\right)\tan\phi' \tag{4.9}$$

$$c_R = c_{Root} + c_{Pile} \tag{4.10}$$

where:
- c' = effective soil cohesion
- ϕ' = effective angle of internal friction
- $\sigma_n^{'}$ = effective normal stress on shear plane
- Δu = soil suction generated by vegetation
- c_R = total apparent reinforcement cohesion
- c_{Root} = apparent cohesion from root reinforcement
- c_{Pile} = apparent cohesion from pile reinforcement

For the current investigation, reinforcement will only be considered from the willow cuttings acting as piles, or soil nails, installed vertically across the slope. Reinforcement due to vegetation rooting and soil-moisture depletion is not considered because these effects are not easily evaluated and they do not provide immediate reinforcement.

Rooting of vegetation depends highly on the type of vegetation used and on the local soil and climate conditions at candidate sites. As demonstrated in Section 3.6, the extent and depth of rooting is a function of the soil-moisture regime, which is a unique characteristic of each site. Gray and Sotir (1996) and Greenway (1987) provide tensile strengths of root fibers for various plant species, including willows, which range considerably depending on the size of the root. The tensile strength of roots representative of current installations can be accurately obtained by testing field specimens, but this is not within the scope of the current investigation.

Soil-moisture depletion is a function of the soil-moisture characteristic of the soil that comprises each slope. Typically, the presence of vegetation results in both a decrease in the static pore water pressure within the sliding mass as the groundwater level lowers, and also an increase in negative pore water pressure (soil suction). As stated in Section 4.4, these effects have been monitored at each site by piezometers, tensiometers,

and G-Blocks; however, these effects fluctuate seasonally as the slopes become nearly saturated during winter and dry out during summer. This cyclic effect reduces the reinforcement provided through soil-moisture depletion to essentially zero during the winter season as the slope saturates, and thus will not be included in stability analyses.

The reinforcement provided by vegetation will be incorporated into stability analyses by modeling the poles such that they act as piles, or soil nails. The evaluation of this effect was described in Section 3.5 as an additional equivalent increase in soil shear strength as determined by the limiting soil resistance calculated for three common types of failure modes: 1) "flow mode" where the soil flows around the pole, 2) "pile mode" where the pole is analyzed as a laterally loaded pile, and 3) shear failure of the pole at the slip surface.

In the "flow mode", the limiting soil resistance is developed in the zone above the slip surface and the soil flows around the pole. The soil reaction (bearing pressure at yielding of soil, or passive earth pressure), q_y, and resultant reinforcement force provided by a single pole, T_x, are calculated as shown in Equations 4.11 through 4.13.

$$q_y = s_u N_c \tag{4.11}$$

$$N_c = 2\left(1 + z/d\right) \leq 9 \tag{4.12}$$

$$T_x = q_y d\, z \tag{4.13}$$

where: q_y = soil reaction
s_u = undrained shear strength
z = depth to slip surface
d = average pole diameter
T_x = resultant lateral resistance

In the "pile mode", the pole is analyzed as a laterally loaded pile. Broms (1964) presents a simple analysis method for this case. The pole is either analyzed as a "short pile", where failure occurs in the soil below the slip surface and the pole is pushed through the stable soil; or it is analyzed as a "long pile", where failure occurs in the pole by bending. The parameter βL determines which analysis method best represents the pile deflection that is expected. For cohesive soils, $\phi' = 0$,

$$\beta = \sqrt[4]{\frac{kd}{4EI}} \tag{4.14}$$

where kd is approximately $30 s_u$ (Wu, 2009), and E and I are the Young's Modulus and moment of inertia, respectively, for the willow poles installed.

The value of the parameter βL that determines whether the pole should be analyzed as a "short pile" or "long pile" is $\beta L = 2.25$. Broms (1964) solution for

determining the ultimate lateral load of a "short pile" ($\beta L \leq 2.25$) is presented Equations 4.15 through 4.17 and Figure 4.5. These are used to determine the ultimate lateral resistance, and consequently the ultimate lateral load, as a function of the dimensionless embedment length $\frac{L}{d}$.

$$\text{Dimensionless Embedment Length } (EL) = \frac{L}{d} \tag{4.15}$$

$$\text{Dimensionless Ultimate Lateral Resistance } (ULR) = \frac{T_{xu}}{s_u d^2} \tag{4.16}$$

$$T_{xu} = (ULR) s_u d^2 \tag{4.17}$$

where: d = diameter of pole
L = total embedment length of pole
T_{xu} = ultimate lateral resistance
s_u = undrained shear strength of soil mass

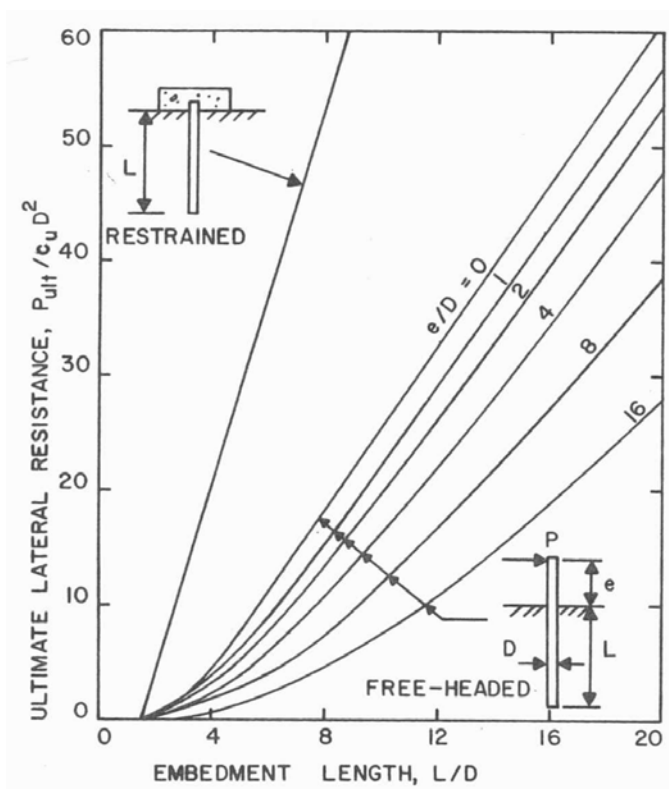


Figure 4.5: Dimensionless relationship for determining ultimate lateral resistance for "short" laterally loaded piles in cohesive soils (Broms, 1964).

Broms (1964) solution for determining the ultimate lateral load of a "long pile" ($\beta L > 2.25$) is presented in Equations 4.18 through 4.22 and Figure 4.6 below. These are used to determine the ultimate lateral resistance, and consequently the ultimate lateral load, as a function of the dimensionless moment resistance of the pile section, $\frac{M_{yield}}{s_u d^3}$.

$$\text{Dimensionless Yield Moment } (YM) = \frac{M_{yield}}{s_u d^3} \tag{4.18}$$

$$\text{Dimensionless Ultimate Lateral Resistance } (ULR) = \frac{T_{xu}}{s_u d^2} \tag{4.19}$$

$$M_{yield} = \frac{\sigma_t I}{r} \tag{4.20}$$

$$I = \frac{\pi r^4}{4} \tag{4.21}$$

$$T_{xu} = (ULR) s_u d^2 \tag{4.22}$$

where: M_{yield} = yield moment resistance of the pile (pole) section
s_u = undrained shear strength of soil mass
d = diameter of pile (pole)
T_{xu} = ultimate lateral resistance
σ_t = tensile strength of pile (pole)
I = moment of inertia of the pile section
r = radius of the pile section

The third failure mode is shear failure of the pole at the slip surface. In this case, the shear resistance of the willow pole is less than the shear resistance of the soil around the pole, and the pole fails in shear at the shear surface of the slide. The shearing resistance of the pole is calculated using Equation 4.23.

$$V_u = \frac{\tau_u \pi d^2}{4} \tag{4.23}$$

where: V_u = shear resistance of pole
τ_u = shear strength of pole
d = diameter of pole

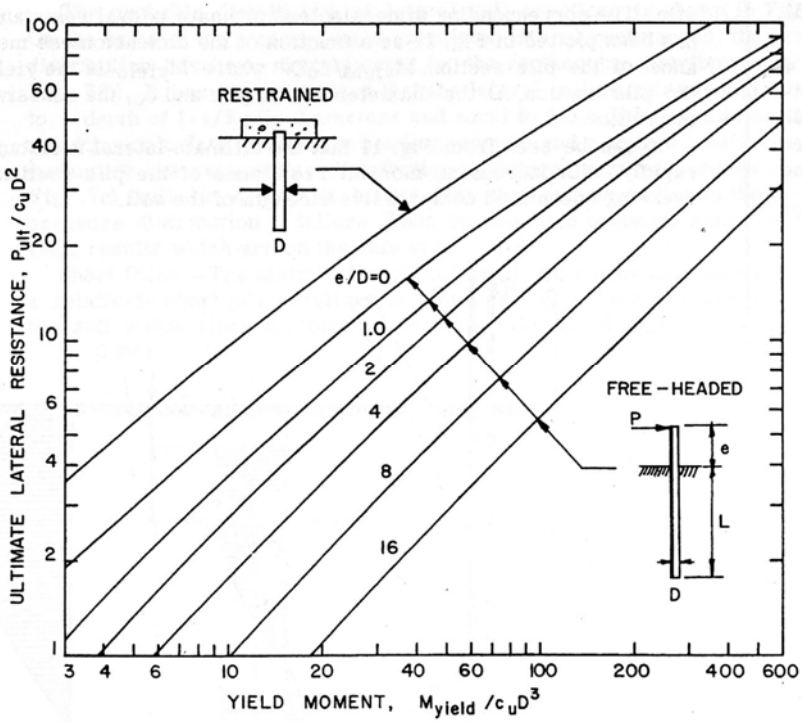


Figure 4.6: Dimensionless relationship for determining ultimate lateral resistance for "long" laterally loaded piles in cohesive soils (Broms 1964).

The minimum limiting resistance determined from analysis of the three failure modes is used to calculate the corresponding apparent reinforcing cohesion as,

$$c_R = \frac{T_x \cos\beta}{s^2} \tag{4.24}$$

$$c_R = \frac{T_{xu} \cos\beta}{s^2} \tag{4.25}$$

$$c_R = \frac{V_u \cos\beta}{s^2} \tag{4.26}$$

where: c_R = apparent reinforcement cohesion
T_x = resultant lateral resistance from "flow mode"
T_{xu} = ultimate lateral resistance from "pile mode"
V_u = shear resistance of pole
β = slope angle of natural ground surface
s = pole spacing along slope

4.5.2 Circular Slip Slope Stability Analysis

The preliminary slope stability analysis for deep-seated rotational failure at the Logan County demonstration site was conducted using the commercially available slope stability analysis package, SLOPE/W, developed by Geo-Slope International. The software uses the Modified Bishop's (Bishop 1955), ordinary method of slices (Fellenius 1927; Fellenius 1936), and Janbu (Janbu et al. 1956; Janbu 1973) circular slip methods for analyzing slope stability. Slope geometry was determined from a survey of the site topography prepared by ODOT. Groundwater levels were determined using data collected over time from piezometers throughout the site. Soil strength parameters, such as the angle of internal friction, cohesion, and soil density were determined from laboratory tests conducted by OSU and ODOT personnel. Using this information, a model for the slope prior to and after mitigation was generated using the software. The failure surface was determined from inclinometer surveys as well as visual identification of scarp and bulge locations on the slope. Specific information on mitigation techniques considered and implemented, including solutions prior to and after mitigation, are presented in Chapter 5.

4.6 VEGETATION SOURCES

One of the key issues that influence the feasibility of soil bioengineering is the ability to readily obtain site specific living vegetation for a project, which may not be locally available. This could be a major factor as bioengineering materials are not as readily available as typical construction materials such as concrete or steel. However, several agencies can provide bioengineering materials. Commercial nurseries can usually provide a reliable stock of vegetative material that is specific to the needs of a project. This can be expensive, however, making bioengineering methods seem unattractive due to increased costs. Additional sources such as local farmers, landowners, business, and public lands can be drawn upon. The harvesting process is usually beneficial to both parties involved as it can take care of routine maintenance issues for the source by cutting back vegetation overgrowth and provides the necessary stock for a bioengineering project. Furthermore, vegetation requests for environmentally friendly projects are generally well received.

Vegetation stock for this project was secured from two locations. Honda of America, Inc., allows annual harvesting from a drainage channel in Marysville, Ohio. Many hardwood species, such as willow and poplar, are growing in abundance along the channel banks. This could prove to be a reliable source for future projects in the area should additional bioengineering installations be considered. The bulk of the vegetation stock was secured through the permission of the Ohio Department of Natural Resources (ODNR) from the Delaware Wildlife Area in Delaware County, Ohio. ODNR supervises this wetland reserve, and permits the harvesting of willow and other hardwood species. This vegetation source is plentiful and ODNR allows harvesting because they routinely clear cut much of the willow growth as part of their wetland maintenance. Table 4.1 provides contact information for these two sources.

Table 4.1: Bioengineering vegetation sources.

Source	Contact Information	Comments
Honda of America Mfg., Inc. Marysville, Ohio	Sharon Wagner (937) 644-6644 Sharon_Wagner@ham.honda.com	1+ mile of drainage ditch with extensive growth of willow and poplar. ¼ of all material may be harvested annually.
ODNR: Delaware Wildlife Area	Tim Davis (740) 499-3019 tim.davis@dnr.state.oh.us	Various areas in the wetland have extensive willow sources.

4.7 CLIMATE DATA COLLECTION AND MONITORING

Success of a bioengineering installation is largely dependent on the climate conditions of the region after vegetation has been planted. Initial moisture conditions during the first month of spring within the planted section of the slope are critical. It is during this period that the vegetation is germinating and initial hair fiber roots develop from the cutting. Willow species, largely utilized for all three demonstration site installations, are a hardy plant that can survive in climates that constantly shift between extremely wet and dry periods. However, during the first 3 to 6 months of germination after construction, a high level of moisture must be available in order for the plant to establish itself. Therefore, it is important for bioengineering contracts to include provisions for monitoring and watering the site as needed for the first growing season of the installation. This however was not provided explicitly for the current research. Precipitation and temperature data has been published by the National Climatic Data Center (NCDC) and the Midwestern Regional Climate Center (MRCC) and is also provided by the Ohio Department of Natural Resources (ODNR) for stations near the Muskingum, Logan, and Union County demonstration sites. Daily records were obtained for periods during and immediately after construction, as well as daily and monthly data from the time of construction to the present.

4.8 VERIFICATION OF PILE EQUATIONS

Bioengineering materials do not have constant physical and mechanical properties like conventional construction materials, such as concrete and steel. Pile equations used for analysis predictions are based on properties obtained from literature on the mechanical properties of wood materials, specifically black willows, not from representative samples used in the site installations. The following sections describe methods for determining the vertical (upward) and lateral load capacity of willow poles

modeled as piles. Site specific data and analysis will be presented in their respective chapters. The predicted values will then be compared with load tests conducted on dead willows at each demonstration site. Dead willows are used because they represent the worst case scenario of rotted wood with no roots attached to the pole.

4.8.1 Vertical (Upward) Load Capacity

The vertical (upward) load capacity was calculated using the total stress analysis (α method) as presented by Coduto (2000). Equations 4.27 and 4.28 and Figure 4.7 indicate that the method determines the unit side-friction resistance, f_s, using the range in undrained soil shear strength as determined in the field and from laboratory tests along with appropriate adhesion factors. The unit side-friction resistance is then multiplied by the embedded surface area of the pole to obtain the vertical load capacity. The range in vertical load capacity is dependent on the maximum and minimum unit side-friction resistance as well as the maximum and minimum diameter of poles installed. Calculated vertical load capacities were verified by field tests conducted on dead willows. A post popper with a friction slip attached to the end and wrapped around the pole is used to generate enough upward force to pull it out of the ground. The load displayed using an s-type load cell and readout at certain increments of vertical displacement was recorded. Figure 4.8 shows a picture of the setup.

$$P_{upward} = f_s A_s \tag{4.27}$$

$$f_s = \alpha \, s_u \tag{4.28}$$

where: P_{upward} = vertical load capacity
f_s = unit side-friction resistance
A_s = embedded surface area of pole
α = adhesion factor
s_u = undrained shear strength of soil

4.8.2 Lateral Load Capacity

The lateral load capacity was calculated using Broms (1964) solution presented in Section 4.5.1.1. The yield moment resistance of the pile section, M_{yield}, was determined from standard beam equations. Mechanical properties of the vegetation, such as tensile strength, σ_t, and Young's Modulus, E, were evaluated in the lab by conducting flexure tests on green and dry poles recovered from vertical pullout tests. Lateral load testing was conducted at several of the demonstration sites to verify lateral capacities calculated from the pile solutions. Figure 4.9 shows a schematic of the setup for laterally testing a pole. To accomplish this, OSU personnel drilled several willow poles into flattened or benched areas below the slope. A high strength webbing ratchet towing strap was then wrapped around each pole and fastened down tightly. This point acts as the reaction

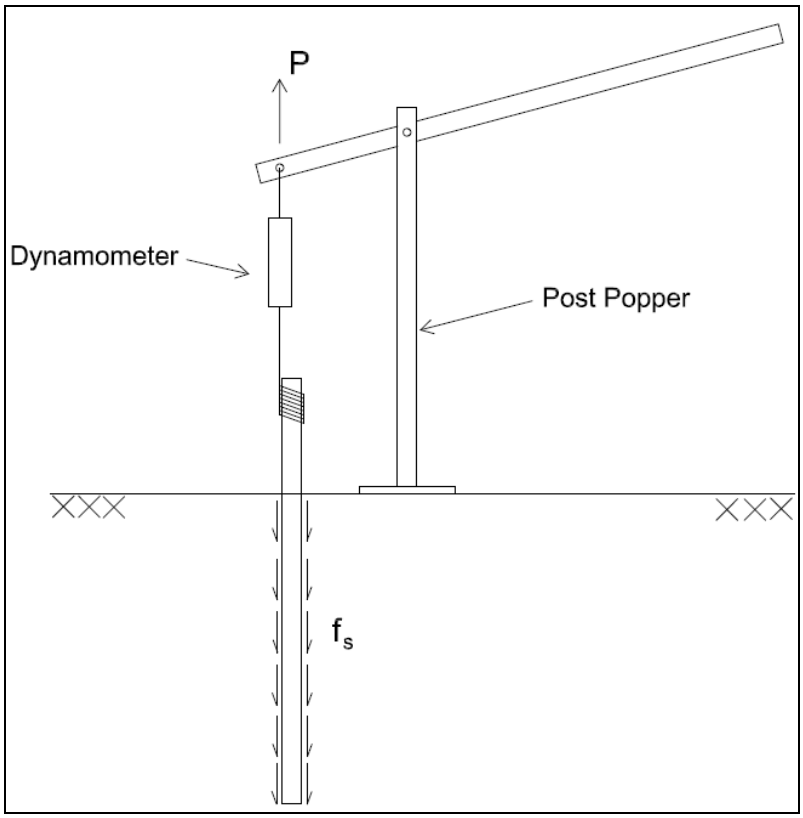


Figure 4.7: Schematic diagram of vertical pullout test setup.

Figure 4.8: Picture of vertical pullout test conducted at the Muskingum County demonstration site.

force that provides adequate reaction such that negligible deflection is produced during the loading process. Another towing strap is run from this point to a ratchet towing wench. A chain is secured around the willow pole and attached to one end of an s-type load cell. The towing wench is fasted to the other end of the load cell, and then the system is drawn taught so that a small load with no deflection occurs at the pole. The towing wench is then slowly drawn in so that the pole is laterally loaded, and load readings are recorded for various deflections. A picture of the setup is provided in Figure 4.10.

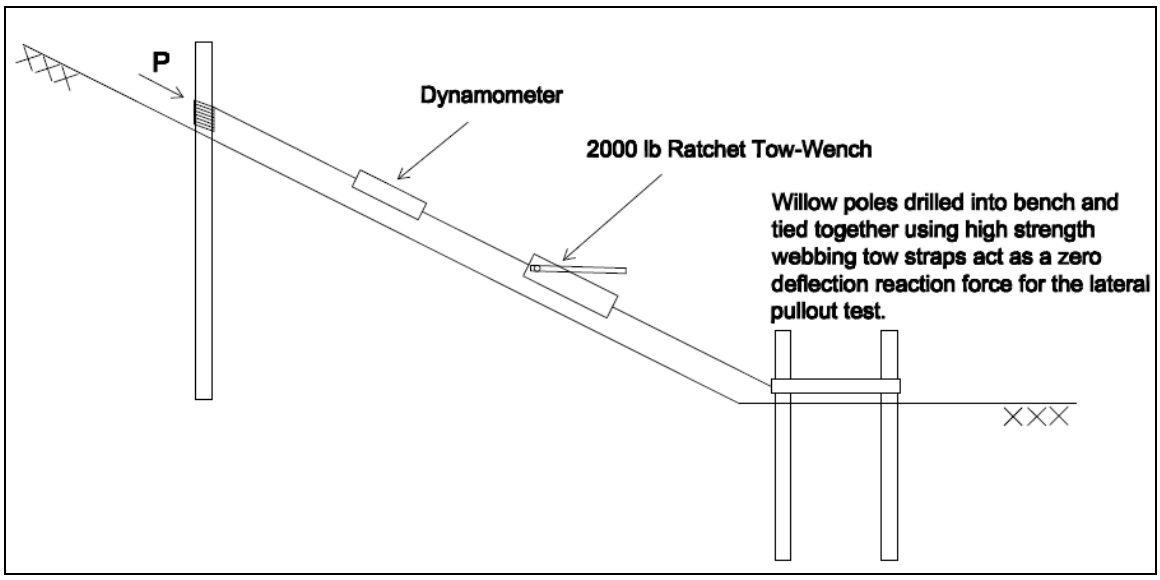


Figure 4.9: Schematic diagram of lateral pullout test setup.

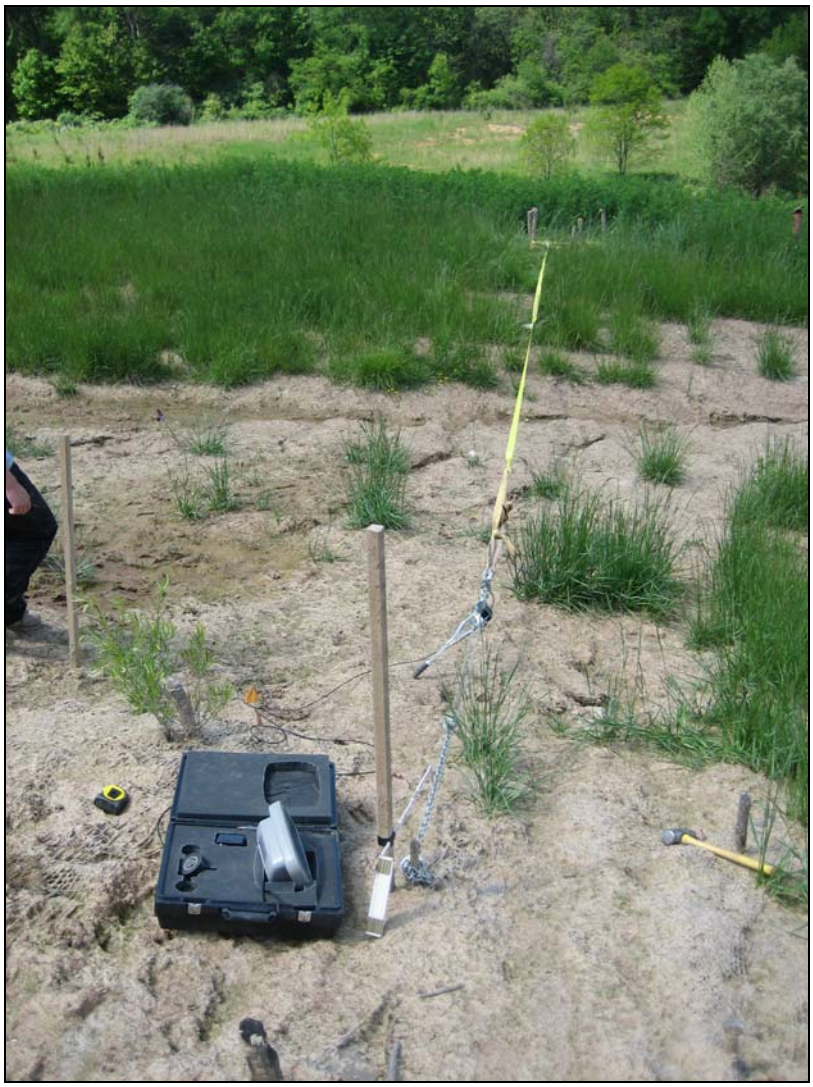


Figure 4.10: Picture of lateral pullout test conducted at the Muskingum County demonstration site.

Chapter 5 MUSKINGUM COUNTY DEMONSTRATION SITE

INTERSECTION: I-70/SR-83

5.1 INTRODUCTION

5.1.1 Project Location Description

The Muskingum County demonstration site is located along the westbound entrance ramp (Ramp A) of the I-70/SR-83 interchange in Muskingum County, Ohio. The interchange is located just outside of the village of New Concord, approximately 20 miles east of Zanesville, Ohio, and 70 miles east of Columbus, Ohio. Figure 5.1 shows a map indicating the project location, and Figure 5.2 shows a view of the region as provided from current construction plans for this project. The focus of the investigation at this site is the remediation of shallow sliding and erosion that occurred on the slope supporting the onramp from SR-83 to westbound (WB) I-70 (area shown in Figure 5.3). Several areas in the region have experienced sliding and erosion due to geological factors that will be discussed in Section 5.2.2. Additional sliding is evident on the slope above the onramp supporting westbound I-70 and is shown in Figure 5.3.

5.2 SITE CONDITIONS

5.2.1 General Layout

The location of the Muskingum County demonstration site is along Ramp A from SR-83 to I-70 WB between Sta. 731+00 and Sta. 733+00 (station baseline is referenced to I-70 WB). Figure 5.4 shows a site plan of the area including drainage routes. Currently, the embankment supporting the onramp to westbound I-70 is a 2H:1V slope with a 10H:1V bench constructed about midway down the slope. Figure 5.5 shows a cross section of the top portion of the slope near the onramp down to the bench. This area has experienced severe erosion and shows signs of shallow sliding. According to drilling logs, the slope is comprised mostly of compacted brown and red silt and clay, silty clay and clay (AASHTO A-6a, A-6b and A-7-6).

5.2.2 Regional Geology

Muskingum County lies on the unglaciated, dissected Allegheny Plateau. The underlying bedrock in the county is primarily sandstone, siltstone, clay shale, and limestone; all of which were derived from sediments laid down during the Late Mississippian, Pennsylvanian, and Early Permian periods (Stout 1918; Steiger 1996). Geologically, the Conemaugh formation is predominate in this area and has been mapped by ODNR as being subject to severe slope failure (Hansen 1995). Embankments constructed of and cut slopes in the Conemaugh formation have historically been notorious for slope failures. Since their construction, ODOT has observed regular embankment slope failures along I-77 and I-70 in Muskingum and surrounding counties where Conemaugh red clays have been used for construction (Kokesh 2009).

Figure 5.1: Vicinity Map: Muskingum County I-70/SR-83 demonstration site.

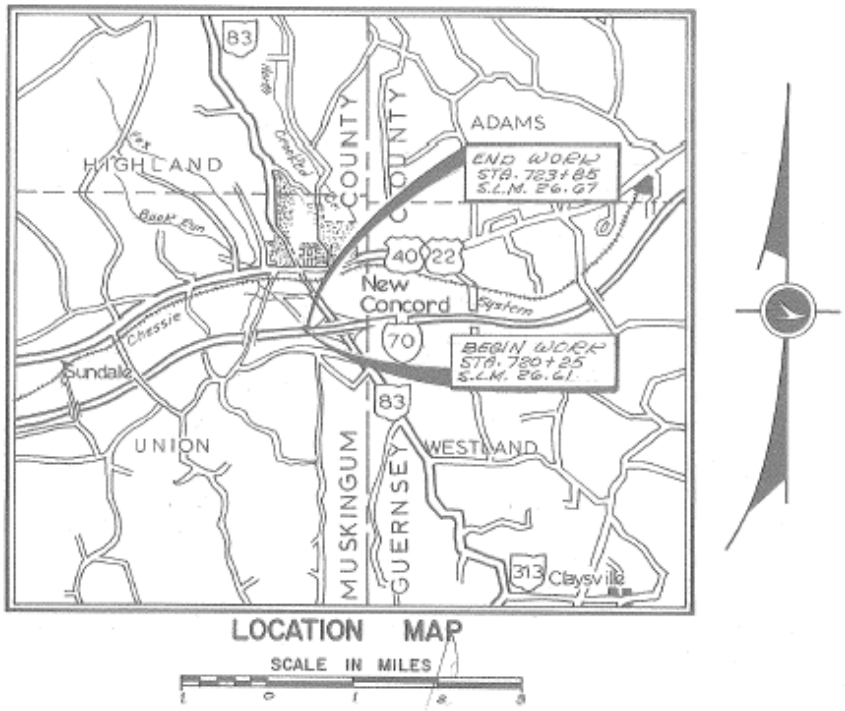


Figure 5.2: Regional map of Muskingum County (ODOT 1985 plans Mus-70-26.61).

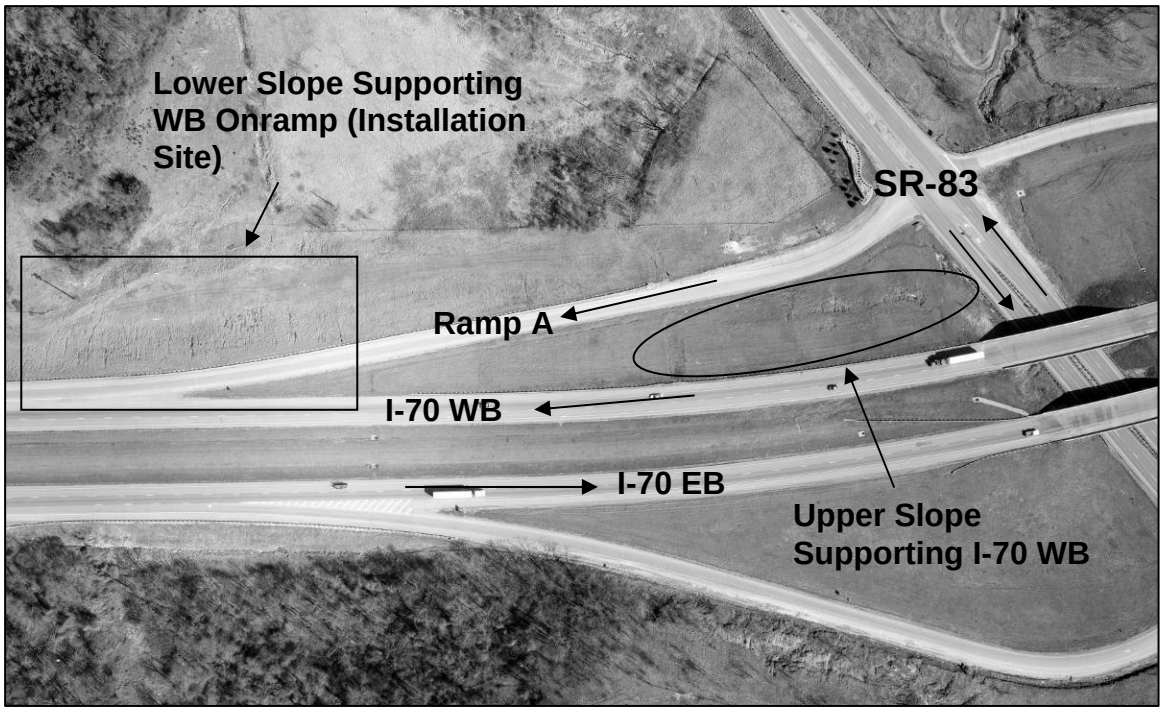


Figure 5.3: Site Map: Aerial view of I-70/SR-83 interchange (Arial Photo: 10938-2-14; taken April 2003; provided by ODOT Aerial Engineering Department).

5.2.3 Climate

Historical climate data has been published by the National Climatic Data Center (NCDC) and the Midwestern Regional Climate Center (MRCC) and is also provided by ODNR for stations located throughout Ohio. This data represents average values of data collected over a 30-year period dating from 1971 to 2000. A summary of climate data collected for Cambridge, Ohio, approximately ten miles east of the demonstration site, is provided in Appendix A and includes monthly temperature and precipitation normals. The average annual precipitation recorded at this station was 39.16 in. During the growing season (March to June), the average monthly precipitation ranged from 3.01 in. in March to 4.03 in. in June. July has the highest average monthly precipitation with 4.25 in. while February has the lowest average monthly precipitation with 2.3 in. The annual mean temperature over this period was 52.5F. July has the highest mean temperature at 73.6°F, while January has the lowest mean temperature at 29.1°F.

Precipitation data has been published by the NCDC and was obtained from the ODNR central office in Columbus, Ohio, for the Cambridge and Zanesville, Ohio, stations. The Muskingum County demonstration site is approximately 20 miles east of Zanesville, and 10 miles west of Cambridge. Monthly precipitation data from January 2005 through April 2009 (the period for this study), along with daily precipitation data for May, June and July 2005, was obtained for these stations and an overview of the climate conditions is presented below. Data for both locations can is provided in Appendix A.

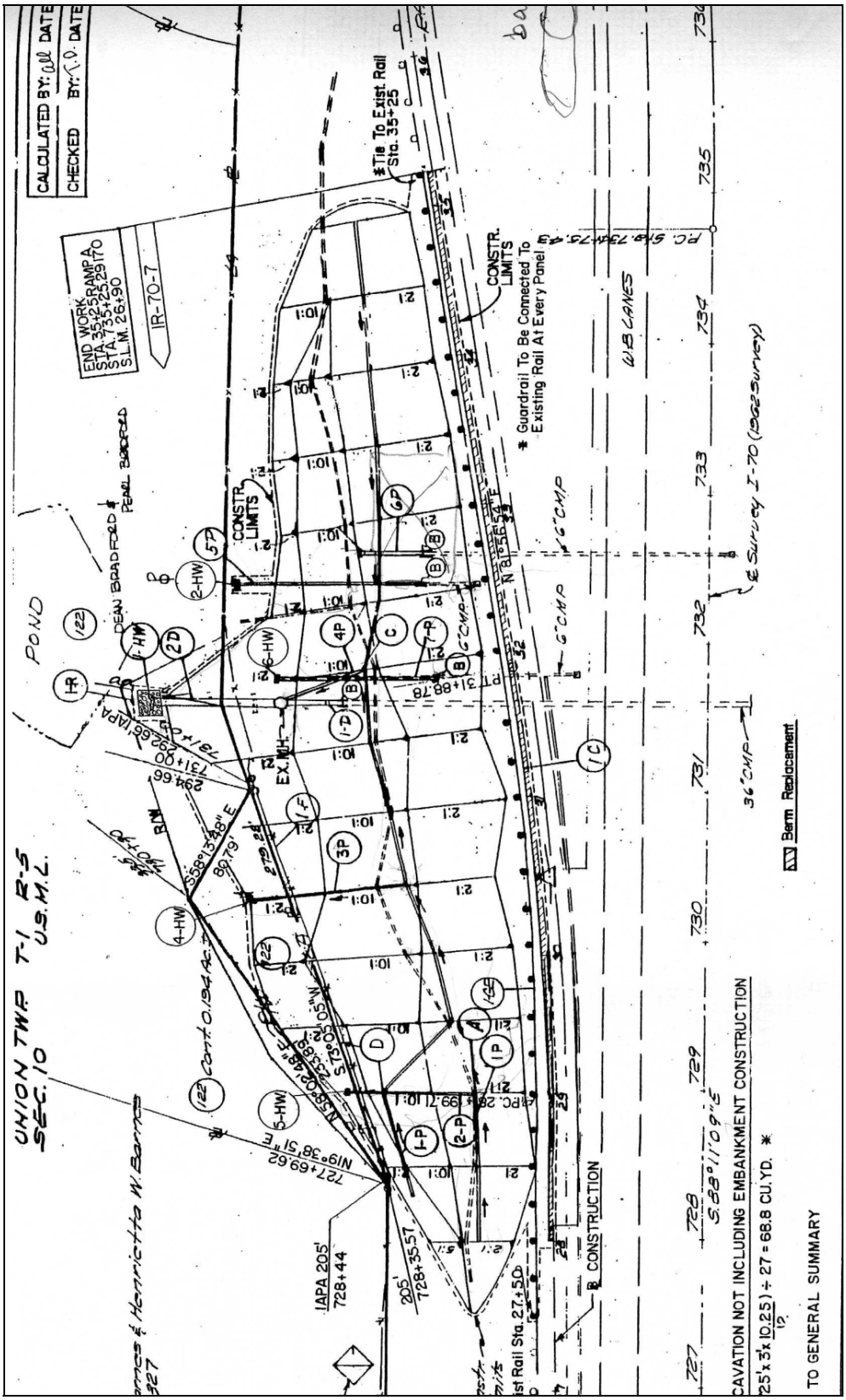


Figure 5.4: Site plan of Muskingum County demonstration site.

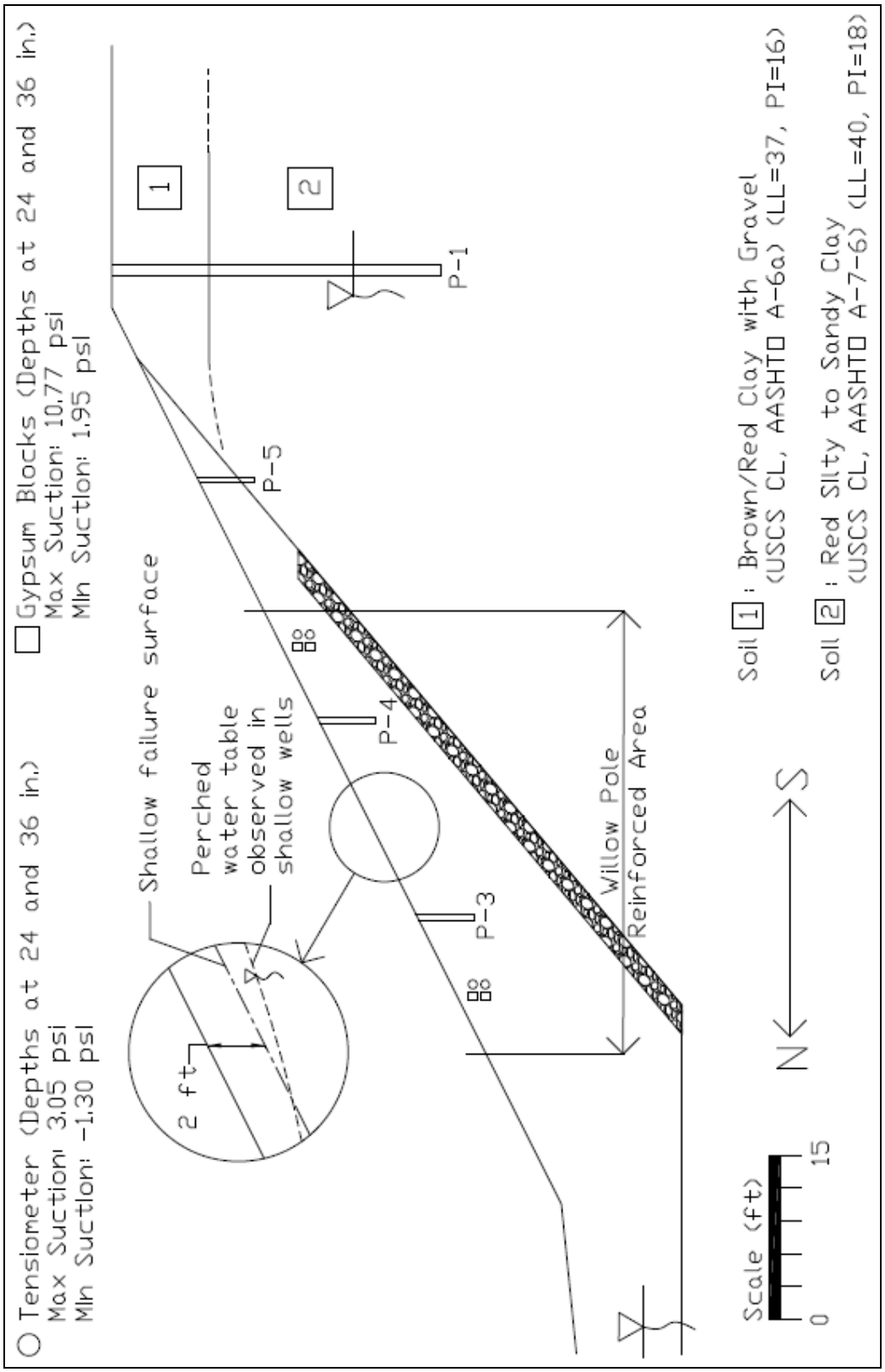


Figure 5.5: Cross section of Muskingum County demonstration site with instrumentation details (Section A-A, Sta. 732+38).

Daily precipitation data show that during the last week of May and the entire month of June, 2005, the Cambridge and Zanesville stations received 1.16 and 4.50 in. of total precipitation and were 3.36 and 0.67 in. lower, respectively, than the 30 yr. normal for June. Over the same period, the Zanesville station recorded four rainfall events that exceeded 0.25 in., whereas the Cambridge station recorded only two rainfall events that exceeded 0.25 in. One event exceeding 0.25 in. was recorded within the first two weeks of July at the Cambridge station. Trace and small amounts, less than 0.25 in., of precipitation were also observed over these months. However, these events were widely scattered and are not optimal for establishing vegetation growth.

It should be noted that one rainfall event at the Zanesville station, recorded on June 28, 2005, was 2.2 in. in a 24 hr. period. This is a relatively uncommon event and most of the precipitation during that period would be lost to runoff. Removing this event from the recorded data for June would yield 1.14 in. of total precipitation, which is 2.87 in. lower than the 30 yr. average for June. If this one event is not removed from the record for June 2005, total rainfall was 0.67 in. lower than the 30 yr. average. Total precipitation for July was 2.30 and 2.52 in. for the Cambridge and Zanesville stations, respectively. These totals are approximately 2 in. lower than the 30 yr. average for both stations.

For the remainder of 2005, with the exception of December, monthly precipitation remained at or above average. Annual precipitation for 2005 was over 2.5 in. above average. Precipitation during 2006 was substantially different between the Cambridge and Zanesville stations. Annual precipitation for the year was 5.35 in. above average for the Cambridge station, while the Zanesville station was 2.34 in. below average. Monthly precipitation for February through June 2006 was near or below average at both stations, and monthly precipitation for July though October was well above average with the exception of August. Monthly precipitation data was not available for the Zanesville station for 2007. Annual precipitation for 2007 was 2.97 in. above average for the Cambridge station. Monthly precipitation for April through November 2007 was near or below average, with June and July being the only two months at 0.90 in. above average each. Annual precipitation for 2008 was 4.60 in. above average for the Cambridge station. Monthly precipitation data was not available for the Zanesville station for October and December 2008. However, total precipitation for the remaining ten months was 0.70 in. below average. If similar amounts of precipitation occurred for the Zanesville station as was recorded at the Cambridge station, then the annual precipitation would be approximately 1.5 in. above average for the Zanesville station.

Conditions were relatively dry during the first growing season (2005), with precipitation at or below average for May, June, July and September. Conditions were slightly wetter during the 2006 growing season, with precipitation at or above average for May, June, July, September and October. The 2007 growing season was drier than any of the seasons for which precipitation data was obtained, with precipitation below average for May, June, September and October. The 2008 growing season was relatively dry as well, with precipitation below average for July, August, September and October.

5.3 FIELD EXPLORATION

5.3.1 Field Reconnaissance

Shallow slope failures are not new to this site or this area of the state. In the late 1980's and early 90's, this slope experienced severe sliding activity that required remedial repairs. As part of the repairs, the original 2H:1V embankment slope was reconstructed with a 10H:1V bench approximately midway down-slope as indicated in Figure 5.6. In addition, a new subsurface blanket drain was installed to alleviate pore pressures in the slope. Groundwater is channeled from the drain to a perforated underdrain at El. 945.75 that runs the length of the benched portion of the slope with outlet drains as indicated in Figure 5.4.

Numerous field visits have been conducted throughout this project to evaluate site conditions. Measurements were recorded from instrumentation, vegetation was inspected, survival of vegetation was determined, and general notes and photographs were taken to maintain an accurate log of events at the site. Landslide and erosion features prior to biostabilization were identified and mapped by Dr. T. H. Wu and C. Kokesh. Figure 5.7 shows an aerial photograph of the slope along with a hand sketch of prominent features. The extent and magnitude of erosion is clearly visible in the photograph.

Several areas along Ramp A and the I-70 WB alignment have been identified as having a very shallow groundwater table, and in some cases, have had water visibly seeping out on the slope face as shown in Figure 5.8. These areas are defined by the presence of standing water and growth of cattails and other hydrophilic vegetation. It should be noted that these areas occur at regular intervals along the alignment and may be caused by clogged drainage outlet pipes that appear to be installed at approximately the same intervals. It should also be noted that landslide areas within the alignment appear to coincide with areas where seepage has been observed and where surface runoff channels come down from the above highway.

5.3.2 Subsurface Investigation

Drilling and sampling were conducted at the Muskingum County site by ODOT drilling crews. On March 8 and 9, 2005, three borings, designated as borings B-1 through B-3, were drilled using a truck-mounted rig with hollow stem augers to depths ranging from 10 to 35 ft. The locations of borings B-1 and B-2 are indicated on the site plan in Figure 5.9. Standard penetration tests (SPT) were conducted, and the retrieved soil samples were visually identified in the field and classified at the ODOT Geotechnical Laboratory. Relatively undisturbed soil samples were obtained using Shelby tubes and preserved with paraffin/petroleum jelly seals. The boring logs from this subsurface investigation program were prepared by ODOT engineers. Log B-2 is provided in Figure 5.10, and the logs for borings B-1 and B-3are included in Appendix A.

The basic stratification is identified on the cross section provided in Figure 5.5. The subsurface soils encountered were visually identified and classified according to the USCS as low plasticity brown/red clay with gravel (CL) to a depth of approximately 10 ft. below the ground surface, overlying low plasticity red silty to sandy clay (CL). The

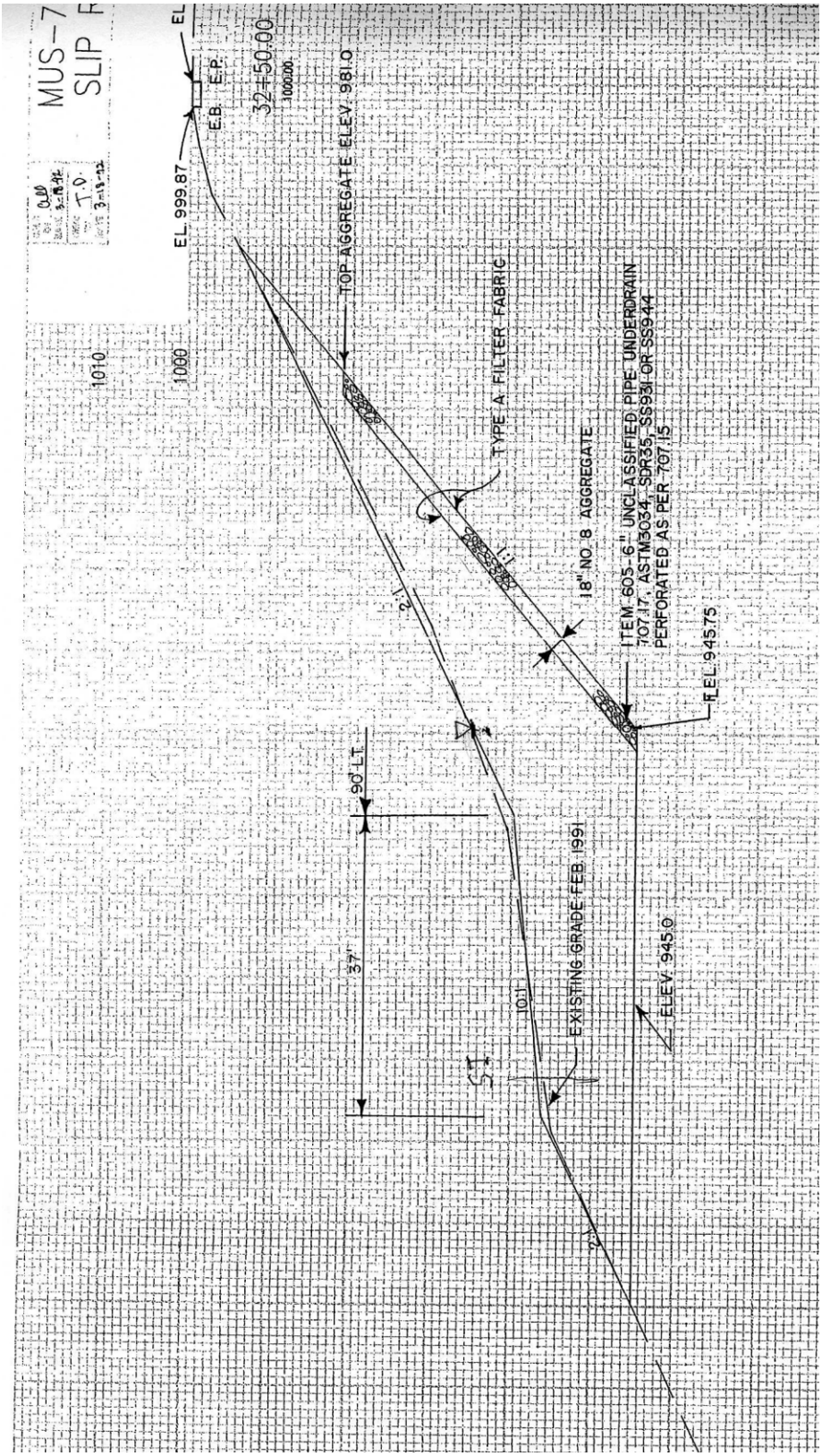


Figure 5.6: Cross section of Sta. 732+50 (Sta. 32+50 from original ODOT 1991 remediation plans).

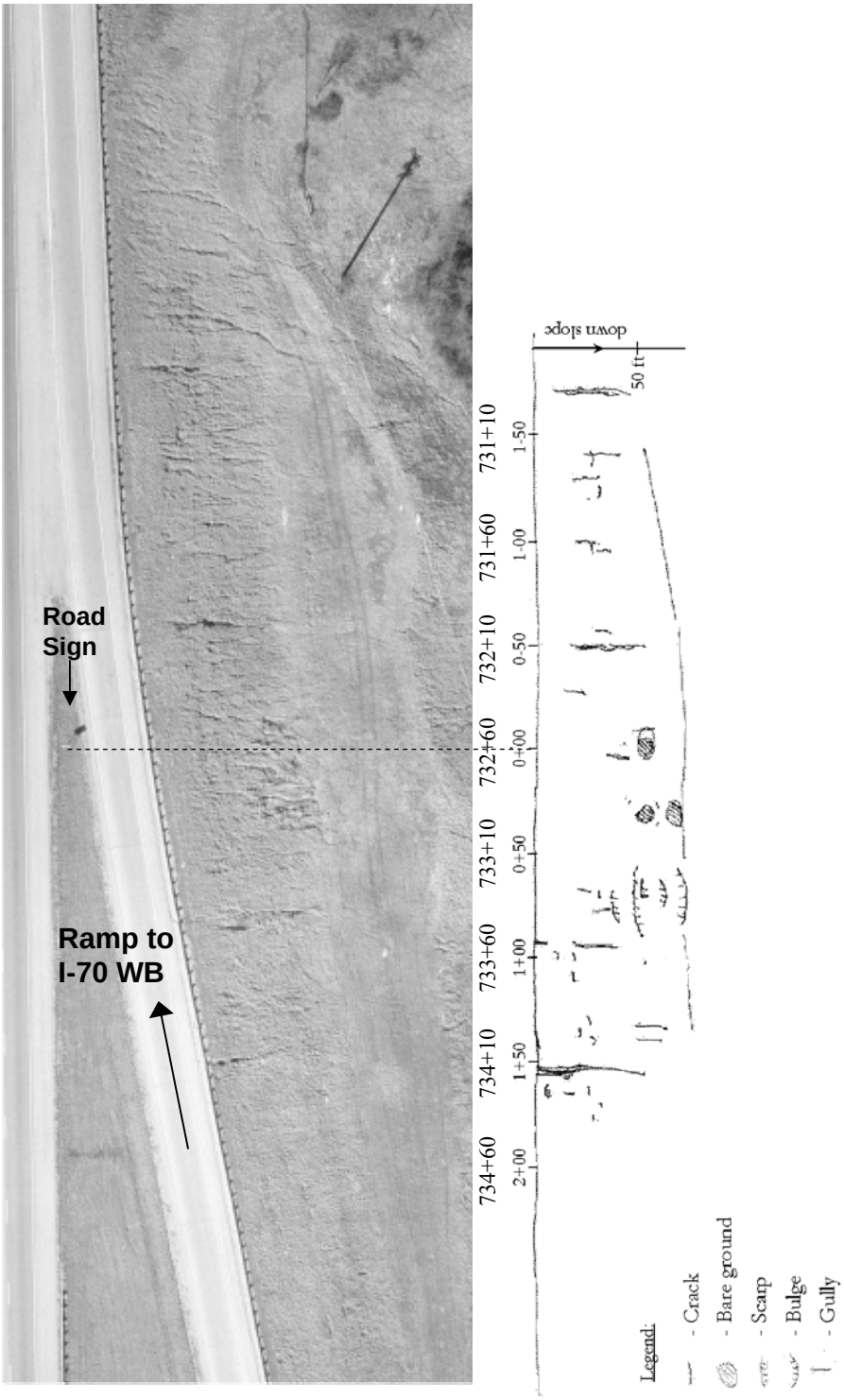


Figure 5.7: Aerial photo of Muskingum County demonstration site and sketch of slope erosion and landslide features. Note: Station 0+00 on the sketch is in-line with road sign in aerial photo (I-70 WB, Sta. 732+60) (survey and sketch conducted September 12, 2009, by Dr. T.H. Wu and C. Kokesh).

Figure 5.8: Standing water at the base of the slope near Sta. 732+60 at the Muskingum County site (picture taken May 13, 2008).

subsurface soils were also visually identified and classified according to AASHTO as brown and red silt and clay (A-6a) to a depth of approximately 10 ft. below the ground surface, overlying brown and red clay (A-7-6). These classifications were based on visual descriptions and laboratory testing conducted at the ODOT Geotechnical Laboratory. These visual descriptions and test results are provided on the borings logs in Appendix A.

Two areas are identified in Figure 5.9, the main pole plot and upper pole plot, where the biostabilization was implemented. Two of the borings, B-1 and B-2, are within the limits of the bioengineering project (Figure 5.9), while the third boring, B-3, was installed in the upper slope (Figure 5.3). Boring B-1 (I-70 WB Sta. 732+49, 271' Lt.) was drilled at the bottom of the 10H:1V bench to a depth of 33 ft. A deep inclinometer was installed in this boring to monitor possible deep seated slope movements in the embankment (see Section 5.5.6). Boring B-2 (I-70 WB Sta. 732+38, 154' Lt.) was drilled at the top of the embankment near the guard rail of the entrance ramp to a depth of 32 ft., and a monitoring well was installed (see Section 5.5.3). Boring B-3 (I-70 WB Sta. 741+42, 112' Lt.) was drilled near the top of the embankment above Ramp A supporting I-70 WB to a depth of 10 ft., and a monitoring well was installed (see Section 5.5.3).

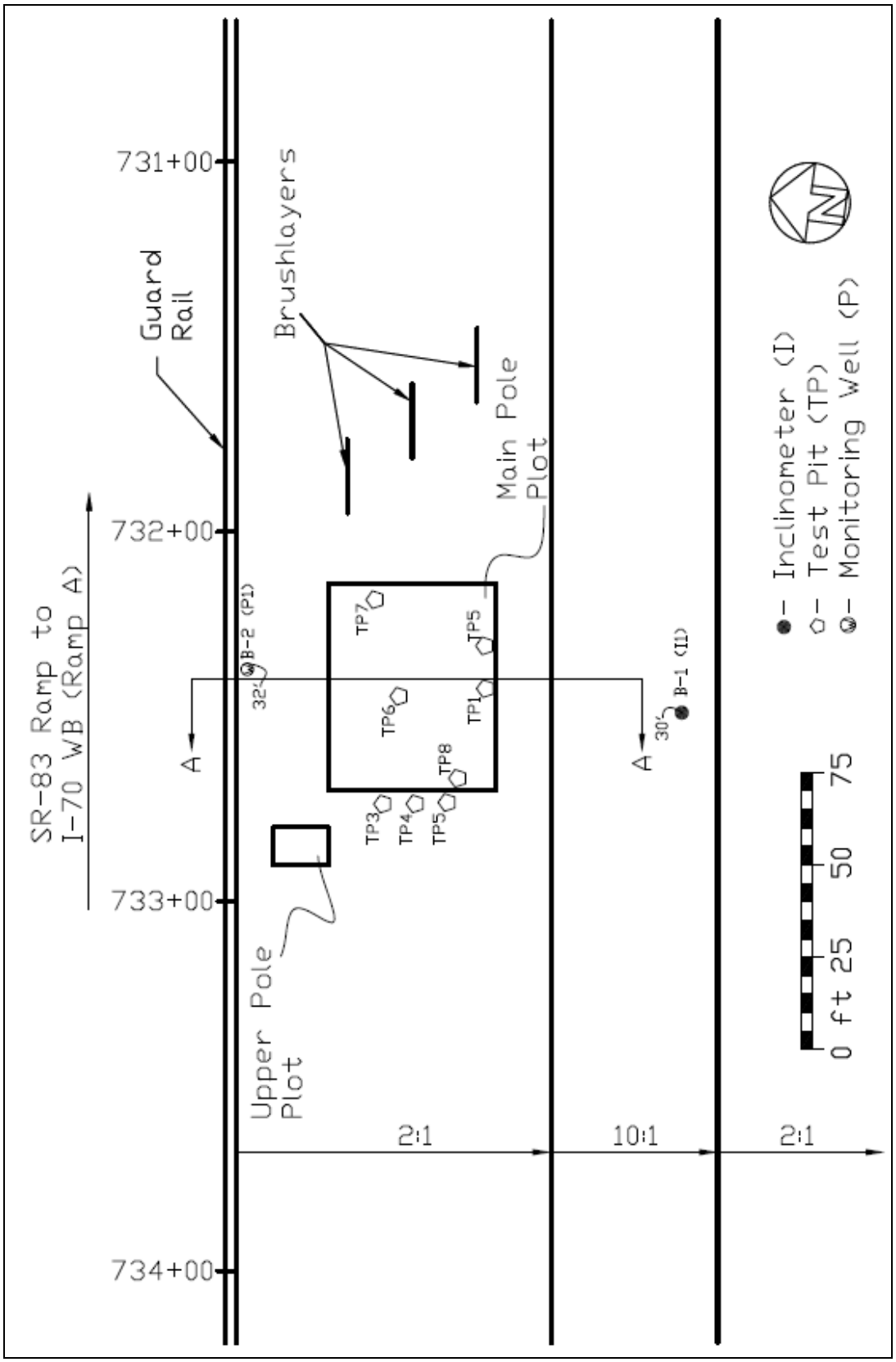


Figure 5.9: Muskingum County site plan and subsurface investigation layout.

Stat f Ohio
Department o ansportation
Office of Geotechnical Engineering

2/3

LOG OF BORING

Date Started 3/9/05 Sampler: Type SS Dia. 1 3/8 Water Elev. DRY Project Identification: MUSKINGUM
Date completed 3/9/05 MUS-70-26.87
Boring No. B-2 *Station & Offset Approx. 732+38, 154' LT. (APPROX.) Surface Elev. 995.5' LANDSLIDE INVESTIGATION (RESEARCH PROJECT)

Elev.	Depth	Std. Pen./ R.Q.D.	Rec. ft	Loss ft	Description	Sample No.	Physical Characteristics % Agg	% C.S.	% F.S.	% Silt	% Clay	L.L.	P.I.	W.C.	ODOT Class
995.5	0														
	2														
	4														
990.5	6	4/5/6			BROWN AND RED SILT AND CLAY (REC. 1.5')	6	8	4	7	40	41	34	14	22	A-6a
	8														
985.5	10	P.S. **			BROWN SANDY CLAY (DRILLER'S DESCRIPTION) (REC. 2.0')	7-P	-	-	-	-	-	-	-	-	VISUAL
	12														
	14														
980.5	16	4/7/8			BROWN AND RED CLAY	8	13	3	3	38	43	42	22	17	A-7-6
	18														
975.5	20	P.S. **			BROWN AND RED CLAY (DRILLER'S DESCRIPTION) (REC. 1.6')	9-P	-	-	-	-	-	-	-	-	VISUAL
	22														
	24														
970.5	26	5/9/10			BROWN AND RED CLAY (REC. 1.5')	10	0	0	2	41	57	41	22	20	A-7-6
	28														
965.5	30	P.S. **			BROWN AND RED CLAY (DRILLER'S DESCRIPTION) (REC. 1.9')	11-P	-	-	-	-	-	-	-	-	VISUAL
963.5	32														

BOTTOM OF BORING

Particle Sizes: Agg= >2.00mm, Coarse Sand= 2.00-0.42mm, Fine Sand= 0.42-0.074mm, Silt= 0.074-0.005mm, Clay= <0.005mm

* NOTE: WATER MONITORING WELL INCLUDING 2.0' OF SCREEN & 32.0' OF SOLID INSTALLED IN THIS HOLE.

** NOTE: P.S. = PRESS SAMPLE. (THESE SAMPLES WERE HANDED OVER TO THE OHIO STATE UNIVERSITY.)

Figure 5.10: Boring log B-2 (prepared by ODOT).

Additional exploration was conducted by OSU personnel using hand tools to excavate shallow (temporary) test pits in areas of interest. These test pits were excavated to depths of approximately 1.5 to 3.0 ft. below the ground surface. Locations of these test pits, referenced as TP-1 through TP-6, are shown on Figure 5.9. These test pits were used to obtain shallow disturbed bucket samples and relatively undisturbed samples for laboratory testing, soil nutrient testing, and for vane shear testing. Relatively undisturbed samples were obtained by pressing thin walled tubes into the soil at the bottom of the test pits and were preserved with paraffin/petroleum jelly seals.

5.4 LABORATORY TESTING

5.4.1 Physical Properties

Laboratory testing has been conducted on soil samples obtained from field explorations by OSU and ODOT personnel at the OSU and ODOT laboratories. Complete test reports including data and charts are included in Appendix A. Soil classification, Atterberg limits, sieve analysis and moisture contents were conducted by ODOT technicians at the ODOT Geotechnical Laboratory on samples obtained during drilling. These results are tabulated in the boring logs included in Figure 5.10 and Appendix A. The material at the unstable depths has been classified as silt and clay and silty clay (AASHTO A-6a and A-6b).

Soil-moisture characteristic testing was conducted by Dr. R. Lal and graduate research assistants from the Agronomy School at Ohio State University. Sample preparation and testing was done in accordance with ASTM C1699. The resulting soil-moisture retention characteristic curve is shown in Figure 5.11. This curve will be used to understand how vegetation is affecting moisture conditions within the slope and to help verify that field instrument measurements are reliable.

Two consolidation tests were conducted on undisturbed samples obtained from shallow test pits TP-2 and TP-3. Sample preparation and testing was done in accordance with ASTM D 2435. The preconsolidation pressures, $\sigma_p^{'}$, for TP-2 and TP-3 were graphically determined as 3,500 psf and 3,100 psf, respectively. The coefficient of consolidation, c_v, was calculated using the square-root of time method for each stage of loading for TP-2 and TP-3. Figure 5.12 is a plot of the coefficient of consolidation for each stage of loading for TP-2 and TP-3. The average coefficient of consolidation from TP-2 and TP-3 at normal stresses of 1,430, 2,860 and 11,435 psf was calculated to be 0.0162, 0.0091 and 0.0046 in^2/min.

Two unconfined compressive strength (UCS) triaxial tests were conducted by OSU personnel at the OSU Soil Mechanics Laboratory. Soil samples consisted of undisturbed specimens obtained from test pits TP-1 and TP-2. The unconfined compressive strength of the samples obtained from TP-1 and TP-2 were 1626 psf (lb/ft^2) and 998 psf, and the corresponding undrained shear strengths were 813 psf and 499 psf, respectively. Vane shear testing was conducted in TP-4, TP-5 and TP-6 using a CL-600 Torvane hand-held vane shear device manufactured by Soiltest, Inc., to determine if field shear strengths were within the range measured from laboratory testing (499 – 813 psf). The undrained shear strength measured ranged from 475 – 650 psf in TP-4, 675 – 710 psf

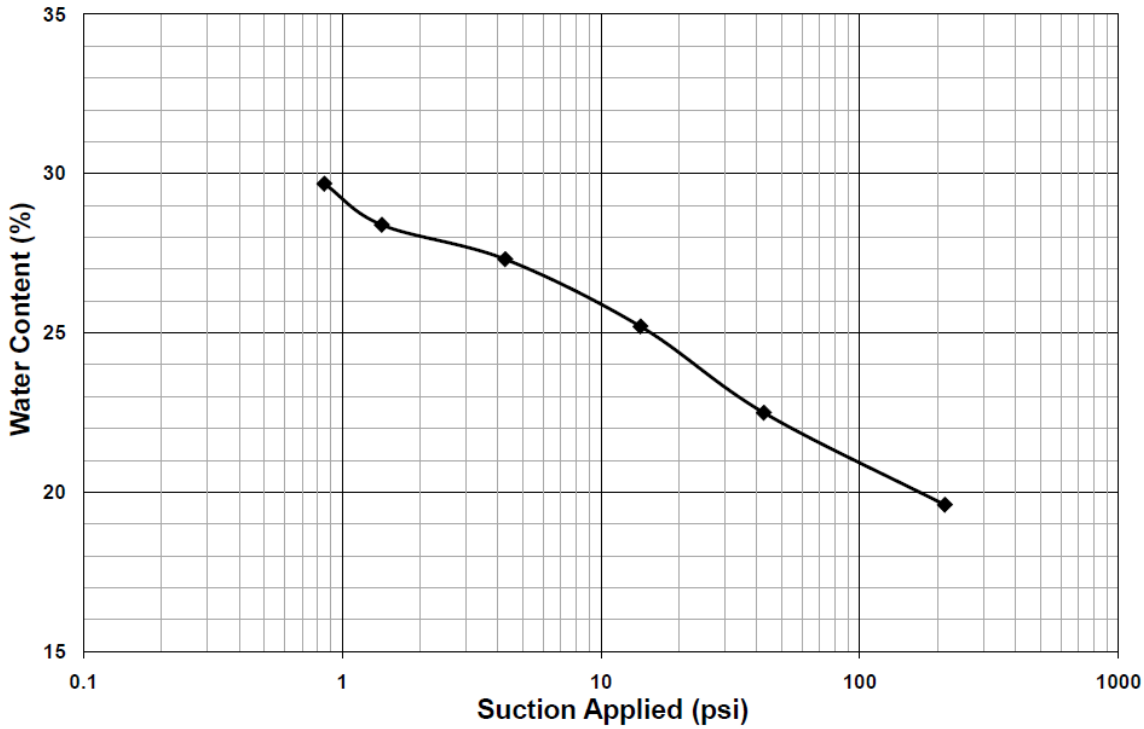


Figure 5.11: Soil-moisture retention characteristic curve (testing by Dr. R. Lal).

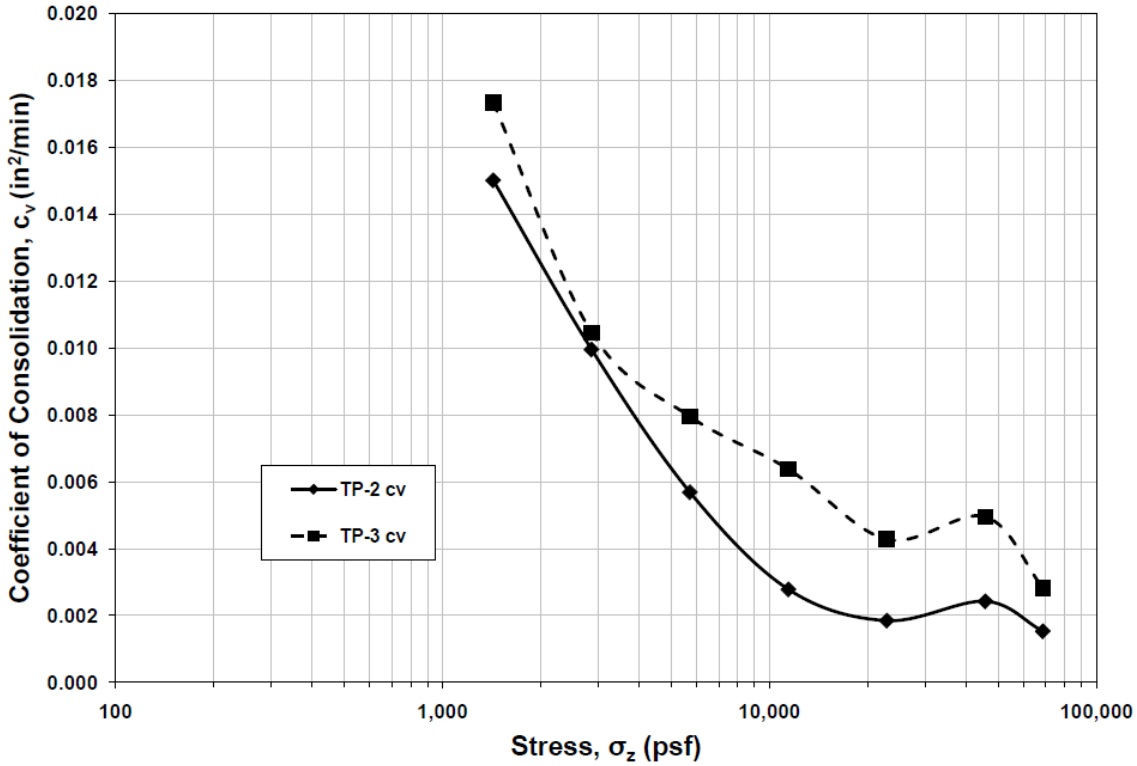


Figure 5.12: Coefficient of consolidation using square-root of time method for TP-2 and TP-3.

in TP-5, and 425 – 525 psf in TP-6. The undrained shear strength from all vane shear tests ranges from 425 – 710 psf with an average of 596 psf and a standard deviation of 102 psf.

Direct shear tests were conducted on reconstituted samples obtained from shallow test pits to determine softened and residual strength parameters. Sample preparation involved: breaking the sample apart and removing any rocks or other debris (including any organic material), wetting the sample and hand kneading it to a uniform consistency with an initial water content $w = 29.6\%$ ($LL = 37\%$ for this material), and then lightly compacting the sample by hand into the shear box. To ensure drained conditions, a strain rate of 0.001 in/min was used based on calculations conducted in accordance with ASTM standard methodology. The test consisted of a four point series with increasing increments of normal stress. A residual angle of $\phi'_r = 21.2°$ and a fully softened friction angle $\phi'_{fs} = 26.6°$ were graphically determined as shown in Figure 5.13. Complete test reports, including data and charts, are included in Appendix A.

Two multistage (two-point series) consolidated-undrained (CU) triaxial tests were performed on samples obtained from boring B-001. Boring B-001 was not part of the subsurface investigation for this project and was not covered in Section 5.3.2. However, this boring was performed approximately 1000 ft. west of the project site along I-70 westbound in the shoulder of the entrance ramp as part of a subsurface investigation for a future bioengineering site. Two undisturbed Shelby tube samples were obtained from 5.0-7.0 ft. and 10.0-12.0 ft. below the ground surface. Testing was performed on these samples. Triaxial testing was not performed on samples obtained from the subsurface investigation for this project.

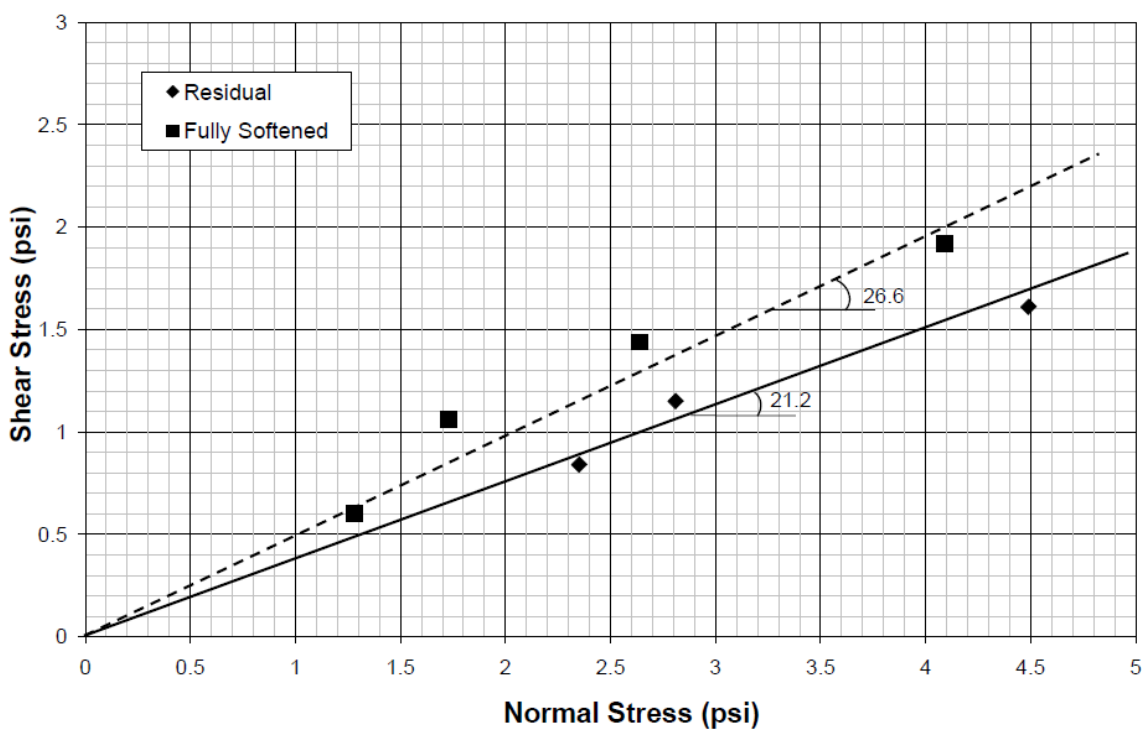


Figure 5.13: Muskingum County direct shear test failure envelopes.

Results from the CU triaxial series performed on the sample obtained from 5.0-7.0 ft. is included in this report to provide peak shear strength parameters of the soil. Sample preparation was conducted in accordance with ASTM D2850. The material tested from boring B-001 was classified as red and brown silt and clay with shale fragments (AASHTO A-6a) and an effective peak friction angle, ϕ'_p = 27.6°, was graphically determined as shown in Figure 5.14. This friction angle is slightly higher than the fully softened friction angle measured in the direct shear test. This is expected as the direct shear sample was remolded and sheared multiple times, creating a smoother/slicker shear surface as the clay particles realigned with each stage of shearing.

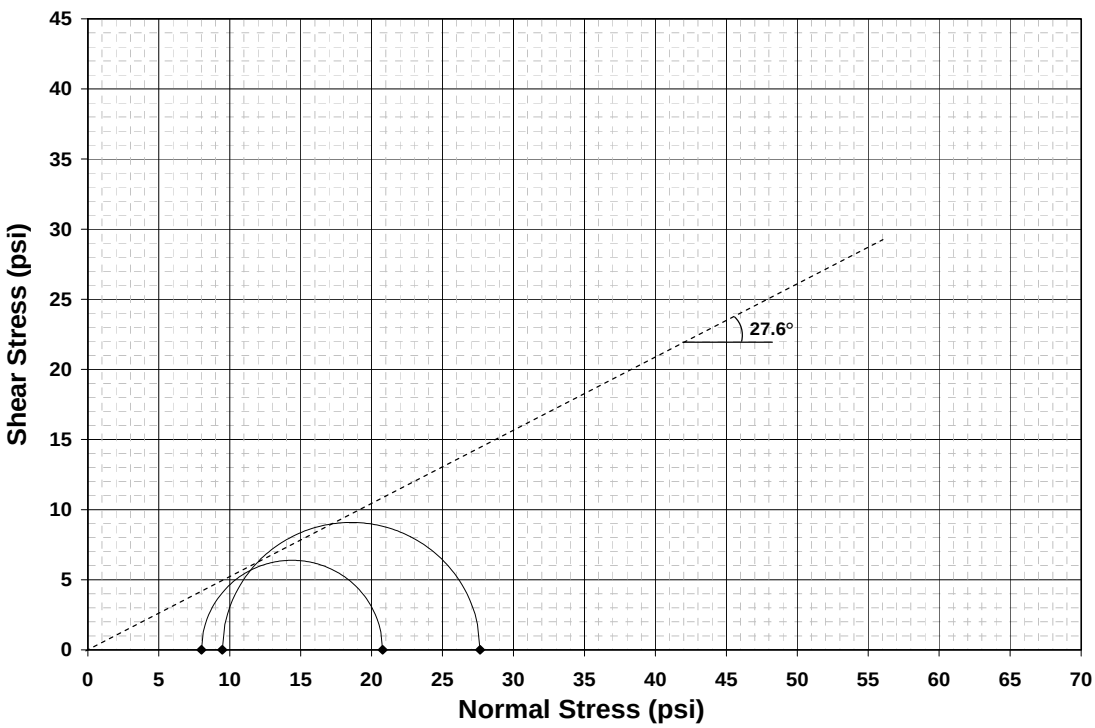


Figure 5.14: Muskingum County CU triaxial test results for B-001.

5.4.2 Chemical Properties

Soil nutrient testing was conducted by Calmar, Inc., of Westerville, Ohio, on two separate bag samples from shallow test pits. The first sample, submitted in February 2006, was obtained from several locations across the repaired area and from depths of approximately 2 – 3 ft. The second sample, submitted in September 2007, was obtained from TP-4. Results and recommendations of the soil nutrient tests are summarized in Table 5.1 and Table 5.2, respectively. These reports indicate that the soil pH value is very high and that sulfur, or other acidifying products, should be added to lower the pH value. The reports also indicate that the phosphorus, potassium, and organic matter levels are lower than optimum for growth of hardwood trees and brushes. It was noted that the low level of organic matter and high pH will adversely affect plant growth. Recommendations for adding phosphorus, potassium, nitrogen, and sulfur to the soil to

achieve optimum conditions for growing hardwood trees and brushes were also included in the first report. Complete reports and recommendations are included in Appendix A.

Table 5.1: Soil nutrient test results provided by Calmar, Inc.

	pH	Organic Matter (%)	Phosphorus (lb/acre)	Potassium (lb/acre)	Magnesium (lb/acre)	Calcium (lb/acre)
First Results	8.4	1.4	5	307	1513	6830
Second Results	8.1	1.3	12	312	1383	7442

Table 5.2: Recommendations for soil nutrient improvements provided by Calmar, Inc.

	Sulfur [1] (lb/acre)	Nitrogen [2] (lb/acre)	Phosphorus (lb/acre)	Potassium (lb/acre)
Recommendations for Addition to Soil	700	120	150	135

[1] Addition of sulfur is recommended to bring soil pH to optimal growing conditions.

[2] Addition of nitrogen is recommended to bring organic matter to optimal growing conditions.

5.5 INSTRUMENTATION

Instrumentation and site monitoring is a key issue on this project as it is the only basis for determining feasibility and success. Figure 5.15 shows a plan view of site instrumentation with locations and types labeled. Groundwater and moisture data was collected using tensiometers, gypsum blocks, piezometers, and monitoring wells. Displacement data was obtained using shallow and deep inclinometers, as well as surveys of the existing poles after installation and surveys of stakes placed along the length of the slope face. The following sections provide specific details pertaining to the site instrumentation. Complete records for all data obtained can be found in Appendix A.

5.5.1 Tensiometers

Fourteen tensiometers were installed throughout the site; seven each at 24 in. and 36 in. depths. Locations of each station are shown in Figure 5.15, and data is presented in Section 5.7.1. All measurements have been corrected for elevation of the water column in the tensiometer (see Section 4.4.1).

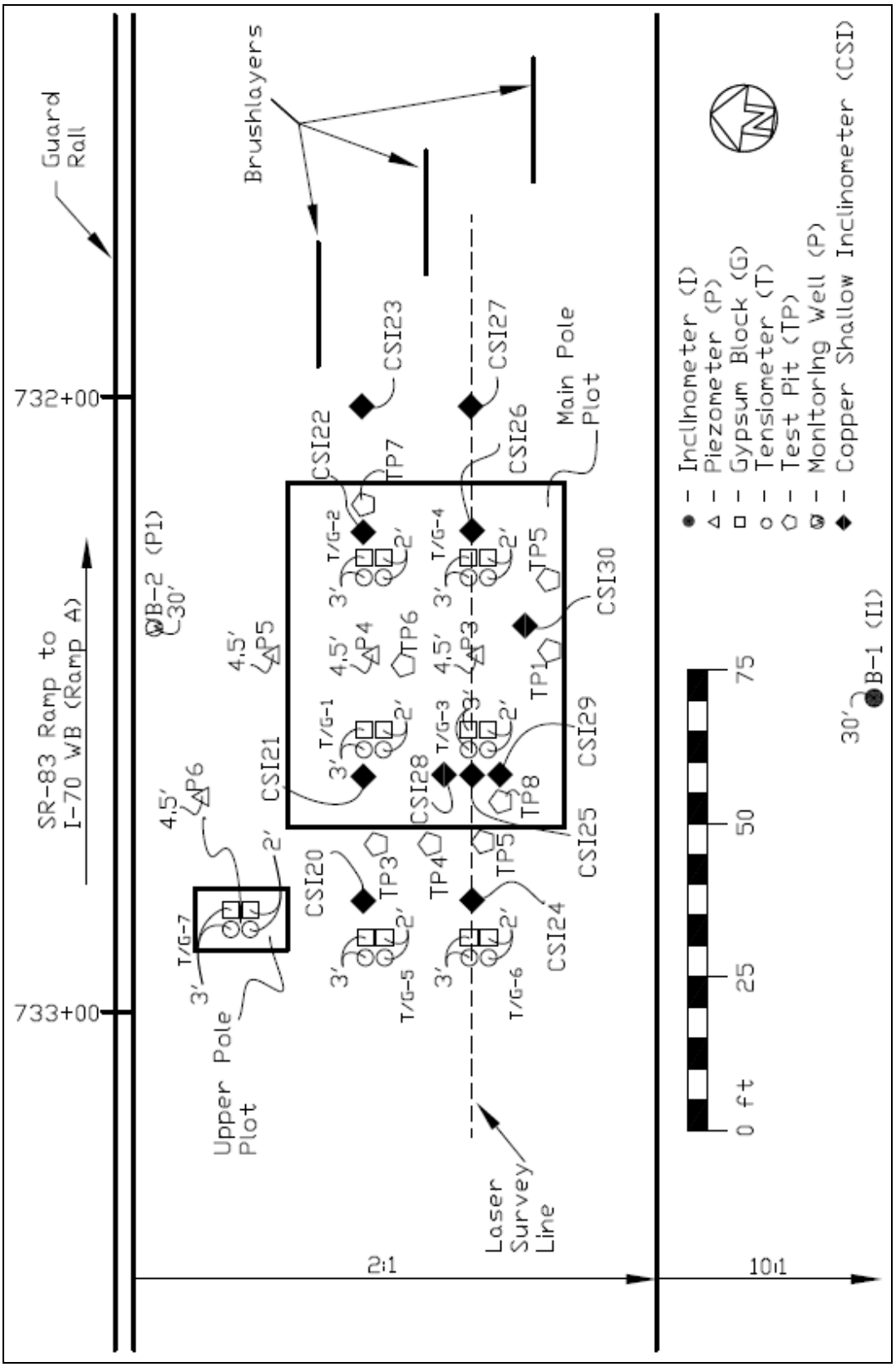


Figure 5.15: Muskingum County instrumentation layout.

5.5.2 Gypsum Moisture Blocks

In addition to tensiometers, gypsum moisture blocks (G-Blocks) were also installed at the site to monitor moisture conditions in the upper 3 ft. of the slope. Fourteen G-Blocks were installed through the site, including seven at 24 in. depths and seven at 36 in. depths, at the same locations where tensiometers were installed. The G-Blocks were installed next to the tensiometers in order to provide redundant data on changes in soil suction and water content over time. Data for the G-Blocks is presented in Section 5.7.1. OSU personnel conducted laboratory tests to determine a correlation between the G-Block reading and water content for representative soil samples from the Muskingum county site. This calibration curve is shown in Figure 5.16.

5.5.3 Monitoring Wells

Monitoring wells were installed throughout the demonstration site to measure static groundwater conditions. One monitoring well, designated P-1, was installed to a depth of 32 ft. with 2 ft. of screen just off the shoulder of the on-ramp to I-70 WB above the main plot area. Four shallow wells were installed to depths of approximately 4.5 ft. Monitoring wells P-3, P-4 and P-5 are located within the main pole plot at the bottom, middle, and top of the planting area, respectively. The fourth shallow well, P-6, is located within the upper pole plot. Data for the monitoring wells is presented in Section 5.7.1.

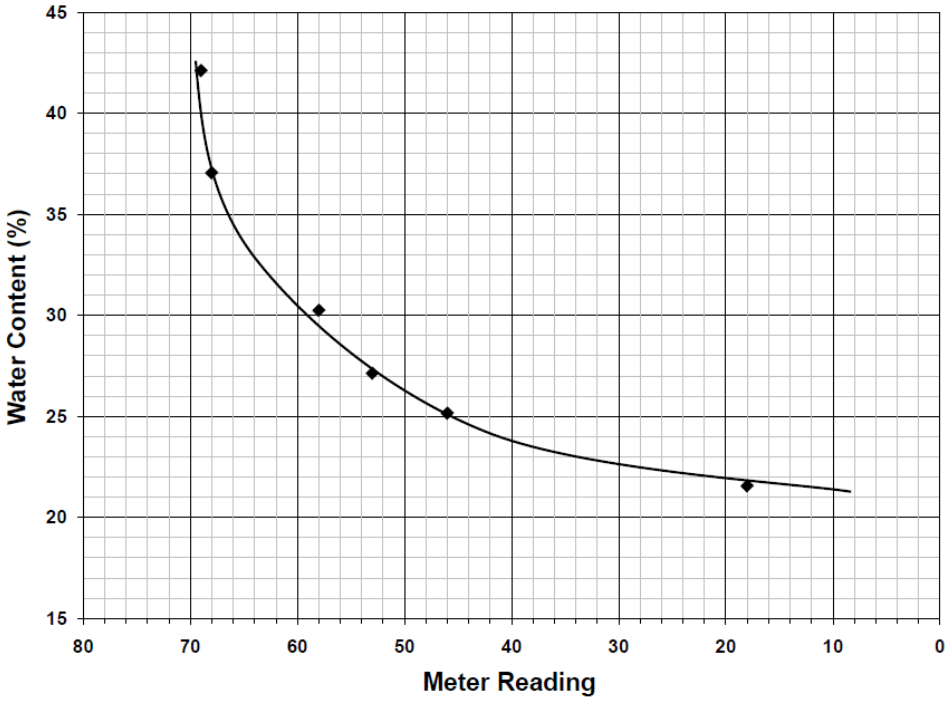


Figure 5.16: Muskingum County water content calibration curve for G-Blocks.

5.5.4 Shallow Inclinometers

Shallow slope displacements were assessed for both pre-construction and post-construction conditions using copper shallow inclinometers (CSIs). Nine installations, designated CSI-1 through CSI-9, were installed at this site between December 2004 and January 2005. CSI-1 through CSI-4 were located throughout the upper slope supporting I-70 WB near the overpass (area shown in Figure 5.3). CSI-5 through CSI-9 were installed in the lower slope throughout the remediated area. Figure 5.17 shows the locations of CSI-6 through CSI-9 just after installation. Additional CSI's, designated CSI-20 through CSI-30, were installed in August 2006 and August of 2007 to assess post-construction movements. Information on slope displacements measured from CSI's is presented in Section 5.7.3.

5.5.5 Laser Monitoring of Survey Stakes

Shallow slope displacements were also assessed by monitoring movements of survey stakes that were installed at regular spacing midway up the slope and laterally across the installation area (Figure 5.15). The stakes were installed during 2005 after the completion of construction at the site. During the monitoring period, it was assumed that the outermost survey stakes were installed in areas that experienced little to no slope movement; therefore, these stakes were used as benchmarks. Methodology and results from surveys conducted over the monitoring period are presented in Section 5.7.3.

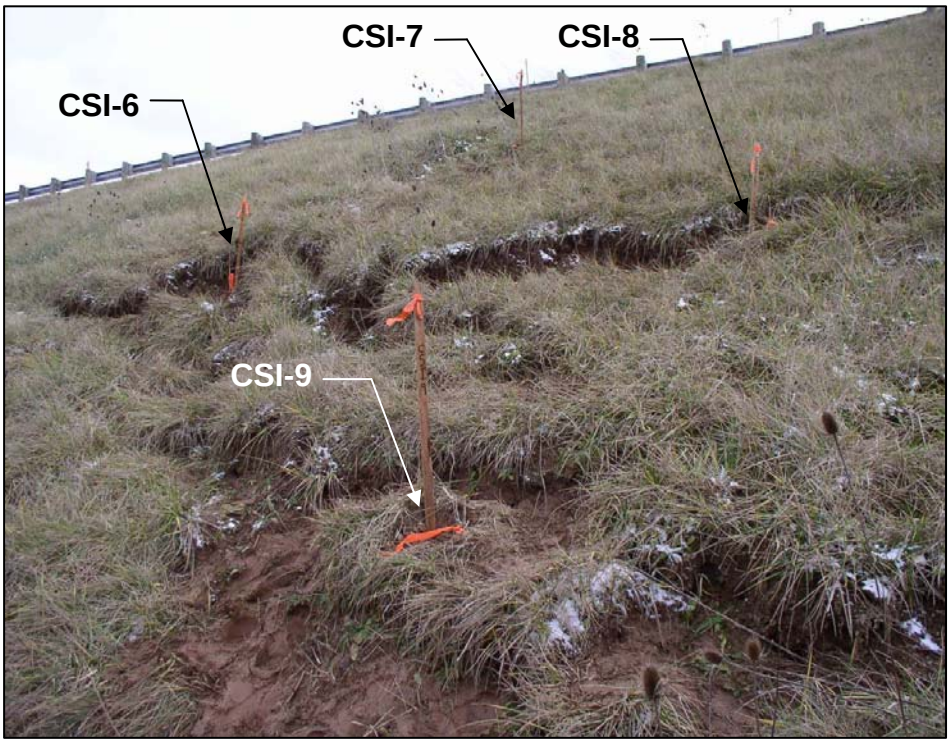


Figure 5.17: Copper shallow inclinometers installed during January 2005 at the Muskingum County demonstration site (photo taken by C. Kokesh).

5.5.6 Deep Inclinometers

One 30 ft. inclinometer, manufactured by Slope Indicator Co., was installed in boring B-1 at the toe of the 10:1 bench (Figure 5.15). The upper section of the inclinometer casing became disconnected from the lower sections shortly after the installation. As a result, data for this inclinometer could not be obtained.

5.6 CONSTRUCTION

The following sections describe details of the bioengineering design and construction. All vegetation, live poles and brushlayers, was harvested from Honda of America, Inc., in Marysville, Ohio, during April 2005 while still in the dormant state and cold stored at 32°F to maintain dormancy until installation. Two refrigerated walk-in storage coolers were used during this period; the first was at Acorn Farms in Zanesville, Ohio, and the second was at the Ohio State University Howlett Hall Greenhouse in Columbus, Ohio. To prevent desiccation, the vegetation was wrapped in burlap and routinely sprayed to maintain moisture. Dr. M. Alford of the OSU Herbarium conducted a microscopic examination of leaf specimens and identified the specie to be *Salix exigua*, common name "sandbar willow", but also indicated that the specie may possibly be *Salix longifolia* "long leaf willow". Since field identification was challenging, some other species, believed to be poplar, were also harvested. All species not identified as willows will be referred to as non-willows.

5.6.1 Construction Plans

Construction limits were set by OSU personnel and range approximately from Sta. 731+40 to Sta. 732+90 (Figure 5.9). The main pole plot was 45×55 ft., while the upper pole plot was 10×15 ft. in plan view. Figure 5.15 shows the approximate limits of the main pole plot relative to the instrumentation. Figure 5.18 illustrates a typical installation cross section with details pertaining to backfill and installation specifications. Further information about installation techniques will be discussed in the following section.

Construction at the Muskingum County demonstration site was intended to occur before mid-April 2005, while the vegetation was still in the dormant state. However, installation was delayed due to unsuccessful submissions after the contract was put out to bid. Due to lack of knowledge of performing such installations, all contractors that bid the project submitted proposals that exceeded the maximum allowable cost. Due to time constriction, OSU personnel decided to perform construction at the site. Construction crews of six to eight students/faculty were headed by Dr. T. H. Wu, Dr. P. Fox, C. Kokesh, and D. H. Barker during May and June of 2005. The final installation was completed after 15 working days and consisted of a total of 319 live poles and three brushlayer berms.

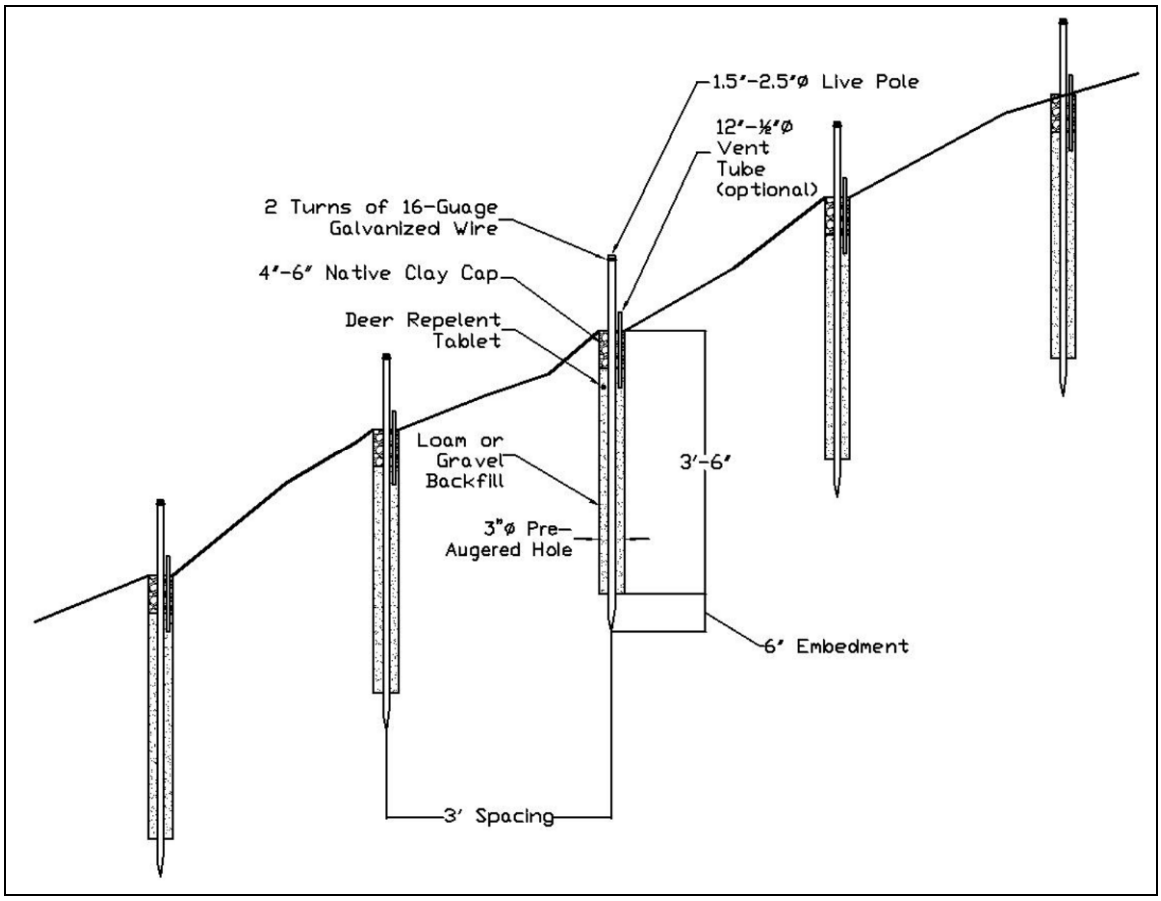


Figure 5.18: Typical live pole installation (Kokesh 2009).

5.6.2 Construction Procedures

5.6.2.1 Main pole plot

Construction of the main pole plot started in the last week of May and continued throughout the first two weeks of June 2005. Prior to installation, the face of this slope was re-graded by ODOT personnel. All scarps, bulges, and gullies that had resulted from previous erosion and sliding were filled and smoothed using a dozer. A total of 256 live poles were installed in a staggered grid pattern with a 3 ft. center-to-center spacing throughout the 55×45 ft. section. Poles were approximately 5 ft. in length and had diameters ranging from 1.0 to 2.25 in. An additional nine poles were installed in an erosion gully above the main plot to help arrest further erosion by diminishing the velocity of runoff from the above roadway. The general preparation and installation procedure for the main pole plot was:

1. Soaking – Prior to installation, the live pole and brushlayer cuttings were soaked in water for a minimum of three days. This was achieved by rotating the bundled vegetation from cold storage to a pond at Acorn Farms as needed.

2. Transportation – Using either a box truck or pickup truck, the cuttings were transported from the Acorn Farms' pond to the site. During the transfer the cuttings were covered with a tarpaulin to prevent drying.
3. Onsite storage – Cuttings were stored onsite in water-filled livestock feed troughs prior to installation. The water in the trough was drained and replenished every couple of days as the water would become spoiled due the heat at the site.
4. Live pole preparation – Pole dimensions were recorded, the butt end of each pole was shaped to a point, and any protruding branches and knobs were trimmed flush. Several turns of 16-gauge galvanized wire were secured to the top end of each pole to prevent splitting during installation.
5. Live pole installation – Holes were augered vertically into the slope using a two-man power auger with a 3 in. diameter auger bit to depths of 4.5 ft. One live pole each was placed into each pre-augered hole. The pole was then hammered firmly about 6 in. into the base of the hole using a large wooden mallet (this promotes intimate contact of the pole and the soil and stimulates root growth and accelerates the establishment of each willow). The annular space between each pole and its respective hole was backfilled with all-purpose sand in 6 in. lifts to about 4 to 6 in. below the ground surface and was tamped with a rod to fill all of the void space. A 0.5 in. diameter, 1 ft. length PVC pipe was placed in each hole adjacent to the pole protruding 3 in. above the ground surface and extending into the sand backfill to permit the circulation of air to the rooting zone (recommended by Alex Watson (personal communication with T. H. Wu)). The top 4 to 6 in. of each hole was then capped with granular bentonite to seal the hole and prevent rainwater from collecting inside (which would increase static pore pressures and further destabilize the slope). Each pole top was trimmed at a slight angle leaving 9 to 12 in. exposed above the ground surface. The pole tops were re-wired to prevent splitting due to desiccation. Treekote® tree wound dressing was also applied to prevent desiccation. Finally, an 18 in. diameter biodegradable weed control mat was pinned around the base of each pole to reduce competitive flora growth.
6. Surface erosion control – Geo-jute matting was installed following the live pole installation to reduce surficial erosion on the graded slope.
7. Seeding – Seeding of the slope was supposed to occur at the completion of the installation. However, due to scheduling conflicts and lack of resources, seeding did not occur at the site until July 2006.

The installation procedure was the same for each pole installed, with the exception of the type of backfill used. This was done so that the research team could get a side-by-side comparison of the effects of different backfill materials. It was also noted that several of the gravel backfilled pole installations had 0.5 in. diameter vent tubes. These tubes were installed, as recommended by A. Watson (personal communication with Dr. T. H. Wu), with the intent of providing a source of air for roots as the live poles became established.

A complete visual log for each step in the installation is presented in Appendix A. Figure 5.19 shows the main pole plot at the completion of the installation. Figure 5.20 shows the main pole plot as surveyed by OSU personnel with the locations of the various backfill techniques. Figure 5.21 shows the main pole plot with the locations of different species of vegetation.

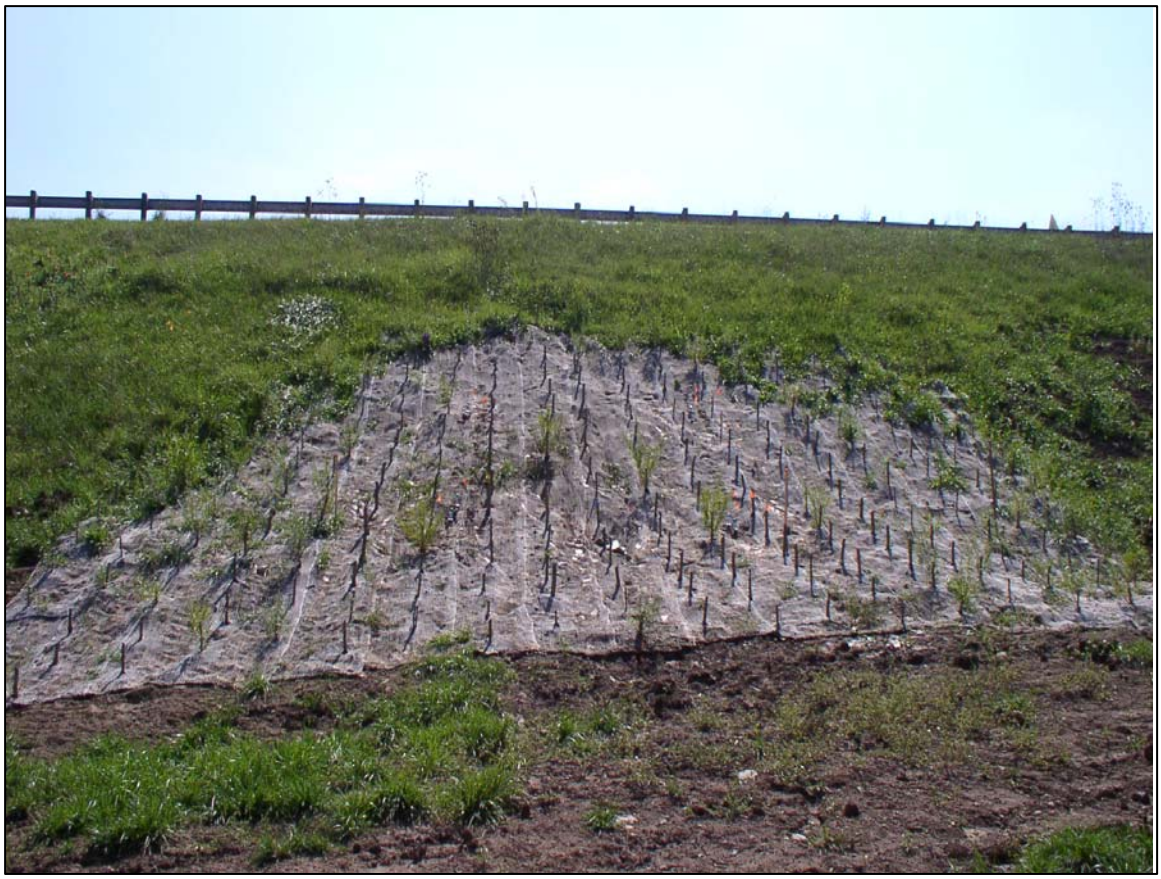


Figure 5.19: Muskingum County main pole plot at completion of installation.

5.6.2.2 Upper pole plot

Construction of the upper pole plot took place during the second week of June 2005, just after completion of the main pole plot. A total of 62 live poles were installed in a staggered grid pattern with a 2 ft. center-to-center spacing throughout the 10×15 ft. section. Poles were approximately 5 ft. in length and had diameters ranging from 1 to 2.25 in. Unlike the main pole plot, this area of the slope was not scraped or re-graded with the dozer. The slope was left "as is" so that the research team could get a side-by-side comparison of the effects that are gained/lost by re-grading.

The installation procedure for live poles in the upper plot was modified to a simplified version of the procedure for the main pole plot. Here, the poles were not sharpened to a point at the tip. The poles were also not wrapped with the 16-gauge wire at the top and pounded in. Instead, the poles were dropped into place and backfilled with

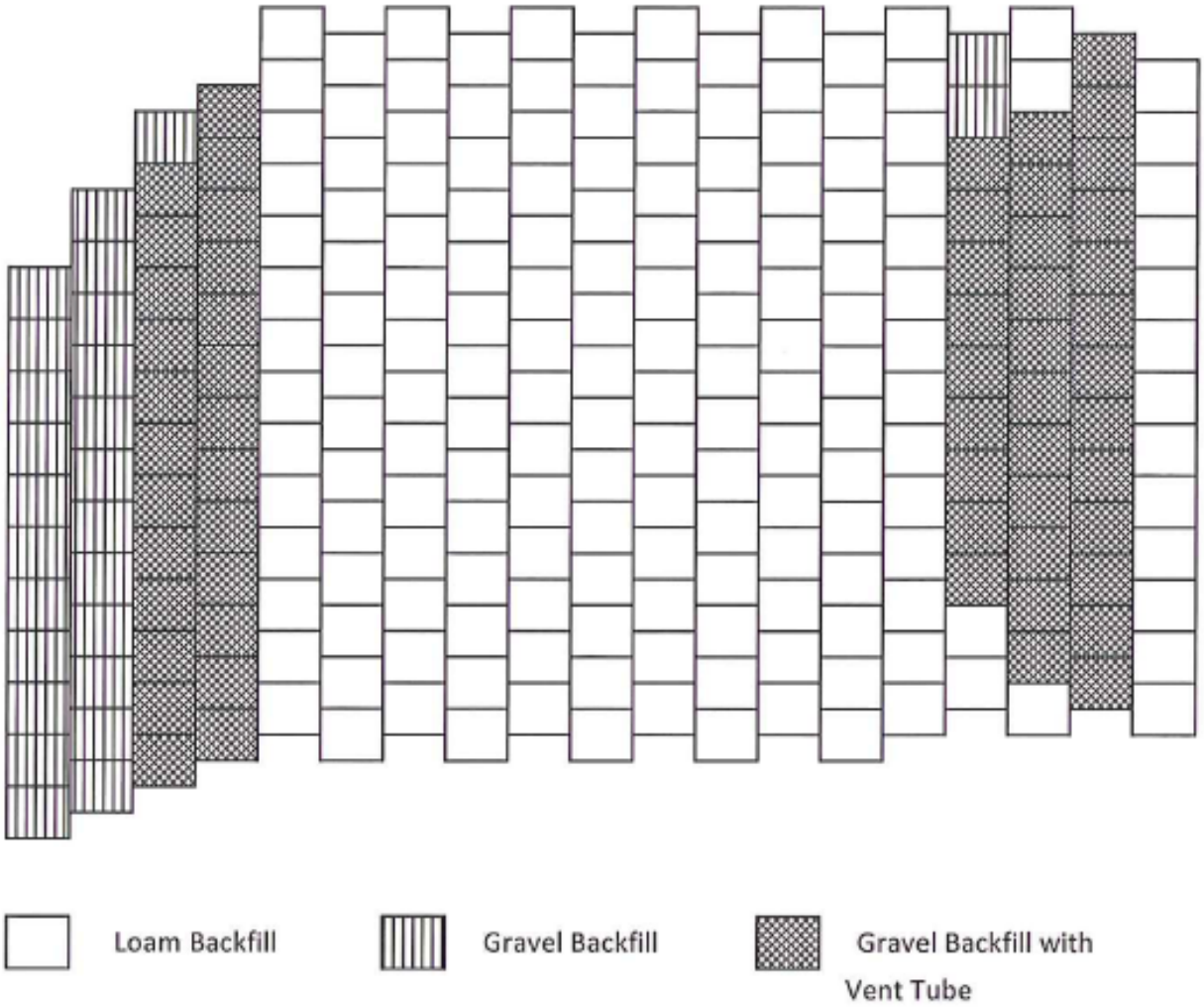


Figure 5.20: Muskingum County main pole plot backfill location layout (prepared by C. Kokesh).

loam only and capped as described in the previous section. The poles were then cut to the specified height and wire-wrapped to prevent splitting due to desiccation. A photograph of the completed installation is shown in Figure 5.22. Figure 5.23 shows the layout of the upper pole plot with the locations of different species of vegetation.

5.6.2.3 Brushlayer Berms

Three brushlayer berms were installed during the second week of June at the Muskingum County demonstration site after completion of the main and upper pole plots. The primary use of brushlayer berms is to provide erosion control rather than slope stability because the root systems are shallow. For this reason, no calculations have been performed to predict or verify the performance of these installations. Rather, the performance of these installations is based on visual observations. An initial cut was

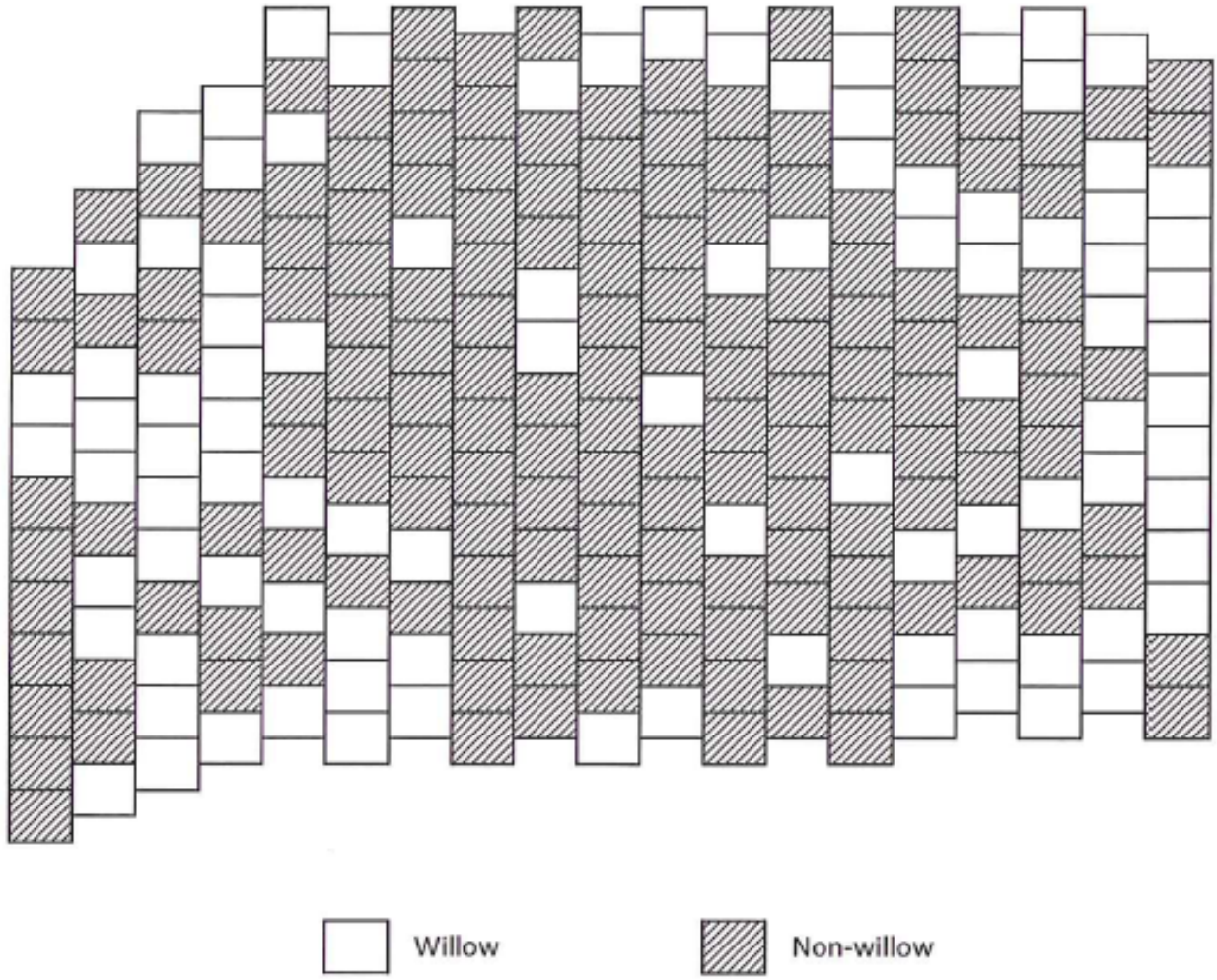


Figure 5.21: Vegetation layout for Muskingum County main pole plot (prepared by C. Kokesh).

made by the dozer to create the bench for each brushlayer. A photograph of the completed installation is shown in Figure 5.24.

The general preparation and installation procedure for the brushlayer berms was (Kokesh, 2009):

1. Live brush preparation (May to June 2005) – Although some of the smaller live pole stock was used, "as is" branch cuttings served as the primary medium for construction and no special preparatory measures were used.
2. Live brush installation (May to June 2005) – The brush material was placed at 2 to 4 in. spacing in a criss-cross overlapping fashion to cover the bottom of the excavated bench. Loam was used to cover the brush material and native clay soil was used to fill the remaining space to return the excavation to the pre-existing slope grade. The brushlayer branches were trimmed to protrude only 1 to 2 ft. from the slope contour.

Figure 5.22: Muskingum County upper pole plot at completion of installation.

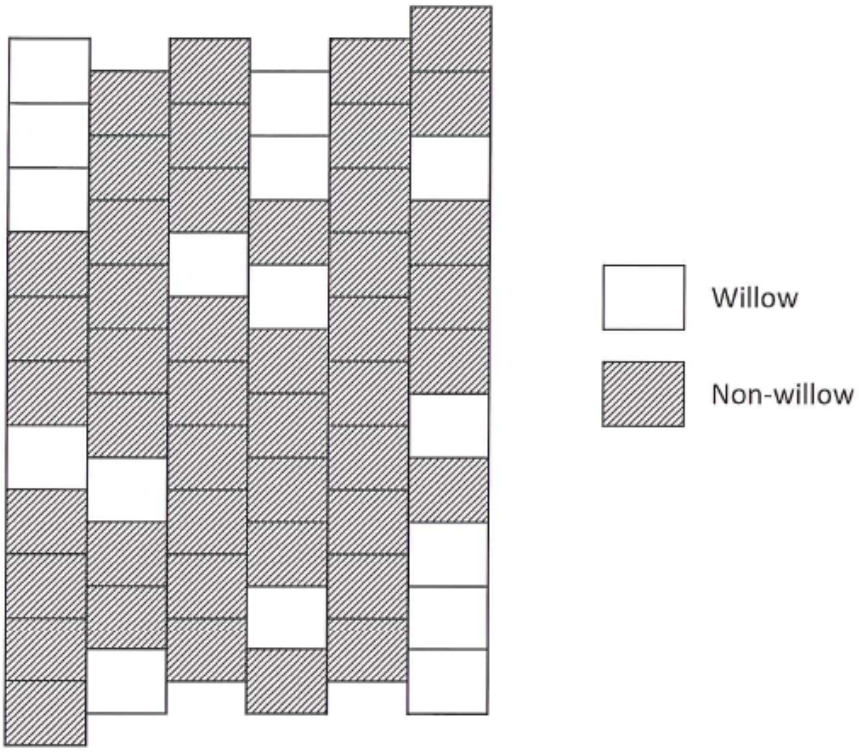


Figure 5.23: Vegetation layout for Muskingum County upper pole plot (prepared by C. Kokesh).

Figure 5.24: Muskingum County brushlayer berms at completion of installation.

5.6.2.4 Replacement Installations

Due to poor initial survival (see Section 5.7.2), two replacement installations were conducted at the Muskingum County demonstration site. The first replacement was conducted on April 7-9, 2006, when 39 new poles were installed in the main and upper pole plots. This replacement included performing vertical pullout tests (see Section 4.8.1) on 30 dead poles in the main pole plot and 9 dead poles in the upper pole plot. Additional information on the vertical pullout test procedure and results is provided in Section 5.7.4. After the dead poles were extracted, recently harvested poles were replanted in the same hole using the installation procedure outlined in Section 5.6.2.1. All poles for this installation were harvested one week prior to planting from the Delaware Wildlife Area in Delaware County, Ohio, and were kept under water in a trough to prevent desiccation until planting. Figure 5.25 and Figure 5.26 shows the layout of the main and upper pole plots respectively after the first replacement installation. All replacement poles are designated with yellow markers.

Due to a further decrease in survival over the summer of 2006, a second replacement was conducted on December 15-17, 2006. This installation involved replacing 30 dead poles within the main pole plot. No vertical pullout tests were conducted at this time. Replacement poles were harvested from the Delaware Wildlife Area in Delaware County, Ohio, and were kept under water in a trough to prevent drying

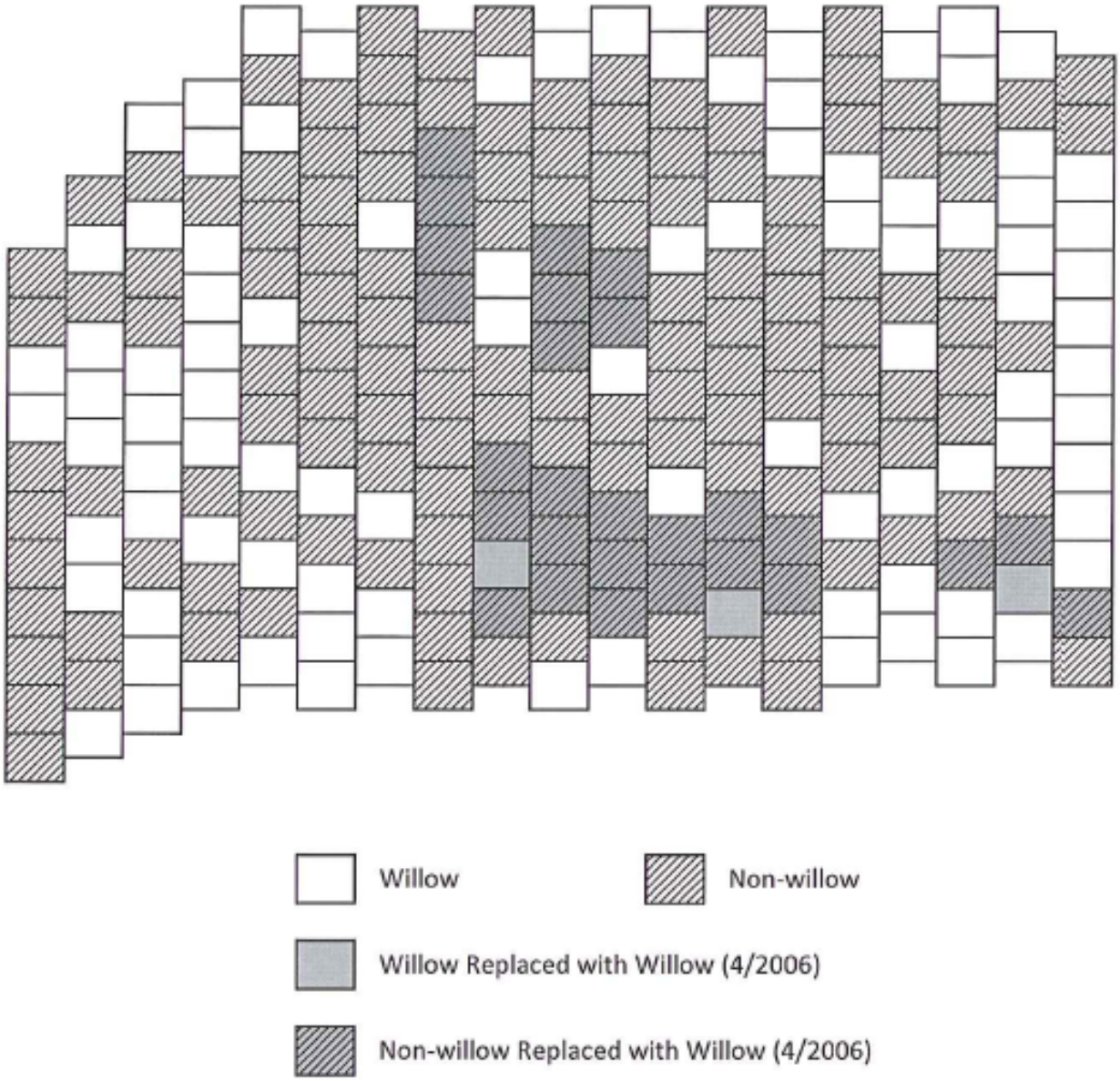


Figure 5.25: Muskingum County main live pole layout after first replacement installation.

and desiccation until planting. After the dead poles were extracted, recently harvested poles were replanted in the same hole using the installation procedure outlined in section 5.6.2.1. Figure 5.27 shows the layout of the main pole plot after the second replacement installation. All replacement poles from the second installation are designated with red markers, and all replacement poles from the first installation are designated with yellow markers.

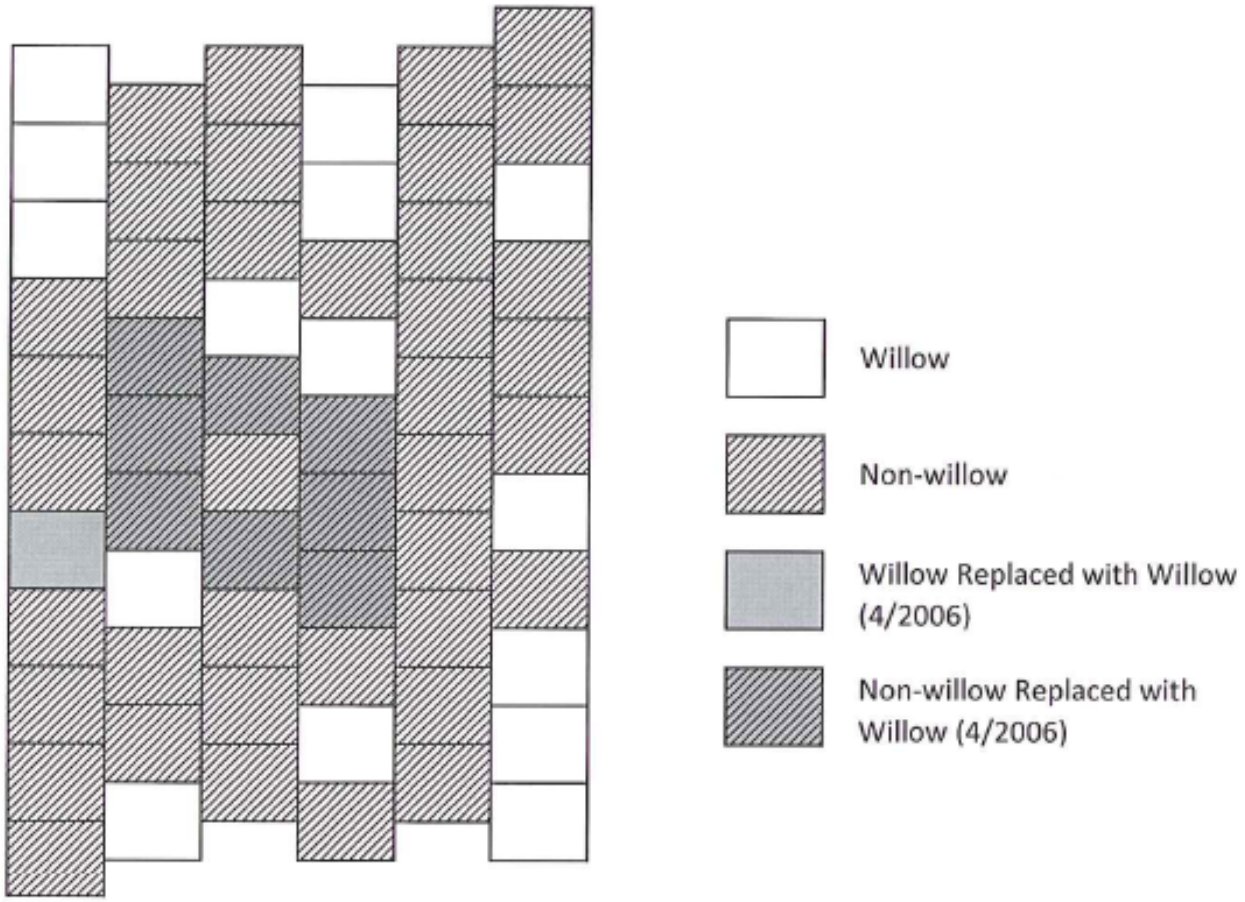


Figure 5.26: Muskingum County upper live pole layout after first replacement installation.

5.7 PERFORMANCE

This section presents performance data pertaining to the installations completed during spring 2005, and spring and winter of 2006 at the Muskingum County demonstration site. Biostabilization performance is based primarily on vegetation survival rates and slope deformation that has occurred subsequent to installation. Moisture conditions within the stabilized portion of the slope were closely monitored as that is one of the factors that influences survival. Climate was also monitored as that has a large impact on slope moisture conditions. Additionally, stability and cost was evaluated, and pile testing was conducted on live and dead poles to verify pile equations that were used in stability analyses.

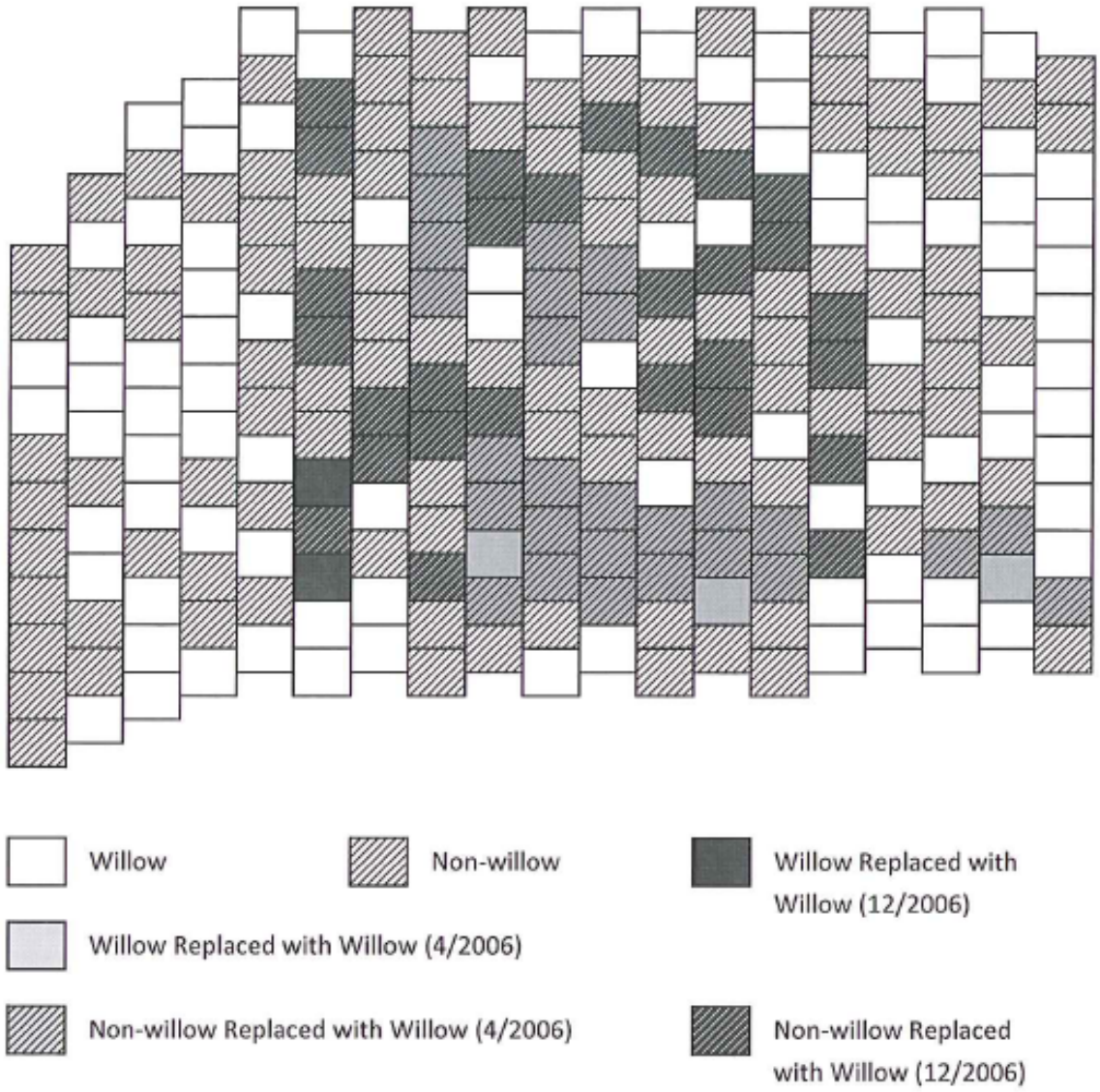


Figure 5.27: Muskingum County main live pole layout after second replacement installation.

5.7.1 Groundwater and Moisture Conditions

Groundwater and moisture conditions within the slope have been monitored throughout the project. Figure 5.28 through Figure 5.30 show graphs of soil suctions as measured by tensiometers, water contents measured by G-Blocks, piezometric levels from shallow monitoring wells, and monthly precipitation data, respectively, for stations 1 and 3, stations 2 and 4, and stations 5 to 7 from January 2005 through December 2008.

Soil suctions measured by tensiometers for the main and upper pole plots are shown in Figure 5.28(a), Figure 5.29(a) and Figure 5.30(a). Soil suctions in the upper 3 ft. of the slope are generally less than 3 psi. Suctions are similar for stations 1 through 4

and show no consistent trend with depth. A general increase in soil suction occurred in 2007 and continued through 2008. According to precipitation data, late spring and early summer 2007 (May through June) were considerably drier than the previous years, with monthly precipitation more than an inch below average during all three months. Stations outside of the main and upper pole plots (stations 5 and 6) show a slightly lower increase than those inside the live pole plots. This trend is expected for stations within the main pole plot due to vegetation demands; however, low survival within the upper pole plot (see Section 5.7.2) reduced the vegetation demand and thus soil suctions were lower in the upper pole plot. Root growth and establishment of vegetation within the live pole plots typically cause an increase in soil suction. This could explain the differences in measured suction within and outside the main pole plot.

Soil suction values were obtained from empirical relationships for G-Blocks provided by the manufacturer. G-Block water contents (as determined from the OSU laboratory calibration curve) for the main and upper pole plots are shown in Figure 5.28(b), Figure 5.29(b) and Figure 5.30(b). Soil suctions and water contents ranged from 2.0 to 10.8 psi and 22.5 to 45%, respectively. A table and charts of soil suction values and water contents from G-Blocks for each station are provided in Appendix A.

G-Block water contents are generally scattered and show no corresponding trend that the water content within the zones of increased suction was decreasing. In-situ moisture contents measured indirectly through G-Blocks show no significant changes over the monitoring period. In general, moisture contents in the lower portion of the slope within the main pole plot (stations 3 and 4) were higher than those in the upper portion of the slope (stations 1 and 2). The water contents ranged from 25% to over 45%. The water content measured outside of the reinforced areas (stations 5 and 6) ranged from 35% to over 45%, with most readings indicating water contents over 45%. There was no clear correlation between water contents measured from G-Blocks and soil suctions measured from tensiometers over the monitoring period.

The piezometric levels from shallow wells P-3 through P-6 are shown in Figure 5.28(c), Figure 5.29(c) and Figure 5.30(c). Piezometric levels of 21.6 to 22.9 ft. below the ground surface have been observed in piezometer P-1 since its installation during March of 2005. Piezometric levels for shallow monitoring wells within the main pole plot as high as 0.4 ft. below the ground surface have been observed in the P-3; dry conditions have also been recorded for each well. Piezometric levels in monitoring well P-6 ranged from 2.6 to 3.6 ft. below the ground surface. Groundwater levels observed in the shallow monitoring wells (at depths less than 4 ft.) also indicate that a perched water table is present throughout the area as levels observed in piezometer P-1 fluctuated slightly at depths greater than 20 ft. Groundwater has been observed seeping along the slope face near the base of the slope (above the bench) at regular intervals along the entrance ramp and I-70 westbound where drainage outlets are located (Figure 5.4). The drainage blanket installed during the last renovation of the slope may be clogged or malfunctioning, thus preventing water from draining properly. A complete table of piezometric data is presented in Appendix A.

Water levels observed in the deep piezometer (P-1) remained relatively constant, whereas levels in the shallow monitoring wells within the main pole plot showed more fluctuations and were lower in 2007 than previous years, which is consistent with the soil suction measurements. This drying trend could be attributed to below-average

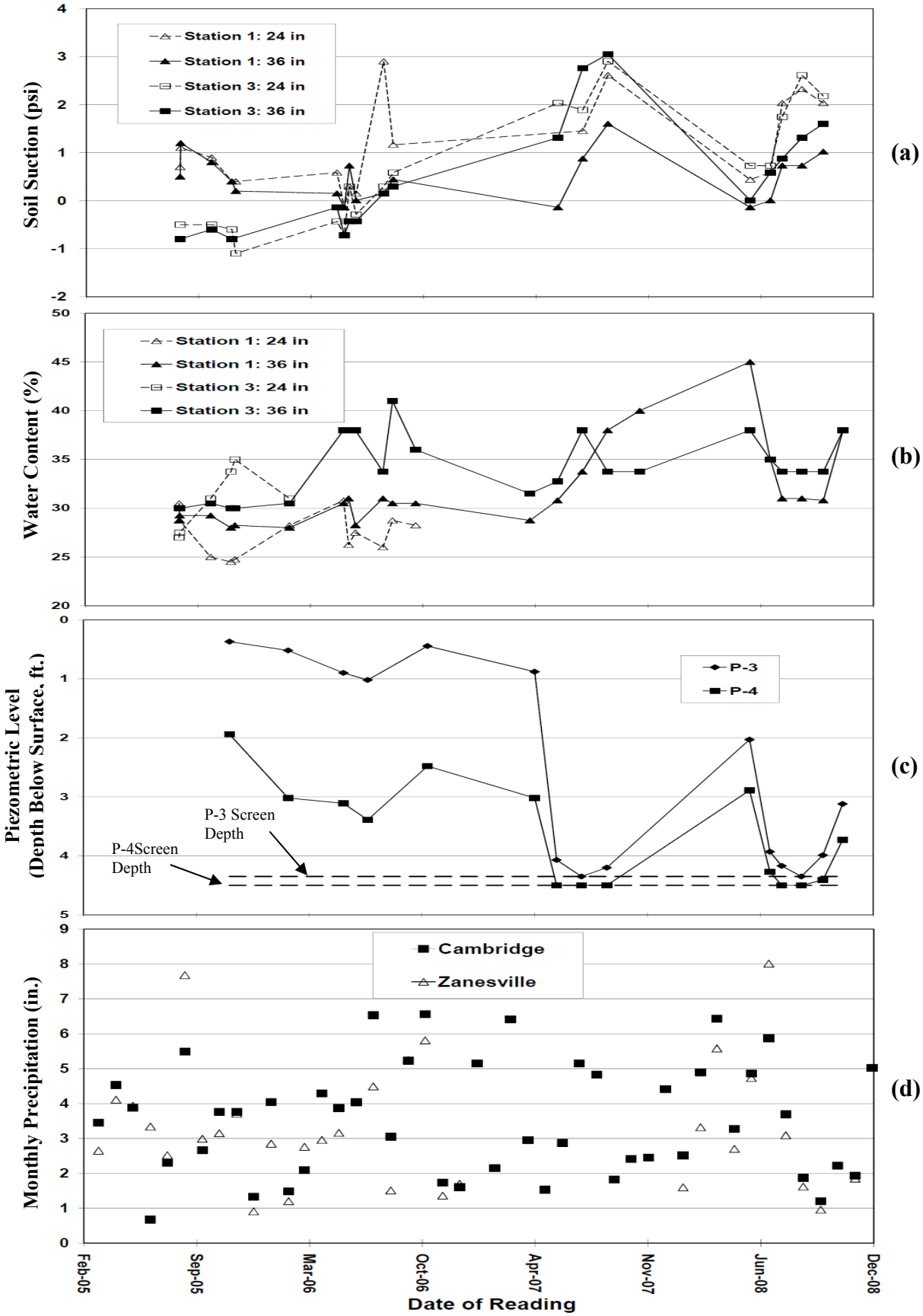


Figure 5.28: Graphs of: a) soil suctions from tensiometers, b) water contents from G-Blocks for stations 1 and 3, c) piezometric head levels from shallow monitoring wells and d) monthly precipitation for Muskingum County, Ohio.

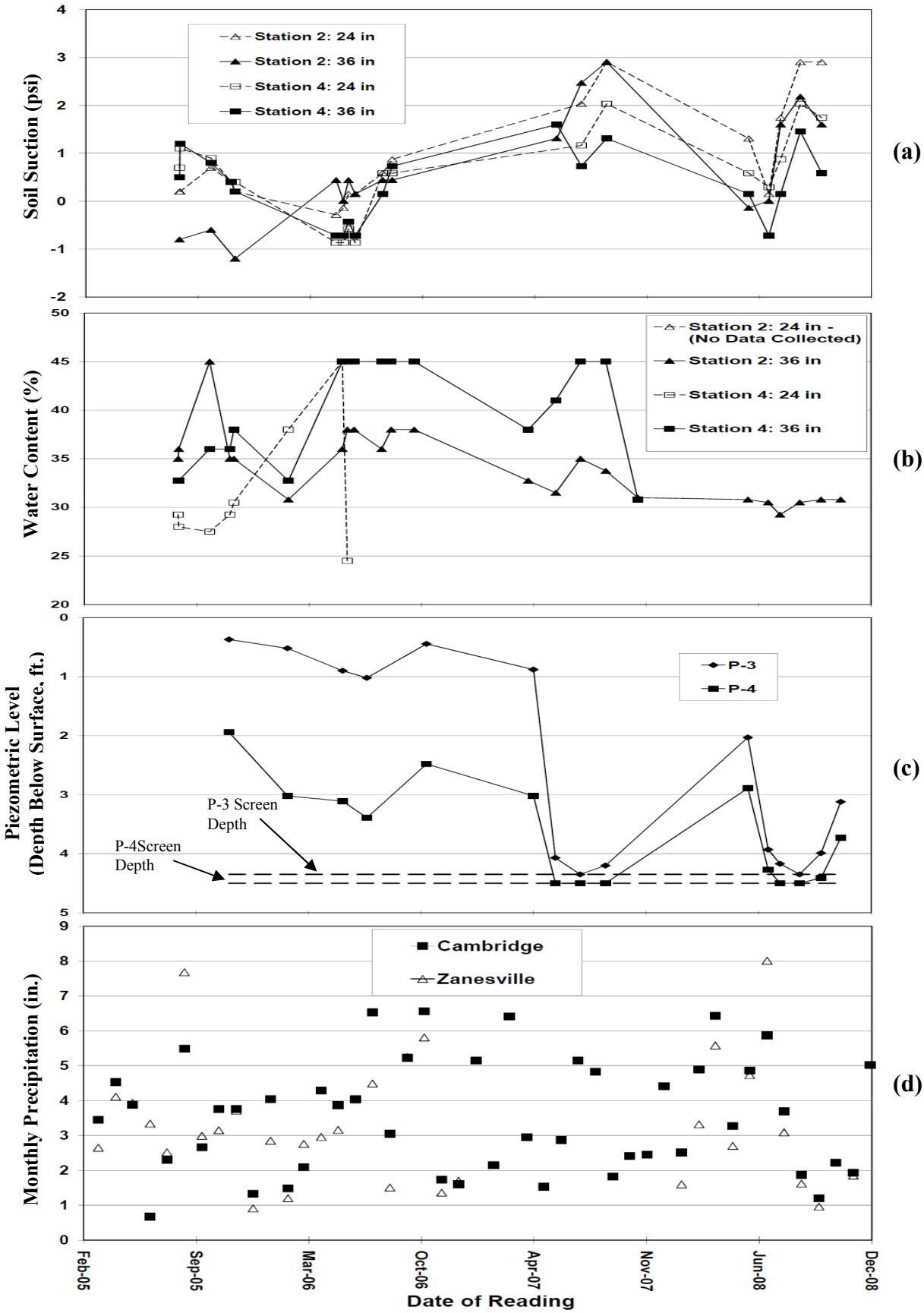


Figure 5.29: Graphs of: a) soil suction from tensiometers, b) water contents from G-Blocks for stations 2 and 4, c) piezometric head levels from shallow monitoring wells and d) monthly precipitation for Muskingum County, Ohio.

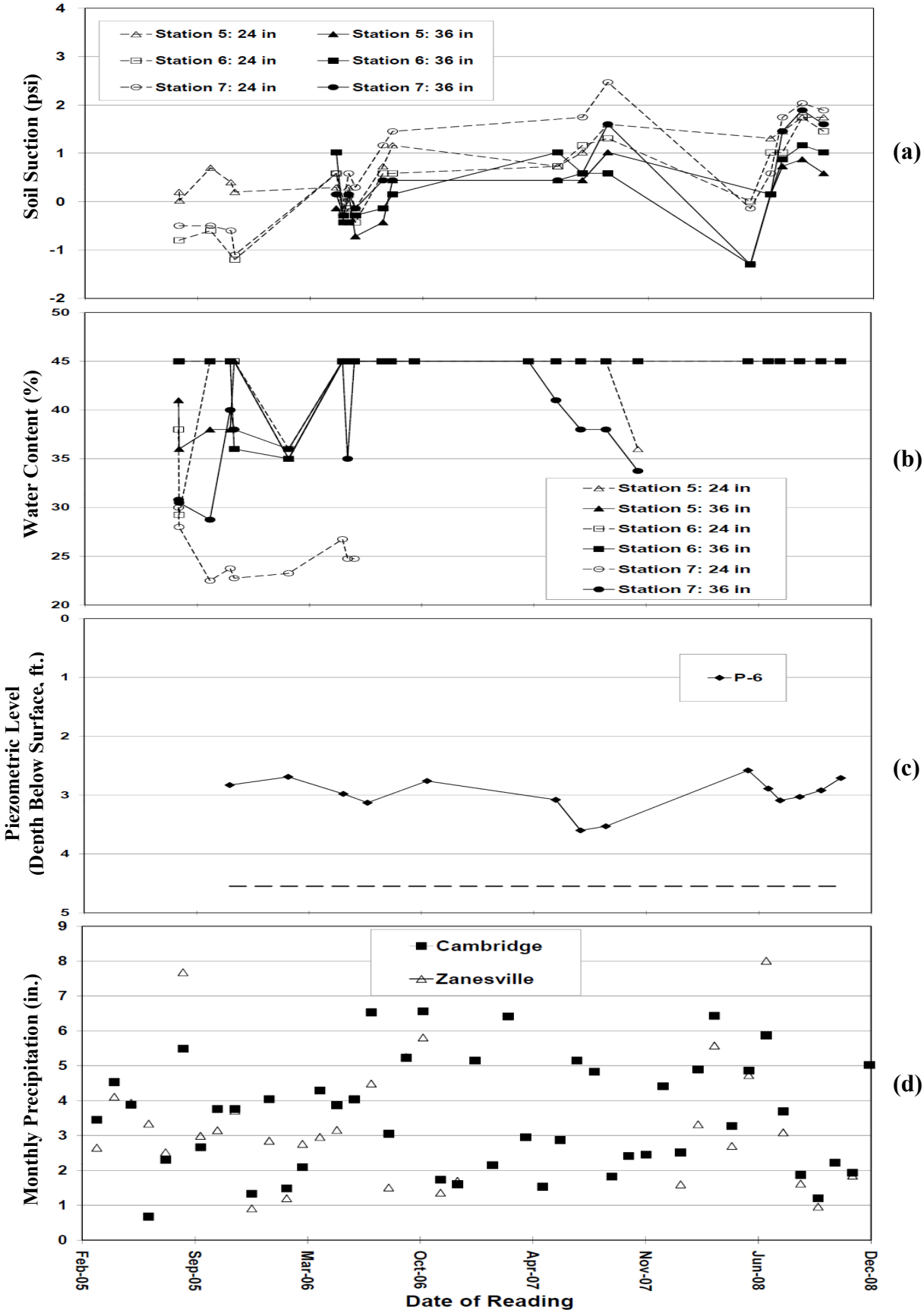


Figure 5.30: Graphs of: a) soil suctions from tensiometers, b) water contents from G-Blocks for stations 5 to 7, c) piezometric head levels from shallow monitoring wells and d) monthly precipitation for Muskingum County, Ohio.

precipitation and the establishment of vegetation, which may have drawn water from the soil. It was noted that piezometric levels in the perched water table within the upper portion of the main pole plot decreased substantially during this period. A similar trend was not observed for the shallow well in the upper pole plot (P-6). Piezometric levels at this station remained relatively constant throughout the project. Poor vegetation survival, and consequently little to no root growth, produced low additional water demand in this section of the site.

5.7.1.1 Correlations Between Field and Laboratory Measurements of Soil Suction

Figure 5.31 shows a comparison of soil suction measured directly from tensiometers with values determined indirectly through correlations of measured G-Block water contents with the soil-moisture characteristic curve (SMCC) (Figure 5.11). Suctions measured from the tensiometers were inconsistent with values based on G-Block water contents at the same locations. The dotted line in Figure 5.31 represents the trend for which suction values are equal. The scatter in the data may be due to the large variation in water content at low suctions. Figure 5.32 shows a comparison of the water content vs. soil suction from field measurements with the laboratory SMCC. Field soil-moisture values consist of soil suctions measured from tensiometers and water contents measured from G-Blocks converted using the laboratory calibration curve. The laboratory SMCC was extrapolated using a best-fit regression to include soil suctions for the measured range of water contents observed in the field. Figure 5.32 indicates that there is no clear trend in soil moisture measured in the field as compared with the laboratory SMCC.

5.7.2 Vegetation Survival Rates and Statistics

One of the key performance issues that relate to the success and feasibility of the project is vegetation survival. An inventory of all live poles has been conducted during the late spring/early summer and late fall seasons in order to assess survival rates over time. Table 5.3 and Figure 5.33 presents a summary of survival rates for the initial planting, first and second replacement installations, and overall survival of vegetation for the main pole plot. A graphical log of each survival inventory for the main and upper pole plots is provided in Appendix A.

Table 5.3 indicates that there was a poor survival rate from the initial planting. This could be attributed to a several factors. First, the initial installation occurred well after the optimal planting window, which is between November 1 and April 1 (Barker, 1997). Second, refrigerated storage of the cuttings from the time of harvest to installation almost certainly contributed to low survival as the vegetation may have dried out and died during this 6-week time period. Table 5.4 shows the individual survival rates of willows and non-willows from the initial installation. Willow vegetation establishment was initially higher than non-willow. After that, non-willow survival declined dramatically. The remainder of non-willows still living has since then declined severely over the winter of 2005/2006, and eventually fell to zero by the summer of 2007. This indicates that the non-willows are less durable than willows under adverse climate.

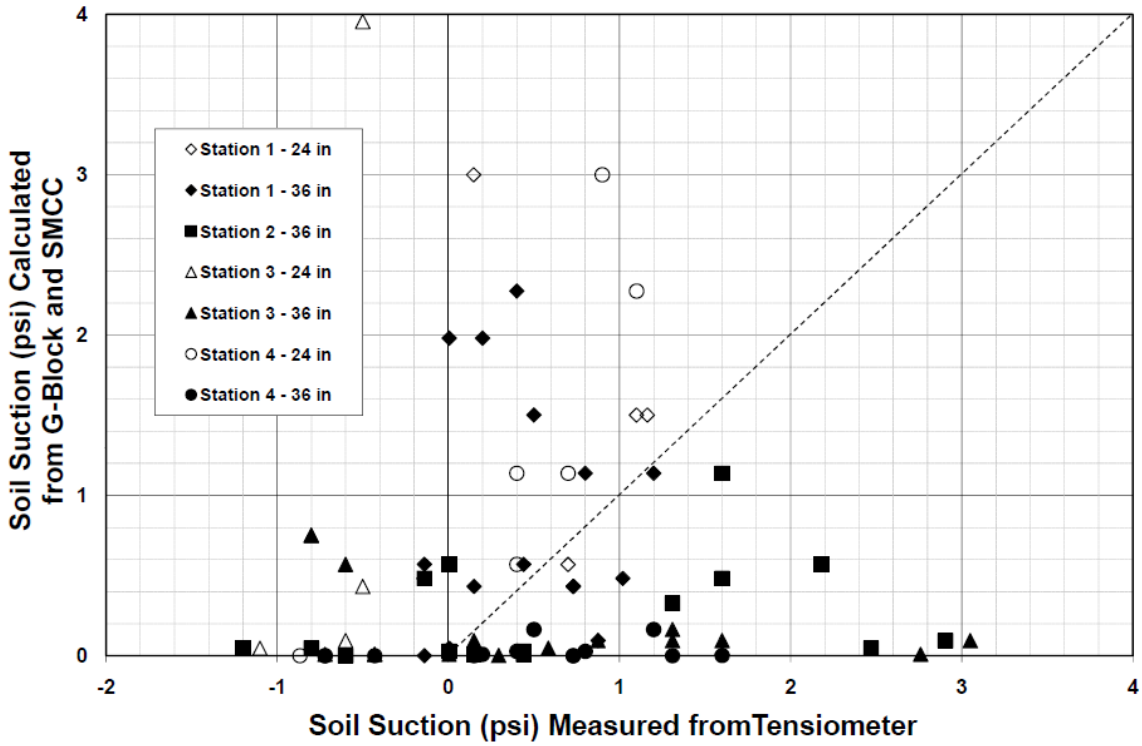


Figure 5.31: Comparison of soil suction measured from tensiometers and calculated from measured G-Block water contents and Soil Moisture Characteristic Curve (SMCC).

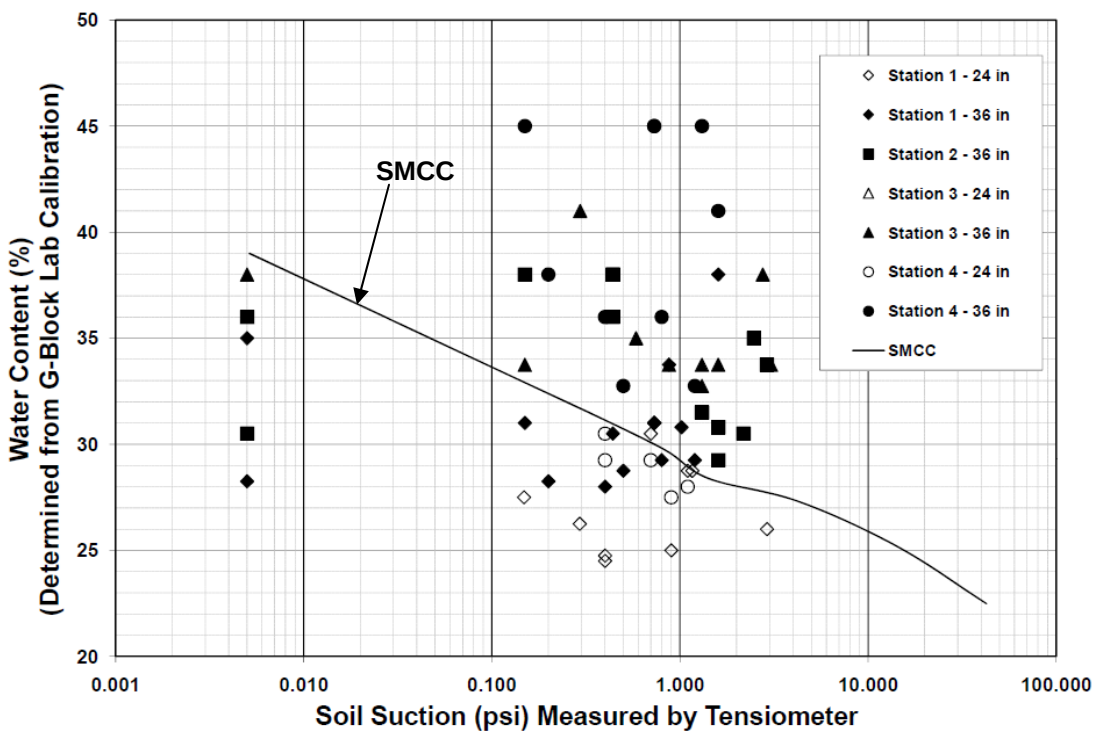


Figure 5.32: Comparison of soil suctions measured from tensiometers and calculated from measured G-Block water contents and the SMCC.

Table 5.3 [1]: Summary of vegetation survival rates for the main pole plot at the Muskingum County demonstration site.

Date	Initial Planting Survival Rate (%) [2]	First Replacement (Apr. 06) Survival Rate (%)	Second Replacement (Dec. 06) Survival Rate (%)	Overall Survival Rate (%) [3]
28-Sep-05	54.0	-	-	54.0
12-Jun-06	28.7	90.0	-	39.1
25-Sep-06	27.2	90.0	-	37.6
6-Jun-07	22.6	86.7	63.3	39.9
3-Sep-07	22.6	86.7	53.3	38.0
13-May-08	22.6	83.3	50.0	37.9
20-Sep-08	22.6	83.3	50.0	37.9
15-May-09	22.6	80.0	50.0	37.6

[1] Initial and overall survival rates are based on a total of 261 poles installed. The first and second replacement survival rates are based on a total of 30 poles installed for each replacement.

[2] Initial planting survival rate counts any replacement poles as dead.

[3] Overall survival rate is the current percentage of all live poles. It includes all poles still living from the initial planting and from both replacements.

Table 5.3 also provides survival rates for the first and second replacement installations. The vegetation used in these installations was willow species harvested from the Delaware Wildlife Area, and was visually identified by ODNR personnel prior to harvesting. The first replacement installation was conducted in early April 2006. Initial survival was recorded at 90% by the end of the summer of 2006, and has fallen slightly to 80% in May 2009. The second replacement installation was conducted in mid-December 2006. Initial survival of this installation was 64%, which is very close to that observed from the initial planting survival rate for willow species only (Table 5.4). However, the survival rate for this installation has fallen to 50% in May 2009. The lower survival rates observed for the second replacement installation may be related to the time of harvesting and installation (late fall). While the second replacement occurred during the appropriate time window (November 1 to April 1), the poles had to survive the winter. This may have adversely affected vegetation survival as the poles had just entered the dormant stage prior to harvesting and may not have had sufficient biomass to sustain them during the remainder of the dormant season. It was also noted that precipitation during the spring and early summer months of 2007 was lower than during 2006. This, combined with the time of installation, may have had an adverse effect on the survival rate of second replacement installation.

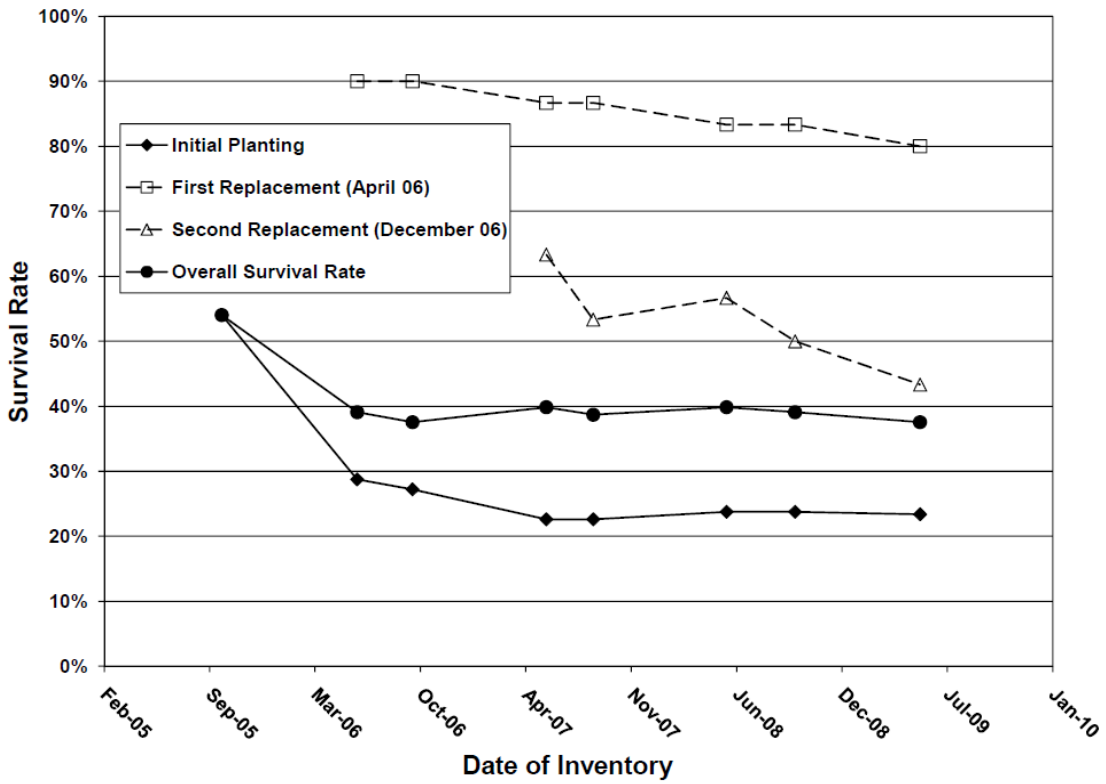


Figure 5.33: Vegetation survival rates for the main pole plot at the Muskingum County demonstration site.

Table 5.4: Summary of survival rates of willows and non-willows from the initial installation of the main pole plot at the Muskingum County demonstration site.

Date	Willow Survival Rate (Initial Planting) [1]	Non-Willow Survival Rate (Initial Planting) [2]	Overall Initial Planting Survival Rate [3]
28-Sep-05	65.6%	47.3%	54.0%
12-Jun-06	64.6%	7.88%	28.7%
25-Sep-06	64.6%	5.45%	27.2%
6-Jun-07	61.5%	0.00%	22.6%
3-Sep-07	61.5%	0.00%	22.6%
13-May-08	61.5%	0.00%	22.6%
20-Sep-08	61.5%	0.00%	22.6%
15-May-09	61.5%	0.00%	22.6%

[1] Willow survival rate is based on a total of 96 willows planted during initial installation.

[2] Non-willow survival rate is based on a total of 165 non-willows planted during initial installation.

[3] Initial planting survival rate counts replacement poles as dead.

Survivability data clearly indicates that willow species are more durable than non-willow species for the Muskingum County demonstration site. Although the replacement installations were small in comparison to the initial installation, the data does suggest that the time of installation is an important factor in the success of vegetation establishment. Initial survival of vegetation may also be heavily influenced by precipitation and temperature fluctuations during the first months after installation. Further details pertaining to climate effects will be presented in the following section.

Table 5.5 presents the survival statistics for the upper pole plot. The survival rate from the initial installation is consistent with the survival rate of the initial installation for the main pole plot. Once again, this may be attributed to the fact that the initial installation occurred well after the optimal planting window. Approximately 25% of the initial installation in the upper pole plot was visually identified as willow species. It is suspected that the remaining poles were poplar cuttings. Of the nearly 21% surviving vegetation from the initial planting, all are willow species; no non-willow species survived the first winter of 2006. During the first replacement of April 2006, 9 dead poles, mostly non-willows, were replaced with willows. However, the initial survival rate of this replacement within the upper pole plot was significantly lower than that observed in the main pole plot, and has since then fallen to 11% survival. Drier near-surface moisture conditions may have adversely affected vegetation establishment.

Table 5.5 [1]: Summary of survival rates for the upper pole plot at the Muskingum County demonstration site.

Date	Initial Planting Survival Rate [2]	First Replacement Survival Rate (April 06)	Overall Survival Rate (%) [3]
28-Sep-05	48.4%	N/A	48.4%
12-Jun-06	24.3%	66.7%	33.9%
25-Sep-06	19.4%	66.7%	29.0%
6-Jun-07	19.4%	33.3%	24.2%
3-Sep-07	19.4%	11.1%	21.0%
13-May-08	19.4%	11.1%	21.0%
20-Sep-08	19.4%	11.1%	21.0%
15-May-09	19.4%	11.1%	21.0%

[1] Initial and overall survival rates are based on a total of 62 poles installed. The first replacement survival rate is based on a total of 9 poles installed.

[2] Initial planting survival rate counts replacement poles as dead.

[3] Overall survival rate is the current percentage of all live poles. It includes all poles still living from the initial planting and from replacement.

Survival of the brushlayer berms was based on observations made during site visits. Extensive growth has been observed for each of these berms over the duration of the project. The average shoot length of the vegetation is over 6 ft. for each berm. The extent of the dense growth occurring at the berms suggests that the root systems of the vegetation would be sufficient to prevent erosion along the slope face.

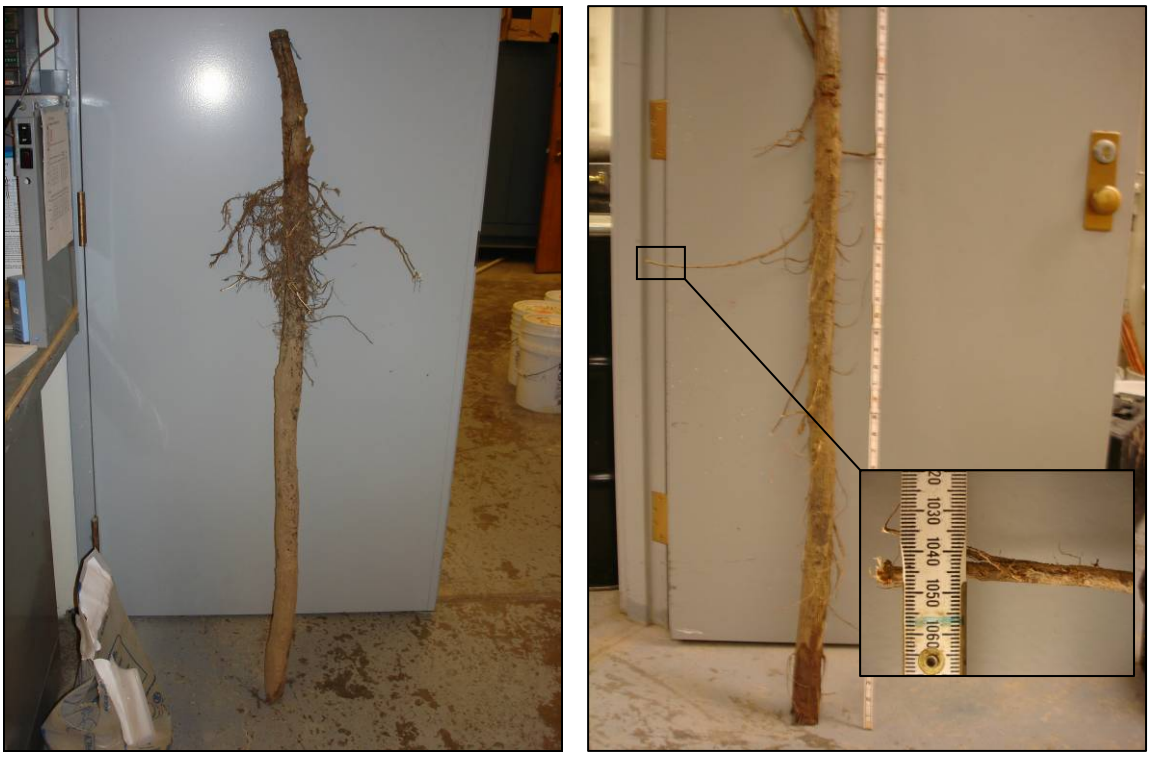
5.7.2.1 Extent of Growth and Rooting From Extracted Live Poles

Two live poles from the main pole plot, poles 15-2 (column number-pole number with respect to bottom pole in respective column) and 8-10, were pulled to obtain both the ultimate force required to pull a live, rooted pole vertically out of the ground and to obtain data on the rooting zone and typical root sizes of established vegetation. The poles had a total and embedded length of approximately 5.0 and 3.9 ft., respectively. As noted from the pole identifications, pole 15-2 was located at the bottom of the slope, while pole 8-10 was near the top of the slope. It was noted in Section 5.7.1 that a perched groundwater table is present at the site. Data obtained from shallow monitoring wells indicate that the phreatic surface of this perched groundwater is closer to the ground surface near the bottom of the slope. In general, the bottom well (P-3) had groundwater levels ranging from 0.37 ft. to 1.02 ft. below the ground surface for the duration that pole 15-2 was growing. Groundwater levels in the upper portion of the slope ranged from 1.92 ft. below the ground surface to below 4.5 ft. (dry well). This trend in groundwater fluctuations seems to have affected the rooting zone and extent of rooting at these locations.

Roots were observed just below the ground surface along the embedded portion of both poles. Rooting extended to a depth of 1.4 ft. below the ground surface on pole 15-2, while roots were observed along the entire length of the embedded portion of pole 8-10. From Figure 5.34(a), it can be seen that pole 15-2 contains a "root ball" consisting of a dense network of fine to large roots, ranging in size from 0.008 to 0.150 in. in diameter. Maximum root lengths were approximately 6 to 12 in.; however, the roots were damaged by the extraction process and these lengths are considered unreliable. The shallow depth of rooting for pole 15-2 is consistent with observed shallow groundwater levels in near-surface wells (and water running out of open holes near the bottom of the slope). This indicates that the embedded portion of the pole not containing root growth was submerged below the groundwater table. In contrast, Figure 5.34(b) shows that pole 8-10 mostly had larger roots, ranging in diameter from 0.040 to 0.240 in., with a small percentage of fine roots present along the entire length. Groundwater levels fluctuated in this region of the slope, ranging from partially submerged during the winter to mostly dry during the summer.

Similar results were observed from the laboratory study of the effects of soil-moisture on willow survival by Pezeshki et al. (1998b) presented in detail in Section 3.6. However, there is no clear trend in survivability for the main pole plot that suggests certain groundwater conditions promote survival better than others. This is further supported as there is also no trend in survivability between the upper pole plot and the upper portion of the main pole plot, where similar groundwater conditions were present.

It should be noted that since these poles were pulled vertically, the amount and size of roots remaining attached may not be representative of actual in-situ conditions.



(a) (b)

Figure 5.34: Live willow poles with attached roots from vertical pullout tests: a) pole 15-2, and b) pole 8-10.

Finer roots that could not withstand the stress during the pullout test may have broken off, thus leading to a smaller number of finer-sized roots observed.

5.7.2.2 New Additional Growth

During late summer 2007 and throughout 2008, new growth has been observed within areas of the main pole plot that were not planted by the research team. Figure 5.35 shows an example of such growth. This is a promising sign that the vegetation is further establishing and propagating throughout the installation area. New growth provides additional stability to the slope with the new root systems growing and intertwining with plants that have already become established.

5.7.3 Displacements

Prior to slope re-grading and installation of live poles, slope displacements were observed and recorded at the Muskingum County demonstration site using CSIs. In May 2005, five CSI's (CSI-5 to CSI-9) were exhumed from the lower slope. Of these, only CSI-8 and CSI-9 were recovered successfully without damage. Slope displacements of approximately 2.0 in. at the top were directly measured by CSI-8 and CSI-9 for the 5-

Figure 5.35: New growth within the Muskingum County main pole plot. Growth on the right is from an established willow.

month period between January and May 2005. Figure 5.36 shows pictures of the exhumed CSIs.

Post-installation displacements have been monitored using CSIs, by laser surveying a line of stakes placed laterally along the mid-slope of the installation area, and by surveying the poles along the slope face. Survey stakes were aligned and surveyed using a laser level supported on a tripod.

Since the initial pole installation in May/June 2005, small isolated bulges and shallow movements have been observed along the bottom and eastern side of the main pole plot. CSIs were installed at these locations to quantify any additional movements. A large gully has formed near the top of the main pole plot near the center. It is uncertain whether this gully was repaired prior to construction, or whether it formed since the completion of construction. The gully is in-line with the shallow monitoring wells installed within the main pole plot as well as with the area of observed surface seepage. There is also evidence of erosion and shallow sliding in the non-stabilized area between the main pole plot and the brushlayer berms. Figure 5.37 shows photographs of these features.

Subsequent to the installation of live poles, slope displacements were observed and recorded at the Muskingum County demonstration site using CSIs. In August 2009, two CSI's (CSI-22 and CSI-29) were exhumed from the main pole plot. Negligible slope displacements were measured by these CSI's for the 24 – 36-month periods between August 2006/2007 and August 2009. Figure 5.38 shows pictures of the exhumed CSIs.

To further identify and quantify the amount and extent of slope movements within

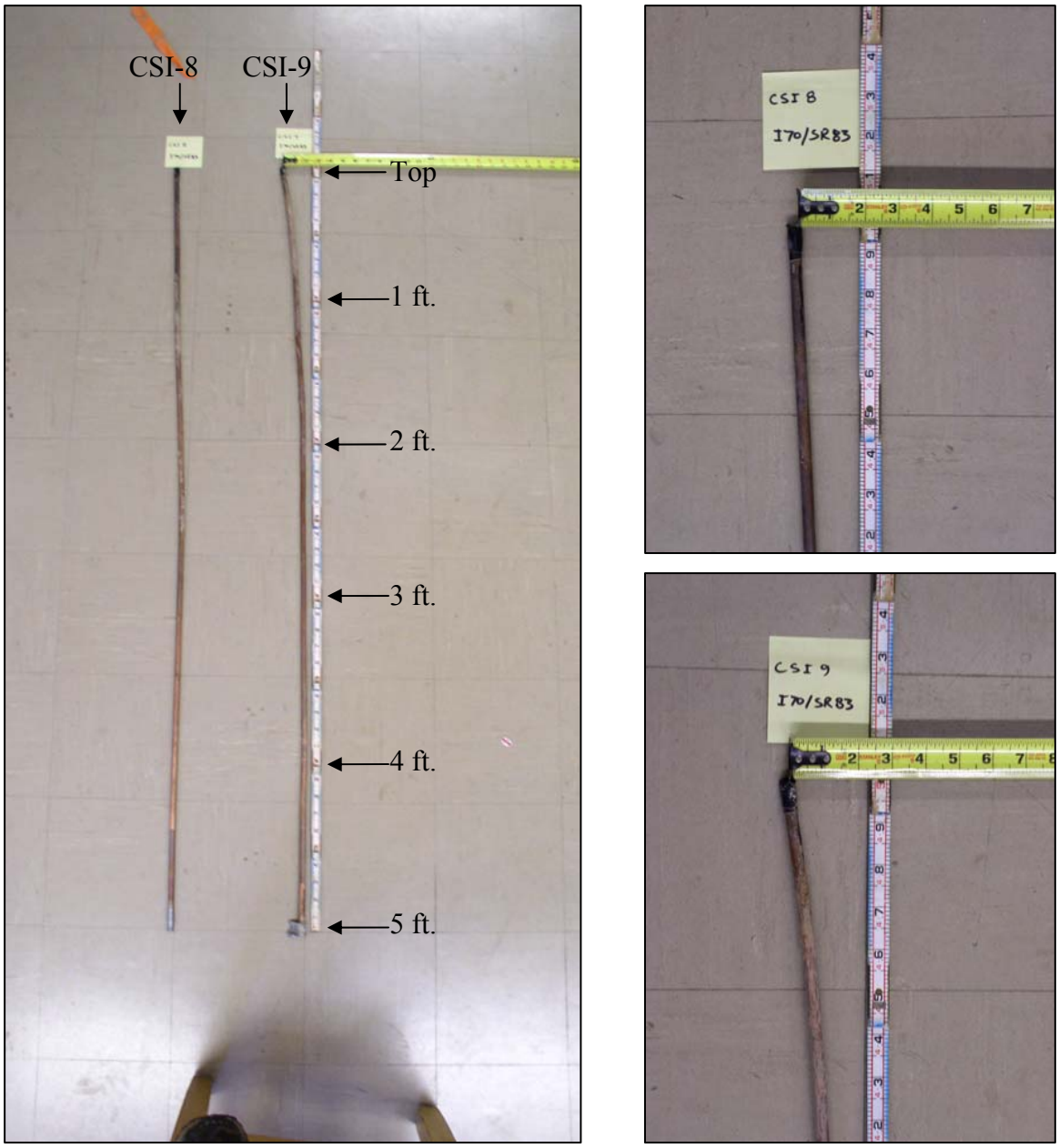


Figure 5.36: Copper shallow inclinometers CSI-8 and CSI-9 exhumed during May of 2005 from Muskingum County demonstration site.

the main pole plot, surveys of the installed poles themselves were conducted by reading pole locations relative to a fixed benchmark along the bottom of the slope. Figure 5.39shows the results of two surveys; the first conducted on April 10, 2006, and the second conducted on May 15, 2009. Initial pole locations, designated with white circles, were measured ten months after installation. The second survey, designated with red diamonds, was conducted three years and eleven months after the initial installation. It should be noted that the accuracy of these measurements is approximately ± 6.0 in. due to weaving the tape measure around the dense vegetation along the slope.

(a)

(b)

Figure 5.37: Photographs of slope erosion features at the Muskingum County demonstration site: a) photo taken 5/30/2007, and b) photo taken 10/31/2007.

The setup for surveying the stakes is shown in Figure 5.40. A laser level was setup over the western-most stake outside of the pole plot such that it was centered plumb over the survey stake and level on the tripod, and the plane of vertical laser disk was offset 5 ⅝ in. from the center of the end point stakes. Measurements were then recorded using an infrared device that indicates the location of the plane of vertical laser disk. The distance from the plane of vertical laser disk and the center of the survey stake was determined, and then corrected for the 5 ⅝ in. offset from the end points of the survey stakes to determine the slope displacement. Displacements of the survey stakes up to 5.75 in. have been measured relative to the end points, and are shown in Figure 5.39.

The willow pole survey data in Figure 5.39 shows that the upper west portion of the main pole plot has experienced slope movements of approximately 0.6 ft. to 1.0 ft. and that other areas have experienced little to no slope movements. However, displacements measured from the survey stakes show larger displacements at the eastern portion of the main pole plot, which is consistent with visual observations of bulges and shallow movements. This contradiction partly reflects the difficulty in obtaining these measurements. For example, the willow pole survey measurements were obtained using a measuring tape drawn up the slope to each pole location. The presence of dense vegetation, especially during the second survey, may have influenced the accuracy of these measurements.

Measured displacements of stakes indicate that little movement occurred along the slope to the west of the stabilized area; however, larger displacements were observed along the slope to the east of the stabilized area. It should be noted that the small displacements observed west of the stabilized area as compared with the eastern portion may indicate that the end stakes are not truly fixed. Rather, the stakes west of the slope may be moving somewhat uniformly, skewing the measured displacements to reflect less movement at this end than what has actually occurred. Due to this uncertainty, the

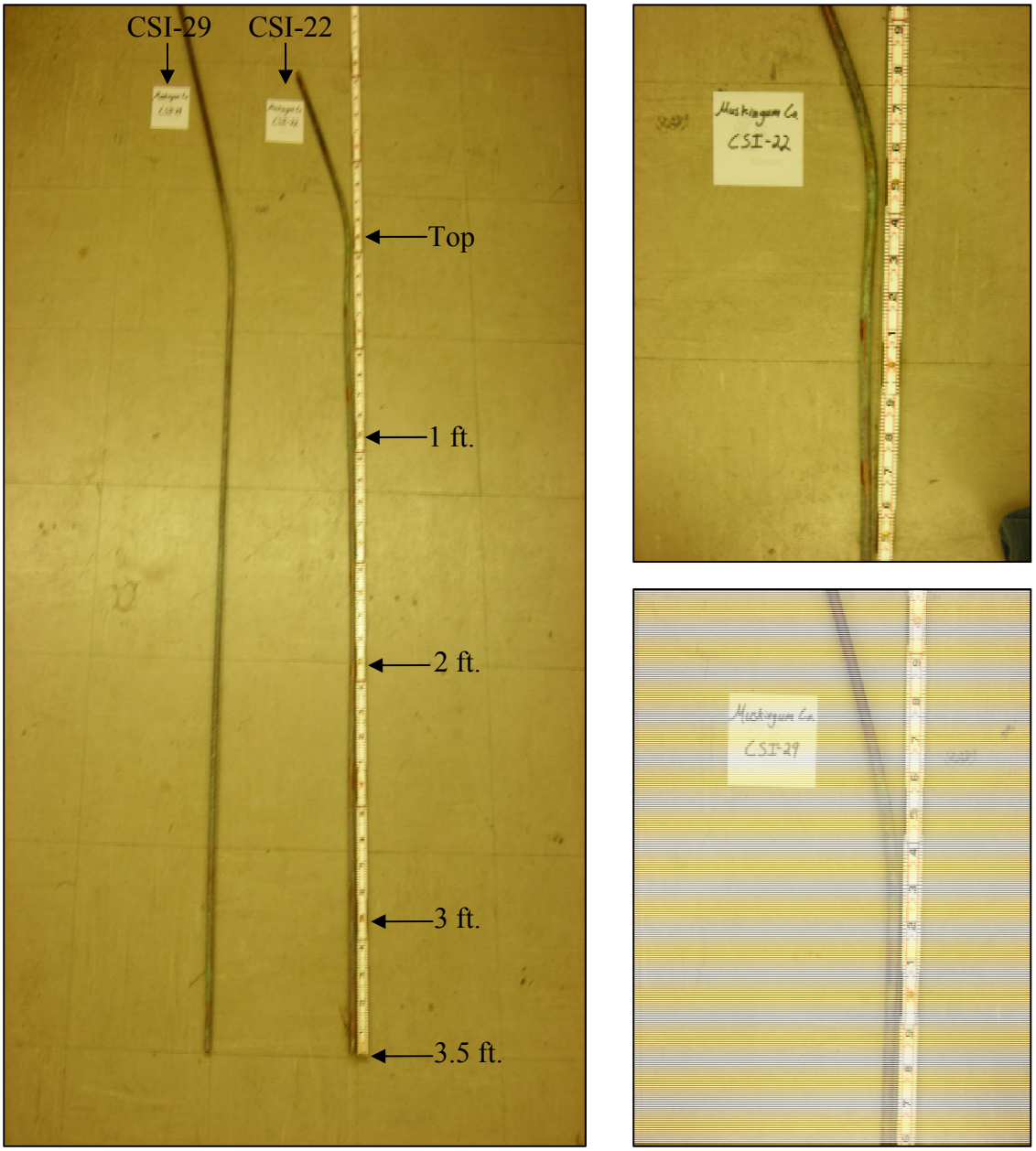


Figure 5.38: Copper shallow inclinometers CSI-22 and CSI-29 exhumed during August of 2009 from Muskingum County demonstration site.

reliability in the data obtained from the survey stakes is considered questionable.

5.7.4 Load Testing

Vertical pullout and lateral load testing was conducted on dead and live poles at the Muskingum County demonstration site. Pictures of the test procedures and test results are provided in Appendix A. Data from these tests were used to with pile

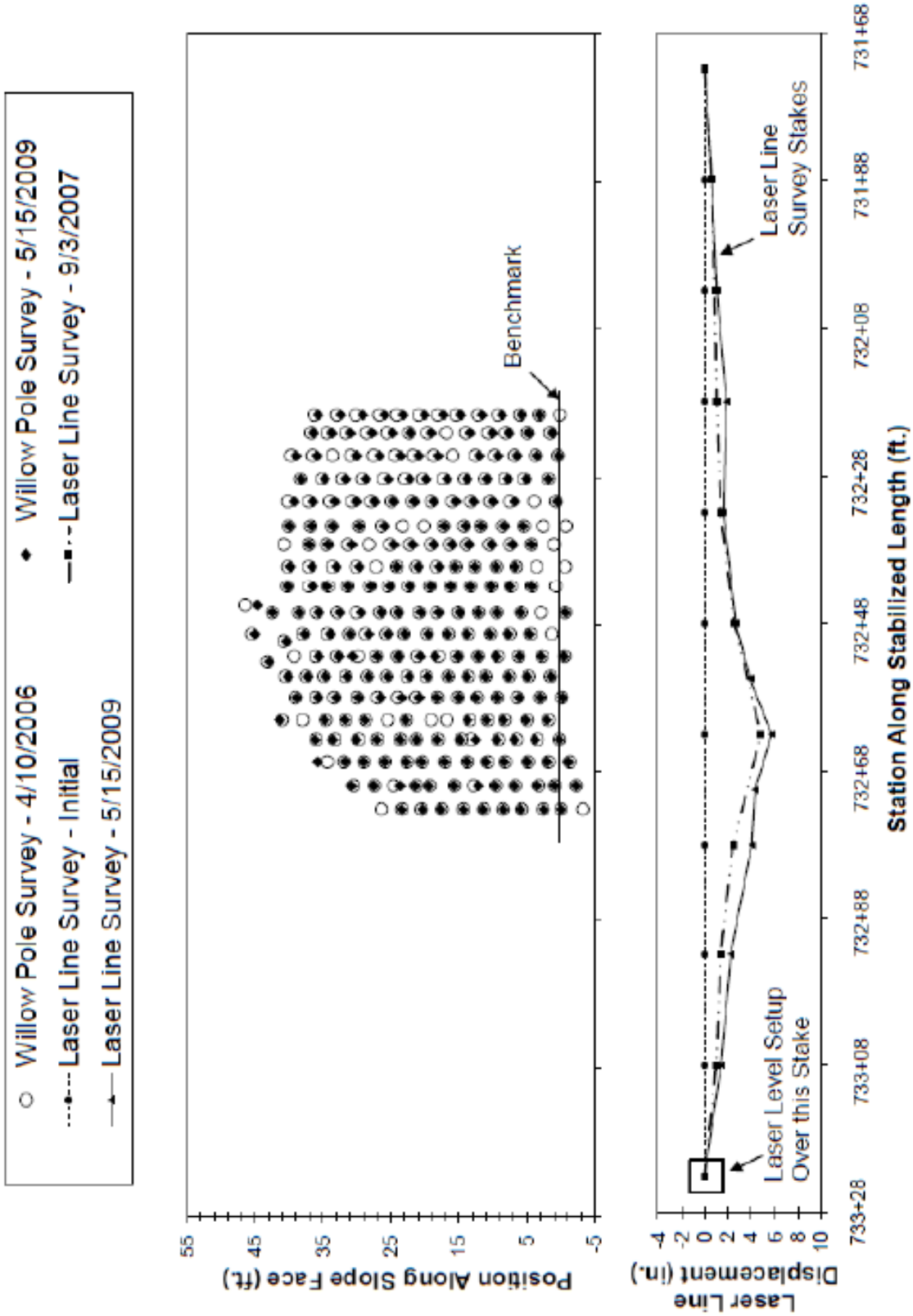


Figure 5.39: Willow pole and laser line survey data from the main pole plot at the Muskingum County demonstration site.

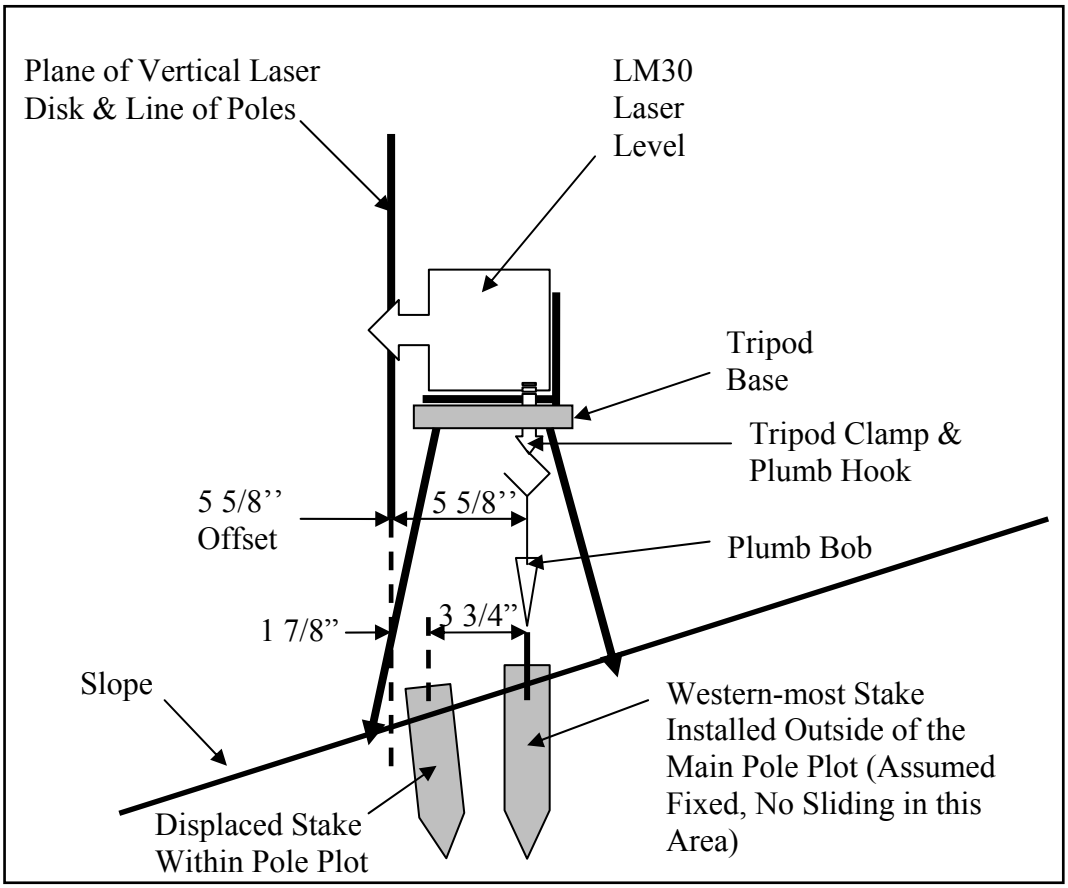


Figure 5.40: Laser level apparatus for measuring displacements of stakes along the mid-slope of the installation area (prepared by C. Kokesh).

equations in stability analyses. Procedures for calculating the ultimate vertical pullout and lateral loads are presented in Section 4.8. Dead poles will provide the least resistance as no root growth is present within the soil, and rot has weakened the internal strength of the poles.

The ultimate vertical load capacity at pullout was estimated using the lower bound undrained shear strength, from Table 5.10, as a skin friction value and pole dimensions based on measured maximum, minimum and average diameters and lengths of embedment of extracted poles. Calculated values of the vertical load capacity, presented in Table 5.6, range from 360 to 2,164 lb. Figure 5.41 presents load verses displacement curves for 17 vertical pullout tests conducted on dead poles extracted from the main pole plot. Table 5.7 lists the lower and upper limits of vertical pullout resistance as calculated using the methods described in Section 4.8.1 and recorded from vertical pullout tests conducted in the field. The bulk of measured ultimate loads in Figure 5.41 are closer to the lower range of calculated values. This can be attributed to the lack of root growth and poor contact between the pole and backfill material. Figure 5.42 indicates that there is no relationship between the measured vertical load capacity at pullout and pole diameter.

Table 5.6: Calculated ultimate vertical resistance of dead poles.

	Minimum	Average	Maximum
Undrained Shear Strength, s_u (psf) [1]	425	596	710
Unit Side-friction Resistance, f_s (psi)	2.95	3.94	4.41
Adhesion Factor, α	1	0.95	0.90
Diameter of Pole, D (in.) [2]	1.01	1.80	2.72
Embedment Length of Pole L_e (in.)	38.4	48.7	57.4
Embedded Surface Area of Pole, A_s (in.^{2})	122	275	490
Calculated Vertical Load Capacity, P_{upward} (lb)	360	1,085	2,164

[1] – Undrained shear strengths are based on measurements from vane shear tests.

[2] – Pole dimensions are based on measurements from poles extracted during vertical pullout tests.

Table 5.7: Measured and calculated resistances for vertical pullout tests of dead poles.

	Measured	Calculated
Vertical Resistance (lb)	65-700	360-2,184
Average (lb)	250	1,085

Two live poles were extracted from the main pole plot. Pole 15-2 was extracted on July 12, 2007, approximately 13 months after it was planted. The peak load recorded from this test was 1,046 lb. Pole 8-10 was extracted on May 15, 2009, approximately 25 months after it was planted. The peak load recorded from this test was 1,283 lb. A vertical pullout test was attempted on pole 15-10, which is a living pole from the initial installation. A maximum vertical load of 1,550 lb was applied; however, due to the limitations of the equipment and labor, this pole was unable to be extracted. Similar results recorded from pullout tests conducted on 3 yr. old live poles in clay have given a tensile resistance of approximately 1,100 lb (Wu, 2009). This indicates that there is approximately 50 to 130% increase in shear strength due to the rooting of live vegetation (based on average undrained shear strength of 475 psf in TP-6 and maximum undrained shear strength of 710 psf from all vane shear tests).

The ultimate lateral load was estimated using Broms (1964) solution presented in Chapter 3. Limits for the calculations were based on the maximum and minimum diameter of poles extracted, the yield strength of the vegetation as determined by

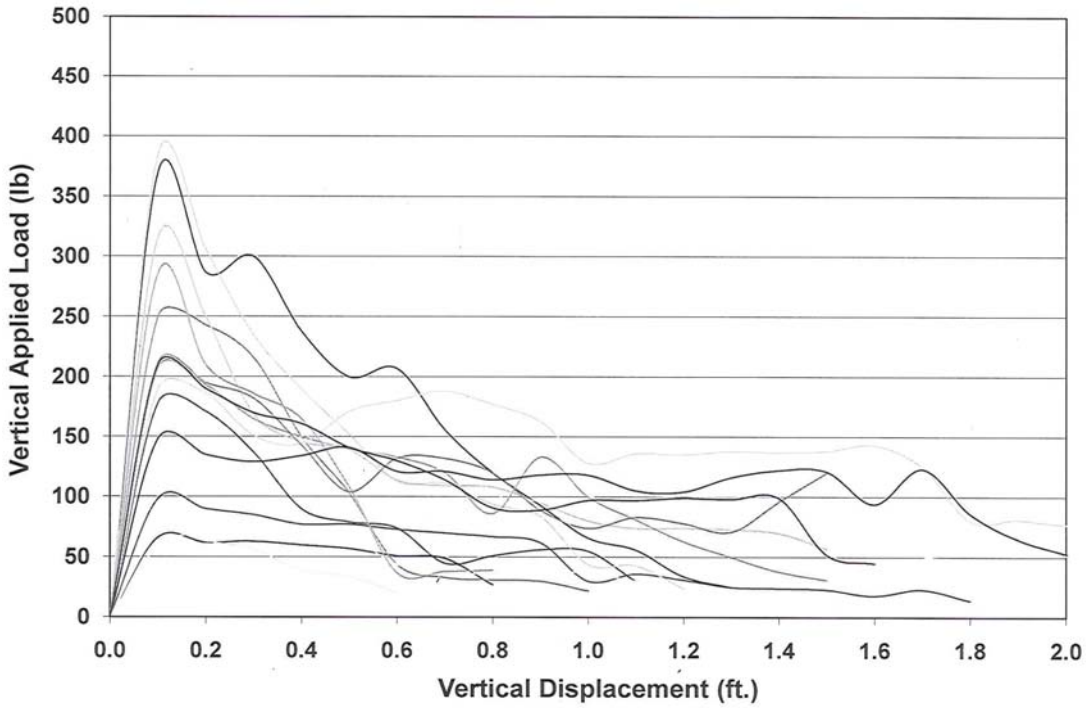


Figure 5.41: Load-displacement curves from vertical pullout tests conducted on dead poles at the Muskingum County demonstration site. Some test results are not shown to improve clarity.

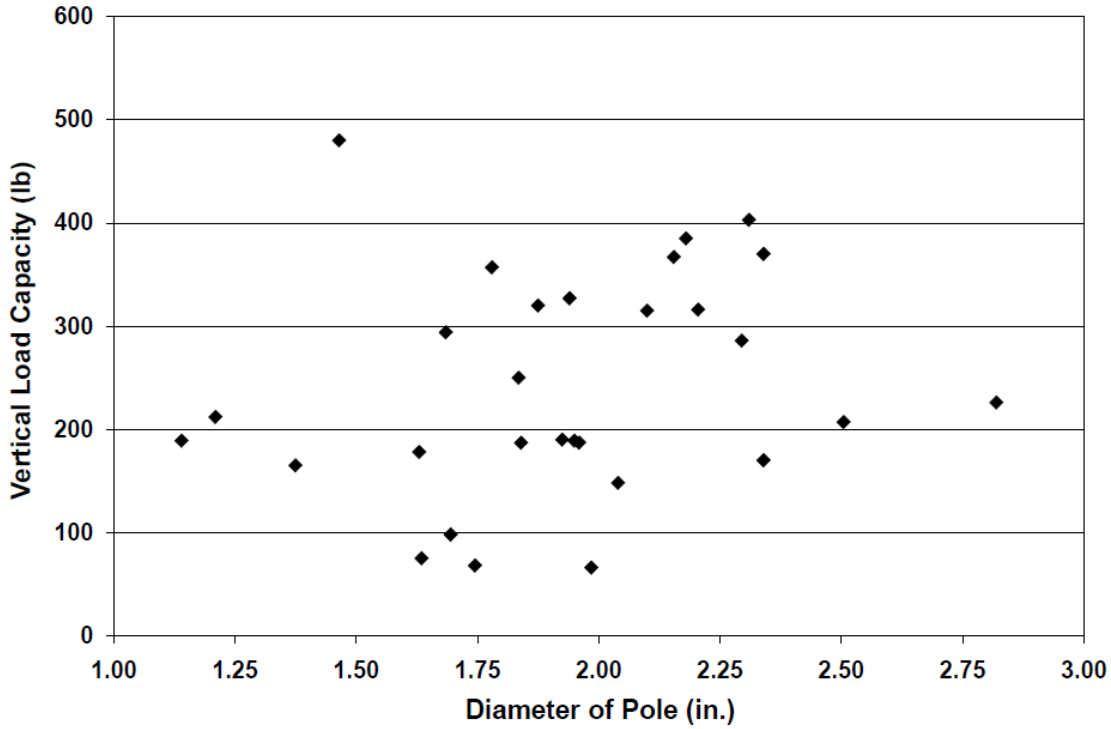


Figure 5.42: Maximum load verses pole diameter for vertical pullout tests conducted at the Muskingum County demonstration site.

laboratory flexure tests, and the undrained soil shear strength as determined in the field and laboratory and indicated in Table 5.8. Complete results of the flexure tests are provided in Appendix A.

Table 5.8: Calculated ultimate lateral resistance of dead poles.

	Minimum	Average	Maximum
Undrained Shear Strength, s_u (psf) [1]	425	596	710
Diameter of Pole, D (in.) [2]	1.01	1.80	2.72
Yield Moment Resistance of Pole, M_{yield} (lb·in.)	860	4,867	16,793
Dimensionless Yield Moment, YM [3]	283	202	169
Dimensionless Ultimate Lateral Resistance, ULR [4]	54	49	41
Calculated Lateral Load Capacity, T_{xu} (lb)	163	657	1,496

[1] – Undrained shear strengths are based on measurements from vane shear tests.

[2] – Pole dimensions are based on measurements from poles extracted during vertical pullout tests.

[3] – Yield Moment (YM) - dimensionless parameter defined by Broms (1964) (see Section 4.5.1.1).

[4] – Ultimate Lateral Resistance (ULR) - dimensionless parameter defined by Broms (1964) (see Section 4.5.1.1).

Calculated values of the lateral load capacity, presented in Table 5.8, range from 163 to 1,496 lb. Figure 5.43 shows the results of four lateral load tests that were conducted on dead poles in the main pole plot. Poles 11-1 and 12-1 had brittle failures at loads of 246 and 254 lb, snapping a few inches below the ground surface. The test on pole 10-1 was stopped at a displacement of 0.8 in. and a load of 547 lb when the chain started to dig into the soil as additional load was applied. Pole 8-1 was pulled completely out of the ground. A maximum load of 460 lb was applied at the initial failure when the pole snapped at a displacement of 1.0 ft. The pole remained intact after the initial failure, and loading continued at a constant residual load of 205 lb until the pole was completely extracted from the soil. As seen in Table 5.9, measured peak lateral loads were within the range calculated for ultimate lateral load resistance.

Table 5.9: Measured and calculated resistances for lateral pullout tests of dead poles.

	Measured	Calculated
Lateral Resistance (lb)	245-550	163-1,496
Average (lb)	400	657

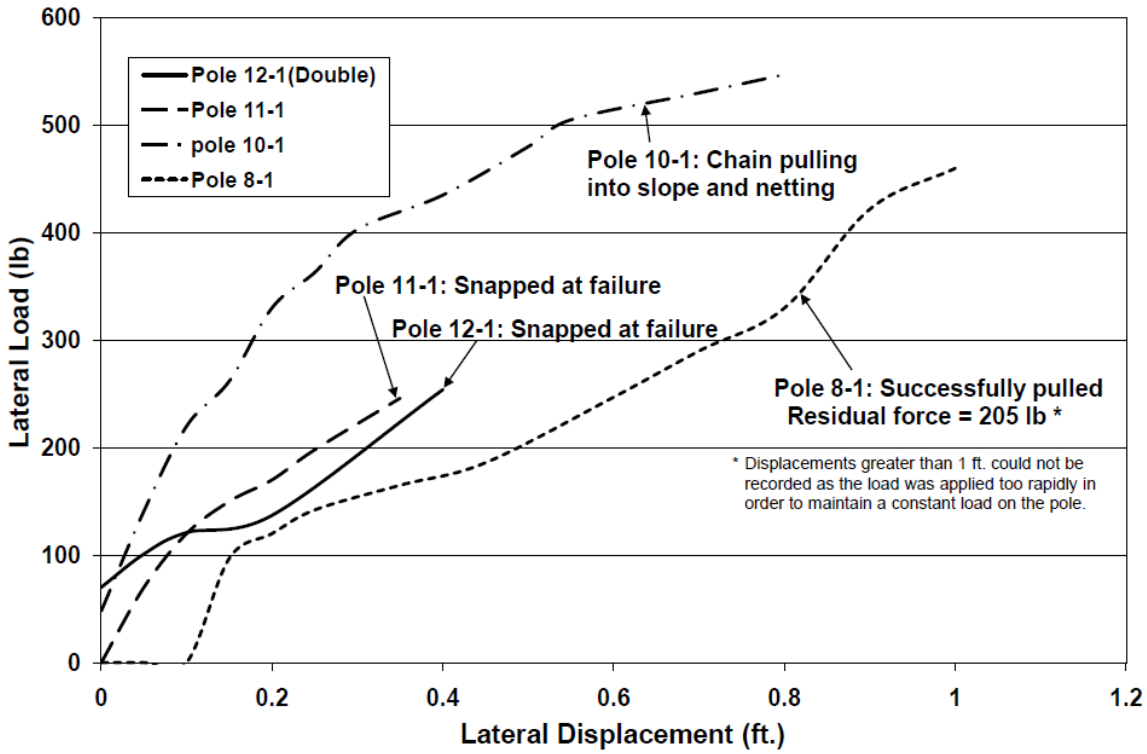


Figure 5.43: Load-displacement curves for lateral pullout tests conducted on dead poles at the Muskingum County demonstration site.

5.7.5 Slope Stability Assessment

As previously noted in this chapter, this area of Muskingum County frequently experiences landslides due to the geology of the region. It was also noted that this is not the first time landslide remediation as been performed at the Muskingum County demonstration site. Prior to site selection, shallow sliding and erosion was observed on the slope face. During the period between January and May 2005, mid-slope movements of approximately 2.0 in. were directly measured using CSIs within the limits of the remediation area. Numerous additional movements were observed during site visits over this time period as well. Most consisted of shallow block-type failure modes that appeared to be approximately 2 ft. deep.

These landslide and erosion events were likely triggered by above-average precipitation during the winter and spring of 2005. During January of 2005, approximately 8.0 in. of precipitation occurred, which is nearly 5.5 in. above average. Observations and data collected from shallow monitoring wells along the slope face over several years indicate that the entire slope is nearly saturated or saturated during the winter months. During summer and early fall, the slope typically experiences long drying periods which leads to a dry and desiccated surface crust several inches thick that forms, with saturated to near saturated soils not encountered until approximately 2.5 to 4 ft. below the ground surface. This cycle of saturation and desiccation within the slope, along with extensive weathering and desiccation near the surface, leads to movements being triggered and propagating over the winter months. Thus, the factor of safety

against sliding is generally greater than unity ($FS > 1$), but falls to approximately unity during these critical wet periods when landslide events are triggered.

5.7.5.1 Slope Stability Analysis

The slope stability analysis completed for the Muskingum County demonstration site followed the infinite slope procedures presented in Gray and Sotir (1996) and discussed in Section 4.5.1. For this analysis, the slope and failure surface geometries were determined from observations made during field reconnaissance of the site. In addition, piezometer data was used to determine groundwater conditions. Personal communications with D. H. Barker suggested that, based on empirical data on from previous trials (Barker 1997; Steele et al. 2004), a live pole spacing of 3 ft. would increase the factor of safety from 1 to 1.2 (Kokesh 2009).

An infinite slope stability analysis was performed according to the infinite slope analysis presented in Section 4.5.1 using the parameters outlined in Table 5.10 for a range of failure depths. The reinforcement cohesion, c_R, was determined using methods in Section 4.5.1.1. To represent the worst-case scenario, it is assumed that the slope is saturated. The seepage flow direction, θ, was assumed to be vertical and parallel to the slope, and the failure surface depth, *H*, was taken as 2 ft. based on observations from CSIs exhumed from the site.

The results of the infinite slope stability analysis are presented in Table 5.11. In calculating the non-reinforced (initial) factor of safety, the reinforcement cohesion, c_R, was taken as zero. For the reinforced (final) factor of safety, c_R was calculated according to the methods in Section 4.5.1.1. Calculations indicate that the pile mode controls based on the geometry of the system and the physical properties of the soil. The factor of safety generally decreases with depth. The unreinforced calculated factor of safety is well below 1.0. It should be noted that this is based on the assumption of seepage parallel to the slope face. If vertical seepage is assumed, the unreinforced factor of safety increases to unity ($FS = 1$). Slope movements were observed prior to remediation, indicating that the factor of safety was approximately 1.0. These results suggest that the seepage angle, θ, is somewhere between parallel and vertical.

The calculated reinforced factor of safety for a slip surface 2 ft. below the ground surface is unity for the case where seepage is parallel to the slope face, and is 1.5 for vertical seepage. This indicates a significant strength increase provided by the poles. It is important to realize that this scenario (reinforcement is only provided by the poles acing as micropiles) represents the minimal strength increase provided by the vegetation. Establishment and rooting of the vegetation over time could provide strength increases as high as 20% as demonstrated in the case study conducted by Steele et al. (2004) (see Sections 3.4).

Table 5.10: Parameters used in slope stability analyses.

Parameter	Measured Value	Source
Slope Angle, β	26.6°	Field Measurement
Unit Weight of Water, γ_w	62.4 pcf	Constant
Saturated Unit Weight of Soil, γ_{sat}	123 pcf	UCS and Consolidation
Undrained Shear Strength, s_u [1]	400 – 800 psf	UCS and Torvane
Effective Peak Friction Angle, ϕ'_p	27.6°	CU Triaxial
Effective Fully Softened Friction Angle, ϕ'_{fs} [2]	26.6°	Direct Shear
Effective Residual Friction Angle, ϕ'_r	21.2°	Direct Shear
Effective Cohesion, c'	0 psf	Direct Shear
Embedment Depth of Poles, L	4.5 ft.	Field Measurement
Diameter of Poles, d	1.5 in.	Field Measurement
Radius of Poles, r	0.75 in.	Field Measurement
Moment of Inertia of Poles, I	0.2485 in.^{4}	Based on Field Measurement
Modulus of Elasticity of Poles, E	1.0E+06 psi	Flexure Test
Ultimate Tensile Strength of Poles, σ_u	8500 psi	Flexure Test
Yield Moment Resistance of Poles, M_y	2816 lb-in.	Flexure Test / Field Measurements
Shear Strength of Poles, τ_u	580 psi	Barker et al. (1997)
Eccentricity of Poles Loading, e/d	0	Assumed
Spacing of Poles, s	3 ft.	Field Measurement

[1] Lower bound of s_u is used in calculating the soil reaction in the "flow mode" calculation, and the upper bound is used in calculating the ultimate lateral resistance in the "pile mode" calculation of the reinforcement shear strength.

[2] Fully softened effective friction angle, ϕ'_{fs}, is used in the analysis as it most closely represents field conditions.

Table 5.11: Summary of stability analysis for the Muskingum County site.

Seepage Direction	Unreinforced *FS* ($c_R = 0$)	Reinforced *FS* ($c_R = 49.7$ psf)
Parallel to Slope Face ($\theta = 26.6°$)	0.49	1.0
Vertical ($\theta = 90°$)	1.0	1.5

5.8 COST ANALYSIS

The cost of bioengineering remediation as compared to conventional remediation techniques is of key interest to the project. Further information on conventional construction methods and cost is provided in Chapter 6. The total cost of construction at the Muskingum County site, including slope re-grading, was determined to be $25,000 and the total length and area of construction was 65 ft. and 2,625 sq. ft. (291.67 sq. yd.), respectively. Thus, the total cost per lineal foot (LFT) was $385/LFT, and the total cost per sq. yd. (SY) was $86/SY. Please note that this cost is for the initial installation only and does not include the cost of additional installations. A production level of about 25 fully installed poles per day was achieved. It should be noted that the total cost is substantially lower than a typical contractor would charge because construction was performed mostly by OSU students. Further cost comparison between all demonstration sites and conventional methods will be presented in Chapter 7.

5.9 SUMMARY AND CONCLUSIONS

This chapter presents research efforts completed for the Muskingum County demonstration site. Throughout this chapter, data and analyses are presented and discussed with regard to site conditions, including the geology, climate and subsurface, field exploration, laboratory testing, site instrumentation and performance data. Performance data includes vegetation survival rates and slope displacements. Stability analyses and cost considerations are also presented.

The Muskingum County demonstration site has provided valuable information that was implemented in subsequent biostabilization plans for the Logan County (Chapter 5) and Union County (Chapter 6) demonstration sites. Live staking (live poles) and brushlayer berms were chosen by the research team as the primary means to mitigate shallow failures and erosion, respectively, occurring on the lower slope. Two live pole plots and three brushlayer berms were constructed within areas where significant sliding had taken place during May and June 2005. The initial installation took place during May and June 2005, and two replacement installations were conducted in April and December 2006.

Groundwater data suggests that soil suctions within the main pole plot were slightly higher than the surrounding area and the upper pole plot. Piezometric levels observed in shallow wells within the main pole plot were also lower during the dry

season than for the upper pole plot. This indicates that vegetation in the main pole plot is removing water from the soil through rooting. There was no trend in soil moisture measured in the field as compared with the laboratory SMCC, however, soil moisture determined from calibration curves for G-Blocks showed a consistent trend with the SMCC.

Initial survival rates were somewhat lower than expected; however, replacement survival rates suggest that improved climate and installation time can lead to better results. It was also determined that willow species are far more durable in surviving the erratic climate conditions of the Ohio region than other non-willow species that were planted during the initial installation. Some post-mitigation slope movements were observed, but these consisted primarily of small, localized bulges. No significant sliding has taken place at the site since the time of construction.

The stability analysis for initial conditions suggests that orientation of seepage was somewhere between vertical and parallel to the slope face. This is evident by the fact that unstable conditions were observed through slope movements prior to installation. The factor of safety calculated for the stabilized slope was 1.5 for the case of vertical seepage and 1.0 for the case of parallel seepage. Vertical and lateral load tests conducted on dead poles were within the ranges calculated using pile equations. Vertical pullout tests conducted on live poles suggests that additional strength gain from rooting of the vegetation could significantly increase the stability of the slope. The total cost of the project was $25,000, corresponding to a rather low unit cost of $385/LFT and $86/SY as compared to conventional construction methods. More cost comparison information is provided in Chapter 7.

Chapter 6 LOGAN COUNTY DEMONSTRATION SITE

INTERSECTION: US-33/SR-347

6.1 INTRODUCTION

6.1.1 Project Location Description

The Logan County demonstration site is located within the infield of the interchange of eastbound US-33 and SR-347 (Loop Ramp "B") in Logan County, Ohio. The interchange is located just outside of the town of East Liberty, approximately 10 miles east of Bellefontaine, Ohio, and 45 miles northwest of Columbus, Ohio. Figure 6.1 shows a map of the state with the project location, and Figure 6.2 shows a view of the region as provided in the construction plans for this project. An aerial view of the site is provided in Figure 6.3, indicating the area of the bioengineering project. The focus of the investigation at this site is twofold: 1) the remediation of shallow sliding and erosion on both slopes of a drainage channel running through the infield (one of which is shown on the cover page of this chapter); and 2) remediation of deep-seated, rotational style failures that are also occurring for both slopes.

This demonstration site, unlike the Muskingum and Union County sites, is comprised of cut slopes rather than embankments. The drainage channel directs flow from areas northwest of the site down toward the Darby Creek Watershed. This is an environmentally sensitive and protected area. Silt and clay eroding from the slopes is being deposited in the creek below and carried downstream to the Bog Darby Creek, another environmentally sensitive area. One of the main goals from the installation is to arrest the shallow sliding and prevent large quantities of sediment from leaving the area.

6.2 SITE CONDITIONS

6.2.1 General Layout

The location of the demonstration area is within the infield of Loop Ramp "B" of the US-33 and SR-347 interchange, approximately adjacent to Sta. 592+00. Figure 6.4 shows a site plan of the area, from the construction documents, indicating limits and types of construction that are to be implemented by the contractor. The drainage channel was originally constructed with 2H:1V slopes. A topographic survey of the project area was conducted by ODOT and is shown in Figure 6.5. Figure 6.6 and Figure 6.7 show cross sections A-A and B-B from Figure 6.5, which includes both the NE and SW slopes. Both slopes have undergone severe erosion and shallow sliding, as indicated by bare areas and scarps, and bulging has been observed along the slopes in several places. Photographs of these areas are provided in Section 6.3.1. Additionally, deep-seated rotational failures have also occurred within both slopes, indicated by cracks at the central crests and bulging within the creek bed. According to the boring logs, the slopes are comprised mostly of brown gravelly clay (till), gray gravelly sandy silt, and brown sandy clay (AASHTO A-6a, A-4a and A-6b).

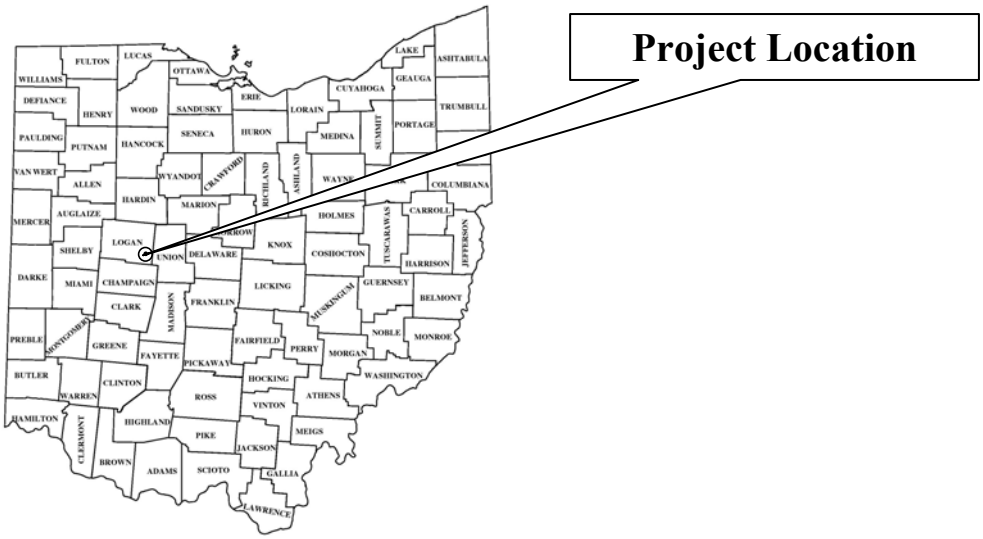


Figure 6.1: Vicinity Map: Logan County US-33/SR-347 demonstration site.

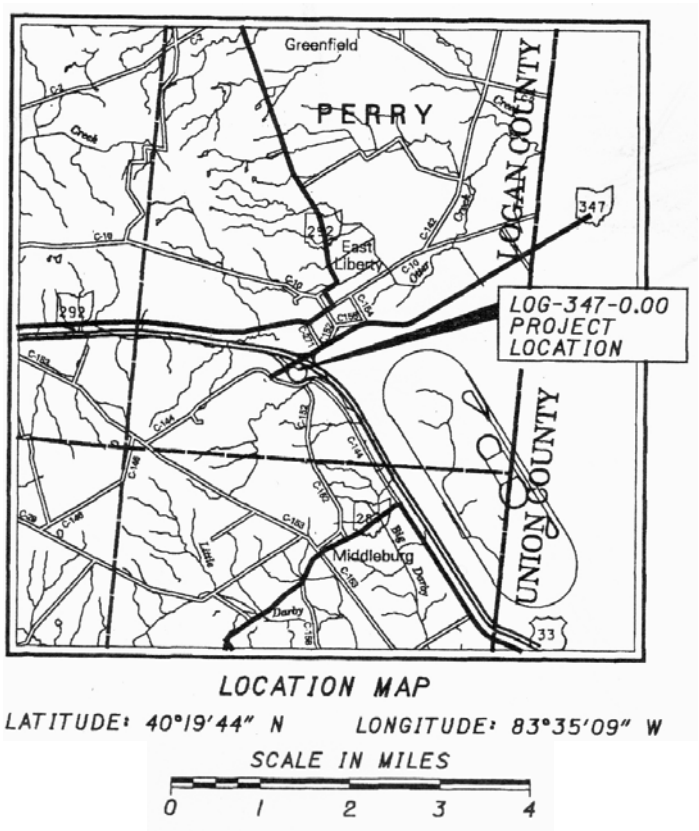


Figure 6.2: Regional map of Logan County area (LOG-33-347, 2005, ODOT).

Figure 6.3: Aerial view of the Logan County demonstration site (Google – Imagery, 2009). Biostabilization was implemented on the northeast and southwest slopes of the drainage ditch.

6.2.2 Regional Geology

Geologic information for Logan County was taken from the *Soil Survey of Logan County* (Waters, 1979). Logan County has been covered by glaciers at least twice. Movements of the glaciers over bedrock consisting of limestone and dolomite enriched the glacial till deposited throughout the county with pebbles and fine material in the form of ground-up limestone and dolomite. During a warm, dry period after the glacial period, winds blew fine silt-sized particles from the glacial drift out of regions to the west and deposited the material to varying depths within the county. Deposits of this silty windblown material (loess) are as thick as 18 in. Melt water from the last glacial retreat cut channels through the glacial drift, creating most of the drainage patterns that exist today. The most recent geologic deposits consist of alluvium in stream valleys and flood plains from eroded upland and terrace soils.

6.2.3 Climate

Historical data has been published by the National Climatic Data Center (NCDC) and the Midwestern Regional Climate Center (MRCC) and is also provided by the Ohio Department of Natural Resources (ODNR). This data represents the average of values

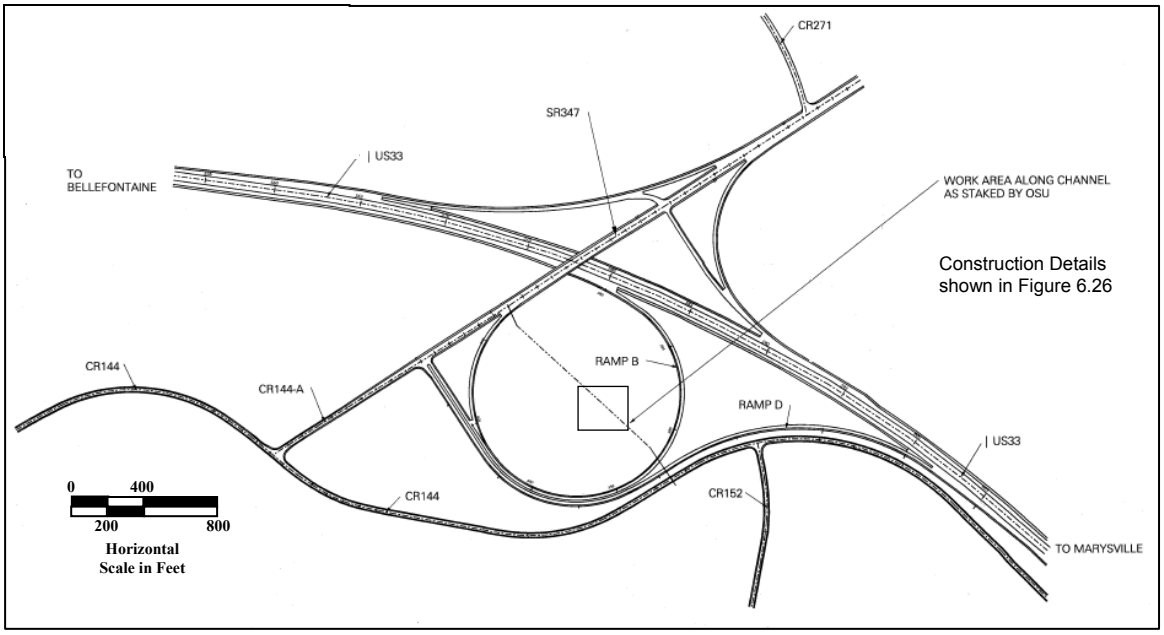


Figure 6.4: Site plan for the Logan County demonstration site (from ODOT plans LOG/UNI-347/33-0.00/8.36).

collected over a 30 year period from 1971 to 2000. A summary of climate data collected for Bellefontaine and Marysville, Ohio, is provided in Appendix B. The average annual precipitation recorded at Bellefontaine and Marysville were 37.4 and 36.6 in., respectively. During the growing season (March to June), the average monthly precipitation ranged from 2.70 and 2.60 in., respectively, in March to 4.11 and 4.35 in., respectively, in June. June has the highest average monthly precipitation at both stations with 4.11 and 4.35 in., while February has the lowest with 2.02 and 1.97 in. The annual mean temperature was 49.9 and 51.1°F, respectively. July experienced the highest mean temperature at 72.7 and 73.9°F, while January experienced the lowest mean temperature at 23.8 and 25.8°F, respectively, for Bellefontaine and Marysville.

Temperature and precipitation data for the time frame of the project was obtained from the ODNR central office in Columbus, for the Marysville and Bellefontaine stations. Monthly precipitation data from January 2007 through April 2009, along with daily precipitation and temperature data for March, April and May 2007, was obtained for these stations and an overview of the climate conditions is presented below. Data for both locations is provided in Appendix B.

Bioengineering construction at the Logan County site was completed on March 8, 2007. A warming trend occurred for about six days immediately thereafter, from March 10-15, where temperatures reached highs ranging from the mid-fifties to the mid-seventies, and nearly an inch of precipitation fell. Temperatures returned to normal for the following week. The region experienced another warming trend for nearly two weeks

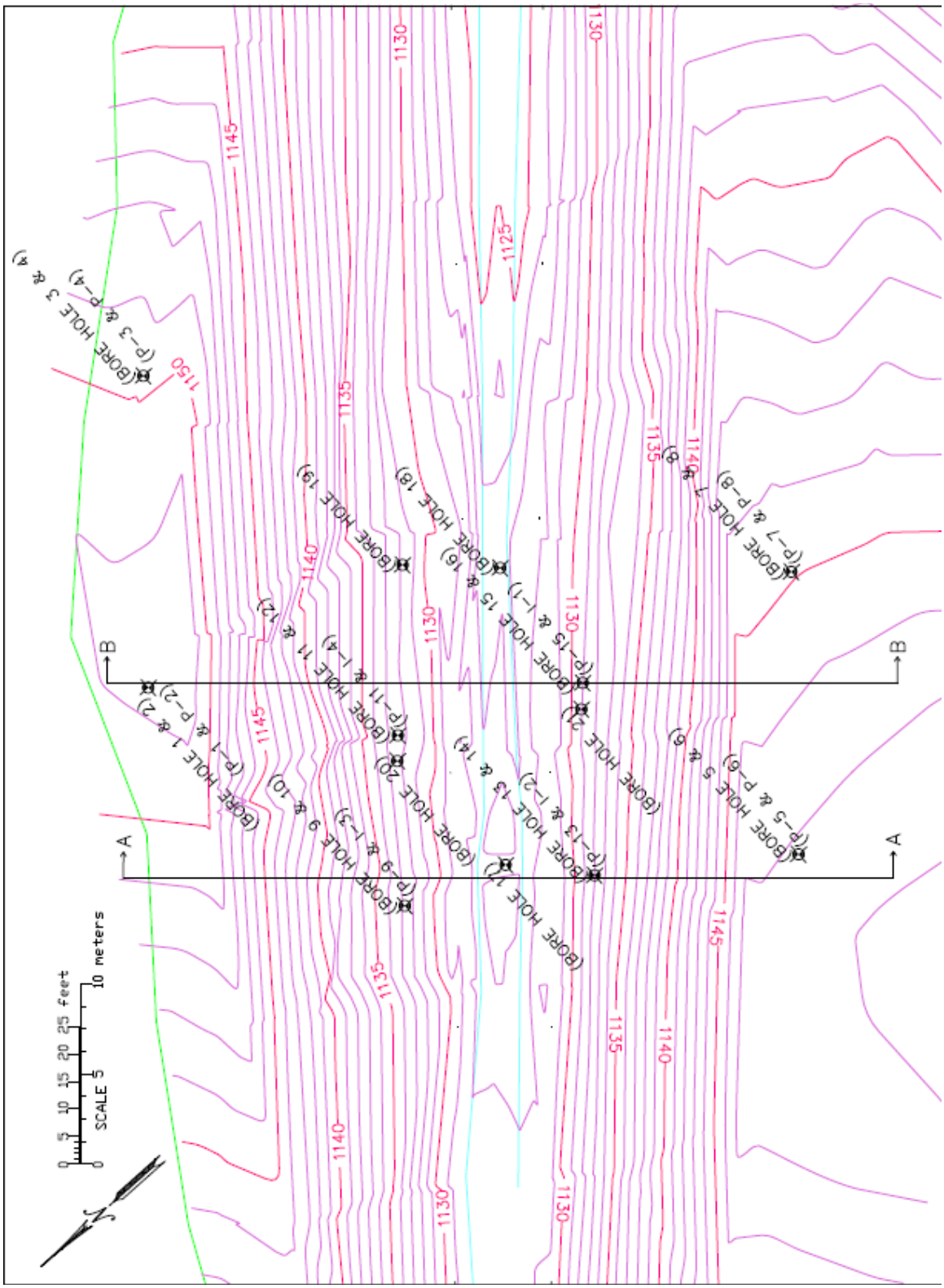


Figure 6.5: Topographic plan view of Logan County demonstration site with locations of bore holes.

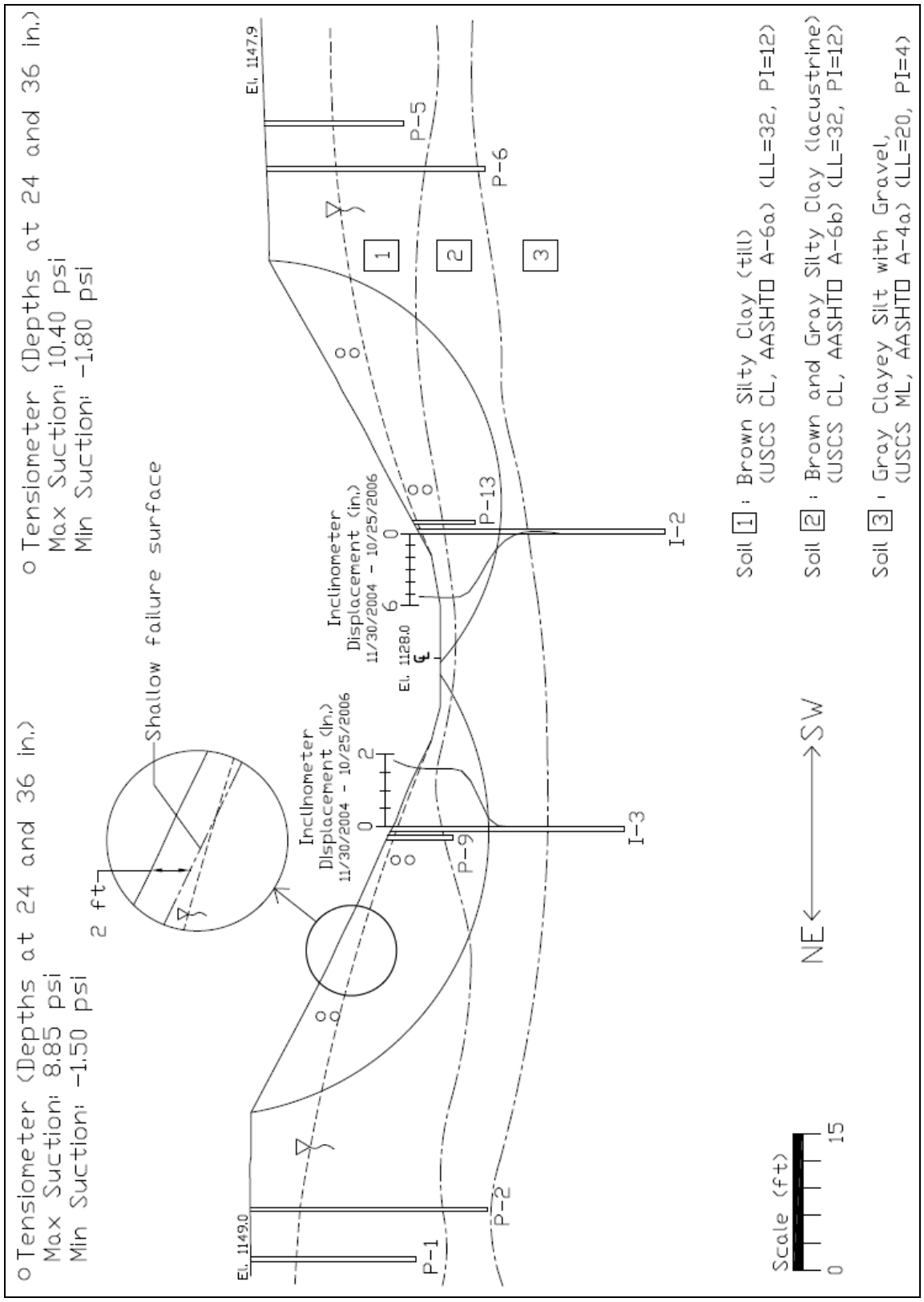


Figure 6.6: Cross section A-A for the Logan County demonstration site with instrumentation details.

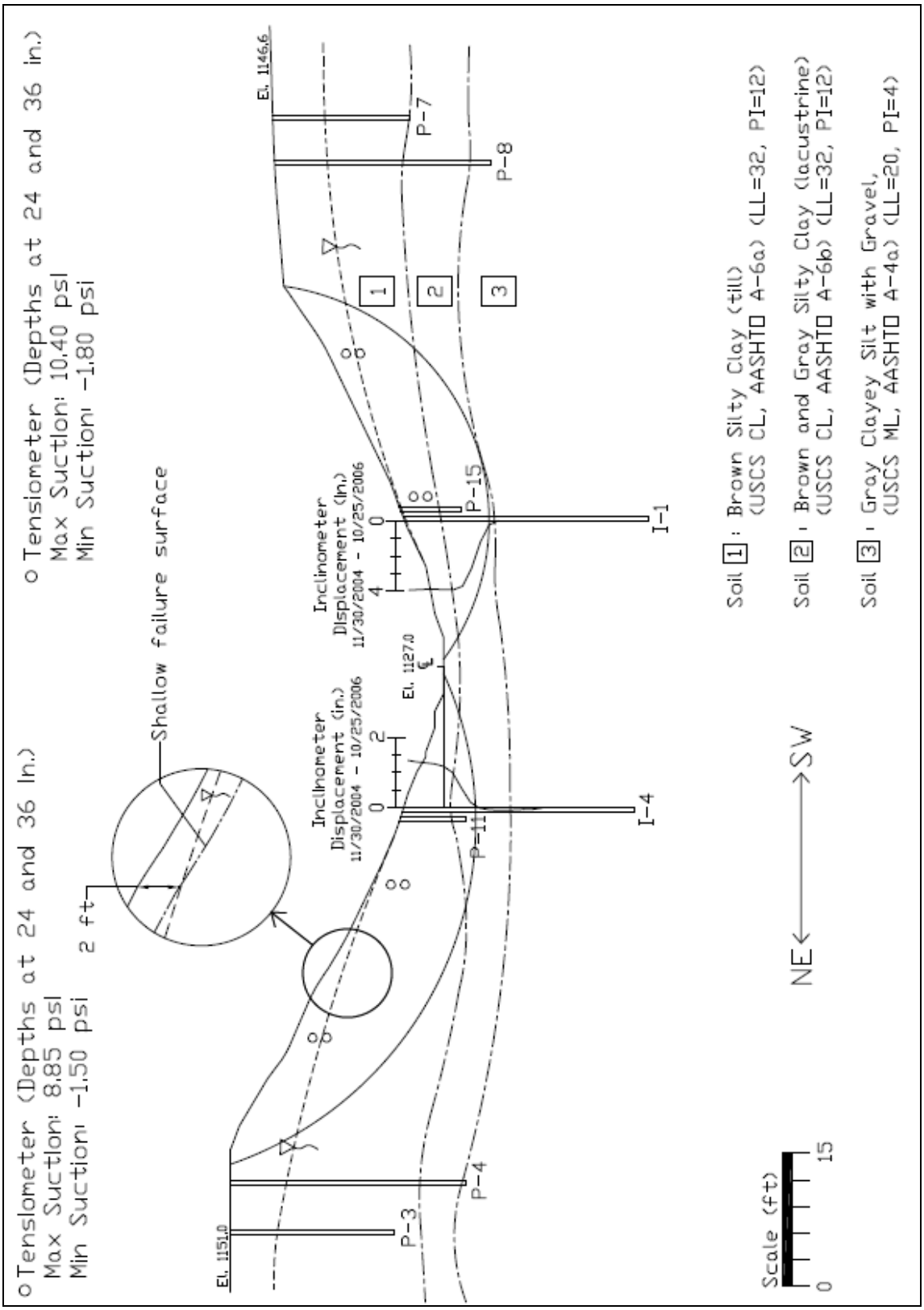


Figure 6.7: Cross section B-B for the Logan County demonstration site with instrumentation details.

between March 22 and April 4, 2007. Over this period, temperatures ranged from the mid-forties to the low-seventies each day, with the high peaking at 80°F. Nearly 1.5 in. of precipitation fell over that period at both the Marysville and Bellefontaine stations. During field visits at the beginning of April 2008, buds were observed sprouting from a majority of the vegetation. This is the critical period in the establishment of vegetation as the first hair fiber roots are branching out from the pole and into the soil. In order for these roots to continue to grow and provide enough nutrients and water to the vegetation, the soil needs to maintain high moisture concentrations, either through periodic precipitation or site watering.

During the following 11 days, April 5-15, 2007, temperatures dropped back to freezing, with ranges falling in the low twenties to the mid-forties, and precipitation over this period was nearly 2 in. Following this cooling event, the remaining days in April experienced slightly above average temperatures with nearly an inch of precipitation. May 2007 was unusually warm and dry, with only 1.35 and 2.83 in. of precipitation recorded at the Bellefontaine and Marysville stations and average temperatures nearly 6°F above normal. Precipitation at both stations for May was well below the 30 year average, with the Bellefontaine and Marysville stations 2.67 and 1.06 in. below average, respectively. Over the 20 day period from April 28 to May 15, only one significant precipitation event of 0.37 in. was recorded at the Marysville station.

It should be noted that one event at the Marysville station, recorded on May 16, was 1.48 in. of rain. This is a highly uncommon event and most of the precipitation during this period would be lost to runoff. Removing this event would yield a total of 1.35 in. for May, which is approximately 2.67 in. below the 30 year average. Total precipitation for June was 3.10 and 2.62 in. for the Bellefontaine and Marysville stations, respectively. These are approximately 1.0 in. below the 30 year average for both stations. July experienced slightly higher amounts of precipitation at both stations, but remained nearly 0.5 to 1.0 in. below normal.

6.3 FIELD EXPLORATION

6.3.1 Field Reconnaissance

Numerous field visits have been made over a multi-year period to evaluate site conditions. During these visits, measurements were taken from instrumentation, vegetation was inspected, survival of vegetation was determined, and general notes and photographs were taken to maintain an accurate log of events at the site. Photographs of the site prior to remediation are shown in Figure 6.8 through Figure 6.11 for the NE slope and Figure 6.12 through Figure 6.13 for the SW slope. As seen in the photographs, most notably for the NE slope, extensive erosion and shallow slides were initially present on both slopes. Scarps and bulges were observed everywhere, and some large soil masses had separated from the slope and started to slide down the slope face. Cracks along the crests of both slopes and bulging within the center of the channel bed indicated that deep-seated movements were also occurring.

Figure 6.8: Scarps and erosion features on the Northeast (NE) slope of the Logan County demonstration site (picture taken by C. Kokesh, August, 2004).

Figure 6.9: Scarps and erosion features on the Northeast (NE) slope of the Logan County demonstration site (picture taken by C. Kokesh, February, 2005).

Figure 6.10: Scarps and erosion features on the Northeast (NE) slope of the Logan County demonstration site (picture taken by C. Kokesh, November, 2005).

Figure 6.11: Scarps and erosion features on the Northeast (NE) slope of the Logan County demonstration site (picture taken by C. Kokesh, November, 2005).

Figure 6.12: Scarps and erosion features on the Southwest (SW) slope of the Logan County demonstration site (picture taken by C. Kokesh, August, 2004).

Figure 6.13: Scarps and erosion features on the Southwest (SW) slope of the Logan County demonstration site (picture taken by C. Kokesh, November, 2005).

6.3.2 Subsurface Investigation

Drilling and sampling were conducted at the Logan County site by ODOT and FMSM Engineers, Inc. On October 25 – 28, 2005, 19 borings, designated as B-1 through B-19, were drilled to depths ranging from 15 to 32 ft. Borings B-1 through B-8 were drilled using a truck-mounted drill rig and hollow-stem augers operated by ODOT. Borings B-9 through B-19 were drilled using a track-mounted drill rig and hollow-stem augers operated by FMSM Engineers. Standard penetration tests (SPT) were conducted, and the retrieved soil samples were visually identified in the field and classified at the ODOT laboratory. Relatively undisturbed soil samples were obtained using Shelby tubes and preserved with paraffin/petroleum jelly seals. The locations of the borings are shown in Figure 6.5, as well as the site plan shown in Figure 6.14. Boring logs from the subsurface investigation program were prepared by ODOT and FMSM Engineers Inc. and are included in Appendix B.

On February 9 – 10, 2009, two additional borings, designated as B-21 and B-22, were drilled to depths of approximately 27 ft. within the NE and SW slopes, respectively, and additional instrumentation was installed in each. These borings were drilled using a track-mounted drill rig and hollow-stem augers operated by Ohio Testbore, Inc. Standard penetration tests (SPT) were conducted continuously to a depth of 15 ft., and at 5 ft. intervals to termination. The locations of the borings are shown in Figure 6.5 and Figure 6.14. No logs were prepared for these borings.

The basic stratification for the site is shown on the cross section provided in Figure 6.6. A typical boring log from the site is shown in Figure 6.15. The subsurface consisted of essentially three soil layers. Each was identified visually and classified according to the USCS. The top layer extends to a depth of approximately 15 ft. and consists of low plasticity brown silty clay (CL). The second layer consists of low plasticity brown and gray silty lacustrine clay (CL) ranging in thickness from 6 to 10 ft. The lower layer consists of low plasticity gray clayey silt with gravel (ML). These soils were also classified according to AASHTO as brown gravelly clay (till) (AASHTO A-6a and A-6b) to approximately 25 to 30 ft. in depth and brown and gray gravelly sandy silt (AASHTO A-4a) below approximately 30 ft. Soil classifications were based on visual descriptions and laboratory testing conducted at the ODOT Geotechnical Laboratory and by FMSM Engineers, Inc.

During drilling for borings B-20 and B-21, a thin layer of sand, approximately 4 ft. thick, was encountered at a depth of approximately 8 ft. This layer was not identified in the previous borings and is likely a small localized pocket. At a depth of approximately 23 ft., a layer of coarse sand and gravel was encountered in B-21 at the base of the SW slope. Artesian flow from this layer was observed, and water levels in the auger stems were measured as high as 3 ft. above the ground surface during drilling.

All of the borings are located within the limits of the bioengineering areas (Figure 6.14). Borings B-1 through B-4 and borings B-5 through B-8 were drilled above the NE and SW slopes, respectively, to depths ranging from 15 to 32 ft., and piezometers were installed (see Section 6.5.3). Shallow monitoring wells were installed in bore holes B-9, B-11, B-13 and B-15 to monitor groundwater near the bottom of the NE and SW slopes

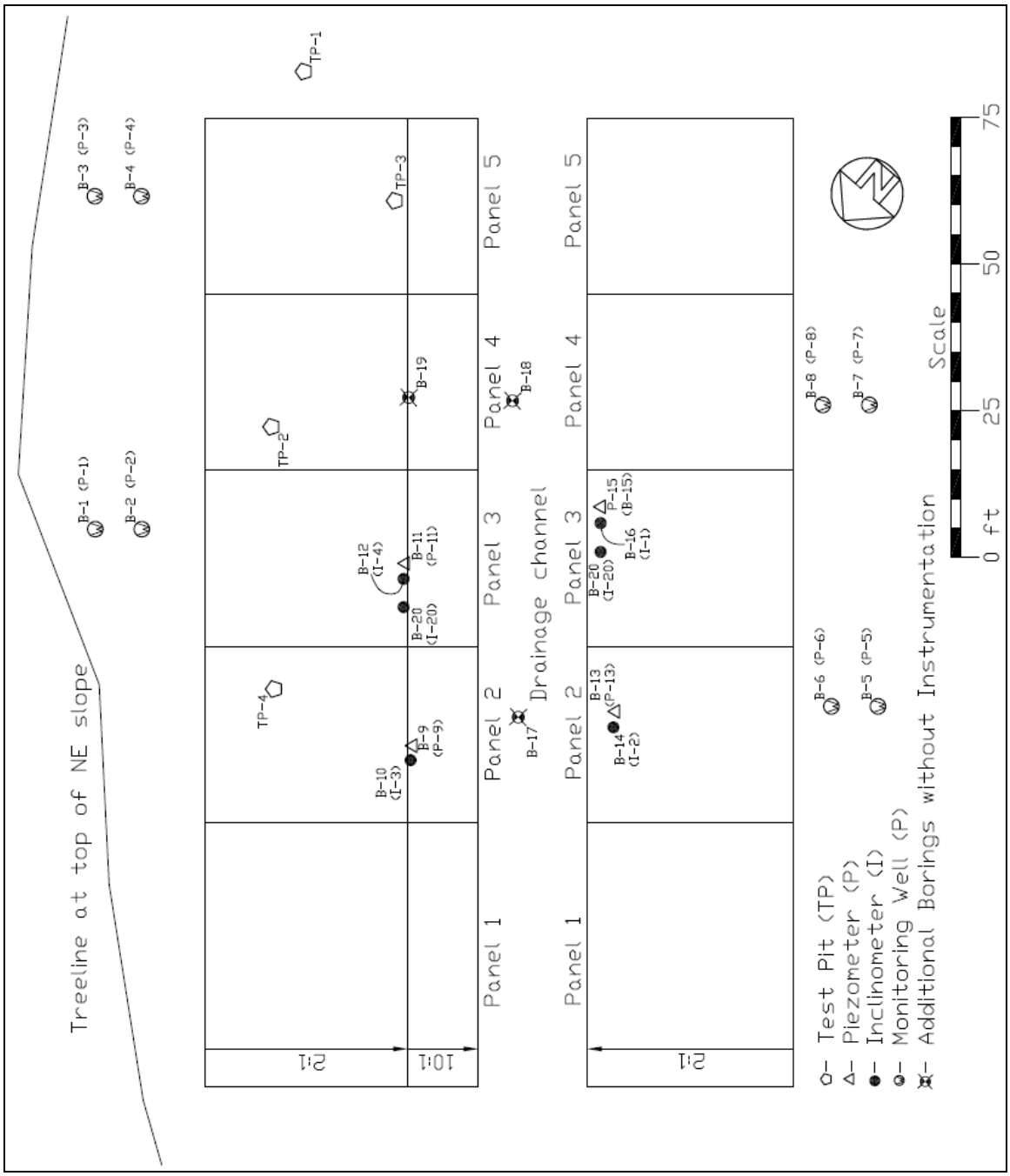


Figure 6.14: Subsurface investigation layout for the Logan County demonstration site.

at the channel bed elevation. Borings B-10, B-12, B-14 and B-16 were drilled, respectively, next to borings B-9, B-11, B-13 and B-15 at the bottom of the NE and SW slopes. Deep inclinometers were installed in each of these borings to monitor deep-seated movements (see Section 6.5.5). Additional deep inclinometers were installed in borings B-20 and B-21 in February 2009. Borings B-17, B-18 and B-19 were drilled in the middle of the channel bed and at the base of the NE slope as shown in Figure 6.5 and Figure 6.14.

State of Ohio
Department of Transportation
Office of Geotechnical Engineering

8/12

LOG OF BORING

Date Started 10/25/04 Sampler: Type SS Dia. _____ Water Elev. 1129.5' Project Identification: LOGAN
Date completed 10/25/04 Approx. LOG-347- 0.00
Boring No. B-6 Station & Offset 6+00,CL Surface Elev. 1155.0' LANDSLIDE & MONITORING WELL INSTALL.

Elev.	Depth	Std. Pen./ R.Q.D.	Rec. ft	Loss ft	Description	Sample No.	Physical Characteristics % Agg	% C.S.	% F.S.	% Silt	% Clay	L.L.	P.I.	W.C.	ODOT Class
1155.0	0														
	2														
	4														
1150.0	6	11/14/16			BROWN SILT AND CLAY	1	8	4	7	30	51	34	14	18	A-6a
	8														
1145.0	10														
	12	7/12/13			BROWN SANDY CLAY	2	11	5	7	31	46	31	12	17	A-6b
	14														
1140.0	16	5/7/11			BROWN AND GRAY SANDY CLAY	3	13	5	8	30	44	30	12	16	A-6a
	18														
1135.0	20														
	22	10/8/8			BROWN AND GRAY GRAVELLY CLAY W/BOULDERS	4	39	4	6	21	30	30	12	17	A-6a
	24														
1130.0	26	9/6/4			BROWN AND GRAY GRAVELLY SANDY SILT	5	16	4	13	41	26	20	4	24	A-4a
	28				SAND (DRILLER'S DESCRIPTION)	-	-	-	-	-	-	-	-	-	VISUAL
1125.0	30														

BOTTOM OF BORING

Particle Sizes: Agg= >2.00mm, Coarse Sand= 2.00-0.42mm, Fine Sand= 0.42-0.074mm, Silt= 0.074-0.005mm, Clay= <0.005mm

Form TE-151 Revised 9/95

Figure 6.15: Boring log B-6 (prepared by ODOT).

Additional exploration was conducted by OSU personnel using hand tools to excavate shallow test pits in areas of interest to depths of approximately 1.5 to 4 ft. Locations of these test pits, designated as TP-1 through TP-4, are shown on the site plan in Figure 6.14. These test pits were used to obtain shallow soil samples for laboratory testing, soil nutrient testing, and for vane shear testing.

6.4 LABORATORY TESTING

6.4.1 Physical Properties

Soil physical properties have been determined through laboratory tests performed by OSU personnel and the ODOT Geotechnical Laboratory. All test reports are included in Appendix B. Soil classification, Atterberg limits, sieve analysis and moisture content determination were conducted by ODOT technicians at the ODOT Geotechnical Laboratory on samples obtained during drilling. These results are tabulated in the boring logs included in Appendix B. The material at the shallow unstable depths has been classified as silt and clay and sandy silt (AASHTO A-6a and A-4a).

Soil-moisture characteristic testing was conducted by Dr. R. Lal and graduate research students from the Agronomy school at Ohio State. Sample preparation and testing was conducted in accordance with ASTM C1699. The resulting soil-moisture retention characteristic curve is shown in Figure 5.11. This curve will be used to assess the effect of vegetation on moisture conditions within the slope and the reliability of field instrument measurements.

Three consolidation tests were conducted on relatively undisturbed samples obtained from Shelby tubes in borings B-10 and B-16. Sample preparation and testing was done in accordance with ASTM standards (ASTM 2435). The preconsolidation pressures, σ_p', for B-10_1, B-10_2 and B-16 were 3313, 2610 and 2088 psf, respectively. The corresponding values of overconsolidation ratio (OCR) are 8.3, 6.5 and 4.7. The average coefficient of consolidation, c_v, at normal stresses of 1,430, 2,860 and 11,435 psf was 0.021, 0.057 and 0.020 in^2/min.

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Vane shear tests were also conducted in TP-2 and TP-3 using a CL-600 Torvane handheld shear device manufactured by Soiltest, Inc. A profile of water content (w) and undrained shear strength (s_u) was obtained for TP-2 while exhuming a copper shallow inclinometer (CSI) from the upper portion of the NE slope in March 2008 (see Section 6.5.4). This area of the NE slope experienced severe movement during the winter and early spring of 2008. A diagram of the results is shown in Figure 6.17. The profile shows the variation of water content and undrained shear strength between willow pole

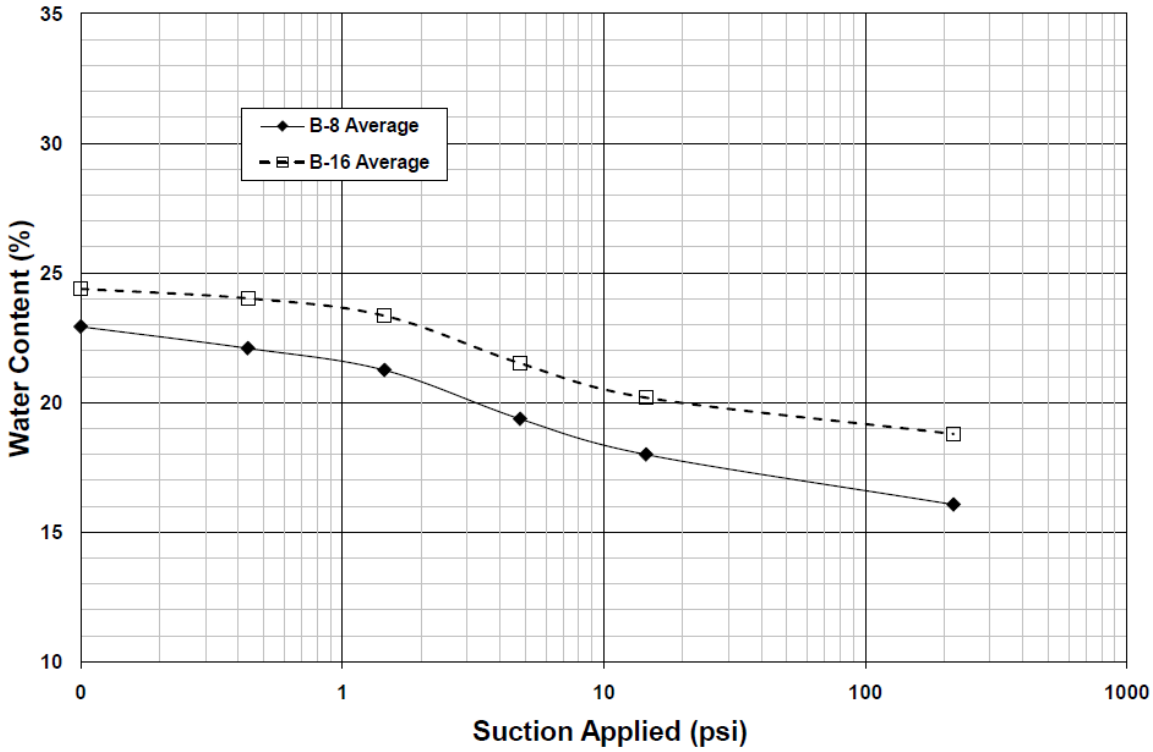


Figure 6.16: Soil-moisture retention characteristic curve for Logan County brown till and gray clay (testing by Dr. R. Lal).

13-11 and CSI-37 at different depths. The undrained shear strength measured in TP-2 ranged from 275 psf to 800 psf with an average of 400 psf and a standard deviation of 162 psf. Vane shear testing was also conducted in TP-3 in April 2008 near the area of a lateral pullout test and in TP-4 in August 2009 while exhuming CSI-34. The undrained shear strength measured in TP-3 was 675 psf the undrained shear strength measured in TP-4 ranged from 550 – 700 psf.

As seen from the profile in Figure 6.17, the undrained shear strength near the willow pole was generally higher than the undrained shear strength measured in adjacent areas across the profile. Also, in general, the undrained shear strength increased with depth at areas away from the willow pole; however, near the willow pole, the undrained shear strength was significantly higher in the upper portion of the soil. Shallow root growth from the willow may have removed water from the soil and generated additional strength in this area. It is noted that the undrained shear strength measured in TP-3 is significantly higher than the measured strengths determined in TP-2. This is most likely due to the time at which the measurements were taken. TP-2 was excavated in late winter/early spring during the wettest season, and it was noted during excavation that the groundwater level was approximately 1ft. below the ground surface. TP-3 was excavated during late spring/early summer after the warm dry season had already started.

Direct shear tests to determine residual shear strength were conducted on reconstituted samples obtained from shallow test pits. Sample preparation included: breaking the sample apart and removing any rocks or other debris (including any organic material), wetting the sample and hand kneading it to a uniform consistency with an

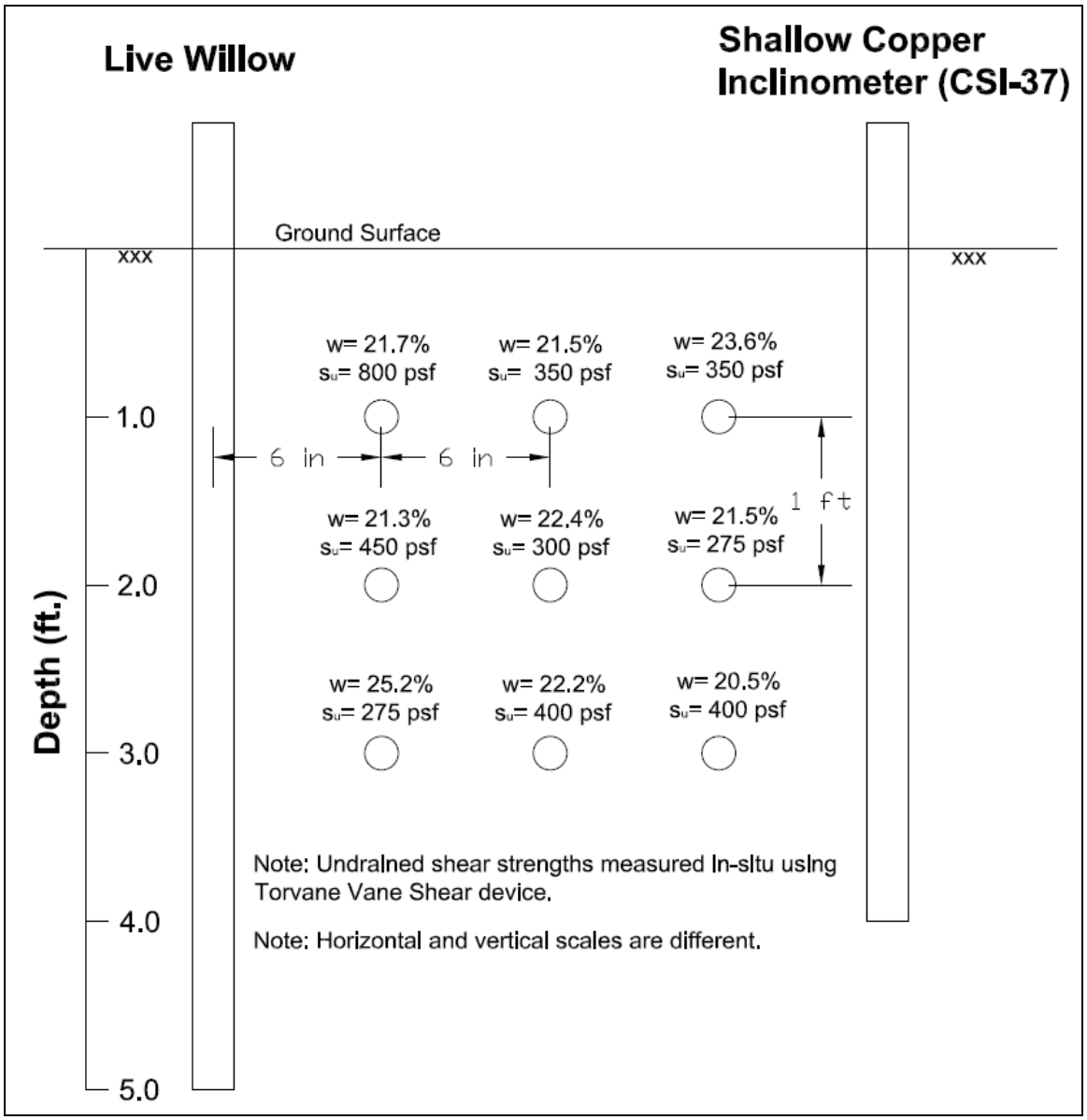


Figure 6.17: Profile of water content and undrained shear strength at TP-2.

initial water content $w = 25.0\%$ ($LL = 32\%$ for this material), and lightly compacting the sample by hand into the shear box. To ensure drained conditions, a strain rate of 0.001 in/min was used in accordance with ASTM standard methodology. The test consisted of a four-stage series with increasing increments of normal stress. A peak friction angle of $\phi'_p = 32.8°$, a residual angle of $\phi'_r = 20.0°$ and a residual cohesion of $c'_r = 0.84$ psi was determined as shown in Figure 6.18.

A total of six triaxial tests were conducted on relatively undisturbed samples obtained from Shelby tubes. Sample preparation was conducted in accordance with ASTM D2850 or other applicable methods. However, due to the limited amount of intact samples, multi-stage testing was used. Each stage of testing was conducted on the same

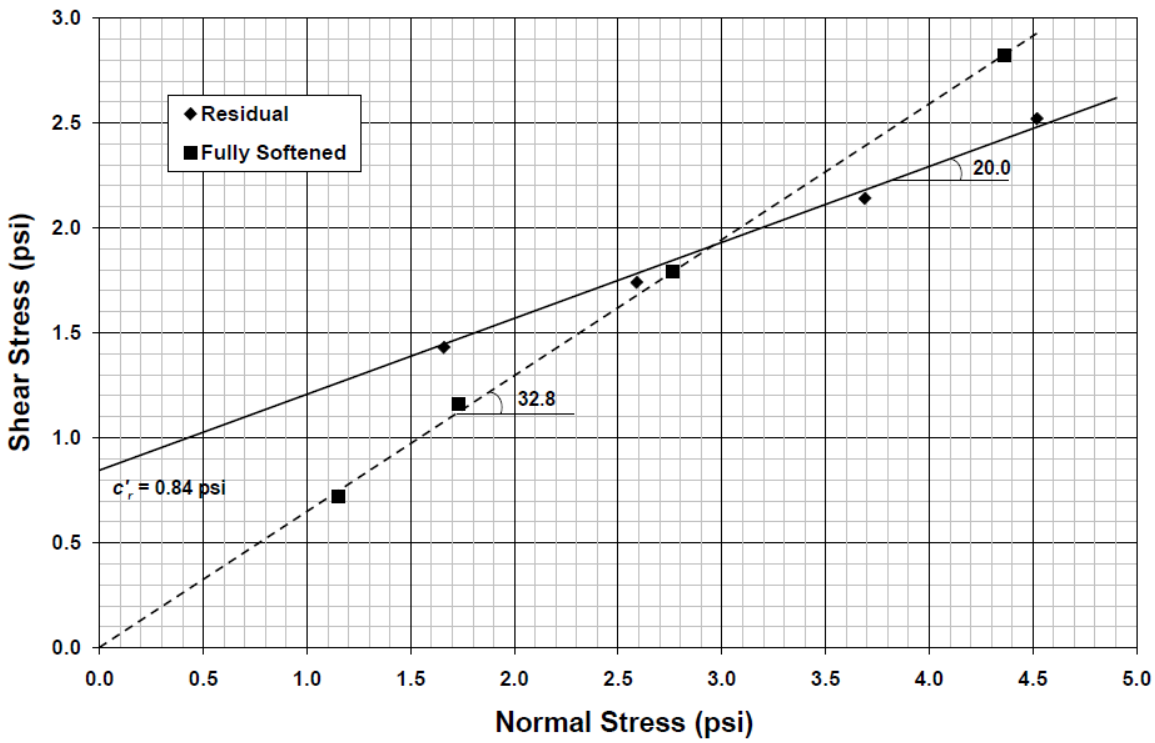


Figure 6.18: Logan County direct shear test failure envelopes.

sample using a progressive loading procedure. Each sample was initially saturated, consolidated and sheared to strains varying from 3 to 10% in accordance with ASTM procedures. Once a desired stress/strain was reached, shearing was discontinued and the sample was subsequently consolidated to a higher confining pressure. At the completion of the second consolidation stage, the sample was sheared to failure unless additional loading stages were required. Additional stages of loading were applied following the same.

Four multistage (two-point series) consolidated-undrained (CU) triaxial tests were performed on two samples from boring B-16 and one sample each from borings B-8 and B-2. The material tested from boring B-2 was classified as brown clay with stones (AASHTO A-6a) and had a peak effective friction angle, $\phi'_p = 28.9°$ (Figure 6.19). The material tested from boring B-16 was classified as gray clay (AASHTO A-6a, A-4a) and had peak effective friction angles, $\phi'_p = 30.2°$ and $\phi'_p = 31.8°$ (Figure 6.20 and Figure 6.21). The results from testing conducted on material recovered from B-8 have not been included due to errors that occurred during testing.

In addition to the CU tests, two multistage consolidated-drained (CD) triaxial tests were performed on two samples from borings B-16 and B-17. A two-stage series CD test was conducted on material obtained from boring B-17. The material was classified as brown clay with few stones (AASHTO A-4a) and had a peak effective friction angle, $\phi'_p = 30.0°$ (Figure 6.22). A three-stage series CD test was conducted on material obtained from boring B-16. The material was classified as gray clay (AASHTO A-6a) and had a peak effective friction angle, $\phi'_p = 24.4°$ (Figure 6.23).

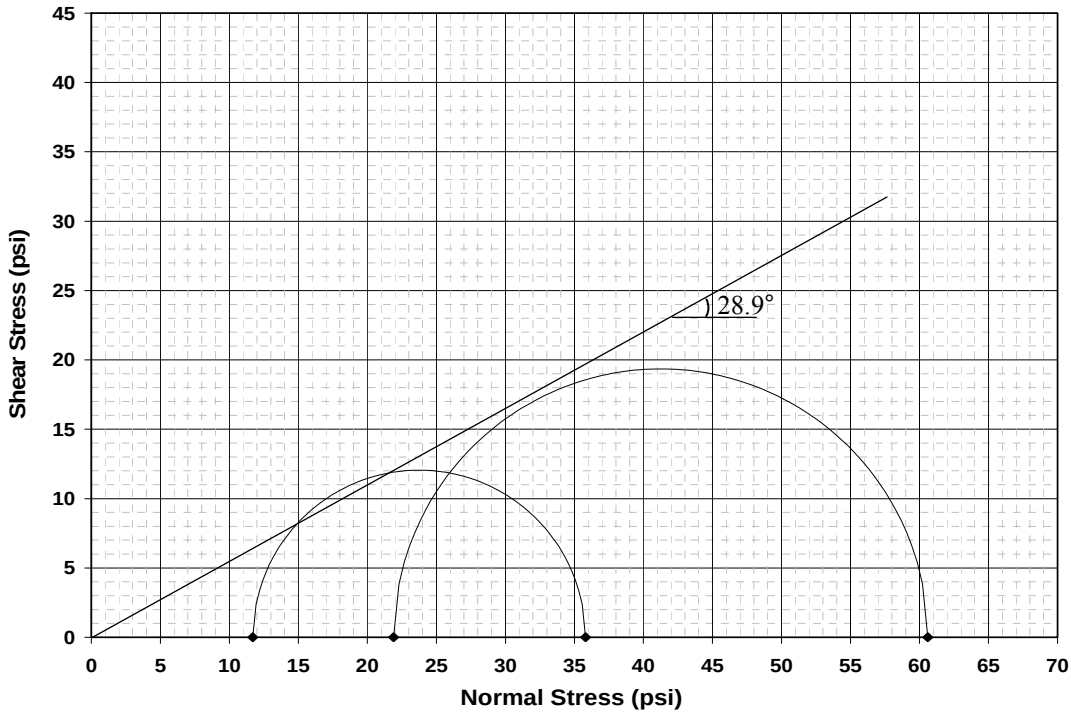


Figure 6.19: Logan County CU triaxial test results for B-2.

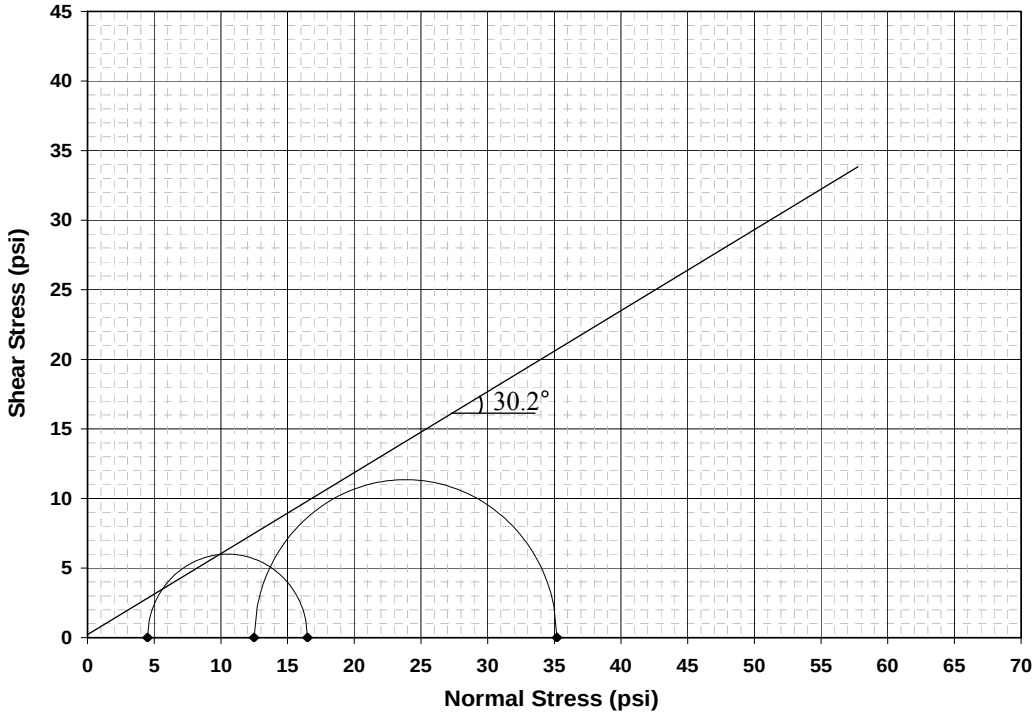


Figure 6.20: Logan County CU triaxial test results for B-16 (1).

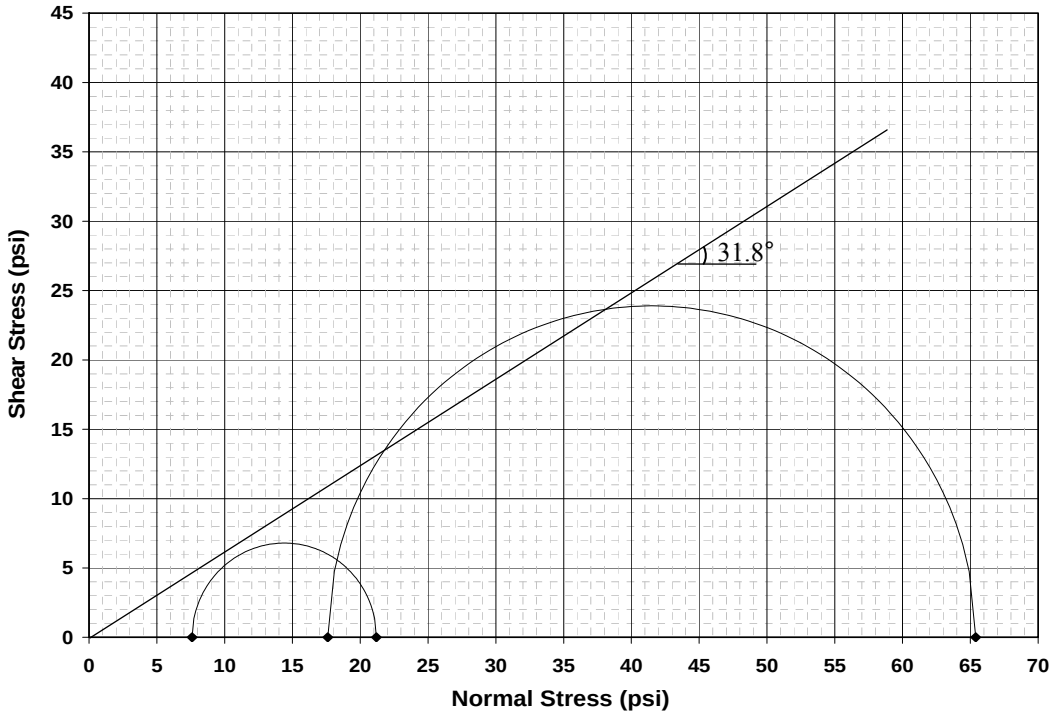


Figure 6.21: Logan County CU triaxial test results for B-16 (2).

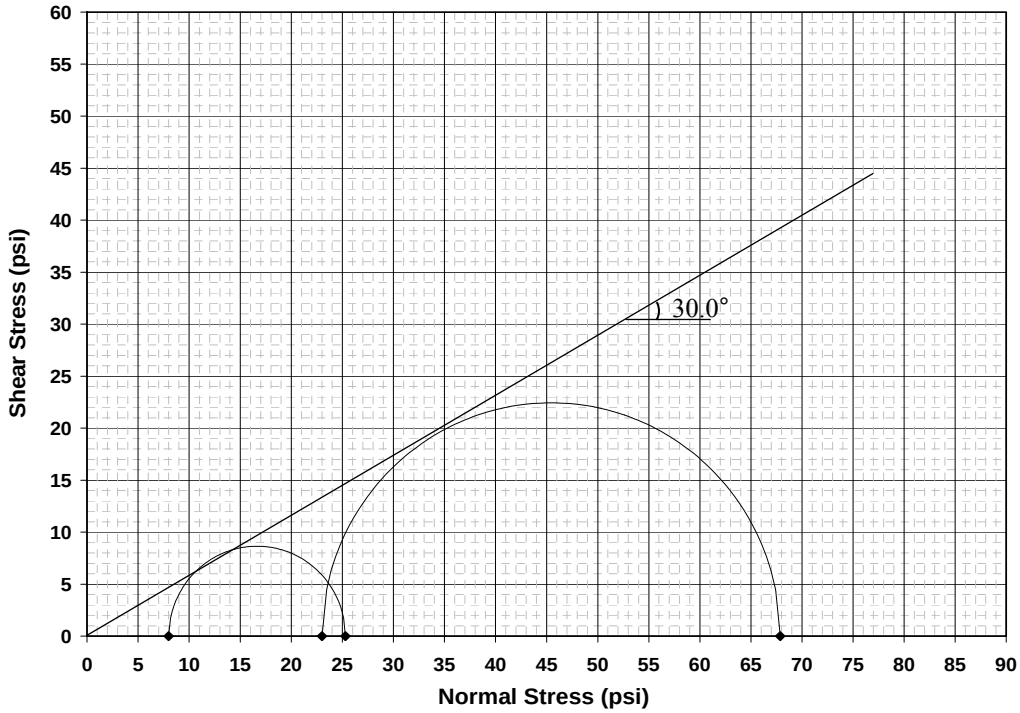


Figure 6.22: Logan County CD triaxial test results for B-17.

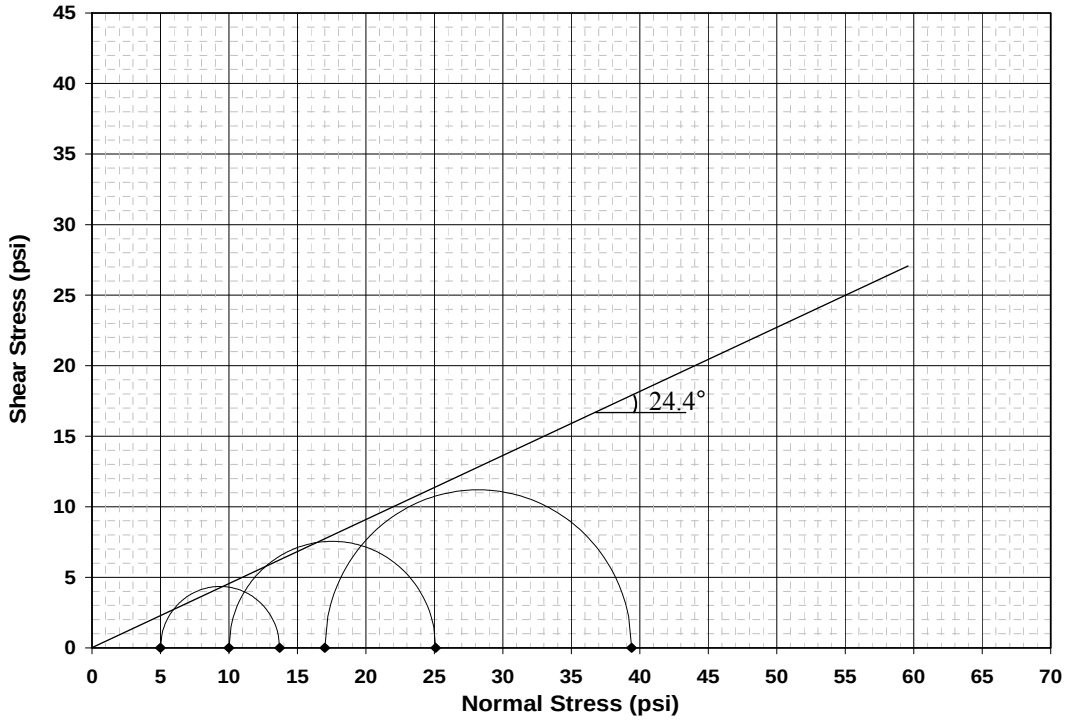


Figure 6.23: Logan County CD triaxial test results for B-16.

6.4.2 Chemical Properties

Soil nutrient testing was conducted by Calmar, Inc., of Westerville, Ohio. Two separate samples were submitted for testing. The first sample, submitted in February of 2006, was obtained from several locations across the repaired area and from depths of approximately 2 – 3 ft. The second sample, submitted in September of 2007, was obtained from TP-1. Results and recommendations of the soil nutrient testing are summarized in Table 6.1 and Table 6.2. These reports indicate that the soil pH is above the optimum and that sulfur, or other acidifying products, should be added to lower the pH value. The reports also indicate that the phosphorus, potassium, and organic matter levels are lower than optimum for growth of hardwood trees and bushes. It was noted that the low organic matter level and high pH value will adversely affect plant growth. Recommendations for adding phosphorus, potassium, nitrogen, and sulfur to the soil to achieve optimum levels for growing hardwood trees and bushes were also included in the first report.

6.5 INSTRUMENTATION

Instrumentation and site monitoring is a key issue on this project as it provides the basis for determining biostabilization feasibility and success. Figure 6.24 shows a plan view of site instrumentation. Groundwater and moisture data were collected using tensiometers, piezometers, monitoring wells, and gypsum blocks. Displacement data was

Table 6.1: Soil nutrient test results provided by Calmar, Inc.

	pH	Organic Matter (%)	Phosphorus (lb/acre)	Potassium (lb/acre)	Magnesium (lb/acre)	Calcium (lb/acre)
First Results	7.5	1.5	4	191	788	10,624
Second Results	7.7	1.4	7	248	835	10,624

Table 6.2: Recommendations for soil nutrient improvements provided by Calmar, Inc.

	Sulfur [1] (lb/acre)	Nitrogen [2] (lb/acre)	Phosphorus (lb/acre)	Potassium (lb/acre)
Recommendations for Addition to Soil	350	120	150	200

[1] Addition of sulfur is recommended to bring soil pH to optimal growing conditions.

[2] Addition of nitrogen is recommended to bring organic matter to optimal growing conditions.

obtained using shallow and deep inclinometers, as well as surveys of the existing poles after installation. The following sections provide specific details pertaining to site instrumentation. Complete records for all collected data are provided in Appendix B.

6.5.1 Tensiometers

Prior to construction, 12 tensiometers were installed; four each at 24, 36, and 60 in. depths within the NE and SW slopes. Subsequent to construction, 16 tensiometers were installed; eight each at 24 in. and 36 in. depths. Locations of each station are shown in Figure 5.15, and a table of values collected can be found in Appendix B. All measurements have been corrected for elevation of the water column in the tensiometer (see Section 4.4.1).

6.5.2 Gypsum Moisture Blocks

In addition to tensiometers, gypsum moisture blocks (G-Blocks) were also installed at the site to monitor moisture conditions in the upper 3 ft. of the slope. Throughout the site, twenty (20) G-Blocks were installed, including eight 24 in. and eight 36 in. depths, at locations where tensiometers were installed and four additional 24 in depths at locations where willow survival was noted to be high and low. The G-Blocks were installed next to the tensiometers in order to confirm soil suction values and to provide water-content changes over time. OSU personnel conducted laboratory tests to determine a correlation between the water content and G-Block reading of representative soil samples from the Logan county site. This calibration curve is shown in Figure 6.25.

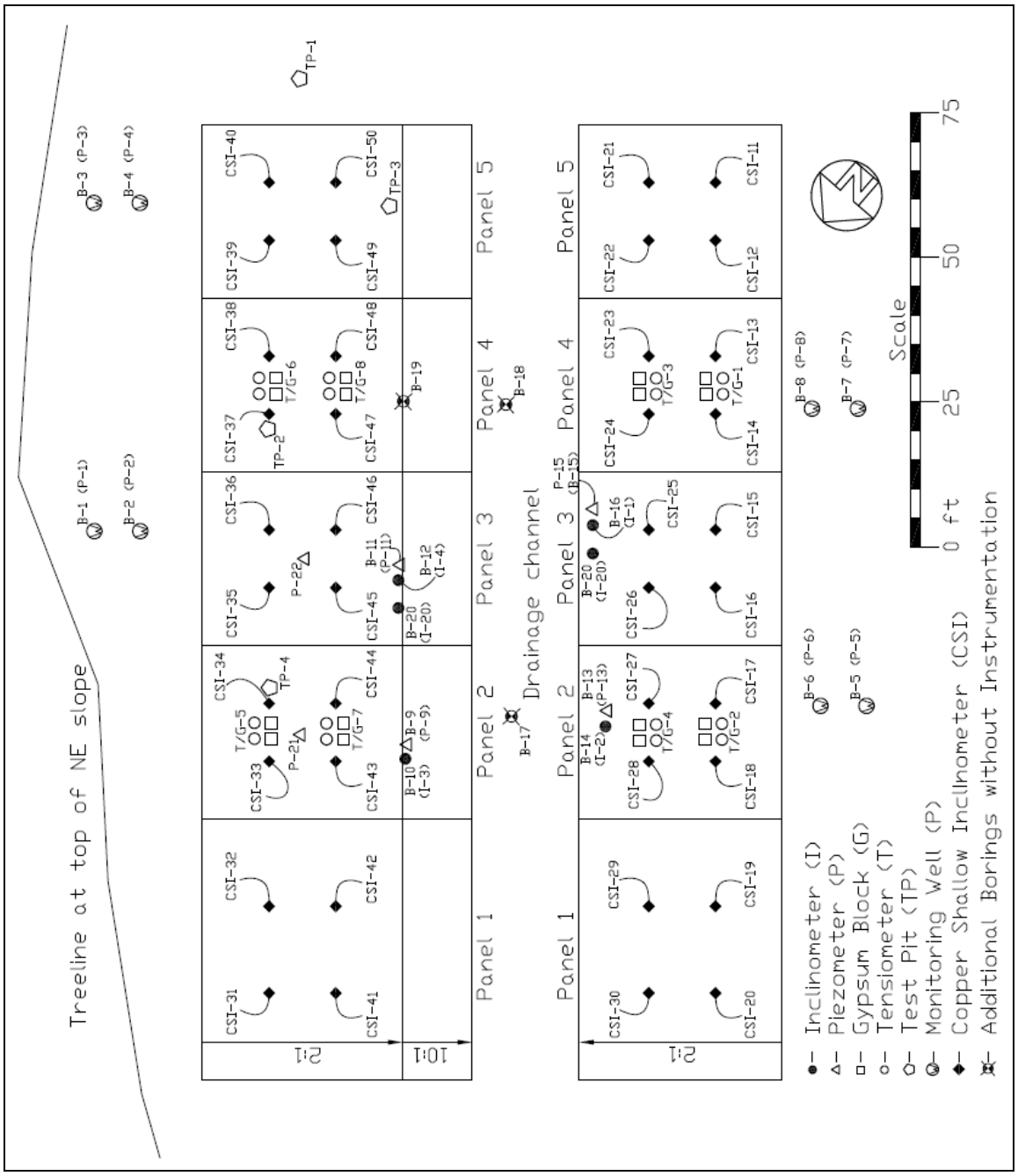


Figure 6.24: Logan County instrumentation layout.

Only a few measurements were obtained from the G-Blocks that were installed at the site. Installation of the G-Blocks occurred during the mid-to-late summer season, and not long after installation, the blocks dried out due to a lack of moisture within the slope. Drying out of the G-Blocks rendered the instruments unreadable, which is a likely indicator of critical moisture condition for poles. These measurements were read in March of 2008, and the water content determined from the laboratory calibration curve was over $w = 35.0\%$.

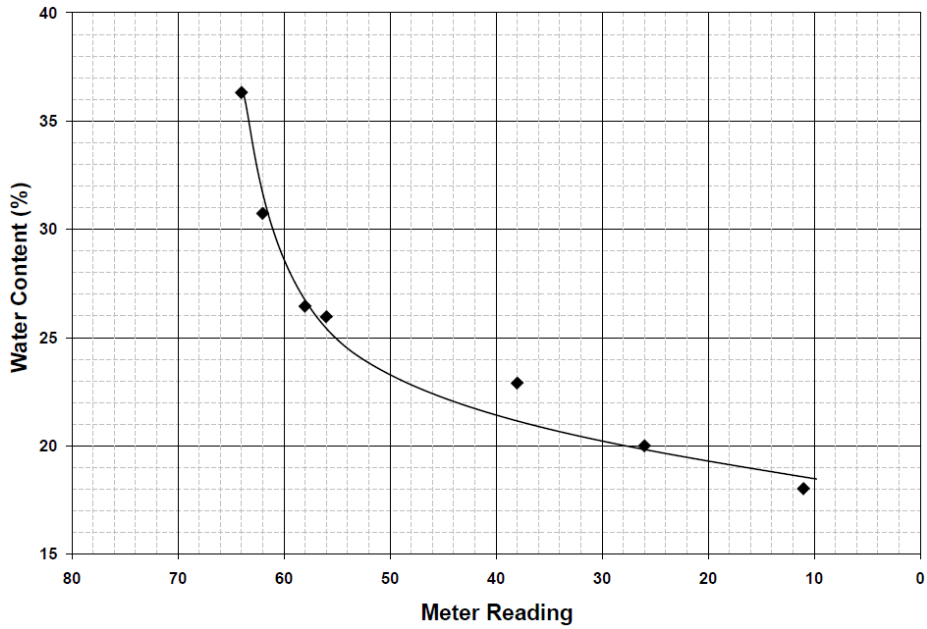


Figure 6.25: Logan County water content calibration curve for G-Blocks.

6.5.3 Monitoring Wells

Piezometers and monitoring wells were also installed throughout the demonstration site to measure static groundwater conditions. The location of each station is shown on the site plan (Figure 6.24). Eight piezometers, designated P-1 through P-4 and P-5 through P-8, were installed above the NE and SW slopes, respectively, to depths ranging from 15 to 22 ft. with 2 ft. of screen. Four shallow wells were installed by each deep inclinometer near the base of the NE and SW slopes to depths of approximately 7 ft. Two additional shallow wells were installed midway down the NE slope to depths of approximately 4.5 ft. during August 2007. A complete table of data and charts is provided in Appendix B.

6.5.4 Shallow Inclinometers

Shallow slope displacements were measured for both pre-construction and post-construction conditions using copper shallow inclinometers (CSIs). Four installations, designated CSI-1 through CSI-4, were installed between December 2004 and January 2005. Forty additional installations, designated CSI-11 through CSI-40, were installed in April 2007 to assess post-construction movements. The location of each CSI installed after construction is shown on Figure 6.24.

6.5.5 Deep Inclinometers

Four 30 ft. inclinometers, designated I-1, I-2, I-3 and I-4, were installed in bore holes B-16, B-14, B-10 and B-12, respectively, near the bottom of the NE and SW slopes. Locations of each inclinometer are shown in Figure 6.24. Prior to construction, the

inclinometers were routinely surveyed using a Slope Indicator vertical probe to measure the extent and rate of deformation occurring in the slopes around each casing. Due to damages during construction and from severe deformation, these inclinometers were rendered unreadable subsequent to construction. Two additional 30 ft. inclinometers, designated I-20 and I-21, were installed in bore holes B-20 and B-21 in the NE and SW slopes, respectively, in February 2009.

6.6 DESIGN AND CONSTRUCTION

The following sections describe details of the bioengineering design and construction. All vegetation, live poles and brushlayers, was harvested in the dormant state from the Delaware Wildlife Area in Delaware County, Ohio, during March 2007. To prevent drying and desiccation during transportation and installation, the vegetation was stored in cattle troughs under water and tarps. Over 90% of the species installed have been visually identified as willows. Therefore, statistics for willows and non-willows will not be provided separately.

Several options for mitigating the deep failures were considered by the research team. Remedial options included slope flatting, toe berm construction, drains, and lime injection. Lime injection was dismissed due to general unfamiliarity with the method and, in particular, uncertainties in the prediction of the soil strength gain with time. Slope dewatering using drains was also dismissed as the groundwater table already lies low within the slope. As a result, the research team decided to use a combination of toe berm construction along the base of the NE slope and flattening along the top of the SW slope to arrest the deep-seated movement. See Section 6.7.5 for stability analysis results and discussion.

Live staking (live poles) and hydro-seeding in conjunction with erosion mats were chosen as the primary means to mitigate the shallow sliding and erosion occurring within the slopes. Two live pole plots, designated as the NE and SW pole plots, were constructed on each side of the drainage ditch.

6.6.1 Construction Plans and Contactor Selection

Figure 6.26 presents the bioengineering design for the Logan County demonstration site. The construction area for the NE slope was approximately 195×40 ft., while the construction area for the SW slope was approximately 165×35 ft. Six panels and three gravity berms were defined on the NE slope and five panels were defined on the SW slope. The construction methods employed for each section were:

- Panel 1: Control section, no work performed;
- Panel 2: Scraped, re-graded, jute mat, and hydroseed;
- Panel 3: Scraped, re-graded, jute mat, willow poles installed using best method (Figure 6.27a), and hydroseed;
- Panel 4: Jute mat, willow poles installed using best method (Figure 6.27a), and hydroseed;

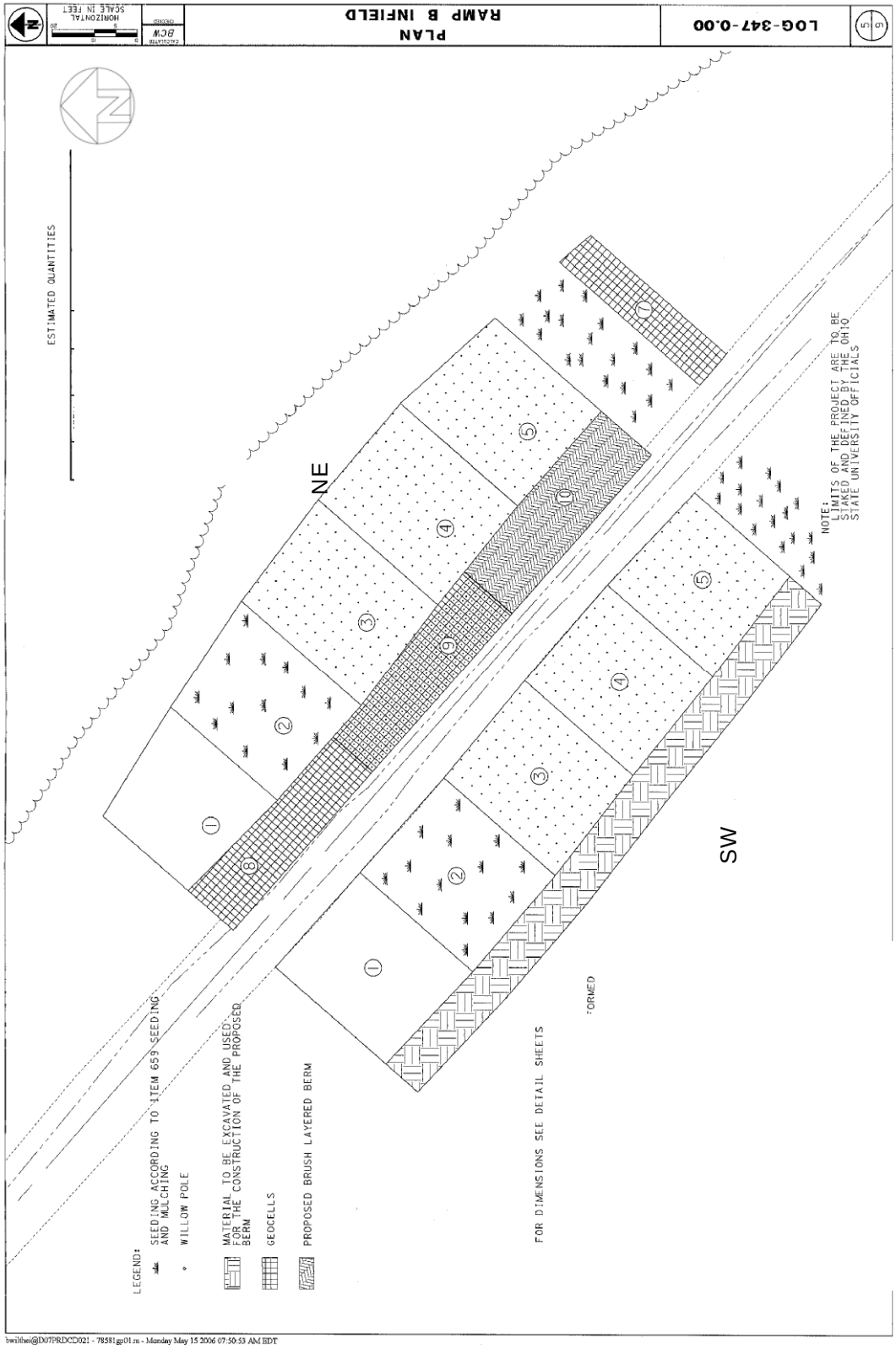
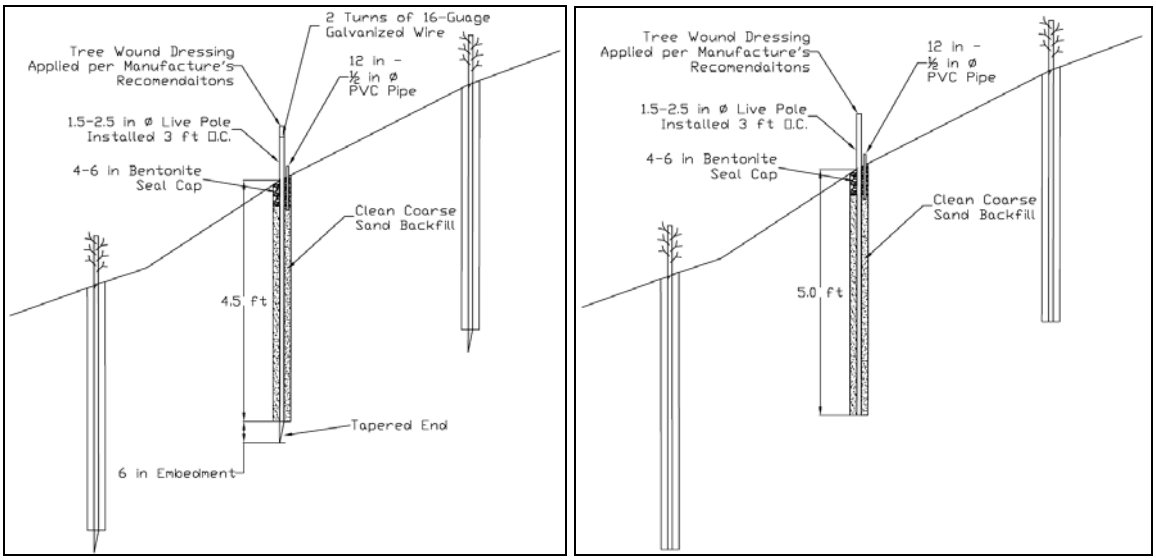


Figure 6.26: Construction plan for Logan County demonstration site.

- Panel 5: Jute mat installed, willow poles installed using minimal method (Figure 6.27b), and hydroseed;
- Panel 6: Control section, no work performed;
- Panel 7: Geocell section installed along slope face;
- Area 8: Geocell gravity berm;
- Area 9: Reinforced geocell gravity berm;
- Area 10: Brushlayer gravity berm.

Figure 6.27a and Figure 6.27b are typical cross sections illustrating installation and backfill techniques for willow poles using the best and minimal methods, respectively. Further information on these methods is given in the following sections.



(a) (b)

Figure 6.27: Live pole installation methods: (a) best method, and (b) minimal method.

Construction at the Logan County demonstration site was scheduled to begin on March 1, 2007, and be completed on or before April 1, 2007, while the vegetation was still in the dormant state. The project, which included installations at both Logan and Union Counties, was first put out to bid in September 2006. Due to a lack of experience, all contractors submitted proposals that exceeded the allowable maximum cost. The project was put out to bid a second time in December 2006, and a proposal from Deitering Landscaping, Inc. of Leipsic, Ohio, was accepted. The project manager was Ron Deitering, one of the co-owners of the company. While the company had never conducted a specific installation of this type on a large scale, they had satisfactorily completed several jobs with ODOT in the past and had conducted similar successful installations (planting tree cuttings).

6.6.2 Construction Procedures

Installation of willows at the Logan County demonstration site began on February 26, 2007, and was completed on March 8, 2007. Construction plans were drafted by ODOT engineers for the Logan bioengineering project. A complete set of the plans has been provided in Appendix B. Prior to installation of the willow poles, the slope face of Panels 2 and 3 were scraped and smoothed using the bucket of a trackhoe. Geo-jute matting was installed over the slope face of Panels 2 through 5 to mitigate surficial erosion during and after construction. The contractor completely installed all poles in the NE slope before starting installation in the SW slope. A total of 402 live poles were installed in a 3 ft. square grid pattern throughout the 90×40 ft. section of Panels 3 through 5 in the NE slope, and 378 live poles were installed in a 3 ft. square grid pattern throughout the 90×35 ft. section of Panels 3 through 5 in the SW slope. Overall, 780 live poles were installed at the Logan County site. Poles were approximately 6 to 7 ft. in length and had typical diameters ranging from 1 to 2 in. Visual logs were kept for the entire installation from harvesting to completion.

6.6.2.1 Best Method of Installation

The best method of installation is labor intensive and is designed to maximize the potential for plant growth and establishment. Actual growth and establishment is dependent on additional factors after installation, in particular temperature and rainfall. This method was implemented in Panels 3 and 4 for both the NE and SW slopes. The general preparation and installation procedure using this method is:

1. Harvesting – The live pole cuttings were harvested from the Delaware Wildlife Area in Delaware County, Ohio, using a gas powered chainsaw on the day of or the day prior to installation.
2. Transportation – Using an industrial pickup truck, the cuttings were transported from the Delaware Wildlife Area to the site. During the transfer, the cuttings were stored in water-filled livestock feed troughs to prevent desiccation.
3. Onsite storage – Cuttings were stored onsite in water-filled livestock feed troughs prior to installation.
4. Live pole preparation – Pole dimensions were recorded, the butt end of each pole was shaped to a point, and any protruding branches and knobs were trimmed flush. Several turns of 16-gauge galvanized wire were secured to the top end of each pole to prevent splitting during installation.
5. Live pole installation – Holes were spiked using a trackhoe with a 50 ft. boom arm. A 3 in. diameter steel spike attachment was fabricated by the contractor and attached to the boom arm in place of a bucket. This was then guided to each point and used to spike a hole 5 ft. deep, vertically, into the slope. One live pole was placed into each 3 in. diameter pre-spiked hole. The pole was then hammered firmly about 6 in. into the base of the hole using a large wooden mallet (this promotes intimate contact of the pole and the soil and stimulates root growth to

accelerate establishment of each willow). The annular space between each pole and its respective hole was backfilled with all-purpose sand in 6 in. lifts to about 4 to 6 in. below the ground surface and was tamped with a rod to fill all of the void space. A 0.5 in. diameter, 1 ft. length PVC pipe was placed in each hole adjacent to the pole protruding 3 in. above the ground surface and extending into the sand backfill to permit the circulation of air to the rooting zone (recommended by Alex Watson (personal communication with T. H. Wu)). The top 4 to 6 in. of each hole was then capped with granular bentonite to seal the hole and prevent rainwater from collecting inside (which would increase static pore pressures and further destabilize the slope). Each pole top was trimmed at a slight angle leaving 9 to 12 in. exposed above the ground surface. The pole tops were re-wired to prevent splitting due to desiccation. Treekote® tree wound dressing was also applied to prevent desiccation. Finally, an 18 in. diameter biodegradable weed control mat was pinned around the base of each pole to reduce competitive flora growth.

6. Seeding – Seeding was performed following completion of the installation for both slopes and in areas that required restoration from equipment damage.

Figure 6.28 shows an installed live pole using the best method. Pictures of completed construction for the NE and SW live pole plots are presented Section 6.6.2.6. A visual log for each step of the best method installation procedure is provided in Appendix B.

Figure 6.28: Completed installation of a live pole using the best method.

6.6.2.2 Minimal Method of Installation

The minimal method is designed to minimize installation time and maximize field production. This method was implemented only in Panel 5 for both the NE and SW slopes. The general preparation and installation procedure using the minimal method is:

1. Harvesting – The live pole cuttings were harvested from the Delaware Wildlife Area in Delaware County, Ohio, using a gas powered chainsaw on the day of or the day prior to installation.
2. Transportation – Using an industrial pickup truck, the cuttings were transported from the Delaware Wildlife Area to the site. During the transfer, the cuttings were stored in water-filled livestock feed troughs to prevent desiccation.
3. Onsite storage – Cuttings were stored onsite in water-filled livestock feed troughs prior to installation.
4. Live pole preparation – Pole dimensions were recorded and the poles were trimmed of any protruding branches and knobs. Several turns of 16-gauge galvanized wire were secured to the top end of each pole to prevent splitting during installation.
5. Live pole installation – Holes were spiked using a trackhoe with a 50 ft. boom arm. A 3 in. diameter steel spike attachment was fabricated by the contractor and attached to the boom arm in place of a bucket. This was then guided to each point and used to spike a hole 5 ft. deep, vertically, into the slope. One live pole was placed into each 3 in. diameter pre-spiked hole. The annular space between each pole and its respective hole was backfilled with all-purpose sand in 6 in. lifts to about 4 to 6 in. below the ground surface and was tamped with a rod to fill all of the void space. A 0.5 in. diameter, 1 ft. length PVC pipe was placed in each hole adjacent to the pole protruding 3 in. above the ground surface and extending into the sand backfill to permit the circulation of air to the rooting zone (recommended by Alex Watson (personal communication with T. H. Wu)). The top 4 to 6 in. of each hole was then capped with granular bentonite to seal the hole and prevent rainwater from collecting inside (which would increase static pore pressures and further destabilize the slope). Each pole top was trimmed at a slight angle leaving 9 to 12 in. exposed above the ground surface. Treekote® tree wound dressing was applied to each pole to prevent desiccation. Finally, an 18 in. diameter biodegradable weed control mat was pinned around the base of each pole to reduce competitive flora growth.
6. Seeding – Seeding was performed following completion of the installation for both slopes and in areas that required restoration from equipment damage.

Figure 6.29 shows an installed live pole using the minimal method. Pictures of completed construction for the NE and SW live pole plots are presented Section 6.6.2.6. A visual log for each step of the best method installation procedure is provided in Appendix B.

Figure 6.29: Completed installation of a live pole using the minimal method.

6.6.2.3 Geocell Slope Erosion Protection

Panel 7, located approximately 20 ft. to the south of Panel 5 on the NE slope (Figure 6.26), is a 10 ft. wide section of geocells that extends approximately 40 ft. down the face of the slope from top to bottom. At ODOT's request, the purpose of this section was to allow side-by-side comparison of the effectiveness of erosion control using either geocells or geo-jute matting. Effectiveness was determined by visual observations. This area was covered with a single section of geocells to a depth of 4 in. The general preparation and installation procedure is:

1. Preparation – Prior to excavation, the geocell section was stretched out across the designated area and outlined using construction spray paint.
2. Excavation – The area was then cleared and excavated uniformly using a bobcat and a telescoping front end loader to a depth of approximately 4 in.

3. Installation – Once excavation was complete, the geocell section was stretched and placed in the excavated area. Rebar was placed around the edges to anchor the section. Top soil was spread over the entire section and compacted using a plate vibrator. This process was repeated until all geocells were filled and compacted flush with the surrounding slope.
4. Seeding – ODOT standard mixture hydroseed was applied to the entire section at the completion of construction.

6.6.2.4 Geocell Gravity Berms

Two geocell gravity berms, measuring 50 ft. long, designated as Areas 8 and 9 in Figure 6.26, were constructed in conjunction with a brushlayer gravity berm to mitigate the deep-seated failure occurring within the NE slope. The berms are approximately 8 ft. wide and have a surface grade of 10H:1V. The berm faces have a slope of 1H:1V (see Appendix B for a schematic detail). Each 8×8 ft. geocell section consists of 64 cells, each having 1 ft.^{2} surface area and 6 in. depth. Pictures of the berms at the completion of construction are provided in Figure 6.30 and Figure 6.31. Stability analyses are provided in Section 6.7.5.2 and are the same for each gravity berm type (i.e., essentially same dead weight). The general preparation and installation procedure for both geocell gravity berms is:

1. Excavation and preparation – All vegetation and soil was excavated from the area using a Bobcat, a telescoping loader and a trackhoe, and set aside as stock pile. The excavation extended 1 ft. below the creek bed elevation. A geotextile fabric was placed inside the excavation.
2. Installation – Once area preparation was complete, the geocell section was stretched within the excavated area. Rebar was placed around the edges to keep the section stretched and anchored. Moist soil from an ODOT stockpile was placed in each lift of geocells for Area 9 and compacted using a plate vibrator. Crushed stone was placed in each lift of geocells for Area 8 and compacted using a plate vibrator. All geocells were filled and compacted until the fill material was flush with the top of the section. This process was repeated for the first seven lifts of both Areas 8 and 9. For the last lift, top soil was spread over both Areas 8 and 9 and compacted using a plate vibrator. This process was repeated until all geocells were filled. Topsoil was placed over top of the geocells and tapered into the existing slope face.
3. Vegetation installation – Brush material was placed vertically in a 3 ft. square grid pattern along the surface of Area 9 to a depth of approximately 1 ft.
4. Seeding – ODOT standard mixture hydroseed was applied to the entire section at the completion of construction.

During construction of the center geocell gravity berm (Area 9), which occurred prior to construction of the left geocell gravity berm (Area 8), it was determined that onsite soil was unsuitable for use as backfill due to high water content and the cohesive consistency. This soil was not easily compacted into the cells using a plate vibrator; however, the

geocells would experience permanent deformation under the weight of construction machinery. The fill material used for the remainder of the construction of the berms was obtained from local ODOT stockpiles and private contractors. Fill material consisting of clay and topsoil that was cleaned out from ditches throughout the county was obtained from a local ODOT stockpile. This material, however, also did not easily compact into the geocells. Therefore, a granular material consisting of crushed stone (ODOT 304 stone) was used to fill the remainder of the cells, using topsoil for the front cells and the final lift to promote vegetative growth. All removed material that was not utilized as fill was distributed throughout areas damaged by construction traffic during site restoration activities.

Figure 6.30: Geocell gravity berm after construction (photo taken April 18, 2007).

6.6.2.5 Brushlayer Gravity Berm

A brushlayer gravity berm, measuring 50 ft. long and designated as Area 10 in Figure 6.26, was constructed in conjunction with two geocell gravity berms to mitigate the deep-seated failure occurring within the NE slope. The berm is approximately 12 ft. wide and has a surface grade of 10H:1V. The berm face has a slope of 1H:1V (see Appendix B for a schematic detail). All fill material for this berm was procured from areas onsite. A picture of the berm at the completion of construction is shown in Figure 6.32. Stability analyses are provided in Section 6.7.5.2 and are the same for each gravity berm type (i.e., essentially same dead weight). The general preparation and installation procedure for the brushlayer berms is:

Figure 6.31: Reinforced geocell gravity berm after construction (photo taken April 18, 2007).

1. Excavation and preparation – All vegetation and soil was excavated from the area using a bobcat, a telescoping loader and a trackhoe, and set aside as stock pile. The excavation extended 1 ft. below the creek bed elevation. A geotextile fabric was placed inside the excavation.
2. Vegetation harvesting and preparation – Branch cuttings and small poles served as primary reinforcement for the berm. No special preparatory measures were used for this vegetation.
3. Fill and construction – Excavated soil from the brushlayer berm and also from the geocell berms, as well as soil removed from the top of the SW slope was used as fill for the brushlayer berm. Material was placed in 6 in. lifts and compacted using the weight of the trackhoe and telescoping loader.
4. Vegetation installation – The brush material was placed at a spacing of approximately 4 in. along the length of each lift starting with the first lift above the creek bed elevation, and protruding approximately 6 in. from the berm face.
6. Seeding – ODOT standard mixture hydroseed was applied to the entire section at the completion of construction.

Figure 6.32: Brushlayer berm after construction (photo taken April 18, 2007).

6.6.2.6 Completed Construction

Figure 6.33 and Figure 6.34 show the NE and SW slopes, respectively, after completion of all construction activities.

6.6.2.7 Additional Installations

Due to poor initial survival, additional vegetation installations were conducted on the side slopes during the spring and winter of 2008 and spring of 2009. No vegetation was replaced on the berms. All poles for these installations were harvested several days prior to planting from the Delaware Wildlife Area in Delaware County, Ohio, and were kept under water in a trough to prevent drying and desiccation until planting. All additional poles were installed using the minimal method outlined in Section 6.6.2.2. Contrary to replacement installations at the Muskingum County demonstration site, dead poles were not extracted from the Logan County site. Instead, new poles were planted as shown in Figure 6.35. Figure 6.36 shows the areas where new poles were installed. Areas selected for additional installations generally exhibited little to no survival of original vegetation, and were experiencing additional slope movements.

Figure 6.33: NE slope after construction (photo taken April 18, 2007).

Figure 6.34: SW slope after construction (photo taken April 18, 2007).

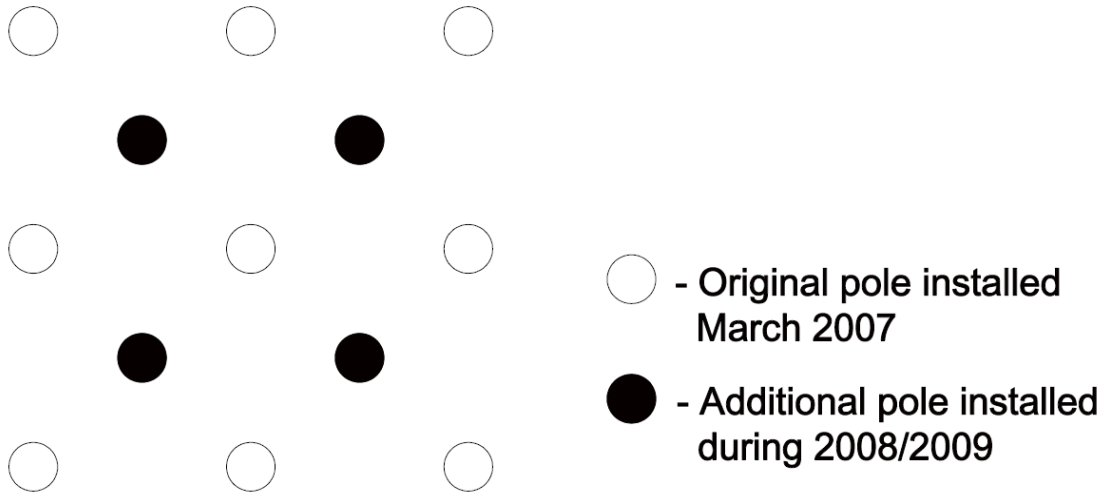


Figure 6.35: Pole layout for additional installations.

6.7 PERFORMANCE

This section presents performance data pertaining to the installations completed during late winter/early spring 2007, spring and winter of 2008, and spring 2009 at the Logan County demonstration site. Performance is assessed primarily on vegetation survival rate and slope deformation that has occurred subsequent to installation. Climate conditions and moisture levels within the reinforced portion of the slopes were closely monitored as these are important factors that influence survival.

6.7.1 Groundwater and Moisture Conditions

Groundwater and moisture conditions within the slope are shown on the cross sections provided in Figure 6.6 and Figure 6.7 and have been monitored throughout the project (November 2004 through September 2008). Figure 6.37 and Figure 6.38 show graphs of soil suctions as measured by tensiometers, piezometric levels from shallow monitoring wells, and monthly precipitation, respectively, for stations 1 through 4, and stations 5 through 8. Figure 6.24 indicates station locations (i.e., T/G-1 through T/G-8). Additional data and charts for all stations are provided in Appendix B.

Soil suctions measured from June 2005 through September 2008 using tensiometers at stations 1 through 4 in the SW slope and stations 5 through 8 in the NE slope are shown Figure 6.37a and Figure 6.38a, respectively. It can be seen from the charts that soil suctions in the upper 3 ft. of the NE slope ranged from zero (saturated) to as high as 11.5 psi. Soil suctions in the upper 3 ft. of the SW slope ranged from zero (saturated) to as high as 10.5 psi. Initial readings at the site indicate that both slopes were experiencing near-saturated to slightly dry conditions, as indicated by zero to small suctions, prior to construction. Soil suctions after installation show a steady and substantial increase with time. Soil suctions measured at stations outside of the biostabilized areas (stations 2 and 4 on the SW slope and stations 5 and 7 on the NE

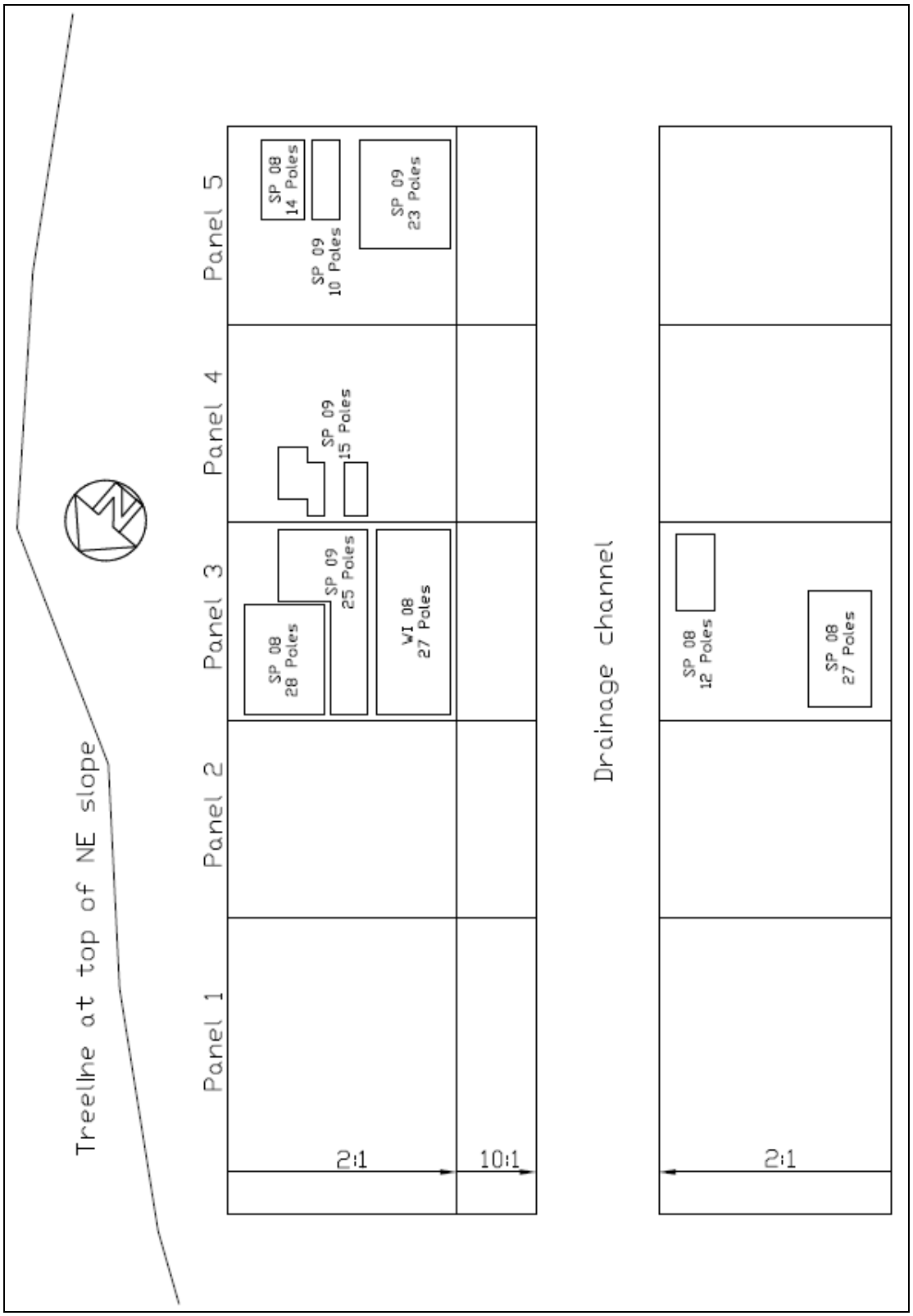


Figure 6.36: Locations and numbers of poles installed after initial installation.

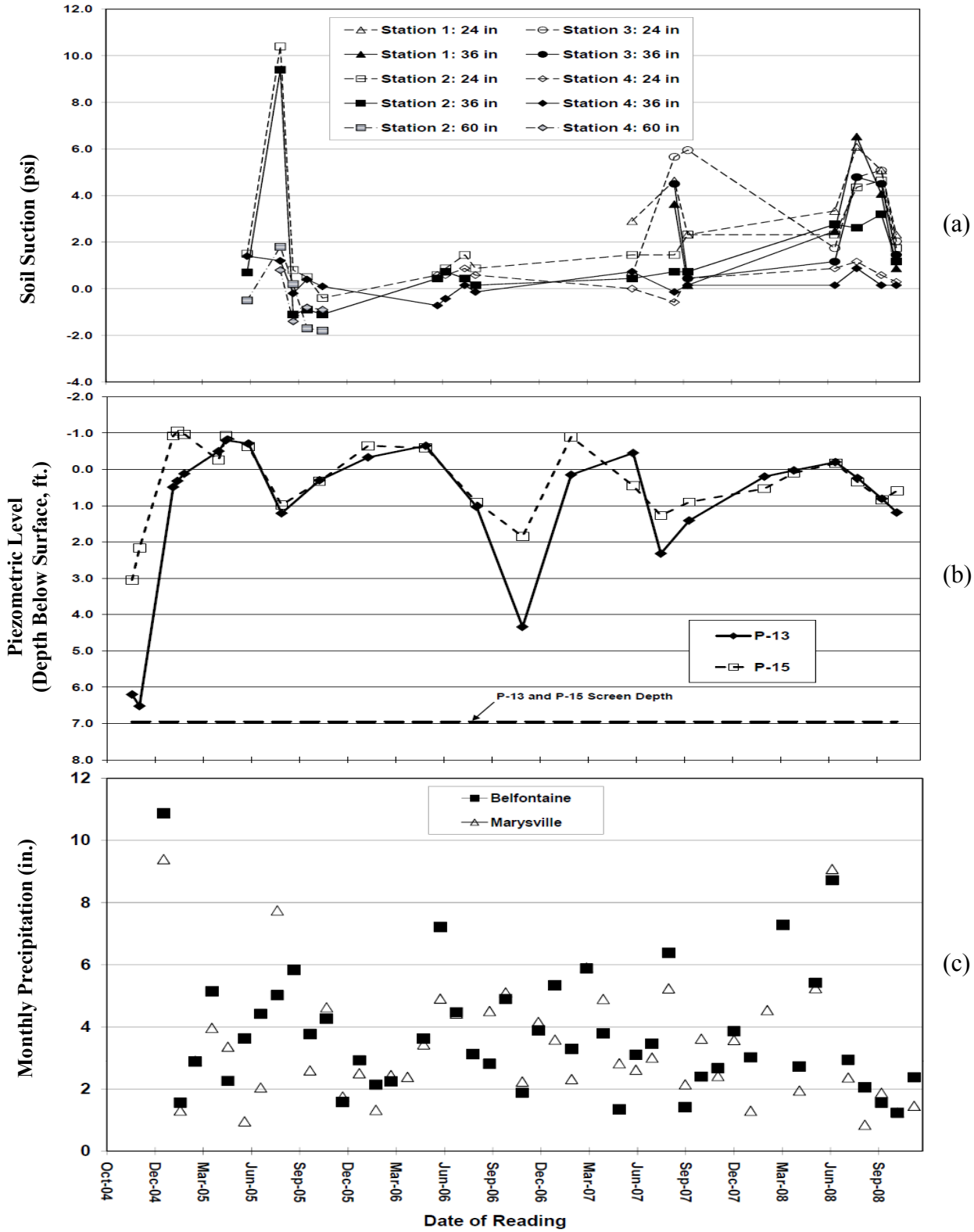


Figure 6.37: Graphs of: a) soil suctions from tensiometers for stations 1 through 4, b) piezometric head levels from shallow monitoring wells and c) monthly precipitation for Logan County, Ohio.

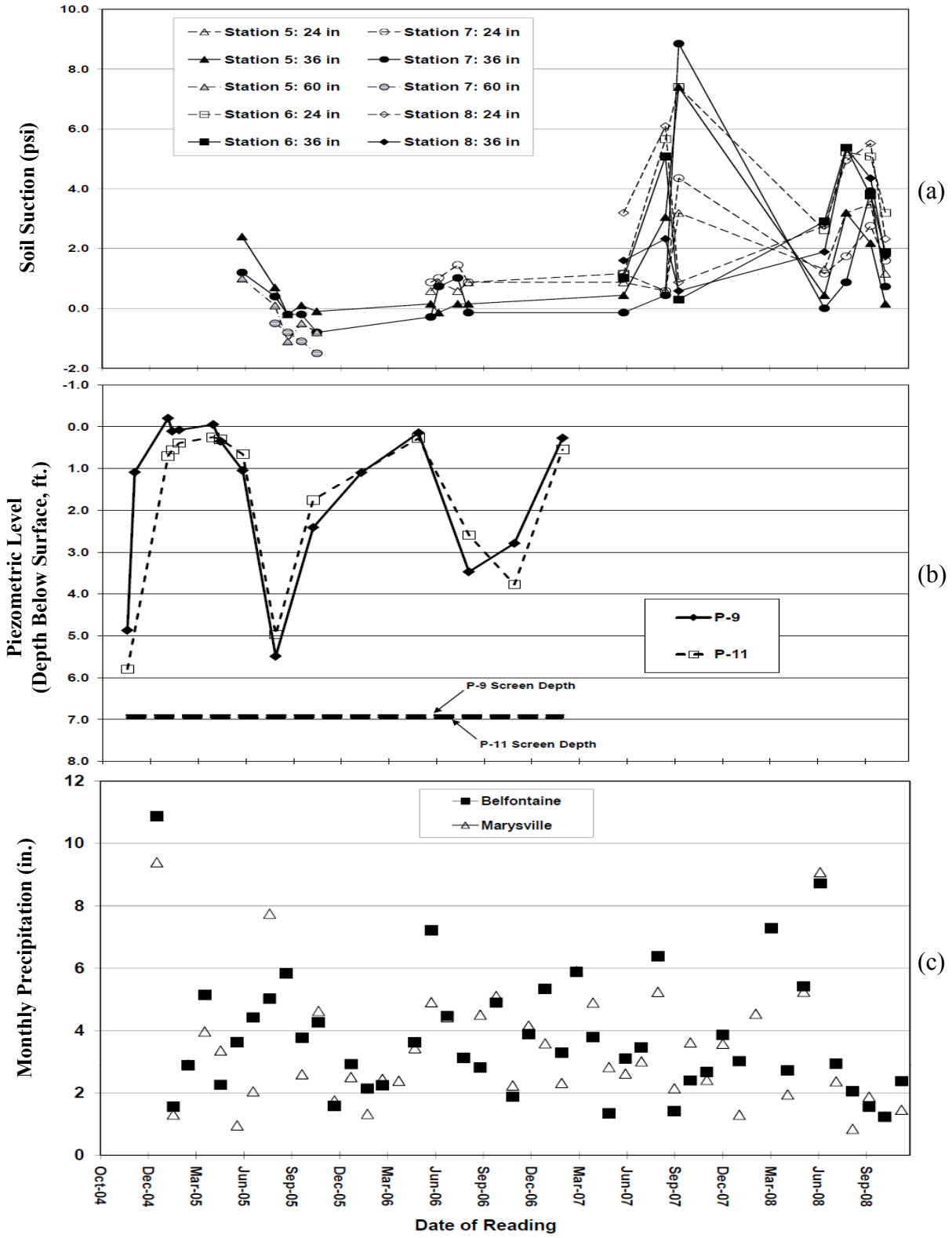


Figure 6.38: Graphs of: a) soil suctions from tensiometers for stations 5 through 8, b) piezometric head levels from shallow monitoring wells and c) monthly precipitation for Logan County, Ohio.

slope) show a slightly lower increase than those inside the biostabilized areas. Drier and warmer conditions in each subsequent year since the initial installation have caused a slight increase in soil suction. Root growth and establishment of vegetation in the live pole plots can also cause an increase in soil suction. However, the low survival rate at this site suggests that this latter effect would be minimal.

The piezometric levels from shallow wells installed in the NE and SW slopes are shown in Figure 6.37b and Figure 6.38b. Piezometric levels as high as 1 ft. above grade have been measured, and dry conditions have also been recorded in some of the wells. Piezometric levels in the shallow wells installed midway up the NE slope have been as high as 2.0 ft. below grade and dry conditions have also been observed at these locations. Piezometric levels in the shallow monitoring wells at the base of the NE and SW slopes were slightly higher in 2007 and 2008 than in previous years. Poor vegetation survival, and consequently little to no root growth, along with increased infiltration at areas where the bentonite cap has washed away from pole installations, may have allowed groundwater levels to build inside the slopes.

In general, a significant increase in soil suction occurred in 2007 and continued through 2008. According to precipitation data, spring and early summer 2007 (May through June) were somewhat drier than previous years, with monthly precipitation more than an inch below average during all three months. Also, piezometric levels at the lower portion of the slope near the stream bed have remained relatively low. This drying trend could be attributed to several factors. The establishment of vegetation may be drawing water from the soil and creating an increase in soil suction. The drying trend could also be due to below average precipitation during the summer months.

Piezometric levels for piezometers P-1 through P-4 for the NE slope and P-5 through P-8 for the SW slope are shown in Figure 6.39 and Figure 6.40. Piezometric levels in the NE slope ranged from 4.7 to 18.0 ft. below grade in the shallow piezometers and 15.4 to 20.8 ft. below grade in the deeper piezometers. Figure 6.40 shows that piezometric levels in the SW slope ranged from 4.7 to 15.1 ft. below grade in the shallow piezometers and 10.0 to 19.0 ft. below grade in the deeper piezometers.

The elevation of the screen interval for P-2 and P-4 in the NE slope is near the elevation of the sand seam encountered in boring B-20. Groundwater was also encountered at the same elevation in boring B-20, as well as in borings B-2 and B-4. The elevation of the screen interval for P-5 and P-7 in the SW slope is near the elevation of the sand seam encountered in boring B-21. Groundwater was also encountered at the same elevation in boring B-21, as well as in borings B-5 and B-7. During drilling for boring B-21, at a depth of approximately 22 ft., a layer of gravel with cobbles was encountered. A confined aquifer with artesian flow exists within this layer. Groundwater flowed out of the borings upon advancing into the gravel layer, and the water level in the auger stems was measured at approximately 3.0 to 4.0 ft. above grade. It should be noted that water levels in deep inclinometers I-1 and I-2 have been observed at similar levels.

6.7.2 Survival Rates and Statistics

An inventory of all live poles has been conducted each year during late spring/early summer and late fall in order to assess vegetation survival rates over time.

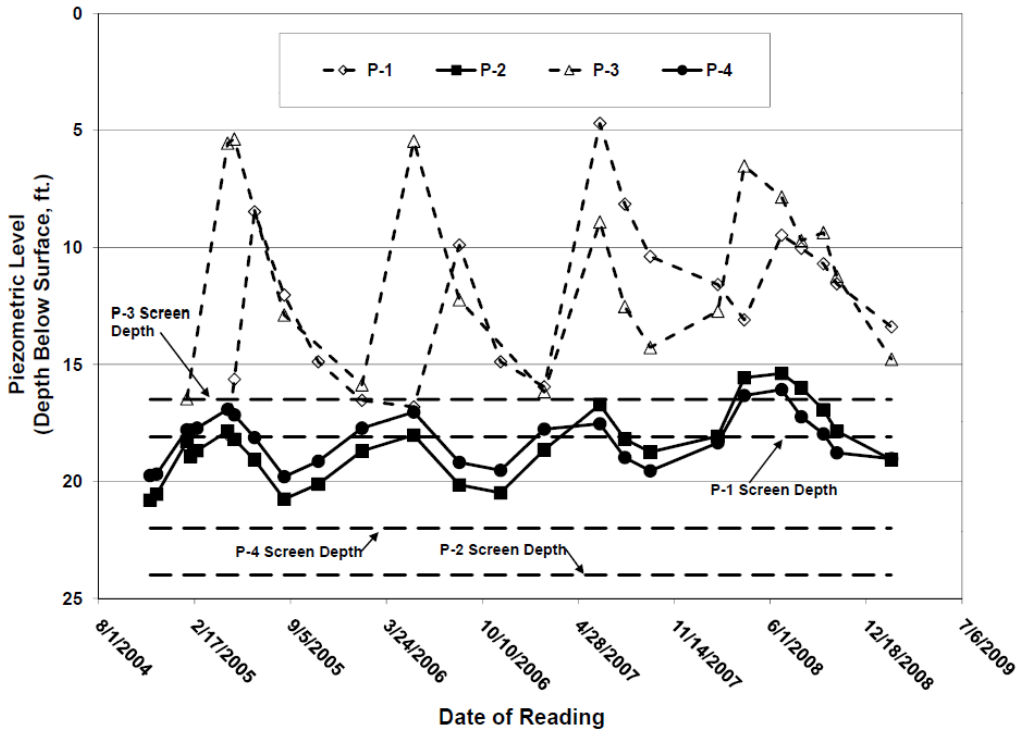


Figure 6.39: Piezometric levels measured in P-1 through P-4 for the NE slope.

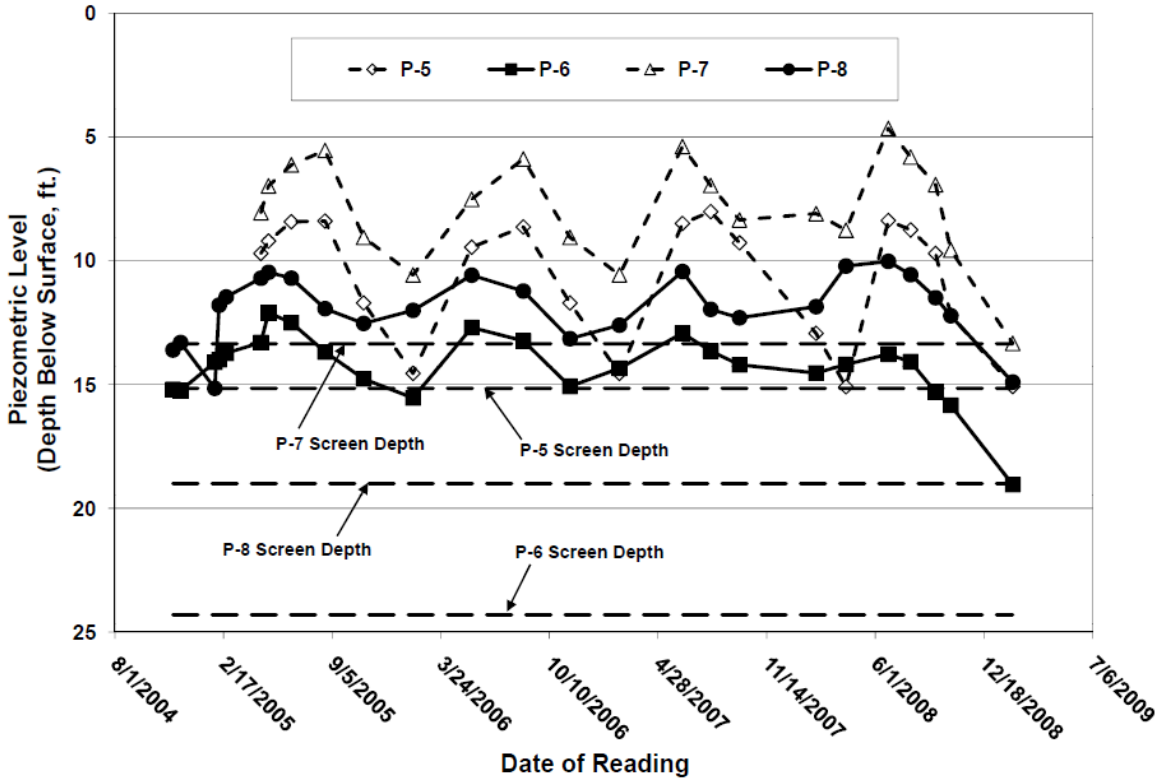


Figure 6.40: Piezometric levels measured in P-5 through P-8 for the SW slope.

Table 6.3 and Figure 6.41a presents a summary of survival rates for NE and SW pole plots as well as the overall vegetation survival rate at the site. Table 6.4 and Figure 6.41b presents survival rates according to the three different installation techniques for Panels 3, 4 and 5. A graphical log of each survival inventory is presented in Appendix B.

Table 6.3: Summary of survival rates for the NE and SW pole plots at the Logan County demonstration site.

Date	NE Slope Survival Rate (%)	SW Slope Survival Rate (%)	Overall Survival Rate (%)
12-Jun-07	49.8	71.7	60.4
7-Aug-07	27.6	27.5	27.6
25-Sep-07	25.9	23.8	24.9
12-Jun-08	22.4	18.3	20.4
20-Sep-08	18.4	17.2	17.8
15-Jun-09	12.2	15.3	13.7

Table 6.4: Summary of survival rates for different installation techniques used at the Logan County demonstration site.

Date	Panel 3 Survival Rate (%) (Scraping w/ Best Method)	Panel 4 Survival Rate (%) (Best Method)	Panel 5 Survival Rate (%) (Minimal Method)
12-Jun-07	60.0	63.2	57.9
7-Aug-07	30.4	24.4	27.7
25-Sep-07	26.4	22.5	25.6
12-Jun-08	20.4	19.0	21.9
20-Sep-08	18.2	17.1	18.2
15-Jun-09	12.9	14.0	14.5

Table 6.3 and Figure 6.41a indicate that initial survival rate for the SW live pole plot was fairly high (over 70%), and was lower (50%) for the NE slope. This difference is likely due to the amount of sunlight received by each slope. The NE slope receives direct sunlight for nearly the full day, while the SW slope tends to be cast in shadow during the afternoon and evening. Thus, soils on the SW slope were less likely to dry out during the summer. By the August 2007 inventory, survival for both slopes declined

dramatically to less than 30% and were nearly identical. It is likely that dry climate conditions subsequent to installation stressed the vegetation severely. Precipitation for the preceding three months was well below normal and temperatures were slightly above average. The intense heat of late afternoon summer days, along with direct sunlight and low precipitation adversely affected plant growth on both slopes. It should also be noted that personal communications with Dr. D. Struve of the Ohio State University horticulture and crop science department determined the period at the end of April 2007 when temperature dropped below freezing to be a "killing frost", as most vegetation grown at nurseries and other research sites suffered high mortality rates as well.

Table 6.4 and Figure 6.41b indicate that installation technique had little effect on the establishment and survival of vegetation. For each inventory, the survival rates for all three techniques are within 6%. It is therefore concluded, at least for the conditions of this study, that the additional effort and expense associated with the best method is not warranted and that the minimal method produces similar results with regard to vegetation survival.

Figure 6.42 through Figure 6.44 show graphical representations of vegetation survival for the NE and SW slopes during the first growing season in 2007. Initially, survival on the SW slope was high and evenly distributed. A large region within Panel 3 of the NE slope had high mortality as a majority of the willows sprouted and then died. By the September 2007 inventory, vegetation near the bottom of the NE slope (lower 4 rows) experienced nearly complete mortality. A similar trend was observed near the bottom of the SW slope (lower 5 rows). Variations in soil nutrients, pH, and soil-moisture conditions may have adversely affected vegetation survival in these areas. It should also be noted that weeds, visually identified as birdsfoot trefoil or alfalfa, were growing extensively within Panel 3 of the NE slope, predominantly within the large region of high mortality. Competition from these weeds may have drawn the little available moisture out of the soil and caused the willow poles to die. These weeds spread throughout the NE slope and were observed in most areas of high pole mortality.

Currently, survival at the Logan County site is shown in Figure 6.45 and has fallen to 12 – 15% overall, a very low value. Small regions of living vegetation have been observed within both the NE and SW slopes, there is still no trend that suggests that installation technique affects the survival rate. It is suspected that the small regions of growth are within areas where the soil chemistry is more favorable than the surrounding areas.

6.7.2.1 Additional Installation Survival Rates and Statistics

Survival rates of vegetation planted during the second installations (Spring 2008, Winter 2008, Spring 2009) were more promising than values observed from the initial installation (Spring 2007). Table 6.5 indicates that survival rates during the first growing season (April – September 2008, for the Spring 2008 installation) were much higher than those observed from the initial installation. However, the survival rate of the spring 2008 installation fell dramatically after the following winter season. The initial survival rate of the winter 2008 installation looks promising; however, survival may drop dramatically during the upcoming winter (i.e., the first winter season since the plants have experienced growth). The survival rate of the spring 2009 installation was significantly lower than for

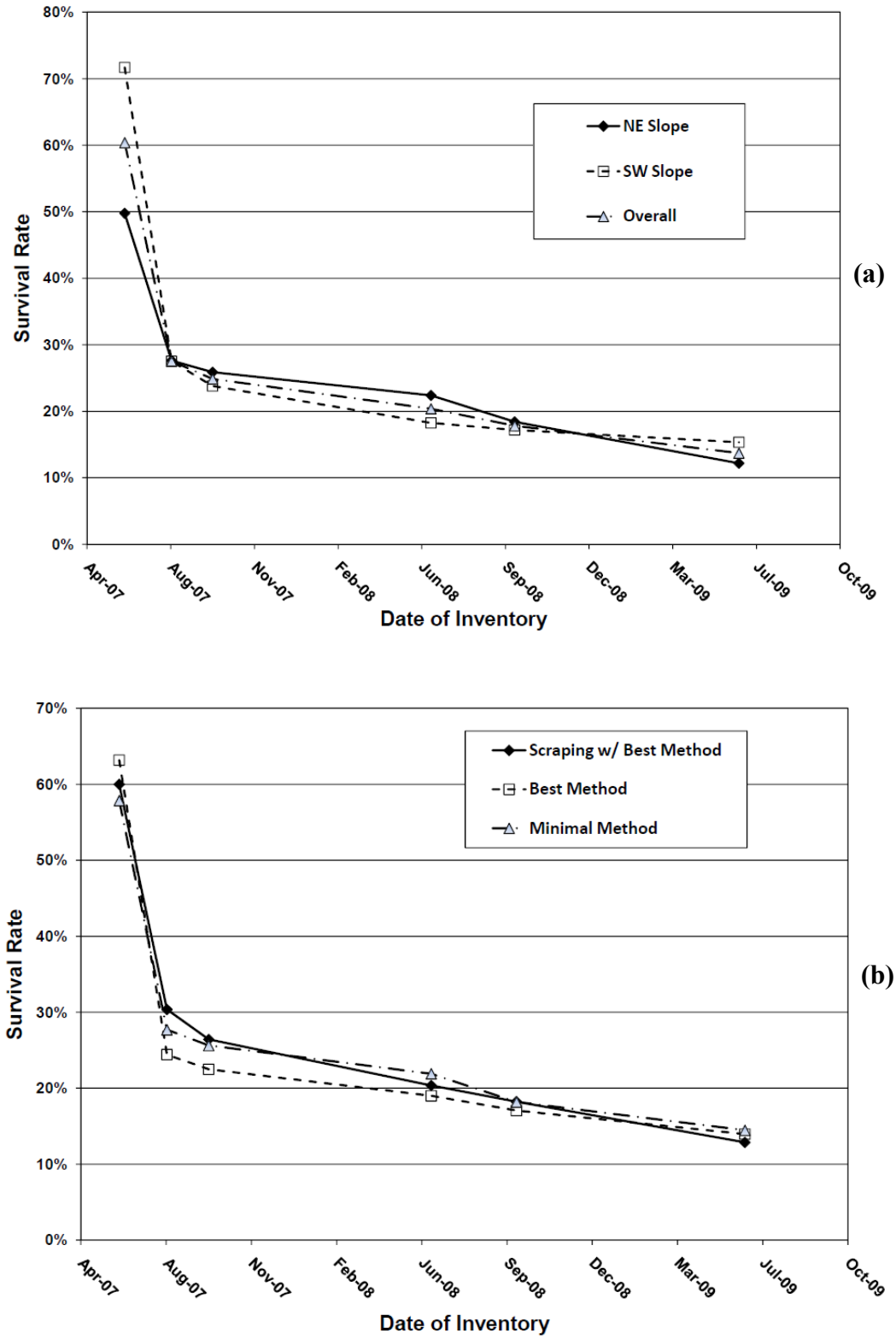


Figure 6.41: Vegetation survival rates for the Logan County demonstration site: a) identified by slope, b) identified by installation method.

Survival Statistics June 12, 2007

NE Slope

Overall Survival: 49.8%

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
14	1	1	1	1	2	2	2	2	3	2	2	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	3	2	2	3
13	1	1	1	1	2	2	2	2	2	2	2	1	1	1	1	2	1	2	2	1	1	1	1	1	1	1	3	3	3	1
12	1	1	1	1	3	2	2	1	2	2	2	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	3	3	2	2
11	1	1	1	2	3	2	2	2	3	3	2	1	1	1	1	1	1	3	1	2	3	3	3	2	2	1	1	2	3	1
10	1	1	1	1	3	2	2	2	3	2	2	1	1	1	1	1	1	2	1	1	2	2	3	2	2	1	3	1	1	1
9	1	1	1	2	3	2	2	2	2	2	3	1	1	1	3	3	1	2	3	2	2	2	2	3	2	1	1	1	1	1
8	1	1	1	1	2	3	3	3	3	2	3	1	1	1	1	1	1	3	1	2	1	1	1	1	1	2	2	3	2	1
7	1	1	1	1	3	3	2	2	2	2	1	1	1	1	2	1	3	2	1	3	1	1	1	3	2	1	2	1	1	1
6	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	1	3	1	2	1	1	1	1	1	1	1	1	1	1	1
5	2	2	1	1	3	3	3	3	3	3	3	2	2	2	1	1	2	3	3	2	1	1	2	1	1	3	3	2	3	2
4	1	1	2	2	2	2	2	2	1	1	1	2	1	2	1	2	2	1	3	2	2	2	3	1	2	3	2	2	3	2
3	3	1	1	1	1	1	1	1	1	2	3	3	2	2	2	1	2	1	2	2	3	2	1	1	1	1	3	3	3	3
2	2	1	1	1	1	1	2	1	2	1	2	2	3	3	1	1	2	1	3	2	1	3	2	1	1	1	3	3	3	
1	2	2	1	1	1	1	2	1	2	1	3	2	2																	

(Survival: 43.6%)
Panel 3
Scraped Slope/Best Method
(76.4%)

(57.1%)
Panel 4
No Scraping/Best Method
(72.8%)

(51.9%)
Panel 5
No Scraping/Minimal Method
(64.6%)

	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	1	1	1	1	1	1	3	1	1	3	1	1	1		1															
2	1	1	1	2	3	1	1	1	3	1	1	1	1	3	1	1	1	3	3	1	1	1	3							
3	2	1	3	1	3	1	1	1	1	3	1	1	1	1	3	1	1	3	1	2	3	3	3	1	1	1	1	3	1	3
4	3	1	1	1	1	1	2	1	2	1	3	1	1	3	1	1	3	3	3	1	1	1	3	1	1	3	1	3	1	1
5	1	1	2	1	1	2	3	2	2	1	1	1	3	3	3	1	1	1	2	1	1	1	2	1	1	1	1	3	1	3
6	1	1	3	1	1	1	3	1	1	1	2	1	1	1	1	3	2	1	1	2	1	2	3	1	3	1	1	3	1	1
7	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2	1	2	1	1	1	1	2	3	1	3	1
8	1	1	2	3	1	2	1	1	3	1	1	1	1	1	1	2	1	1	3	1	1	1	1	1	3	1	3	1	1	3
9	1	2	1	2	1	1	3	2	1	1	1	1	1	1	1	1	1	1	3	1	3	1	2	3	1	3	1	3	3	1
10	1	3	1	1	1	1	1	1	1	2	1	1	1	3	3	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1
11	1	1	1	1	1	1	1	3	1	1	1	2	1	1	1	1	1	1	1	1	3	1	1	1	1	3	3	1	1	1
12	1	1	1	1	1	1	1	1	3	1	1	2	3	1	3	1	1	3	1	1	2	1	1	1	1	1	1	3	3	1
13	1	1	1	1	1	1	1	1	2	1	1	1	1	1	3	3	2	1	1	1	3	2	1	3	1	1	2	1	1	1
14	1	1	3	1	1	1	1	1	1	1	1																			

SW Slope

Overall Survival: 71.7%

1 Willow survived 2 Willow sprouted, then died 3 Willow died

Figure 6.42: Graphical representation of survival of the NE and SW live pole plots at the Logan County demonstration site on June 12, 2007.

Survival Statistics August 7, 2007

NE Slope

Overall Survival: 27.6%

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
14	1	2	2	2	2	2	2	2	3	2	2	1	1	2	2	3	2	2	2	2	2	2	2	2	2	1	3	2	2	3
13	1	2	1	1	2	2	2	2	2	2	2	1	1	1	1	2	1	2	2	2	2	2	2	1	1	1	3	3	3	2
12	1	1	1	1	3	2	2	1	2	2	2	1	1	1	1	1	1	1	3	2	1	1	1	1	1	1	3	3	2	2
11	1	1	1	2	3	2	2	2	3	3	2	1	1	1	1	1	1	3	1	2	3	3	3	2	2	1	2	2	3	1
10	1	1	1	1	3	2	2	2	3	2	2	1	1	1	1	1	1	2	1	1	2	2	3	2	2	2	3	2	1	1
9	1	1	1	2	3	2	2	2	2	2	3	1	1	1	3	3	1	2	3	2	2	2	2	3	2	1	1	1	1	1
8	1	1	1	1	2	3	3	3	3	2	3	1	1	2	1	2	1	3	2	2	1	1	1	2	1	2	2	3	2	2
7	1	1	1	1	3	3	2	2	2	2	2	1	2	2	2	1	3	2	1	3	1	1	1	3	2	1	2	1	1	2
6	1	1	1	3	3	3	3	3	3	3	3	2	2	2	1	2	3	2	2	2	1	1	1	2	1	1	2	1	1	1
5	2	2	1	1	3	3	3	3	3	3	3	2	2	2	2	2	2	3	3	2	2	2	2	2	2	3	3	2	3	2
4	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	2	2	2	3	2	2	3	2	2	3	2
3	3	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	3	2	2	2	2	2	3	3	3	3
2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	3	2	2	3	2	2	2	2	3	3	3	
1	2	2	2	2	2	1	2	2	2	2	3	2	2																	

(Survival: 23.6%)
Panel 3
Scraped Slope/Best Method
(37.1%)

(30.8%)
Panel 4
No Scraping/Best Method
(17.6%)

(28.7%)
Panel 5
No Scraping/Minimal Method
(26.6%)

	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	1	2	1	2	1	1	3	1	2	3	2	2	2		2															
2	1	2	1	2	3	2	2	2	3	2	2	2	2	3	2	2	2	3	3	2	2	2	3							
3	2	1	3	2	3	1	1	2	2	3	2	2	2	2	3	2	2	3	2	2	3	3	3	2	1	1	1	3	1	3
4	3	2	2	2	2	2	2	2	2	2	3	2	2	3	2	2	3	3	3	2	2	2	3	2	2	3	1	3	1	1
5	2	2	2	2	2	2	3	2	2	2	2	2	3	3	3	2	2	2	2	2	2	2	2	2	2	1	1	3	1	3
6	2	2	3	2	2	2	3	2	2	2	2	2	2	2	2	3	2	2	2	2	2	2	3	1	3	1	1	3	2	1
7	2	2	1	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	1	3	1
8	1	1	2	3	2	2	2	1	3	2	2	2	2	2	2	2	1	2	3	2	2	2	2	1	3	1	3	1	1	3
9	1	2	1	2	2	2	3	2	2	1	2	2	1	2	1	2	2	2	3	2	3	2	2	3	1	3	1	3	3	2
10	1	3	1	2	1	1	1	1	1	2	1	1	1	3	3	1	2	1	1	1	1	1	2	1	1	2	3	2	2	2
11	1	1	1	2	1	1	2	3	1	1	2	2	2	1	1	1	1	1	1	1	3	2	1	1	1	3	3	1	2	2
12	1	1	1	1	1	1	1	1	3	1	1	2	3	1	3	1	2	3	1	2	2	2	2	2	2	2	2	3	3	2
13	1	1	1	2	1	1	1	2	2	1	2	1	2	2	3	3	2	2	2	2	3	2	2	3	2	2	2	2	2	2
14	1	2	3	1	1	1	2	2	2	2	2																			

SW Slope

Overall Survival: 27.5%

1 Willow survived 2 Willow sprouted, then died 3 Willow died

Figure 6.43: Graphical representation of survival of the NE and SW live pole plots at the Logan County demonstration site on August 7, 2007.

Survival Statistics September 25, 2007

NE Slope

Overall Survival: 25.9%

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
14	1	2	2	2	2	2	2	2	3	2	2	1	1	2	2	3	2	2	2	2	2	2	2	2	2	1	3	2	2	3
13	1	2	1	1	2	2	2	2	2	2	2	1	1	1	1	2	1	2	2	2	2	2	2	1	1	1	3	3	3	2
12	1	1	1	1	3	2	2	1	2	2	2	1	1	1	1	2	1	1	3	2	1	1	1	1	1	1	3	3	2	2
11	1	1	1	2	3	2	2	2	3	3	2	1	1	1	1	1	1	3	1	2	3	3	3	2	2	1	2	2	3	1
10	1	1	1	1	3	2	2	2	3	2	2	1	1	1	1	1	1	2	1	1	2	2	3	2	2	1	3	2	1	1
9	1	1	2	2	3	2	2	2	2	2	3	1	1	2	3	3	1	2	3	2	2	2	2	3	2	1	1	1	1	1
8	1	1	1	1	2	3	3	3	3	2	3	1	1	2	1	2	2	3	2	2	1	1	1	2	1	2	2	3	2	2
7	1	1	2	1	3	3	2	2	2	2	2	2	2	2	2	1	3	2	1	3	1	1	1	3	2	1	2	1	1	2
6	1	1	1	3	3	3	3	3	3	3	3	2	2	2	1	2	3	2	2	2	1	1	1	2	1	1	2	1	1	1
5	2	2	2	2	3	3	3	3	3	3	3	2	2	2	2	2	2	3	3	2	2	2	2	2	2	3	3	2	3	2
4	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	2	2	2	3	2	2	3	2	2	3	2
3	3	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	3	2	2	2	2	2	3	3	3	3
2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	3	2	2	3	2	2	2	2	3	3	3	
1	2	2	2	2	2	1	2	2	2	2	3	2	2																	

(Survival: 20.7%)	(27.8%)	(29.5%)
Panel 3	Panel 4	Panel 5
Scraped Slope/Best Method	No Scraping/Best Method	No Scraping/Minimal Method
(32.1%)	(16.8%)	(21.2%)

	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	2	2	1	2	1	1	3	1	2	3	2	2	2		2															
2	2	1	2	2	3	1	1	1	3	1	2	2	2	3	2	2	2	3	3	2	2	2	3							
3	2	2	3	2	3	1	1	2	2	3	2	2	2	2	3	2	2	3	2	2	3	3	3	2	1	2	2	3	1	3
4	3	2	2	2	2	2	2	2	2	2	3	2	2	3	2	2	3	3	3	2	2	2	3	2	2	3	1	3	2	1
5	2	2	2	2	2	2	3	2	2	2	2	2	3	3	3	2	2	2	2	2	2	2	2	2	2	1	1	3	1	3
6	2	2	3	2	2	2	3	2	2	2	2	2	2	2	2	3	2	2	2	2	2	2	3	2	3	1	1	3	2	1
7	2	2	1	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	1	1	1
8	1	1	2	3	2	2	2	1	3	2	2	2	2	2	2	2	2	2	3	2	2	2	2	1	3	1	3	1	1	3
9	1	2	1	2	2	2	3	2	2	1	2	2	2	2	1	2	2	2	3	2	3	2	2	3	2	3	1	3	3	2
10	1	3	1	2	1	1	1	2	1	2	1	1	1	3	3	1	2	1	1	1	1	1	2	1	1	2	3	2	2	2
11	2	2	1	2	1	1	2	3	1	2	2	2	2	1	1	1	1	1	1	1	3	2	2	2	1	3	3	1	2	2
12	1	2	1	1	1	1	1	1	3	1	1	2	3	1	3	1	2	1	1	2	2	2	2	2	2	2	2	3	3	2
13	2	1	1	2	1	1	1	2	2	1	2	1	2	2	3	3	2	2	2	2	3	2	2	3	2	2	2	2	2	2
14	2	2	3	1	1	2	2	2	2	2	2																			

SW Slope

Overall: 27.5%

1 Willow survived 2 Willow sprouted, then died 3 Willow died

Figure 6.44: Graphical representation of survival of the NE and SW live pole plots at the Logan County demonstration site on September 25, 2007.

Survival Statistics June 15, 2009

NE Slope

Overall Survival: 12.2%

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
14	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
13	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
12	3	1	3	3	3	3	3	3	3	3	3	1	1	1	1	3	1	3	3	3	3	3	1	3	1	3	3	3	3	3
11	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
10	1	1	1	1	3	3	3	3	3	3	3	3	1	3	3	3	1	3	1	1	3	3	3	3	3	3	3	3	1	1
9	3	1	3	3	3	3	3	3	3	3	3	1	1	3	3	3	1	3	3	3	3	3	3	3	3	3	1	1	1	1
8	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
7	1	3	3	1	3	3	3	3	3	3	3	3	3	3	3	1	3	3	1	3	1	1	3	3	3	3	3	1	3	3
6	1	1	1	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3	3	3	3	3	1	3	3	3	3	3	3	3
5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
1	3	3	3	3	3	3	3	3	3	3	3	3	3																	

(Survival: 12.1%)
Panel 3
Scraped Slope/Best Method
(16.4%)

(15.0%)
Panel 4
No Scraping/Best Method
(12.8%)

(9.3%)
Panel 5
No Scraping/Minimal Method
(16.8%)

	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	3	3	3	3	3	3	3	3	3	3	3	3	3		3															
2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3							
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3	1	3
4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	3	1
5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3
6	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	3	3	1
7	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1
8	3	1	3	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	1	3	1	1	3
9	3	3	3	3	3	3	3	3	3	1	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3
10	3	3	3	3	1	1	1	3	1	3	1	1	1	3	3	1	3	1	3	3	3	1	3	1	3	3	3	1	3	3
11	3	3	3	3	1	1	3	3	1	3	3	3	3	1	1	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3
12	3	3	3	1	1	1	1	1	3	1	1	3	3	1	3	1	3	1	3	3	3	3	3	3	3	3	3	3	3	3
13	3	3	3	3	1	1	1	3	3	1	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
14	3	3	3	1	1	3	3	3	3	3	3																			

SW Slope

Overall: 15.3%

1 Willow survived 3 Willow died

Figure 6.45: Graphical representation of survival of the NE and SW live pole plots at the Logan County demonstration site on June 15, 2009.

the winter 2008 installation. This could be attributed to the installation time as the winter 2008 installation occurred at the beginning of the dormant season when the vegetation's stored biomass was highest.

Table 6.5: Summary of survival rates from second installation for the NE and SW live pole plots at the Logan County demonstration site.

Date	Spring 2008 Installation Survival Rate (%)	Winter 2008 Installation Survival Rate (%)	Spring 2009 Installation Survival Rate (%)	Overall Survival Rate (%)
12-Jun-08	82.5	N/A	N/A	82.5
20-Sep-08	62.5	N/A	N/A	62.5
15-Jun-09	12.5	88.9	33.3	34.4

6.7.3 Slope Displacements

Prior to construction, slope displacements were observed and recorded at the Logan County demonstration site using CSIs and deep inclinometers. These instruments indicated that the Logan County slide is a complex failure with both deep and shallow movements. Slope movements are shown in the cross sections provided in Figure 6.6 and Figure 6.7. In October 2005, CSI-2 was exhumed from the lower portion of the NE slope. A displacement of 3.25 in. was measured at the top of CSI-2 for the 10-month period between December 2004 and October 2005. Figure 6.46 shows a picture of exhumed CSI-2.

Figure 6.47 through Figure 6.50 present cumulative and incremental displacements vs. depth taken over time for inclinometers I-1 to I-4. Only one data set was measured for I-1 before slope movements distorted the casing such that the survey probe would no longer move down. Slope movements of 4.0 to 5.25 in. were recorded for inclinometers I-1 and I-2 within the SW slope. Slope movements of 1.5 to 2.0 in. were recorded for inclinometers I-3 and I-4 within the NE slope. In general, the depth of the slip surface was approximately 6.0 to 8.0 ft. This depth is near the interface between the gray clay encountered in the upper 8 ft. of the soil profile and the sand lens observed in borings B-20 and B-21. After construction, no further readings could be obtained from any of the inclinometers. Slope movements distorted the casing if inclinometer I-2 around the time of construction such that the survey probe would no longer move down. Construction of the gravity toe berm at the NE slope distorted the casings of inclinometers I-3 and I-4.

Post-construction displacements have been monitored using shallow CSI's and by surveying the positions of poles along the NE slope face. Deep inclinometers remained installed in both slopes but deformations, most likely from construction activities, rendered them unreadable after construction. Additional deep inclinometers, I-20 and I-21, were installed at the site (one each in the NE and SW slopes) during late February 2009 to verify that deep-seated sliding within the slopes has ceased. Figure 6.51 and

Figure 6.52 present cumulative and incremental displacements vs. depth taken from February 13, 2009 to August 13, 2009 for inclinometers I-20 and I-21. A slope movement of less than 0.25 in. was recorded for inclinometer I-20 in the NE slope, and no movement was recorded from I-21 in the SW slope.

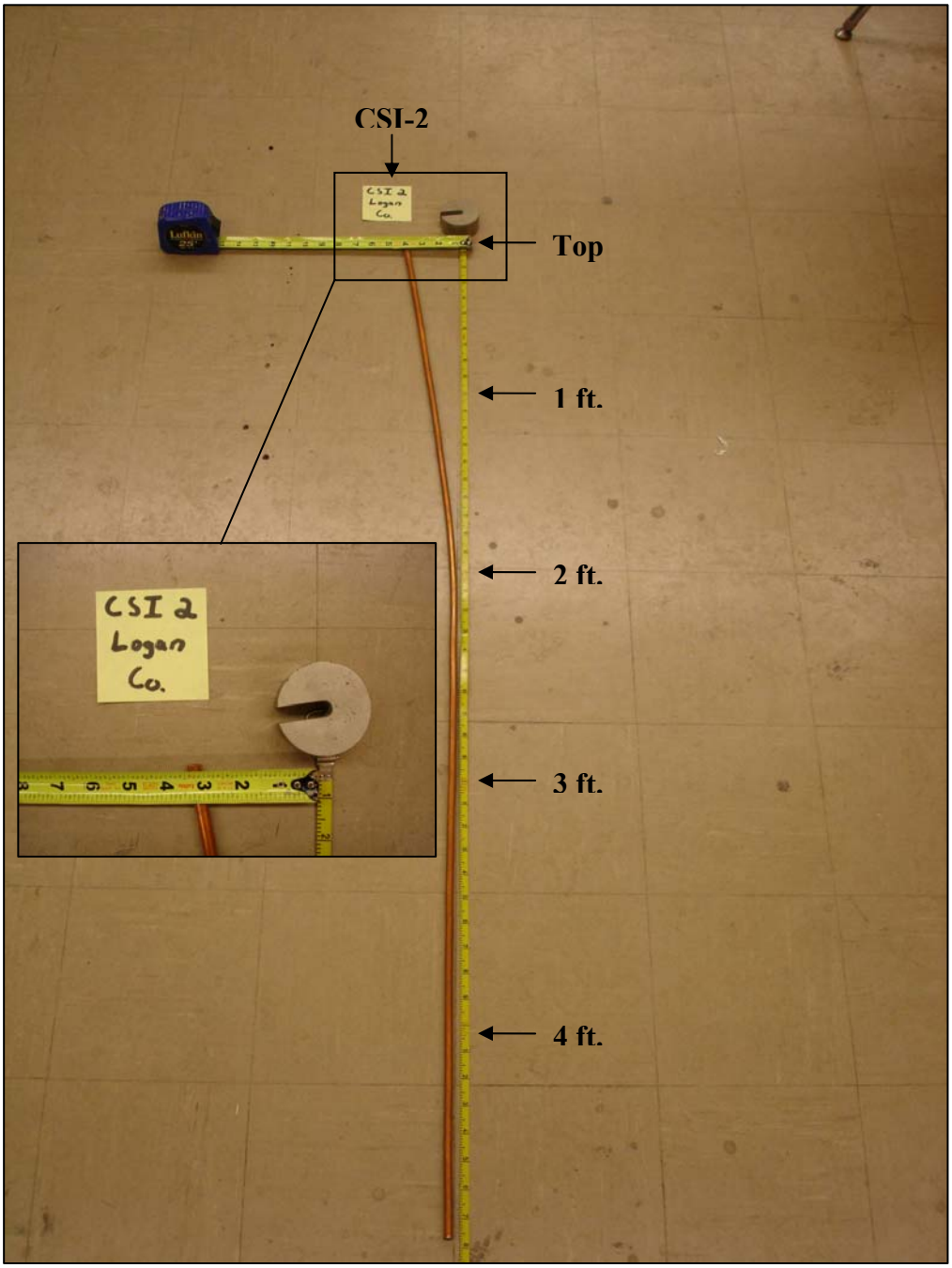


Figure 6.46: Copper shallow inclinometer, CSI-2, exhumed from Logan County demonstration site.

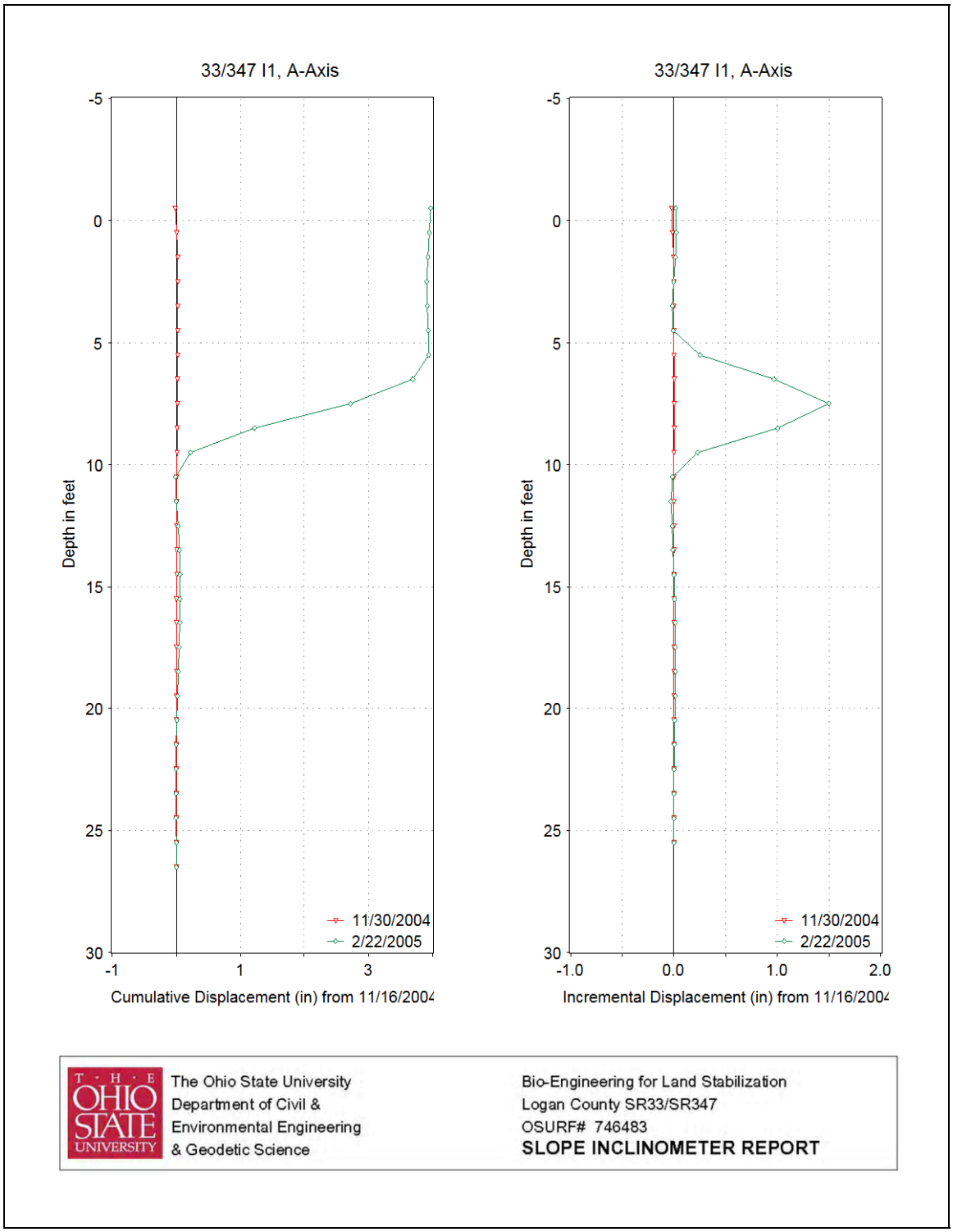


Figure 6.47: Data from inclinometer I-1 at the Logan County demonstration site. Cumulative and incremental displacements from November 2004 to October 2006 are displayed.

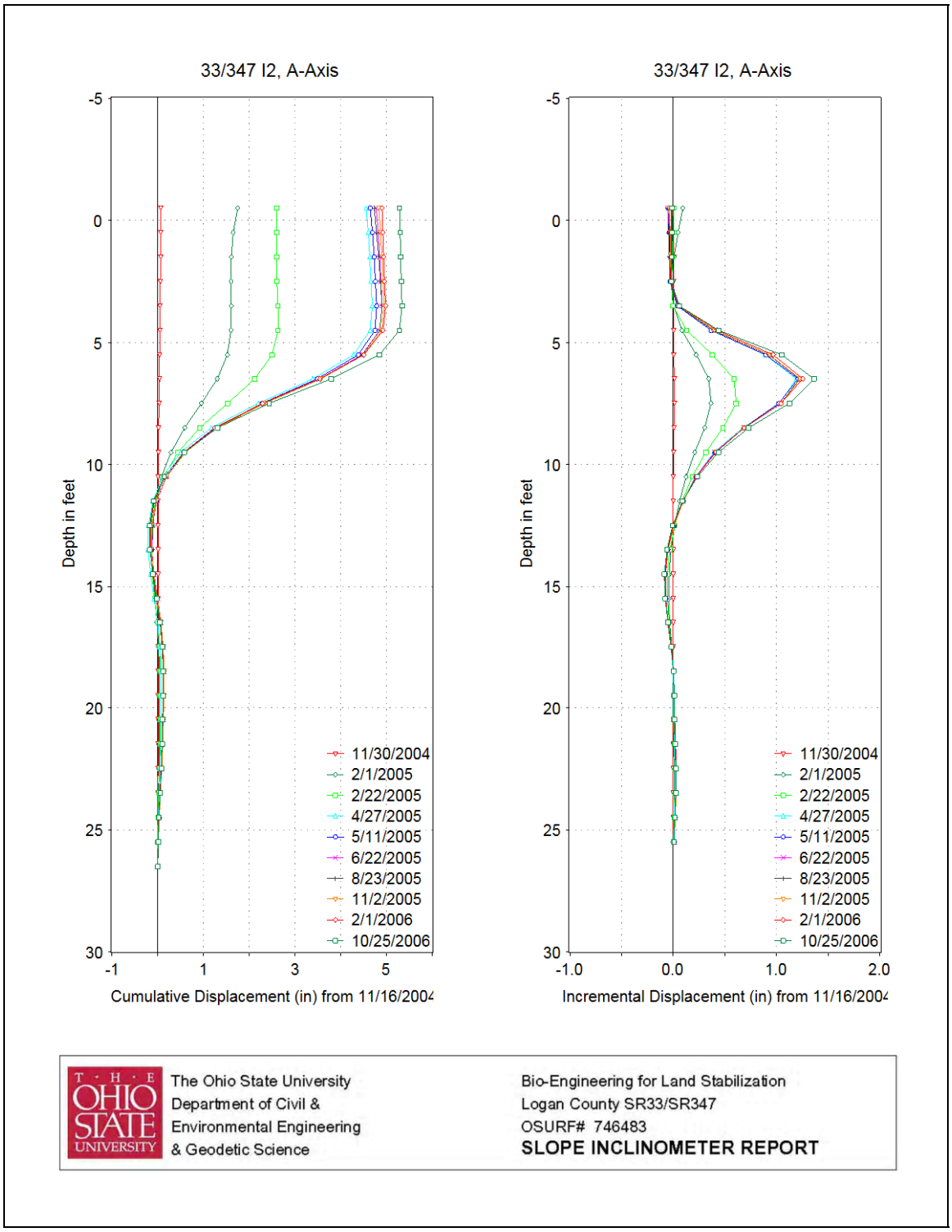


Figure 6.48: Data from inclinometer I-2 at the Logan County demonstration site. Cumulative and incremental displacements from November 2004 to October 2006 are displayed.

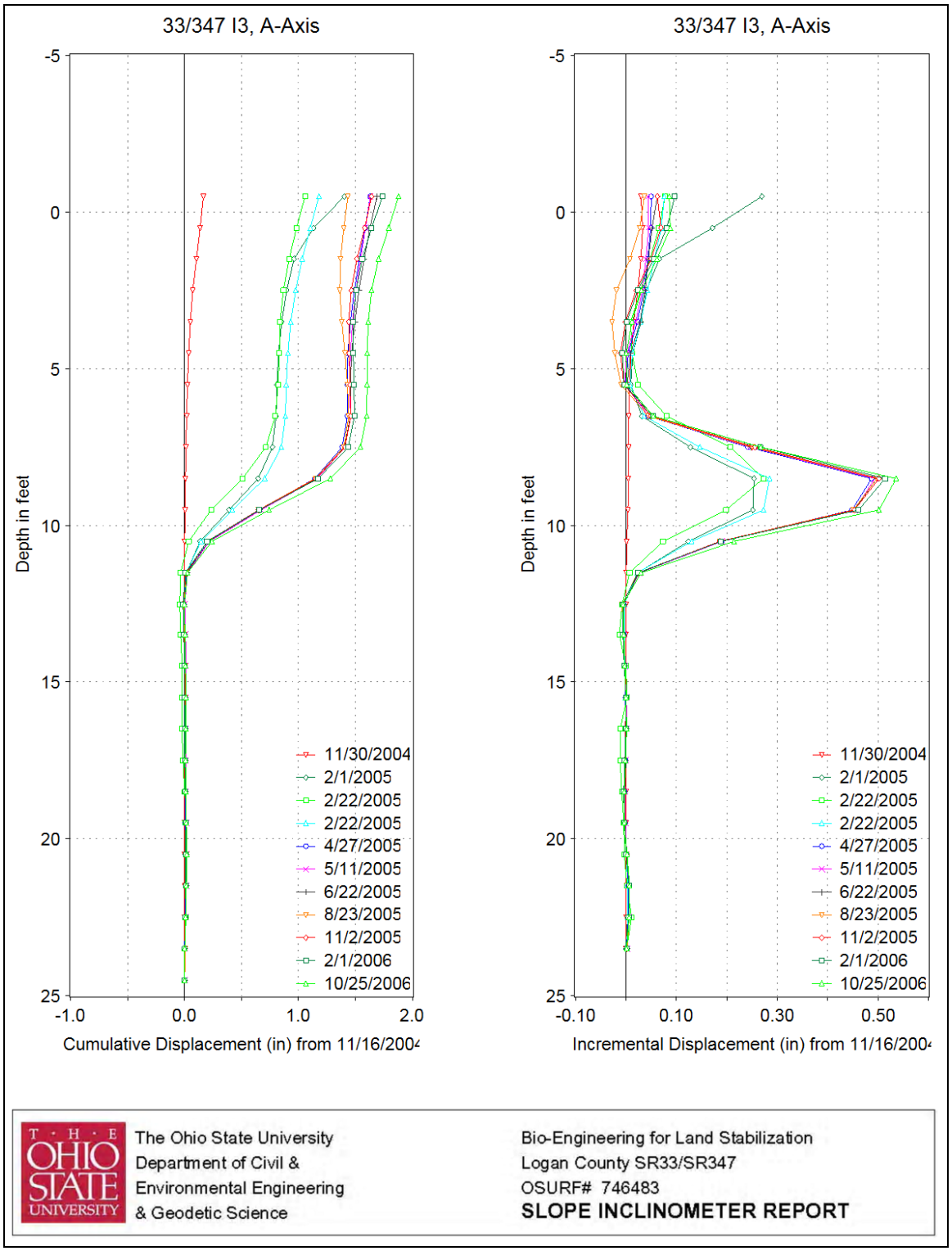


Figure 6.49: Data from inclinometer I-3 at the Logan County demonstration site. Cumulative and incremental displacements from November 2004 to October 2006 are displayed.

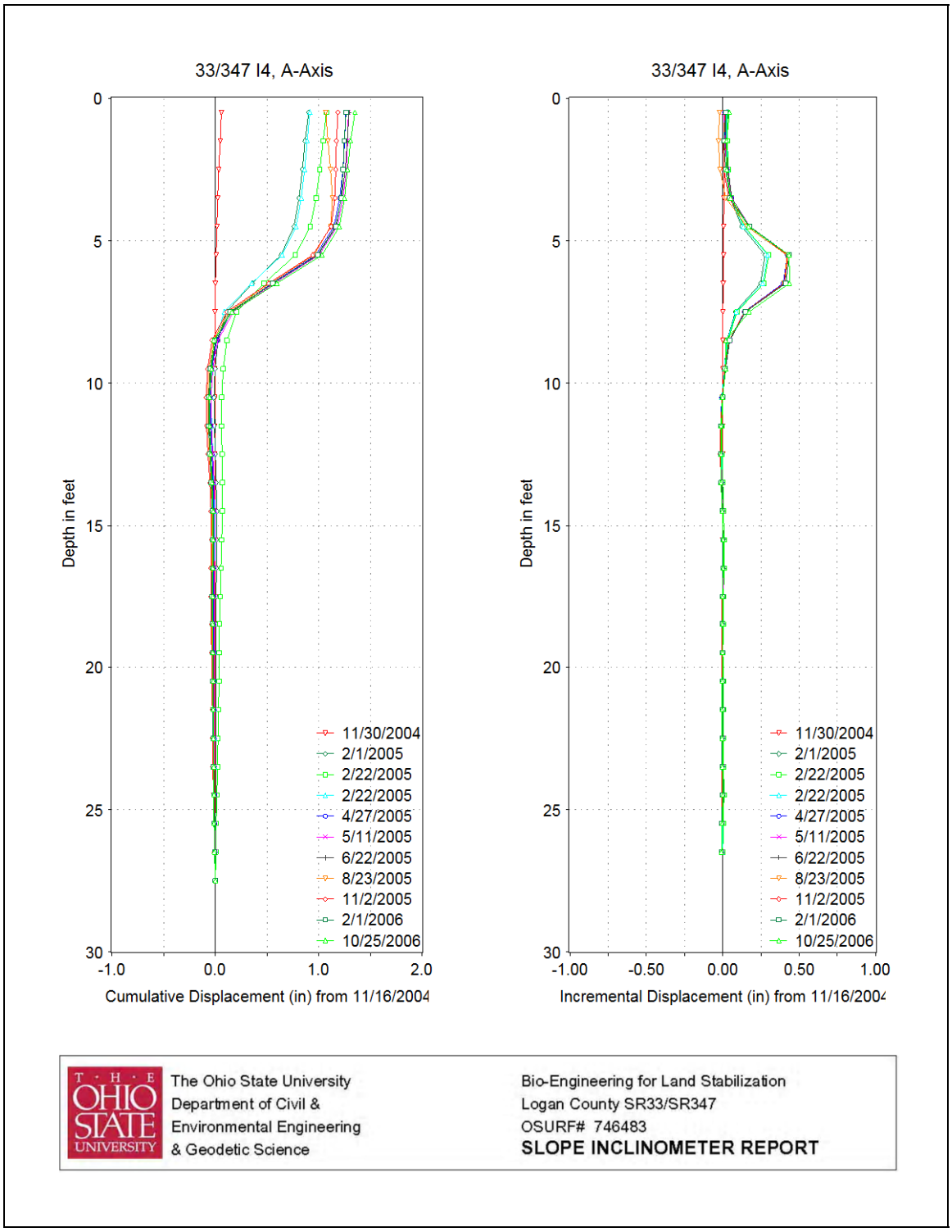


Figure 6.50: Data from inclinometer I-4 at the Logan County demonstration site. Cumulative and incremental displacements from November 2004 to October 2006 are displayed.

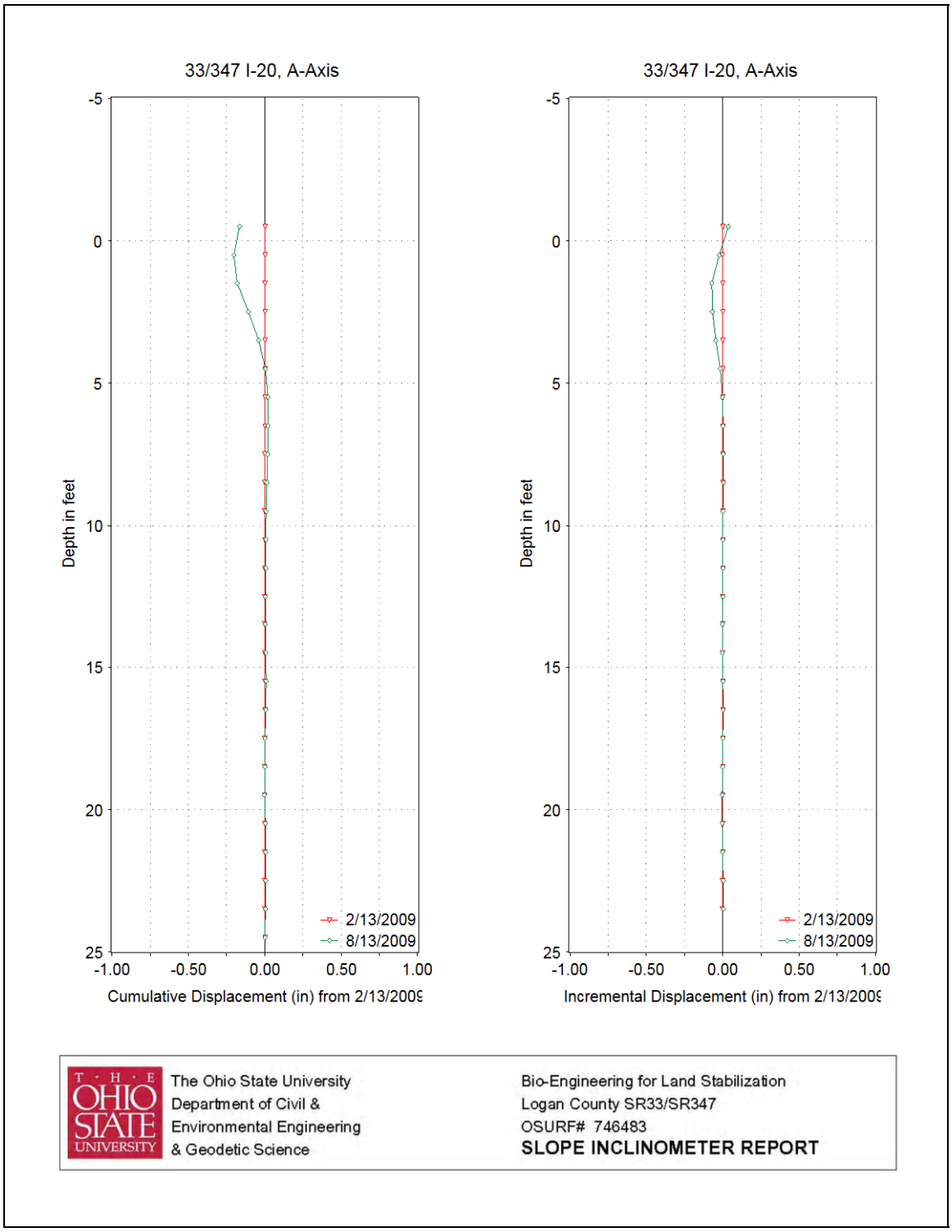


Figure 6.51: Data from inclinometer I-20 at the Logan County demonstration site. Cumulative and incremental displacements from February 2009 to August 2009 are displayed.

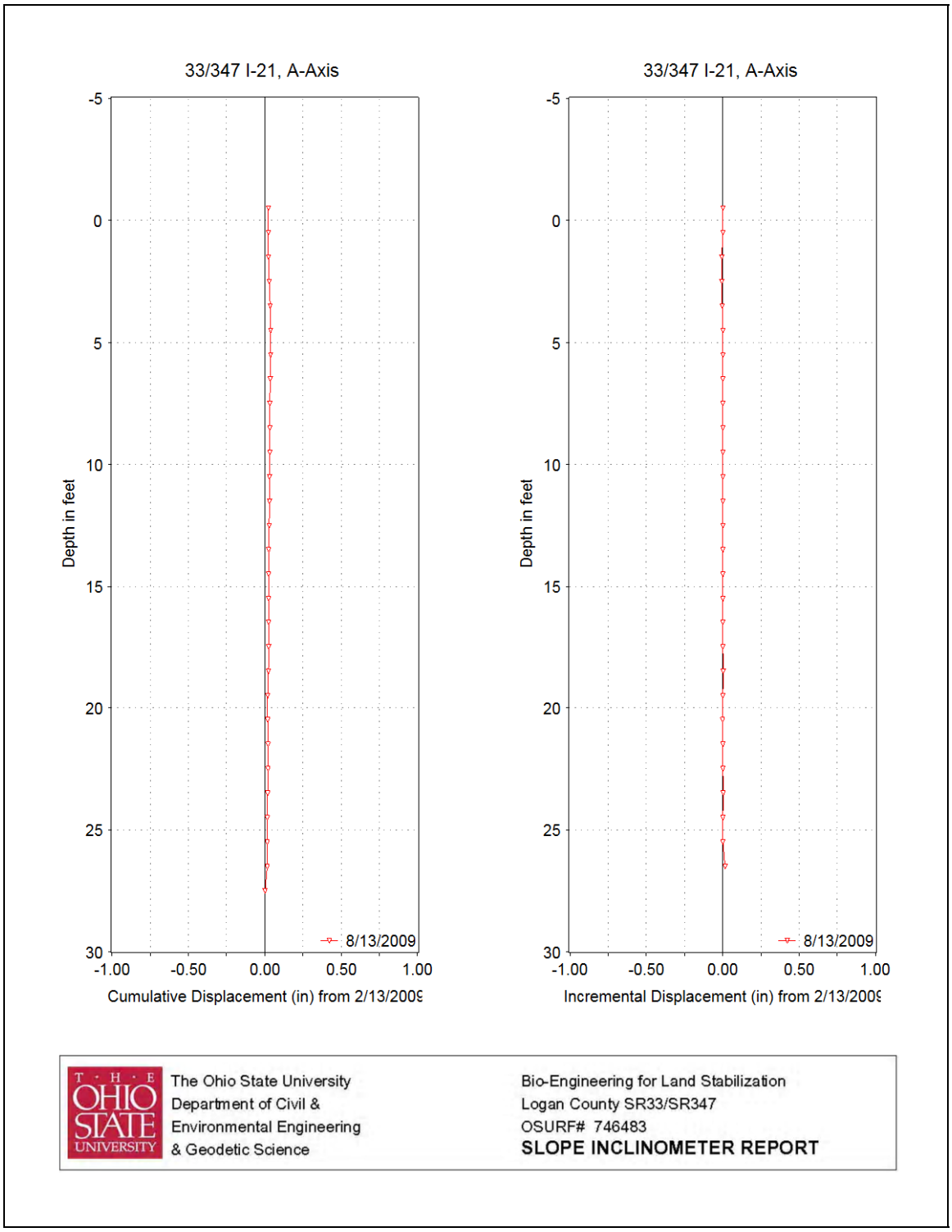


Figure 6.52: Data from inclinometer I-21 at the Logan County demonstration site. Cumulative and incremental displacements from February 2009 to August 2009 are displayed.

Over the summer and fall of 2007, shallow sliding occurred on the NE slope. Figure 6.53 shows a map of slope movement features as observed on March 21, 2008. Initial evidence of movements was first observed in mid-July, 2007, when a large crack appeared at the top of Panel 1 and spread continuously to Panel 4. This crack was closely monitored during the following months. By mid-September, 2007, the crack had opened as a major rupture and progressed across the top of the entire NE slope, extending into Panel 7, where the geocell slope erosion protection prevented it from spreading further (Figure 6.54). In general, the rupture ran parallel with the top of the slope approximately 4 ft. down from the crest. The displacement at the rupture varied along the slope but was approximately 2 ft. at the maximum point (Panel 1). By the end of September 2007, shallow sliding progressed downslope from the initial rupture and resulted in multiple other cracks and bulges along the slope.

A shallow inclinometer (CSI-37) was removed from the slip area indicated in Figure 6.54 on March 21, 2008. A displacement of 11.25 in., relative to the base of the CSI, was recorded at the ground surface. This value may underestimate the actual displacement as it appears that the base of the CSI may have also moved with the slide. Figure 6.55 and Figure 6.56 are photos taken during excavation of CSI-37 at the site and of the exhumed CSI-37 at the OSU laboratory. Additionally, CSI-34 was exhumed from the top of Panel 2 in the NE slope on August 24, 2009. A displacement of 2.5 in., relative to the base of the CSI, was recorded at the ground surface, and the depth of the slip surface is approximately 3.5 ft. below the ground surface. Figure 6.57 shows a picture of exhumed CSI-34.

To further identify and quantify the amount and extent of slope movement within the NE pole plot, a survey of the installed poles was conducted in June 2009. Pole locations were measured relative to a fixed survey line that followed the contour of the top of the slope. Figure 6.58 shows the results of the survey. Initial pole locations, designated with white circles, were plotted based on the 3 ft. × 3 ft. installation grid, with the assumption that the top row of poles experienced insignificant to no displacement since construction. This is a reasonable assumption, as most of these poles were actually installed behind the crest of the slope. Pole locations in 2009 are designated with red diamonds. Figure 6.58 indicates that extensive sliding has occurred throughout the NE slope and is particularly large in Panels 3 and 4.

The largest displacements are concentrated in the upper portion of the slope. This is also where vegetation survival is highest (Figure 6.45), particularly in Panels 3 and 4. Displacements have continued because the reinforcement provided from the poles that are currently alive is not sufficient to stabilize the movements due to the extent and depth of sliding that has occurred.

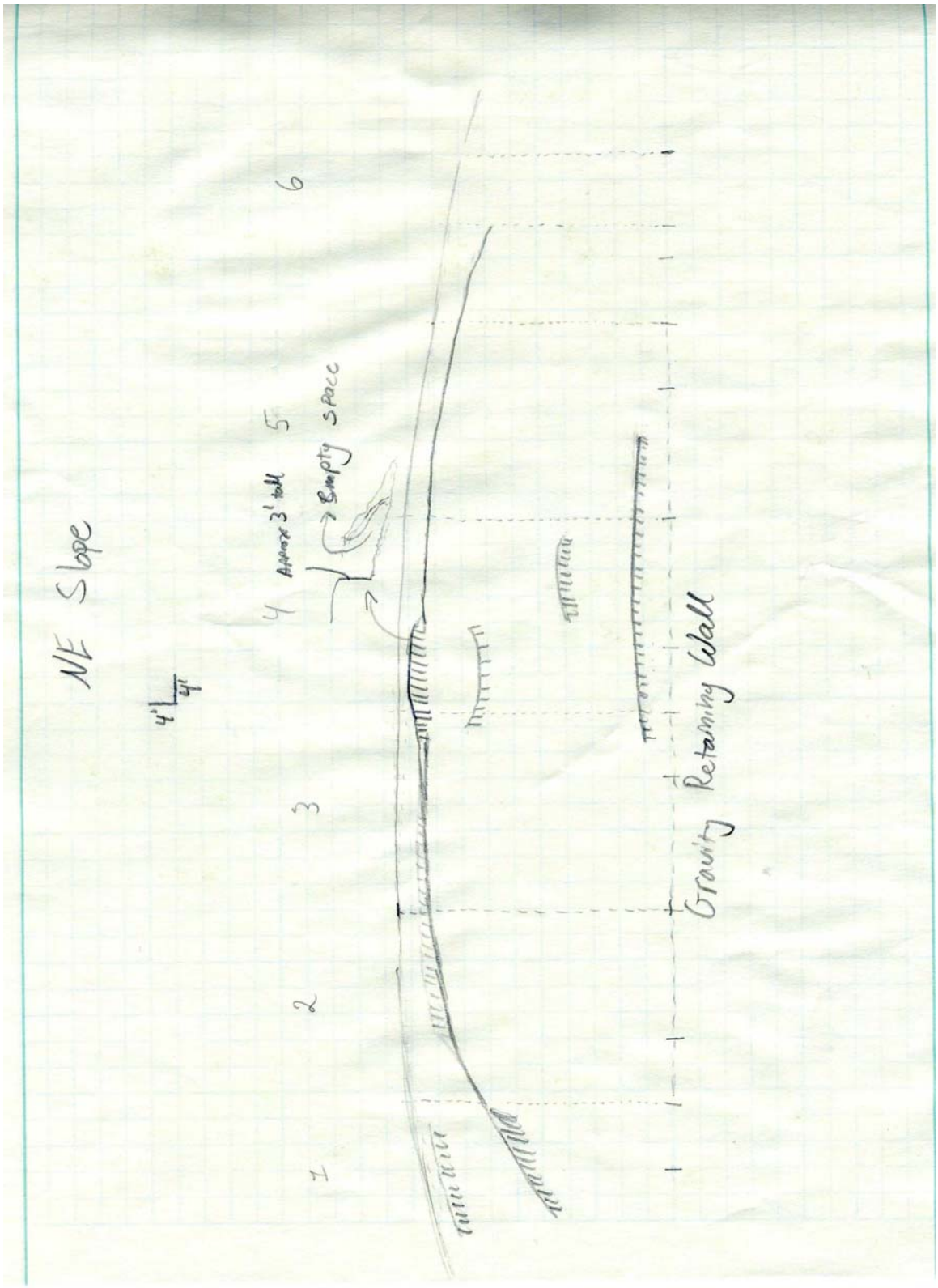


Figure 6.53: Slope movement features for the NE slope at the Logan County demonstration site (March 21, 2008).

Figure 6.54: Evidence of shallow sliding for Panels 3 and 4 on the NE Slope (photo taken September 25, 2007).

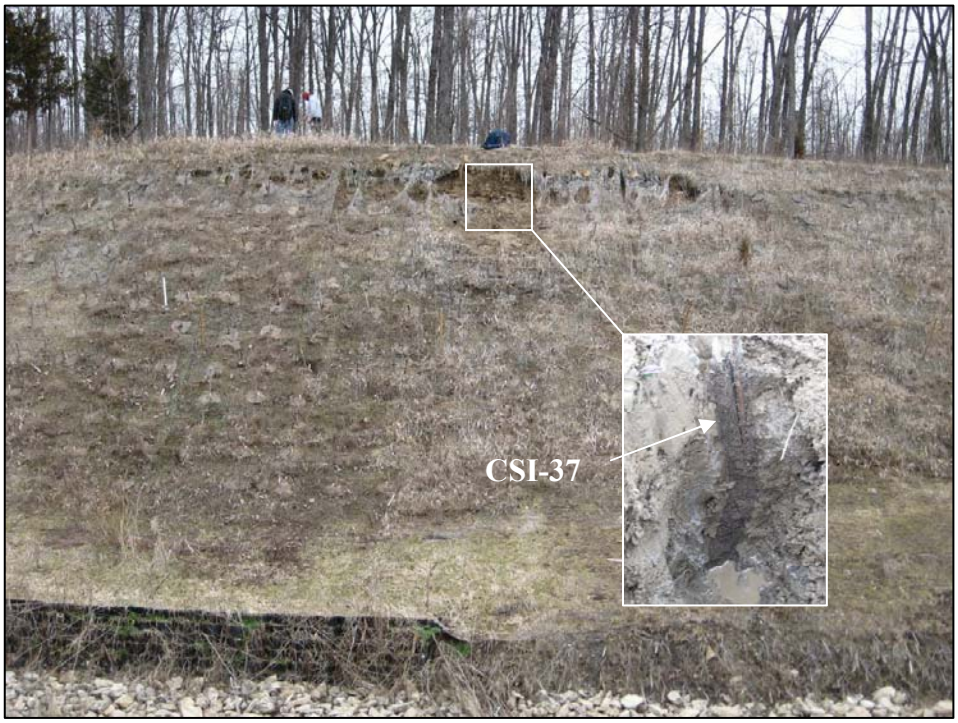


Figure 6.55: Photograph of CSI-37 taken during excavation. The copper tube is bending back into the slope at a depth of approximately 1.0 ft.

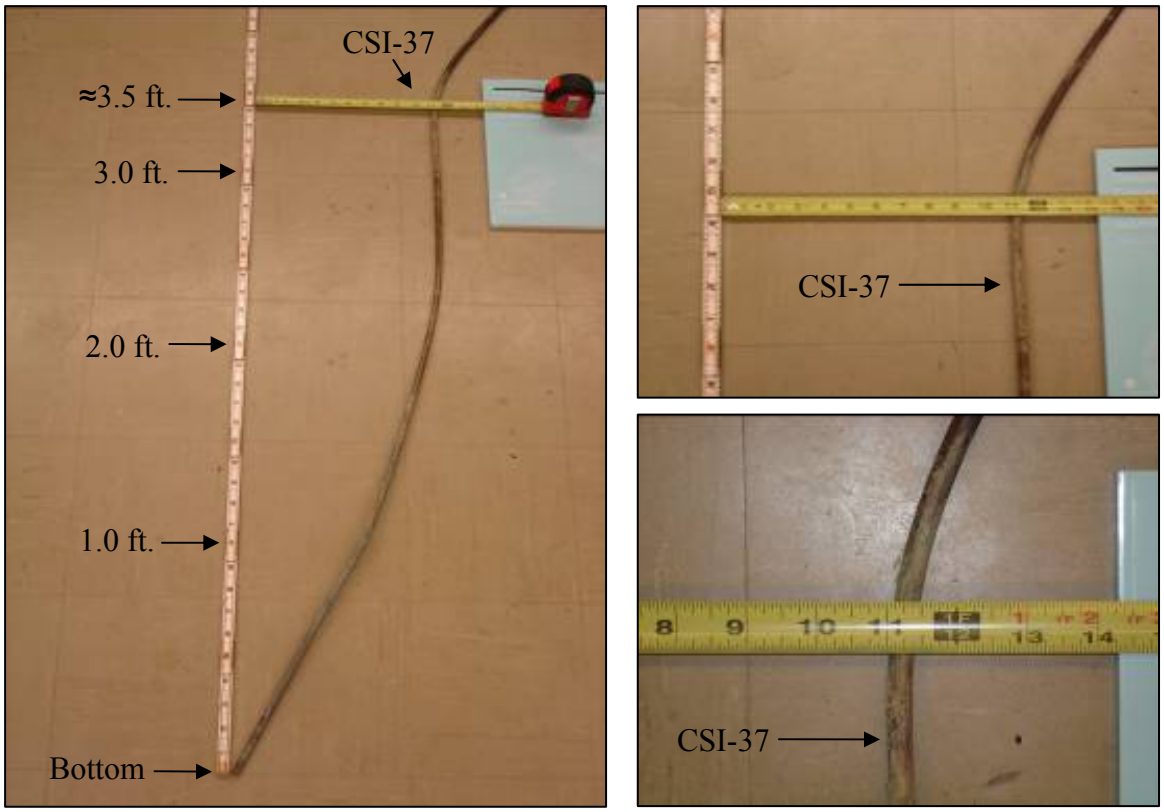


Figure 6.56: Copper shallow inclinometer, CSI-37, exhumed from Logan County demonstration site on March 21, 2008.

6.7.4 Lateral Load Testing

Three lateral load tests were conducted on dead poles at the Logan County demonstration site. Results of these tests and photos of the setup and procedures are provided in Appendices A and B. Data from this test was used to verify pile equations that were used in stability analyses. Dead poles represent the worst case with regard to resistance as no root growth is present within the soil, and rot has weakened the internal strength of the poles.

The ultimate lateral load was calculated using the Broms (1964) solution presented in Chapter 3. Limits for the calculations were based on the maximum and minimum diameter of poles measured during installation, the yield strength of the pole as determined by laboratory flexure tests, and the soil undrained shear strength as determined in field and laboratory tests, as indicated in Table 5.8. Complete results of flexure tests are available in Appendix B. Figure 6.59 shows the results of three lateral load tests that were conducted on dead poles in the NE slope. As seen in Table 6.7, measured peak lateral loads were concentrated at the lower limit of the calculated values of ultimate lateral load resistance. This is most likely due to rot that occurred within the poles prior to testing.

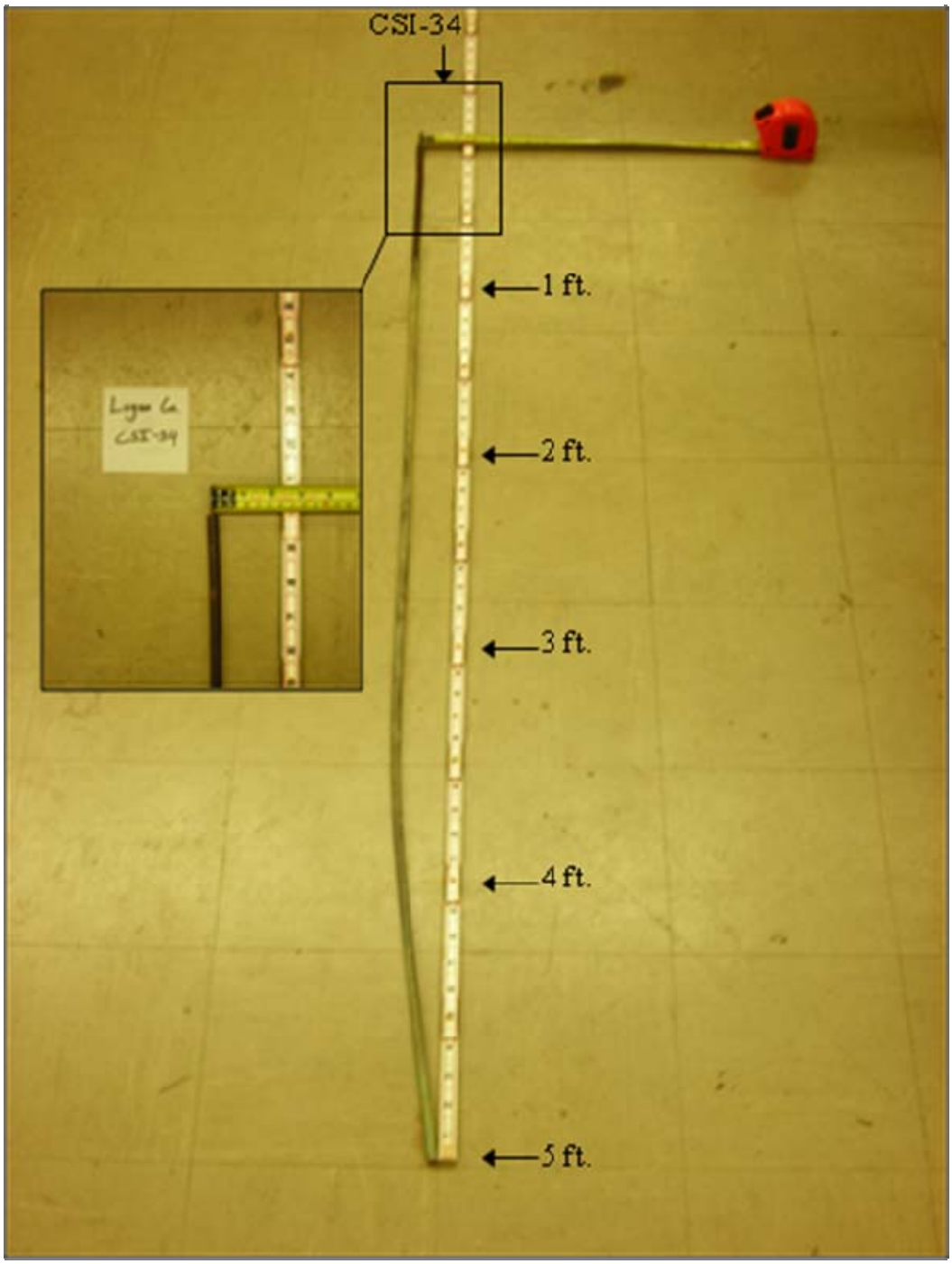


Figure 6.57: Copper shallow inclinometer, CSI-34, exhumed from Logan County demonstration site on August 24, 2009.

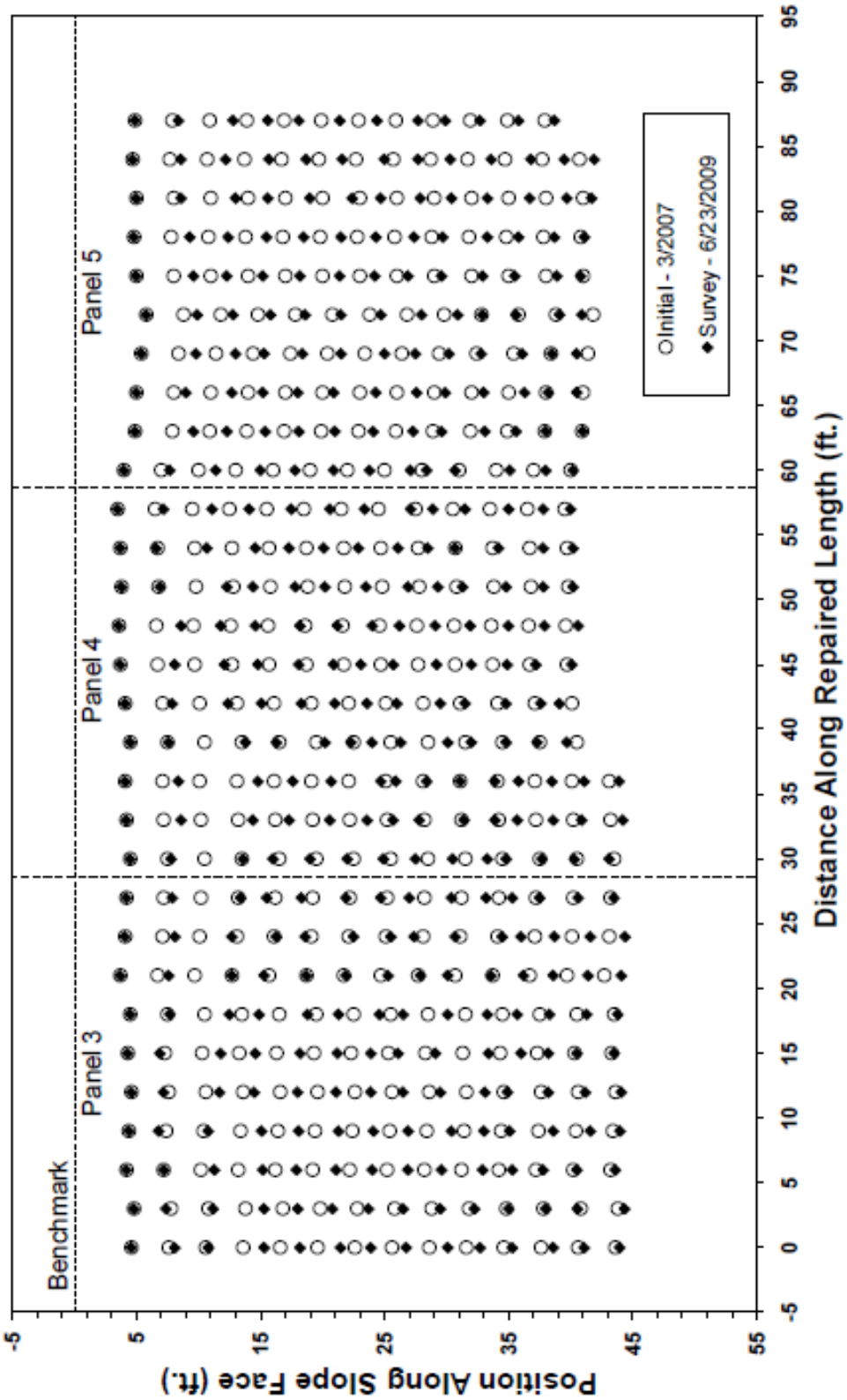


Figure 6.58: Willow pole survey of the NE slope at the Logan County demonstration site (June 23, 2008).

Table 6.6: Calculated ultimate lateral resistance of dead poles.

	Minimum	Average	Maximum
Undrained Shear Strength, s_u (psf) [1]	275	400	800
Diameter of Pole, D (in) [2]	0.68	1.45	2.09
Yield Moment Resistance of the Pole, M_{yield} (lb·in)	262	2544	7618
Dimensionless Yield Moment, YM [3]	436	300	150
Dimensionless Ultimate Lateral Resistance, ULR [4]	78	54	39
Calculated Lateral Load Capacity, T_{xu} (lb)	69	315	946

[1] – Undrained shear strengths are based on measurements from vane shear tests conducted in TP-2.

[2] – Pole dimensions are based on measurements from poles extracted during vertical pullout tests.

[3] – Yield Moment (YM) - dimensionless parameter defined by Broms (1964) (see Section 4.5.1.1).

[4] – Ultimate Lateral Resistance (ULR) - dimensionless parameter defined by Broms (1964) (see Section 4.5.1.1).

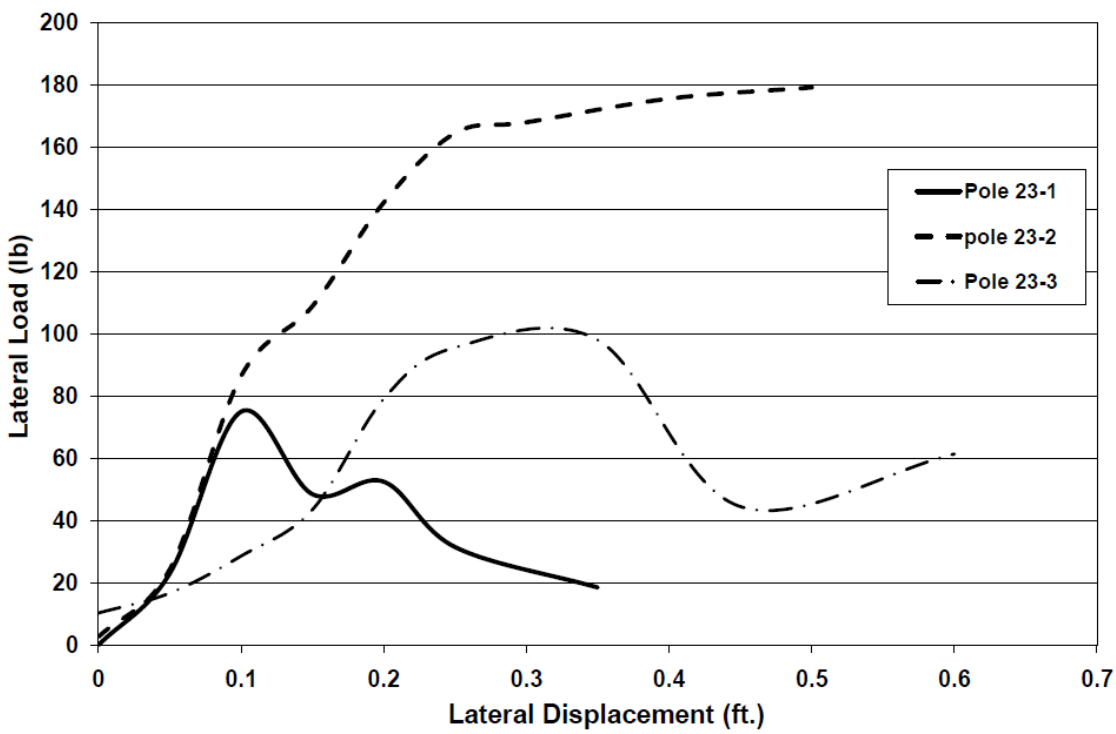


Figure 6.59: Load-displacement curves for lateral pullout tests conducted on dead poles at the Logan County demonstration site.

Table 6.7: Measured and calculated resistances for lateral load tests of dead poles.

	Measured	Calculated
Lateral Resistance	75-180 lb	69-946 lb

6.7.5 Slope Stability Assessment

The primary objectives at the Logan County demonstration site were to mitigate erosion and shallow sliding near the surface and to stabilize the deep rotational failures for both slopes. The following is an assessment of slope stability improvement for the stabilization methods implemented at the site. Sample calculations are provided in Appendix B.

The most significant slope movements at the Logan County site were observed between December 2004 and April 2005 (Kokesh, 2009). Typical mid-slope movements of 2.0 to 5.0 in. were measured from inclinometer surveys conducted from December 2004 to October 2006. Deep failure surfaces on both slopes were identified from inclinometer data at approximately 6.0 to 8.0 ft. below grade. Shallow displacements within the NE slope of approximately 3.0 in. were directly measured from exhumed CSI-2. The shallow failure surface at this location was identified at 1.5 ft. below grade.

According to records obtained from ODNR, precipitation during winter 2005 was well above average, suggesting that the slope was saturated or nearly saturated. Approximately 11.0 in. of precipitation occurred in January 2005 alone, which is nearly 8.5 in. above average. Prior to this project, ODOT records and field monitoring indicate no large movements have occurred on this site since the initial failure in 1997. During August of that year, approximately 9 in. of rain fell in the Logan County region. These isolated periods of substantial movements would suggest that the factor of safety against sliding is slightly greater than unity ($FS > 1$), but decreases to approximately unity during these critical periods of heavy precipitation.

6.7.5.1 Shallow (Infinite) Slope Stability Analysis

A shallow slope stability analysis was completed for the Logan County demonstration site followed using the infinite slope procedure. The analysis and methodology is presented in Gray and Sotir (1996) and is discussed in Section 4.5.1. The slope and failure surface geometries were determined from observations made during field reconnaissance and groundwater conditions were characterized from piezometer data. Personal communications with D. H. Barker suggest that, based on empirical evidence from previous live pole trials (Barker 1997; Steele et al. 2004), a live pole spacing of 3 ft. would increase the factor of safety from 1 (failure) to approximately 1.2 (Kokesh 2009).

An infinite slope stability analysis was performed using the parameters outlined in Table 6.8 and for a range of failure surface depths. The equivalent reinforcement cohesion, c_R, was determined using methods described in Section 4.5.1.1. To represent the worst-case scenario, the slope was assumed to be saturated. The seepage flow

direction, θ, was varied from vertical to parallel with the slope face, and the failure surface depth, H, was taken as 2 ft. based on observations from CSIs exhumed from the site.

Table 6.8: Parameters used in slope stability analyses for the Logan County demonstration site.

Parameter	Value	Source	Strata Number [1] / Stability Input
Slope Angle, β	26.6°	Field Measurement	All
Unit Weight of Water, γ_w	62.4 pcf	Constant	All
Saturated Unit Weight of Soil, γ_{sat}	129 – 136 pcf	CU/CD Triaxial	All
Undrained Shear Strength, s_u [2]	275 – 800 psf	Vane Shear	1
Effective Peak Friction Angle, ϕ'_p, and Undrained Shear Strength, s_u [3]	29°/33°	Triaxial/Direct Shear	1
	645 psf		
Effective Residual Friction Angle, ϕ'_r, and Cohesion, c'_r	19°	Direct Shear	1
	0.84 psi		
Effective Peak Friction Angle, ϕ'_p, and Undrained Shear Strength, s_u [3]	24°/31°	CD/CU Triaxial	2
	1320 psf		
Effective Peak Friction Angle, ϕ'_p, and Undrained Shear Strength, s_u [3]	30°	CD Triaxial	3
	1320 psf (4)		
Effective Cohesion, c'	0	Direct Shear/Triaxial	All
Embedment Depth of Poles, L	5.0 ft.	Field Measurement	Reinforcement Cohesion
Diameter of Poles, d	1.25 in.	Field Measurement	Reinforcement Cohesion
Moment of Inertia of Poles, I	0.1198 in.^{4}	Based on Field Measurement	Reinforcement Cohesion

[1] – Strata number refers to the soil layer shown on Figure 6.6.

[2] – Strength parameter used in shallow stability analysis. Lower bound of s_u is used in the "flow mode" calculation, and the upper bound is used in the "pile mode" calculation of equivalent reinforcement cohesion.

[3] – Strength parameter used in deep-seated stability analysis for the gravity toe berm at the base of the NE slope.

[4] – CU triaxial testing was not conducted on this material. The undrained shear strength determined for layer 2 used in the stability analysis.

Table 6.8 (*Continued*)

Parameter	Value	Source	Strata Number [1] / Stability Input
Modulus of Elasticity of Poles, E	1.0E+06 psi	Flexure Test	Reinforcement Cohesion
Ultimate Tensile Strength of Poles, σ_u	8500 psi	Flexure Test	Reinforcement Cohesion
Yield Moment Resistance of Poles, M_y	1630 lb-in.	Flexure Test / Field Measurements	Reinforcement Cohesion
Shear Strength of Poles, τ_u	580 psi	Barker et al. (1997)	Reinforcement Cohesion
Eccentricity of Pole Loading, e/d	0	Assumed	Dimension
Spacing of Poles, s	3 ft.	Field Measurement	Dimension

[1] – Strata number refers to the soil layer shown on Figure 6.6.

[2] – Strength parameter used in shallow stability analysis. Lower bound of s_u is used in the "flow mode" calculation, and the upper bound is used in the "pile mode" calculation of equivalent reinforcement cohesion.

[3] – Strength parameter used in deep-seated stability analysis for the gravity toe berm at the base of the NE slope.

[4] – CU triaxial testing was not conducted on this material. The undrained shear strength determined for layer 2 used in the stability analysis.

The results of the infinite slope stability analysis are presented in Table 6.9. In calculating the non-reinforced (initial) factor of safety, the equivalent reinforcement cohesion, c_R, term is taken as zero. In calculating the reinforced (final) factor of safety, c_R was calculated using the limiting resistance obtained from methods in Section 4.5.1.1. Based on the geometry of the system and the physical properties of the soil, calculations indicate that the pile mode controls stability. The factor-of-safety generally decreases with depth. The calculated non-reinforced factor-of-safety for the worst-case scenario, where seepage is parallel to the slope face, is well below 1.0. When including seepage forces in the stability analysis, the factor of safety for drained conditions ($c' = 0$) is reduced by the factor $1 - \gamma_w / \gamma_{sat}$. If vertical seepage is specified, the factor-of-safety increases to $FS = 1.11$. Slope movements were observed prior to remediation, indicating that the factor-of-safety was less than one. However, the extent of sliding suggests that the seepage angle, θ, is somewhere between parallel and vertical.

The calculated reinforced calculated factor-of-safety for a slip surface 2 ft. below the ground surface is 0.84 for the case of parallel seepage and 1.35 for the case of vertical seepage. This indicates a strength increase of approximately 40% and 20%, respectively, provided by the poles acting as micropiles. It is important to realize that this scenario (with reinforcement only provided by poles acing as micropiles) represents the minimal

Table 6.9: Summary of factors-of-safety for shallow stability at the Logan County demonstration site.

Seepage Direction	Non-Reinforced *FS* ($c_R = 0$)	Reinforced *FS* ($c_R = 26.7$ psf)
Parallel to Slope Face ($\theta = 26.6°$)	0.60	0.84
Vertical ($\theta = 90°$)	1.11	1.35

strength increase provided by the vegetation. Establishment and rooting of poles over time could provide additional strength increases as high as 20% as demonstrated in the case study conducted by Steele et al. (2004).

6.7.5.2 Slope Stability Analysis Using SLOPE/W

Slope stability analysis of the deep-seated failure condition and remediation for the Logan County site was conducted using the slope stability analysis program SLOPE/W. General information on the software and its utilization in the design are presented in Section 4.5.2. The slope geometry was determined from cross sections generated using topographic surveys. Subsurface soil conditions were determined from field borings and laboratory tests. The failure surfaces were deduced from inclinometer data and field observations of scarp and bulge locations. Groundwater conditions were identified using piezometer data. Using parameters listed in Table 6.8, analyses were conducted using SLOPE/W for the site prior to, during and subsequent to construction.

Three stability analysis models were generated for the NE slope prior to and subsequent to mitigation assuming drained conditions and one for short term stability for the fully excavated condition of the gravity toe berm assuming undrained conditions. The undrained shear strength of each soil layer was determined from the total stress failure envelope from CU triaxial test results based on the overburden stress at the depth of the layer (except for Layer 3 as CU triaxial testing was not conducted on this material). Material properties for the toe berm were based on values typical of compacted fill slopes.

The factor-of-safety against sliding was determined for each scenario using the modified Bishop method of slices and are presented in Table 6.10. The results indicate that the factor-of-safety prior to construction was just slightly less than unity. After construction of the gravity toe berms, the calculated factor-of-safety for drained conditions increases to 1.21. Thus, the analysis indicates that the gravity toe berm should arrest deep-seated slope movements. Slope movements subsequent to construction were monitored using deep inclinometers and results indicate that sliding has indeed subsided. The factor-of-safety determined for undrained conditions during excavation for the gravity toe berm was 1.81. Thus, undrained soil strength was sufficiently high to prevent slope failure during construction, which is consistent with field observations. Graphical

output from the stability analyses are presented in Figure 6.60 through Figure 6.63. The input parameters for each strata are provided on the outputs.

Table 6.10: Summary of factors-of-safety for deep-seated stability the Logan County demonstration site.

	Analysis Type	*FS*
Pre-Construction	Drained	0.99
Post-Construction	Drained	1.21
During Excavation	Undrained	1.81
	Drained	< 1.0

6.7.6 Cost Analysis

One of the key issues that the research team is evaluating is the cost of bioengineering remediation as compared to conventional stabilization methods. Further information on conventional construction methods and cost is presented in Chapter 6. The bid cost of construction, including bioengineering installation, gravity toe berms, geocell slope erosion protection and site restoration, was approximately $143,000. It should be noted, however, that for the purposes of determining the cost of biostabilization alone (areas 3, 4 and 5 from the plan view provided in the construction documents in Appendix B), all costs pertaining to the gravity toe berm and geocell slope erosion protection were excluded from the bioengineering cost analysis. As shown in Table 6.11, over 40% of the total cost for the project included items not related to the bioengineering installation. However, the bid cost for the bioengineering installation ($79,000) is higher than what was anticipated. Bid costs are assumed to be conservative (i.e., high) and actual cost incurred by the contractor are not known. Please note that the costs presented in Table 6.11 are for the initial construction only and do not include the cost of additional installations. It should be noted that the bulk of the total bioengineering cost was the lump sum for installation of the willow poles. The cost of this item is expected to decrease, possibly substantially, in the future as contractors familiarize themselves with the technique. An itemized list of costs and quantities submitted during the bidding process is provided in Appendix B.

Table 6.11: Cost analysis for Logan County demonstration site.

Construction Activity	Duration (days)	Total Cost ($)	$/LFT	$/SY
Bioengineering	7	79,000	439	110
Gravity Berms and Slope Protection	24	64,000	400	-
Overall	26	143,000	511	-

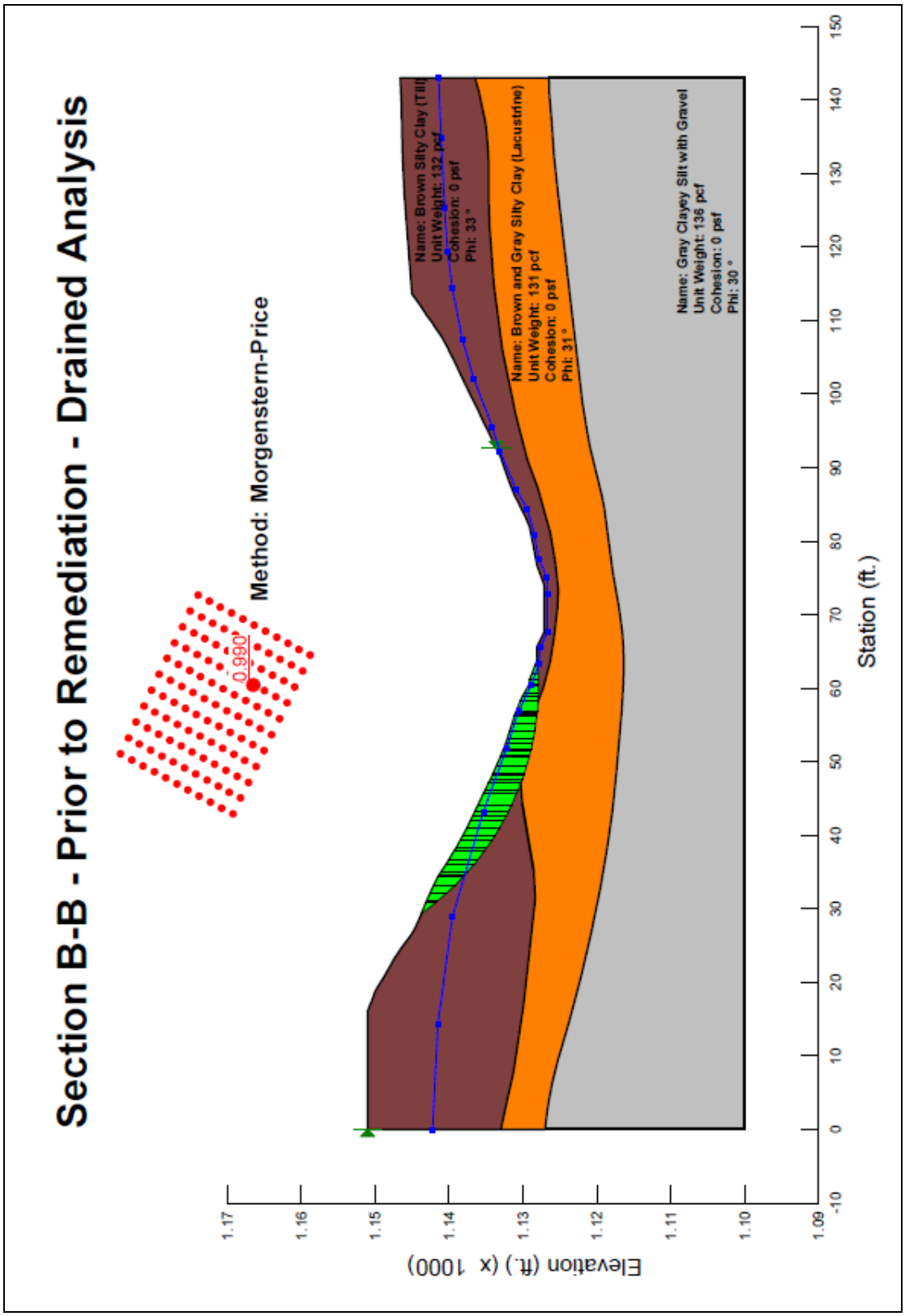


Figure 6.60: Graphical output of SLOPE/W analysis for Section B-B prior to remediation.

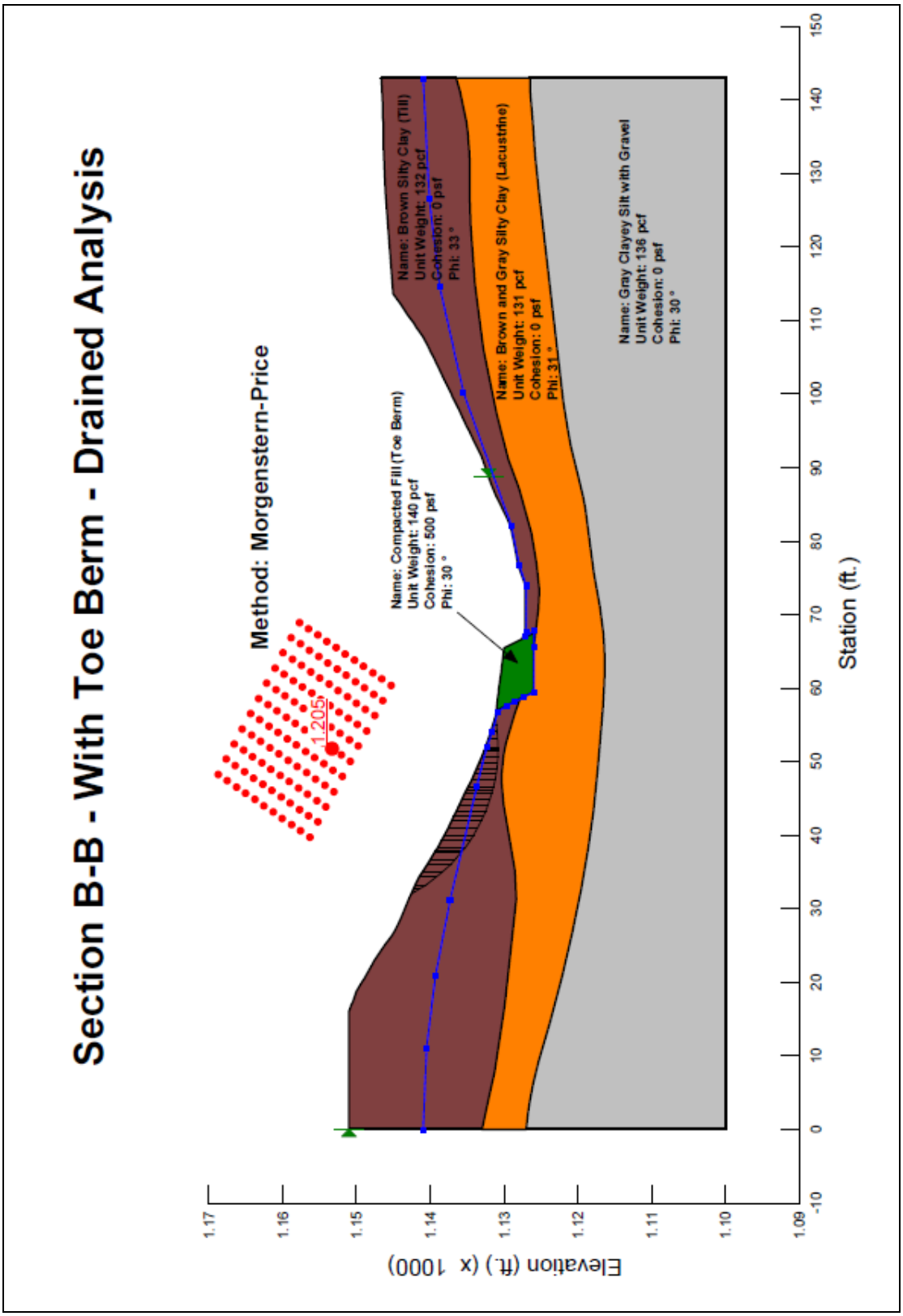


Figure 6.61: Graphical output of SLOPE/W analysis for Section B-B at the completion of construction with the gravity toe berm.

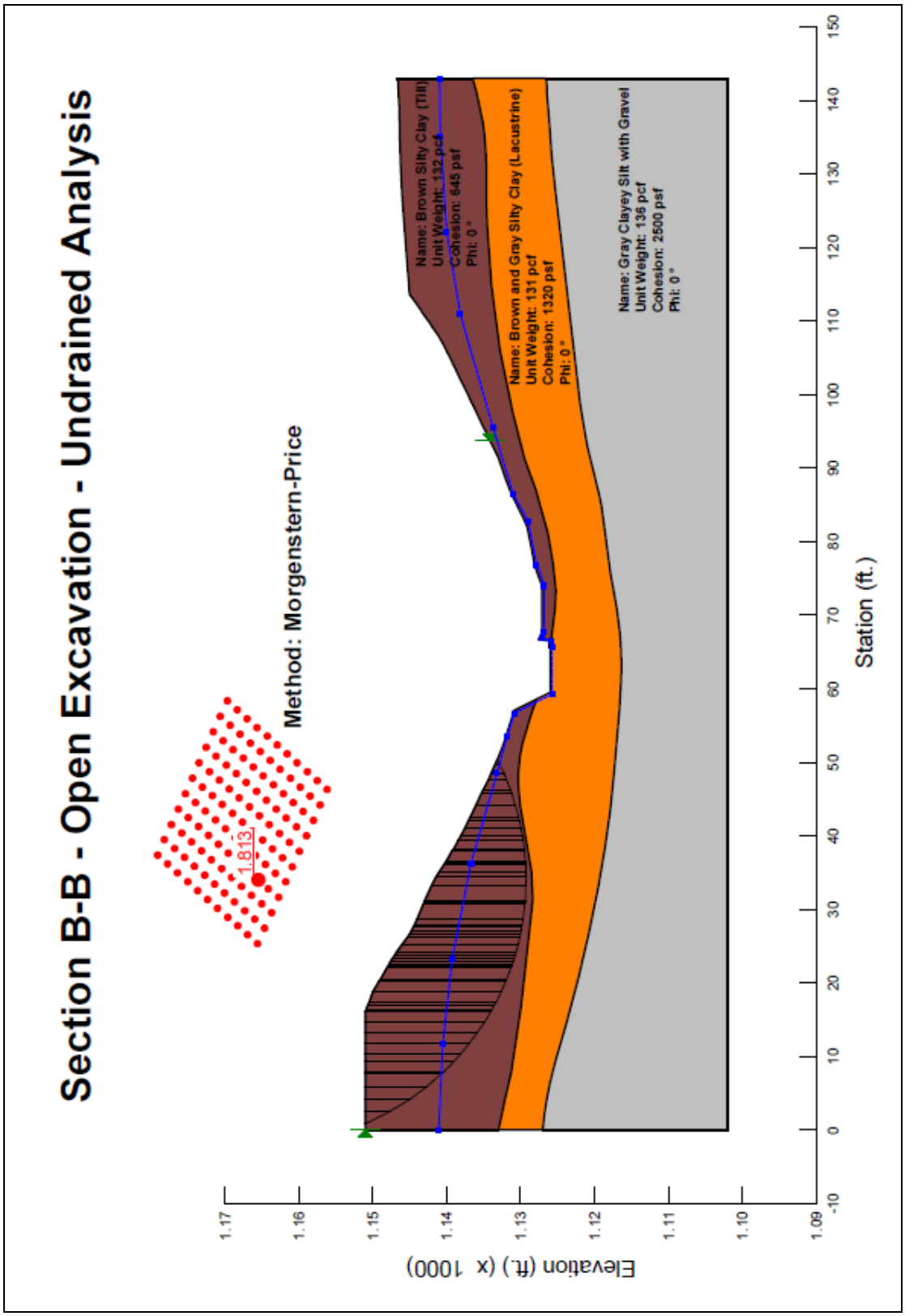


Figure 6.62: Graphical output of SLOPE/W analysis for Section B-B during construction of the gravity toe berm where the excavation is open (undrained analysis).

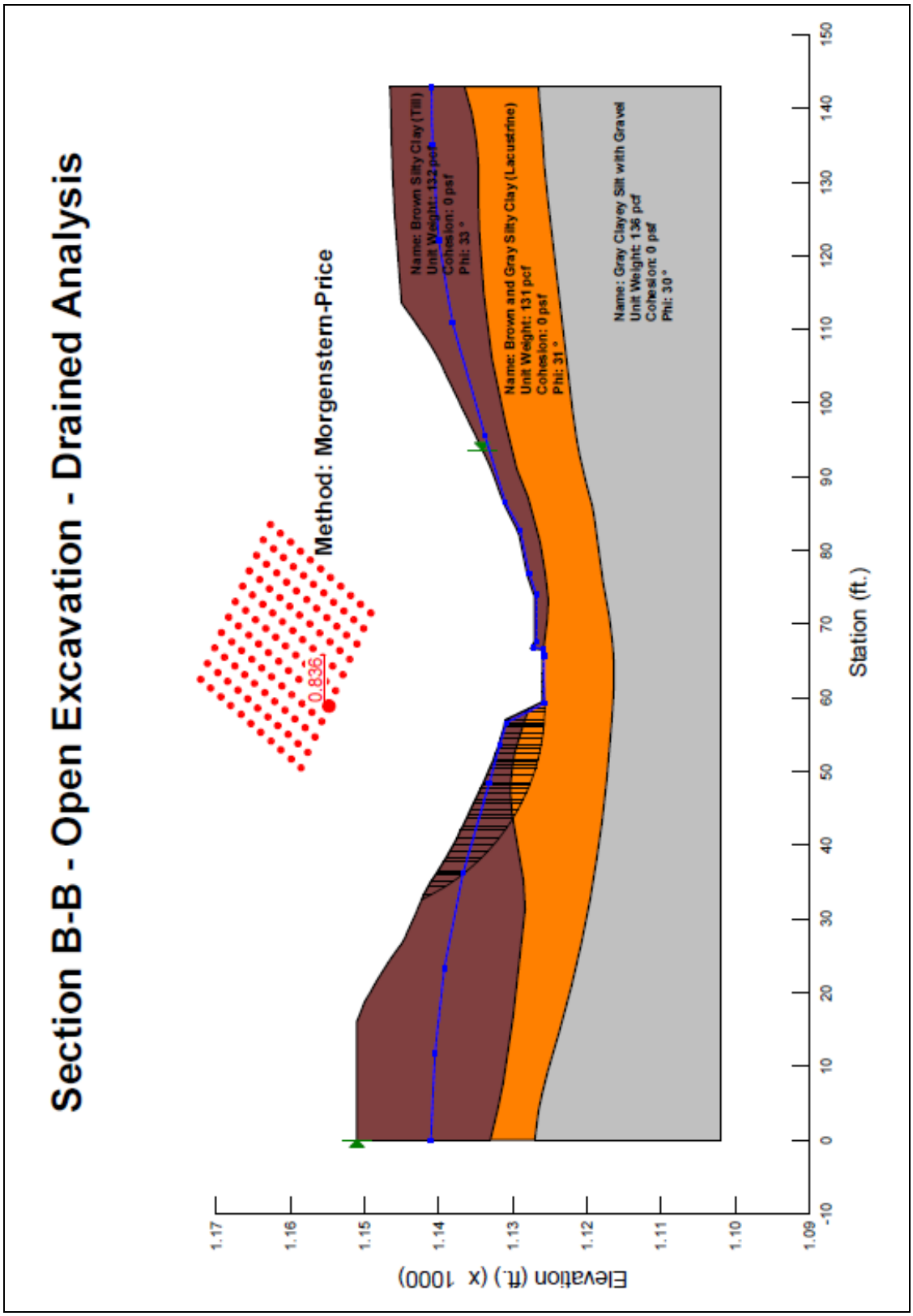


Figure 6.63: Graphical output of SLOPE/W analysis for Section B-B during construction of the gravity toe berm where the excavation is open (drained analysis).

6.8 SUMMARY AND CONCLUSIONS

This chapter presents research efforts completed for the Logan County demonstration site. Throughout this chapter, data and analyses are presented and discussed with regard to site conditions, including the geology, climate and subsurface, field exploration, laboratory testing, site instrumentation and performance data. Performance data includes vegetation survival rates and slope displacements. Stability analyses and cost considerations are also presented.

The Logan County demonstration site presented the research team with valuable knowledge on installation techniques and construction limitations for future bioengineering installations. Live staking (live poles) and gravity toe berms were chosen by the research team as the primary means to mitigate shallow and deep failures occurring at the site. Two live pole plots were constructed on the NE and SW slopes within areas where significant sliding had taken place during winter 2005, and a gravity toe berm was constructed along the bottom of the NE slope to arrest deep-seated sliding. Construction took place during March 2007, and several additional pole installations were conducted in the spring and winter 2008 and spring 2009.

Groundwater data suggests that soil suctions within the NE and SW pole plots were slightly higher than the surrounding region. Piezometric levels observed in shallow wells at the base of the NE and SW slopes were slightly higher during 2007 and 2008 than in previous years. Static water levels may be building within the slopes due to poor vegetation survival (less water being drawn from the soil) and increased infiltration at areas where the bentonite seal has been washed away at pole locations. Shallow sliding has occurred within the NE slope since the initial installation in the winter of 2007. Slope movements of 12 in. have been measured from exhumed CSI-37 in the NE slope.

Initial survival rates were well below what was anticipated; cyclic fluctuations in temperature combined with well below average precipitation during May, June and July 2007 were the primary factors that contributed to the low initial survival rates. Ideal climate conditions during late March and early April 2007 produced buds on most of the poles; however, cold temperatures that followed during late April apparently prevented most of them from producing the necessary rooting systems required for sustained growth. Personal communications with Dr. D. Struve of the Ohio State University horticulture and crop science department indicated that this period was a “killing frost”, as most vegetation grown at nurseries and other research sites suffered high mortality rates as well. Low survival rates for additional installations suggest that climate and soil chemistry may be adversely affecting the establishment of vegetation at the site. Side-by-side panel comparisons indicated that varying installation techniques do not affect the survivability of vegetation.

Stability analysis for initial conditions suggests that the orientation of seepage direction within the slope is between vertical and parallel to the slope face. This is evident by the fact that unstable conditions were observed on the slope prior to installation and the calculated factor-of-safety for vertical seepage was 1.35 and for parallel seepage was 0.84. Lateral load tests conducted on dead poles gave a capacity that was well below the ranges calculated using pile equations. This is most likely due to the weak internal strength of the rotted poles tested. Biostabilization was not successful at arresting shallow sliding at this site. The depth of the failure surface was determined

from CSI's exhumed from the NE slope and is below 3 – 4 ft. Stability analysis for the deep-seated failure indicates that the factor of safety for the initial condition is slightly below 1.0 and increases to 1.2 with the gravity toe berm along the base of the slope. The gravity toe berm was successful in arresting deep-seated sliding at the site based on data from inclinometers I-20 and I-21 installed in 2009. The total cost of the bioengineering installation at the Logan County demonstration site was $79,000 and the unit costs were $439/LFT and $110/SY. More cost comparison information is provided in Chapter 7.

Chapter 7 UNION COUNTY DEMONSTRATION SITE

INTERSECTION: US-33/SR-36,4

7.1 INTRODUCTION

7.1.1 Project Location Description

The Union County demonstration site is located along the interchange (Road U) of the US-33/SR-36,4 in Union County, Ohio. The interchange is located just outside of the city of Marysville, approximately 35 miles northwest of Columbus, Ohio. Figure 7.1 shows a map of the state with the project location, and Figure 7.2 shows a view of the region as provided from the ODOT construction plans for this project. An aerial view of the site is provided in Figure 7.3, indicating the areas of the bioengineering project. The focus of the investigation at this demonstration site was the remediation of shallow sliding along the slopes supporting the onramps to US-33 and SR-36,4 using bioengineering techniques. The motivation for the project was severe sliding in areas between the bioengineering construction areas and the bridge abutments supporting the overpass of SR-36,4 and US-33. Conventional remediation methods were utilized to mitigate the sliding that occurred within these areas.

7.2 SITE CONDITIONS

7.2.1 General Layout

The location of the Union county demonstration site is along Road U (interchange of US-33/SR-36,4) between Sta. 82+28 and Sta. 82+82 (Lt.) for the southwest (SW) slope, and between Sta. 82+57 and Sta. 83+27 (Rt.) for the northeast (NE) slope. Figure 7.4 shows a site plan of the area indicating the limits of construction. Currently, the embankment supporting both onramps has 2H:1V slopes. Slopes in the adjacent areas, near the US-33 overpass, were flattened from 2H:1V to 2.5H:1V slopes as part of the conventional mitigation to stabilize those areas. Further details on the conventional construction methods utilized at this site are presented in Section 7.6.1. Figure 7.5 shows a cross section of the site, including both the NE and SW slopes. This section has experienced minimal sliding, but provides critical data with regard to vegetation survivability and for comparison of bioengineering and conventional stabilization methods. According to boring logs, the slopes are primarily comprised of compacted brown silty clay and brown/gray clay (AASHTO A-6b and A-7-6).

7.2.2 Regional Geology

Geologic information for Union County was taken from the *Soil Survey of Union County* (Waters, 1975). Union County is in the Central Lowland province of the United States. The soil composition of Union County consists primarily of till material of varying thickness over limestone bedrock. Glaciers have covered Union County at least twice, with the first glaciation taking place during the Illinoian age, and the second during the Wisconsin age. The Wisconsin glaciers completely covered the glacial drift deposited by the earlier Illinoian glaciers; therefore, the Illinoian till material is not

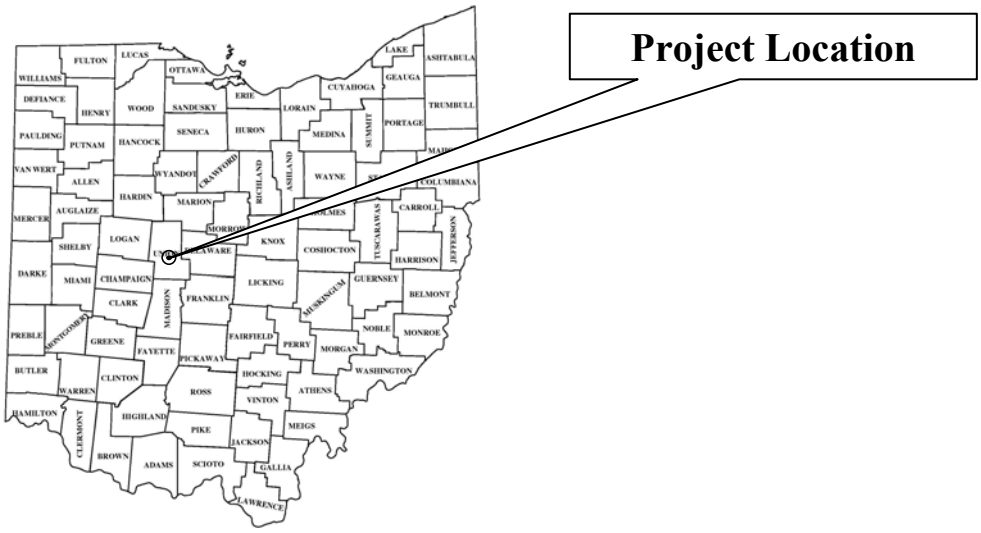


Figure 7.1: Vicinity map: Union County US-33/SR-36,4 demonstration site.

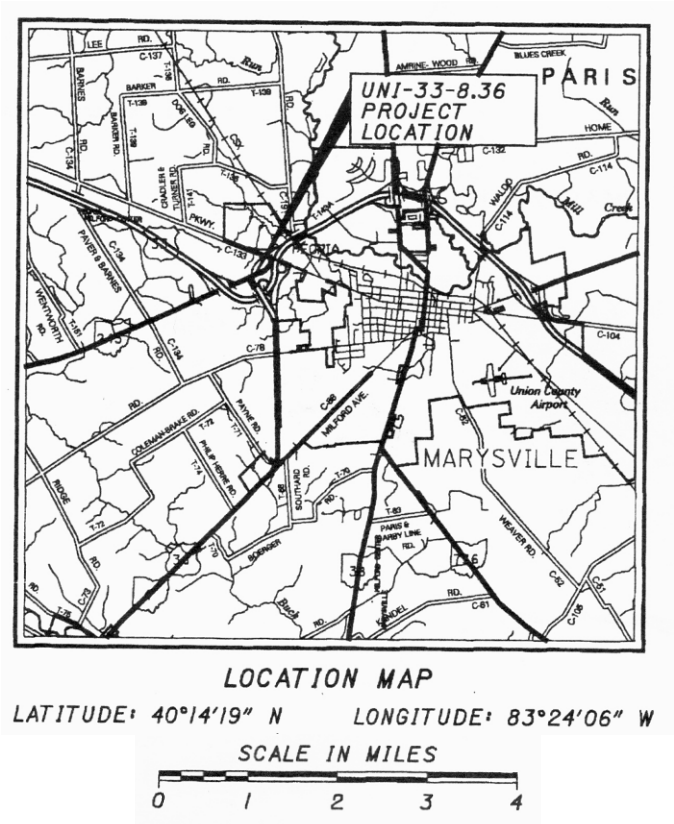


Figure 7.2: Regional map of Union County area (UNI-33-8.33, 2005, ODOT).

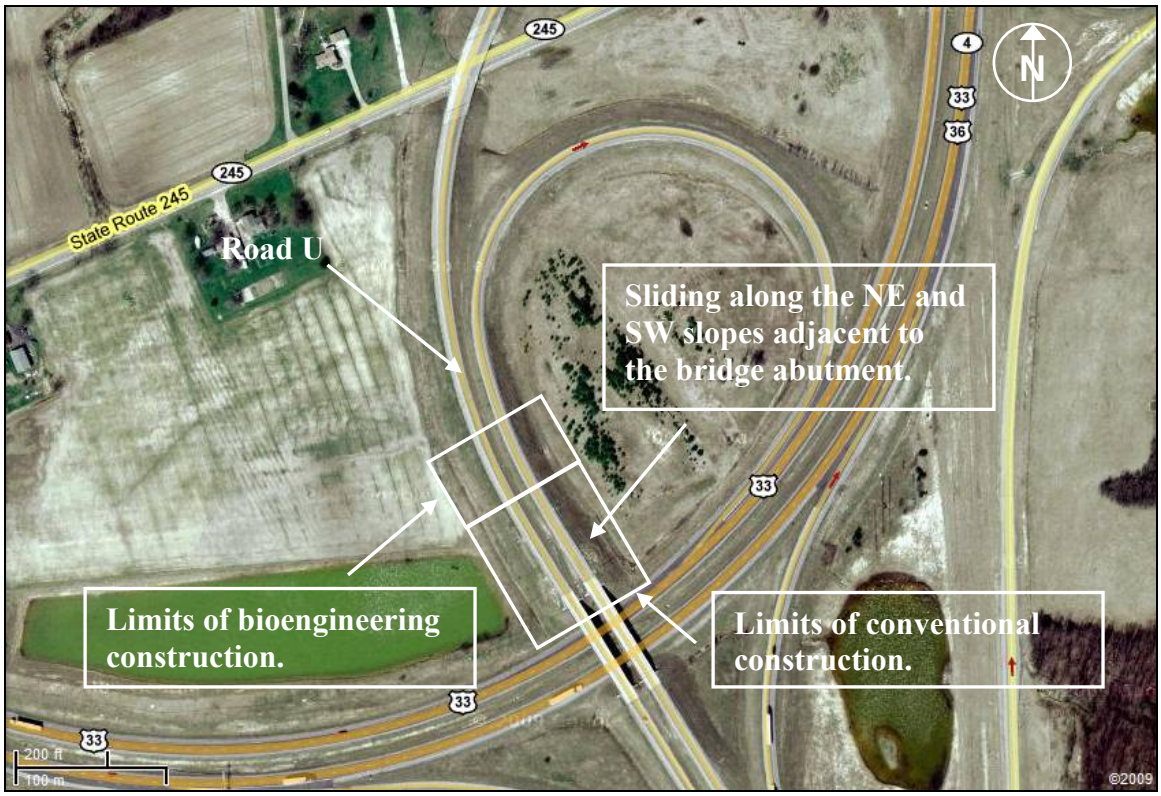


Figure 7.3: Aerial view of the Union County demonstration site (Google – Imagery, 2009). Biostabilization was implemented on the northeast and southwest slopes of the embankment.

exposed in Union County. The glacial till varies in texture and composition and is high in content of calcareous material derived mostly from local limestone bedrock. The glaciers deposited stratified sand and gravel outwash, mostly along a few of the principle streams in the county. Lacustrine material was deposited in relatively small areas on the bottoms of temporary glacial lakes over the glacial till. Recent alluvial material was deposited on the flood plains of existing streams.

7.2.3 Climate

Historical data has been published by the National Climatic Data Center (NCDC) and the Midwestern Regional Climate Center (MRCC) and is also provided by the Ohio Department of Natural Resources (ODNR). This data represents the average values collected over a 30 year period from 1971 to 2000. A summary of the data collected for Marysville, Ohio, is provided in Appendix C. The average annual precipitation recorded at this station is 36.6 in. During the growing season (March to June), the average monthly precipitation ranges from 2.60 to 4.35 in. for March and June, respectively. June has the highest average monthly precipitation while February has the lowest with 1.97 in. The annual mean temperature is 51.1°F. July has the highest mean temperature at 73.9°F, while January has the lowest mean temperature at 25.8°F.

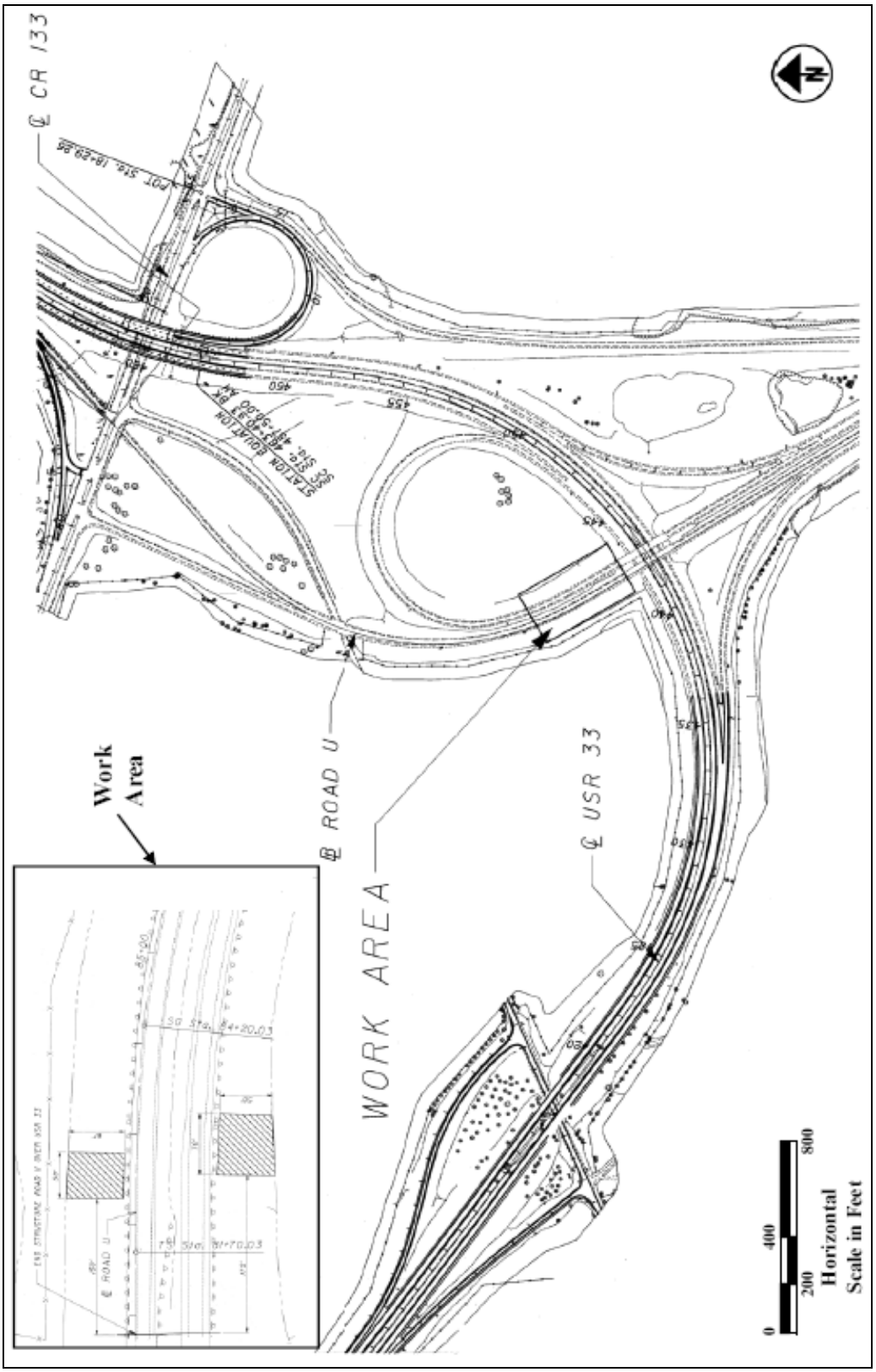


Figure 7.4: Site plan for the Union County demonstration site (from ODOT plans LOG/UNI-347/33-0.00/8.33).

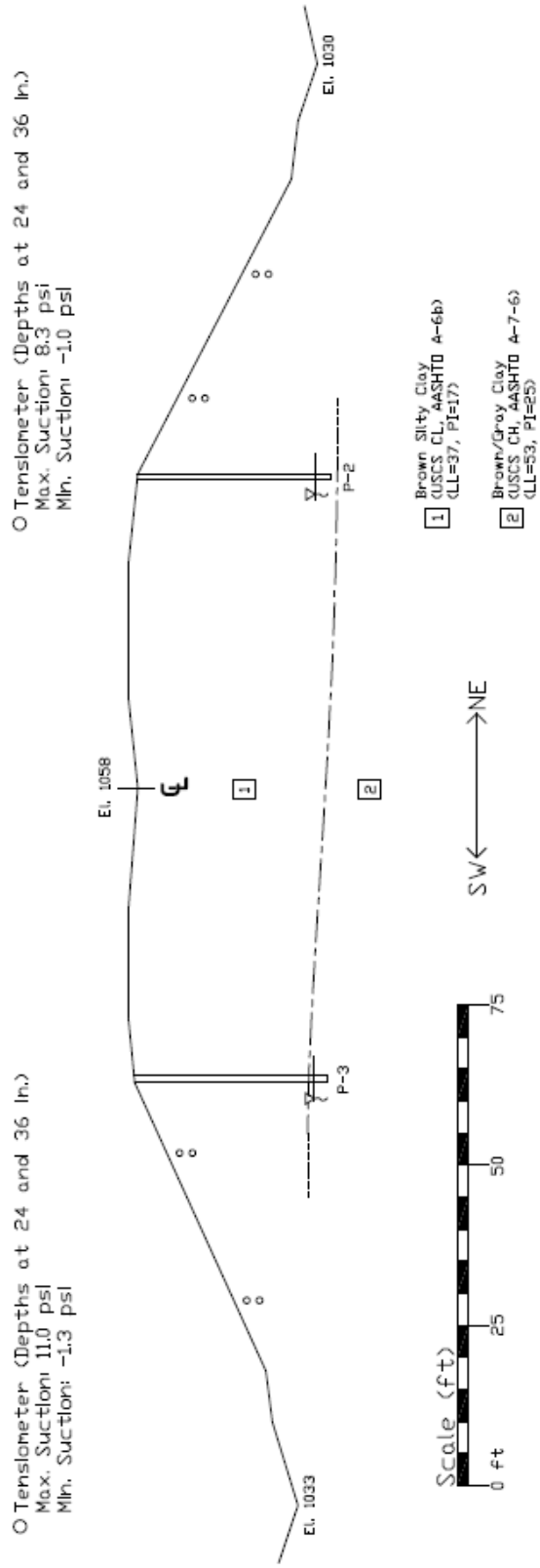


Figure 7.5: Cross section of the Union County demonstration site with instrumentation details.

Temperature and precipitation data for the time frame of the project was obtained from the ODNR central office in Columbus for the Marysville station. Monthly precipitation data from January 2005 through April 2009, along with daily precipitation and temperature data for March, April and May 2007, was obtained for these stations and an overview of the climate conditions is presented below. Figure 7.6 shows the monthly precipitation for this station from January 2005 through December 2008. All data for this station is provided in Appendix C.

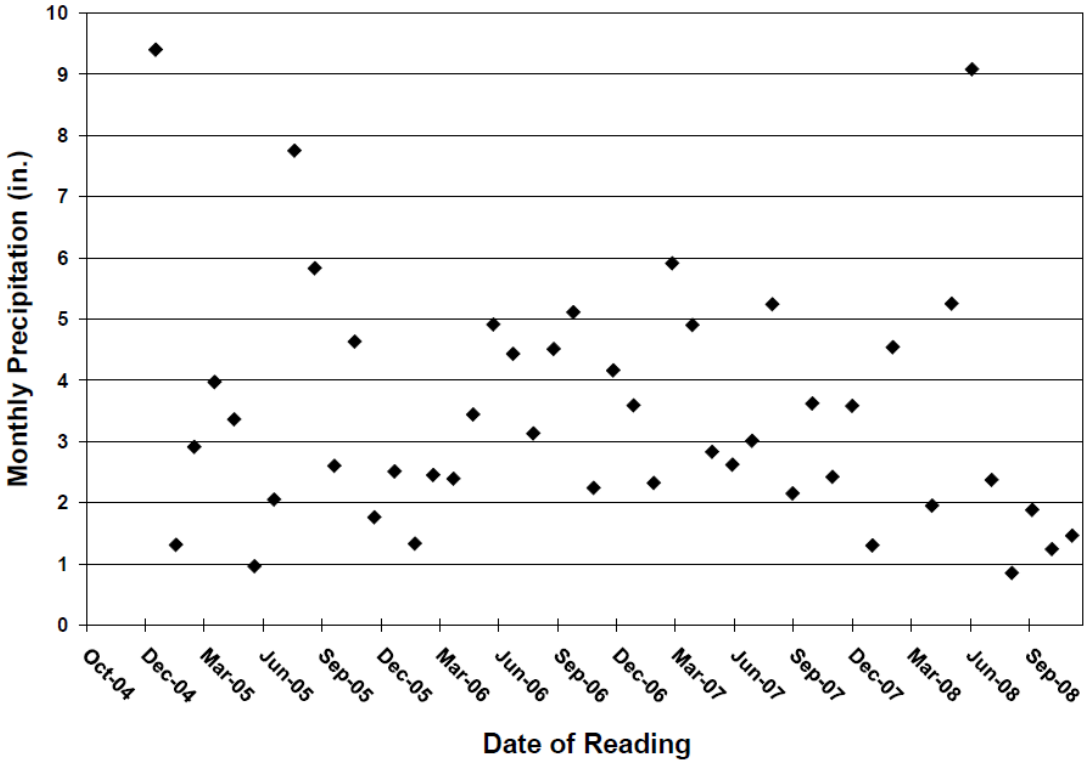


Figure 7.6: Monthly precipitation data for Marysville, Ohio, from 2005 through 2008.

Bioengineering construction at the Union County site was completed on March 16, 2007. After construction, there were three rainfall events that exceeded 0.25 in. by the end of March. Total precipitation over this period was 3.41 in., nearly exceeding the 30 year average for March by 1.0 in. From March 22 through April 4, 2007, the area experienced unseasonably high temperatures and just one significant precipitation event along with trace precipitation throughout the remainder of the period. Over field visits at the beginning of April 2008, buds were observed sprouting from a majority of the vegetation. During the following 11 days, April 5-15, 2007, temperatures dropped dramatically, from mid-to-upper 70's down to the low 30's and below freezing. Throughout the rest of April, temperatures increased to unseasonably high ranges and precipitation was approximately 1.54 in. above the 30-year normal by end of the month. The month of May, 2007, was unseasonably warm and dry with only 2.83 in. of precipitation recorded at the Marysville station, which was 1.06 in. below the 30-year average, and the average daily maximum temperature was approximately 6°F above

average. Over the 20-day period from April 28 to May 15, only one significant precipitation event of 0.37 in. was recorded at the Marysville station.

It should be noted that one event at the Marysville station, recorded on May 16, yielded 1.48 in. of rain. This is a highly uncommon event and most of this precipitation was likely lost to runoff. Removing this event would yield a total of 1.35 in. for May, which is approximately 2.67 in. below the 30-year average. Total precipitation for June was 2.62 in., approximately 1.0 in. below the 30-year average. July experienced a slightly higher amount of precipitation, but remained nearly 1.0 in. below normal.

7.3 FIELD EXPLORATION

7.3.1 Field Reconnaissance

Numerous field visits have been made throughout this project to evaluate site conditions. During these visits, measurements were taken from instrumentation, vegetation was inspected, survival of vegetation was determined, and general notes and photographs were taken to maintain an accurate log of events at the site. Figure 7.7 and Figure 7.8 show pictures of the NE and SW slopes during the site selection process, prior to conventional remediation near the bridge abutments.

Severe sliding was observed in areas near the bridge abutment of the SR-36,4 overpass of US-33 where drainage of stormwater runoff from Road U is routed. Due to the severity of sliding and the importance of long term stability, conventional methods were used to remediate the slopes near the bridge structure. Temporary drainage lines were installed prior to construction to mitigate drainage problems as shown in Figure 7.7. The areas immediately adjacent to the conventional construction, opposite the bridge abutment, were used to demonstrate bioengineering stabilization at the Union County site. Along this portion of the site, the development of tension cracks at the top of both slopes indicated early signs of instability in this area; however, there were no further signs if instability (scarps or slophs) along the slopes in the area of the bioengineering. This site has provided excellent data with regard to vegetation survivability and cost comparison between conventional and bioengineering stabilization methods.

7.3.2 Subsurface Investigation

Drilling and sampling were conducted at the Union County site by ODOT drilling crews on September 13 – 15, 2005. Six borings, designated as borings B-1 through B-6, were drilled using a truck mounted drill rig with hollow stem augers to depths ranging from 15 to 36 ft. The locations of the borings are indicated on the site plan shown in Figure 7.9. Standard penetration tests (SPT) were conducted and the retrieved soil samples were visually identified in the field and classified at the ODOT Geotechnical Laboratory. Relatively undisturbed soil samples were obtained using Shelby tubes and preserved with paraffin/petroleum jelly seals. Boring logs from the subsurface investigation program were prepared by ODOT engineers. Log B-6 is provided as an example in Figure 7.10, and the logs for borings B-1 through B-5 are included in Appendix C.

Figure 7.7: Sliding along the NE slope of Union County demonstration site prior to conventional construction.

Figure 7.8: Sliding along the SW slope of Union County demonstration site prior to conventional construction.

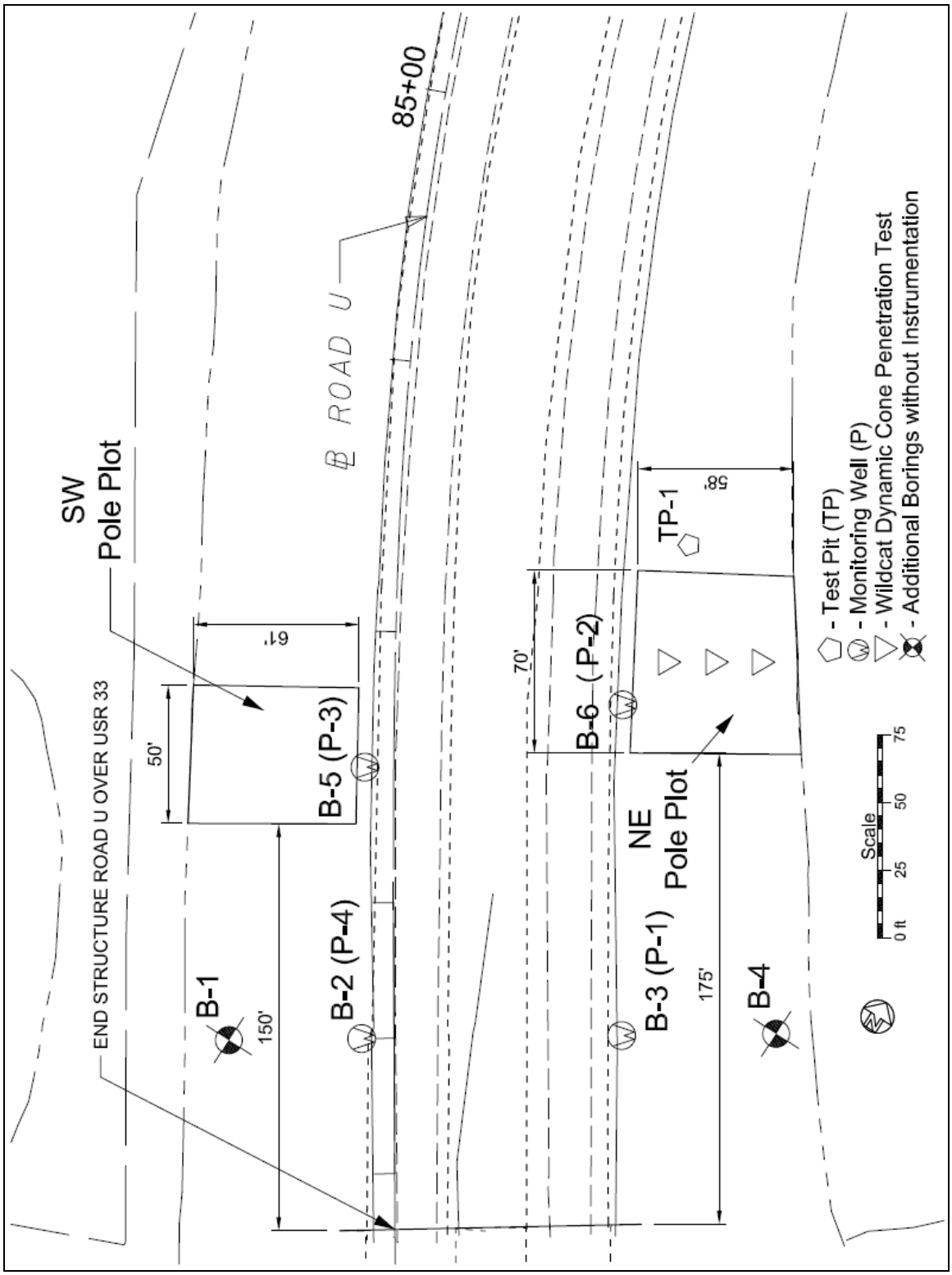


Figure 7.9: Subsurface investigation layout for the Union County demonstration site.

State of Ohio
Department of Transportation
Office of Geotechnical Engineering

6/6

LOG OF BORING

Date Started 9/14/05 Sampler: Type SS Dia. _____ Water Elev. - Project Identification: UNION
Date completed 9/14/05 UNI-33-8.35
Boring No. B-6* Station & Offset 82+75, 84' RT. Surface Elev. 1058.5' RESEARCH PROJECT-SLIP

Elev.	Depth	Std. Pen./ R.Q.D.	Rec. ft	Loss ft	Description	Sample No.	Physical Characteristics % Agg	% C.S.	% F.S.	% Silt	% Clay	L.L.	P.I.	W.C.	ODOT Class
1058.5	0														
1058.0		AUGERED			TOPSOIL	-	-	-	-	-	-	-	-	-	VISUAL
	2														
	4														
1053.5															
	6														
		P.S.			SAMPLE GIVEN TO OSU	31-P	-	-	-	-	-	-	-	-	VISUAL
	8														
1048.5	10														
	12	6/8/11			BROWN SILT AND CLAY (REC. 1.5')	32	0	3	5	41	51	34	15	17	A-6a
	14														
1043.5															
	16														
		P.S.			SAMPLE GIVEN TO OSU	33-P	-	-	-	-	-	-	-	-	VISUAL
	18														
1038.5	20														
	22	6/11/15			BROWN SILTY CLAY W/ORGANIC (REC. 1.5')	34	0	2	5	36	57	39	19	22	A-6b
	24														
1033.5															
	26														
		P.S.			SAMPLE GIVEN TO OSU	35-P	-	-	-	-	-	-	-	-	VISUAL
	28														
1028.5	30														
1027.0		3/7/14			GRAY CLAY W/TRACE OF ORGANIC (REC. 1.5')	36	0	1	4	29	66	51	26	24	A-7-6

P.S. = PRESS SAMPLE

BOTTOM OF BORING

Particle Sizes: Agg= >2.00mm, Coarse Sand= 2.00-0.42mm, Fine Sand= 0.42-0.074mm, Silt= 0.074-0.005mm, Clay= <0.005mm

Form TE-151 Revised 9/95

* NOTE: WATER MONITORING WELL INSTALLED IN THIS HOLE.

Figure 7.10: Boring log B-6 (prepared by ODOT).

The basic stratification for the site is identified on the cross section provided in Figure 7.5. Subsurface soils were visually identified and classified according to the USCS and AASHTO as low plasticity brown silty clay (USCS CL, AASHTO A-6b) to a depth of approximately 30 ft., overlying high plasticity brown/gray clay (USCS CH, AASHTO A-7-6). These classifications were based on visual descriptions and laboratory testing conducted at the ODOT Geotechnical Laboratory and physical characteristics determined by ODOT laboratory technicians. These visual descriptions and test results are provided on the boring logs in Appendix C.

Borings B-1 through B-4 are located outside of the bioengineering areas, within the limits of the conventional construction sections, but are in close proximity to the bioengineering sections and provide additional information, as well as logs of borings which include water monitoring wells. Boring B-1 and B-4 were drilled at the base of the SW and NE slopes, respectively, to a depth of 15 ft. each. Borings B-2 and B-3 were drilled just off the guardrail above the SW and NE slopes, respectively, to a depth of 36 ft. each, and water monitoring wells were installed in each (see Section 7.5.2). The remaining two borings, B-5 and B-6, are within the limits of the bioengineering sections. Borings B-5 and B-6 were drilled just off the guardrail in the shoulder above the SW and NE slopes, respectively, to a depth of 33 ft. each, and water monitoring wells were installed (see Section 7.5.2).

Dynamic cone penetration (DCP) tests were conducted using a Wildcat Dynamic Cone Penetrometer manufactured by Triggs Technologies, Inc. The Wildcat Cone Penetrometer uses a 35 lb. hammer falling 15 in. to drive a 1.0 in. O.D. rod with a 1.4 in. O.D., 1.6 in.^{2} surface area cone. Correlations with SPT results have been conducted by Triggs Technologies and they have a method to convert the number of blows per 10 cm to an equivalent SPT N-value. Thus, the consistency of the subsurface material can be determined continuously from the ground surface to the final termination depth. Figure 7.11 shows the results for one of the DCP tests performed at the site. The reported N' value is the equivalent SPT N-value for each 10 cm (4 in.) interval. Three tests were conducted at the site at ¼ intervals of the slope length. Laboratory testing indicates that the subsurface soils are cohesive. Soil consistency in the upper 1.5 ft. is soft, consistency in the underlying 1.5 to 8.0 ft. is medium stiff to stiff, and consistency of the underlying soil is very stiff to hard. Results from the tests are provided in Appendix C.

SPT results from the borings conducted at the Union County site are tabulated on the boring logs provided in Figure 7.10 and in Appendix C. Borings B-5 and B-6 were conducted within the limits of the bioengineering construction, however, only two SPT tests were conducted in the upper 30 ft. One test was conducted at a depth of 10 ft. in each of the borings. The consistency of the soil, as determined from correlations with the blow count (N-value), ranges from stiff in boring B-5 to very stiff in boring B-6. The consistency of the soil, as determined from the Wildcat test conducted at the top of the NE slope, is stiff, with N' values ranging from 9 to 15 over the 1.5 ft. interval of the SPT test. The consistency of the soil encountered in borings B-2 and B-3 in the upper 4 ft. is medium stiff, consistency in the underlying 6.0 to 8.0 ft. is stiff, and consistency of the underlying soil is very stiff to hard. Thus, the SPT data matches well with data obtained from the Wildcat DCP tests.

WILDCAT DYNAMIC CONE LOG

Page 1 of 2

The Ohio State University
CEEGS
Columbus, Ohio

PROJECT NUMBER: OSURF #: 746483
DATE STARTED: 01-06-2005
DATE COMPLETED: 01-06-2005

HOLE #: sta 82+85, elev 1039
CREW: Kokesh, Trenner
PROJECT: OSU/ODOT Bioengineering
ADDRESS: Union County - 33-8.33
LOCATION: Marysville, Ohio

SURFACE ELEVATION: 1039
WATER ON COMPLETION:
HAMMER WEIGHT: 35 lbs.
CONE AREA: 10 sq. cm

DEPTH	BLOWS PER 10 cm	RESISTANCE Kg/cm²	GRAPH OF CONE RESISTANCE 0 50 100 150	N'	TESTED CONSISTENCY NON-COHESIVE	COHESIVE
-	2	8.9	••	2	VERY LOOSE	SOFT
-	2	8.9	••	2	VERY LOOSE	SOFT
- 1 ft	2	8.9	••	2	VERY LOOSE	SOFT
-	5	22.2	••••••	6	LOOSE	MEDIUM STIFF
-	4	17.8	•••••	5	LOOSE	MEDIUM STIFF
- 2 ft	4	17.8	•••••	5	LOOSE	MEDIUM STIFF
-	6	26.6	•••••••	7	LOOSE	MEDIUM STIFF
-	8	35.5	••••••••••	10	LOOSE	STIFF
- 3 ft	8	35.5	••••••••••	10	LOOSE	STIFF
- 1 m	8	35.5	••••••••••	10	LOOSE	STIFF
-	10	38.6	•••••••••••	11	MEDIUM DENSE	STIFF
- 4 ft	14	54.0	••••••••••••••••	15	MEDIUM DENSE	STIFF
-	14	54.0	••••••••••••••••	15	MEDIUM DENSE	STIFF
-	9	34.7	•••••••••••	9	LOOSE	STIFF
- 5 ft	9	34.7	•••••••••••	9	LOOSE	STIFF
-	6	23.2	••••••	6	LOOSE	MEDIUM STIFF
-	6	23.2	••••••	6	LOOSE	MEDIUM STIFF
- 6 ft	8	30.9	••••••••	8	LOOSE	MEDIUM STIFF
-	7	27.0	•••••••	7	LOOSE	MEDIUM STIFF
- 2 m	8	30.9	••••••••	8	LOOSE	MEDIUM STIFF
- 7 ft	8	27.4	•••••••	7	LOOSE	MEDIUM STIFF
-	8	27.4	•••••••	7	LOOSE	MEDIUM STIFF
-	9	30.8	••••••••	8	LOOSE	MEDIUM STIFF
- 8 ft	12	41.0	•••••••••••	11	MEDIUM DENSE	STIFF
-	20	68.4	••••••••••••••••••••	19	MEDIUM DENSE	VERY STIFF
-	25	85.5	••••••••••••••••••••••••••	24	MEDIUM DENSE	VERY STIFF
- 9 ft	28	95.8	••••••••••••••••••••••••••••••	25+	MEDIUM DENSE	VERY STIFF
-	32	109.4	••••••••••••••••••••••••••••••••••••	25+	DENSE	HARD
-	26	88.9	••••••••••••••••••••••••••••	25	MEDIUM DENSE	VERY STIFF
- 3 m 10 ft	26	88.9	••••••••••••••••••••••••••••	25	MEDIUM DENSE	VERY STIFF
-	25	76.5	••••••••••••••••••••••••	21	MEDIUM DENSE	VERY STIFF
-	25	76.5	••••••••••••••••••••••••	21	MEDIUM DENSE	VERY STIFF
-	22	67.3	••••••••••••••••••••••	19	MEDIUM DENSE	VERY STIFF
- 11 ft	22	67.3	••••••••••••••••••••••	19	MEDIUM DENSE	VERY STIFF
-	23	70.4	•••••••••••••••••••••••	20	MEDIUM DENSE	VERY STIFF
-	25	76.5	••••••••••••••••••••••••	21	MEDIUM DENSE	VERY STIFF
- 12 ft	23	70.4	•••••••••••••••••••••••	20	MEDIUM DENSE	VERY STIFF
-	24	73.4	••••••••••••••••••••••••	20	MEDIUM DENSE	VERY STIFF
-	24	73.4	••••••••••••••••••••••••	20	MEDIUM DENSE	VERY STIFF
- 4 m 13 ft	25	76.5	••••••••••••••••••••••••	21	MEDIUM DENSE	VERY STIFF

Marysville - Lower Hole - Wildcat Data

Figure 7.11: Sample log of Wildcat Dynamic Cone Penetration test for the Union County demonstration site.

Additional exploration was conducted by OSU personnel using hand tools to excavate a shallow test pit, designated as TP-1, in the NE slope to a depth of approximately 2.5 ft. The location of this test pit is shown on Figure 7.9. Soil obtained from this test pit was used for laboratory testing and soil nutrient testing.

7.4 LABORATORY TESTING

7.4.1 Physical Properties

Laboratory testing was conducted on field soil samples personnel at the OSU and ODOT laboratories. Complete test reports including data and charts are provided in Appendix C. Soil classification, Atterberg limits, sieve analysis and water contents were conducted by ODOT technicians at the ODOT Geotechnical Laboratory on samples obtained during drilling. The results are tabulated on the boring logs included in Figure 7.10 and Appendix C. The material at the unstable depths has been classified as silt and clay, silty clay, and clay (AASHTO A-6a, A-6b, and A-7-6).

Soil-moisture characteristic testing was conducted by Dr. R. Lal and graduate research assistants from the Agronomy school at Ohio State University. Sample preparation and testing was done in accordance with ASTM C1699. The resulting soil-moisture retention characteristic curve is shown in Figure 7.12. This curve will be used to understand how vegetation is affecting moisture conditions within the slope and to help verify that field instrument measurements are reliable.

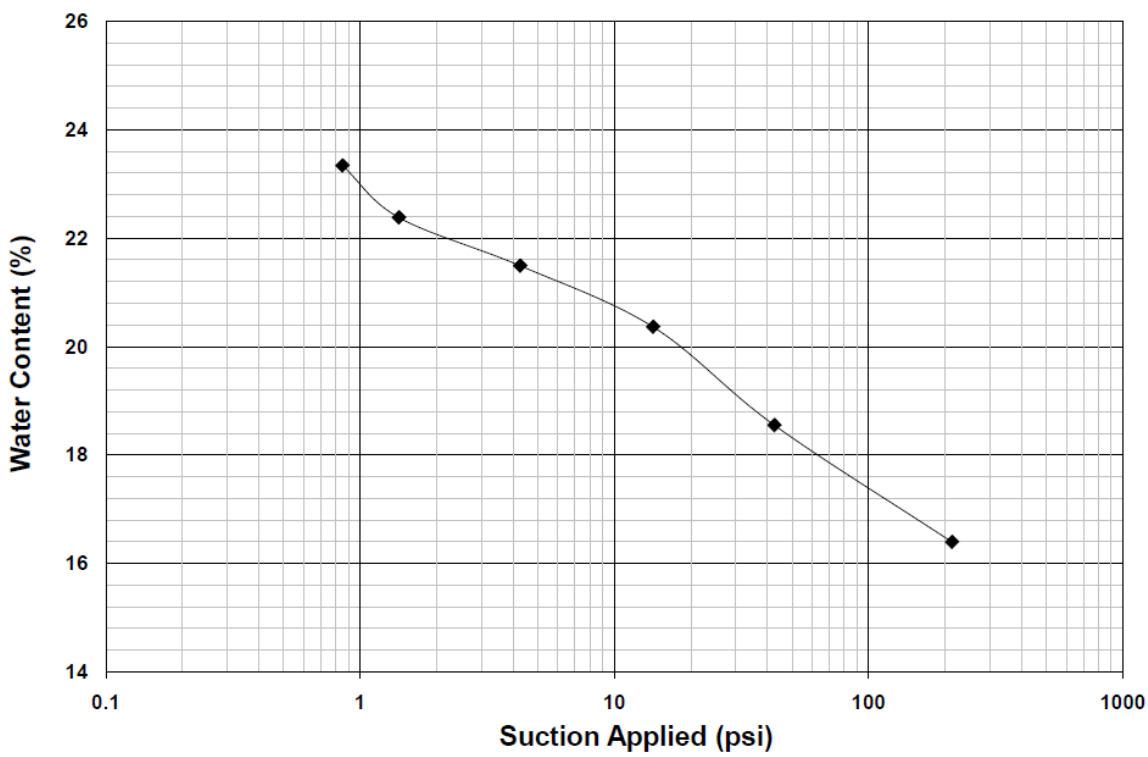


Figure 7.12: Soil-moisture retention characteristic curve for Logan County brown till and gray clay (testing by Dr. R. Lal).

7.4.2 Chemical Properties

Soil nutrient testing was conducted by Calmar, Inc. of Westerville, Ohio. The sample, submitted in September of 2007, was obtained from TP-1 at a depth of approximately 2 – 3 ft. Results and recommendations from the soil nutrient test are summarized in Table 7.1 and Table 7.2. The report indicates that soil pH is very high, and that sulfur or other acidifying products should be added to lower the pH. The report also indicates that the phosphorus, potassium, magnesium, and organic matter levels are lower than optimum for growth of hardwood trees. It was noted that the low organic matter level and high pH value will adversely affect plant growth. Recommendations for adding phosphorus, potassium, nitrogen, and sulfur to the soil to achieve optimum levels for growing hardwood trees was also included in the report. The complete report and recommendations are included in Appendix C.

Table 7.1: Soil nutrient test results for the Union County Demonstration site (provided by Calmar, Inc.).

	pH	Organic Matter (%)	Phosphorus (lb/acre)	Potassium (lb/acre)	Magnesium (lb/acre)	Calcium (lb/acre)
Test Results	8.1	1.7	6	242	568	9204

Table 7.2: Recommendations for soil nutrient improvements provided by Calmar, Inc.

	Nitrogen [1] (lb/acre)	Phosphorus (lb/acre)	Potassium (lb/acre)
Recommendations for Addition to Soil	120	150	200

[1] Addition of nitrogen is recommended to bring organic matter to optimal growing conditions.

7.5 INSTRUMENTATION

Instrumentation and site monitoring was a priority issue for this project as it provides the only basis for determining the feasibility and success of biostabilization. Figure 7.13 shows a plan view of the site instrumentation. Groundwater and moisture data was collected using tensiometers and monitoring wells. Slope movement data was obtained from shallow inclinometers. The following sections provide specific details pertaining to the site instrumentation. Complete records for all collected data are provided in Appendix C.

7.5.1 Tensiometers

Prior and subsequent to construction, 16 tensiometers were installed throughout the site; eight each at 24 in. and 36 in. depths. Locations of each station are shown in Figure 7.13 and data is presented in Section 7.7.1. All measurements were corrected for elevation of the water column in the tensiometer (see Section 4.4.1).

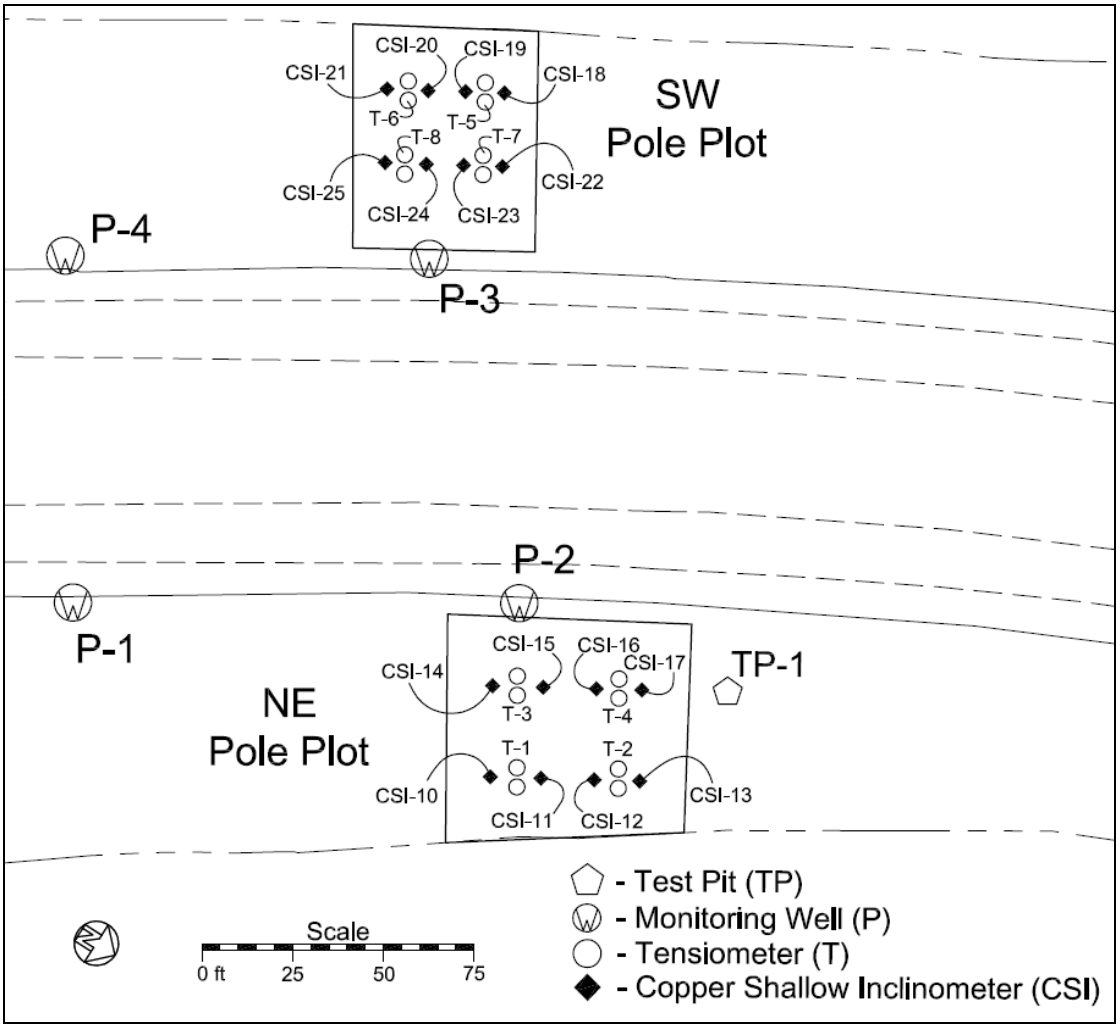


Figure 7.13: Instrumentation layout for the Union County demonstration site.

7.5.2 Monitoring Wells

Monitoring wells were installed throughout the site prior to the start of conventional construction to measure groundwater conditions. Two deep monitoring wells, designated P-1 and P-4, were installed within the limits of the conventional construction areas just off the guardrail above the NE and SW slopes. Each had a depth of 36 ft. and 1 ft. of screening. The remaining two deep monitoring wells, designated P-2 and P-3, were installed within the limits of the bioengineering construction areas in the

shoulder of the interchange ramps above the NE and SW slopes. These had a depth of 33 ft. each with 1 ft. of screening.

7.5.3 Shallow Inclinometers

Shallow slope displacements were measured for both pre-construction and post-construction conditions using copper shallow inclinometers (CSIs). Four CSI's, designated CSI-1 through CSI-4, were installed in the NE slope during April 2006. Sixteen additional CSI's, designated CSI-10 through CSI-25, were installed in April 2007 to assess post-construction movements. The location of each CSI installed after construction is shown on Figure 7.13.

7.6 CONSTRUCTION

Two methods of construction were used at the Union County demonstration site. Conventional remediation methods were utilized in areas adjacent to the bridge abutment where sliding was severe. These methods included slope benching and flattening in conjunction with new drainage installation. Biostabilization techniques (live poles) were utilized in the areas adjacent to conventional construction. These remediation methods are discussed in detail in the following sections.

7.6.1 Conventional Construction

Conventional construction at the Union County demonstration site started in July 2006 and was completed in December 2006. The scope of the project included the US-33/SR-36,4 interchange and also an approximately ¼ mile stretch of US-33 just after the US-36 (eastbound) overpass. This report focuses on construction at the US-33/SR-36,4 interchange. Figure 7.14 and Figure 7.15 show a plan view and cross section of the conventional construction area. The limits of construction considered for this investigation are along Ramp U from Sta. 80+77 (at the bridge abutment) to Sta. 82+28 Lt. and 82+57 Rt. for the SW and NE slopes, respectively.

Severe sliding occurred near the top of the NE and SW slopes in areas immediately adjacent to the bridge abutment of the US-33 overpass and was sufficiently extensive to threaten the stability of the roadway above. ODOT investigations determined that faulty drainage of stormwater runoff from the overpass and roadway during periods of heavy rain most likely triggered these slides. Due to the immediate threat to the supported roadway, ODOT utilized conventional construction methods, rather than experimental bioengineering methods, to mitigate the drainage and stability issues in this area. The conventional methods included: excavation of the upper portion of the existing slopes so that a series of benches could be constructed; removal of existing drains and installation of new drains in the sub-base of the interchange along with a new drainage channel to route stormwater runoff from the roadway down to a rock channel at the base of the embankment; and reconstruction of the embankment to a 2.5H:1V slope. The newly flattened slopes on both sides of the embankment were tapered to meet the existing 2H:1V slopes at the intersection with the bioengineering sections.

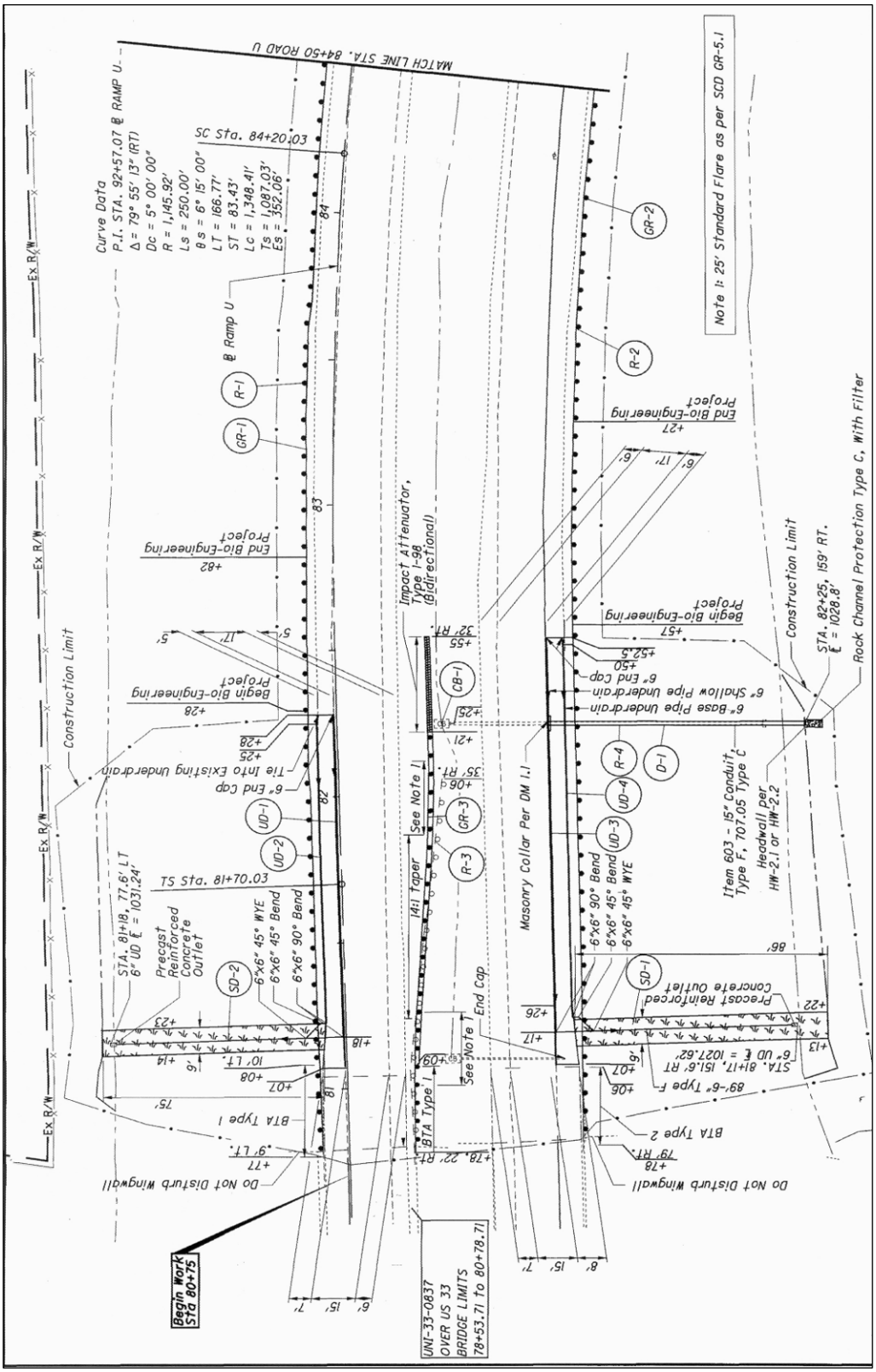


Figure 7.14: Plan view for conventional construction of US-33/SR-36,4 interchange (UNI-33-(8.36)(12.13), 2006, ODOT).

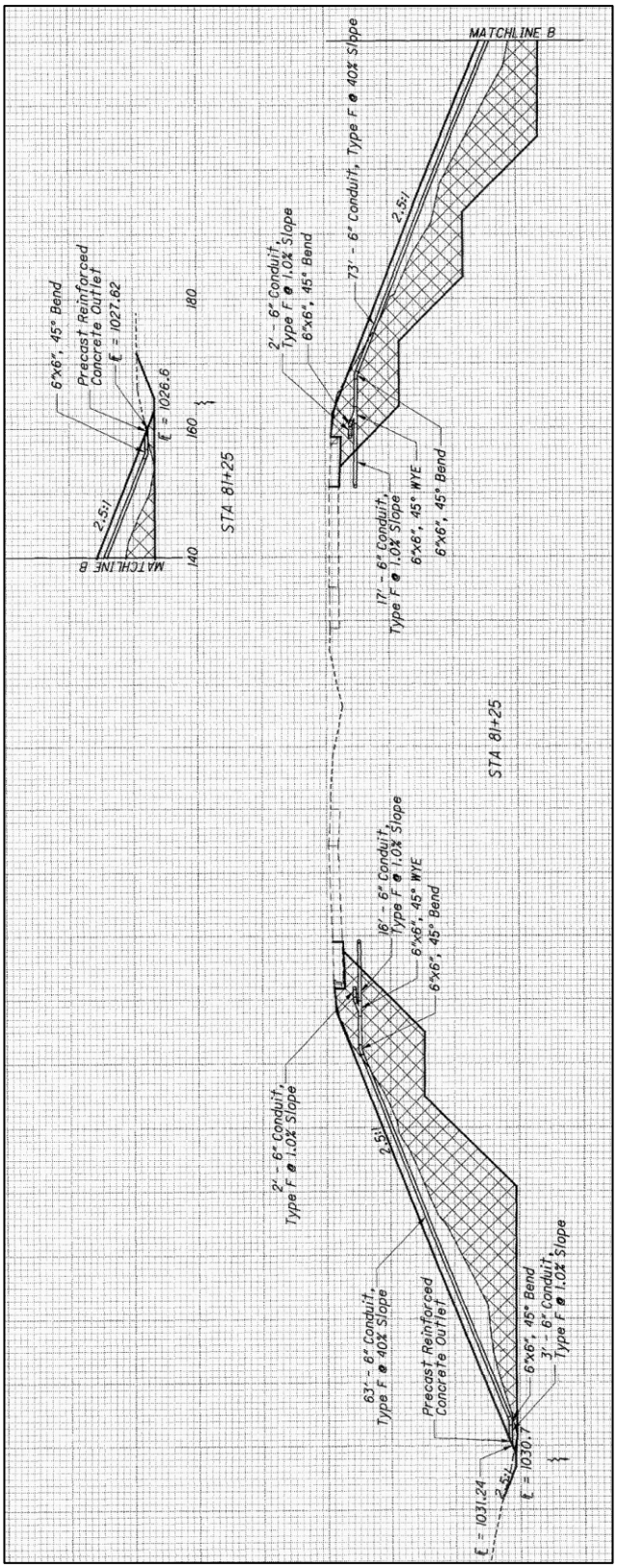


Figure 7.15: Cross section of Sta. 81+25 of the US-33/SR-36,4 interchange (UNI-33-(8.36)(12.13), 2006, ODOT).

7.6.2 Bioengineering Construction

The following section describes the details of the bioengineering construction completed at Union County. All vegetation consisted of live poles and was harvested from the Delaware Wildlife Area in Delaware County, Ohio, during March 2007. To prevent drying and desiccation during transportation and installation, the poles were stored in cattle troughs under water and tarps. Over 90% of the species installed have been visually identified as willows. Therefore, survival rates of willows and non-willows will not be provided separately.

Construction limits were determined by ODOT personnel and ranged from Sta. 82+57 to Sta. 83+27 for the NE slope, and from Sta. 82+28 to Sta. 82+82 for the SW slope. The NE pole plot measured 70×57 ft., while the SW pole plot measured 51×48 ft. The minimal method of installation, as described in Section 6.6.2.2, was used for the entire installation at this site. Figure 7.16 illustrates a typical installation cross section with details pertaining to backfill and installation technique.

Construction at the Union County demonstration site began on March 12, 2007, and was completed on March 16, 2007. Prior to installation, the slope face of this area was not re-graded. Re-grading was determined to be unnecessary due to minimal erosion on the slope face and a healthy stand of grass. A total of 429 live poles were installed in a 3 ft. square grid pattern throughout the NE slope, and a total of 272 live poles were installed in a 3 ft. square grid pattern throughout the SW slope. Overall, a total of 701 live poles were installed at the Union County demonstration site. Poles were approximately 6 to 7 ft. in length and had diameters ranging from 1 to 2 in. The general preparation and installation procedure using the minimal method is presented in Section 6.6.2.2. Visual logs were kept for the entire installation from harvesting to completion. Figure 7.17 shows a newly installed pole with the beginning stage of growth and an established willow. Figure 7.18 and Figure 7.19 show the NE and SW live pole plots, respectively, at the completion of the installation.

7.7 PERFORMANCE

This section presents performance data pertaining to the installation completed during late winter 2007 at the Union County demonstration site. Biostabilization performance is based primarily on vegetation survival and slope deformation that has occurred subsequent to installation. Moisture conditions within the stabilized portion of the slope were closely monitored as that is one of the factors that influences survival. Climate was also monitored as that has a large impact on moisture conditions within the slope. Additionally, a detailed cost analysis is presented for comparison of the conventional and bioengineering remediation methods.

7.7.1 Moisture and Climate Conditions

Groundwater and moisture conditions within the slope have been monitored throughout the project (June 2006 through October 2008). Figure 7.20 and Figure 7.21 provide the soil suctions measured by tensiometers over this period. Soil suctions in the

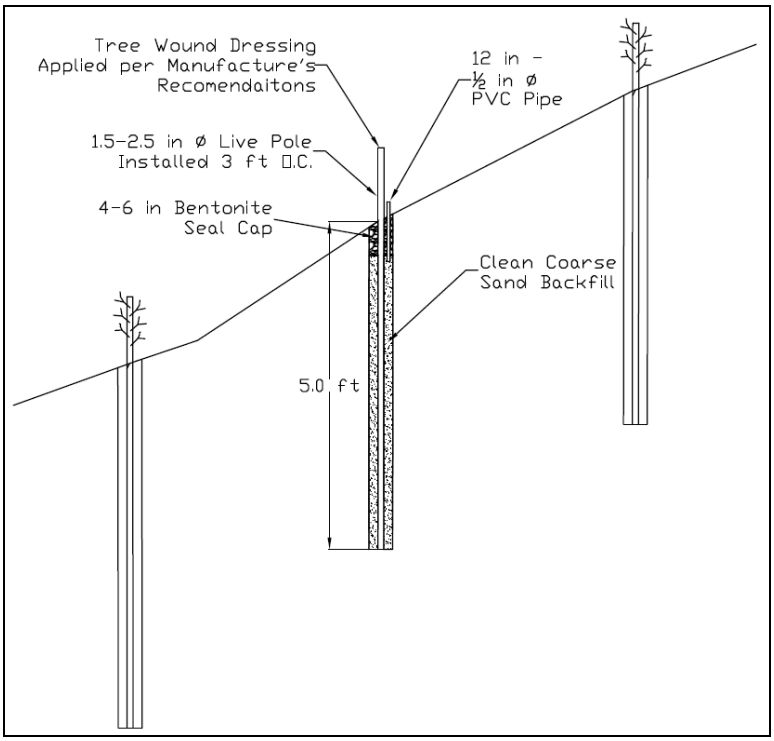


Figure 7.16: Typical live pole installation using the minimal method at the Union County demonstration site.

Figure 7.17: The left picture was taken on April 18, 2007, of a willow post in the NE live pole plot that has started budding. The right picture was taken on May 30, 2007, of an established willow in the NE live pole plot.

Figure 7.18: NE slope after construction (photo taken March 20, 2007).

Figure 7.19: SW slope after construction (photo taken March 20, 2007).

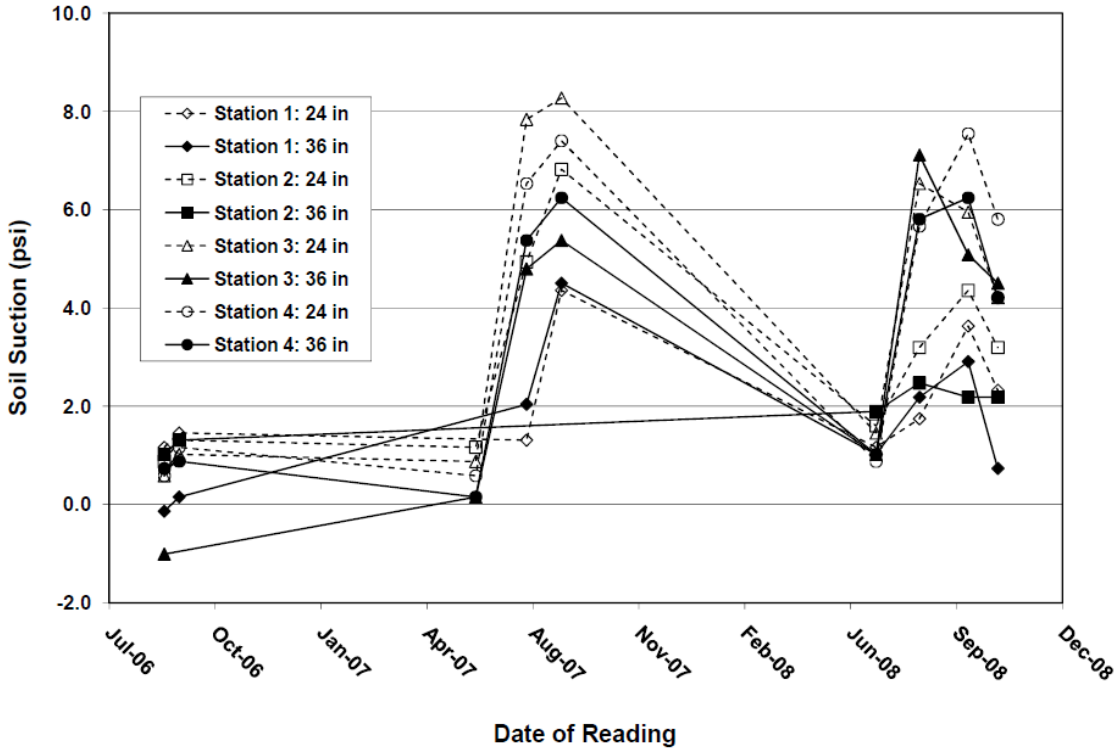


Figure 7.20: Soil suctions measured in the NE slope from July 2006 through October 2008.

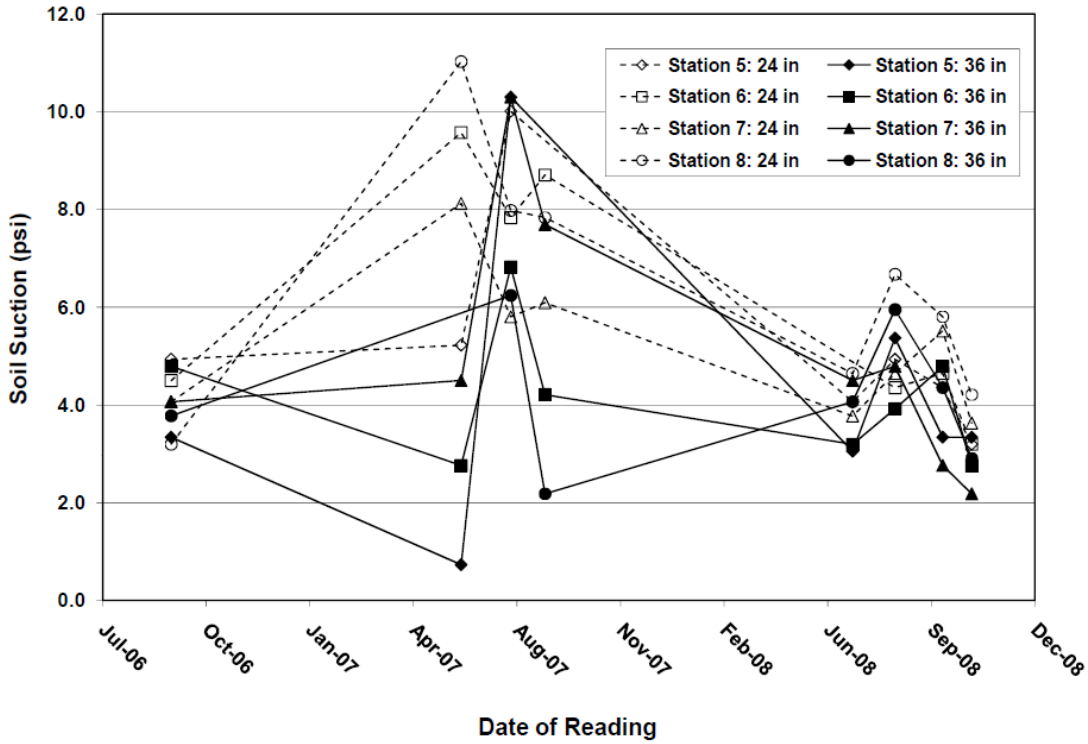


Figure 7.21: Soil suctions measured in the SW slope from July 2006 through October 2008.

upper 3 ft. of the slope range from -1.0 to 8.3 psi for the NE slope, and -1.3 to 11.0 psi for the SW slope. Readings obtained during 2006 (prior to construction) indicate that suctions were generally higher for the SW slope (between 3.0 and 5.0 psi) than those recorded for the NE slope (less than 2.0 psi). There is a large scatter in the data during 2007, after the completion of the bioengineering installation. The SW slope had suctions that were generally higher than those recorded in 2006. Scatter of data from the NE slope was significantly less, with suctions ranging from 0.15 to 8.3 psi and generally above 4.0 psi.

Throughout 2008, soil suctions within the NE slope remained higher at the bottom of the slope (generally above 4.0 psi), and suctions at the top of the slope were lower than those recorded in 2007 (generally less than 4.0 psi). This could be attributed to the dense growth of vegetation at the bottom of the slope. Vegetation survival in this area is nearly 100 % and the poles have grown to heights above 6 ft. While vegetation survival at the top of the slope is above 50%, the poles themselves are not nearly as large as at the bottom of the slope. This suggests that the larger poles are removing higher amounts of water from the slopes. Suctions within the SW slope dropped significantly in 2008, approximately back to within the range recorded during 2006. Low vegetation survival after 2007 within this plot is the most likely explanation for the lower soil suctions during 2008. The plots also generally indicate that soil suctions are higher near the surface (24 in.) than at depth (36 in.) during the growing seasons for both 2007 and 2008.

Piezometric levels for monitoring wells P-1 through P-4 are shown in Figure 7.22. Piezometric levels have remained relatively constant over the monitoring period from August 2006 through October 2008 and ranged from 27.7 to 31.5 ft. below grade. This suggests that the embankment slope failures were likely due to surface runoff as previously discussed.

7.7.2 Survival Rates and Statistics

An inventory of all live poles was conducted during the late spring/early summer and late fall seasons in order to assess survival rates over time. Table 7.3 and Figure 7.23 present a summary of survival rates for NE and SW pole plots as well as the overall vegetation survival rate at the Union County site. A graphical log of each vegetation inventory is presented in Appendix C.

Table 7.3 and Figure 7.23 indicate that initial survival rates for both the NE and SW pole plots was high (over 90%). However, while the survival rate for the NE slope remained relatively high throughout 2007, the survival rate of the SW slope declined to less than 50%. This difference was likely due to the amount of sunlight and differences in moisture conditions within the slopes.

Precipitation for May through July 2007 was well below normal and temperatures were slightly above average. The NE slope receives direct sunlight from morning through early afternoon, while the SW slope receives direct sunlight from mid-afternoon through the evening. Figure 7.24 and Figure 7.25 show soil suctions measured for all stations at 24 in. and 36 in. depths, respectively. At the 24 in. depth, suctions in the SW slope in 2007 were considerably higher at the bottom of the slope than those recorded at the bottom of the NE slope. This is the region on the SW slope where low survival was

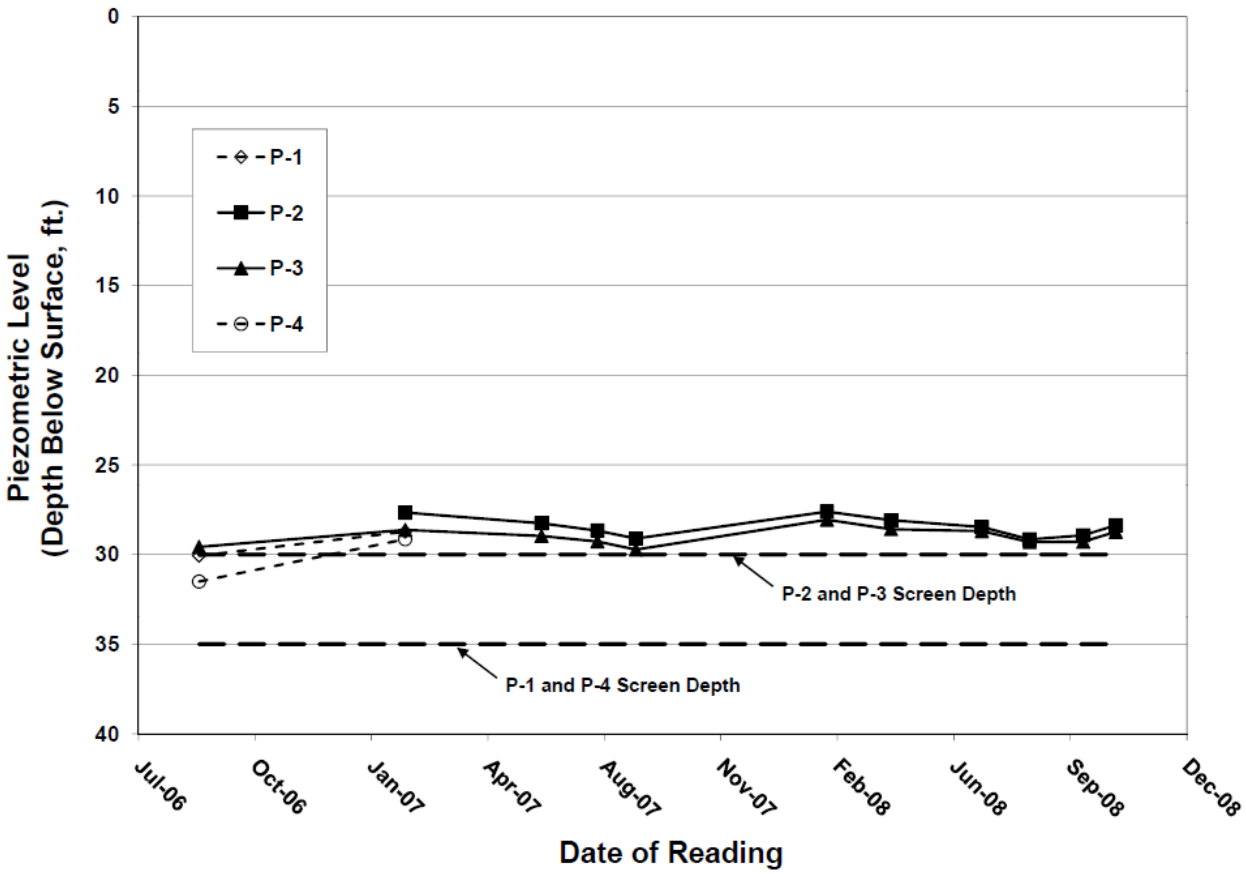


Figure 7.22: Piezometer data for the Union County demonstration site.

Table 7.3: Summary of survival rates for the NE and SW live pole plots at the Union County demonstration site.

Date	NE Slope Survival Rate (%)	SW Slope Survival Rate (%)	Overall Survival Rate (%)
12-Jun-07	90.9	94.5	92.3
31-Jul-07	83.4	60.3	74.5
20-Sep-07	79.5	46.2	66.9
12-Jun-08	74.4	39.6	61.2
20-Sep-08	73.4	33.8	58.5
15-Jun-09	72.1	27.3	54.6

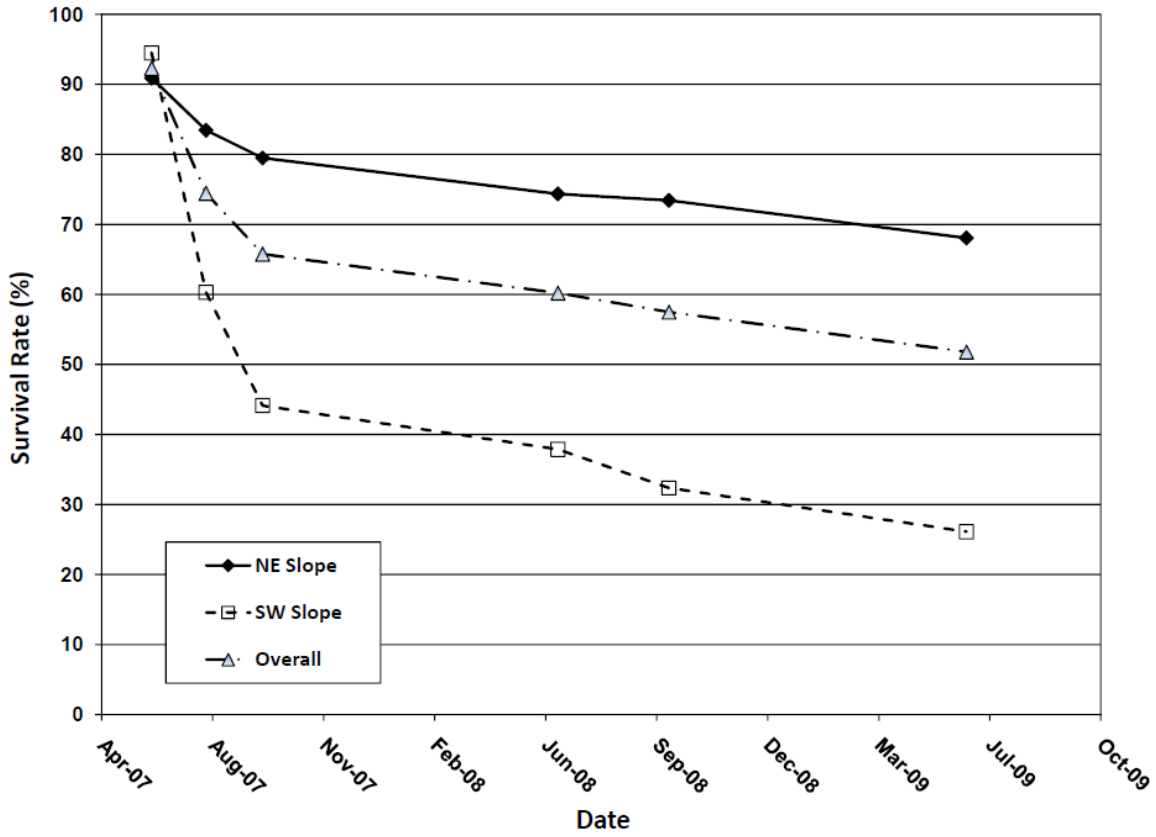


Figure 7.23: Vegetation survival rates for the Union County demonstration site.

initially recorded. At the 36 in. depth, suctions were slightly higher on the SW slope than on the NE slope. This suggests that the intense heat of late afternoon summer days and direct sunlight along with additional depletion of water from the slope by vegetation may have dried out the SW slope more than the NE slope and stressed the vegetation. This trend is not evident in the data collected during 2008; but, at this time more than half of the vegetation in the SW slope had died, and the suctions recorded in the SW slope were within the range originally observed prior to installation. The data in Figure 7.24 and Figure 7.25 clearly indicate that the SW slope was drier than the NE slope during the critical early growing season of spring and summer 2007.

Figure 7.26 through Figure 7.29 show graphical representations of vegetation survival during the first growing season in 2007. The NE slope initially had high survival, with small areas of dead poles throughout the plot and a concentration of dead poles at the top of the slope. Competing growth and lack of water are the most likely sources for the small concentration of dead poles at the top of the NE slope. On the SW slope, however, initial survival was high, but fell to below 50% by the end of the first growing season (2007). In addition, Figure 7.28 and Figure 7.29 show localized areas of low and high survival for the SW slope. Between the lower and middle thirds of the slope, there is a band of dead poles that extends the width of the plot and vertically across about six rows. Survival below and above this area is significantly higher. During the original construction of the embankment, this area of the embankment may have received different fill material with different pH and/or nutrients than the rest of the slope.

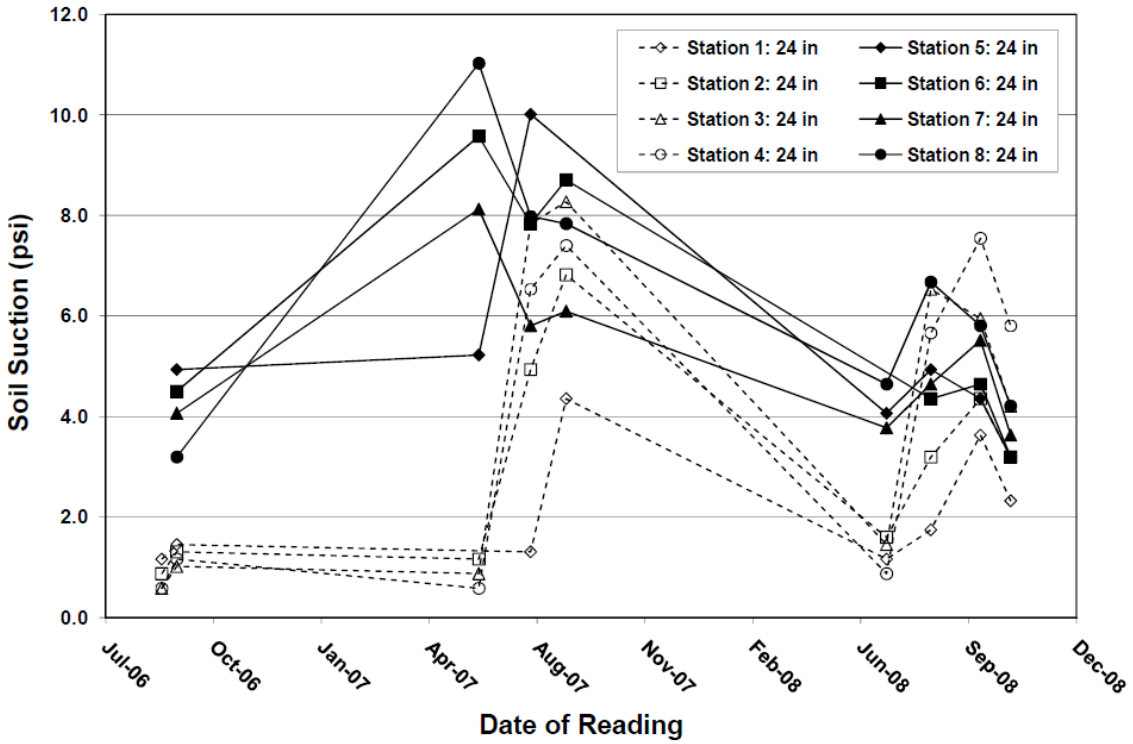


Figure 7.24: Soil suctions measured in the 24 in. depth tensiometers for the NE and SW slopes.

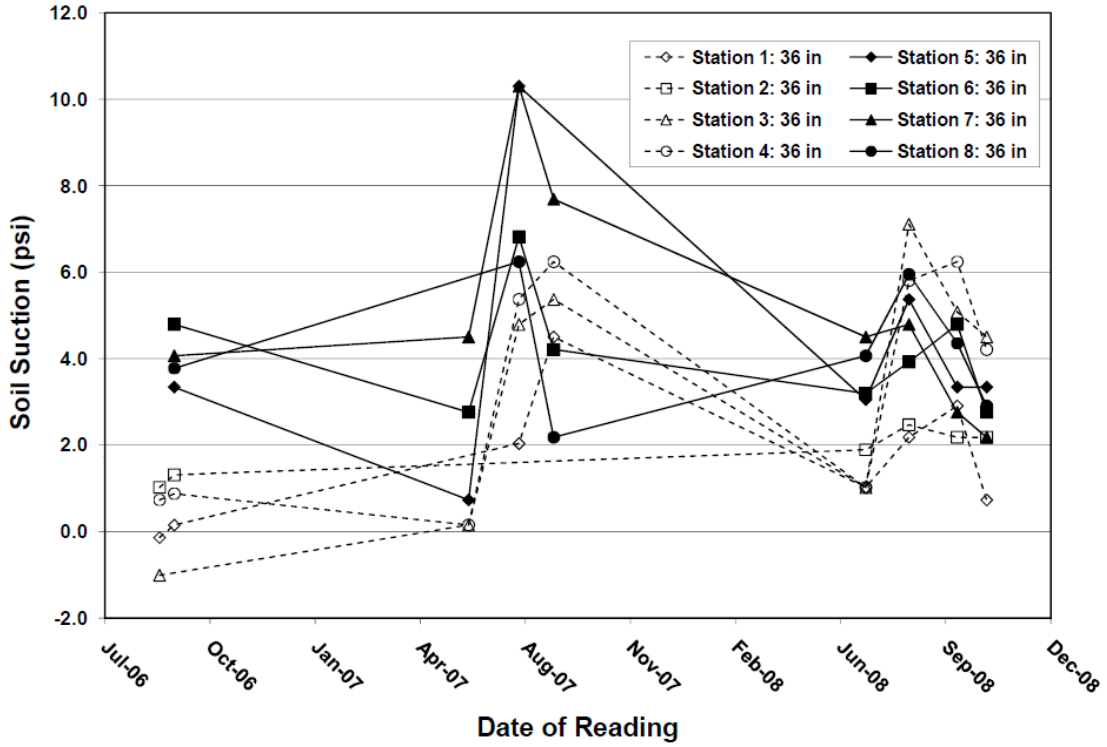


Figure 7.25: Soil suctions measured in the 36 in. depth tensiometers for the NE and SW slopes.

Survival Statistics June 12, 2007

SW Slope
Overall Survival: 94.5%

	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Bottom
2	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	1	
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
5	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	2	
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
7	1	1	1	1	1	2	2	1	1	1	1	1	1	1	1	1	3	
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
10	1	1	1	3	1	1	1	1	1	1	1	1	1	3	1	1	1	
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
12	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
14	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	
15	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	
16	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	Top

1	Willow survived
2	Willow sprouted, then died
3	Willow died

US-33/SR-36,4 Interchange

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
20	1	1	1	2	1	2	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	2	Top
19	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2	1	1	1	1	3	3	
18	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
17	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	
16	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	
15	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	
13	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	3	1	1	1	1	1	1	1	1	
12	1	1	1	1	1	1	1	1	3	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	1	
10	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	3	1	1	3	3	3	
9	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	1	1	3	1	1	1	3	1	
8	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	
7	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	
6	1	1	1	1	1	1	1	1	1	3	1	3	1	1	1	1	1	1							
5	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1								
4	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1									
3	1	1	1	1	1	1	1	1	1	1	1	3	1	3	1										
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1											
1	1	1	1	1	1	1	1	1	1	1	1	1	1												Bottom

NE Slope
Overall Survival: 90.9%

Figure 7.26: Graphical representation of survival of the NE and SW live pole plots at the Union County demonstration site as of June 12, 2007.

Survival Statistics July 31, 2007

SW Slope
Overall Survival: 60.3%

	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Bottom
2	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	2	
3	1	2	1	2	2	2	2	2	1	2	2	1	2	2	3	3	2	
4	2	2	2	2	1	1	1	2	1	1	1	2	1	1	1	2	2	
5	2	1	1	2	3	1	2	2	1	1	2	1	2	1	1	2	2	
6	2	2	2	2	1	2	2	2	1	2	2	1	2	2	2	2	1	
7	2	2	1	2	2	2	2	2	2	2	1	2	2	2	2	2	3	
8	1	1	1	2	1	1	1	1	1	1	1	1	1	2	2	2	2	
9	1	1	1	2	2	1	1	1	1	1	2	1	1	1	1	2	2	
10	1	1	1	3	1	1	1	1	1	2	1	1	1	3	2	2	2	
11	1	2	1	1	2	1	1	1	1	1	1	1	1	1	1	1	2	
12	1	2	1	1	2	1	1	2	1	1	1	2	1	2	1	1	1	
13	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	
14	1	1	1	1	1	1	1	3	2	2	1	1	1	1	1	1	2	
15	1	1	2	2	1	1	3	2	1	1	2	1	1	1	2	1	1	
16	1	1	2	2	2	2	1	2	2	3	1	2	2	2	2	2	2	Top

1	Willow survived
2	Willow sprouted, then died
3	Willow died

US-33/SR-36,4 Interchange

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
20	1	2	2	2	2	2	2	1	2	2	1	1	1	2	1	2	2	2	2	2	2	2	1	2	Top
19	1	1	2	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2	1	1	1	1	3	3	
18	1	1	1	1	1	1	1	1	2	3	1	1	1	1	1	2	1	1	1	1	1	1	1	1	
17	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	3	1	1	1	1	
16	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	
15	1	1	1	1	1	1	1	2	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
14	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	3	1	
13	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	3	1	1	1	1	1	1	1	1	
12	1	1	1	1	1	1	1	1	3	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	
11	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	1	
10	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	2	2	1	3	1	1	3	3	3	
9	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	1	1	3	2	1	1	3	1	
8	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	3	2	2	1	2	2	1	
7	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	
6	1	1	1	1	1	1	1	1	1	3	1	3	1	1	1	1	1	1							
5	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1								
4	1	1	1	1	1	1	3	1	1	2	2	1	1	1	1	1									
3	1	1	1	1	1	1	2	1	1	1	1	3	1	3	1										
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1											
1	1	1	1	1	1	2	2	1	1	1	1	1	1												Bottom

NE Slope
Overall Survival: 83.4%

Figure 7.27: Graphical representation of survival of the NE and SW live pole plots at the Union County demonstration site as of July 31, 2007.

Survival Statistics September 20, 2007

SW Slope
Overall Survival: 46.2%

	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Bottom
2	1	1	1	1	1	2	1	3	1	1	1	1	1	1	2	2	2	
3	1	2	1	2	2	2	2	2	1	2	2	1	2	2	3	3	2	
4	2	2	2	2	2	1	2	2	1	1	2	2	1	2	2	2	2	
5	2	2	1	2	3	1	2	2	1	1	2	1	2	2	2	2	2	
6	2	2	2	2	1	2	2	2	1	2	2	2	2	2	2	2	2	
7	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	
8	2	1	2	2	2	1	2	1	1	1	1	1	1	2	2	2	2	
9	2	1	2	2	2	2	2	1	2	1	2	1	1	1	1	2	2	
10	1	1	1	3	1	1	1	1	2	2	1	2	1	3	2	2	2	
11	2	2	1	2	2	1	1	1	2	1	1	1	1	2	2	2	2	
12	1	2	1	1	2	1	1	2	1	1	1	2	2	2	1	2	1	
13	1	1	1	1	1	2	2	1	1	1	1	2	1	2	1	1	2	
14	1	1	1	1	1	1	1	1	2	2	2	2	1	1	1	2	2	
15	1	1	2	2	1	1	1	2	2	1	2	1	1	2	2	1	1	
16	2	1	2	2	2	X	X	X	X	X	X	X	X	X	X	X	X	Top

1	Willow survived
2	Willow sprouted, then died
3	Willow died
X	Willow destroyed from mowing

US-33/SR-36,4 Interchange

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
20	2	2	2	2	2	2	2	1	2	2	2	1	1	2	2	2	2	2	2	2	2	2	1	2	Top
19	1	1	2	1	1	1	1	1	2	2	1	1	1	1	1	1	1	2	1	1	2	1	3	3	
18	1	1	1	1	1	1	1	1	2	3	1	1	1	1	2	2	1	1	1	1	1	1	2	1	
17	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	3	1	1	1	1	
16	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	2	1	1	3	3	
15	1	1	2	1	1	1	1	2	3	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	
14	1	1	2	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	3	1	
13	1	2	1	1	1	1	1	1	1	2	2	2	1	1	1	3	1	1	1	1	2	1	1	1	
12	1	1	1	1	1	1	1	1	3	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	
11	1	1	2	1	1	1	1	2	1	1	1	1	1	1	2	1	1	1	1	1	1	3	3	1	
10	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	2	2	1	3	1	1	3	3	3	
9	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	1	1	3	2	1	1	3	1	
8	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	3	2	2	1	2	2	1	
7	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	
6	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1							
5	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1								
4	1	1	1	1	1	1	3	1	1	2	2	1	1	1	1	1									
3	1	1	1	1	1	1	2	1	1	1	1	3	1	3	1										
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1											
1	1	1	1	1	1	2	2	1	1	1	1	1	1												Bottom

NE Slope
Overall Survival: 79.5%

Figure 7.28: Graphical representation of survival of the NE and SW live pole plots at the Union County demonstration site as of September 20, 2007.

Currently, overall survival at the Union County site is 55% (Figure 7.29). Survival has remained relatively constant on the NE slope at 72%, as recorded in June 2009. Vegetation at the bottom of the NE slope is well established as shown in Figure 7.30, with dense growth and most poles having multiple branches a height of 6 ft. or more. There are several isolated areas at the top of the NE slope where poles have died out. Lower survival at the top of the slope is most likely due to differences in soil moisture available within the top and bottom portions of the slope. Survival fell on the SW slope to 27%, as recorded in June 2009. Survival throughout the SW slope is sparse, with the exception of the first two rows near the bottom, which accounts for nearly half of the poles that have survived. Soil moisture conditions are wetter at the base of the slope due to the adjacent drainage ditch. The remainder of the living poles consists of small isolated groups concentrated near the top at the eastern half of the plot. It is suspected that the small regions of growth at the top of the slope are within areas where the soil chemistry is more favorable than the surrounding areas. This area also receives more runoff from the pavement above.

7.7.3 Displacements

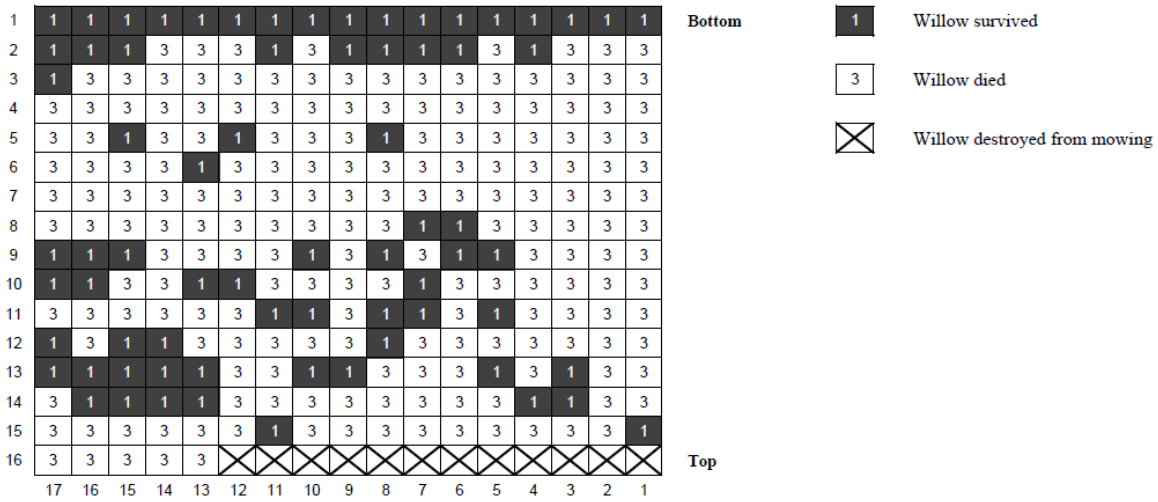
Prior to installation of live poles, in December 2006, CSI-2 and CSI-4 were exhumed from the NE slope. Visual inspection of the CSI's indicated that slope movements for the 9-month period between April 2006 and December 2006 were less than 0.25 in. and were considered negligible as those movements may have occurred during the exhumation and transportation of the rods. Subsequent to construction, slope movements at the site have also been negligible. The slopes have been closely inspected during site visits since construction and no slope movements, scarps or bulges, have been identified within the NE or SW pole plots. Surface cracks have been noted throughout both the NE and SW plots, however, closer inspection of the cracks indicate that they only a few inches in depth and that they are most likely due to soil desiccation.

7.7.4 COST ANALYSIS

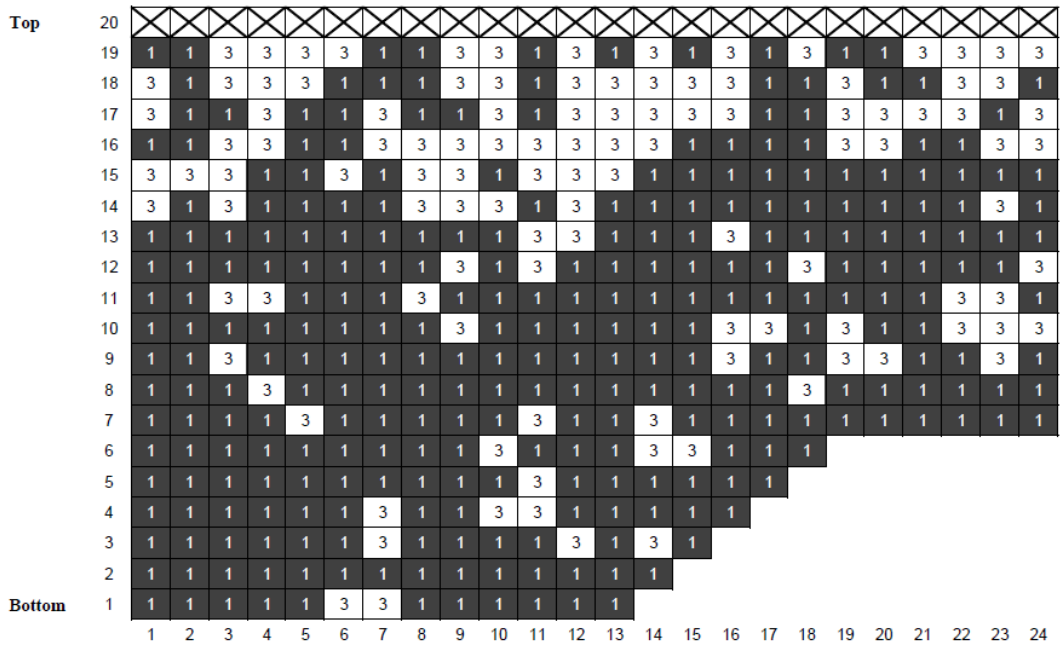
One of the key issues that the research team is evaluating is the cost and benefits for bioengineering remediation as compared to conventional remediation techniques. The Union County demonstration site was selected for this specific reason. By using the minimal installation method to maximize production, an accurate analysis of the economic benefits from using bioengineering methods over conventional methods can be evaluated. The total cost of conventional construction for the areas immediately adjacent to the bioengineering sections was $241,500. This value was calculated using an itemized list of costs provided by ODOT and is available in Appendix C. The total cost of bioengineering construction was $61,000. This value was also calculated using an itemized list of costs from documents provided by ODOT and is available in Appendix C. Table 7.4 summarizes total cost, cost per unit area, and cost per linear foot as well as the duration of construction for both methods. Using the calculated costs per linear foot for comparison, there is a savings of nearly 40% using bioengineering methods over conventional methods. Using the calculated costs per square yard, there is a savings of

Survival Statistics June 15, 2009

SW Slope
Overall Survival: 27.3%



US-33/SR-36,4 Interchange



NE Slope
Overall Survival: 72.1%

Figure 7.29: Graphical representation of survival of the NE and SW live pole plots at the Union County demonstration site as of June 15, 2009.

Figure 7.30: Established growth at the bottom of the NE slope (photo taken August 20, 2009).

nearly 30% using bioengineering methods over conventional methods. Thus, the economic benefits of using bioengineering methods are substantial. Additionally, it should be noted that the bulk of the total cost of the bioengineering method was in the lump sum of the planting and installation of the willow poles. The cost of this item is expected to decrease, possibly substantially, in the future as contractors familiarize themselves with the technique. In addition to cost savings, the bioengineering installation was much faster, by a factor of 20, than the conventional method. Thus, bioengineering methods can save considerable time as well as cost.

Table 7.4: Comparison of duration and cost of construction for both methods at the Union County demonstration site.

Method	Duration (days)	Total Cost ($)	$/LFT	$/SY [1]
Conventional	60	241,500	833	112
Bioengineering	3	61,000	508	77

[1] – Note: The area used for the conventional method is based on the original 2H:1V slope.

7.8 SUMMARY AND CONCLUSIONS

This chapter presents research completed for the Union County demonstration site. Site conditions including the geology, climate, and subsurface and groundwater conditions are discussed, as well as the program for field exploration, laboratory testing, and site instrumentation. Lastly, the performance of the bioengineering installation, including survival rates of vegetation, climate conditions and displacements, are presented.

The Union County demonstration site provided valuable data with regard to bioengineering performance and cost. Initial vegetation survival was high (over 90%) for this site. However, the two side slopes of the embankment performed quite differently with regard to vegetation survivability. The initial vegetation survival rate for the NE slope was high (over 90%), and has declined slightly to approximately 70% in spring 2009. While the initial vegetation survival rate was relatively high for the SW slope, it declined steadily to nearly 50 % by the end of 2007, and ultimately to less than 30% in spring 2009. Direct sunlight during the late afternoon, well below average precipitation, along with no provisions for site watering, and differences in fill material and soil nutrients could account for this. Tensiometer data indicates that suctions in the SW slope during 2007 were significantly higher at the 24 in. depth and slightly higher at the 36 in. depth than suctions recorded in the NE slope. Higher soil suctions correspond to lower levels of moisture available for vegetation.

Groundwater data suggests that soil suctions within the NE and SW pole plots increased significantly in 2007 after the completion of the installation. Soil suctions remained elevated in the NE slope, particularly at the bottom of the slope where vegetation growth was dense; however, soil suctions returned to the range observed prior to installation in the SW slope. Piezometric levels observed in the monitoring wells remained relatively constant and at low levels throughout the project. Slope movements prior and subsequent to installation have been negligible. The cost of the bioengineering construction was 30 to 40% lower than for the conventional construction at this site. Additional savings are anticipated as contractors become more familiar with bioengineering installation methods. Also, the bioengineering construction was completed in only 5% of the time required for the conventional construction.

Chapter 8 CONCLUSIONS AND RECOMMENDATIONS

8.1 INTRODUCTION

This chapter presents conclusions and recommendations based on the completed research, including: 1) factors that influence vegetation survival; 2) construction considerations for the successful application of bioengineering methods; 3) effectiveness of site instrumentation; 4) stability analyses for bioengineering methods; 5) cost of bioengineering verses conventional stabilization; 6) recommended procedures for landslide stabilization using bioengineering in Ohio; and 7) general assessment of project success. Recommendations for future research are also provided.

8.2 CONCLUSIONS AND RECOMMENDATIONS

8.2.1 Factors that Influence Vegetation Survival

Rate of vegetation survival is a primary factory that determines the effectiveness of bioengineering stabilization methods. Key factors that influence vegetation survival are:

1. Harvesting and installation of vegetation should be completed during the dormant season (November 1 to April 1) and storage of vegetation after harvesting, even under refrigerated conditions, should be avoided. For the Muskingum County site, live poles were harvested in early April and then refrigerated for up to two months prior to installation in late May/early June 2005. The resulting initial rate of survival after this procedure was low (53%). Installation of live poles at the Logan and Union County sites took place immediately after harvesting during March of 2007 and yielded much higher initial survival rates (60 and 92%, respectively). Additional supporting evidence comes from the recorded survival rates for replacement installations at the Muskingum County site, which were much higher than for the initial installation. Preferably, vegetation should be installed during the early spring to minimize the opportunity for desiccation, reduce the difficulty of drilling/spiking holes for installation, and to maximize availability of moisture for root systems to become established before the hot, dry summer months. The wide range in the survival rates may be expected because of the many variables that affect survival. The soil moisture and installation techniques that influence root growth are considered particularly important and controlled experiments should yield very useful results.

2. Local climate conditions, and in particular sunlight, temperature and precipitation, have a large impact on the survival rate of vegetation. Climate conditions were hot and dry after vegetation installation at the Muskingum

County site and this produced low initial survival. However, conditions at the Logan and Union County sites after vegetation installation were ideal during the first several weeks in April, with ample amounts of precipitation along with slightly above average temperatures. However, a late frost killed a large fraction of vegetation at the Logan County site. The Union County site indicates that survivability can vary dramatically on either side of a single embankment due to differing sunlight intensity. Consideration of site-specific climatic data (i.e., sunlight, temperature and precipitation,) would be useful in developing species selection criteria for potential bioengineering sites across the state.

3. Vegetation survivability is particularly sensitive to soil moisture conditions during the initial growing season. During each year of the project, precipitation during the late spring and summer was typically at or below average and temperatures were typically at or above average. Artificial watering was not provided at any of the demonstration sites during the initial growing season and this likely lowered vegetation survival rates. For spring planting, the first several months after installation (i.e., summer) is a critical time period during which the vegetation requires adequate soil moisture to establish a root system. It is recommended that artificial watering be provided as needed for future bioengineering installations and in particular for the initial growing season.

4. Various live pole installation techniques were used at the three demonstration sites and were directly compared at the Logan County site. Results indicate that vegetation survival is not enhanced by using the best method of installation and that the minimal method of installation is satisfactory. The minimal method of installation, as described previously in this report, saves considerable time and effort as compared to other methods and should be used for installation of live poles in Ohio.

5. Vegetation survival was strongly dependent on vegetation species. In particular, willows had a significantly higher rate of survival than poplars in this study. Final survival rates (2 to 4 yrs) for willows varied considerably, ranging from 13% to 60% depending on the demonstration site. Final survival rates for non-willows (poplars) were consistently 0%. For the climatic region of central and eastern Ohio, willow species were found to be heartier and more appropriate than poplar species for bioengineering designs.

6. Local soil composition, including soil pH and nutrients, influences vegetation survival but is generally not a limiting factor for survival. Soil nutrient testing was conducted for each demonstration site and recommendations were provided for modifying the soil chemistry to promote optimal growth. Soil pH was high and organic matter levels were low at all three sites. Although no modifications of soil chemistry were attempted in this research, such efforts may be considered as part of future research or implementation activities. Local variations in soil composition and chemistry may have lead

to variations in vegetation survival across the Logan and Union County demonstration sites.

7. Transportation and storage of vegetation from harvesting to the completion of installation may affect survivability. The vegetation must be kept moist/wet during all stages of handling (i.e., harvesting, transporting, storage, preparation, and installation). It is recommended that vegetation be harvested and then soaked for several days prior to installation. Humid cold storage of dormant willow and poplar vegetation was used to delay pole installation at the Muskingum County site. This method was generally unsuccessful and likely contributed to the low initial survival rate.

8.2.2 Construction Considerations for Successful Application of Bioengineering Methods

Method of construction and installation is a primary consideration with regard the success and feasibility of bioengineering design. Key findings with regard to construction methods are:

1. Vegetation installation technique has a large impact on the duration and cost of construction as labor requirements for various installation techniques vary considerably. The best method of installation was very time consuming and labor intensive. Manual installation of live poles using a gas powered hand-held earth auger is also very labor intensive, and survival rates recorded from the demonstration sites showed little difference for the various installation techniques. Where possible, vegetation should be installed using the minimal method and holes should be created using a spike or drill attached to a long-reach backhoe. This will increase production levels by 5 to 10 times as compared to using the best installation method with manually drilled holes. The minimal consists of spiking a hole, dropping in pole cut to required length, backfilling with sand, and placement of weed control mat to reduce vegetation competition.

2. Slope regrading prior to vegetation installation appeared to have little effect on the performance of the bioengineering installations in this study. However, regrading provides the advantage of positive water drainage from a slope and reduces water infiltration to the slip plane. Initial slope regrading is generally recommended and should be evaluated on a case-by-case basis.

3. Vegetation survivability appeared to be unaffected by type of soil backfill in the installation holes. In particular, bentonite used at the Logan and Union County sites eroded out of the holes, leaving them open to collect water. Native soil backfill was successfully used at the Muskingum and Logan County sites. Recommended backfill materials are sand and native soil (i.e., soil cuttings).

4. Competitive vegetation growth from weeds and other native flora was problematic at some demonstration sites and can affect live pole survivability. Weed barriers were used at each demonstration site along with hydroseeding at the Muskingum and Logan County sites, but these measures were not entirely successful. Better methods to reduce competition from other vegetation should be developed, such as the use of chemical herbicides or physical barriers.

8.2.3 Effectiveness of Site Instrumentation

The effectiveness of field instrumentation at the demonstration sites is summarized as follows:

1. Gypsum moisture blocks (G-Blocks) and tensiometers were used to monitor soil moisture conditions within the slopes. Based on data collected from the Muskingum County site, soil suctions measured by tensiometers were inconsistent with values obtained from G-Blocks. In general, the G-Blocks were less reliable than the tensiometers. During non-winter periods, these instruments should optimally be monitored every two weeks. Comparison of measured soil suctions with predicted suctions based on measured water contents and the laboratory soil moisture characteristic curves also showed no clear correlations. G-Blocks are prone to drying out and breaking and are not reliable for measuring soil suctions.

2. There is a trend in vegetation survivability with soil suctions measured from tensiometers. Poor survival rates and high soil suctions were measured in the SW slope of the Union County site as compared to the NE slope. Similarly, the Muskingum County site experience lower soil suctions measured from tensiometers and higher survival rates than the Logan County site.

3. Copper shallow inclinometers (CSIs) were successfully used at each demonstration site to assess slope movements within approximately 4 ft. of the ground surface. Installation and excavation of these instruments is, however, very labor intensive and is only recommended for research purposes. CSIs measure only shallow movements and do not provide the same information as deep inclinometers.

4. Conventional field instruments, such as piezometers and slope inclinometers, performed satisfactorily for the project. However, the usefulness of these types of instruments is limited for the shallow depths associated with bioengineering applications. Although not used in this study, time domain reflectometry (TDR) may be an attractive method for measuring soil moisture conditions at shallow depths.

8.2.4 Stability Analyses for Bioengineering Methods

A stability analysis was conducted for each demonstration site to assess the benefit of bioengineering remediation. Key findings with regard to these stability analyses are:

1. The infinite slope formulas presented in Gray and Sotir (1996) were used to assess shallow stability. The effect of vegetation was modeled by treating the poles as laterally loaded piles and was incorporated in the analysis using an equivalent reinforcement cohesion. The reinforcement cohesion was determined as a limiting soil resistance calculated for three common failure modes: 1) "flow mode" in which soil flows around the pole, 2) "pile mode" in which the pole acts as a laterally loaded pile, and 3) shear failure of the pole at the slip surface. Stability analyses indicate that the initial factor of safety was below 1.0 for the Muskingum and Logan County sites and that the seepage angle is somewhere between parallel and vertical to the slope face. Factors of safety that include vegetation reinforcement are greater than 1.0 for measured failure depths of 2 ft. and a seepage angle between parallel and vertical. Recent slope movements at the Logan County site indicate that the failure surface is deeper than 3 or 4 ft., corresponding to a factor of safety below 1.0.

2. Deep-seated stability for the Logan County demonstration site was analyzed using the limit equilibrium circular analysis methods (Slope/W), including the Modified Bishop's method and the Morganstern-Price Method. The initial factor of safety prior to construction was slightly below 1.0. The final factor of safety incorporating the gravity toe berm at the base of the NE slope was 1.2. Undrained and drained analysis for the case where the toe berm excavation was open indicated that the excavation would be stable for short periods.

3. Vertical and lateral pullout tests were conducted on live and dead poles to determine the shear resistance for stability analysis. Results of these tests were within the expected range as calculated using empirical methods with typical field measurements for soil shear strength and pole diameter.

8.2.5 Cost of Bioengineering Verses Conventional Stabilization

Potential economic benefits of bioengineering verses conventional stabilization methods is a key consideration. Conventional remediation methods were utilized at the Union County demonstration site in areas immediately adjacent to the bioengineering installations and included: excavation of the upper portion of the existing slopes so that a series of benches could be constructed; removal of existing drains and installation of new drains in the sub-base of the interchange along with a new drainage channel to route stormwater runoff from the roadway down to a rock channel at the base of the embankment; and reconstruction of the embankment to a 2.5H:1V slope.

Table 8.1 provides the total cost, cost per lineal foot, and the cost per sq. yd. for each bioengineering demonstration site, as well as for the conventional construction performed at the Union County site. The cost/sq. yd. for bioengineering construction at the Union County site was 30% less than for conventional construction. Similarly, the Muskingum County site indicates a savings of 23% over conventional methods. However, the Logan County site was only 2% less expensive per sq. yd. than conventional construction at the Union County site. The higher cost for Logan County is attributed to slope scraping, moderate slope reconstruction, and more rigorous installation methods that were not used for the bioengineering site at Union County. Bioengineering construction costs at Muskingum County are not representative of typical construction costs because the work was performed by OSU students. Future costs for bioengineering construction are expected to decrease as contractors become more familiar with the technique.

Table 8.2 provides the duration of construction, total cost, number of poles installed, production rate, and unit cost per pole for each demonstration site. Please note that the costs presented for the bioengineering remediation methods for both Muskingum and Logan Counties are for the initial installation only and do not include the cost of additional installations. The data indicate that production rate is much higher (by a factor of 5 to 10) when poles are installed using mechanical spiking rather than manual drilling. The unit cost per pole ranges from $79 to $102 and is also expected to decrease as contractors become more familiar with the technique in the future.

Table 8.1: Cost comparison for bioengineering and conventional construction methods.

Site	Remediation Method	Duration (days)	Total Cost ($)	($/LFT)	($/SY) [1]
Muskingum County	Bioengineering	15	25,000	385	86
Logan County	Bioengineering	7	79,000	439	110
Union County	Bioengineering	3	61,000	508	77
Union County	Conventional	60	241,500	833	112

[1] – Areas measured from plan view.

Table 8.2: Cost and productivity comparison for the Muskingum, Logan and Union County demonstration sites.

Site	Duration (days)	Total Cost ($)	Number of Poles Installed	Production Rate (Poles Installed/Day)	Unit Cost ($/Pole)
Muskingum County	15	25,000	318	21	79
Logan County	7	79,000	780	111	102
Union County	3	61,000	701	234	87

8.2.6 Recommended Procedures for Landslide Stabilization using Bioengineering in Ohio

The following procedures are recommended for the use of bioengineering methods for landslide stabilization in Ohio:

1. The best biostabilization method for shallow landslides is live staking because of the immediate and direct reinforcement to the slide plane. Other bioengineering methods, such as brush layers and fascines, are generally surficial treatments and do not provide deeper stabilization effects, at least not right away. Advantages of live staking include minimal invasiveness to slope, rapid construction, low cost, and immediate reinforcing effect. Disadvantages of the method include possible low vegetation survival, time required for root development, restrictive time window (spring) for construction, and susceptibility to climate conditions. The primary limitation is that the method is only suitable for shallow slides.

2. In Ohio, willows should be used for live staking installations. Other species (mostly poplar) were found to have significantly less survivability than willows in this study.

3. For best survivability, poles should be harvested and installed between March 1 and April 15. Survivability for poles installed during summer, fall or winter was not as high in this study.

4. For optimal cost savings, poles should be installed using the minimal method as described in this report. Installation method was found to have no effect on vegetation survivability. Pole harvesting and installation should occur within days of one another. Poles should be kept continuously moist or wet between harvesting and installation. Refrigeration of pole stock will be required if a significant amount of time (more than one or two weeks) will pass between harvesting and installation. However, it should be noted that refrigeration may have a detrimental effect on vegetation survivability as was observed from the initial installation at the Muskingum County demonstration site.

5. After installation, key factors to monitor are competition from other vegetation, drought conditions, and late spring freeze after budding, all of which can significantly reduce survivability. Although not used in this research, provisions should be made to water the slope during drought conditions. However, too much water will destabilize the slope.

8.2.7 General Assessment of Project Success

The project met with both success and failure. The Muskingum County site yielded low vegetation survival rates for the initial installation and higher survival rates for subsequent replacement installations, but was generally successful with regard to stability. The Logan County site was largely a failure with respect to both survival and

shallow stability. Deep-seated movements at the Logan County site were stabilized using the toe berms. The Union County site, which showed some early signs of instability by the detection of tension cracking at the top of the slopes, was largely successful with regard to survival. The possibility of low vegetation survival rates are a key obstacle for the routine use of biostabilization in Ohio and must be addressed before practical implementation of the methods occurs.

8.3 RECOMMENDATIONS FOR FUTURE RESEARCH

The following recommendations are provided with regard to possible future research on the use of bioengineering methods for landslide stabilization:

1. Research is needed on the routine use and effectiveness of artificial watering at bioengineering stabilization sites during the first growing season and possibly beyond to improve survivability. Standard horticulture methods for watering should be considered and well as optimal amounts of infiltration that will promote good plant growth but will not destabilize the slope.

2. Additional research is recommended to investigate the effectiveness of using different types of vegetation for varying bioengineering applications. Vegetation selection criteria should be developed that considers local soil and climate conditions as well as the availability of adequate vegetation source material for harvesting.

3. Research is recommended to investigate methods to reduce vegetation competition for bioengineering installations.

4. More research is needed to establish the depth of rooting zones for live staking and the increase of effective root cohesion coefficient with time for use in stability analyses.

5. Research is needed on possible applications of bioengineering for failures (i.e., sliding surfaces) that are deeper than approximately 4 ft. and, in particular, on combinations of bioengineering methods with geosynthetics for such applications.

6. Whenever possible, more information is needed on cost comparisons for bioengineering and conventional construction methods. Only one such comparison was possible in the current study.

7. Comparison of other bioengineering techniques that may be applicable to shallow landslide stabilization.

IMPLEMENTATION PLAN

The investigators have concluded that, although important questions have been answered regarding the use of biostabilization in Ohio, the current research is not yet ready for implementation. Additional research will be needed to more clearly establish the potential and limitations of biostabilization as a practical remediation method. If successful, such work may lead to the ultimate goal of producing a geotechnical design bulletin (i.e., guidance document) for use of bioengineering for land stabilization.

The following plan is recommended to guide additional research on the topic, leading to implementation:

1. The first question that must be answered for a given case is what bioengineering methodology or combination of bioengineering and geosynthetics is most appropriate for a given field site. Thus, a broader investigation should be conducted to establish the potential and limitations of other types of bioengineering methods (such as fascines and brushlayering) for Ohio conditions. In particular, the recommended bioengineering method, if any, should be indentified for each primary type of landslide problem. Identification of typical depth of effectiveness should be made for each bioengineering method.
2. Once the various methodologies are indentified and investigated, the next issue is to determine general design guidelines for each. This work will need to be verified using additional field demonstration sites. Cost and performance comparisons to conventional construction methods should be made wherever possible.
3. Once the various guidelines are established, the next most important issue is to ensure survivability of the vegetation, both short-term and long-term. Future research projects should have a botanist or agronomist as one of the investigators to strengthen this aspect of the research. Vegetation species selection and possible treatments should also be investigated as a means to improve survivability. Use of seedlings as opposed to cut poles should be investigated as well.
4. The above efforts should lead to the development of a geotechnical bulletin that provides design guidelines and expected levels of performance for each bioengineering method, and reliable cost data as a guide for routine use.

Example areas in Ohio where bioengineering technology is expected to be valuable include:

- Shallow landslides along SR 33 between Marysville and Bellefontaine,
- Shallow landslides along I-71, north of I-76,
- Stabilization of stream banks, especially in scenic river areas, and
- Remediation of shallow failures along highway embankments due to poor compaction at the surface (a common problem throughout the state).

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APPENDIX A

SUPPORTING DOCUMENTS FOR MUSKINGUM COUNTY FIELD DEMONSTRATION SITE

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Muskingum County 30 Year Data

Climate Data for Station: 331197 CAMBRIDGE, OH - Source: MRCC, NCDC, ODNR

Temperature Summary
1971-2000 NCDC Normals

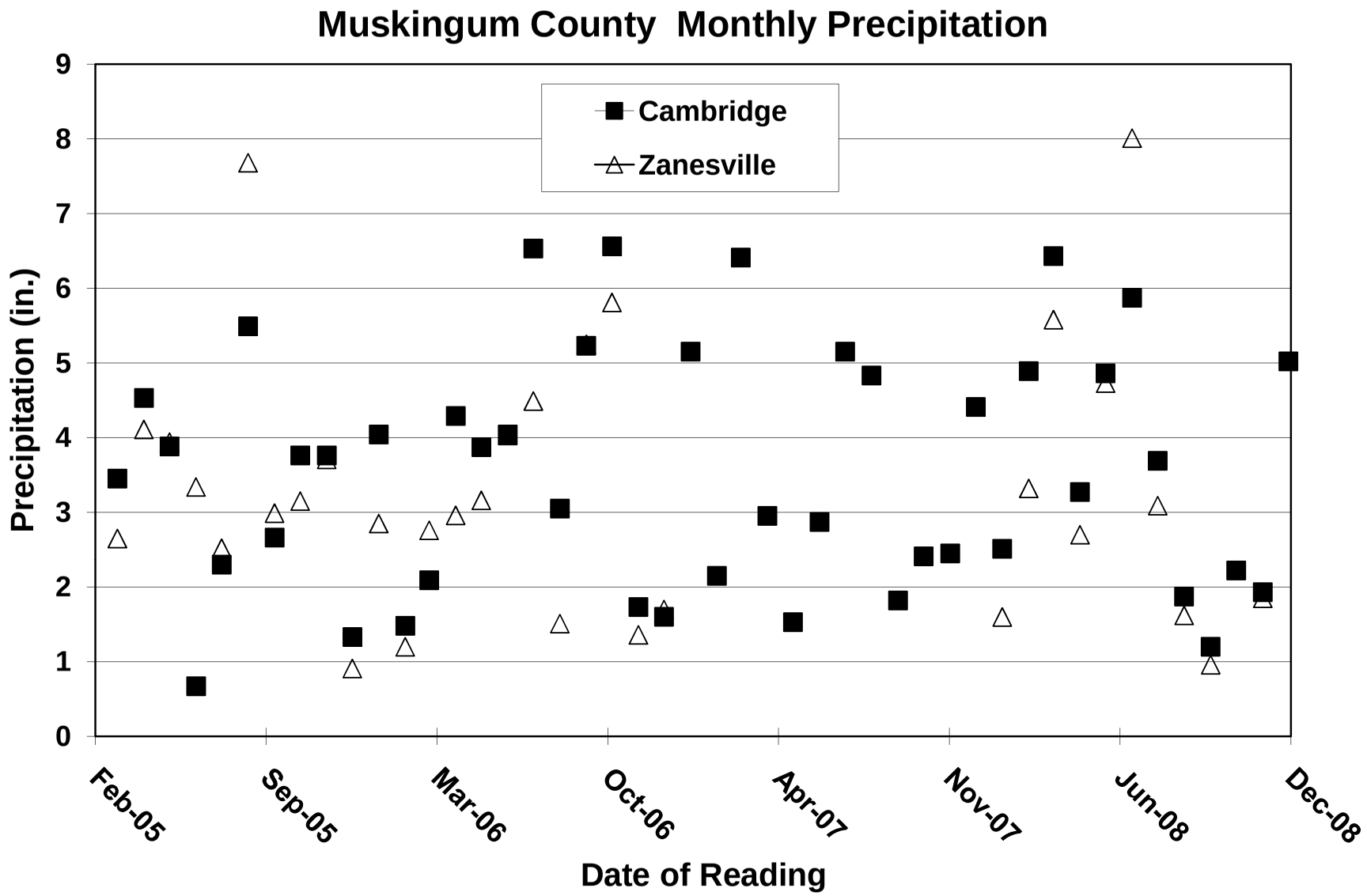
Element	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Max °F	37.9	42.5	53.4	64.9	74.5	81.8	85	83.3	76.8	65.9	53.3	42.3	63.5
Min °F	20.3	22.7	30.8	39.3	49	57.8	62.2	60.9	53.9	41.9	33.8	25.4	41.5
Mean °F	29.1	32.6	42.1	52.1	61.8	69.8	73.6	72.1	65.4	53.9	43.6	33.9	52.5

Precipitation Summary
1971-2000 NCDC Normals

Element	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Precip (in)	2.73	2.30	3.01	3.34	3.95	4.03	4.25	3.93	2.99	2.56	3.24	2.83	39.16

Growing Season Summary
Derived from 1971-2000 Averages

	Date of Last Spring Occurrence					Date of First Fall Occurrence				
Base Temp °F	Median	Early	90%	10%	Late	Median	Early	90%	10%	Late
32	5/2	4/10	4/20	5/20	6/12	10/11	9/24	9/29	10/21	11/4
30	4/26	4/9	4/11	5/10	6/12	10/17	10/3	10/7	10/29	11/4
28	4/15	3/24	4/3	4/28	5/4	10/27	10/3	10/8	11/12	11/21
24	4/8	3/16	3/19	4/21	4/27	11/5	10/14	10/21	11/23	12/2
20	3/24	3/12	3/13	4/10	4/14	11/19	10/21	11/3	12/13	12/17
16	3/13	2/8	2/18	3/27	4/10	12/3	11/5	11/14	12/23	1/2


Muskingum County Monthly Precipitation
Cambridge
Zanesville
Precipitation (in.)
0
1
2
3
4
5
6
7
8
9
Feb-05
Sep-05
Mar-06
Oct-06
Apr-07
Nov-07
Jun-08
Dec-08
Date of Reading

Muskingum County Monthly Precipitation Data

Climate Data for Station: 331197 CAMBRIDGE, OH - Source: ODNR

Precipitation Summary
NCDC

2005 Monthly Precipitation and Departure From Normal (inches)

Location	January		February		March		April		May		June	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Cambridge	7.98	5.25	1.87	-0.43	3.45	0.44	4.53	1.19	3.88	-0.07	M 0.67	M -3.36
Zanesville	8.40	6.21	1.83	-0.55	2.65	-0.86	4.11	0.56	3.94	-0.08	3.34	-0.67

Location	July		August		September		October		November		December	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Cambridge	M 2.3	M -1.95	5.49	1.56	2.66	-0.33	3.76	1.20	3.76	0.52	1.33	-1.50
Zanesville	2.52	-1.97	7.68	3.87	2.99	0.02	3.15	0.80	3.71	0.51	0.91	-2.03

Location	Annual	
	Precip.	Depart.
Cambridge	M 41.68	M 2.52
Zanesville	45.23	5.81

Muskingum County Monthly Precipitation Data

Climate Data for Station: 331197 CAMBRIDGE, OH - Source: ODNR

Precipitation Summary
NCDC

2006 Monthly Precipitation and Departure From Normal (inches)

Location	January		February		March		April		May		June	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Cambridge	M 4.04	M 1.31	1.48	-0.82	2.09	-0.92	4.29	0.95	3.87	-0.08	4.04	0.01
Zanesville	2.85	0.66	1.20	-1.18	2.76	-0.75	2.96	-0.59	3.16	-0.86	4.03	0.02

Location	July		August		September		October		November		December	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Cambridge	6.53	2.28	3.05	-0.88	5.23	2.24	6.56	4.00	1.73	-1.51	1.60	-1.23
Zanesville	4.49	0.00	1.51	-2.30	5.25	2.28	5.81	3.46	1.36	-1.84	1.70	-1.24

Location	Annual	
	Precip.	Depart.
Cambridge	M 44.51	M 5.35
Zanesville	37.08	-2.34

Muskingum County Monthly Precipitation Data

Climate Data for Station: 331197 CAMBRIDGE, OH - Source: ODNR

Precipitation Summary
NCDC

2007 Monthly Precipitation and Departure From Normal (inches)

Location	January		February		March		April		May		June	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Cambridge	5.15	2.42	2.15	-0.15	6.41	3.40	2.95	-0.39	1.53	-2.42	2.87	-1.16
Zanesville												

Location	July		August		September		October		November		December	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Cambridge	5.15	0.90	4.83	0.90	1.82	-1.17	2.41	-0.15	2.45	-0.79	4.41	1.58
Zanesville												

Location	Annual	
	Precip.	Depart.
Cambridge	42.13	2.97
Zanesville		

Muskingum County Monthly Precipitation Data

Climate Data for Station: 331197 CAMBRIDGE, OH - Source: ODNR

Precipitation Summary
NCDC

2008 Monthly Precipitation and Departure From Normal (inches)

Location	January		February		March		April		May		June	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Cambridge	2.51	-0.22	4.89	2.59	6.43	3.42	3.27	-0.07	4.86	0.91	5.87	1.84
Zanesville	1.6	-0.59	3.32	0.94	5.58	2.07	2.7	-0.85	4.73	0.71	8.01	4

Location	July		August		September		October		November		December	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Cambridge	3.69	-0.56	1.87	-2.06	1.2	-1.79	2.22	-0.34	1.93	.1.31	5.02	2.19
Zanesville	3.09	-1.4	1.62	-2.19	0.96	-2.01	-	-	1.85	-1.35	-	-

Location	Annual	
	Precip.	Depart.
Cambridge	43.76	4.6
Zanesville	M 33.46	M -5.96

Muskingum County Monthly Precipitation Data

Climate Data for Station: 331197 CAMBRIDGE, OH - Source: ODNR

Precipitation Summary
NCDC

2009 Monthly Precipitation and Departure From Normal (inches)

Location	January		February		March		April		May		June	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Cambridge	3.10	0.37	1.17	-1.13	1.17	-1.84	3.54	0.20				
Zanesville	-	-	-	-	-	-	-	-	-	-		

Location	July		August		September		October		November		December	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Cambridge												
Zanesville												

Location	Annual	
	Precip.	Depart.
Cambridge		
Zanesville		

Muskingum County

May 2005 Daily Precipitation (inches)

Location	Day of the Month																															Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Cambridge	T	T	T	-	-	0.02	-	0.18	-	-	0.03	0.19	-	1.54	0.26	-	-	-	-	0.94	0.02	-	0.06	0.15	T	-	-	0.31	0.13	-	0.05	3.88
Zanesville	T	T	-	T	0.05	-	T	-	T	0.11	0.36	T	0.35	0.33	-	-	-	-	1.36	0.58	-	0.01	0.15	0.02	-	-	T	0.58	-	0.04	-	3.94

June 2005 Daily Precipitation (inches)

Location	Day of the Month																															Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Cambridge	-	-	0.01	0.01	-	-	-	-	0.05	-	0.03	-	T	-	0.08	0.05	0.08	-	-	-	-	0.31	-	-	-	-	-	-	0.05	-	-	0.67
Zanesville	-	T	-	-	-	-	-	-	-	0.11	0.02	T	T	0.12	-	0.01	-	-	-	-	-	0.62	-	-	-	-	-	2.2	-	0.26	-	3.34

July 2005 Daily Precipitation (inches)

Location	Day of the Month																															Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Cambridge	-	-	-	-	-	0.51	-	-	0.12	-	-	-	T	0.04	0.01	0.33	0.06	0.08	0.69	T	0.01	-	0.33	-	-	0.1	-	0.02	-	-	-	2.30
Zanesville	0.07	-	-	-	0.22	-	-	0.12	-	-	T	-	0.01	0.7	0.07	0.12	0.26	0.18	T	-	0.01	0.52	-	0.02	0.2	T	0.02	-	-	-	-	2.52

State Ohio
Department of Transportation
Office of Geotechnical Engineering

1/3

LOG OF BORING

Date Started 3/8/05 Sampler: Type SS Dia. 1 3/8 Water Elev. DRY Project Identification: MUSKINGUM
Date completed 3/8/05 Approx. MUS-70-26.87
Boring No. B-1 * Station & Offset 732+49, 271' LT. (APPROX.) Surface Elev. 952.0' LANDSLIDE INVESTIGATION (RESEARCH PROJECT)

Elev.	Depth	Std. Pen./ R.Q.D.	Rec. ft	Loss ft	Description	Sample No.	Physical Characteristics % Agg	% C.S.	% F.S.	% Silt	% Clay	L.L.	P.I.	W.C.	ODOT Class
952.0	0														
951.5		AUGERED			TOPSOIL	-	-	-	-	-	-	-	-	-	VISUAL
	2														
	4	AUGERED			BROWN & RED CLAY (DRILLER'S DESCRIPTION)	-	-	-	-	-	-	-	-	-	VISUAL
947.0															
	6	6/8/12			BROWN & RED GRAVELLY CLAY (REC. 1.5')	1	13	5	7	32	43	37	16	21	A-6b
	8														
942.0	10				ATEMPTED TO TAKE A PRESS SAMPLE BUT FAILED										
	12														
	14														
937.0	16	21/27/31			RED SILTY GRAVELLY SAND W/BOULDERS	2	37	25	15	14	9	43	9	10	A-2-5
	18														
932.0	20														
	22	14/24/26			RED SANDY CLAY (REC. 1.5')	3	13	8	9	29	41	42	20	19	A-7-6
	24														
927.0	26	14/15/18			RED SILTY CLAY	4	7	4	5	35	49	40	19	21	A-6b
	28														
922.0	30														
920.5		11/13/14			RED & BROWN SILTY CLAY (REC. 1.5')	5	9	4	5	33	49	40	19	22	A-6b

BOTTOM OF BORING

Particle Sizes: Agg= >2.00mm, Coarse Sand= 2.00-0.42mm, Fine Sand= 0.42-0.074mm, Silt= 0.074-0.005mm, Clay= <0.005mm

* NOTE: INCLINOMETER TUBING INSTALLED IN THIS HOLE.

Stat f Ohio
Department o ansportation
Office of Geotechnical Engineering

2/3

LOG OF BORING

Date Started 3/9/05 Sampler: Type SS Dia. 1 3/8 Water Elev. DRY Project Identification: MUSKINGUM
Date completed 3/9/05 MUS-70-26.87
Boring No. B-2 *Station & Offset 732+38, 154' LT. (APPROX.) Surface Elev. Approx. 995.5' LANDSLIDE INVESTIGATION (RESEARCH PROJECT)

Elev.	Depth	Std. Pen./ R.Q.D.	Rec. ft	Loss ft	Description	Sample No.	Physical Characteristics % Agg	% C.S.	% F.S.	% Silt	% Clay	L.L.	P.I.	W.C.	ODOT Class
995.5	0														
	2														
	4														
990.5	6	4/5/6			BROWN AND RED SILT AND CLAY (REC. 1.5')	6	8	4	7	40	41	34	14	22	A-6a
	8														
985.5	10	P.S. **			BROWN SANDY CLAY (DRILLER'S DESCRIPTION) (REC. 2.0')	7-P	-	-	-	-	-	-	-	-	VISUAL
	12														
	14														
980.5	16	4/7/8			BROWN AND RED CLAY	8	13	3	3	38	43	42	22	17	A-7-6
	18														
975.5	20	P.S. **			BROWN AND RED CLAY (DRILLER'S DESCRIPTION) (REC. 1.6')	9-P	-	-	-	-	-	-	-	-	VISUAL
	22														
	24														
970.5	26	5/9/10			BROWN AND RED CLAY (REC. 1.5')	10	0	0	2	41	57	41	22	20	A-7-6
	28														
965.5	30	P.S. **			BROWN AND RED CLAY (DRILLER'S DESCRIPTION) (REC. 1.9')	11-P	-	-	-	-	-	-	-	-	VISUAL
963.5	32														

BOTTOM OF BORING

Particle Sizes: Agg= >2.00mm, Coarse Sand= 2.00-0.42mm, Fine Sand= 0.42-0.074mm, Silt= 0.074-0.005mm, Clay= <0.005mm

* NOTE: WATER MONITORING WELL INCLUDING 2.0' OF SCREEN & 32.0' OF SOLID INSTALLED IN THIS HOLE.

** NOTE: P.S. = PRESS SAMPLE. (THESE SAMPLES WERE HANDED OVER TO THE OHIO STATE UNIVERSITY.)

State of Ohio
Department of Transportation
Office of Geotechnical Engineering

3/3

LOG OF BORING

Date Started 3/9/05 Sampler: Type SS Dia. 1 3/8 Water Elev. - Project Identification: MUSKINGUM
Date completed 3/9/05 Approx. MUS-70-26.87
Boring No. B-3 * Station & Offset 741+42, 112' LT. (Approx.) Surface Elev. 986.0' LANDSLIDE INVESTIGATION
(RESEARCH PROJECT)

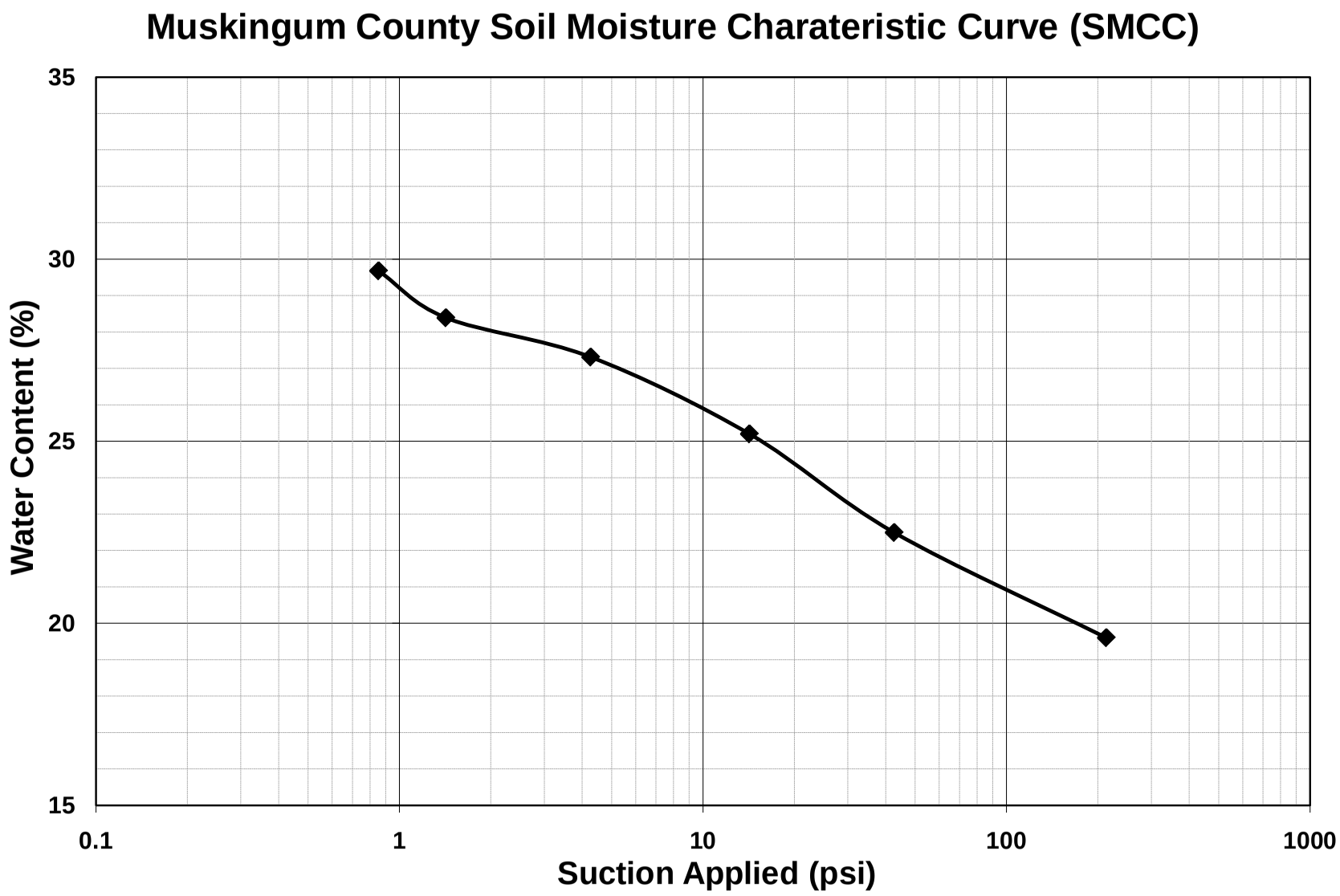
Elev.	Depth	Std. Pen./ R.Q.D.	Rec. ft	Loss ft	Description	Sample No.	Physical Characteristics % Agg	% C.S.	% F.S.	% Silt	% Clay	L.L.	P.I.	W.C.	ODOT Class
986.0	0														
	2														
	4														
981.0	6	10/11/12			RED AND BROWN CLAY (REC. 1.5')	12	14	2	1	34	49	40	21	17	A-6b
	8														
977.5															
976.0	10	P.S. **			RED & BROWN CLAY (DRILLER'S DESCRIPTION) (REC. 1.5')	-	-	-	-	-	-	-	-	-	VISUAL

BOTTOM OF BORING

Particle Sizes: Agg= >2.00mm, Coarse Sand= 2.00-0.42mm, Fine Sand= 0.42-0.074mm, Silt= 0.074-0.005mm, Clay= <0.005mm

* NOTE: WATER MONITORING WELL INCLUDING 2.0' OF SCREEN & 10.0' OF SOLID INSTALLED IN THIS HOLE.

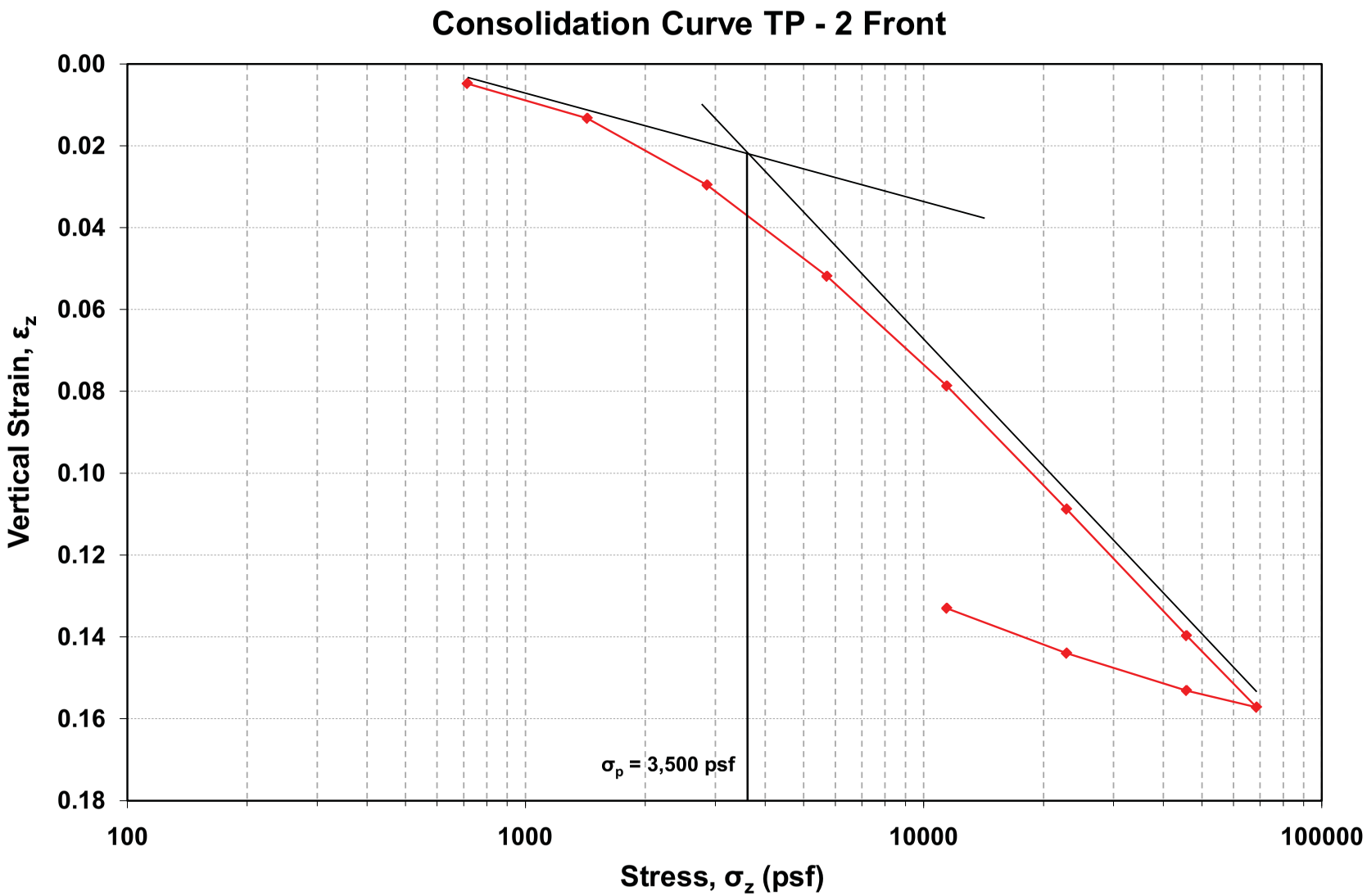
** NOTE: P.S. = PRESS SAMPLE. (THIS SAMPLE WAS HANDED OVER TO THE OHIO STATE UNIVERSITY.)

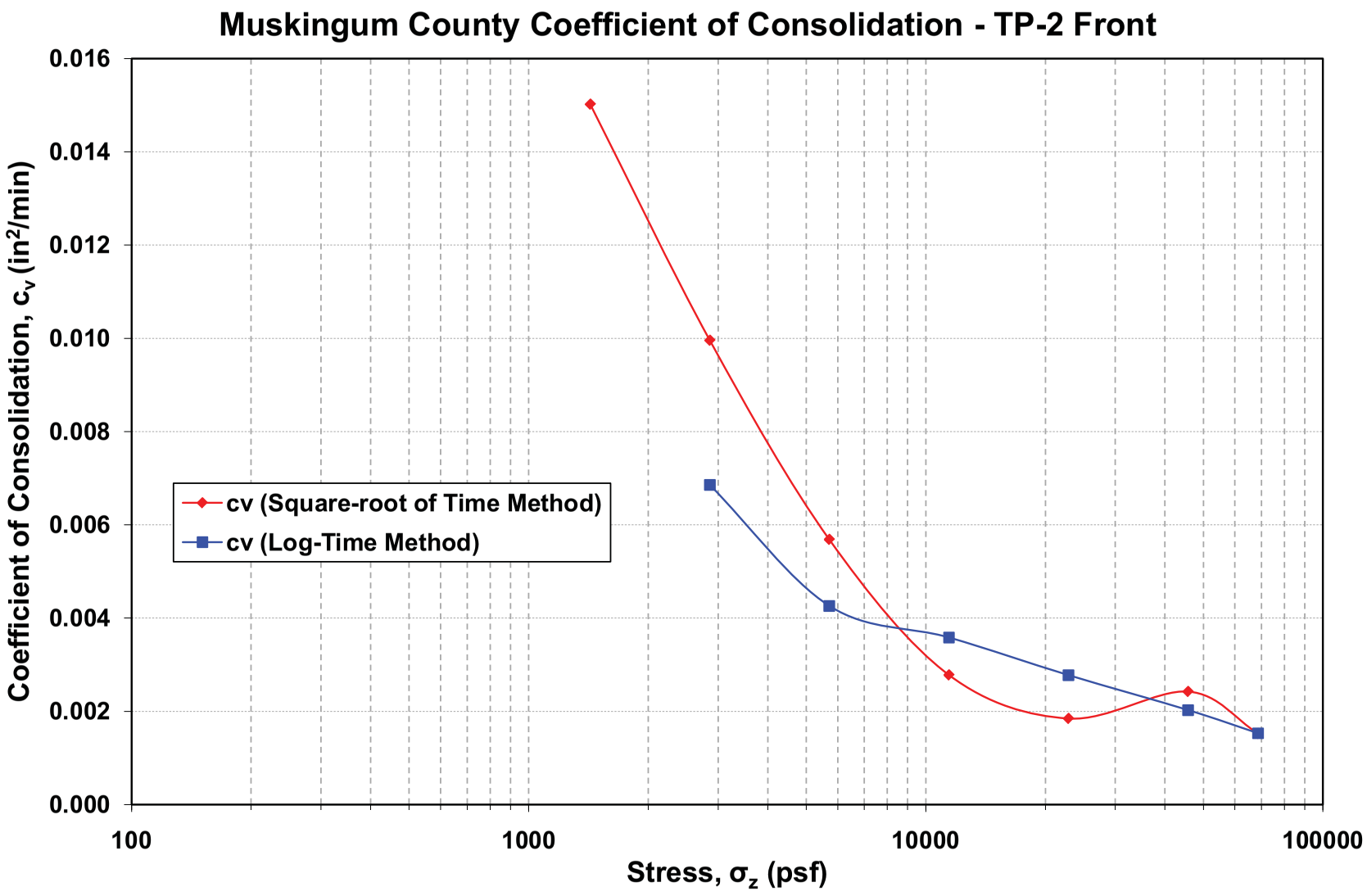

Muskingum County Soil Moisture Charateristic Curve (SMCC)
Water Content (%)
35
30
25
20
15
0.1
1
10
100
1000
Suction Applied (psi)

Soil Moisture Retention at Different Suctions

Date: 12/10/2007

Sample:2 (Muskingum County)		
Suction Applied		Moisture Retained
(cm)	(psi)	(%)
60	0.85	29.7
100	1.42	28.4
300	4.27	27.3
1000	14.22	25.2
3000	42.67	22.5
15000	213.35	19.6


Consolidation Curve TP - 2 Front
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
Vertical Strain, ε_z
σ_p = 3,500 psf
100
1000
10000
100000
Stress, σ_z (psf)


Muskingum County Coefficient of Consolidation - TP-2 Front
Coefficient of Consolidation, c_v (in^2/min)
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
100
1000
10000
100000
Stress, σ_z (psf)
cv (Square-root of Time Method)
cv (Log-Time Method)

TP-2 Consolidation Compression Data

Load: 1000g

Time (min)	Compression Reading (in)	Strain, ε
0	0.1847	0
0.5	0.182	0.0027
1	0.1812	0.0035
3	0.1809	0.0038
5	0.1808	0.0039
10	0.1807	0.004
15	0.1807	0.004
30	0.1807	0.004
55	0.1807	0.004
100	0.1807	0.004
160	0.1801	0.0046
280	0.1801	0.0046
1440	0.1799	0.0048

Load: 2000g

Time (min)	Compression Reading (in)	Strain, ε
0	0.1799	0.0048
0.5	0.1771	0.0076
1	0.1767	0.008
2	0.1763	0.0084
4	0.1757	0.009
8	0.1752	0.0095
15	0.1746	0.0101
30	0.1739	0.0108
60	0.1734	0.0113
120	0.173	0.0117
240	0.1727	0.012
480		
960		
1440	0.1714	0.0133

Load: 4000g

Time (min)	Compression Reading (in)	Strain, ε
0	0.1675	0.0172
0.5	0.1658	0.0189
1	0.1651	0.0196
2	0.1641	0.0206
4	0.1628	0.0219
8	0.1614	0.0233
15	0.1599	0.0248
30	0.1585	0.0262
60	0.1574	0.0273
120	0.1566	0.0281
240	0.1561	0.0286
480	0.1557	0.029
960		
1440	0.1551	0.0296

Load: 8000g

Time (min)	Compression Reading (in)	Strain, ε
0	0.1504	0.0343
0.5	0.1486	0.0361
1	0.1475	0.0372
2	0.1463	0.0384
4	0.1448	0.0399
8	0.1427	0.042
15	0.1406	0.0441
30	0.1379	0.0468
60	0.1359	0.0488
120	0.1347	0.05
240	0.134	0.0507
480	0.1336	0.0511
960		
1440	0.1328	0.0519

Load: 16000g

Time (min)	Compression Reading (in)	Strain, ε
0	0.1285	0.0562
0.5	0.1259	0.0588
1	0.1247	0.06
2	0.1234	0.0613
4	0.1215	0.0632
8	0.1189	0.0658
15	0.1171	0.0676
30	0.1127	0.072
60	0.1099	0.0748
120	0.1086	0.0761
240	0.1076	0.0771
480	0.1069	0.0778
960		
1440	0.106	0.0787

Load: 32000g

Time (min)	Compression Reading (in)	Strain, ε
0	0.1005	0.0842
0.5	0.0975	0.0872
1	0.0966	0.0881
2	0.0953	0.0894
4	0.0934	0.0913
8	0.0908	0.0939
15	0.0878	0.0969
30	0.0845	0.1002
60	0.0802	0.1045
120	0.0784	0.1063
240	0.0775	0.1072
480	0.0768	0.1079
960		
1440	0.0759	0.1088

TP-2 Consolidation Compression Data

Load: 64000g

Time (min)	Compression Reading (in)	Strain, ε
0	0.0716	0.1131
0.5	0.0697	0.115
1	0.0687	0.116
2	0.0673	0.1174
4	0.0653	0.1194
8	0.0625	0.1222
15	0.0592	0.1255
30	0.0562	0.1285
60	0.0517	0.133
120	0.0493	0.1354
240	0.0481	0.1366
480	0.0474	0.1373
960		
1440	0.045	0.1397

Load: 96000g

Time (min)	Compression Reading (in)	Strain, ε
0	0.0424	0.1423
0.5	0.0415	0.1432
1	0.0409	0.1438
2	0.0402	0.1445
4	0.0393	0.1454
8	0.0379	0.1468
15	0.0364	0.1483
30	0.0342	0.1505
60	0.0322	0.1525
120	0.0306	0.1541
240	0.0294	0.1553
480	0.0286	0.1561
960		
1440	0.0275	0.1572

Load: 64000g (Unload)

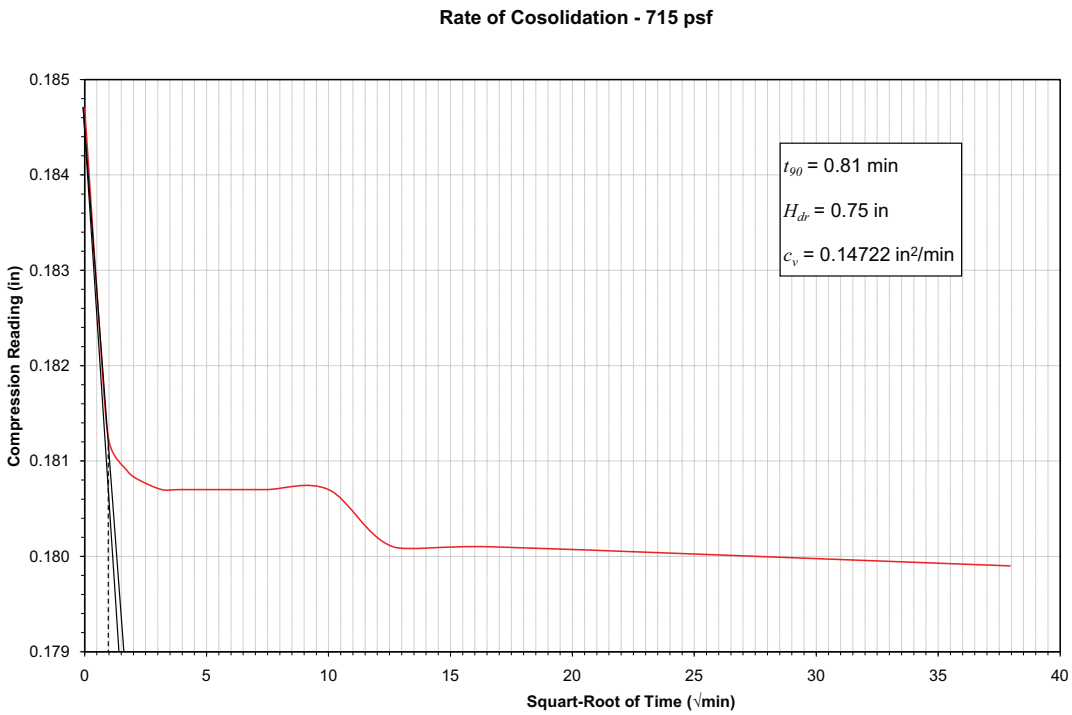
Time (min)	Compression Reading (in)	Strain, ε
0	0.0295	0.1552
0.5	0.0298	0.1549
1	0.0299	0.1548
2	0.0301	0.1546
4	0.0303	0.1544
8	0.0307	0.154
15	0.031	0.1537
30	0.0312	0.1535
60	0.0314	0.1533
120		
240	0.0315	0.1532
480		
960		
1440	0.0316	0.1531

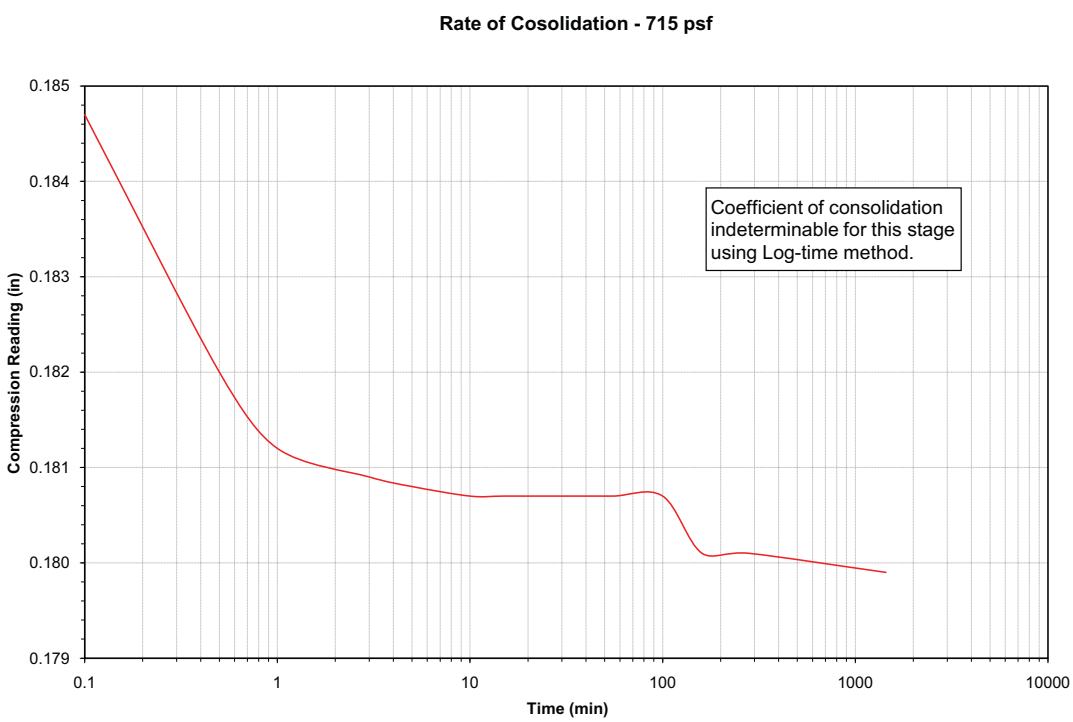
Load: 32000g (Unload)

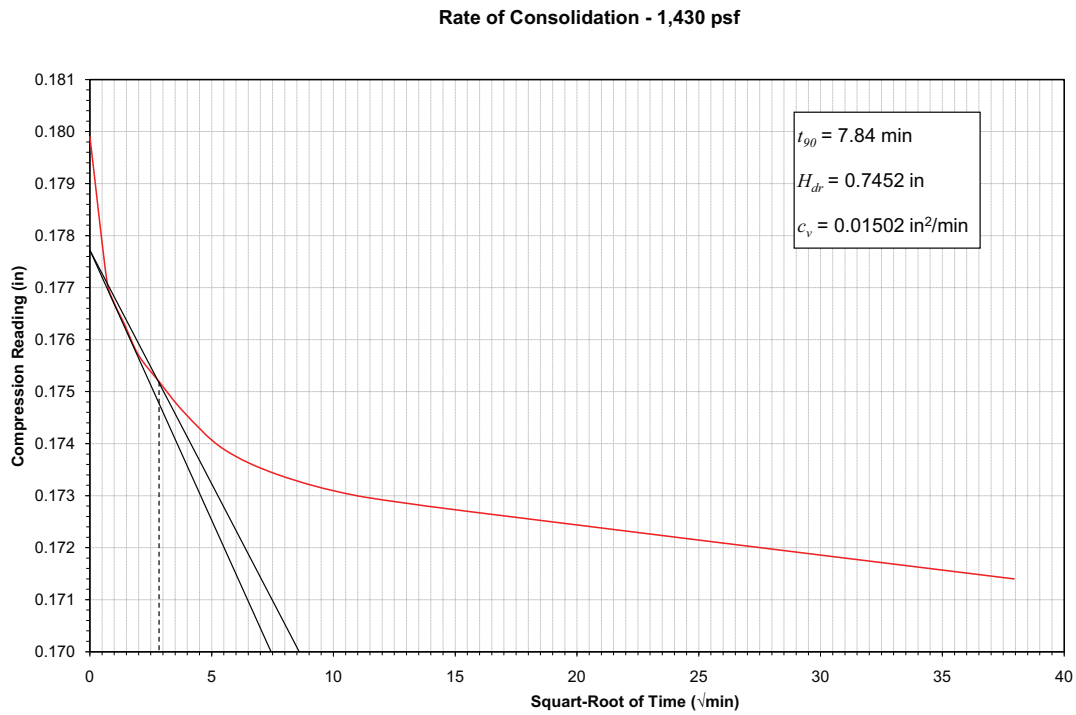
Time (min)	Compression Reading (in)	Strain, ε
0	0.0342	0.1505
0.5	0.0346	0.1501
1	0.0351	0.1496
2	0.0356	0.1491
4	0.0361	0.1486
8	0.0369	0.1478
15	0.0378	0.1469
30	0.0388	0.1459
60	0.0989	0.0858
120		
240		
480		
960		
1440	0.0407	0.144

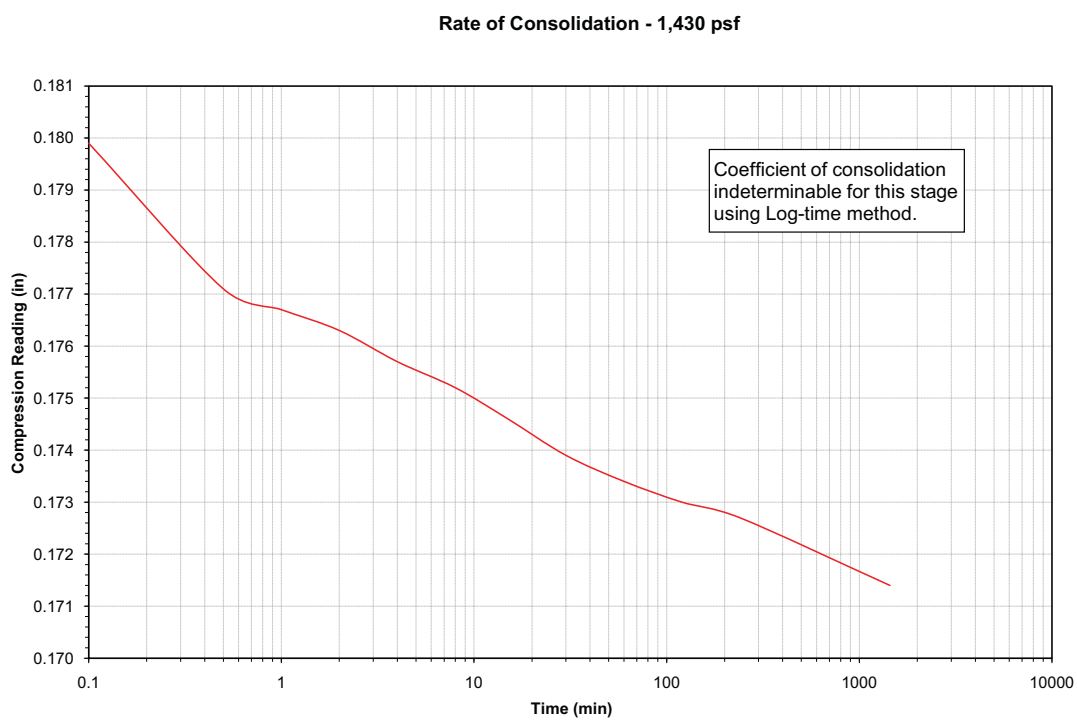
Load: 16000g (Unload)

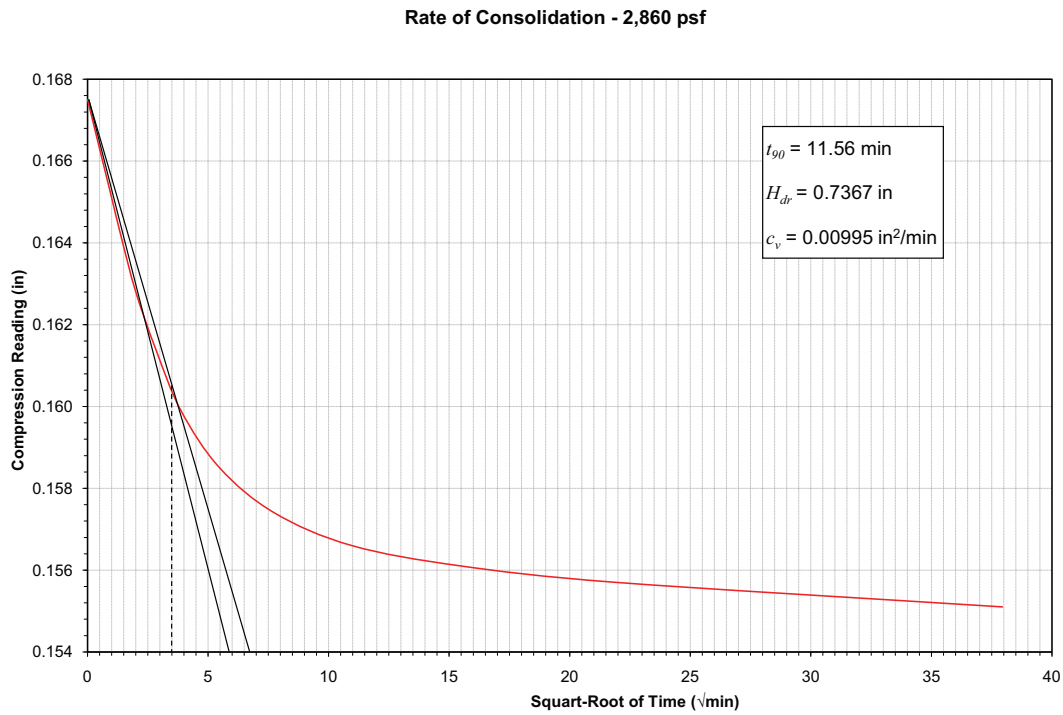
Time (min)	Compression Reading (in)	Strain, ε
0	0.0426	0.1421
0.5	0.0432	0.1415
1	0.0435	0.1412
2	0.0439	0.1408
4	0.0445	0.1402
8	0.0453	0.1394
15	0.0463	0.1384
30	0.0478	0.1369
60	0.0492	0.1355
120		
240	0.051	0.1337
480		
960		
1440	0.0517	0.133

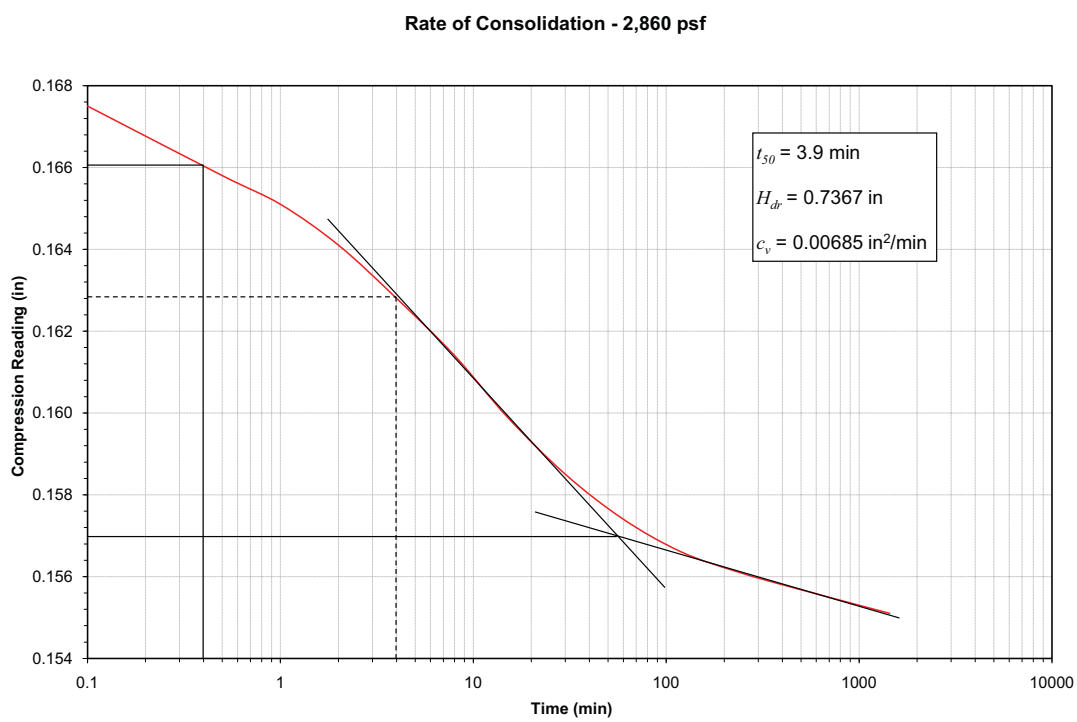

Rate of Cosolidation - 715 psf
t_{90} = 0.81 min
H_{dr} = 0.75 in
c_v = 0.14722 in²/min
Compression Reading (in)
0.185
0.184
0.183
0.182
0.181
0.180
0.179
0
5
10
15
20
25
30
35
40
Squart-Root of Time (√min)

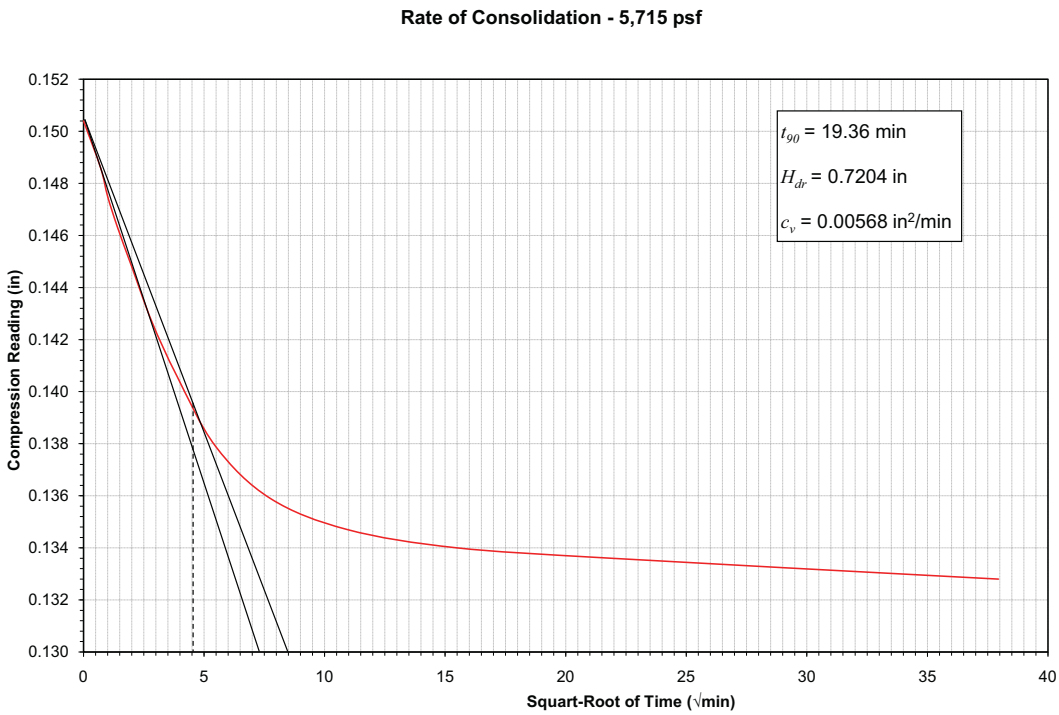

Rate of Cosolidation - 715 psf
Coefficient of consolidation indeterminable for this stage using Log-time method.
Compression Reading (in)
0.185
0.184
0.183
0.182
0.181
0.180
0.179
0.1
1
10
100
1000
10000
Time (min)

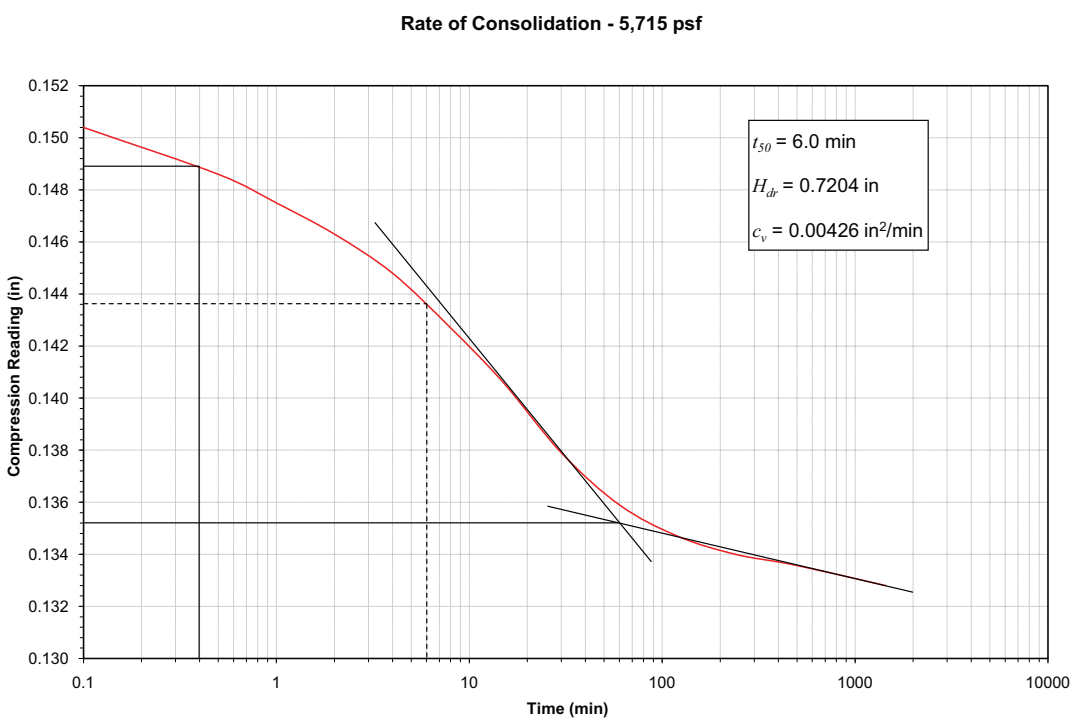

Rate of Consolidation - 1,430 psf
t_{90} = 7.84 min
H_{dr} = 0.7452 in
c_v = 0.01502 in²/min
Compression Reading (in)
Squart-Root of Time (√min)
0.181
0.180
0.179
0.178
0.177
0.176
0.175
0.174
0.173
0.172
0.171
0.170
0
5
10
15
20
25
30
35
40

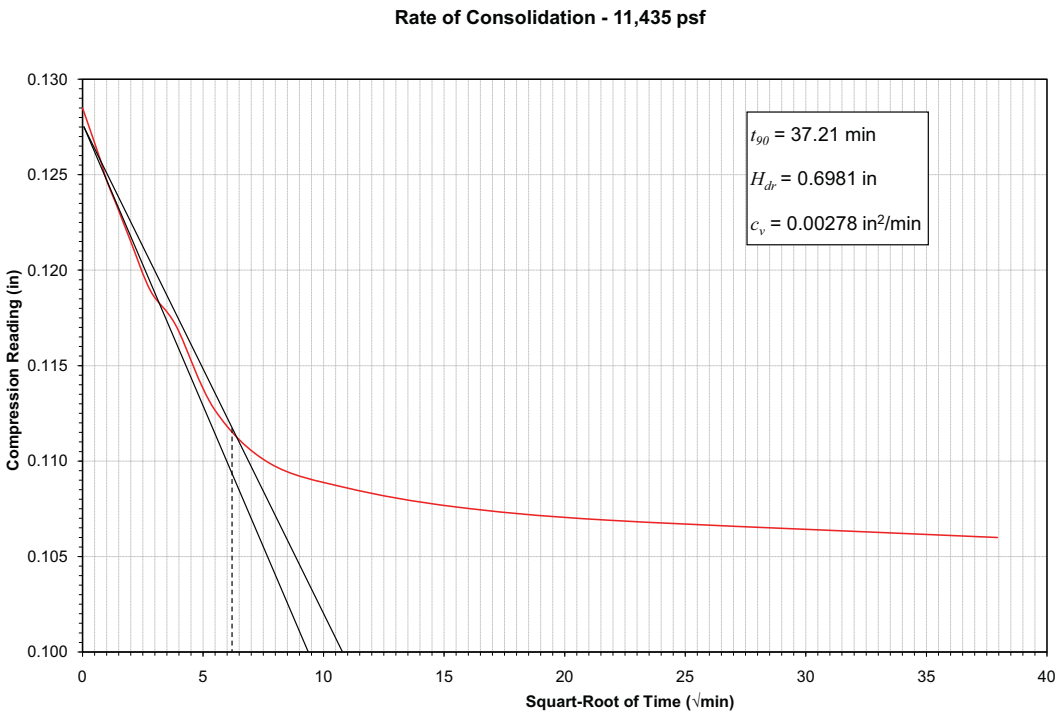

Rate of Consolidation - 1,430 psf
Coefficient of consolidation indeterminable for this stage using Log-time method.
Compression Reading (in)
Time (min)
0.181
0.180
0.179
0.178
0.177
0.176
0.175
0.174
0.173
0.172
0.171
0.170
0.1
1
10
100
1000
10000

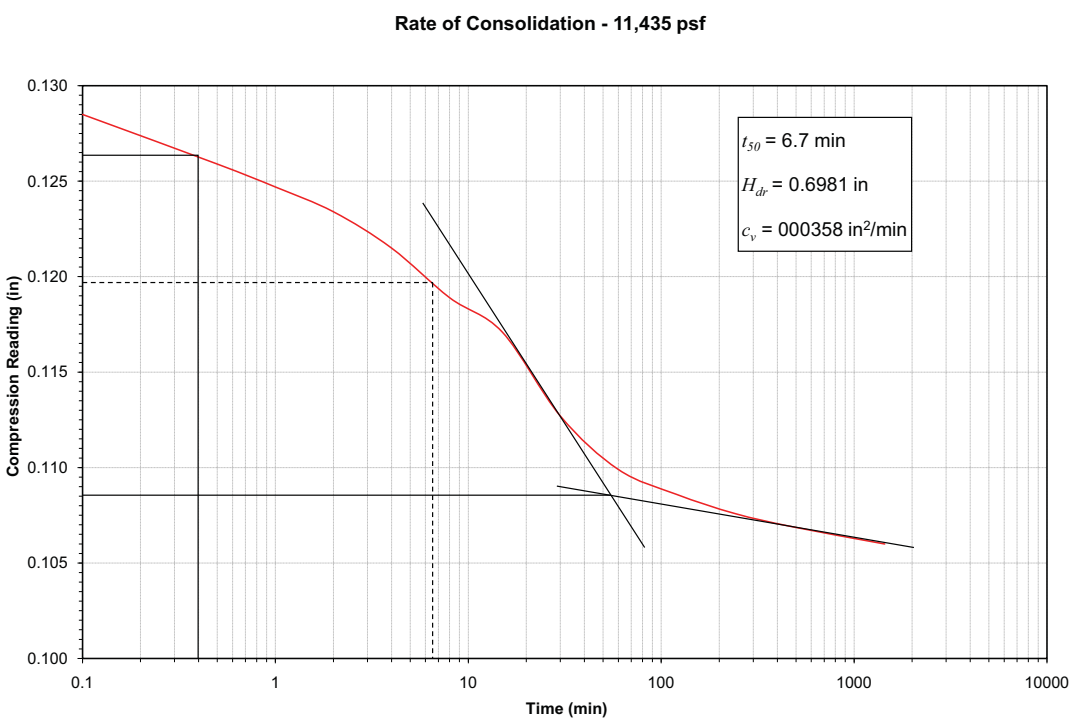

Rate of Consolidation - 2,860 psf
t_{90} = 11.56 min
H_{dr} = 0.7367 in
c_v = 0.00995 in²/min
Compression Reading (in)
Squart-Root of Time (√min)
0.168
0.166
0.164
0.162
0.160
0.158
0.156
0.154
0
5
10
15
20
25
30
35
40

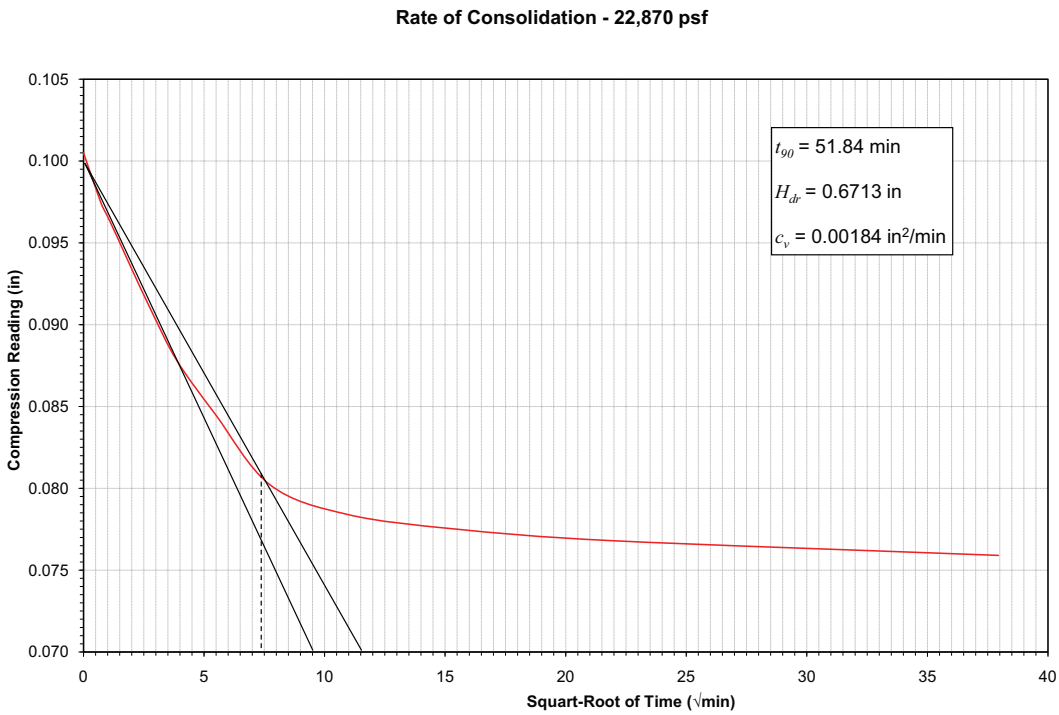

Rate of Consolidation - 2,860 psf
t_{50} = 3.9 min
H_{dr} = 0.7367 in
c_v = 0.00685 in²/min
Compression Reading (in)
Time (min)
0.168
0.166
0.164
0.162
0.160
0.158
0.156
0.154
0.1
1
10
100
1000
10000

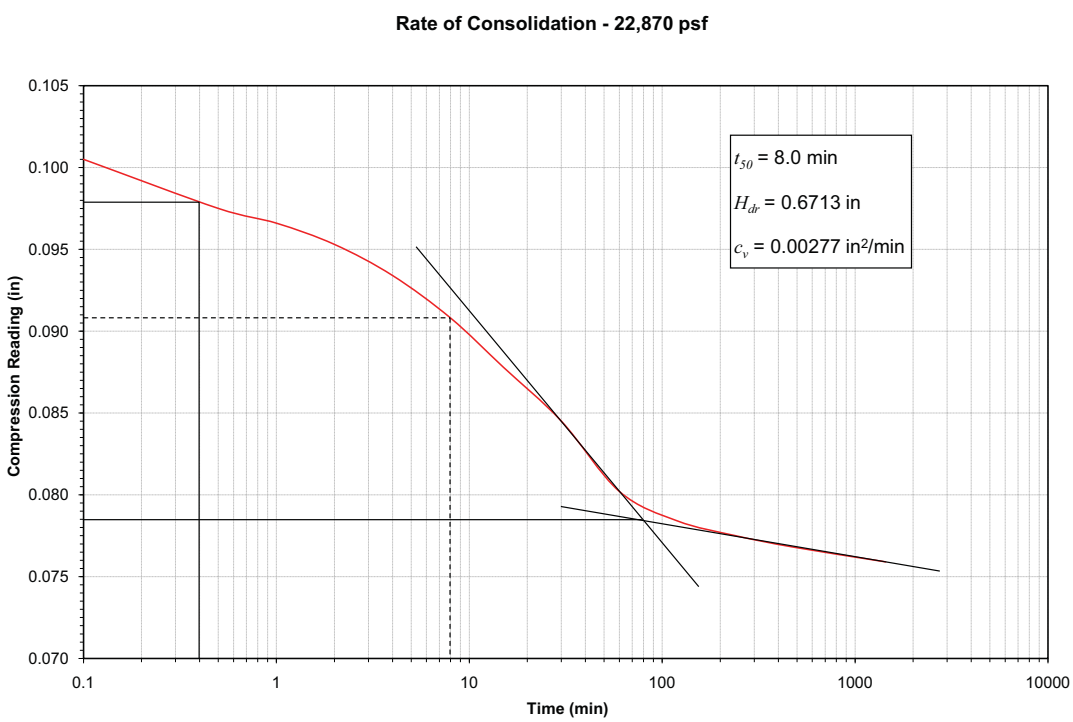

Rate of Consolidation - 5,715 psf
t_{90} = 19.36 min
H_{dr} = 0.7204 in
c_v = 0.00568 in²/min
Compression Reading (in)
Squart-Root of Time (√min)
0.152
0.150
0.148
0.146
0.144
0.142
0.140
0.138
0.136
0.134
0.132
0.130
0
5
10
15
20
25
30
35
40

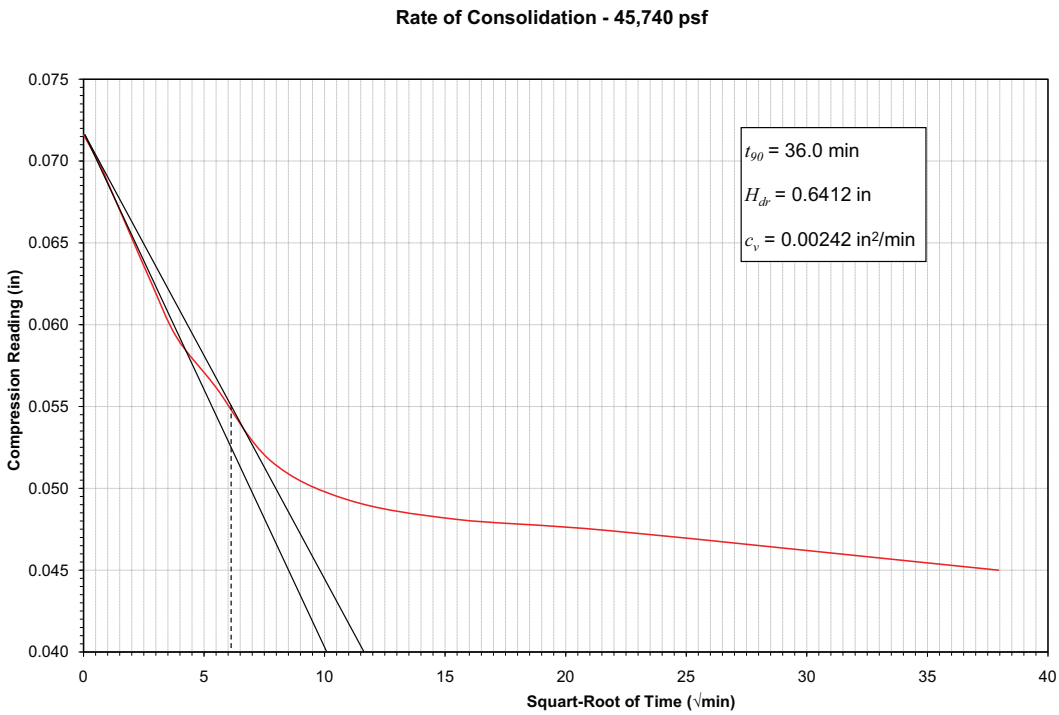

Rate of Consolidation - 5,715 psf
t_{50} = 6.0 min
H_{dr} = 0.7204 in
c_v = 0.00426 in²/min
Compression Reading (in)
Time (min)
0.152
0.150
0.148
0.146
0.144
0.142
0.140
0.138
0.136
0.134
0.132
0.130
0.1
1
10
100
1000
10000

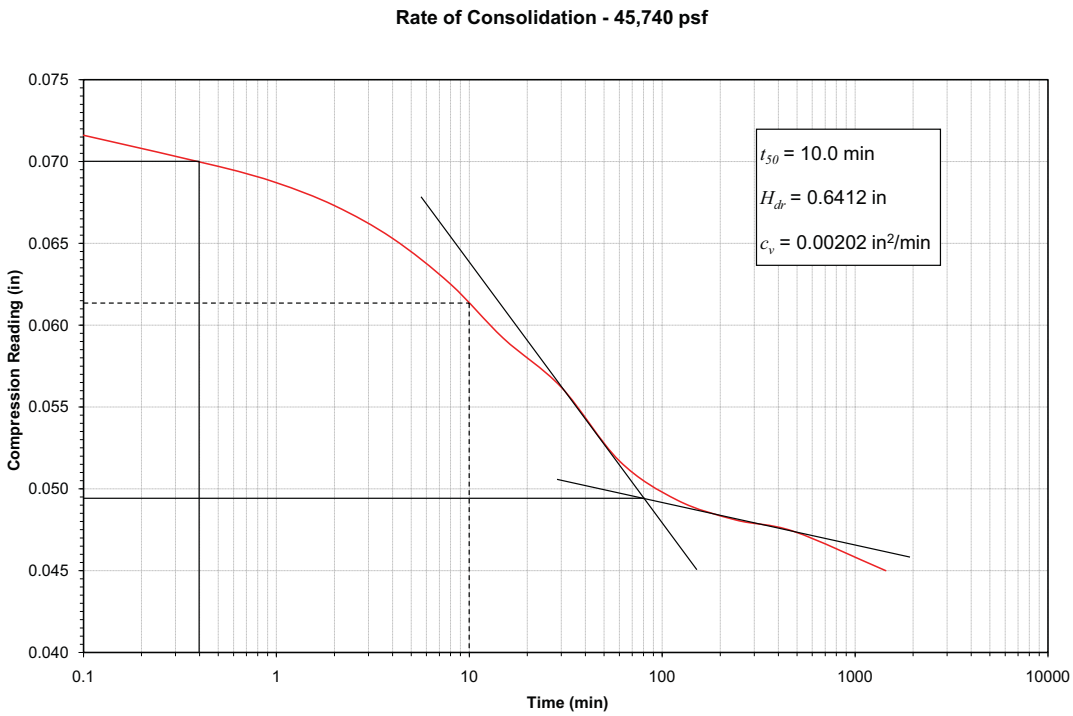

Rate of Consolidation - 11,435 psf
t_{90} = 37.21 min
H_{dr} = 0.6981 in
c_v = 0.00278 in²/min
Compression Reading (in)
0.130
0.125
0.120
0.115
0.110
0.105
0.100
0
5
10
15
20
25
30
35
40
Squart-Root of Time (√min)

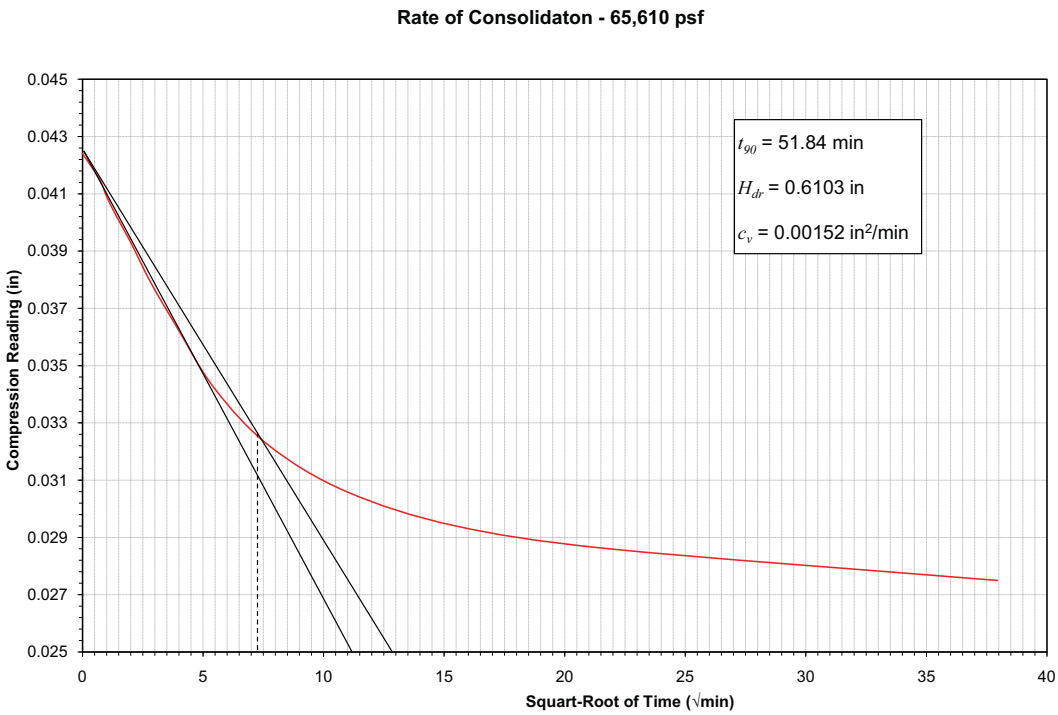

Rate of Consolidation - 11,435 psf
t_{50} = 6.7 min
H_{dr} = 0.6981 in
c_v = 000358 in²/min
Compression Reading (in)
0.130
0.125
0.120
0.115
0.110
0.105
0.100
0.1
1
10
100
1000
10000
Time (min)

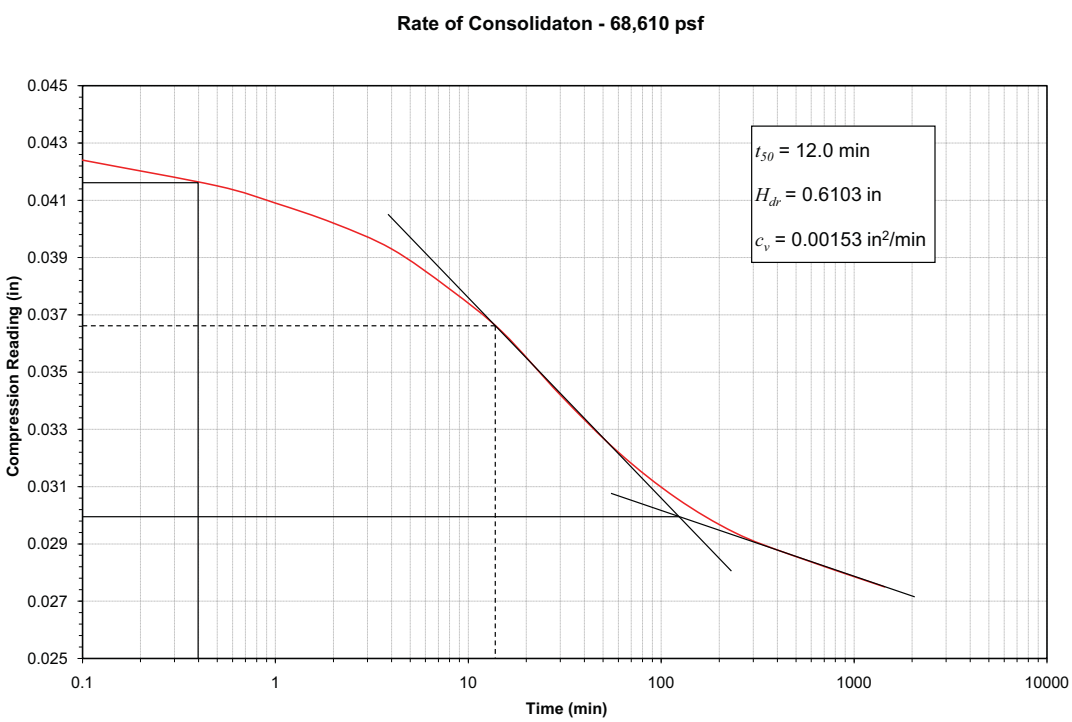

Rate of Consolidation - 22,870 psf
t_{90} = 51.84 min
H_{dr} = 0.6713 in
c_v = 0.00184 in²/min
Compression Reading (in)
Squart-Root of Time (√min)
0.105
0.100
0.095
0.090
0.085
0.080
0.075
0.070
0
5
10
15
20
25
30
35
40

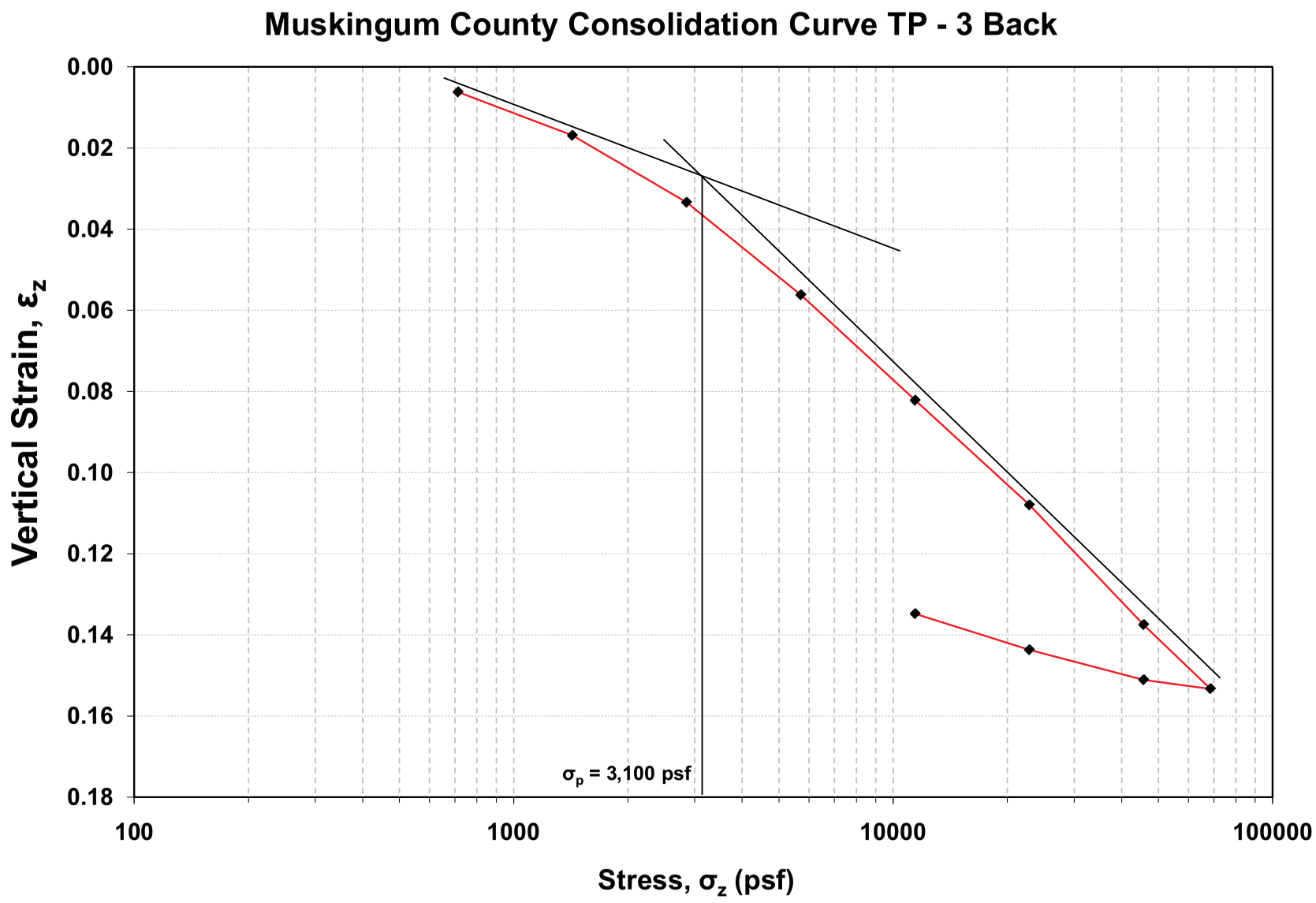

Rate of Consolidation - 22,870 psf
t_{50} = 8.0 min
H_{dr} = 0.6713 in
c_v = 0.00277 in²/min
Compression Reading (in)
Time (min)
0.105
0.100
0.095
0.090
0.085
0.080
0.075
0.070
0.1
1
10
100
1000
10000

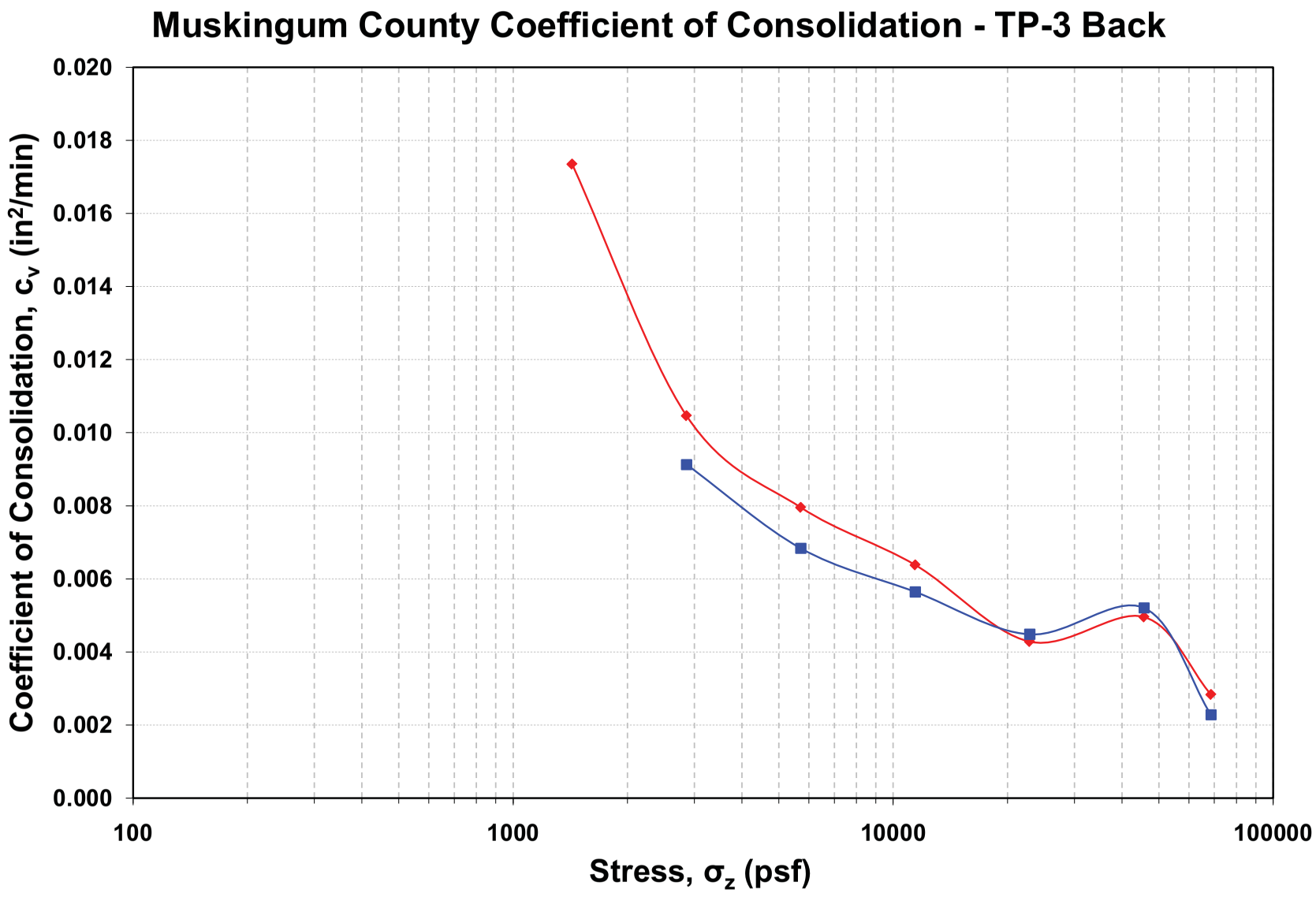

Rate of Consolidation - 45,740 psf
t_{90} = 36.0 min
H_{dr} = 0.6412 in
c_v = 0.00242 in²/min
Compression Reading (in)
Squart-Root of Time (√min)
0.075
0.070
0.065
0.060
0.055
0.050
0.045
0.040
0
5
10
15
20
25
30
35
40


Rate of Consolidation - 45,740 psf
t_{50} = 10.0 min
H_{dr} = 0.6412 in
c_v = 0.00202 in²/min
Compression Reading (in)
Time (min)
0.075
0.070
0.065
0.060
0.055
0.050
0.045
0.040
0.1
1
10
100
1000
10000


Rate of Consolidaton - 65,610 psf
t_{90} = 51.84 min
H_{dr} = 0.6103 in
c_v = 0.00152 in²/min
Compression Reading (in)
Squart-Root of Time (√min)
0.045
0.043
0.041
0.039
0.037
0.035
0.033
0.031
0.029
0.027
0.025
0
5
10
15
20
25
30
35
40


Rate of Consolidaton - 68,610 psf
t_{50} = 12.0 min
H_{dr} = 0.6103 in
c_v = 0.00153 in²/min
Compression Reading (in)
Time (min)
0.045
0.043
0.041
0.039
0.037
0.035
0.033
0.031
0.029
0.027
0.025
0.1
1
10
100
1000
10000


Muskingum County Consolidation Curve TP - 3 Back
Vertical Strain, ε_z
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
σ_p = 3,100 psf
100
1000
10000
100000
Stress, σ_z (psf)


Muskingum County Coefficient of Consolidation - TP-3 Back
Coefficient of Consolidation, c_v (in^2/min)
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
100
1000
10000
100000
Stress, σ_z (psf)

TP-3 Consolidation Compression Data

Load: 1000g

Time (min)	Compression Reading (in)	Strain, ε
0	0.0626	0
0.5	0.0650	0.0024
1	0.0659	0.0033
5	0.0665	0.0039
10	0.0670	0.0044
20	0.0676	0.005
30	0.0680	0.0054
50	0.0682	0.0056
110	0.0685	0.0059
160		
280		
1440	0.0688	0.0062

Load: 2000g

Time (min)	Compression Reading (in)	Strain, ε
0	0.0688	0.0062
0.5	0.0716	0.009
1	0.0721	0.0095
2	0.0728	0.0102
4	0.0736	0.011
8	0.0745	0.0119
15	0.0754	0.0128
30	0.0763	0.0137
60	0.0771	0.0145
120	0.0776	0.015
240	0.078	0.0154
480		0.0626
960		
1440	0.0795	0.0169

Load: 4000g

Time (min)	Compression Reading (in)	Strain, ε
0	0.0815	0.0189
0.5	0.084	0.0214
1	0.0849	0.0223
2	0.086	0.0234
4	0.0874	0.0248
8	0.0889	0.0263
15	0.0904	0.0278
30	0.0919	0.0293
60	0.093	0.0304
120	0.0939	0.0313
240	0.0947	0.0321
480	0.0953	0.0327
960		
1440	0.096	0.0334

Load: 8000g

Time (min)	Compression Reading (in)	Strain, ε
0	0.0996	0.037
0.5	0.1021	0.0395
1	0.1032	0.0406
2	0.1047	0.0421
4	0.1066	0.044
8	0.109	0.0464
15	0.1114	0.0488
30	0.1137	0.0511
60	0.1154	0.0528
120	0.1165	0.0539
240	0.1174	0.0548
480	0.118	0.0554
960		
1440	0.1188	0.0562

Load: 16000g

Time (min)	Compression Reading (in)	Strain, ε
0	0.1222	0.0596
0.5	0.1252	0.0626
1	0.1264	0.0638
2	0.1283	0.0657
4		0.0626
8	0.1337	0.0711
15	0.1365	0.0739
30	0.1393	0.0767
60	0.1412	0.0786
120	0.1424	0.0798
240	0.1432	0.0806
480	0.1439	0.0813
960		
1440	0.1448	0.0822

Load: 32000g

Time (min)	Compression Reading (in)	Strain, ε
0	0.149	0.0864
0.5	0.1514	0.0888
1	0.1526	0.09
2	0.1542	0.0916
4	0.1564	0.0938
8	0.1593	0.0967
15	0.1622	0.0996
30	0.1648	0.1022
60	0.1667	0.1041
120	0.168	0.1054
240	0.1689	0.1063
480	0.1696	0.107
960		
1440	0.1706	0.108

TP-3 Consolidation Compression Data

Load: 64000g

Time (min)	Compression Reading (in)	Strain, ε
0	0.1756	0.113
0.5	0.1782	0.1156
1	0.1797	0.1171
2	0.1818	0.1192
4	0.1846	0.122
8	0.188	0.1254
15	0.1914	0.1288
30	0.1944	0.1318
60	0.1965	0.1339
120	0.1978	0.1352
240	0.1987	0.1361
480	0.1991	0.1365
960		
1440	0.2001	0.1375

Load: 96000g

Time (min)	Compression Reading (in)	Strain, ε
0	0.2027	0.1401
0.5	0.2038	0.1412
1	0.2045	0.1419
2	0.2053	0.1427
4	0.2055	0.1429
8	0.2085	0.1459
15	0.2098	0.1472
30	0.2116	0.149
60	0.2131	0.1505
120	0.2135	0.1509
240	0.2151	0.1525
480	0.2155	0.1529
960		
1440	0.2159	0.1533

Load: 64000g (Unload)

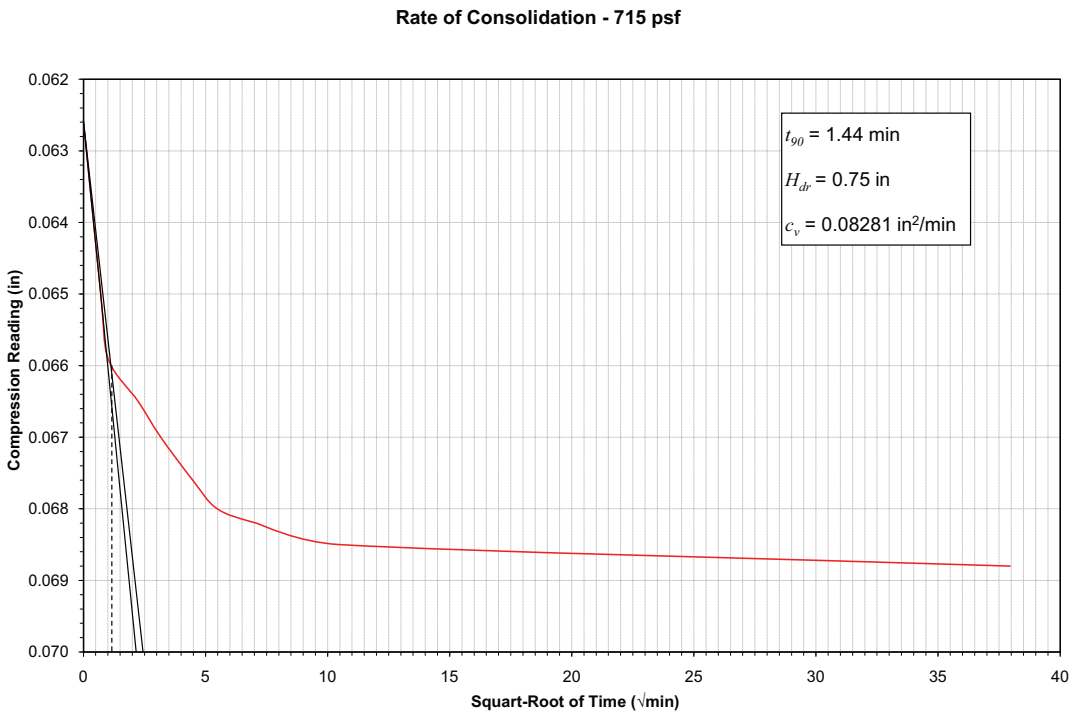
Time (min)	Compression Reading (in)	Strain, ε
0	0.2149	0.1523
0.5	0.2147	0.1521
1	0.2145	0.1519
2	0.2144	0.1518
4	0.2142	0.1516
8	0.2141	0.1515
15	0.214	0.1514
30	0.2139	0.1513
60	0.2139	0.1513
120		0.0626
240	0.2138	0.1512
480		0.0626
960		
1440	0.2137	0.1511

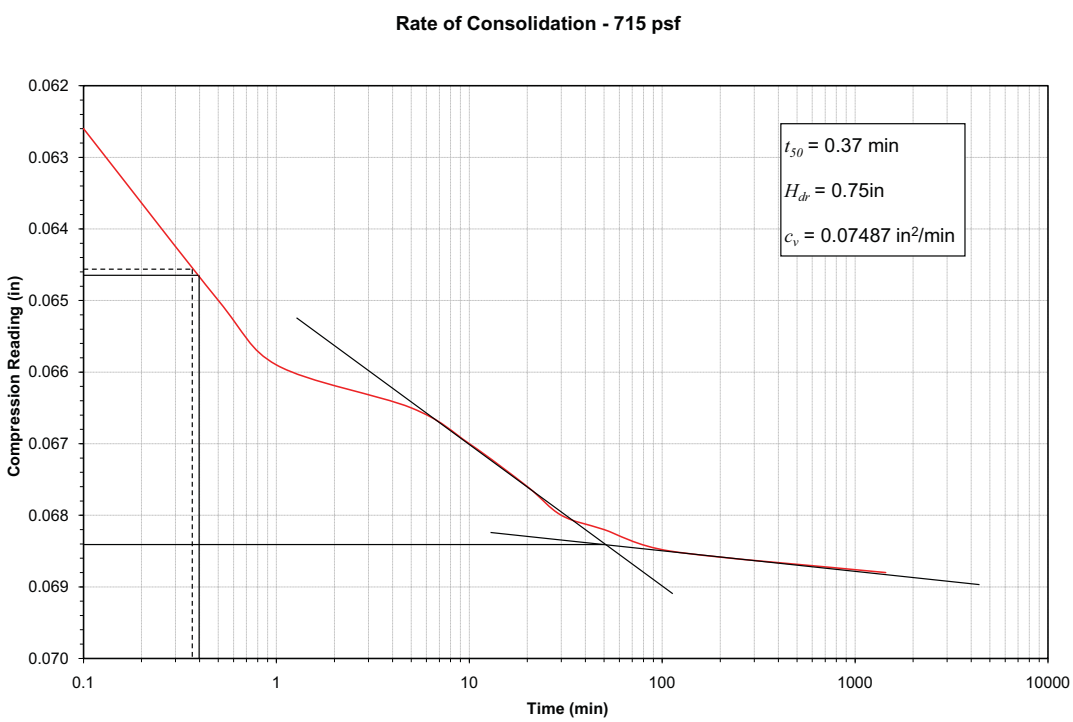
Load: 32000g (Unload)

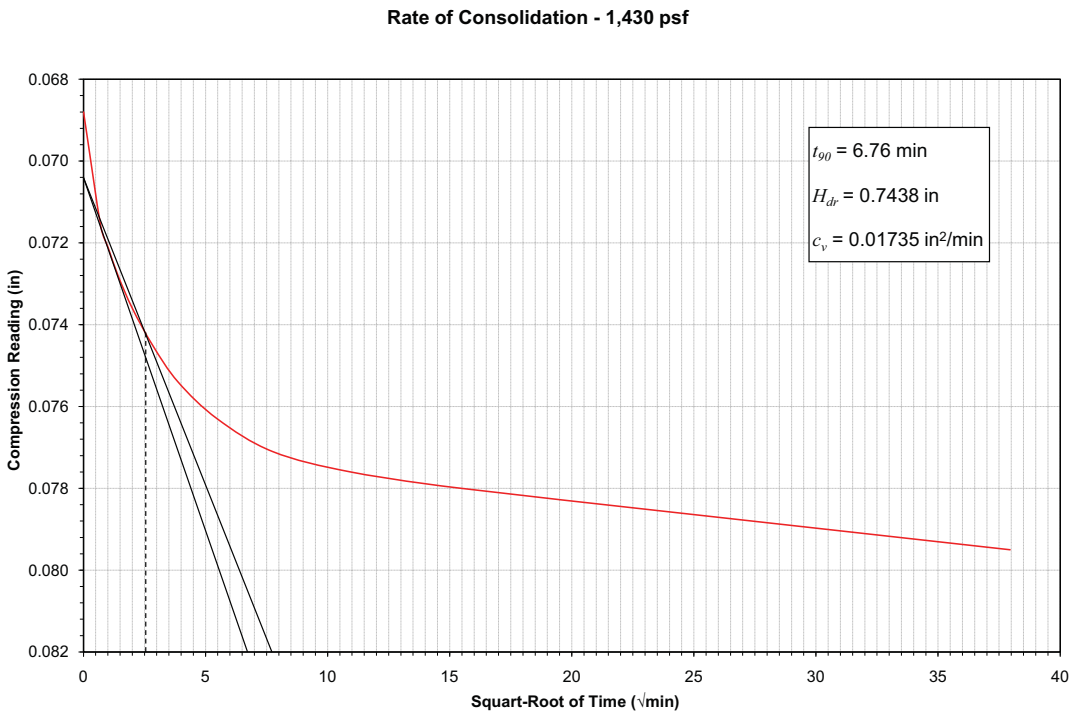
Time (min)	Compression Reading (in)	Strain, ε
0	0.2108	0.1482
0.5	0.21	0.1474
1	0.2097	0.1471
2	0.2093	0.1467
4	0.2087	0.1461
8	0.2081	0.1455
15	0.2076	0.145
30	0.2072	0.1446
60	0.2069	0.1443
120		
240		
480		
960		
1440	0.2063	0.1437

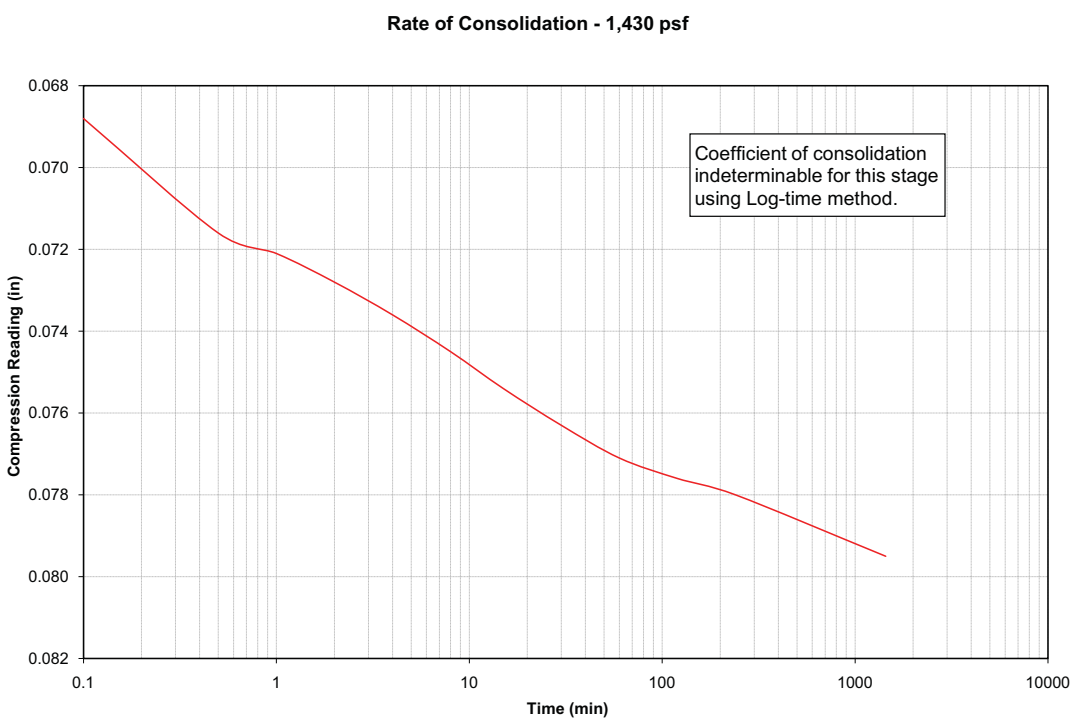
Load: 16000g (Unload)

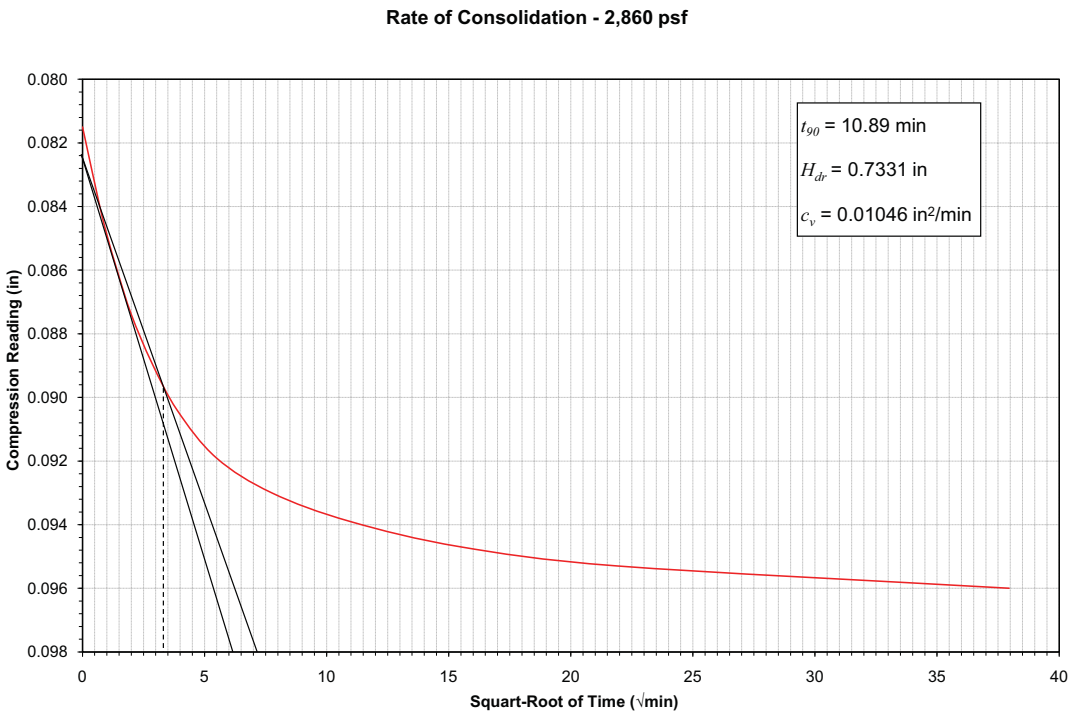
Time (min)	Compression Reading (in)	Strain, ε
0	0.2043	0.1417
0.5	0.2037	0.1411
1	0.2033	0.1407
2	0.2028	0.1402
4	0.2021	0.1395
8	0.2013	0.1387
15	0.2004	0.1378
30	0.1994	0.1368
60	0.1987	0.1361
120		
240	0.1979	0.1353
480		
960		
1440	0.1974	0.1348

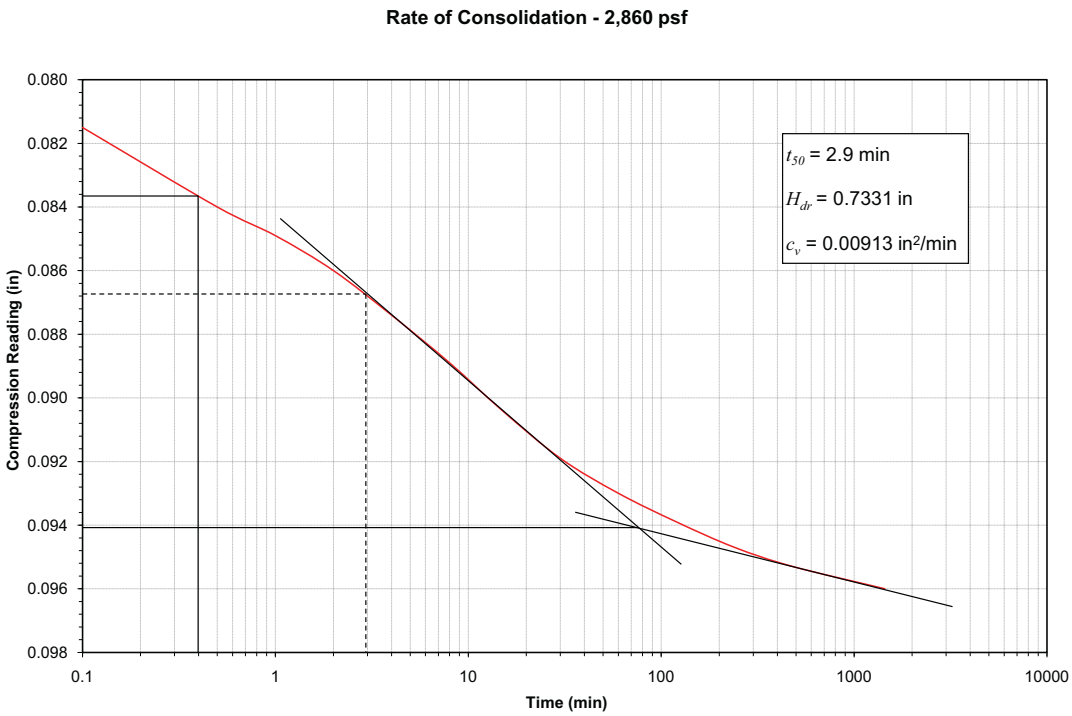

Rate of Consolidation - 715 psf
t_{90} = 1.44 min
H_{dr} = 0.75 in
c_v = 0.08281 in²/min
Compression Reading (in)
0.062
0.063
0.064
0.065
0.066
0.067
0.068
0.069
0.070
0
5
10
15
20
25
30
35
40
Squart-Root of Time (√min)

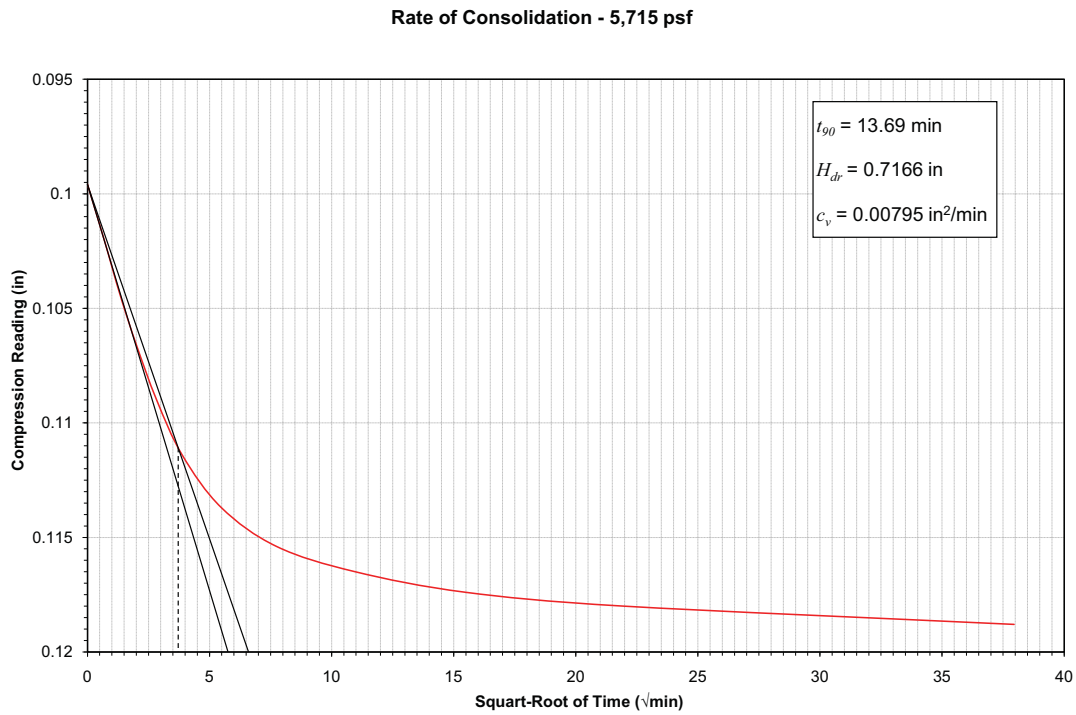

Rate of Consolidation - 715 psf
t_{50} = 0.37 min
H_{dr} = 0.75in
c_v = 0.07487 in²/min
Compression Reading (in)
0.062
0.063
0.064
0.065
0.066
0.067
0.068
0.069
0.070
0.1
1
10
100
1000
10000
Time (min)

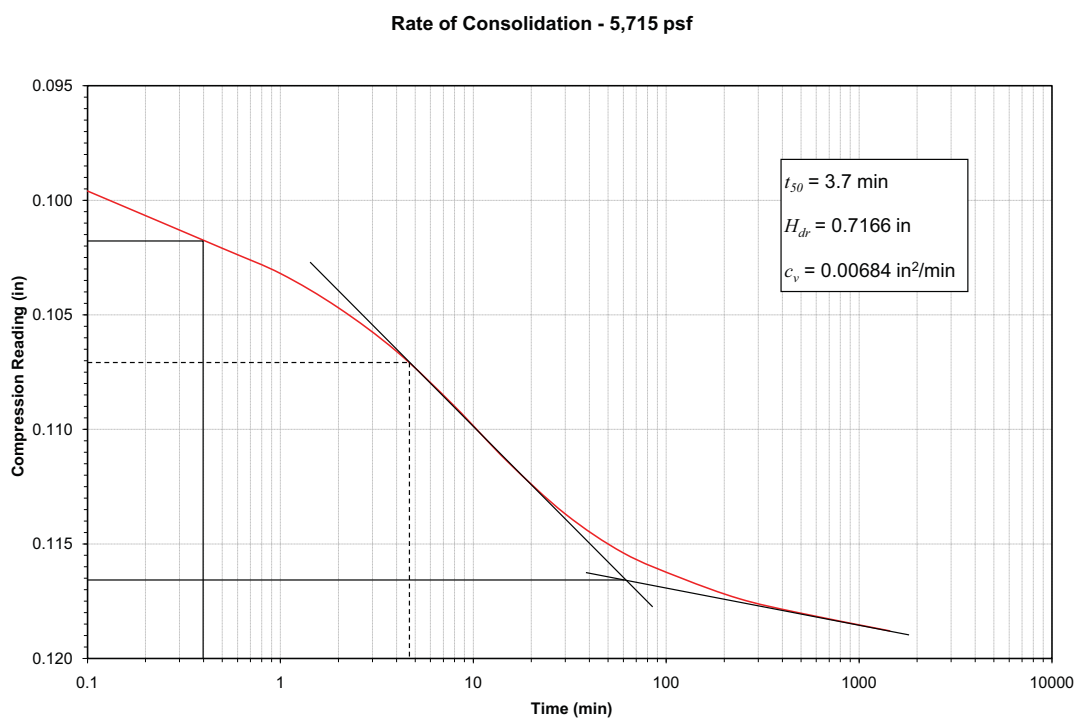

Rate of Consolidation - 1,430 psf
t_{90} = 6.76 min
H_{dr} = 0.7438 in
c_v = 0.01735 in²/min
Compression Reading (in)
0.068
0.070
0.072
0.074
0.076
0.078
0.080
0.082
0
5
10
15
20
25
30
35
40
Squart-Root of Time (√min)

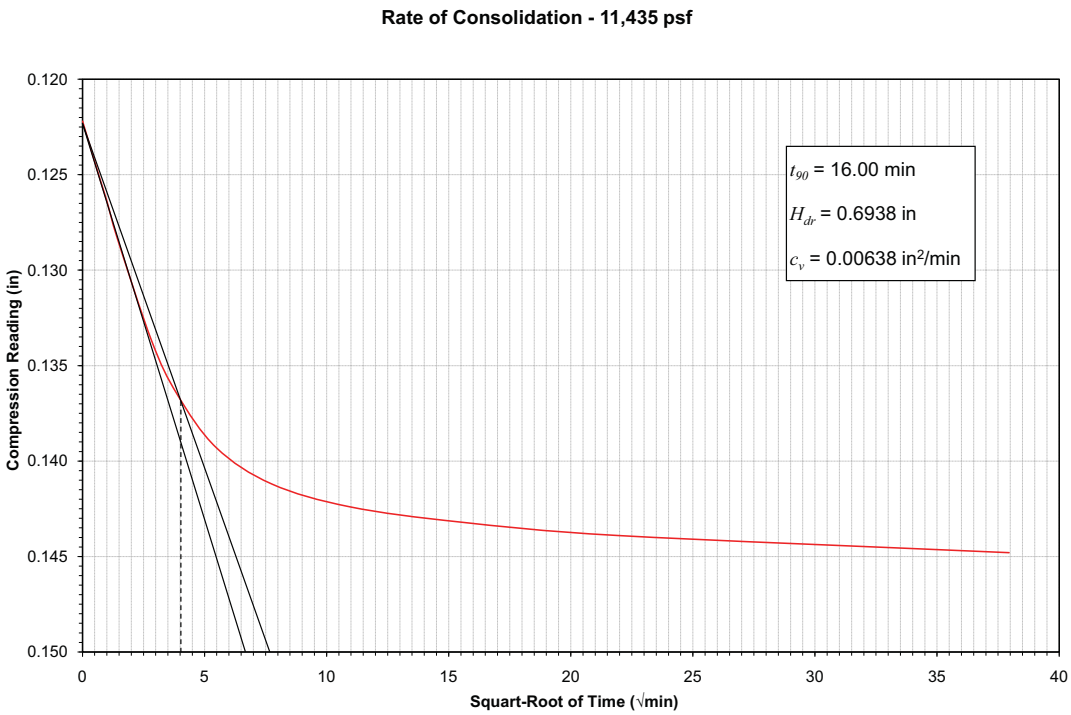

Rate of Consolidation - 1,430 psf
Coefficient of consolidation indeterminable for this stage using Log-time method.
Compression Reading (in)
0.068
0.070
0.072
0.074
0.076
0.078
0.080
0.082
0.1
1
10
100
1000
10000
Time (min)

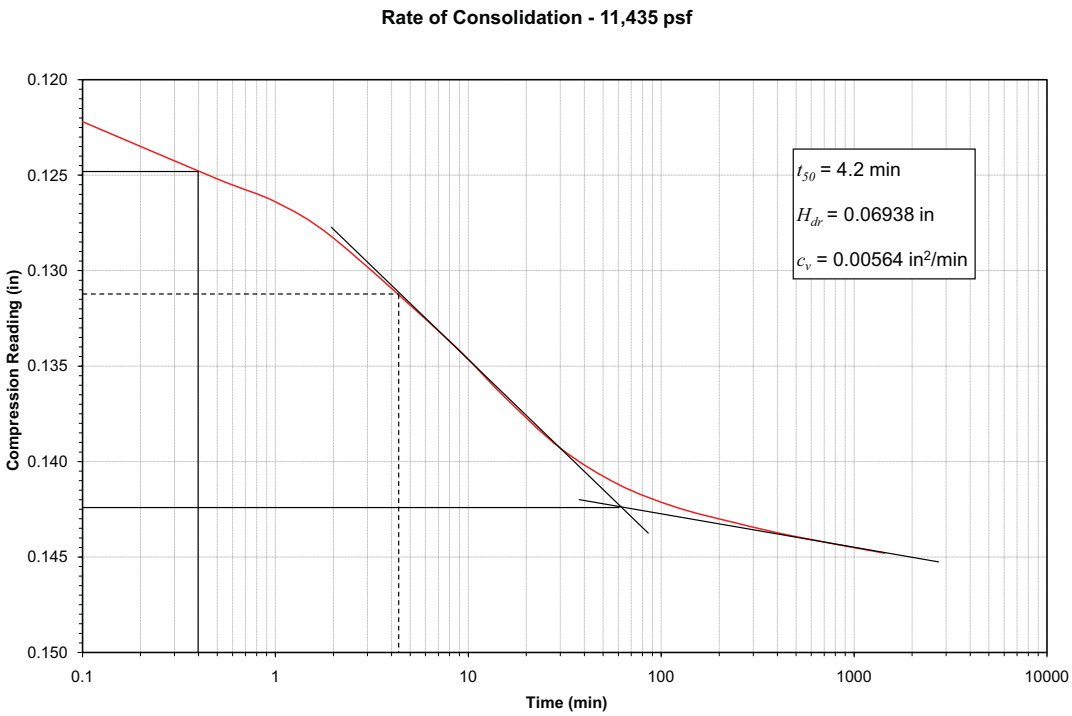

Rate of Consolidation - 2,860 psf
t_{90} = 10.89 min
H_{dr} = 0.7331 in
c_v = 0.01046 in²/min
Compression Reading (in)
Squart-Root of Time (√min)
0.080
0.082
0.084
0.086
0.088
0.090
0.092
0.094
0.096
0.098
0
5
10
15
20
25
30
35
40

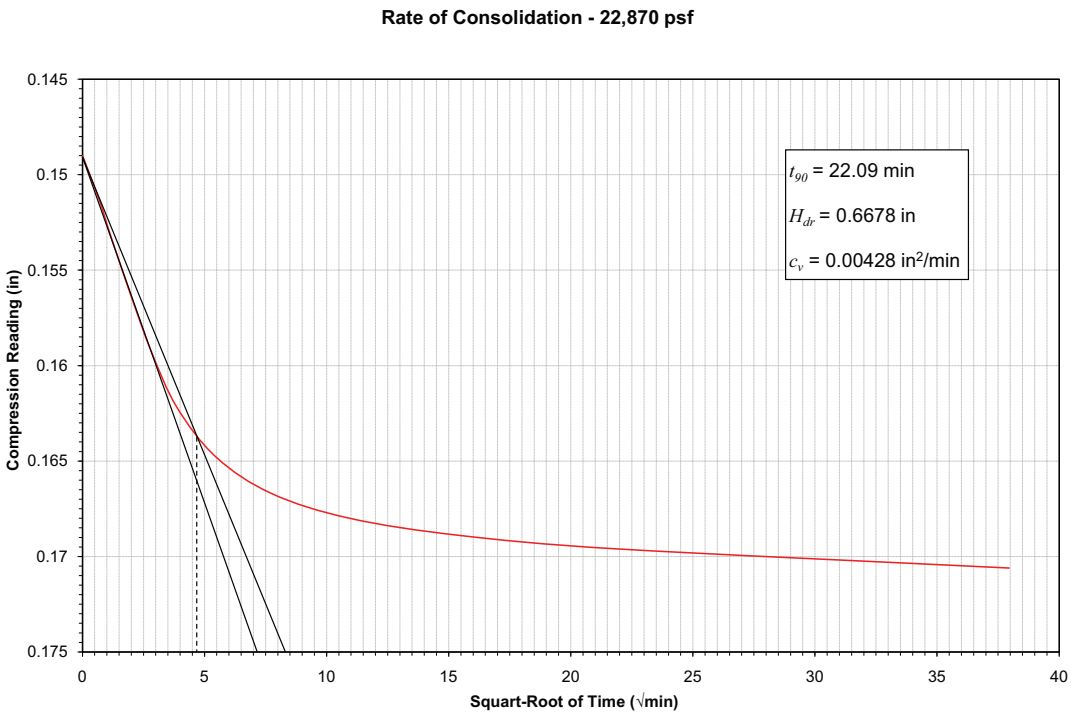

Rate of Consolidation - 2,860 psf
t_{50} = 2.9 min
H_{dr} = 0.7331 in
c_v = 0.00913 in²/min
Compression Reading (in)
Time (min)
0.080
0.082
0.084
0.086
0.088
0.090
0.092
0.094
0.096
0.098
0.1
1
10
100
1000
10000

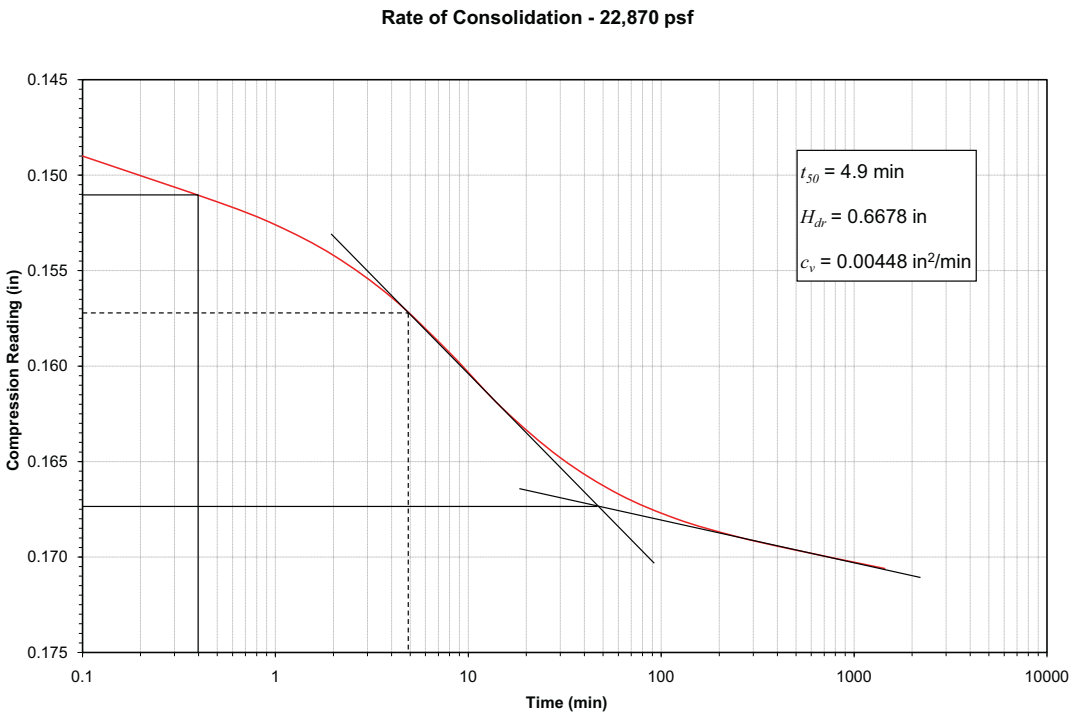

Rate of Consolidation - 5,715 psf
t_{90} = 13.69 min
H_{dr} = 0.7166 in
c_v = 0.00795 in²/min
Compression Reading (in)
0.095
0.1
0.105
0.11
0.115
0.12
0
5
10
15
20
25
30
35
40
Squart-Root of Time (√min)

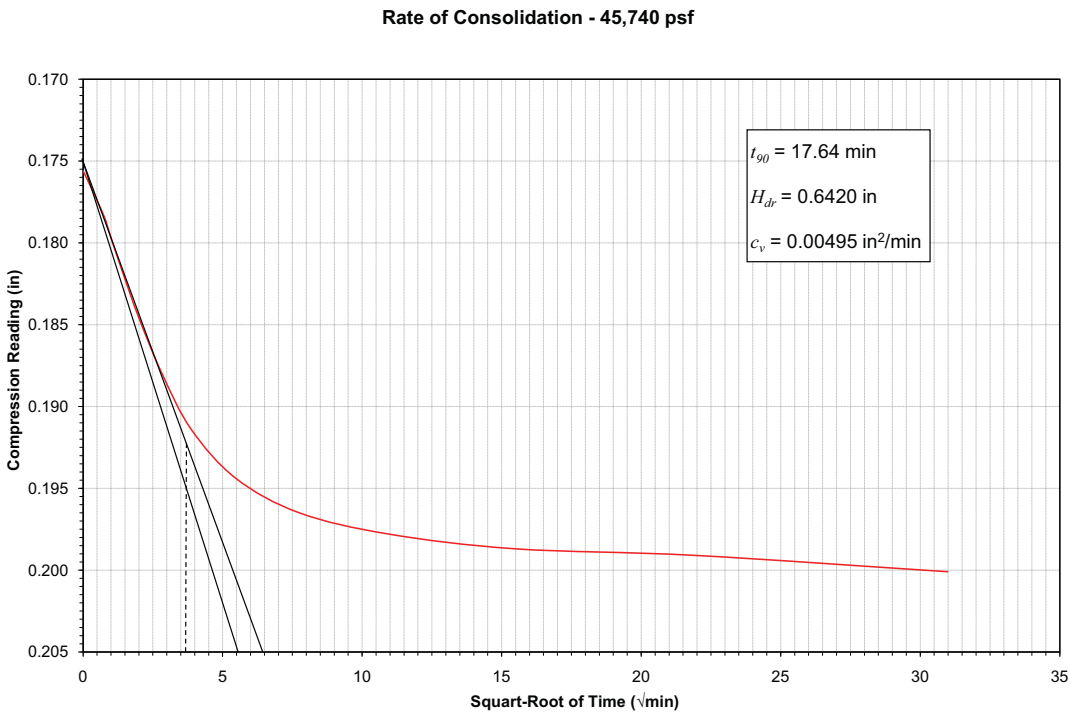

Rate of Consolidation - 5,715 psf
t_{50} = 3.7 min
H_{dr} = 0.7166 in
c_v = 0.00684 in²/min
Compression Reading (in)
0.095
0.100
0.105
0.110
0.115
0.120
0.1
1
10
100
1000
10000
Time (min)

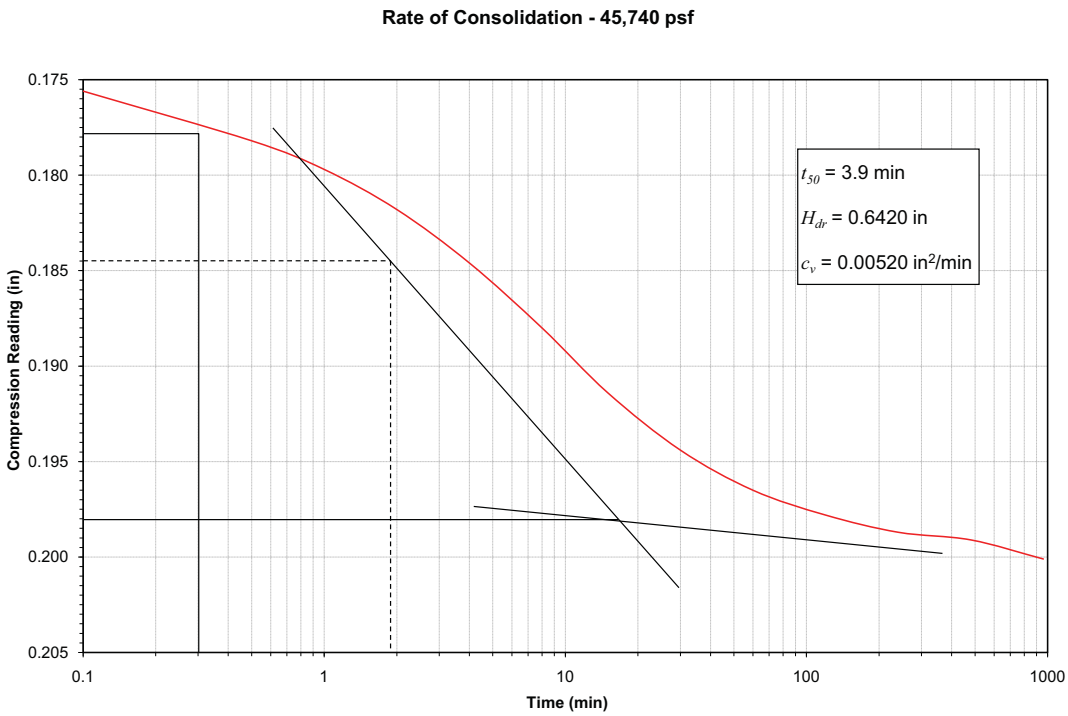

Rate of Consolidation - 11,435 psf
t_{90} = 16.00 min
H_{dr} = 0.6938 in
c_v = 0.00638 in²/min
Compression Reading (in)
0.120
0.125
0.130
0.135
0.140
0.145
0.150
0
5
10
15
20
25
30
35
40
Squart-Root of Time (√min)

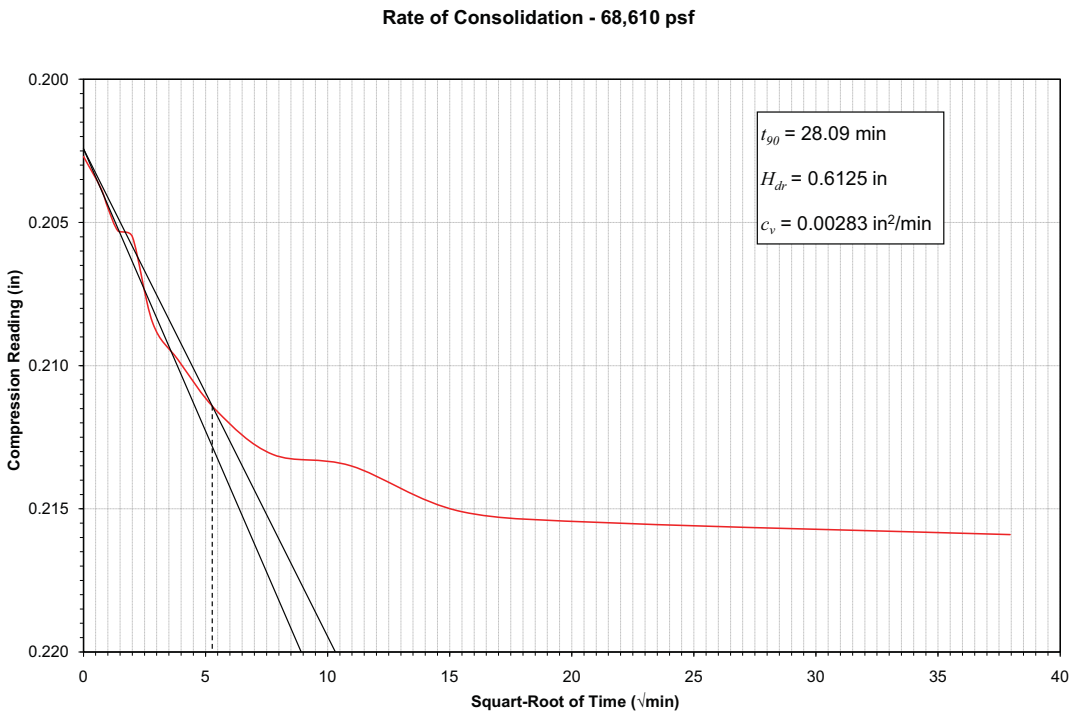

Rate of Consolidation - 11,435 psf
t_{50} = 4.2 min
H_{dr} = 0.06938 in
c_v = 0.00564 in²/min
Compression Reading (in)
0.120
0.125
0.130
0.135
0.140
0.145
0.150
0.1
1
10
100
1000
10000
Time (min)

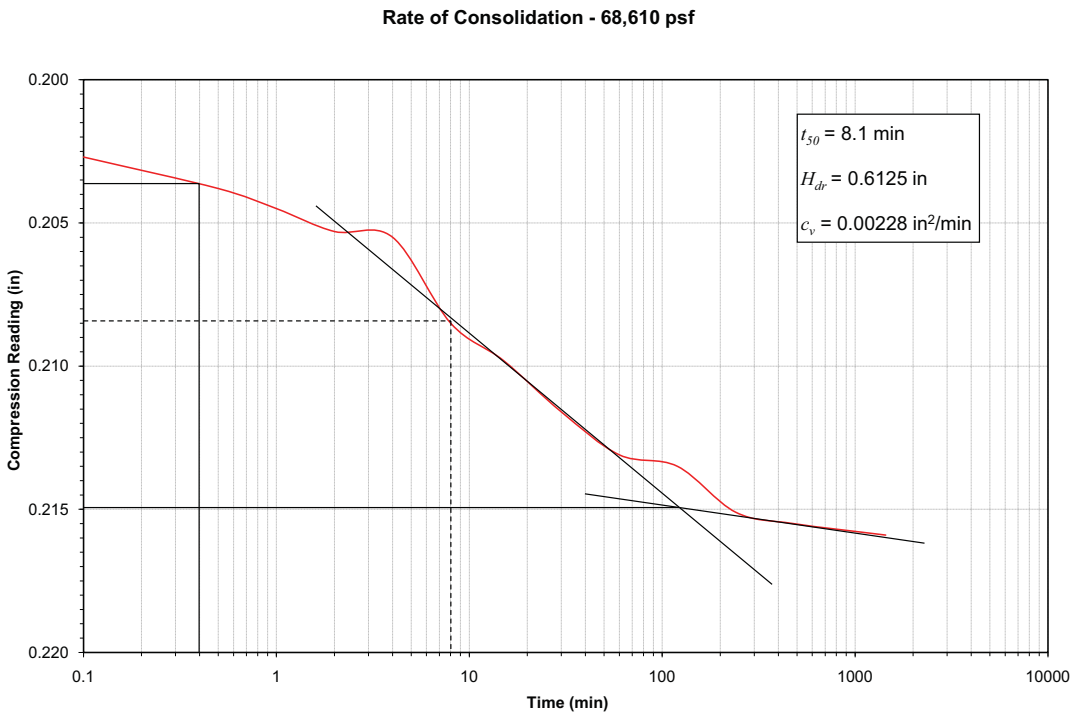

Rate of Consolidation - 22,870 psf
t_{90} = 22.09 min
H_{dr} = 0.6678 in
c_v = 0.00428 in²/min
Compression Reading (in)
Squart-Root of Time (√min)
0.145
0.15
0.155
0.16
0.165
0.17
0.175
0
5
10
15
20
25
30
35
40


Rate of Consolidation - 22,870 psf
t_{50} = 4.9 min
H_{dr} = 0.6678 in
c_v = 0.00448 in²/min
Compression Reading (in)
Time (min)
0.145
0.150
0.155
0.160
0.165
0.170
0.175
0.1
1
10
100
1000
10000

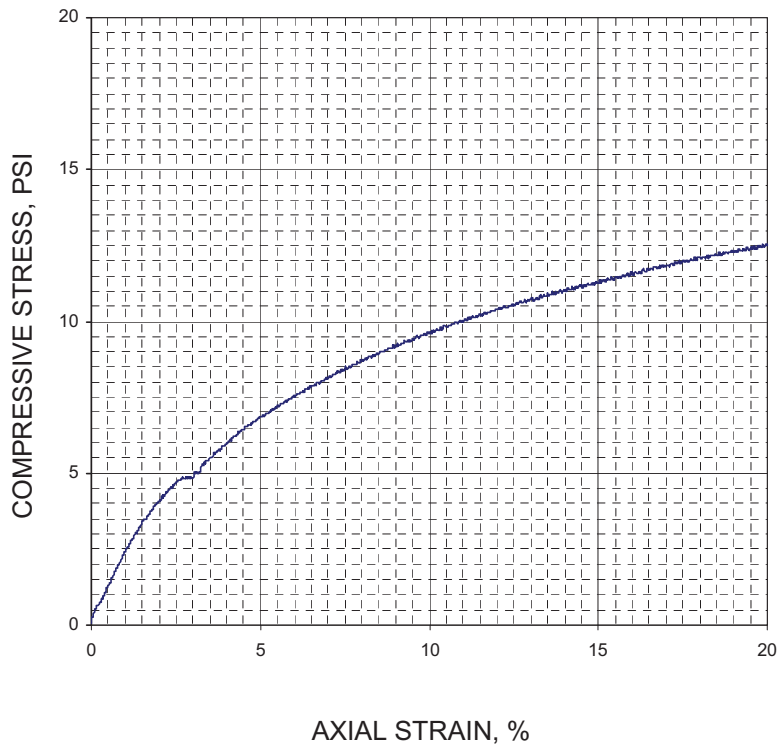

Rate of Consolidation - 45,740 psf
t_{90} = 17.64 min
H_{dr} = 0.6420 in
c_v = 0.00495 in²/min
Compression Reading (in)
0.170
0.175
0.180
0.185
0.190
0.195
0.200
0.205
0
5
10
15
20
25
30
35
Squart-Root of Time (√min)


Rate of Consolidation - 45,740 psf
t_{50} = 3.9 min
H_{dr} = 0.6420 in
c_v = 0.00520 in²/min
Compression Reading (in)
0.175
0.180
0.185
0.190
0.195
0.200
0.205
0.1
1
10
100
1000
Time (min)


Rate of Consolidation - 68,610 psf
t_{90} = 28.09 min
H_{dr} = 0.6125 in
c_v = 0.00283 in²/min
Compression Reading (in)
0.200
0.205
0.210
0.215
0.220
0
5
10
15
20
25
30
35
40
Squart-Root of Time (√min)


Rate of Consolidation - 68,610 psf
t_{50} = 8.1 min
H_{dr} = 0.6125 in
c_v = 0.00228 in²/min
Compression Reading (in)
0.200
0.205
0.210
0.215
0.220
0.1
1
10
100
1000
10000
Time (min)

THE OHIO STATE UNIVERSITY SOIL MECHANICS LABORATORY

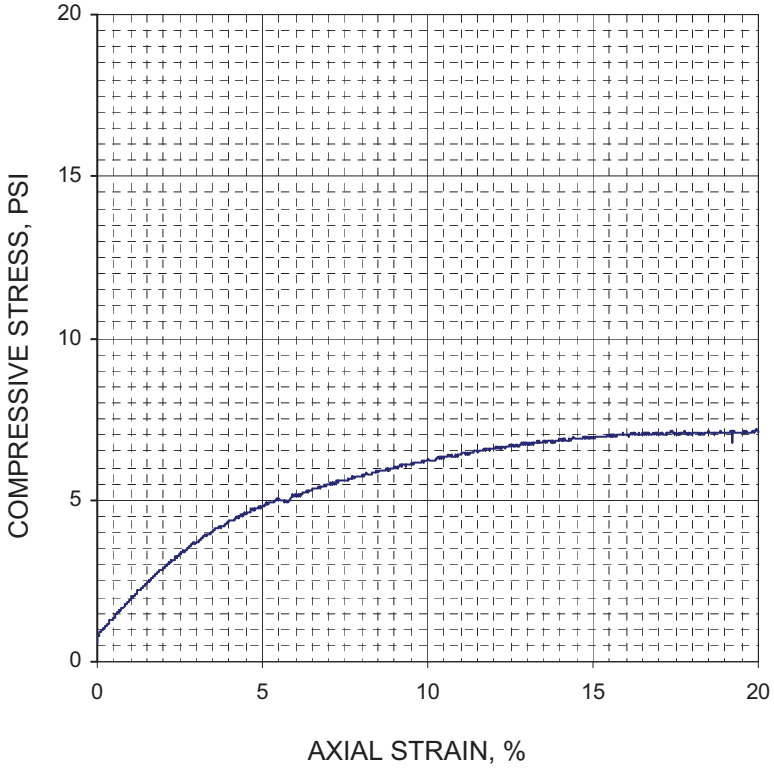


DESCRIPTION	red clay with few small stones				INITIAL	HEIGHT	3.1 in
SPECIMEN TYPE	undisturbed					DIAMETER	1.488 in
AXIAL STRAIN RATE	1%/min					HEIGHT/DIAMETER	2.08
SHEAR STRENGTH	5.65 psi	USC	11.29 psi			WATER CONTENT	29.05%
STRAIN AT FAILURE	15%					DRY DENSITY	93.94 pcf
CLASSIFICATION	A-7-6 (ODOT class.)					VOID RATIO	0.8002
LL 42	PL 21	PI 21	G_s 2.71			SATURATION	98.37 %

REMARKS G_s assumed	PROJECT	Bio-Engineering for Land Stabilization	
	AREA	Muskingum County—I70/SR83	
	BORING ID	TP-1	SAMPLE NO. -
	DEPTH/ELEV.	1.5 ft	DATE February 17, 2006
	TECH	CMK	CHECKED
	UNCONFINED COMPRESSION TEST REPORT		

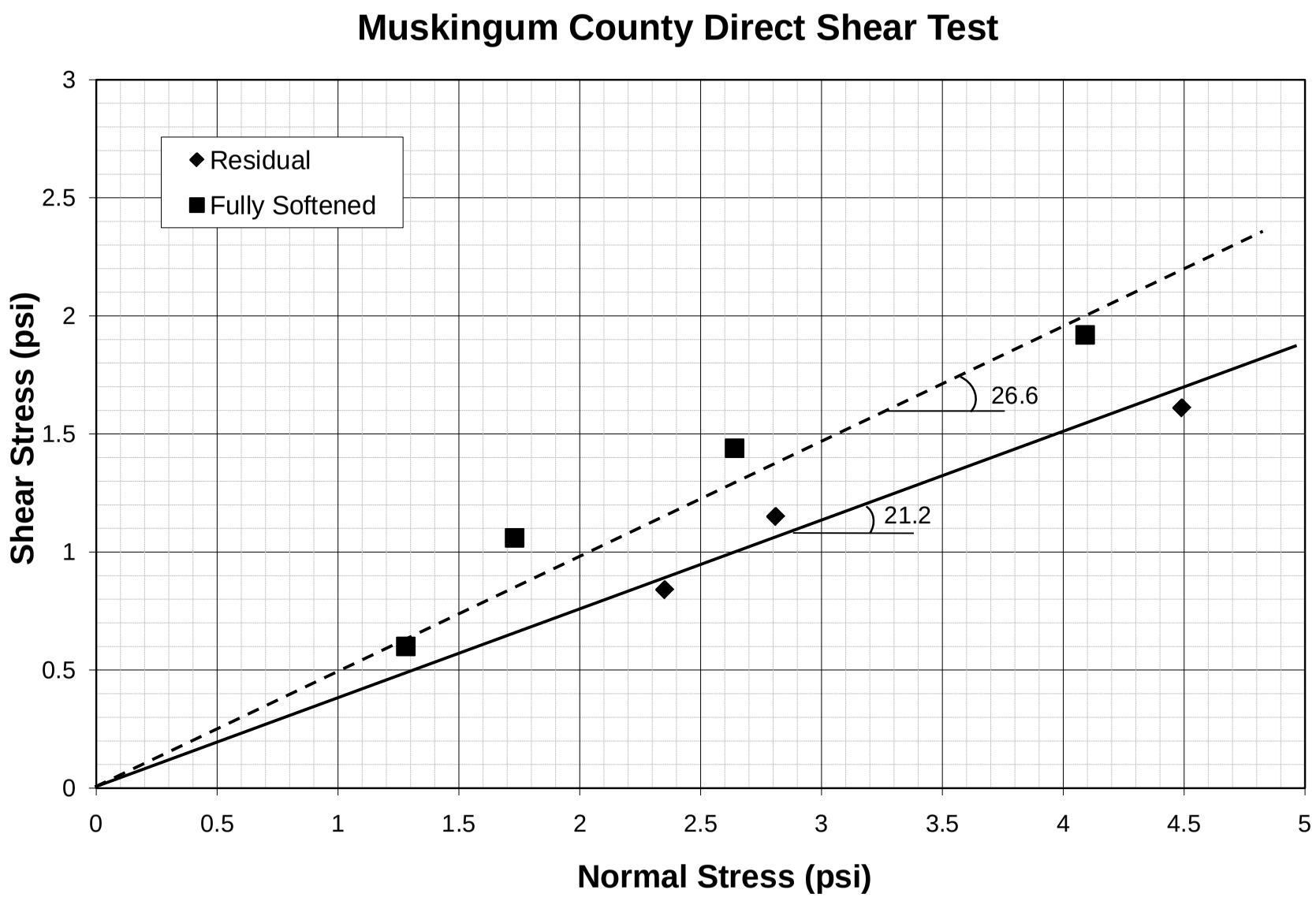
THE OHIO STATE UNIVERSITY SOIL MECHANICS LABORATORY

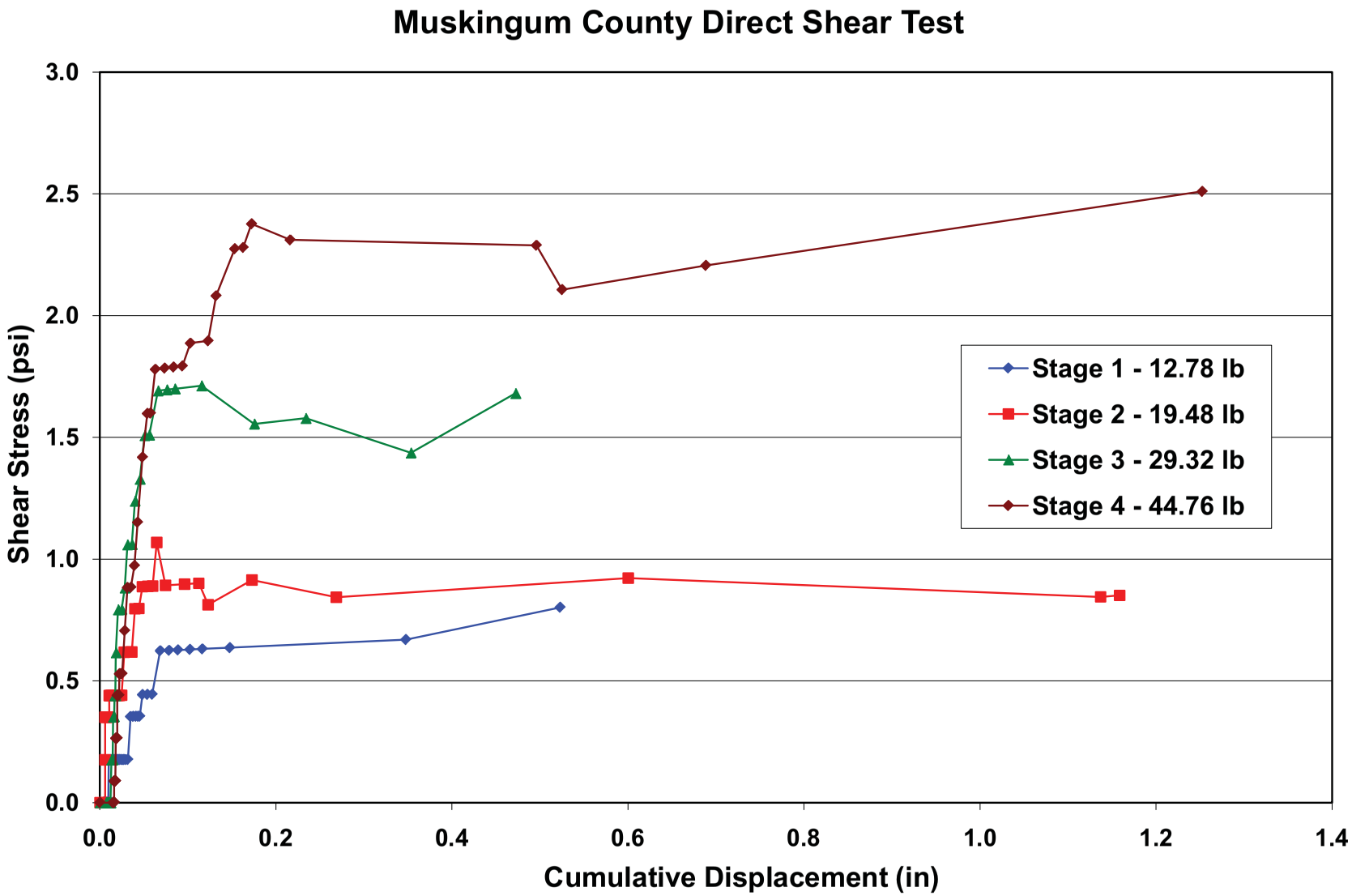
SPECIMEN AT FAILURE



DESCRIPTION	red clay with few small stones			INITIAL	HEIGHT	3.25 in
SPECIMEN TYPE	undisturbed				DIAMETER	1.489 in
AXIAL STRAIN RATE	1%/min				HEIGHT/DIAMETER	2.18
SHEAR STRENGTH	3.47 psi	USC	6.93 psi		WATER CONTENT	27.58%
STRAIN AT FAILURE	15%				DRY DENSITY	96.85%
CLASSIFICATION	A-4a (ODOT class.)				VOID RATIO	0.7480
LL 25	PL 2	PI 27	G_s 2.65		SATURATION	100%

REMARKS G_s assumed	PROJECT	Bio-Engineering for Land Stabilization	
	AREA	Muskingum County—I70/SR83	
	BORING ID	TP-2	SAMPLE NO. B
	DEPTH/ELEV.	1.5 ft	DATE February 22, 2006
	TECH	CMK	CHECKED
	UNCONFINED COMPRESSION TEST REPORT		


Muskingum County Direct Shear Test
Residual
Fully Softened
26.6
21.2
Shear Stress (psi)
Normal Stress (psi)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


Muskingum County Direct Shear Test
Shear Stress (psi)
Cumulative Displacement (in)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Stage 1 - 12.78 lb
Stage 2 - 19.48 lb
Stage 3 - 29.32 lb
Stage 4 - 44.76 lb

Muskingum County - Direct Simple Shear Test - Stage 1

Normal Load:	5796.4	g
	12.78	lb
Friction Force:	2	lb
Initial Area:	11.41	in^2
Initial Length:	4.15	in
Initial Width:	2.75	in

Time	Load (LED)	Displacement Reading (LVDT)	Displacement Reading (in)	Cumulative Displacement (in)	Corrected Area (in^2)	Relative Strain (in/in)	Corrected Shear Load (lb)	Shear Load Applied (lb)	Shear Stress (lb/in^2)	Normal Stress (lb/in^2)	Strain Rate (in/min)	Incremental Strain Rate (in/min)
Initial (zero)	47	75.98	3.8294	0.0000	11.4125	0.00000	47	-	0.00000	1.11972	-	-
Initial (after seating)	50	75.90	3.8254	0.0040	11.4014	0.00097	50	0	0.00000	1.12081	-	-
0.166666667	50	75.89	3.8249	0.0045	11.4000	0.00109	50	0	0.00000	1.12095	0.02722	-
0.333333333	50	75.89	3.8249	0.0045	11.4000	0.00109	50	0	0.00000	1.12095	0.01361	0.0000
0.5	50	75.89	3.8249	0.0045	11.4000	0.00109	50	0	0.00000	1.12095	0.00907	0.0000
0.666666667	50	75.89	3.8249	0.0045	11.4000	0.00109	50	0	0.00000	1.12095	0.00680	0.0000
0.833333333	50	75.89	3.8249	0.0045	11.4000	0.00109	50	0	0.00000	1.12095	0.00544	0.0000
1	50	75.89	3.8249	0.0045	11.4000	0.00109	50	0	0.00000	1.12095	0.00454	0.0000
1.25	50	75.85	3.8228	0.0066	11.3945	0.00158	50	0	0.00000	1.12150	0.00524	0.0081
1.5	50	75.85	3.8228	0.0066	11.3945	0.00158	50	0	0.00000	1.12150	0.00437	0.0000
1.75	50	75.85	3.8228	0.0066	11.3945	0.00158	50	0	0.00000	1.12150	0.00374	0.0000
2	50	75.85	3.8228	0.0066	11.3945	0.00158	50	0	0.00000	1.12150	0.00328	0.0000
2.5	50	75.84	3.8223	0.0071	11.3931	0.00170	50	0	0.00000	1.12163	0.00282	0.0010
3	50	75.84	3.8223	0.0071	11.3931	0.00170	50	0	0.00000	1.12163	0.00235	0.0000
3.5	50	75.82	3.8213	0.0081	11.3903	0.00194	50	0	0.00000	1.12190	0.00230	0.0020
4	50	75.81	3.8208	0.0086	11.3889	0.00206	50	0	0.00000	1.12204	0.00214	0.0010
4.5	50	75.81	3.8208	0.0086	11.3889	0.00206	50	0	0.00000	1.12204	0.00190	0.0000
5	50	75.79	3.8198	0.0096	11.3862	0.00231	50	0	0.00000	1.12231	0.00192	0.0020
5.5	50	75.79	3.8198	0.0096	11.3862	0.00231	50	0	0.00000	1.12231	0.00174	0.0000
6	50	75.79	3.8198	0.0096	11.3862	0.00231	50	0	0.00000	1.12231	0.00160	0.0000
6.5	52	75.78	3.8193	0.0101	11.3848	0.00243	52	2	0.17567	1.12245	0.00155	0.0010
7	52	75.76	3.8183	0.0111	11.3820	0.00267	52	2	0.17572	1.12272	0.00158	0.0020
7.5	52	75.76	3.8183	0.0111	11.3820	0.00267	52	2	0.17572	1.12272	0.00148	0.0000
8	52	75.75	3.8178	0.0116	11.3806	0.00279	52	2	0.17574	1.12286	0.00145	0.0010
8.5	52	75.75	3.8178	0.0116	11.3806	0.00279	52	2	0.17574	1.12286	0.00136	0.0000
9	52	75.73	3.8168	0.0126	11.3779	0.00304	52	2	0.17578	1.12313	0.00140	0.0020
9.5	52	75.73	3.8168	0.0126	11.3779	0.00304	52	2	0.17578	1.12313	0.00133	0.0000
10	52	75.70	3.8153	0.0141	11.3737	0.00340	52	2	0.17584	1.12355	0.00141	0.0030
11	52	75.69	3.8148	0.0146	11.3723	0.00352	52	2	0.17587	1.12368	0.00133	0.0005
12	52	75.67	3.8138	0.0156	11.3695	0.00376	52	2	0.17591	1.12396	0.00130	0.0010
13	52	75.66	3.8133	0.0161	11.3681	0.00389	52	2	0.17593	1.12409	0.00124	0.0005
14	52	75.64	3.8123	0.0171	11.3654	0.00413	52	2	0.17597	1.12437	0.00122	0.0010
15	52	75.64	3.8123	0.0171	11.3654	0.00413	52	2	0.17597	1.12437	0.00114	0.0000
16	52	75.63	3.8118	0.0176	11.3640	0.00425	52	2	0.17599	1.12450	0.00110	0.0005
17	52	75.60	3.8102	0.0192	11.3598	0.00461	52	2	0.17606	1.12492	0.00113	0.0015
18	52	75.58	3.8092	0.0202	11.3571	0.00486	52	2	0.17610	1.12519	0.00112	0.0010
19	52	75.55	3.8077	0.0217	11.3529	0.00522	52	2	0.17617	1.12560	0.00114	0.0015
20	52	75.53	3.8067	0.0227	11.3501	0.00547	52	2	0.17621	1.12588	0.00113	0.0010
22	52	75.49	3.8047	0.0247	11.3446	0.00595	52	2	0.17630	1.12643	0.00112	0.0010
24	52	75.46	3.8032	0.0262	11.3404	0.00632	52	2	0.17636	1.12684	0.00109	0.0008
26	52	75.44	3.8022	0.0272	11.3377	0.00656	52	2	0.17640	1.12712	0.00105	0.0005
28	52	75.40	3.8002	0.0292	11.3321	0.00704	52	2	0.17649	1.12767	0.00104	0.0010
30	52	75.35	3.7976	0.0318	11.3252	0.00765	52	2	0.17660	1.12836	0.00106	0.0013
33	54	75.29	3.7946	0.0348	11.3169	0.00838	54	4	0.35345	1.12919	0.00105	0.0010
36	54	75.23	3.7916	0.0378	11.3086	0.00911	54	4	0.35371	1.13002	0.00105	0.0010
39	54	75.17	3.7886	0.0408	11.3002	0.00984	54	4	0.35397	1.13085	0.00105	0.0010

Muskingum County - Direct Simple Shear Test - Stage 1

Normal Load:	5796.4	g
	12.78	lb
Friction Force:	2	lb
Initial Area:	11.41	in^2
Initial Length:	4.15	in
Initial Width:	2.75	in

Time	Load (LED)	Displacement Reading (LVDT)	Displacement Reading (in)	Cumulative Displacement (in)	Corrected Area (in^2)	Relative Strain (in/in)	Corrected Shear Load (lb)	Shear Load Applied (lb)	Shear Stress (lb/in^2)	Normal Stress (lb/in^2)	Strain Rate (in/min)	Incremental Strain Rate (in/min)
42	54	75.12	3.7860	0.0433	11.2933	0.01044	54	4	0.35419	1.13154	0.00103	0.0008
45	54	75.08	3.7840	0.0454	11.2878	0.01093	54	4	0.35437	1.13210	0.00101	0.0007
50	55	75.02	3.7810	0.0484	11.2794	0.01166	55	5	0.44328	1.13293	0.00097	0.0006
55	55	74.91	3.7755	0.0539	11.2642	0.01299	55	5	0.44388	1.13447	0.00098	0.0011
60	55	74.80	3.7699	0.0595	11.2490	0.01433	55	5	0.44449	1.13600	0.00099	0.0011
70	57	74.62	3.7608	0.0685	11.2240	0.01652	57	7	0.62366	1.13853	0.00098	0.0009
80	57	74.42	3.7508	0.0786	11.1963	0.01895	57	7	0.62521	1.14135	0.00098	0.0010
90	57	74.22	3.7407	0.0887	11.1686	0.02137	57	7	0.62676	1.14418	0.00099	0.0010
105	57	73.95	3.7271	0.1023	11.1311	0.02465	57	7	0.62887	1.14803	0.00097	0.0009
120	57	73.67	3.7130	0.1164	11.0923	0.02805	57	7	0.63107	1.15204	0.00097	0.0009
152	57	73.05	3.6817	0.1477	11.0064	0.03558	57	7	0.63599	1.16104	0.00097	0.0010
352	57	69.08	3.4816	0.3478	10.4562	0.08380	57	7	0.66946	1.22214	0.00099	0.0010
531	58	65.60	3.3062	0.5232	9.9738	0.12606	58	8	0.80210	1.28124	0.00099	0.0010

Muskingum County - Direct Simple Shear Test - Stage 2

Normal Load:	8836.2	g
	19.48	lb
Friction Force:	2	lb

Initial Area:	11.41	in^2
Initial Length:	4.15	in
Initial Width:	2.75	in

Time	Load (LED)	Displacement Reading (LVDT)	Displacement Reading (in)	Cumulative Displacement (in)	Corrected Area (in^2)	Relative Strain (in/in)	Corrected Shear Load (lb)	Shear Load Applied (lb)	Shear Stress (lb/in^2)	Normal Stress (lb/in^2)	Strain Rate (in/min)	Incremental Strain Rate (in/min)
Initial (zero)	40	75.99	3.8299	0.0000	11.4125	0.00000	40	-	0.00000	1.70694	-	-
Initial (after seating)	50	75.87	3.8238	0.0060	11.3959	0.00146	50	0	0.00000	1.70943	-	-
0.166666667	52	75.87	3.8238	0.0060	11.3959	0.00146	52	2	0.17550	1.70943	0.03629	-
0.5	54	75.87	3.8238	0.0060	11.3959	0.00146	54	4	0.35100	1.70943	0.01210	0.0000
0.75	54	75.85	3.8228	0.0071	11.3931	0.00170	54	4	0.35109	1.70985	0.00941	0.0040
1	54	75.84	3.8223	0.0076	11.3917	0.00182	54	4	0.35113	1.71006	0.00756	0.0020
1.5	54	75.84	3.8223	0.0076	11.3917	0.00182	54	4	0.35113	1.71006	0.00504	0.0000
2	54	75.82	3.8213	0.0086	11.3889	0.00206	54	4	0.35122	1.71047	0.00428	0.0020
2.5	54	75.82	3.8213	0.0086	11.3889	0.00206	54	4	0.35122	1.71047	0.00343	0.0000
3	54	75.81	3.8208	0.0091	11.3876	0.00219	54	4	0.35126	1.71068	0.00302	0.0010
3.5	54	75.79	3.8198	0.0101	11.3848	0.00243	54	4	0.35135	1.71110	0.00288	0.0020
4	54	75.79	3.8198	0.0101	11.3848	0.00243	54	4	0.35135	1.71110	0.00252	0.0000
4.5	54	75.78	3.8193	0.0106	11.3834	0.00255	54	4	0.35139	1.71131	0.00235	0.0010
5	55	75.78	3.8193	0.0106	11.3834	0.00255	55	5	0.43924	1.71131	0.00212	0.0000
6	55	75.76	3.8183	0.0116	11.3806	0.00279	55	5	0.43934	1.71172	0.00193	0.0010
7	55	75.73	3.8168	0.0131	11.3765	0.00316	55	5	0.43950	1.71235	0.00187	0.0015
8	55	75.72	3.8163	0.0136	11.3751	0.00328	55	5	0.43956	1.71256	0.00170	0.0005
9	55	75.72	3.8163	0.0136	11.3751	0.00328	55	5	0.43956	1.71256	0.00151	0.0000
10	55	75.69	3.8148	0.0151	11.3709	0.00364	55	5	0.43972	1.71318	0.00151	0.0015
12	55	75.66	3.8133	0.0166	11.3668	0.00401	55	5	0.43988	1.71381	0.00139	0.0008
14	55	75.61	3.8107	0.0192	11.3598	0.00461	55	5	0.44015	1.71485	0.00137	0.0013
16	55	75.58	3.8092	0.0207	11.3557	0.00498	55	5	0.44031	1.71548	0.00129	0.0008
18	55	75.55	3.8077	0.0222	11.3515	0.00534	55	5	0.44047	1.71611	0.00123	0.0008
20	55	75.50	3.8052	0.0247	11.3446	0.00595	55	5	0.44074	1.71716	0.00123	0.0013
24	57	75.44	3.8022	0.0277	11.3363	0.00668	57	7	0.61749	1.71842	0.00116	0.0008
28	57	75.35	3.7976	0.0323	11.3238	0.00777	57	7	0.61817	1.72031	0.00115	0.0011
32	57	75.27	3.7936	0.0363	11.3127	0.00874	57	7	0.61877	1.72200	0.00113	0.0010
36	59	75.20	3.7901	0.0398	11.3030	0.00959	59	9	0.79625	1.72348	0.00111	0.0009
40	59	75.11	3.7855	0.0444	11.2905	0.01069	59	9	0.79713	1.72538	0.00111	0.0011
45	60	75.03	3.7815	0.0484	11.2794	0.01166	60	10	0.88657	1.72708	0.00108	0.0008
50	60	74.91	3.7755	0.0544	11.2628	0.01312	60	10	0.88788	1.72963	0.00109	0.0012
55	60	74.80	3.7699	0.0600	11.2476	0.01445	60	10	0.88908	1.73197	0.00109	0.0011
60	62	74.71	3.7654	0.0645	11.2351	0.01555	62	12	1.06808	1.73389	0.00108	0.0009
70	60	74.51	3.7553	0.0746	11.2074	0.01797	60	10	0.89227	1.73818	0.00107	0.0010
91	60	74.08	3.7336	0.0963	11.1478	0.02320	60	10	0.89704	1.74748	0.00106	0.0010
109	60	73.76	3.7175	0.1124	11.1034	0.02708	60	10	0.90062	1.75446	0.00103	0.0009
120	59	73.55	3.7069	0.1230	11.0743	0.02963	59	9	0.81269	1.75907	0.00102	0.0010

Muskingum County - Direct Simple Shear Test - Stage 2

Normal Load:	8836.2	g
	19.48	lb
Friction Force:	2	lb

Initial Area:	11.41	in^2
Initial Length:	4.15	in
Initial Width:	2.75	in

Time	Load (LED)	Displacement Reading (LVDT)	Displacement Reading (in)	Cumulative Displacement (in)	Corrected Area (in^2)	Relative Strain (in/in)	Corrected Shear Load (lb)	Shear Load Applied (lb)	Shear Stress (lb/in^2)	Normal Stress (lb/in^2)	Strain Rate (in/min)	Incremental Strain Rate (in/min)
170	60	72.56	3.6570	0.1729	10.9371	0.04166	60	10	0.91432	1.78114	0.00102	0.0010
266	59	70.66	3.5613	0.2686	10.6738	0.06473	59	9	0.84319	1.82508	0.00101	0.0010
601	59	64.08	3.2296	0.6003	9.7618	0.14464	59	9	0.92196	1.99559	0.00100	0.0010
1142	57	53.43	2.6929	1.1370	8.2857	0.27398	57	7	0.84483	2.35110	0.00100	0.0010
1164	57	53.00	2.6712	1.1587	8.2261	0.27920	57	7	0.85095	2.36813	0.00100	0.0010

Muskingum County - Direct Simple Shear Test - Stage 3

Normal Load:	13297.8	g
	29.32	lb
Friction Force:	3	lb
Initial Area:	11.41	in^2
Initial Length:	4.15	in
Initial Width:	2.75	in

Time	Load (LED)	Displacement Reading (LVDT)	Displacement Reading (in)	Cumulative Displacement (in)	Corrected Area (in^2)	Relative Strain (in/in)	Corrected Shear Load (lb)	Shear Load Applied (lb)	Shear Stress (lb/in^2)	Normal Stress (lb/in^2)	Strain Rate (in/min)	Incremental Strain Rate (in/min)
Initial (zero)	35	75.96	3.8284	0.0000	11.4125	0.00000	35	-	0.00000	2.56881	-	-
Initial (after seating)	50	75.82	3.8213	0.0071	11.3931	0.00170	50	0	0.00000	2.57319	-	-
0.166666667	50	75.81	3.8208	0.0076	11.3917	0.00182	50	0	0.00000	2.57350	0.04536	-
0.5	50	75.81	3.8208	0.0076	11.3917	0.00182	50	0	0.00000	2.57350	0.01512	0.0000
0.75	50	75.79	3.8198	0.0086	11.3889	0.00206	50	0	0.00000	2.57413	0.01142	0.0040
1	50	75.79	3.8198	0.0086	11.3889	0.00206	50	0	0.00000	2.57413	0.00857	0.0000
1.5	50	75.79	3.8198	0.0086	11.3889	0.00206	50	0	0.00000	2.57413	0.00571	0.0000
2	50	75.78	3.8193	0.0091	11.3876	0.00219	50	0	0.00000	2.57444	0.00454	0.0010
2.5	50	75.76	3.8183	0.0101	11.3848	0.00243	50	0	0.00000	2.57507	0.00403	0.0020
3	50	75.75	3.8178	0.0106	11.3834	0.00255	50	0	0.00000	2.57538	0.00353	0.0010
3.5	50	75.75	3.8178	0.0106	11.3834	0.00255	50	0	0.00000	2.57538	0.00302	0.0000
4	50	75.73	3.8168	0.0116	11.3806	0.00279	50	0	0.00000	2.57601	0.00290	0.0020
4.5	50	75.73	3.8168	0.0116	11.3806	0.00279	50	0	0.00000	2.57601	0.00258	0.0000
5	50	75.73	3.8168	0.0116	11.3806	0.00279	50	0	0.00000	2.57601	0.00232	0.0000
6	50	75.72	3.8163	0.0121	11.3792	0.00291	50	0	0.00000	2.57632	0.00202	0.0005
7	52	75.70	3.8153	0.0131	11.3765	0.00316	52	2	0.17580	2.57695	0.00187	0.0010
8	52	75.69	3.8148	0.0136	11.3751	0.00328	52	2	0.17582	2.57727	0.00170	0.0005
9	52	75.69	3.8148	0.0136	11.3751	0.00328	52	2	0.17582	2.57727	0.00151	0.0000
10	52	75.67	3.8138	0.0146	11.3723	0.00352	52	2	0.17587	2.57789	0.00146	0.0010
12	54	75.66	3.8133	0.0151	11.3709	0.00364	54	4	0.35177	2.57821	0.00126	0.0003
14	54	75.64	3.8123	0.0161	11.3681	0.00389	54	4	0.35186	2.57884	0.00115	0.0005
16	55	75.63	3.8118	0.0166	11.3668	0.00401	55	5	0.43988	2.57915	0.00104	0.0003
18	55	75.61	3.8107	0.0176	11.3640	0.00425	55	5	0.43999	2.57978	0.00098	0.0005
20	57	75.60	3.8102	0.0181	11.3626	0.00437	57	7	0.61606	2.58009	0.00091	0.0003
24	59	75.55	3.8077	0.0207	11.3557	0.00498	59	9	0.79256	2.58167	0.00086	0.0006
28	59	75.47	3.8037	0.0247	11.3446	0.00595	59	9	0.79333	2.58419	0.00088	0.0010
32	60	75.40	3.8002	0.0282	11.3349	0.00680	60	10	0.88223	2.58640	0.00088	0.0009
36	62	75.34	3.7971	0.0312	11.3266	0.00753	62	12	1.05946	2.58830	0.00087	0.0008
40	62	75.24	3.7921	0.0363	11.3127	0.00874	62	12	1.06075	2.59147	0.00091	0.0013
45	64	75.17	3.7886	0.0398	11.3030	0.00959	64	14	1.23861	2.59370	0.00088	0.0007
50	65	75.06	3.7830	0.0454	11.2878	0.01093	65	15	1.32887	2.59720	0.00091	0.0011
55	67	74.95	3.7775	0.0509	11.2725	0.01227	67	17	1.50809	2.60071	0.00093	0.0011
60	67	74.85	3.7724	0.0559	11.2587	0.01348	67	17	1.50995	2.60392	0.00093	0.0010
70	69	74.65	3.7624	0.0660	11.2309	0.01591	69	19	1.69176	2.61034	0.00094	0.0010
80	69	74.45	3.7523	0.0761	11.2032	0.01834	69	19	1.69594	2.61680	0.00095	0.0010
90	69	74.27	3.7432	0.0852	11.1783	0.02052	69	19	1.69973	2.62264	0.00095	0.0009
120	69	73.67	3.7130	0.1154	11.0951	0.02781	69	19	1.71247	2.64230	0.00096	0.0010
180	67	72.48	3.6530	0.1754	10.9302	0.04226	67	17	1.55533	2.68217	0.00097	0.0010

Muskingum County - Direct Simple Shear Test - Stage 3

Normal Load:	13297.8	g
	29.32	lb
Friction Force:	3	lb
Initial Area:	11.41	in^2
Initial Length:	4.15	in
Initial Width:	2.75	in

Time	Load (LED)	Displacement Reading (LVDT)	Displacement Reading (in)	Cumulative Displacement (in)	Corrected Area (in^2)	Relative Strain (in/in)	Corrected Shear Load (lb)	Shear Load Applied (lb)	Shear Stress (lb/in^2)	Normal Stress (lb/in^2)	Strain Rate (in/min)	Incremental Strain Rate (in/min)
240	67	71.32	3.5945	0.2339	10.7694	0.05635	67	17	1.57855	2.72221	0.00097	0.0010
360	65	68.95	3.4751	0.3533	10.4409	0.08513	65	15	1.43666	2.80786	0.00098	0.0010
480	67	66.59	3.3561	0.4722	10.1138	0.11379	67	17	1.68087	2.89867	0.00098	0.0010

Muskingum County - Direct Simple Shear Test - Stage 4

Normal Load:	20304.1	g	
	44.76	lb	
Friction Force:	5	lb	or 5
Initial Area:	11.41	in^2	
Initial Length:	4.15	in	
Initial Width:	2.75	in	

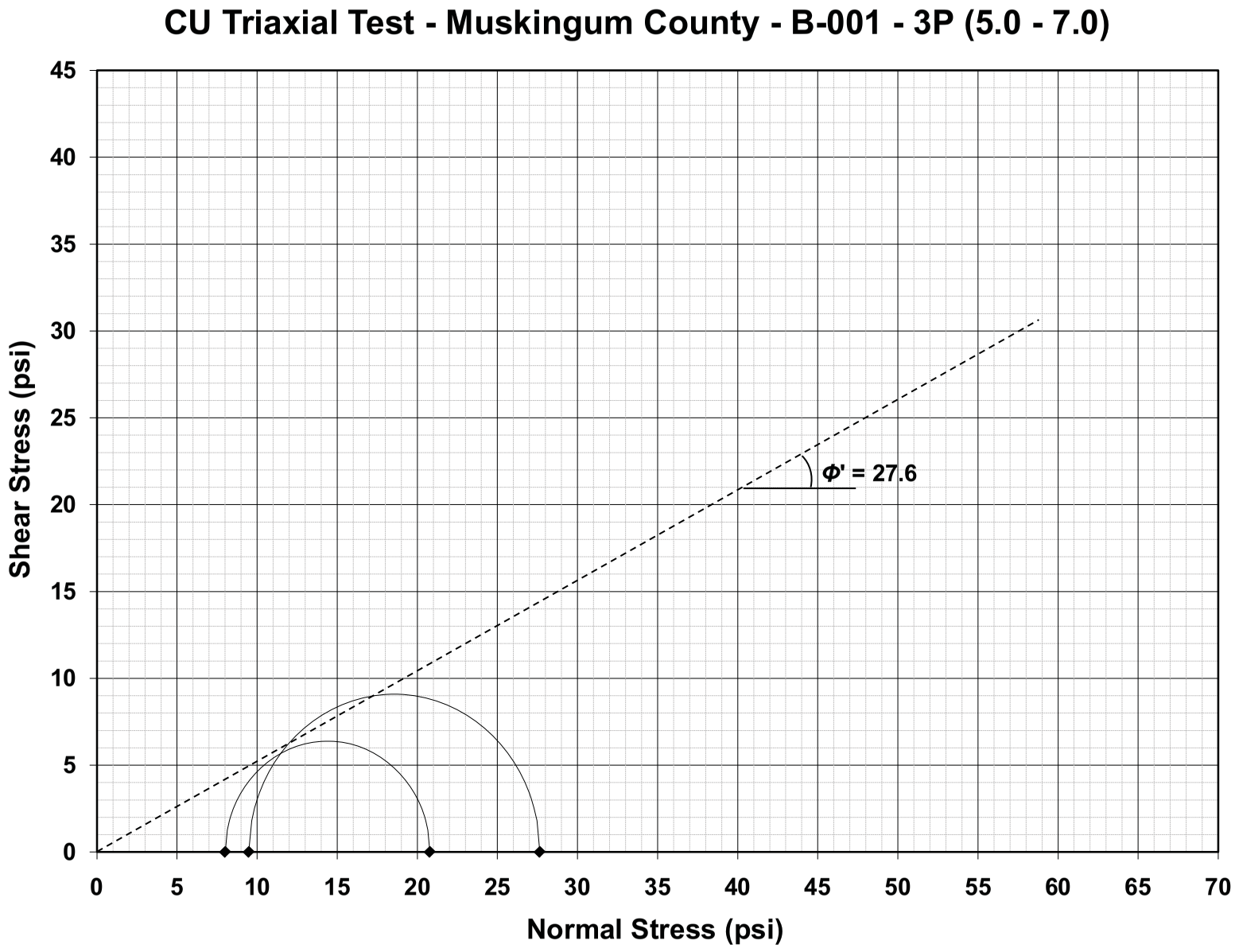
Time	Load (LED)	Displacement Reading (LVDT)	Displacement Reading (in)	Cumulative Displacement (in)	Corrected Area (in^2)	Relative Strain (in/in)	Corrected Shear Load (lb)	Shear Load Applied (lb)	Shear Stress (lb/in^2)	Normal Stress (lb/in^2)	Strain Rate (in/min)	Incremental Strain Rate (in/min)
Initial (zero)	39	75.99	3.8299	0.0000	11.4125	0.00000	39	-	0.00000	3.92226	-	-
Initial (after seating)	49	75.69	3.8148	0.0151	11.3709	0.00364	49	0	0.00000	3.93661	-	-
0.25	49	75.69	3.8148	0.0151	11.3709	0.00364	49	0	0.00000	3.93661	0.06048	-
0.5	49	75.67	3.8138	0.0161	11.3681	0.00389	49	0	0.00000	3.93757	0.03226	0.0040
0.75	49	75.67	3.8138	0.0161	11.3681	0.00389	49	0	0.00000	3.93757	0.02150	0.0000
1	49	75.67	3.8138	0.0161	11.3681	0.00389	49	0	0.00000	3.93757	0.01613	0.0000
1.5	50	75.67	3.8138	0.0161	11.3681	0.00389	50	1	0.08797	3.93757	0.01075	0.0000
2	50	75.66	3.8133	0.0166	11.3668	0.00401	50	1	0.08798	3.93805	0.00832	0.0010
2.5	50	75.66	3.8133	0.0166	11.3668	0.00401	50	1	0.08798	3.93805	0.00665	0.0000
3	50	75.66	3.8133	0.0166	11.3668	0.00401	50	1	0.08798	3.93805	0.00554	0.0000
3.5	50	75.66	3.8133	0.0166	11.3668	0.00401	50	1	0.08798	3.93805	0.00475	0.0000
4	50	75.64	3.8123	0.0176	11.3640	0.00425	50	1	0.08800	3.93901	0.00441	0.0020
4.5	50	75.64	3.8123	0.0176	11.3640	0.00425	50	1	0.08800	3.93901	0.00392	0.0000
5	50	75.64	3.8123	0.0176	11.3640	0.00425	50	1	0.08800	3.93901	0.00353	0.0000
6	52	75.63	3.8118	0.0181	11.3626	0.00437	52	3	0.26402	3.93949	0.00302	0.0005
7	52	75.63	3.8118	0.0181	11.3626	0.00437	52	3	0.26402	3.93949	0.00259	0.0000
8	52	75.61	3.8107	0.0192	11.3598	0.00461	52	3	0.26409	3.94045	0.00239	0.0010
9	52	75.60	3.8102	0.0197	11.3584	0.00474	52	3	0.26412	3.94093	0.00218	0.0005
10	54	75.60	3.8102	0.0197	11.3584	0.00474	54	5	0.44020	3.94093	0.00197	0.0000
12	54	75.58	3.8092	0.0207	11.3557	0.00498	54	5	0.44031	3.94189	0.00172	0.0005
14	54	75.56	3.8082	0.0217	11.3529	0.00522	54	5	0.44042	3.94285	0.00155	0.0005
16	55	75.55	3.8077	0.0222	11.3515	0.00534	55	6	0.52856	3.94333	0.00139	0.0003
18	55	75.52	3.8062	0.0237	11.3474	0.00571	55	6	0.52876	3.94478	0.00132	0.0008
20	55	75.49	3.8047	0.0252	11.3432	0.00607	55	6	0.52895	3.94623	0.00126	0.0008
24	57	75.43	3.8017	0.0282	11.3349	0.00680	57	8	0.70579	3.94912	0.00118	0.0008
28	59	75.37	3.7986	0.0312	11.3266	0.00753	59	10	0.88288	3.95202	0.00112	0.0008
32	59	75.29	3.7946	0.0353	11.3155	0.00850	59	10	0.88375	3.95589	0.00110	0.0010
36	60	75.21	3.7906	0.0393	11.3044	0.00947	60	11	0.97307	3.95977	0.00109	0.0010
40	62	75.14	3.7871	0.0428	11.2947	0.01032	62	13	1.15098	3.96317	0.00107	0.0009
45	65	75.03	3.7815	0.0484	11.2794	0.01166	65	16	1.41851	3.96853	0.00108	0.0011
50	67	74.92	3.7760	0.0539	11.2642	0.01299	67	18	1.59798	3.97390	0.00108	0.0011
55	67	74.85	3.7724	0.0575	11.2545	0.01384	67	18	1.59936	3.97733	0.00104	0.0007
60	69	74.74	3.7669	0.0630	11.2393	0.01518	69	20	1.77948	3.98272	0.00105	0.0011
70	69	74.53	3.7563	0.0736	11.2101	0.01773	69	20	1.78410	3.99306	0.00105	0.0011
80	69	74.33	3.7462	0.0837	11.1824	0.02016	69	20	1.78852	4.00296	0.00105	0.0010
90	69	74.13	3.7362	0.0937	11.1547	0.02259	69	20	1.79297	4.01291	0.00104	0.0010
100	70	73.95	3.7271	0.1028	11.1298	0.02477	70	21	1.88683	4.02191	0.00103	0.0009
120	70	73.55	3.7069	0.1230	11.0743	0.02963	70	21	1.89628	4.04204	0.00102	0.0010

Muskingum County - Direct Simple Shear Test - Stage 4

Normal Load:	20304.1	g	
	44.76	lb	
Friction Force:	5	lb	or 5
Initial Area:	11.41	in^2	
Initial Length:	4.15	in	
Initial Width:	2.75	in	

Time	Load (LED)	Displacement Reading (LVDT)	Displacement Reading (in)	Cumulative Displacement (in)	Corrected Area (in^2)	Relative Strain (in/in)	Corrected Shear Load (lb)	Shear Load Applied (lb)	Shear Stress (lb/in^2)	Normal Stress (lb/in^2)	Strain Rate (in/min)	Incremental Strain Rate (in/min)
130	72	73.37	3.6978	0.1320	11.0494	0.03182	72	23	2.08157	4.05117	0.00102	0.0009
150	74	72.95	3.6767	0.1532	10.9912	0.03692	74	25	2.27456	4.07262	0.00102	0.0011
160	74	72.76	3.6671	0.1628	10.9648	0.03923	74	25	2.28002	4.08240	0.00102	0.0010
170	75	72.57	3.6575	0.1724	10.9385	0.04153	75	26	2.37693	4.09223	0.00101	0.0010
215	74	71.70	3.6137	0.2162	10.8179	0.05210	74	25	2.31098	4.13785	0.00101	0.0010
496	72	66.15	3.3340	0.4959	10.0487	0.11950	72	23	2.28886	4.45460	0.00100	0.0010
525	70	65.57	3.3047	0.5252	9.9683	0.12655	70	21	2.10668	4.49052	0.00100	0.0010
691	70	62.33	3.1414	0.6885	9.5192	0.16589	70	21	2.20606	4.70236	0.00100	0.0010
1260	69	51.14	2.5775	1.2524	7.9683	0.30179	69	20	2.50995	5.61762	0.00099	0.0010

1.605088129


CU Triaxial Test - Muskingum County - B-001 - 3P (5.0 - 7.0)
Shear Stress (psi)
Normal Stress (psi)
Φ' = 27.6
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70

State of Ohio
Department of Transportation
Office of Geotechnical Engineering

CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION TEST

AASHTO T 297 & ASTM D4767

Project Mus - 70 - 26.8 **Station & Offset** **Boring Number** B-001
Depth 5.3 - 6.0 **Sample Number** 3P **Lab Number** 20753 - A

Sample Length			Sample Diameter											Consolidation Volume Lost
L1 =	6.121	in.	D1 =	2.829	in.	Sample Length L =	6.089	in.	Empty Dish Wt. =	47.38	g			
L2 =	6.044	in.	D2 =	2.843	in.	Sample Diam. D =	2.839	in.	Wet Wt. In Dish =	104.24	g			0.028 in^3
L3 =	6.101	in.	D3 =	2.844	in.	$A_o = \pi r^2 = \pi D^2/4$ =	6.329	in^2	Dry Wt. In Dish =	95.33	g			
						$V = \pi r^2 L = \pi D^2 L/4$ =	38.534	in^3	Moisture Loss =	8.91	g			Consolidation Time t_{50}
Rate of Strain =	0.0003	in./min.=	0.005%	/min.					Moisture Content =	18.6%				
Sample Mass =	1371.40	g	**"Wet" Density =**	135.58	pcf				**Dry Density =**	114.34	pcf			80.00 minutes

Reading Number	Time in Minutes	Axial Displac. Inches	Cell Pressure σ3 psi	Pore Pressure u psi	Back Pressure psi	Axial Force P lbf	Volume Gage ΔV in^3	Area Correction in^2	Percent Strain ε	Deviator Stress σ1-σ3	Effective Stress σ3' psi	Axial Stress σ1 psi	Effective Stress σ1' psi	Average Stress p' psi	Maximum Shear q psi
1	0.00	0	74.114	70.916	2.7557	-0.2336	-0.0854	6.326	0.00%	-0.04	3.20	74.08	3.16	3.18	-0.02
2	1.68	5E-04	74.114	70.955	2.7557	0.46693	-0.0854	6.326	0.01%	0.07	3.16	74.19	3.23	3.20	0.04
3	3.36	0.001	74.114	70.932	2.7557	1.16743	-0.0854	6.327	0.02%	0.18	3.18	74.30	3.37	3.27	0.09
4	5.17	0.002	74.114	70.932	2.7557	1.86794	-0.0854	6.327	0.03%	0.30	3.18	74.41	3.48	3.33	0.15
5	6.85	0.002	74.114	70.932	2.7557	2.47515	-0.0854	6.328	0.03%	0.39	3.18	74.51	3.57	3.38	0.20
6	27.42	0.008	74.035	70.815	2.7557	6.77169	-0.0854	6.334	0.14%	1.07	3.22	75.10	4.29	3.75	0.53
7	47.98	0.015	74.05	70.815	2.7557	9.57371	-0.0854	6.341	0.24%	1.51	3.24	75.56	4.75	3.99	0.75
8	68.54	0.021	74.035	70.737	2.7557	12.1422	-0.0854	6.347	0.34%	1.91	3.30	75.95	5.21	4.25	0.96
9	88.97	0.027	74.035	70.737	2.7557	13.9168	-0.0854	6.354	0.44%	2.19	3.30	76.22	5.49	4.39	1.10
10	109.54	0.033	74.035	70.659	2.7557	16.1118	-0.0854	6.361	0.55%	2.53	3.38	76.57	5.91	4.64	1.27
11	130.10	0.04	74.09	70.659	2.7557	17.5128	-0.0854	6.367	0.65%	2.75	3.43	76.84	6.18	4.81	1.38
12	150.66	0.046	74.035	70.581	2.7557	18.4467	-0.0854	6.374	0.75%	2.89	3.45	76.93	6.35	4.90	1.45
13	171.22	0.052	74.05	70.581	2.7557	19.0539	-0.0854	6.380	0.86%	2.99	3.47	77.04	6.46	4.96	1.49
14	191.79	0.058	74.05	70.503	2.7557	20.3149	-0.0854	6.387	0.96%	3.18	3.55	77.23	6.73	5.14	1.59
15	212.35	0.065	74.035	70.464	2.7557	22.6497	-0.0854	6.394	1.06%	3.54	3.57	77.58	7.11	5.34	1.77
16	232.91	0.071	74.035	70.425	2.7557	24.5179	-0.0854	6.400	1.16%	3.83	3.61	77.87	7.44	5.53	1.92
17	253.47	0.077	74.035	70.347	2.7557	25.452	-0.0854	6.407	1.27%	3.97	3.69	78.01	7.66	5.67	1.99
18	273.91	0.083	74.035	70.292	2.7557	26.853	-0.0854	6.414	1.37%	4.19	3.74	78.22	7.93	5.84	2.09
19	294.47	0.09	74.035	70.269	2.7557	29.1878	-0.0854	6.420	1.47%	4.55	3.77	78.58	8.31	6.04	2.27
20	315.03	0.096	74.035	70.214	2.7557	30.5889	-0.0854	6.427	1.58%	4.76	3.82	78.79	8.58	6.20	2.38
21	335.59	0.102	74.114	70.191	2.7557	32.457	-0.0854	6.434	1.68%	5.04	3.92	79.16	8.97	6.45	2.52
22	356.15	0.108	74.074	70.113	2.7557	33.7645	-0.0854	6.440	1.78%	5.24	3.96	79.32	9.20	6.58	2.62
23	376.72	0.115	74.09	70.058	2.7557	34.7921	-0.0854	6.447	1.88%	5.40	4.03	79.49	9.43	6.73	2.70
24	397.28	0.121	74.05	69.98	2.7557	36.1931	-0.0854	6.454	1.99%	5.61	4.07	79.66	9.68	6.87	2.80
25	417.84	0.127	74.114	70.035	2.7557	36.66	-0.0854	6.461	2.09%	5.67	4.08	79.79	9.75	6.92	2.84
26	438.27	0.133	74.114	69.918	2.7557	36.66	-0.0854	6.467	2.19%	5.67	4.20	79.78	9.86	7.03	2.83
27	458.97	0.14	74.114	69.879	2.7557	35.259	-0.0854	6.474	2.30%	5.45	4.24	79.56	9.68	6.96	2.72
28	479.66	0.146	74.114	69.801	2.7557	35.259	-0.0854	6.481	2.40%	5.44	4.31	79.55	9.75	7.03	2.72
29	500.35	0.152	74.09	69.723	2.7557	36.1931	-0.0854	6.488	2.50%	5.58	4.37	79.67	9.95	7.16	2.79
30	521.04	0.159	74.114	69.723	2.7557	37.127	-0.0854	6.495	2.61%	5.72	4.39	79.83	10.11	7.25	2.86
31	541.73	0.165	74.114	69.645	2.7557	38.2011	-0.0854	6.502	2.71%	5.88	4.47	79.99	10.34	7.41	2.94
32	562.42	0.171	74.114	69.567	2.7557	38.9951	-0.0854	6.509	2.81%	5.99	4.55	80.11	10.54	7.54	3.00
33	583.63	0.178	74.05	69.489	2.7557	39.929	-0.0854	6.516	2.92%	6.13	4.56	80.18	10.69	7.63	3.06
34	604.32	0.184	74.114	69.489	2.7557	40.7698	-0.0854	6.523	3.02%	6.25	4.62	80.36	10.88	7.75	3.13
35	625.02	0.19	74.05	69.411	2.7557	41.33	-0.0854	6.530	3.13%	6.33	4.64	80.38	10.97	7.80	3.16
36	645.71	0.197	74.114	69.356	2.7557	42.2641	-0.0854	6.537	3.23%	6.47	4.76	80.58	11.22	7.99	3.23
37	666.40	0.203	74.13	69.333	2.7557	43.3382	-0.0854	6.544	3.33%	6.62	4.80	80.75	11.42	8.11	3.31
38	687.09	0.209	74.074	69.255	2.7557	44.1322	-0.0854	6.551	3.44%	6.74	4.82	80.81	11.56	8.19	3.37
39	707.91	0.216	74.09	69.177	2.7557	45.0661	-0.0854	6.558	3.54%	6.87	4.91	80.96	11.79	8.35	3.44
40	728.60	0.222	74.074	69.099	2.7557	46.4671	-0.0854	6.565	3.64%	7.08	4.98	81.15	12.05	8.51	3.54

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CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION TEST
AASHTO T 297 & ASTM D4767

Project Mus - 70 - 26.8 **Station & Offset** **Boring Number** B-001
Depth 5.3 - 6.0 **Sample Number** 3P **Lab Number** 20753 - A

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L3 =	6.101	in.	D3 =	2.844	in.	$A_o = \pi r^2 = \pi D^2/4$ =	6.329	in^2	Dry Wt. In Dish =	95.33	g		0.028 in^3
						$V = \pi r^2 L = \pi D^2 L/4$ =	38.534	in^3	Moisture Loss =	8.91	g		Consolidation Time t_{50}
Rate of Strain =	0.0003	in./min.=	0.005%	/min.					Moisture Content =	18.6%			
Sample Mass =	1371.40	g	**"Wet" Density =**	135.58	pcf				**Dry Density =**	114.34	pcf		80.00 minutes

Reading Number	Time in Minutes	Axial Displac. Inches	Cell Pressure σ3 psi	Pore Pressure u psi	Back Pressure psi	Axial Force P lbf	Volume Gage ΔV in^3	Area Correction in^2	Percent Strain ε	Deviator Stress σ1-σ3	Effective Stress σ3' psi	Axial Stress σ1 psi	Effective Stress σ1' psi	Average Stress p' psi	Maximum Shear q psi
41	749.29	0.228	74.114	69.099	2.7557	47.4012	-0.0854	6.572	3.75%	7.21	5.01	81.33	12.23	8.62	3.61
42	769.99	0.234	74.114	69.021	2.7557	47.8681	-0.0854	6.579	3.85%	7.28	5.09	81.39	12.37	8.73	3.64
43	790.68	0.241	74.05	68.966	2.7557	48.3353	-0.0854	6.586	3.95%	7.34	5.08	81.39	12.42	8.75	3.67
44	811.37	0.247	74.09	68.943	2.7557	49.0358	-0.0854	6.593	4.06%	7.44	5.15	81.53	12.58	8.87	3.72
45	832.06	0.253	74.05	68.865	2.7557	49.2691	-0.0854	6.600	4.16%	7.46	5.19	81.51	12.65	8.92	3.73
46	852.75	0.26	74.05	68.787	2.7557	49.7363	-0.0854	6.607	4.26%	7.53	5.26	81.58	12.79	9.03	3.76
47	873.44	0.266	74.09	68.787	2.7557	50.2032	-0.0854	6.615	4.37%	7.59	5.30	81.68	12.89	9.10	3.79
48	894.14	0.272	74.035	68.709	2.7557	51.1373	-0.0854	6.622	4.47%	7.72	5.33	81.76	13.05	9.19	3.86
49	914.83	0.279	74.035	68.631	2.7557	53.0052	-0.0854	6.629	4.58%	8.00	5.40	82.03	13.40	9.40	4.00
50	935.52	0.285	74.05	68.576	2.7557	54.8734	-0.0854	6.636	4.68%	8.27	5.47	82.32	13.74	9.61	4.13
51	956.21	0.291	74.035	68.537	2.7557	56.4145	-0.0854	6.643	4.78%	8.49	5.50	82.53	13.99	9.74	4.25
52	977.03	0.297	74.05	68.498	2.7557	58.2824	-0.0854	6.651	4.89%	8.76	5.55	82.81	14.32	9.93	4.38
53	997.72	0.304	74.035	68.475	2.7557	59.2165	-0.0854	6.658	4.99%	8.89	5.56	82.93	14.45	10.01	4.45
54	1018.41	0.31	74.035	68.397	2.7557	60.4774	-0.0854	6.665	5.09%	9.07	5.64	83.11	14.71	10.17	4.54
55	1039.11	0.316	74.035	68.381	2.7557	61.4115	-0.0854	6.672	5.20%	9.20	5.65	83.24	14.86	10.26	4.60
56	1059.80	0.323	74.035	68.319	2.7557	61.4115	-0.0854	6.680	5.30%	9.19	5.72	83.23	14.91	10.31	4.60
57	1185.72	0.361	74.034	68.085	2.7827	60.0104	-0.0864	6.724	5.93%	8.92	5.95	82.96	14.87	10.41	4.46
58	1206.42	0.367	74.034	68.03	2.7827	60.4774	-0.0867	6.732	6.03%	8.98	6.00	83.02	14.99	10.50	4.49
59	1227.12	0.374	73.955	67.929	2.7827	60.851	-0.0867	6.739	6.14%	9.03	6.03	82.98	15.06	10.54	4.51
60	1247.83	0.38	74.034	67.929	2.7827	60.9444	-0.0867	6.747	6.24%	9.03	6.11	83.07	15.14	10.62	4.52
61	1268.53	0.386	74.074	67.929	2.7827	61.5515	-0.0864	6.754	6.34%	9.11	6.15	83.19	15.26	10.70	4.56
62	1289.23	0.392	74.034	67.851	2.7983	61.8784	-0.0869	6.762	6.45%	9.15	6.18	83.19	15.33	10.76	4.58
63	1309.93	0.399	74.034	67.851	2.7827	62.3454	-0.0864	6.769	6.55%	9.21	6.18	83.24	15.39	10.79	4.61
64	1330.98	0.405	74.034	67.773	2.7983	63.186	-0.0875	6.777	6.66%	9.32	6.26	83.36	15.59	10.92	4.66
65	1351.68	0.411	74.034	67.773	2.7827	63.9799	-0.0875	6.784	6.76%	9.43	6.26	83.47	15.69	10.98	4.72
66	1372.38	0.418	74.034	67.695	2.7983	65.1475	-0.0872	6.792	6.86%	9.59	6.34	83.63	15.93	11.14	4.80
67	1393.08	0.424	74.034	67.617	2.7827	66.0815	-0.0875	6.799	6.97%	9.72	6.42	83.75	16.14	11.28	4.86
68	1413.79	0.43	74.034	67.617	2.7827	66.315	-0.0869	6.807	7.07%	9.74	6.42	83.78	16.16	11.29	4.87
69	1434.49	0.437	74.034	67.562	2.7827	66.782	-0.0867	6.815	7.17%	9.80	6.47	83.83	16.27	11.37	4.90
70	1455.19	0.443	74.034	67.539	2.7827	67.1556	-0.0867	6.822	7.28%	9.84	6.50	83.88	16.34	11.42	4.92
71	1475.89	0.449	74.034	67.461	2.7827	67.3891	-0.0867	6.830	7.38%	9.87	6.57	83.90	16.44	11.51	4.93
72	1496.59	0.456	74.05	67.461	2.7827	68.8835	-0.0867	6.837	7.48%	10.07	6.59	84.12	16.66	11.63	5.04
73	1517.30	0.462	74.034	67.383	2.7983	69.0236	-0.0862	6.845	7.59%	10.08	6.65	84.12	16.74	11.69	5.04
74	1538.00	0.468	74.034	67.305	2.7983	71.6855	-0.0862	6.853	7.69%	10.46	6.73	84.50	17.19	11.96	5.23
75	1558.70	0.475	74.034	67.305	2.7983	73.0866	-0.0862	6.860	7.80%	10.65	6.73	84.69	17.38	12.06	5.33
76	1579.40	0.481	74.034	67.227	2.7827	74.0206	-0.0859	6.868	7.90%	10.78	6.81	84.81	17.58	12.20	5.39
77	1600.10	0.487	74.034	67.227	2.7983	75.0947	-0.0859	6.876	8.00%	10.92	6.81	84.96	17.73	12.27	5.46
78	1620.81	0.493	74.034	67.149	2.7983	76.3556	-0.0859	6.884	8.11%	11.09	6.89	85.13	17.98	12.43	5.55
79	1641.51	0.5	74.034	67.134	2.7983	77.2896	-0.0857	6.891	8.21%	11.22	6.90	85.25	18.12	12.51	5.61
80	1662.21	0.506	74.034	67.071	2.7983	78.2236	-0.0859	6.899	8.31%	11.34	6.96	85.37	18.30	12.63	5.67

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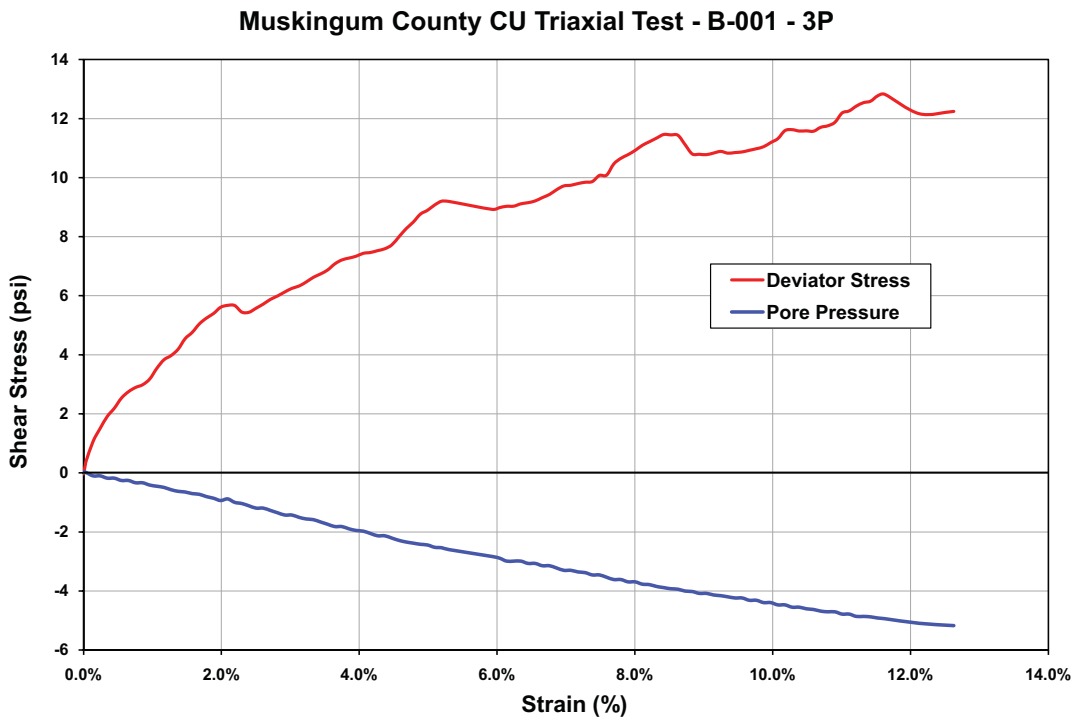
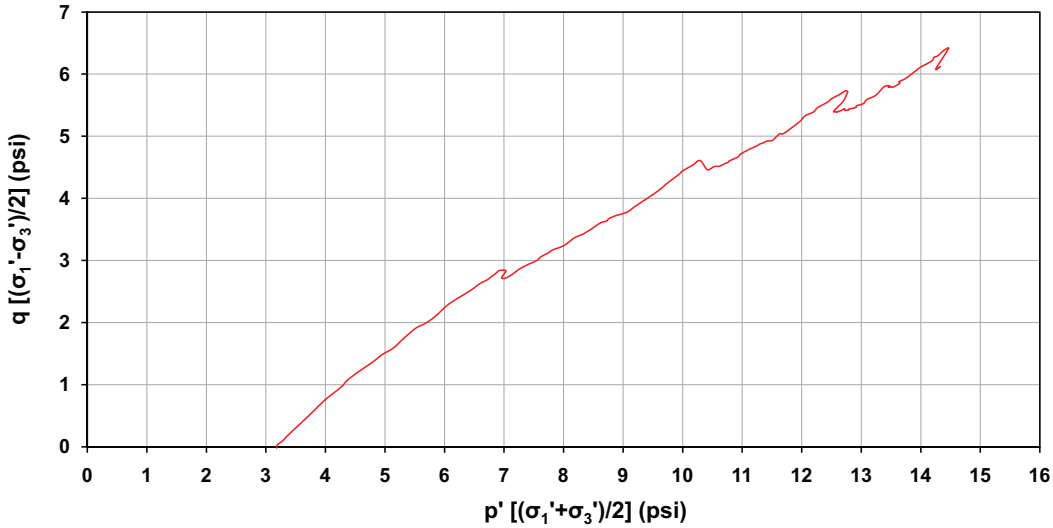
L2 = 6.044 in.		D2 = 2.843 in.		Sample Diam. D =	2.839 in.		Wet Wt. In Dish =	104.24 g		0.028 in^3
L3 = 6.101 in.		D3 = 2.844 in.		$A_O = \pi r^2 = \pi D^2/4$ =	6.329 in^2		Dry Wt. In Dish =	95.33 g		
				$V = \pi r^2 L = \pi D^2 L/4$ =	38.534 in^3		Moisture Loss =	8.91 g		Consolidation Time t_{50}
Rate of Strain = 0.0003 in./min.= 0.005% /min.							Moisture Content =	18.6%		
Sample Mass = 1371.40 g		**"Wet" Density =** 135.58 pcf				**Dry Density =** 114.34 pcf				80.00 minutes

Reading Number	Time in Minutes	Axial Displac. Inches	Cell Pressure σ3 psi	Pore Pressure u psi	Back Pressure psi	Axial Force P lbf	Volume Gage ΔV in^3	Area Correction in^2	Percent Strain ε	Deviator Stress σ1-σ3	Effective Stress σ3' psi	Axial Stress σ1 psi	Effective Stress σ1' psi	Average Stress p' psi	Maximum Shear q psi
81	1682.91	0.512	74.034	67.032	2.7983	79.1577	-0.0857	6.907	8.42%	11.46	7.00	85.49	18.46	12.73	5.73
82	1703.61	0.519	74.034	66.993	2.7983	79.1577	-0.0862	6.915	8.52%	11.45	7.04	85.48	18.49	12.77	5.72
83	1724.32	0.525	74.034	66.978	2.7983	79.1577	-0.0862	6.923	8.62%	11.43	7.06	85.47	18.49	12.77	5.72
84	1745.02	0.531	74.05	66.915	2.7827	77.0561	-0.0857	6.931	8.73%	11.12	7.14	85.17	18.25	12.69	5.56
85	1765.72	0.538	74.034	66.9	2.7983	74.9546	-0.0859	6.938	8.83%	10.80	7.13	84.84	17.94	12.54	5.40
86	1786.42	0.544	74.034	66.837	2.7827	74.9546	-0.0857	6.946	8.93%	10.79	7.20	84.83	17.99	12.59	5.40
87	1807.12	0.55	74.034	66.837	2.7827	74.9546	-0.0857	6.954	9.04%	10.78	7.20	84.81	17.98	12.59	5.39
88	1827.82	0.556	74.034	66.783	2.7983	75.4216	-0.0857	6.962	9.14%	10.83	7.25	84.87	18.09	12.67	5.42
89	1848.53	0.563	74.034	66.759	2.7827	75.8886	-0.0854	6.970	9.24%	10.89	7.28	84.92	18.16	12.72	5.44
90	1869.23	0.569	74.034	66.72	2.7827	75.5617	-0.0859	6.978	9.35%	10.83	7.31	84.86	18.14	12.73	5.41
91	1889.93	0.575	74.05	66.681	2.7827	75.7952	-0.0857	6.986	9.45%	10.85	7.37	84.90	18.22	12.79	5.42
92	1910.63	0.582	74.034	66.681	2.7983	76.0287	-0.0854	6.994	9.56%	10.87	7.35	84.91	18.22	12.79	5.44
93	1931.33	0.588	74.05	66.603	2.7827	76.4957	-0.0859	7.002	9.66%	10.92	7.45	84.98	18.37	12.91	5.46
94	1952.04	0.594	74.034	66.603	2.7983	76.9627	-0.0859	7.010	9.76%	10.98	7.43	85.01	18.41	12.92	5.49
95	1972.74	0.601	74.034	66.525	2.7827	77.5231	-0.0857	7.018	9.87%	11.05	7.51	85.08	18.56	13.03	5.52
96	1993.44	0.607	74.034	66.525	2.7827	78.5972	-0.0857	7.026	9.97%	11.19	7.51	85.22	18.70	13.10	5.59
97	2014.14	0.613	74.034	66.447	2.7983	79.6247	-0.0857	7.034	10.07%	11.32	7.59	85.35	18.91	13.25	5.66
98	2034.84	0.619	74.034	66.447	2.7983	81.6328	-0.0854	7.042	10.18%	11.59	7.59	85.63	19.18	13.38	5.80
99	2055.55	0.626	74.034	66.369	2.7983	81.9597	-0.0857	7.051	10.28%	11.62	7.67	85.66	19.29	13.48	5.81
100	2076.25	0.632	74.034	66.369	2.7827	81.7262	-0.0859	7.059	10.38%	11.58	7.67	85.61	19.24	13.45	5.79
101	2096.95	0.638	74.034	66.315	2.7827	81.8663	-0.0859	7.067	10.49%	11.58	7.72	85.62	19.30	13.51	5.79
102	2117.65	0.645	74.034	66.291	2.7983	81.8663	-0.0857	7.075	10.59%	11.57	7.74	85.61	19.31	13.53	5.79
103	2138.35	0.651	74.034	66.237	2.7827	82.8937	-0.0857	7.083	10.69%	11.70	7.80	85.74	19.50	13.65	5.85
104	2159.06	0.657	73.971	66.213	2.7827	83.3607	-0.0852	7.091	10.80%	11.76	7.76	85.73	19.51	13.64	5.88
105	2179.76	0.664	74.034	66.213	2.7827	84.2947	-0.0857	7.100	10.90%	11.87	7.82	85.91	19.69	13.76	5.94
106	2200.46	0.67	74.011	66.135	2.7827	86.6298	-0.0857	7.108	11.00%	12.19	7.88	86.20	20.06	13.97	6.09
107	2221.16	0.676	74.034	66.135	2.7827	87.2369	-0.0854	7.116	11.11%	12.26	7.90	86.29	20.16	14.03	6.13
108	2241.86	0.682	74.034	66.057	2.7827	88.4978	-0.0857	7.124	11.21%	12.42	7.98	86.46	20.40	14.19	6.21
109	2262.57	0.689	74.011	66.057	2.7827	89.4318	-0.0852	7.133	11.32%	12.54	7.95	86.55	20.49	14.22	6.27
110	2283.27	0.695	74.034	66.042	2.7983	89.8988	-0.0849	7.141	11.42%	12.59	7.99	86.62	20.58	14.29	6.29
111	2303.97	0.701	74.011	66.003	2.7827	91.2998	-0.0854	7.150	11.52%	12.77	8.01	86.78	20.78	14.39	6.39
112	2324.67	0.708	74.034	65.979	2.7827	91.7668	-0.0849	7.158	11.63%	12.82	8.06	86.85	20.88	14.47	6.41
113	2424.73	0.738	73.995	65.823	2.7594	87.5638	-0.0854	7.199	12.13%	12.16	8.17	86.16	20.34	14.25	6.08
114	2524.79	0.769	73.955	65.745	2.7594	88.6379	-0.0867	7.240	12.63%	12.24	8.21	86.20	20.45	14.33	6.12

07/02


Muskingum County CU Triaxial Test - B-001 - 3P
Shear Stress (psi)
Strain (%)
Deviator Stress
Pore Pressure
14
12
10
8
6
4
2
0
-2
-4
-6
0.0%
2.0%
4.0%
6.0%
8.0%
10.0%
12.0%
14.0%


q [(σ1'-σ3')/2] (psi)
p' [(σ1'+σ3')/2] (psi)
7
6
5
4
3
2
1
0
0
1
2
3
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16

State of Ohio
Department of Transportation
Office of Geotechnical Engineering

CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION TEST
AASHTO T 297 & ASTM D4767

Project Mus - 70 - 26.8 **Station & Offset** **Boring Number** B-001
Depth 6.0 - 6.7 **Sample Number** 3P **Lab Number** 20753 - B

Sample Length			Sample Diameter														Consolidation Volume Lost
L1 =	5.703	in.	D1 =	2.858	in.	Sample Length L =	5.674	in.	Empty Dish Wt. =	47.38	g						
L2 =	5.653	in.	D2 =	2.850	in.	Sample Diam. D =	2.854	in.	Wet Wt. In Dish =	104.24	g						0.030 in^3
L3 =	5.667	in.	D3 =	2.853	in.	$A_O = \pi r^2 = \pi D^2/4$ =	6.396	in^2	Dry Wt. In Dish =	95.33	g						
						$V = \pi r^2 L = \pi D^2 L/4$ =	36.292	in^3	Moisture Loss =	8.91	g						Consolidation Time t_{50}
Rate of Strain =	0.0003	in./min.=	0.005%	/min.					Moisture Content =	18.6%							
Sample Mass =	1271.07	g	**"Wet" Density =**	133.42	pcf				**Dry Density =**	112.52	pcf						80.00 minutes

Reading Number	Time in Minutes	Axial Displac. Inches	Cell Pressure σ3 psi	Pore Pressure u psi	Back Pressure psi	Axial Force P lbf	Volume Gage ΔV in^3	Area Correction in^2	Percent Strain ε	Deviator Stress σ1-σ3	Effective Stress σ3' psi	Axial Stress σ1 psi	Effective Stress σ1' psi	Average Stress p' psi	Maximum Shear q psi
1	0.00	0	85.708	79.783	75.93	-0.1401	0.00052	6.392	0.00%	-0.02	5.92	85.69	5.90	5.91	-0.01
2	20.42	0.006	85.63	79.938	75.891	1.30762	-0.0005	6.399	0.10%	0.20	5.69	85.83	5.90	5.79	0.10
3	40.85	0.012	85.606	80.031	75.93	1.30762	-0.0029	6.405	0.20%	0.20	5.57	85.81	5.78	5.68	0.10
4	61.27	0.017	85.59	80.171	75.93	2.24163	-0.0034	6.412	0.31%	0.35	5.42	85.94	5.77	5.59	0.17
5	81.69	0.023	85.551	80.248	75.93	2.94214	-0.0036	6.419	0.41%	0.46	5.30	86.01	5.76	5.53	0.23
6	141.11	0.04	85.551	81.487	75.93	19.7544	-0.0052	6.438	0.71%	3.07	4.06	88.62	7.13	5.60	1.53
7	200.52	0.057	85.63	82.277	75.93	34.9321	-0.006	6.457	1.00%	5.41	3.35	91.04	8.76	6.06	2.70
8	259.94	0.074	85.488	82.494	75.93	46.1403	-0.0065	6.476	1.30%	7.12	2.99	92.61	10.12	6.56	3.56
9	319.35	0.091	85.551	82.61	75.93	54.5464	-0.0072	6.496	1.60%	8.40	2.94	93.95	11.34	7.14	4.20
10	378.76	0.107	85.551	82.509	75.93	61.0845	-0.0072	6.516	1.89%	9.37	3.04	94.93	12.42	7.73	4.69
11	438.18	0.124	85.551	82.354	75.93	68.0896	-0.0078	6.536	2.19%	10.42	3.20	95.97	13.62	8.41	5.21
12	497.59	0.141	85.551	82.122	75.93	73.7871	-0.0078	6.555	2.49%	11.26	3.43	96.81	14.68	9.06	5.63
13	557.00	0.158	85.567	81.797	75.914	79.2978	-0.0072	6.575	2.79%	12.06	3.77	97.63	15.83	9.80	6.03
14	616.42	0.175	85.63	81.58	75.93	84.2013	-0.0072	6.596	3.08%	12.77	4.05	98.40	16.82	10.43	6.38
15	675.83	0.192	85.645	81.332	75.93	87.2369	-0.0076	6.616	3.38%	13.19	4.31	98.83	17.50	10.91	6.59
16	735.25	0.209	85.551	81.022	75.93	88.4978	-0.0076	6.636	3.68%	13.34	4.53	98.89	17.86	11.20	6.67
17	794.66	0.225	85.551	80.713	75.93	91.0663	-0.0078	6.657	3.97%	13.68	4.84	99.23	18.52	11.68	6.84
18	854.07	0.242	85.669	80.48	75.93	93.775	-0.0076	6.678	4.27%	14.04	5.19	99.71	19.23	12.21	7.02
19	913.49	0.259	85.669	80.171	75.93	96.3435	-0.0083	6.698	4.57%	14.38	5.50	100.05	19.88	12.69	7.19
20	972.90	0.276	85.473	79.706	75.93	99.3791	-0.0072	6.719	4.87%	14.79	5.77	100.26	20.56	13.16	7.40
21	1032.32	0.293	85.567	79.474	75.93	102.181	-0.0081	6.740	5.16%	15.16	6.09	100.73	21.25	13.67	7.58
22	1091.73	0.31	85.551	79.164	75.914	104.376	-0.0072	6.761	5.46%	15.44	6.39	100.99	21.82	14.11	7.72
23	1151.14	0.327	85.551	78.932	75.914	108.719	-0.0078	6.783	5.76%	16.03	6.62	101.58	22.65	14.63	8.01
24	1210.56	0.343	85.488	78.622	75.891	112.455	-0.0078	6.804	6.05%	16.53	6.87	102.02	23.39	15.13	8.26
25	1269.97	0.36	85.528	78.312	75.876	114.79	-0.0078	6.826	6.35%	16.82	7.22	102.34	24.03	15.62	8.41
26	1329.38	0.377	85.551	78.134	75.914	116.752	-0.0081	6.848	6.65%	17.05	7.42	102.60	24.47	15.94	8.53
27	1388.49	0.394	85.551	77.886	75.891	114.79	-0.0083	6.869	6.94%	16.71	7.66	102.26	24.38	16.02	8.36
28	1447.28	0.411	85.551	77.631	75.876	114.323	-0.0083	6.891	7.24%	16.59	7.92	102.14	24.51	16.22	8.29
29	1507.91	0.428	85.551	77.383	75.891	114.65	-0.0083	6.914	7.54%	16.58	8.17	102.13	24.75	16.46	8.29
30	1568.54	0.445	85.551	77.166	75.876	117.452	-0.0086	6.936	7.84%	16.93	8.39	102.48	25.32	16.85	8.47
31	1629.17	0.462	85.551	76.918	75.876	119.927	-0.0088	6.959	8.15%	17.23	8.63	102.78	25.87	17.25	8.62
32	1689.80	0.479	85.551	76.686	75.876	122.029	-0.0088	6.982	8.45%	17.48	8.87	103.03	26.34	17.60	8.74
33	1750.43	0.497	85.473	75.989	75.852	127.259	-0.0086	7.006	8.75%	18.17	9.48	103.64	27.65	18.57	9.08
34	1937.83	0.55	85.473	75.927	75.852	127.399	-0.0086	7.078	9.69%	18.00	9.55	103.47	27.54	18.54	9.00
35	1998.46	0.567	85.473	75.757	75.852	125.391	-0.0086	7.102	10.00%	17.66	9.72	103.13	27.37	18.54	8.83
36	2059.09	0.584	85.473	75.602	75.852	123.29	-0.0086	7.126	10.30%	17.30	9.87	102.77	27.17	18.52	8.65
37	2120.48	0.602	85.473	75.447	75.852	120.394	-0.0086	7.151	10.61%	16.84	10.03	102.31	26.86	18.44	8.42
38	2182.07	0.619	85.63	75.447	75.852	119.46	-0.0086	7.175	10.91%	16.65	10.18	102.28	26.83	18.51	8.32
39	2243.66	0.637	85.551	75.292	75.852	120.161	-0.0086	7.200	11.22%	16.69	10.26	102.24	26.95	18.60	8.34
40	2305.26	0.654	85.551	75.153	75.852	121.655	-0.0091	7.225	11.53%	16.84	10.40	102.39	27.24	18.82	8.42

07/02

State of Ohio
Department of Transportation
Office of Geotechnical Engineering

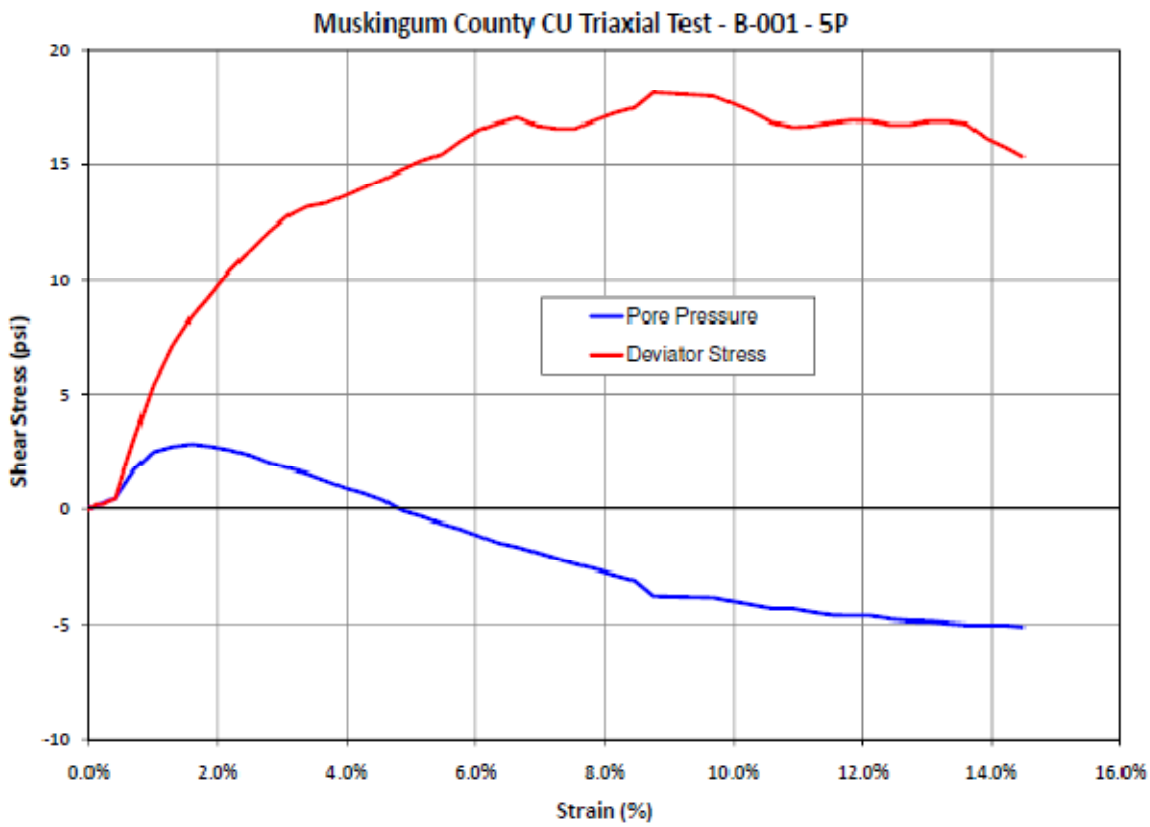
CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION TEST
AASHTO T 297 & ASTM D4767

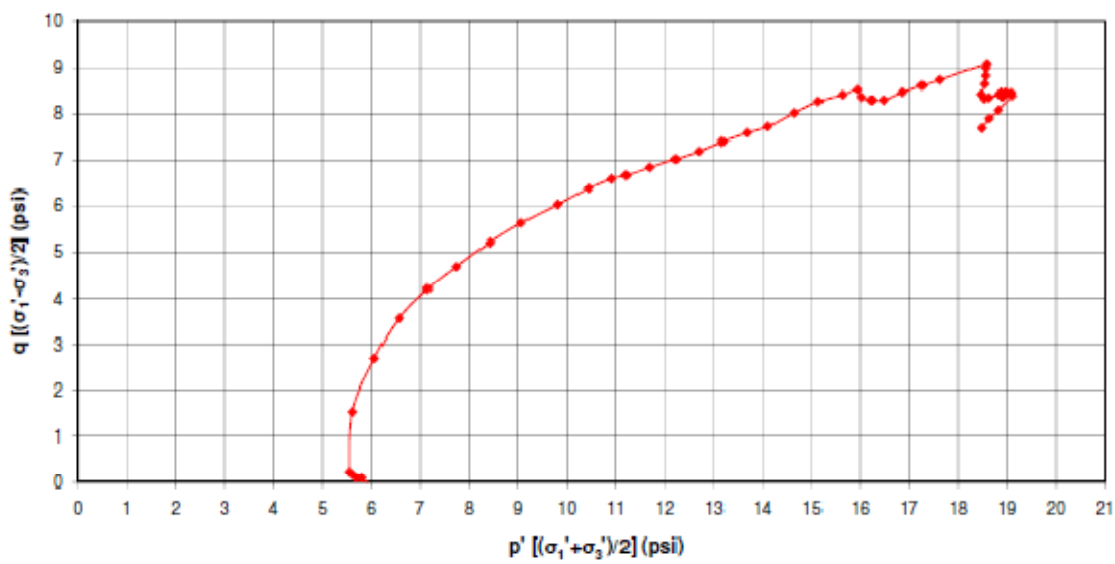
Project Mus - 70 - 26.8 **Station & Offset** **Boring Number** B-001
Depth 6.0 - 6.7 **Sample Number** 3P **Lab Number** 20753 - B

Sample Length			Sample Diameter															Consolidation Volume Lost
L1 =	5.703	in.	D1 =	2.858	in.	Sample Length L =	5.674	in.	Empty Dish Wt. =	47.38	g							
L2 =	5.653	in.	D2 =	2.850	in.	Sample Diam. D =	2.854	in.	Wet Wt. In Dish =	104.24	g							0.030 in^3
L3 =	5.667	in.	D3 =	2.853	in.	$A_O = \pi r^2 = \pi D^2/4 =$	6.396	in^2	Dry Wt. In Dish =	95.33	g							
						$V = \pi r^2 L = \pi D^2 L/4 =$	36.292	in^3	Moisture Loss =	8.91	g							Consolidation Time t_{50}
Rate of Strain =	0.0003	in./min.=	0.005%	/min.					Moisture Content =	18.6%								
Sample Mass =	1271.07	g	**"Wet" Density =**	133.42	pcf				**Dry Density =**	112.52	pcf							80.00 minutes

Reading Number	Time in Minutes	Axial Displac. Inches	Cell Pressure σ3 psi	Pore Pressure u psi	Back Pressure psi	Axial Force P lbf	Volume Gage ΔV in^3	Area Correction in^2	Percent Strain ε	Deviator Stress σ1-σ3	Effective Stress σ3' psi	Axial Stress σ1 psi	Effective Stress σ1' psi	Average Stress p' psi	Maximum Shear q psi
41	2364.98	0.671	85.551	75.137	75.852	122.729	-0.0088	7.250	11.83%	16.93	10.41	102.48	27.34	18.88	8.46
42	2424.70	0.688	85.645	75.137	75.852	123.056	-0.0086	7.274	12.13%	16.92	10.51	102.56	27.42	18.97	8.46
43	2484.43	0.705	85.528	74.998	75.852	122.122	-0.0086	7.299	12.43%	16.73	10.53	102.26	27.26	18.90	8.37
44	2544.15	0.722	85.473	74.92	75.852	122.589	-0.0088	7.324	12.72%	16.74	10.55	102.21	27.29	18.92	8.37
45	2603.88	0.739	85.473	74.905	75.852	124.13	-0.0088	7.349	13.02%	16.89	10.57	102.36	27.46	19.01	8.44
46	2663.60	0.756	85.473	74.827	75.852	124.597	-0.0088	7.375	13.32%	16.90	10.65	102.37	27.54	19.09	8.45
47	2723.33	0.773	85.473	74.75	75.852	124.13	-0.0088	7.400	13.62%	16.77	10.72	102.25	27.50	19.11	8.39
48	2782.92	0.79	85.488	74.75	75.852	119.927	-0.0091	7.426	13.92%	16.15	10.74	101.64	26.89	18.81	8.07
49	2841.71	0.806	85.473	74.75	75.852	117.592	-0.0088	7.451	14.21%	15.78	10.72	101.25	26.50	18.61	7.89
50	2897.26	0.822	85.45	74.67	75.85	114.79	-0.0093	7.476	14.49%	15.36	10.78	100.81	26.14	18.46	7.68

07/02


Muskingum County CU Triaxial Test - B-001 - 5P
Shear Stress (psi)
Strain (%)
Pore Pressure
Deviator Stress
20
15
10
5
0
-5
-10
0.0%
2.0%
4.0%
6.0%
8.0%
10.0%
12.0%
14.0%
16.0%


q [(σ1'-σ3')/2] (psi)
p' [(σ1'+σ3')/2] (psi)
10
9
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5
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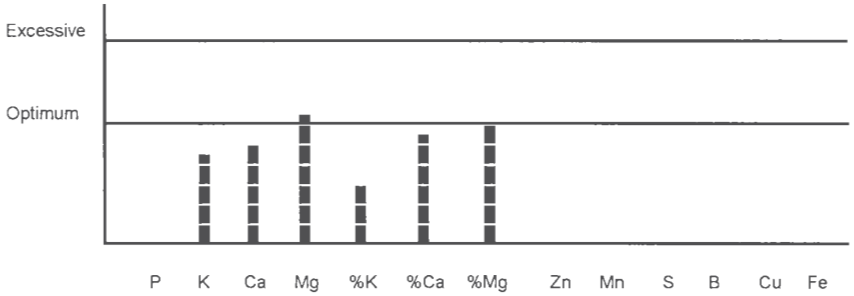
CALMAR
SOIL TESTING LABS

Sample Submitted By	Grower	Date of Report	Report Number	Record Number	Lab #	Field	Sample
CHRISTOPHER KOKESH 6893 MEADOW OAK DR. COLUMBUS, OH 43235	MUSKINGUM CO I 70/SR 83	02/13/06	278.014	20184	02233B		

Organic Matter %	Phosphorus Bray P1	Potassium K	Magnesium Mg	Calcium Ca	pH		Cation Exchange Capacity	Percent Base Saturation			Sulfur S	Zinc Zn	Manganese Mn	Boron B	Copper Cu	Iron Fe
					Soil	Buffer		%K	%Mg	%Ca						
1.7	5	307	1513	6830	8.4		24.1	1.6	26.1	71						

Crop/Yield	Previous Crop	Nitrogen Lbs/A	P_2O_5 Lbs/A	K_2O Lbs/A	Lime		Magnesium Mg Lbs/A	Sulfur S Lbs/A	Zinc Zn Lbs/A	Manganese Mn Lbs/A	Boron B Lbs/A	Copper Cu Lbs/A	Iron Fe Lbs/A
					T/A	Type							
SHRUBS/BUSHES 1 NA		120	150	135	0.0								
HARDWOOD TREES 1 NA		120	150	135	0.0								



Comments:

Test results reported in pounds per acre

Soluble salts: 0.375 mmhos/cm

Na #/A = 167
% Na = 1.5

130 South State Street
Westerville, OH 43081
614-523-1005

CAL MAR
SOIL TESTING LABS

02/13/06
MUSKINGUM CO
I 70/SR 83

Sample submitted by:
CHRISTOPHER KOKESH

6893 MEADOW OAK DR.
COLUMBUS, OH 43235

Test Results

Results are in pounds per acre except pH or as noted

LAB NUMBER 278.014 SAMPLE ID	pH Soil	pH Buffer	Phosphorus (P)	Potassium (K)	Magnesium (Mg)	Calcium (Ca)
2233	8.4		5	307	1513	6830

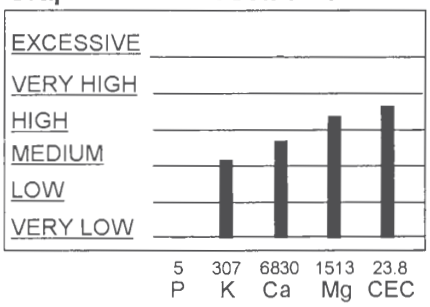
% Organic Matter	Cation Exchange Capacity	PERCENT BASE SATURATION			
		%Potassium	%Magnesium	%Calcium	%Hydrogen
1.7	23.8	1.7	26.5	72	

Recommendations

For optimum growth of your shrubs/bushes we recommend adding the following

NITROGEN (N)	PHOSPHORUS (P205)	POTASSIUM (K2O)	Sulfur- Lbs/1000 Sq.Ft.		
POUNDS / 1000 Sq. Ft. per season	POUNDS / 1000 Sq. Ft. per season	POUNDS / 1000 Sq. Ft. per season	SOIL DEPTH (inches)		
2.8	3.4	3.1	3	5	
			6	11	
			9	16	
			12	21	
			Type		

Graph of current soil test values



Please see notes on page two

page 1

CAL MAR SOIL TESTING LABS, 130 SOUTH STATE STREET, WESTERVILLE, OH 43081
PH: 614-523-1005 FAX: 614.523.1004

CAL MAR
SOIL TESTING LABS

02/13/06
MUSKINGUM CO
I 70/SR 83

Sample submitted by:
CHRISTOPHER KOKESH

6893 MEADOW OAK DR.
COLUMBUS, OH 43235

Notes

Soil pH

Your pH value is very high and may be affecting plant growth. It will be necessary to apply sulfur or other acidifying products in order to lower the soil pH. Sulfur applications should be worked into the soil. If the plant material is already established, use the shallow application amount (3-inches) recommended for now. The next time the soil and sulfur can be mixed thoroughly, apply the remaining amount (i.e.: the difference between the 3-inch recommendation and the 9-inch recommendation).

Nitrogen

Your nitrogen recommendation is based upon the plants to be grown and the soil organic matter. Your nitrogen recommendation has been increased slightly due to a low soil organic matter percentage. Nitrogen should be worked into the soil prior to planting when possible. For established plants, apply only a portion of the recommended nitrogen throughout the growing season. Be very cautious about applying nitrogen in very warm or dry weather, since this can damage the plant tissue.

Phosphorus

Your phosphorus value is very low and it may be affecting plant growth. It will be necessary to apply phosphorus in order to raise the soil phosphorus level. Phosphorus applications should be worked into the soil prior to planting if possible. If the plant material is already established, apply one-half of the recommended phosphorus to the soil surface, for now. The next time soil and phosphorus can be mixed thoroughly, apply the remaining amount recommended.

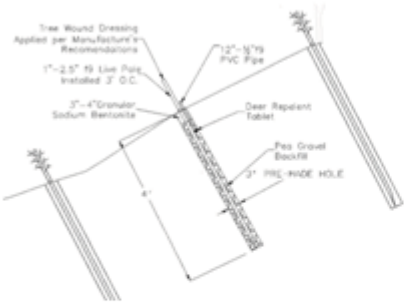
Potassium

The current potassium level is just slightly below the optimum range for the indicated plant type. Your current soil potassium level is not adversely affecting the health of your plants. You may apply a small amount of potassium at this time to adjust the level in your soil. If practical, when you apply potassium, try to thoroughly mix the application into the soil or water in after application.

These notes refer to the recommendations and results on page one. Additional general information is enclosed.

CAL MAR SOIL TESTING LABS, 130 SOUTH STATE STREET, WESTERVILLE, OH 43081
PH: 614-523-1005 FAX: 614.523.1004

Live Pole Installation



Typical live pole installation detail

Drilling holes

Slope scraping

Live Pole Installation

Live poles showing wired ends

Backfilling live pole holes

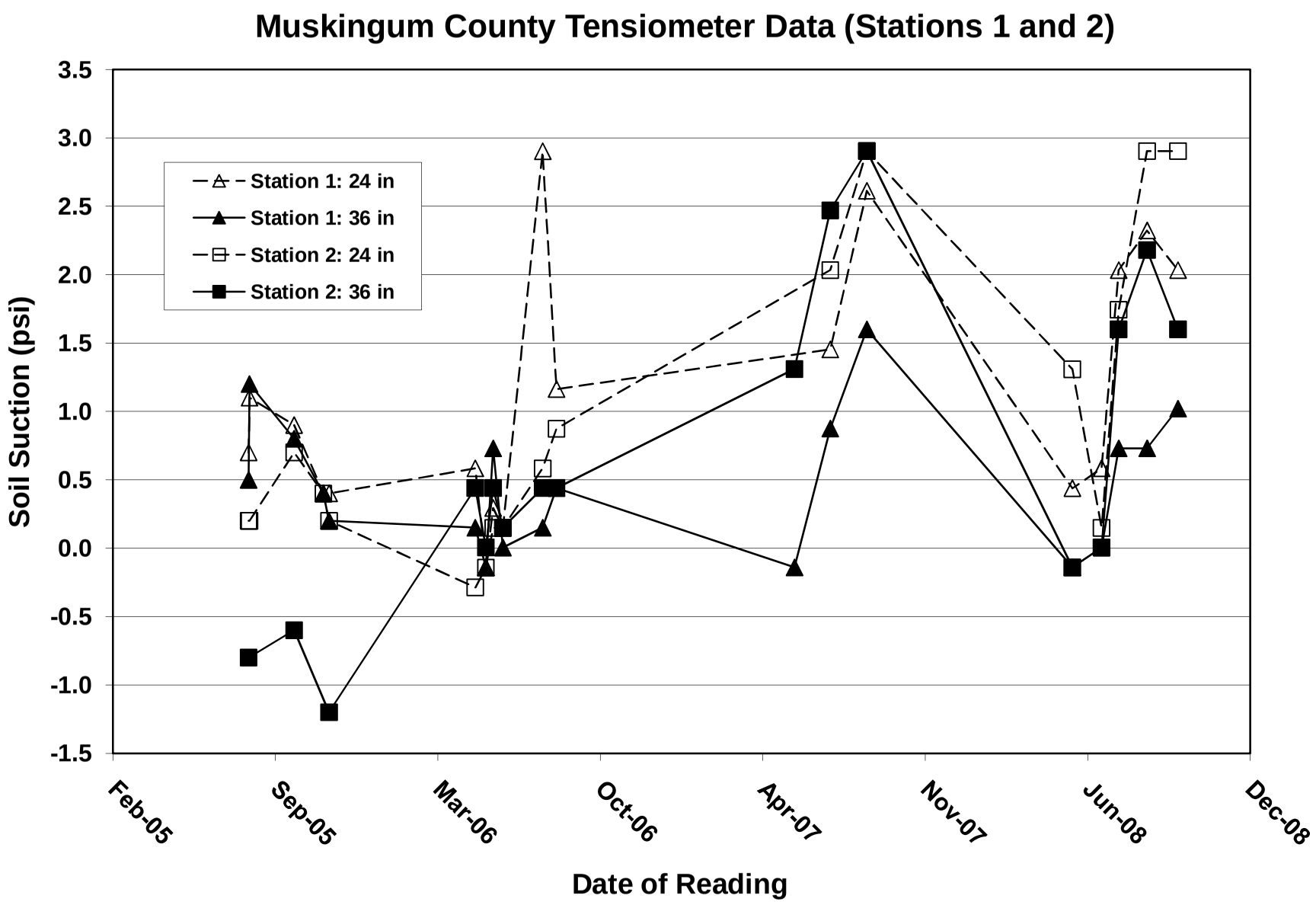
Live pole soaking and preparation

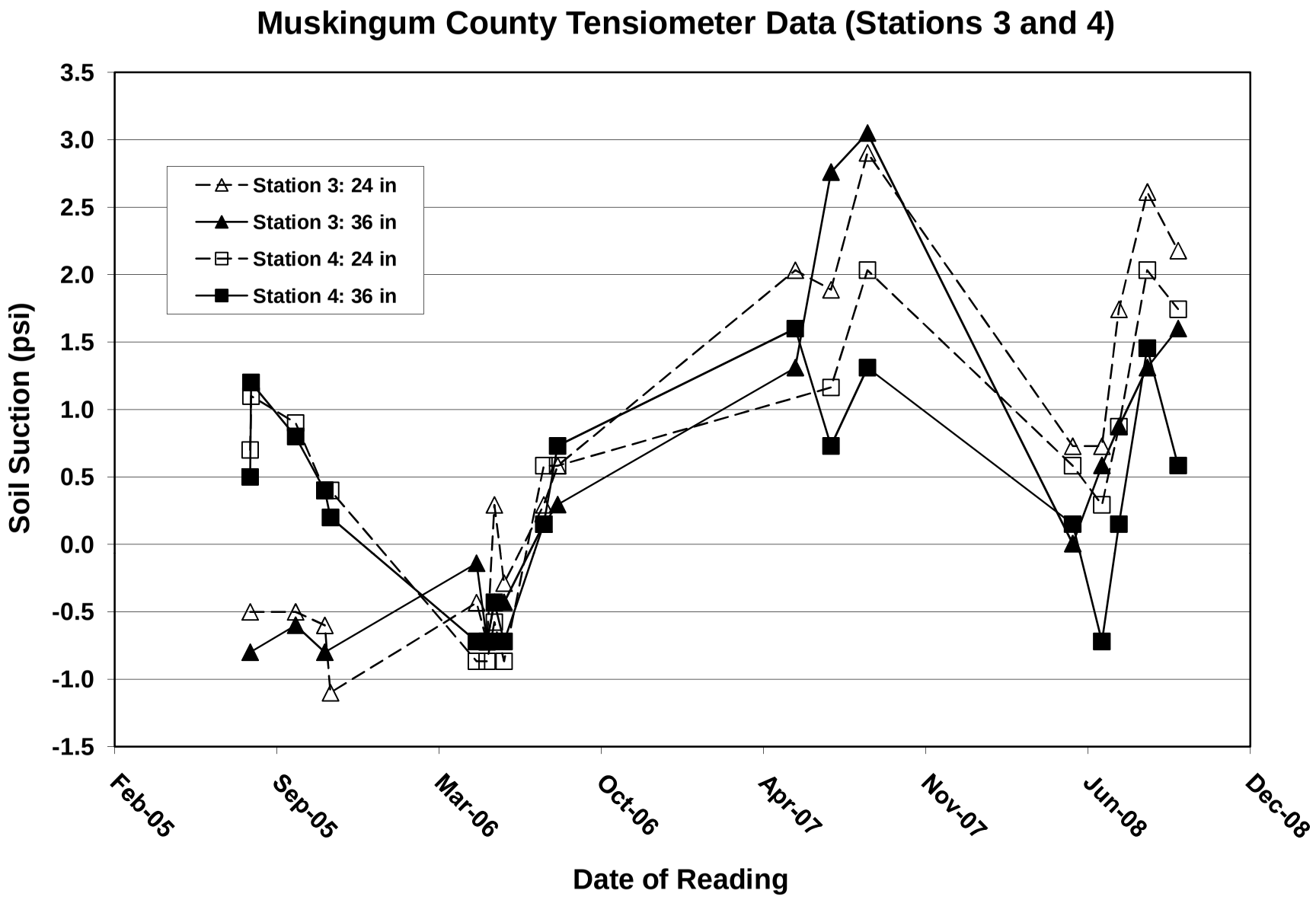
Visual log of construction activities at the Muskingum County demonstration site.

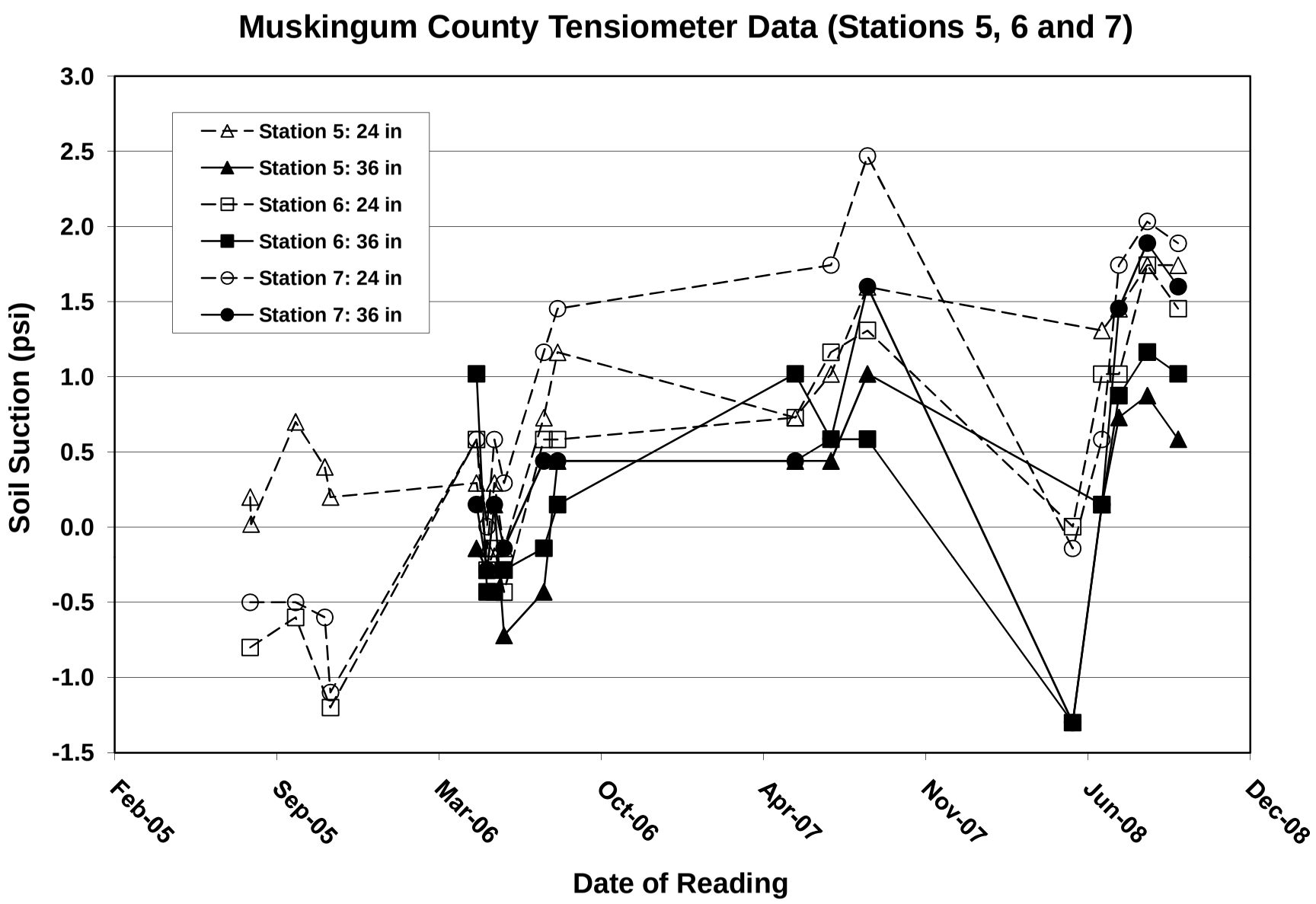
Muskingum County Tensiometer Data

ID	Depth	Soil Suction (psi)*																		
		Date of Reading																		
		8/3/2005	8/4/2005	9/28/2005	11/3/2005	11/10/2005	5/9/2006	5/22/2006	5/31/2006	6/12/2006	7/31/2006	8/17/2006	6/6/2007	7/20/2007	9/3/2007	5/13/2008	6/18/2008	7/9/2008	8/13/2008	9/20/2008
# 1	24 in	0.70	1.10	0.90	0.40	0.40	0.58	-0.14	0.29	0.15	2.90	1.16	-	1.45	2.61	0.44	0.58	2.03	2.32	2.03
	36 in	0.50	1.20	0.80	0.40	0.20	0.15	-0.14	0.73	0.01	0.15	0.44	-0.14	0.88	1.60	-0.14	0.01	0.73	0.73	1.02
# 2	24 in	0.20	0.20	0.70	0.40	0.20	-0.29	-0.14	0.15	0.15	0.58	0.87	-	2.03	2.90	1.31	0.15	1.74	2.90	2.90
	36 in	-0.80	-	-0.60	-	-1.20	0.44	0.01	0.44	0.15	0.44	0.44	1.31	2.47	2.91	-0.14	0.01	1.60	2.18	1.60
# 3	24 in	-0.50	-	-0.50	-0.60	-1.10	-0.43	-0.72	0.29	-0.29	0.29	0.58	2.03	1.89	2.90	0.73	0.73	1.74	2.61	2.18
	36 in	-0.80	-	-0.60	-0.80	-	-0.14	-0.72	-0.43	-0.43	0.15	0.30	1.31	2.76	3.05	0.01	0.59	0.88	1.31	1.60
# 4	24 in	0.70	1.10	0.90	0.40	0.40	-0.87	-0.87	-0.58	-0.87	0.58	0.58	-	1.16	2.03	0.58	0.29	0.87	2.03	1.74
	36 in	0.50	1.20	0.80	0.40	0.20	-0.72	-0.72	-0.43	-0.72	0.15	0.73	1.60	0.73	1.31	0.15	-0.72	0.15	1.46	0.59
# 5	24 in	0.20	0.02	0.70	0.40	0.20	0.29	-0.14	0.29	-0.14	0.73	1.16	0.73	1.02	1.60	-	1.31	1.45	1.74	1.74
	36 in	-	-	-	-	-	-0.14	-0.28	0.15	-0.72	-0.43	0.44	0.44	0.44	1.02	-	0.15	0.73	0.88	0.59
# 6	24 in	-0.80	-	-0.60	-	-1.20	0.58	-0.29	-0.14	-0.43	0.58	0.58	0.73	1.16	1.31	0.00	1.02	1.02	1.74	1.45
	36 in	-	-	-	-	-	1.02	-0.43	-0.43	-0.28	-0.14	0.15	1.02	0.59	0.59	-1.30	0.15	0.88	1.17	1.02
# 7	24 in	-0.50	-	-0.50	-0.60	-1.10	0.58	0.00	0.58	0.29	1.16	1.45	-	1.74	2.47	-0.14	0.58	1.74	2.03	1.89
	36 in	-	-	-	-	-	0.15	-0.28	0.15	-0.14	0.44	0.44	0.44	0.59	1.60	-1.30	0.15	1.46	1.89	1.60

* All values have also been corrected for elevation corresponding to the water column in the tensiometer.

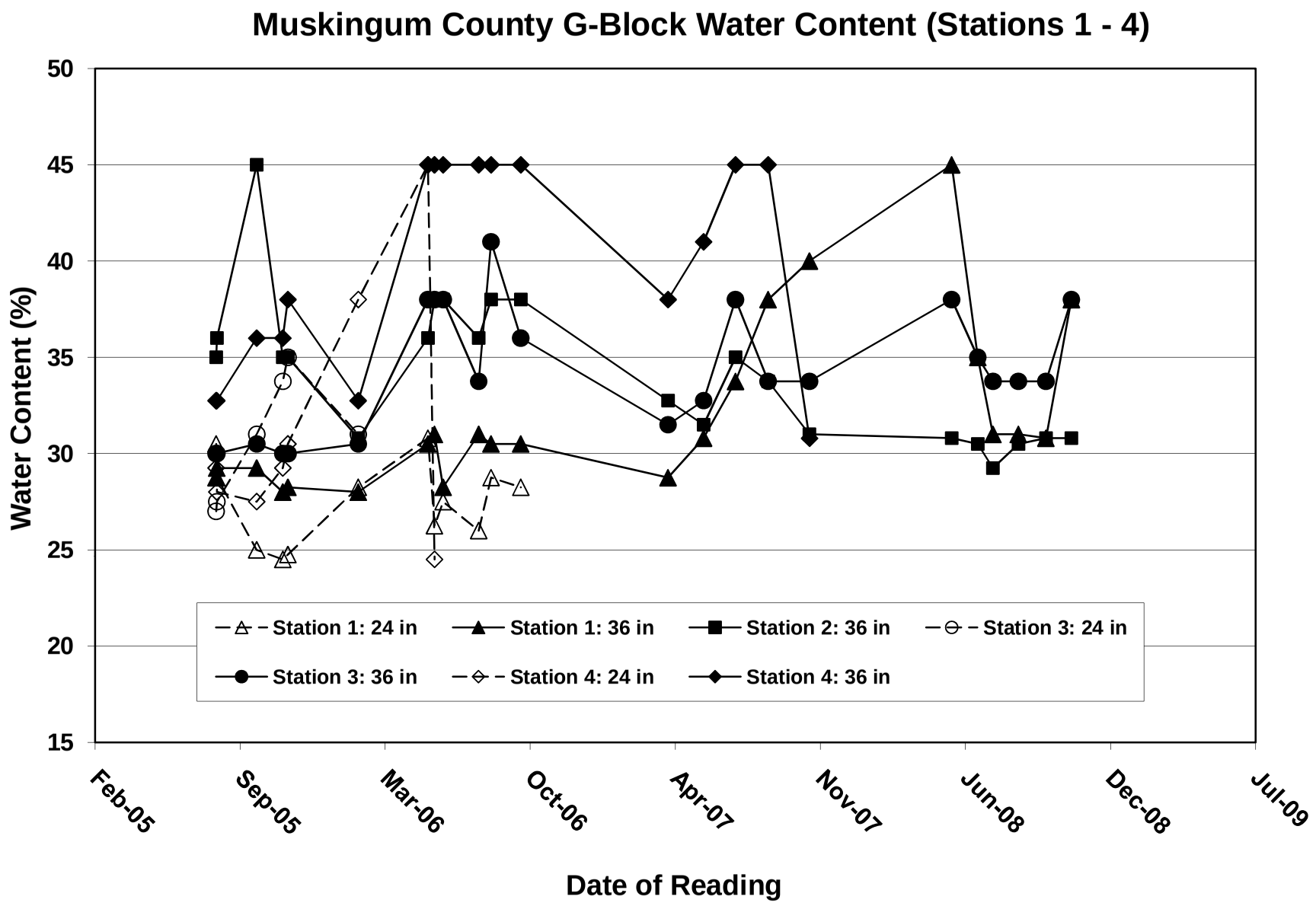

Muskingum County Tensiometer Data (Stations 1 and 2)
Station 1: 24 in
Station 1: 36 in
Station 2: 24 in
Station 2: 36 in
Soil Suction (psi)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
Feb-05
Sep-05
Mar-06
Oct-06
Apr-07
Nov-07
Jun-08
Dec-08
Date of Reading

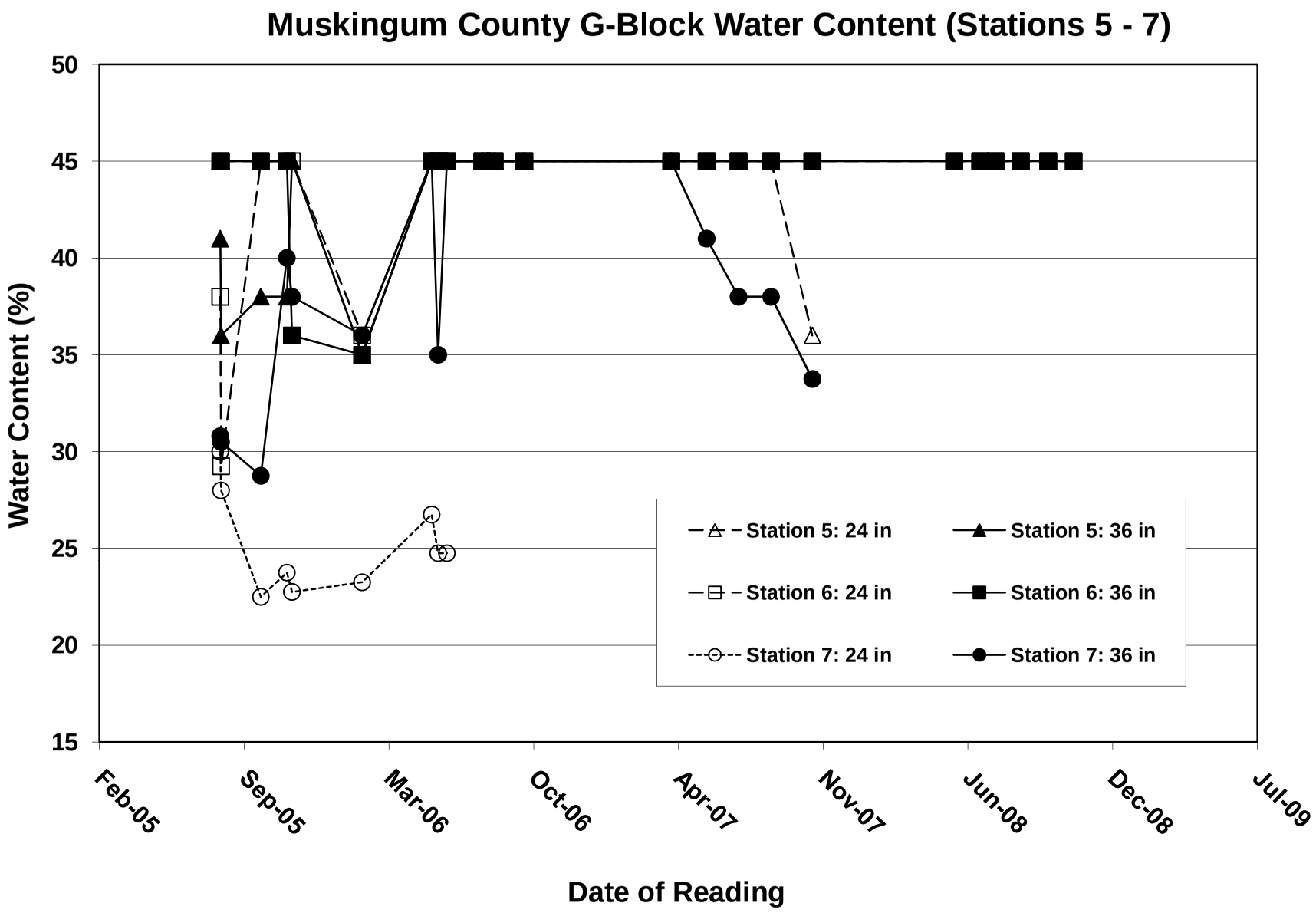

Muskingum County Tensiometer Data (Stations 3 and 4)
Station 3: 24 in
Station 3: 36 in
Station 4: 24 in
Station 4: 36 in
Soil Suction (psi)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
Feb-05
Sep-05
Mar-06
Oct-06
Apr-07
Nov-07
Jun-08
Dec-08
Date of Reading


Muskingum County Tensiometer Data (Stations 5, 6 and 7)
Station 5: 24 in
Station 5: 36 in
Station 6: 24 in
Station 6: 36 in
Station 7: 24 in
Station 7: 36 in
Soil Suction (psi)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
Feb-05
Sep-05
Mar-06
Oct-06
Apr-07
Nov-07
Jun-08
Dec-08
Date of Reading

Muskingum County Gypsum Block Data

Date	01G24		01G36		02G24		02G36		03G24		03G36		04G24		04G36		05G24		05G36		06G24		06G36		07G24		07G36	
	ψ	w (%)	ψ	w (%)	ψ	w (%)	ψ	w (%)	ψ	w (%)	ψ	w (%)	ψ	w (%)	ψ	w (%)	ψ	w (%)	ψ	w (%)	ψ	w (%)	ψ	w (%)	ψ	w (%)	ψ	w (%)
8/3/2005	4.53	30.5	5.03	28.75	-	-	3.61	35	5.75	27	4.69	30	4.86	29.25	3.91	32.75	2.79	45	3.19	41	3.33	38	1.95	45	4.69	30	4.06	30.8
8/4/2005	5.03	28.75	4.86	29.25	-	-	3.47	36	5.56	27.5	4.69	30	5.38	28	3.91	32.75	2.92	45	3.47	36	4.86	29.25	2.30	45	5.38	28	4.53	30.5
9/28/2005	6.95	25	4.86	29.25	-	-	3.06	45	4.37	31	4.53	30.5	5.56	27.5	3.47	36	2.79	45	3.33	38	2.54	45	2.79	45	10.77	22.5	5.03	28.75
11/3/2005	7.39	24.5	5.38	28	-	-	3.61	35	3.76	33.75	4.69	30	4.86	29.25	3.47	36	2.92	45	3.33	38	2.92	45	2.92	45	9.90	23.75	3.19	40
11/10/2005	7.17	24.75	5.20	28.25	-	-	3.61	35	3.61	35	4.69	30	4.53	30.5	3.33	38	2.92	45	3.06	45	2.92	45	3.47	36	10.18	22.75	3.33	38
2/15/2006	5.20	28.25	5.38	28	-	-	4.06	30.8	4.37	31	4.53	30.5	3.33	38	3.91	32.75	3.61	35	3.61	35	3.47	36	3.61	35	8.82	23.25	3.47	36
5/22/2006	4.06	30.8	4.53	30.5	-	-	3.47	36	-	-	3.33	38	2.79	45	3.06	45	2.67	45	3.06	45	2.54	45	2.92	45	5.94	26.75	2.79	45
5/31/2006	6.13	26.25	4.37	31	-	-	3.33	38	-	-	3.33	38	7.39	24.5	3.06	45	2.42	45	2.92	45	2.30	45	2.79	45	7.17	24.75	3.61	35
6/12/2006	5.56	27.5	5.20	28.25	-	-	3.33	38	-	-	3.33	38	-	-	2.92	45	2.67	45	2.92	45	2.30	45	2.79	45	7.17	24.75	2.67	45
7/31/2006	6.33	26	4.37	31	-	-	3.47	36	-	-	3.76	33.75	-	-	2.79	45	2.30	45	2.79	45	2.18	45	2.67	45	-	-	2.54	45
8/17/2006	5.03	28.75	4.53	30.5	-	-	3.33	38	-	-	3.19	41	-	-	2.79	45	2.42	45	2.54	45	2.30	45	2.67	45	-	-	2.79	45
9/27/2006	5.20	28.25	4.53	30.5	-	-	3.33	38	-	-	3.47	36	-	-	2.92	45	2.42	45	2.67	45	2.30	45	2.67	45	-	-	2.54	45
4/18/2007	-	-	5.20	28.75	-	-	3.91	32.75	-	-	4.21	31.5	-	-	3.33	38	3.06	45	-	-	2.92	45	3.06	45	-	-	3.06	45
6/6/2007	-	-	4.06	30.8	-	-	4.21	31.5	-	-	3.91	32.75	-	-	3.19	41	3.06	45	-	-	2.79	45	2.92	45	-	-	3.19	41
7/20/2007	-	-	3.76	33.75	-	-	3.61	35	-	-	3.33	38	-	-	2.92	45	2.67	45	-	-	3.06	45	2.79	45	-	-	3.33	38
9/3/2007	-	-	3.33	38	-	-	3.76	33.75	-	-	3.76	33.75	-	-	2.79	45	2.67	45	-	-	2.79	45	2.67	45	-	-	3.33	38
10/30/2007	-	-	2.92	45	-	-	4.37	31	-	-	3.76	33.75	-	-	4.06	30.8	3.47	36	-	-	2.67	45	2.79	45	-	-	3.76	33.75
5/13/2008	-	-	2.67	45	-	-	4.06	30.8	-	-	3.33	38	-	-	-	-	-	-	-	-	2.79	45	2.92	45	-	-	-	-
6/18/2008	-	-	3.61	35	-	-	4.53	30.5	-	-	3.61	35	-	-	-	-	-	-	-	-	3.06	45	2.79	45	-	-	-	-
7/9/2008	-	-	4.37	31	-	-	4.86	29.25	-	-	3.76	33.75	-	-	-	-	-	-	-	-	3.06	45	3.06	45	-	-	-	-
8/13/2008	-	-	4.37	31	-	-	4.53	30.5	-	-	3.76	33.75	-	-	-	-	-	-	-	-	2.92	45	2.79	45	-	-	-	-
9/20/2008	-	-	4.06	30.8	-	-	4.06	30.8	-	-	3.76	33.75	-	-	-	-	-	-	-	-	2.79	45	2.67	45	-	-	-	-
10/25/2008	-	-	3.33	38	-	-	4.06	30.8	-	-	3.33	38	-	-	-	-	-	-	-	-	2.79	45	2.42	45	-	-	-	-


Muskingum County G-Block Water Content (Stations 1 - 4)
Water Content (%)
50
45
40
35
30
25
20
15
Station 1: 24 in
Station 1: 36 in
Station 2: 36 in
Station 3: 24 in
Station 3: 36 in
Station 4: 24 in
Station 4: 36 in
Feb-05
Sep-05
Mar-06
Oct-06
Apr-07
Nov-07
Jun-08
Dec-08
Jul-09
Date of Reading


Muskingum County G-Block Water Content (Stations 5 - 7)
Water Content (%)
50
45
40
35
30
25
20
15
Feb-05
Sep-05
Mar-06
Oct-06
Apr-07
Nov-07
Jun-08
Dec-08
Jul-09
Date of Reading
Station 5: 24 in
Station 5: 36 in
Station 6: 24 in
Station 6: 36 in
Station 7: 24 in
Station 7: 36 in

Muskingum County Piezometer/Monitoring Well Data

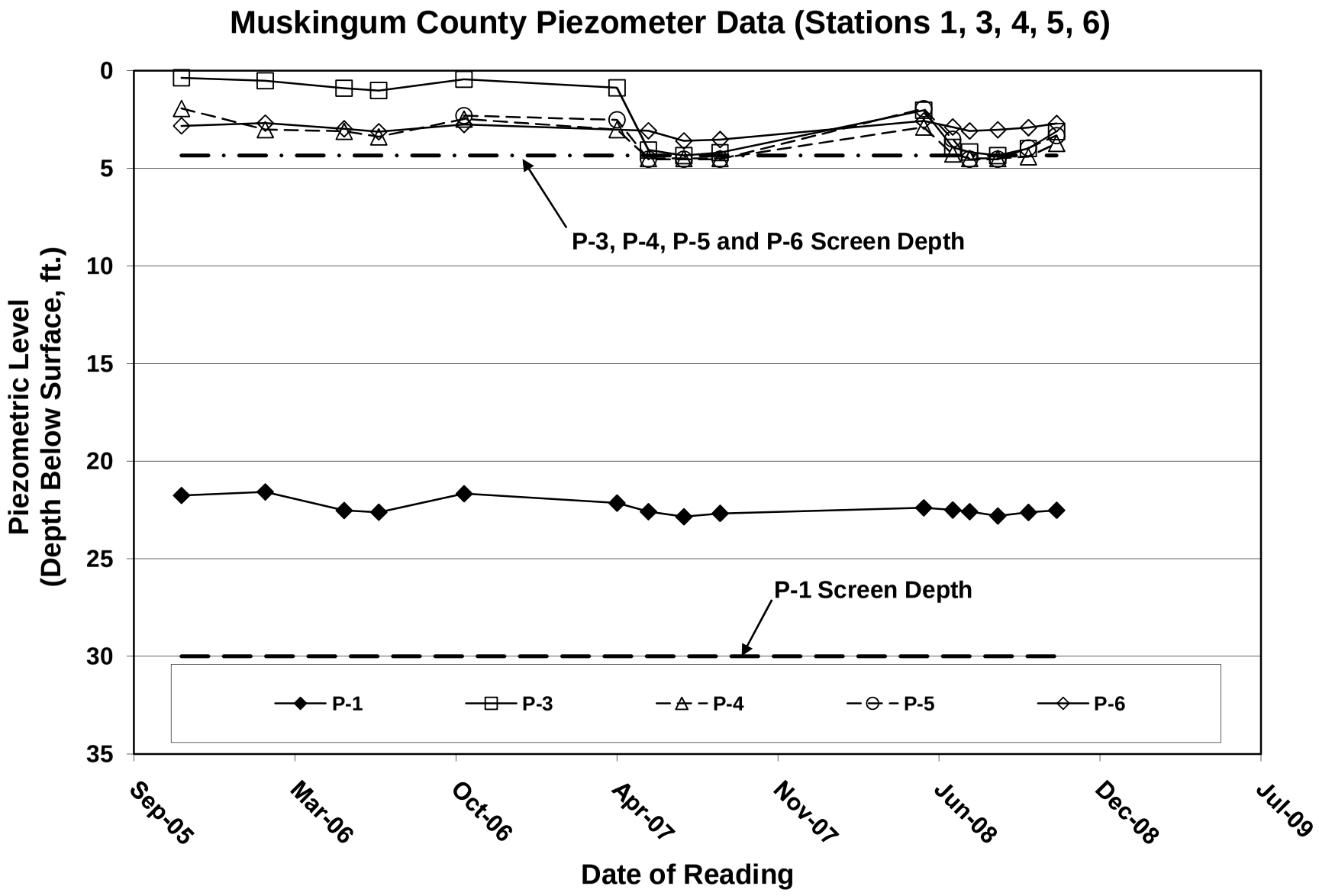
Piezometer/Well ID	D.T.B.	H.O.G.	D.B.G.	Date of Reading							
				11/3/2005	2/15/2006	5/24/2006	7/6/2006	10/20/2006	4/28/2007	6/6/2007	7/20/2007
W2 (lower) - P-1	30.08	0.08	30.00	21.76	21.58	22.53	22.62	21.67	22.15	22.59	22.85
W1 (upper) - P-2	10.00	4.15	5.85	3.12	3.12	-	-	-	0.21	-	-
09P54 - P-3	5	0.65	4.35	0.37	0.52	0.90	1.02	0.45	0.88	4.07	4.35
08P54 - P-4	5	0.5	4.50	1.94	3.02	3.11	3.39	2.48	3.02	4.50	4.50
P-5	6	1.46	4.54	-	-	-	-	2.31	2.52	4.54	4.54
07P54 - P-6	5	0.45	4.55	2.83	2.69	2.98	3.13	2.76	-	3.08	3.60
P-7	2.00	0	2.00	-	-	2.00	2.00	-	2.00	2.00	2.00

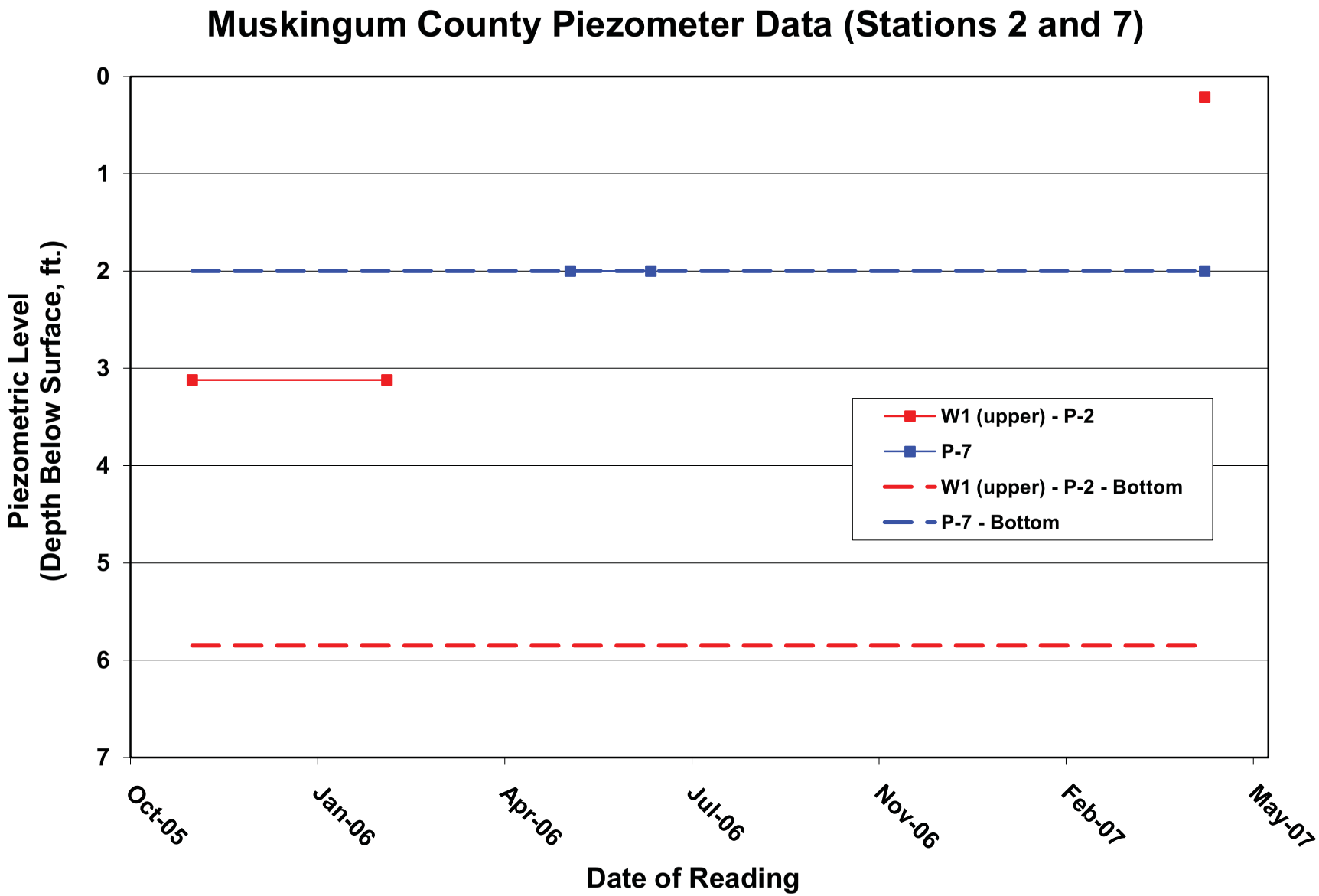
* - All readings indicate the static groundwater depth below the ground surface.

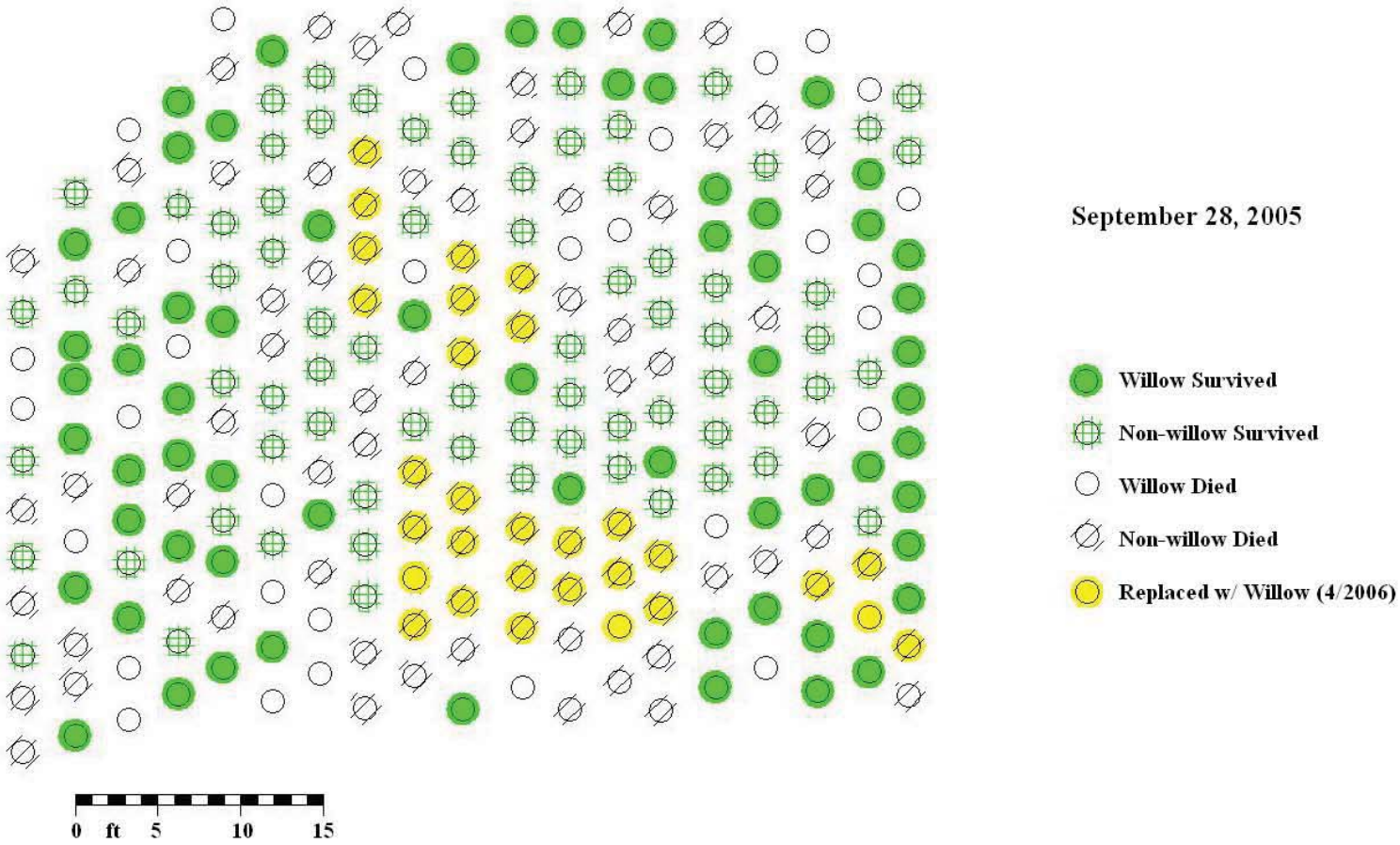
Muskingum County Piezometer/Monitoring Well Data

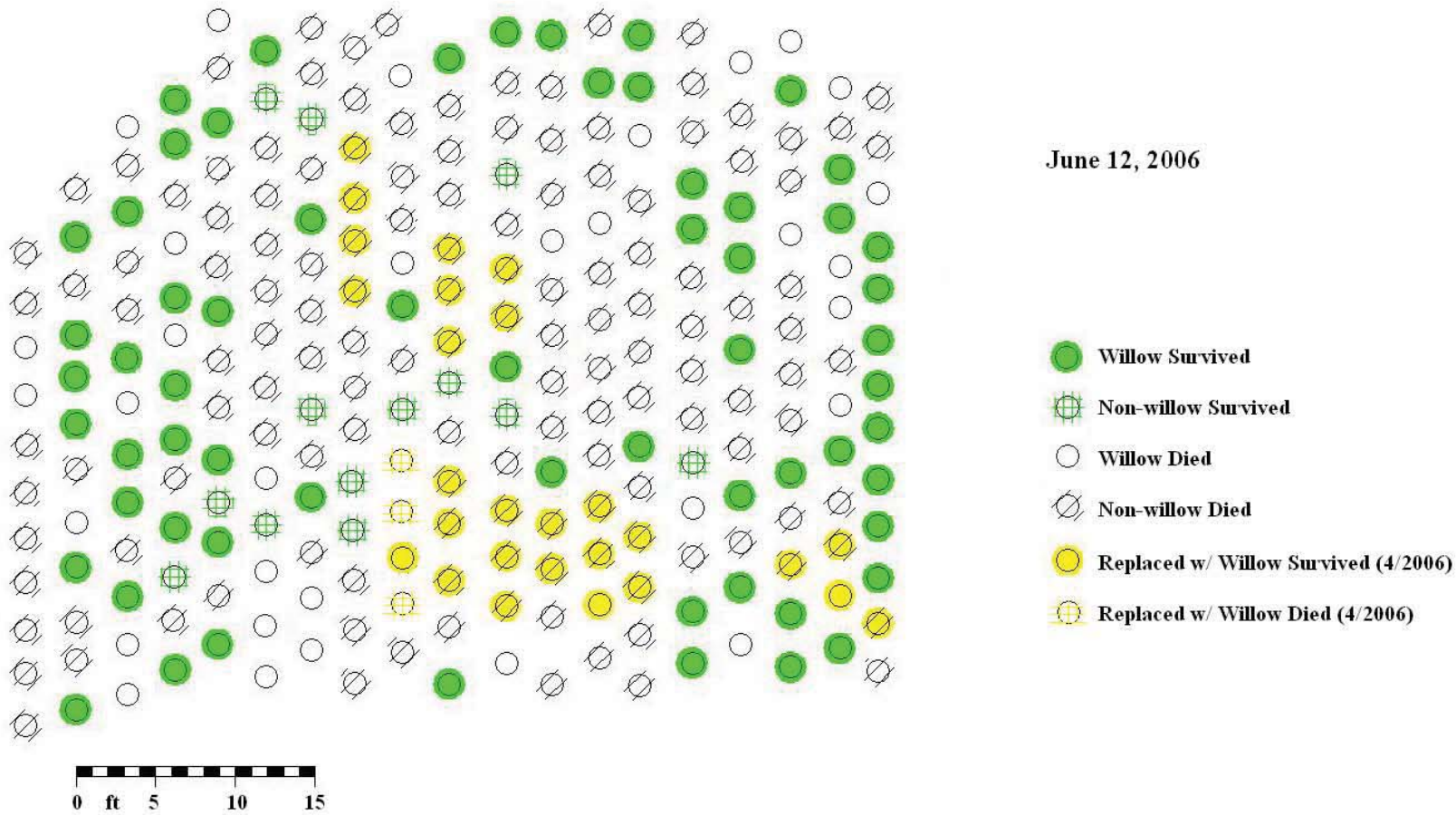
Piezometer/Well ID	D.T.B.	H.O.G.	D.B.G.	Date of Reading						
				9/3/2007	5/13/2008	6/18/2008	7/9/2008	8/13/2008	9/20/2008	10/25/2008
W2 (lower) - P-1	30.08	0.08	30.00	22.68	22.39	22.50	22.59	22.81	22.63	22.52
W1 (upper) - P-2	10.00	4.15	5.85	-	-	-	-	-	-	-
09P54 - P-3	5	0.65	4.35	4.20	2.03	3.93	4.17	4.35	3.99	3.12
08P54 - P-4	5	0.5	4.50	4.50	2.89	4.27	4.50	4.50	4.41	3.73
P-5	6	1.46	4.54	4.54	1.95	3.51	4.54	4.54	3.96	3.33
07P54 - P-6	5	0.45	4.55	3.53	2.58	2.89	3.09	3.03	2.92	2.71
P-7	2.00	0	2.00	2.00	-	-	-	-	-	-

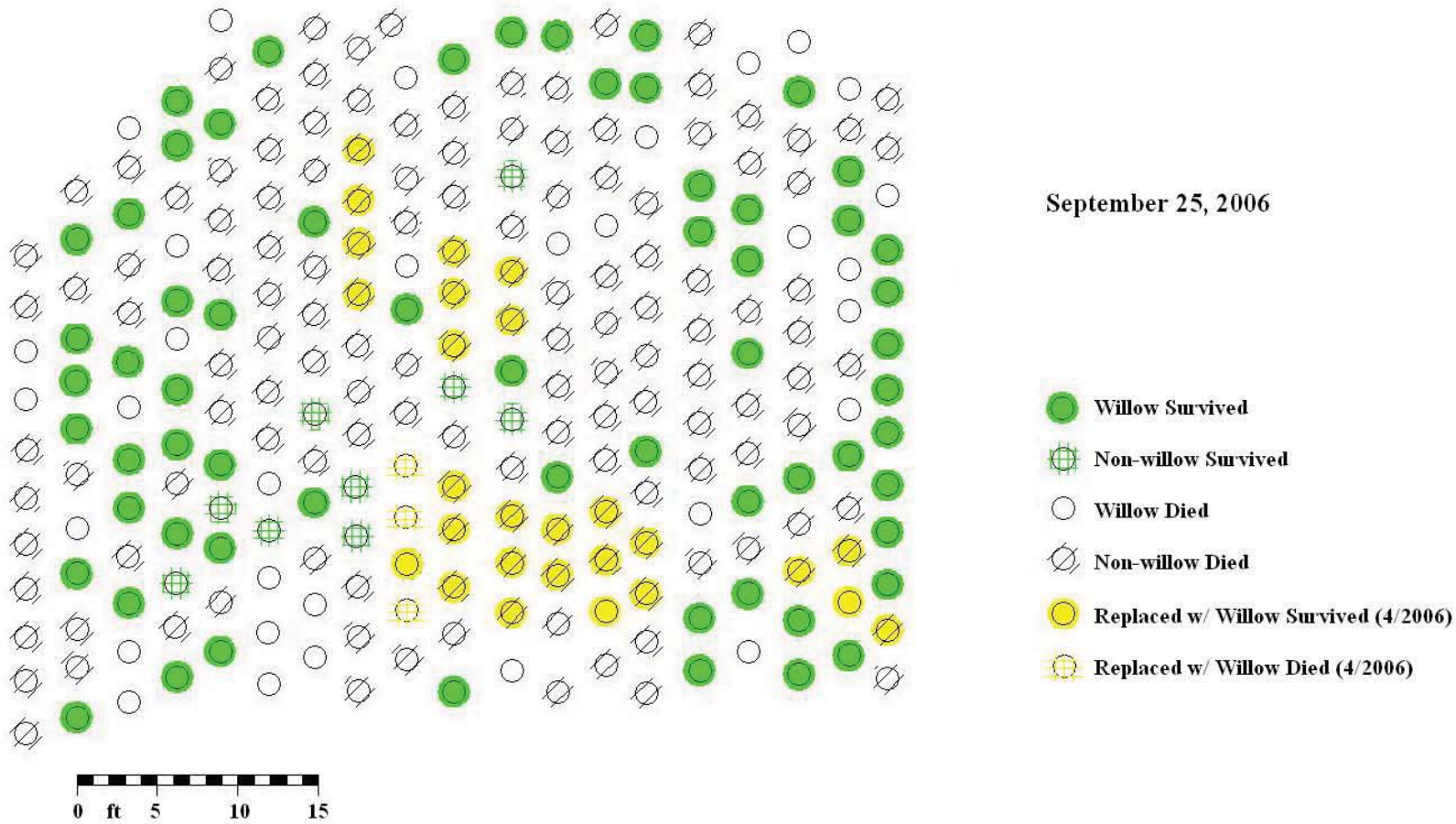
* - All readings indicate the static groundwater depth below the ground surface.

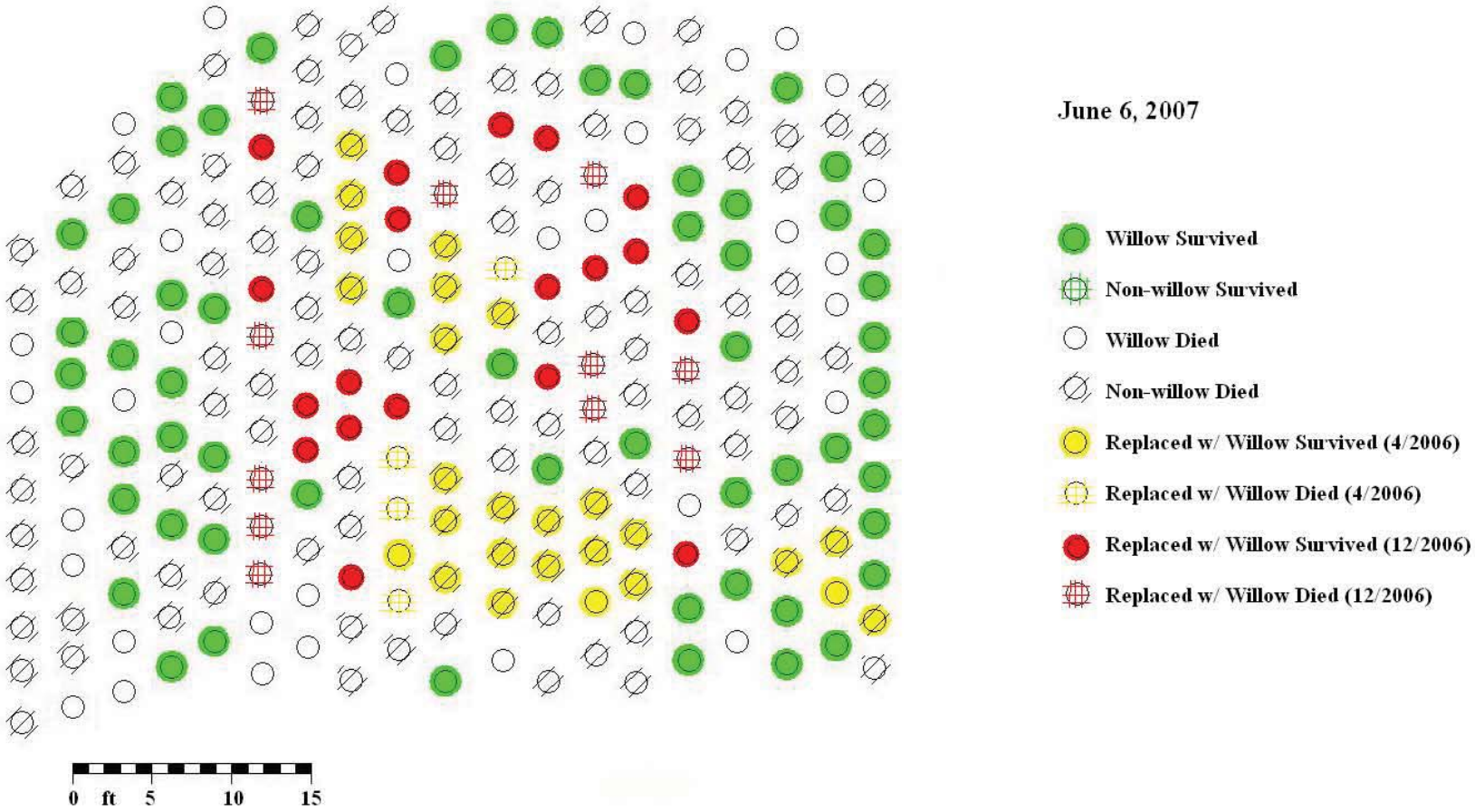

Muskingum County Piezometer Data (Stations 1, 3, 4, 5, 6)
Piezometric Level
(Depth Below Surface, ft.)
0
5
10
15
20
25
30
35
P-3, P-4, P-5 and P-6 Screen Depth
P-1 Screen Depth
P-1
P-3
P-4
P-5
P-6
Sep-05
Mar-06
Oct-06
Apr-07
Nov-07
Jun-08
Dec-08
Jul-09
Date of Reading

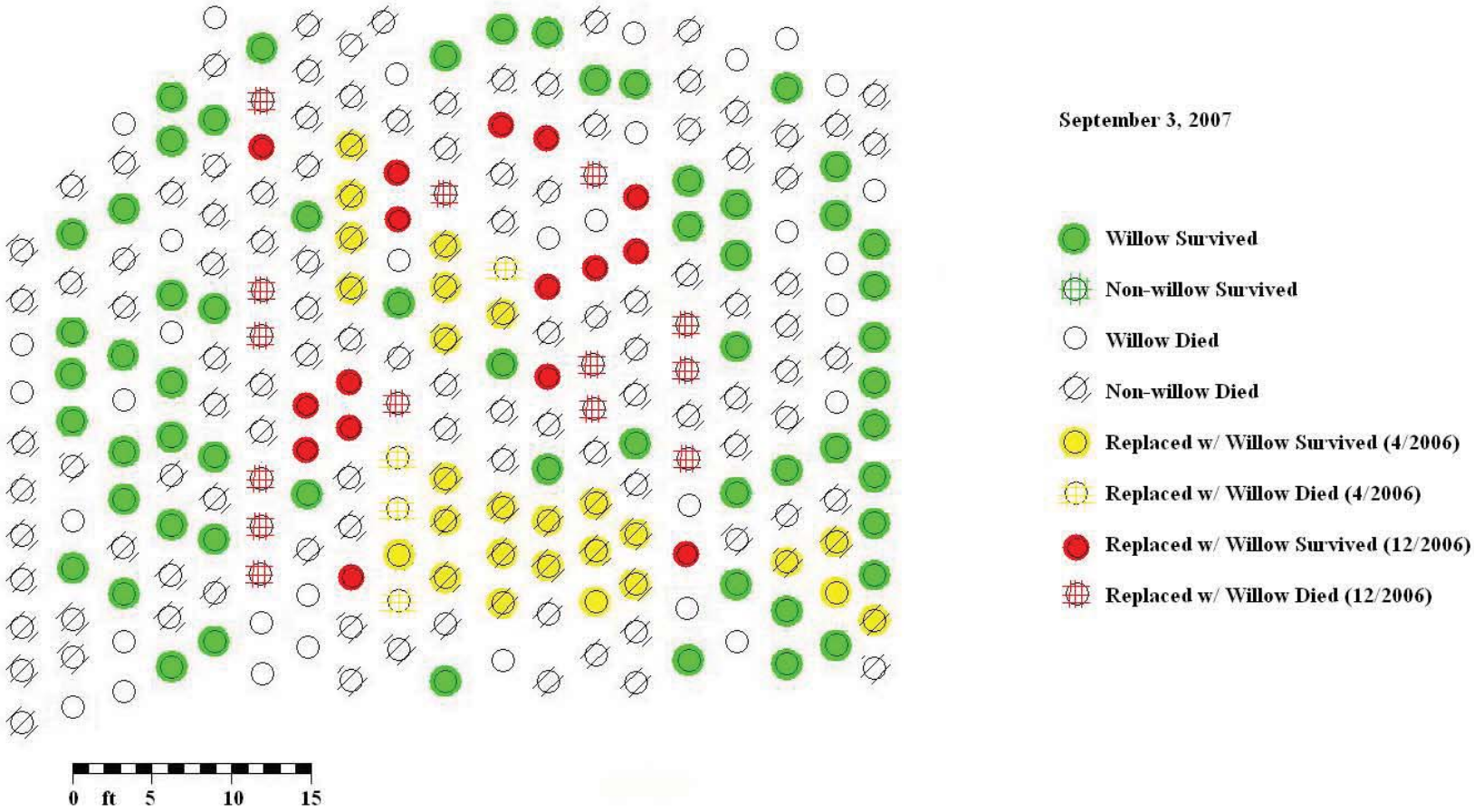

Muskingum County Piezometer Data (Stations 2 and 7)
Piezometric Level
(Depth Below Surface, ft.)
0
1
2
3
4
5
6
7
Oct-05
Jan-06
Apr-06
Jul-06
Nov-06
Feb-07
May-07
Date of Reading
W1 (upper) - P-2
P-7
W1 (upper) - P-2 - Bottom
P-7 - Bottom

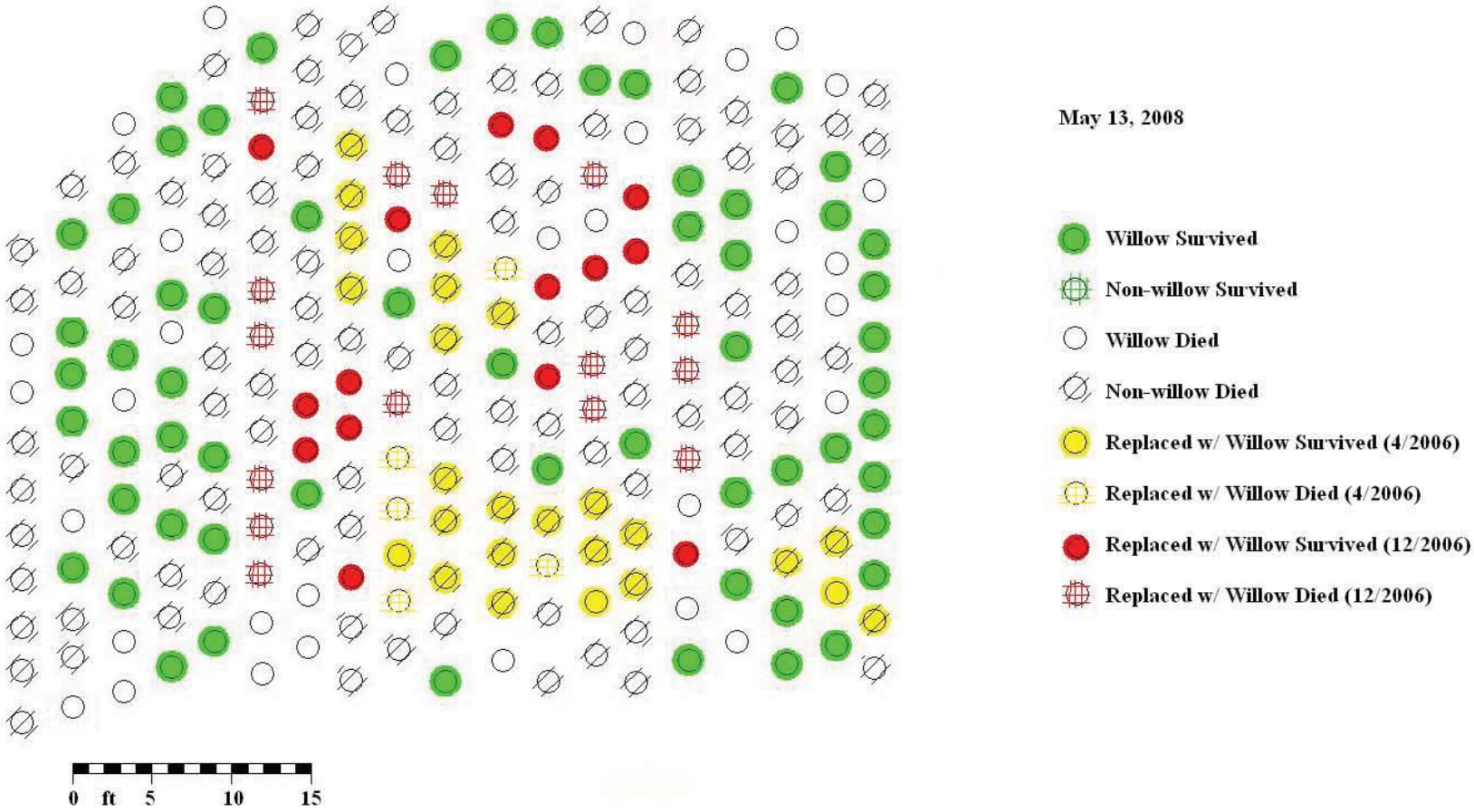

September 28, 2005
Willow Survived
Non-willow Survived
Willow Died
Non-willow Died
Replaced w/ Willow (4/2006)
0 ft 5 10 15

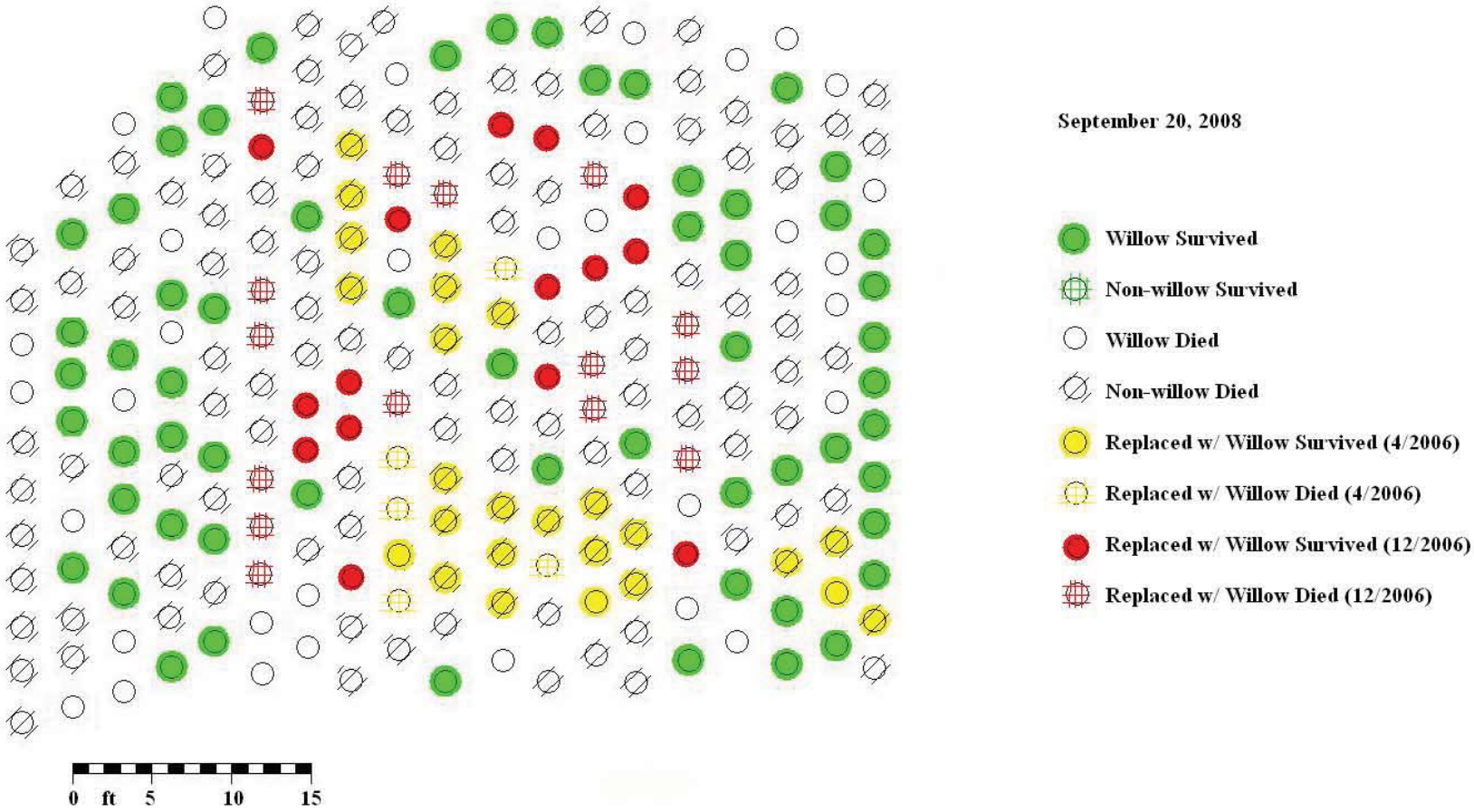

June 12, 2006
Willow Survived
Non-willow Survived
Willow Died
Non-willow Died
Replaced w/ Willow Survived (4/2006)
Replaced w/ Willow Died (4/2006)
0 ft 5 10 15

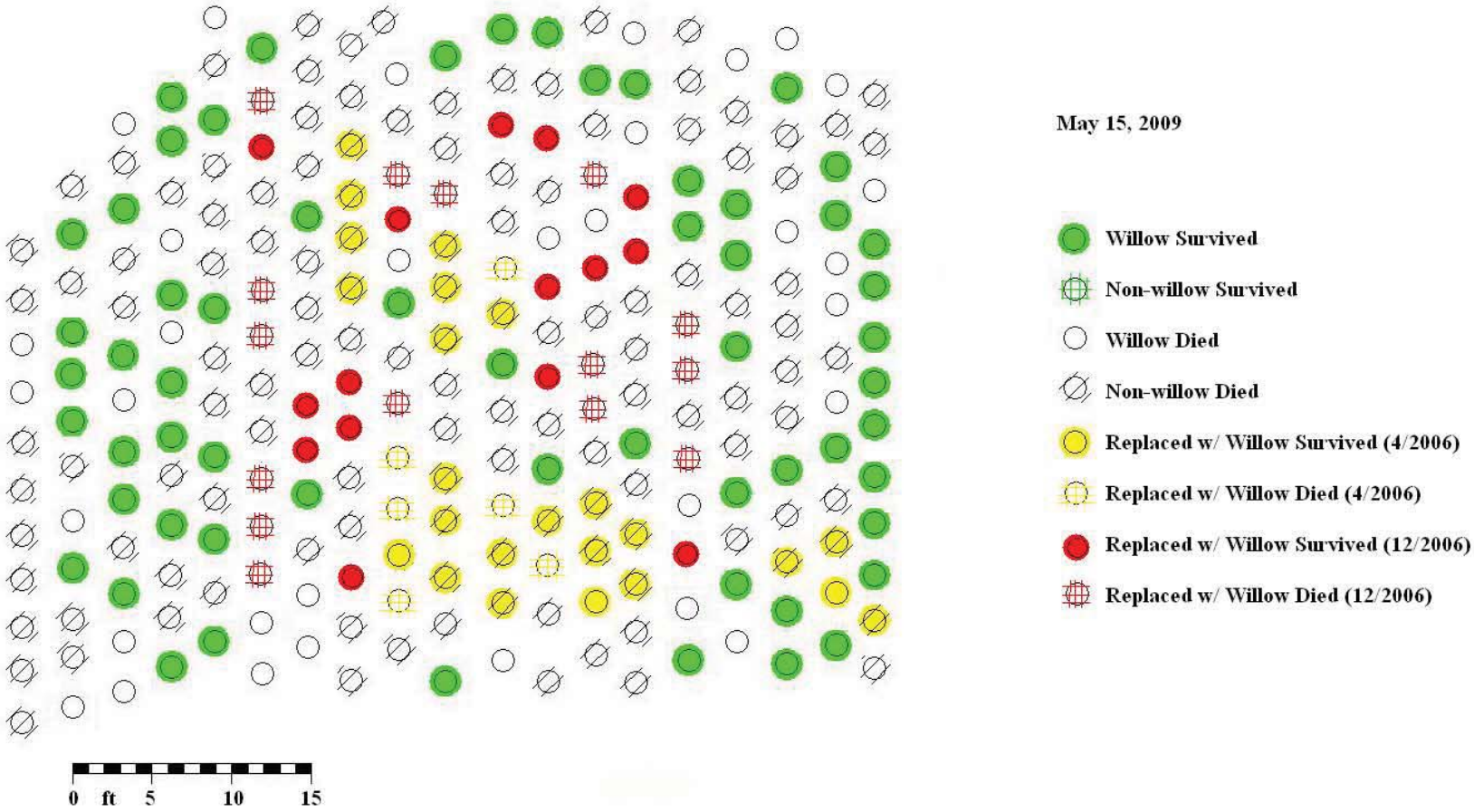

September 25, 2006
Willow Survived
Non-willow Survived
Willow Died
Non-willow Died
Replaced w/ Willow Survived (4/2006)
Replaced w/ Willow Died (4/2006)
0 ft 5 10 15

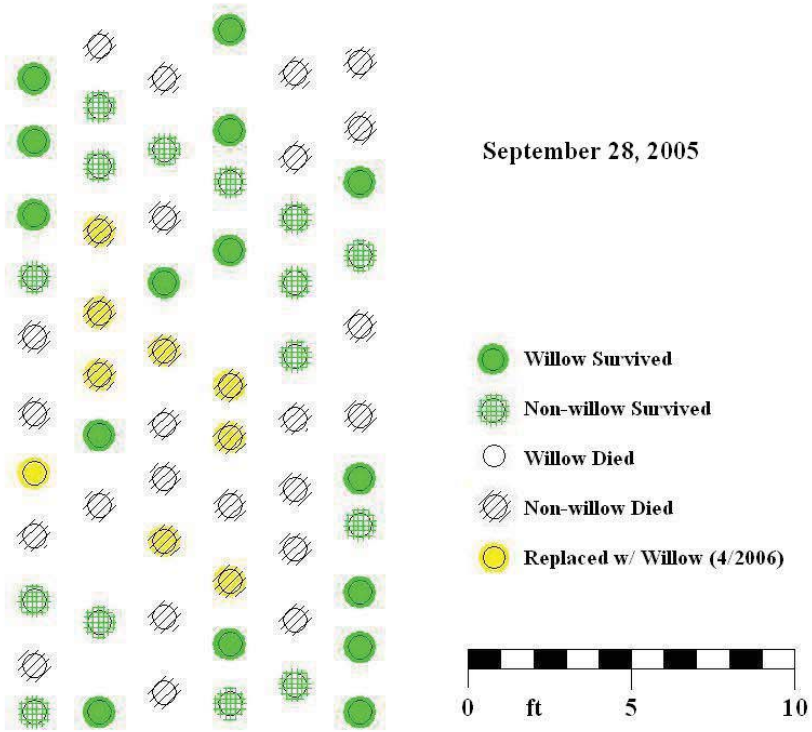

June 6, 2007
Willow Survived
Non-willow Survived
Willow Died
Non-willow Died
Replaced w/ Willow Survived (4/2006)
Replaced w/ Willow Died (4/2006)
Replaced w/ Willow Survived (12/2006)
Replaced w/ Willow Died (12/2006)
0 ft 5 10 15

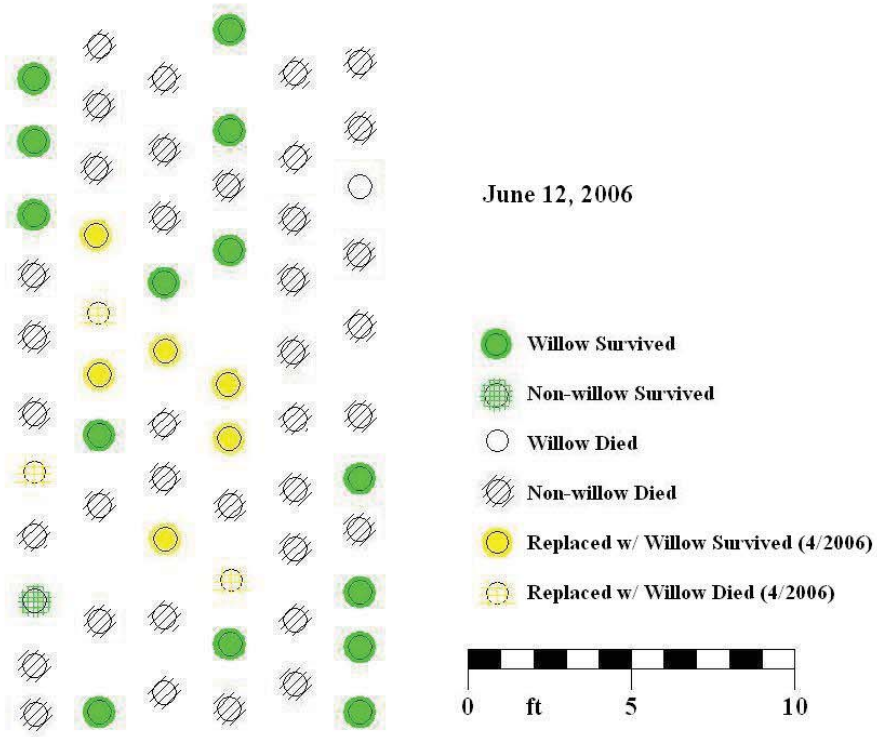

September 3, 2007
Willow Survived
Non-willow Survived
Willow Died
Non-willow Died
Replaced w/ Willow Survived (4/2006)
Replaced w/ Willow Died (4/2006)
Replaced w/ Willow Survived (12/2006)
Replaced w/ Willow Died (12/2006)
0 ft 5 10 15

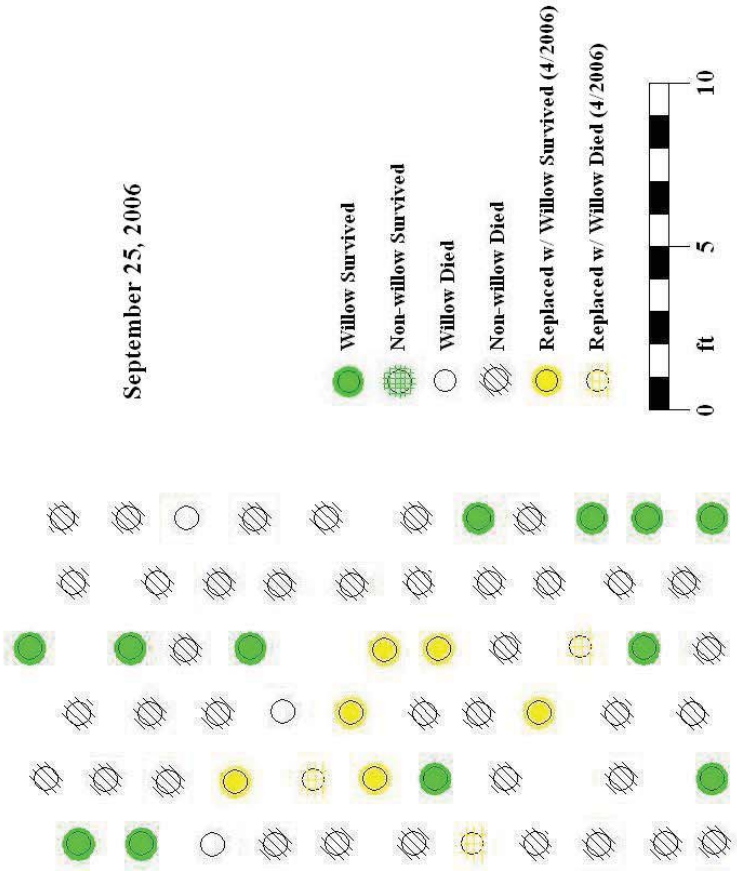

May 13, 2008
Willow Survived
Non-willow Survived
Willow Died
Non-willow Died
Replaced w/ Willow Survived (4/2006)
Replaced w/ Willow Died (4/2006)
Replaced w/ Willow Survived (12/2006)
Replaced w/ Willow Died (12/2006)
0 ft 5 10 15

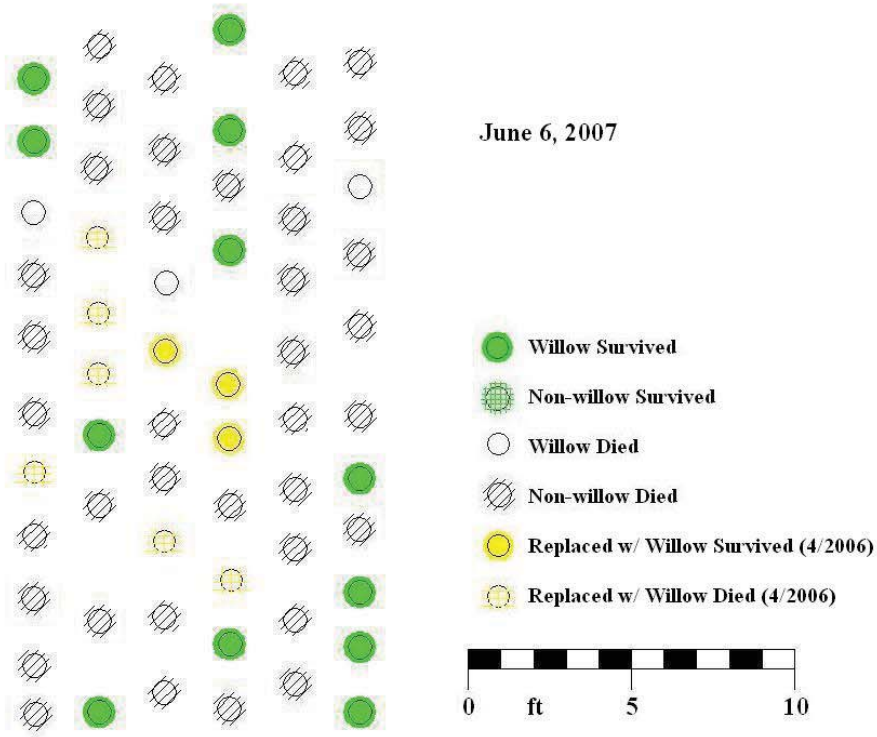

September 20, 2008
Willow Survived
Non-willow Survived
Willow Died
Non-willow Died
Replaced w/ Willow Survived (4/2006)
Replaced w/ Willow Died (4/2006)
Replaced w/ Willow Survived (12/2006)
Replaced w/ Willow Died (12/2006)
0 ft 5 10 15

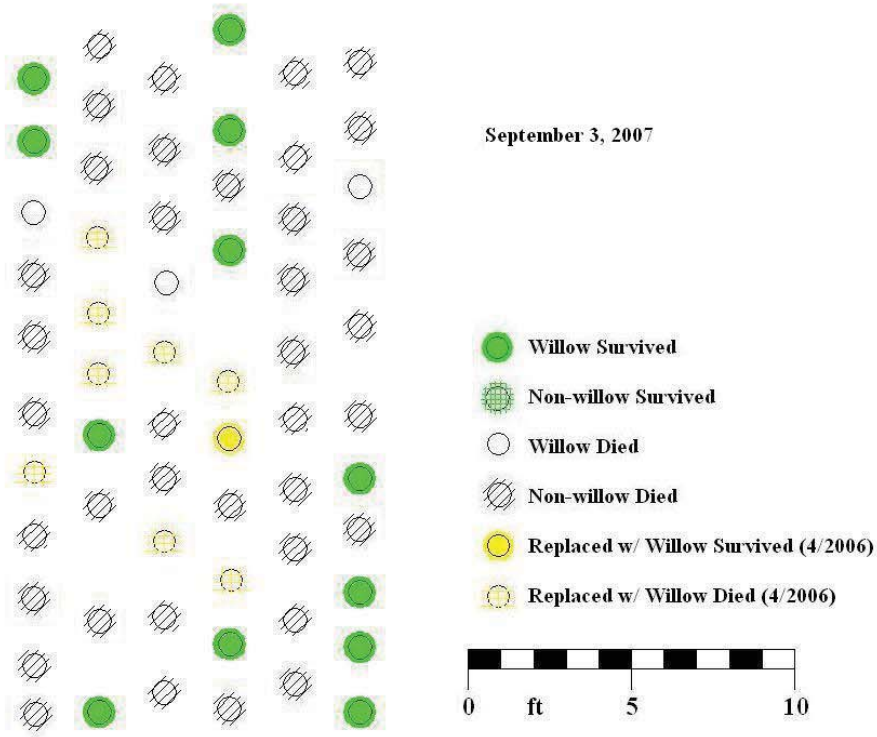

May 15, 2009
Willow Survived
Non-willow Survived
Willow Died
Non-willow Died
Replaced w/ Willow Survived (4/2006)
Replaced w/ Willow Died (4/2006)
Replaced w/ Willow Survived (12/2006)
Replaced w/ Willow Died (12/2006)
0 ft 5 10 15

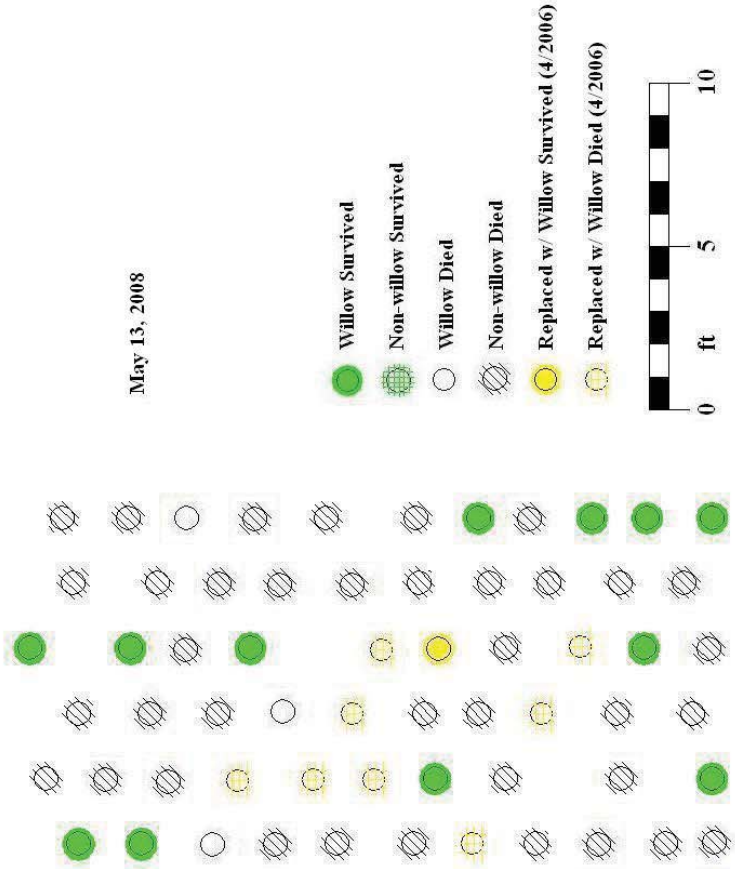

September 28, 2005
Willow Survived
Non-willow Survived
Willow Died
Non-willow Died
Replaced w/ Willow (4/2006)
0
ft
5
10

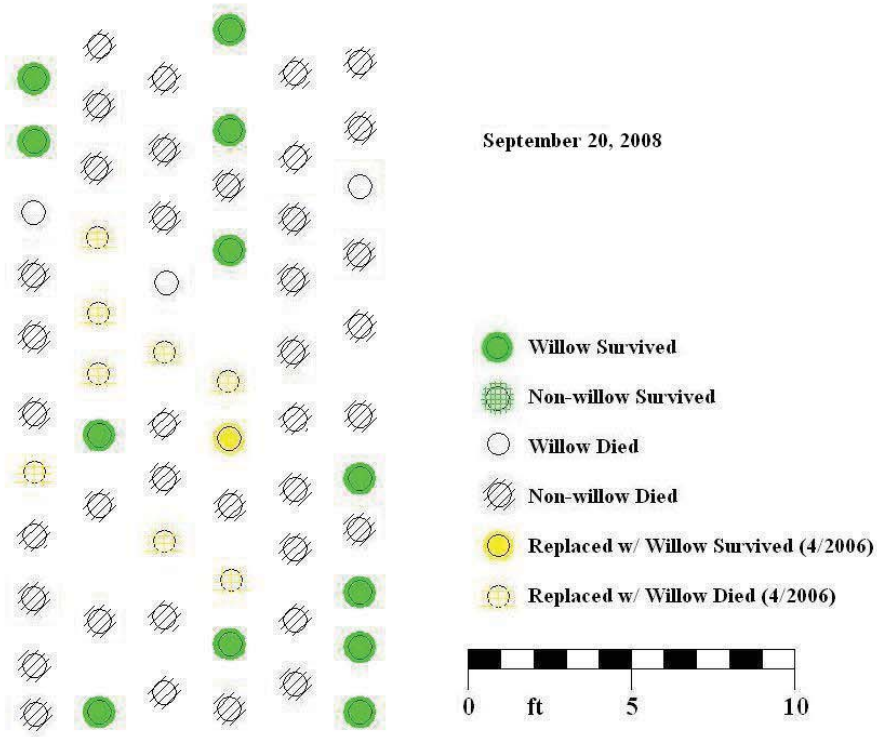

June 12, 2006
Willow Survived
Non-willow Survived
Willow Died
Non-willow Died
Replaced w/ Willow Survived (4/2006)
Replaced w/ Willow Died (4/2006)
0
ft
5
10

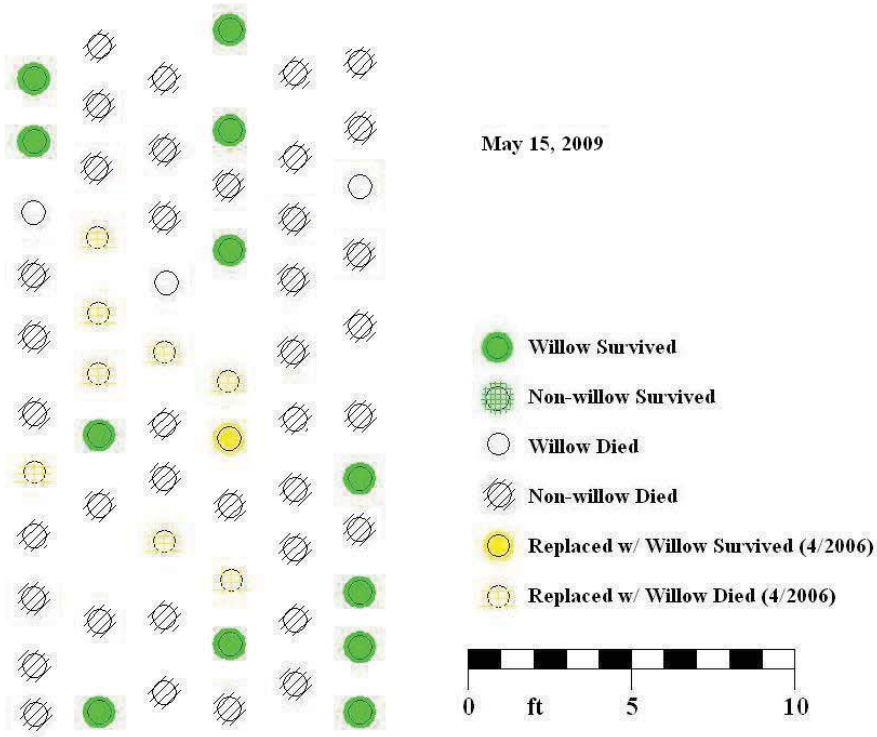

September 25, 2006
Willow Survived
Non-willow Survived
Willow Died
Non-willow Died
Replaced w/ Willow Survived (4/2006)
Replaced w/ Willow Died (4/2006)
0
ft
5
10


June 6, 2007
Willow Survived
Non-willow Survived
Willow Died
Non-willow Died
Replaced w/ Willow Survived (4/2006)
Replaced w/ Willow Died (4/2006)
0
ft
5
10


September 3, 2007
Willow Survived
Non-willow Survived
Willow Died
Non-willow Died
Replaced w/ Willow Survived (4/2006)
Replaced w/ Willow Died (4/2006)
0
ft
5
10


May 13, 2008
Willow Survived
Non-willow Survived
Willow Died
Non-willow Died
Replaced w/ Willow Survived (4/2006)
Replaced w/ Willow Died (4/2006)
0
ft
5
10


September 20, 2008
Willow Survived
Non-willow Survived
Willow Died
Non-willow Died
Replaced w/ Willow Survived (4/2006)
Replaced w/ Willow Died (4/2006)
0
ft
5
10


May 15, 2009
Willow Survived
Non-willow Survived
Willow Died
Non-willow Died
Replaced w/ Willow Survived (4/2006)
Replaced w/ Willow Died (4/2006)
0
ft
5
10

Pictured above is the setup for vertical pullout test. Setup includes a post popper with attached chain connected to an s-type load cell. A towing strap is connected to the other end of the load cell and is wound around the willow pole and used as a friction slip-hook. Displacement is visually read by a third person and loads are recorded at constant displacement intervals.

4/12/2006	Muskingum County	Willow Pole Extractions

Pole #	Bottom Diameter (in)	Top Diameter (in)	Length (ft)	Depth of Embedment, D.O.E. (ft)	Surface Area (in^2)	Comments
?	2.31	1.66	4.64	3.50	261.92	→ D.O.E. Not Marked
10-10	2.48	1.83	5.25	4.26	346.10	
10-3	2.72	2.00	4.77	3.70	329.20	→ D.O.E. Not Marked
10-4	1.72	1.41	5.57	4.47	263.73	
10-5	2.00	1.67	5.02	4.30	297.47	→ D.O.E. Not Marked
10-8	2.39	1.69	4.81	3.99	306.86	
10-9	2.29	1.61	5.12	4.00	294.06	
11-2	2.42	1.61	4.58	3.62	275.00	
11-3	2.11	1.65	4.99	3.96	280.67	
11-4	1.96	1.31	5.00	4.04	249.02	
11-4	2.19	1.73	5.21	4.23	312.56	
11-8	2.40	1.80	5.12	4.55	360.22	
11-9	2.21	1.67	5.32	4.44	324.73	
12-3	2.59	1.77	5.20	4.39	360.80	
12-4	2.68	2.07	5.66	4.78	427.99	
13-2	1.84	1.09	5.17	4.17	230.31	
13-3	2.55	1.86	5.27	4.32	359.11	
14-3	2.74	1.88	5.10	4.03	350.97	
17-3	1.62	1.13	5.09	4.55	235.86	→ D.O.E. Not Marked
18-2	1.33	0.95	5.06	3.95	169.76	
18-3	1.53	0.89	5.58	4.55	207.56	
19-2	1.92	1.45	5.07	4.16	264.26	
8-10	2.22	1.63	4.84	3.96	287.39	
8-11	2.62	1.97	5.15	4.39	379.83	
8-12	2.13	1.43	5.16	4.34	291.24	
8-9	2.83	2.18	4.92	3.80	358.87	
9-2	2.89	2.54	4.64	3.58	366.43	
9-3	1.79	1.54	4.62	3.66	229.74	
9-4	1.87	1.39	5.18	3.99	245.19	
A-5	1.99	1.07	4.85	3.48	200.74	
B-5	1.65	1.03	5.23	4.27	215.71	
B-6	1.56	1.31	4.27	3.20	173.12	→ D.O.E. Not Marked
B-7	1.19	0.82	4.60	3.55	134.50	→ D.O.E. Not Marked
C-3	1.80	1.28	4.89	3.90	226.42	
C-6	1.85	1.38	5.32	4.30	261.80	
D-3	1.54	1.16	4.88	3.77	191.87	
D-5	1.38	0.87	4.95	4.11	174.31	
D-6	1.79	1.23	5.19	4.15	236.25	
13-4	1.87	1.62	5.34	4.03	265.11	

Max	2.89	2.54	5.66	4.78	489.25
Avg	2.08	1.52	5.04	4.06	275.19
Min	1.19	0.82	4.27	3.2	121.24

Muskingum County - I70/SR83 - Vertical Pullout Tests
Date: 4/8/06 - 4/9/06

Pole 9-2:

Deflection (ft)	Load (lbs)
0	0
0.1	31
0.2	223
0.3	226
0.4	204
0.5	155
0.6	159
0.7	145
0.8	150
0.9	149
1	149
1.1	114
1.2	85
1.3	106
1.4	78
1.5	78
1.6	60
1.7	55
1.8	45
1.9	40
2	35
2.1	30
2.2	30
2.3	25
2.4	22

Maximum Load = 226 lb

Top Diameter :	2.75	in
Bottom Diameter :	2.89	in
Total Length :	4.65	ft
Depth of Embedment :	3.6	ft
Average diameter over length :	2.82	in

Pole 9-3:

Deflection (ft)	Load (lbs)
0	0
0.1	98
0.2	90
0.3	85
0.4	77
0.5	77
0.6	73
0.7	70
0.8	67
0.9	62
1	30
1.1	36
1.2	31
1.3	25
1.4	24
1.5	23
1.6	18
1.7	23
1.8	14

Maximum Load = 98 lb

Top Diameter :	1.54	in
Bottom Diameter :	1.85	in
Total Length :	4.6	ft
Depth of Embedment :	3.65	ft
Average diameter over length :	1.695	in

Muskingum County - I70/SR83 - Vertical Pullout Tests
Date: 4/8/06 - 4/9/06

Pole 10-3:

Deflection (ft)	Load (lbs)
0	0
0.1	90
0.2	110
0.3	124
0.4	121
0.5	133
0.6	154
0.7	126
0.8	170
0.9	138
1	126
1.1	118
1.2	112
1.3	84
1.4	78
1.5	77
1.6	74
1.7	62
1.8	26
1.9	20
2	18
2.1	18

Maximum Load = 170 lb

Top Diameter :	2.01	in
Bottom Diameter :	2.67	in
Total Length :	4.66	ft
Depth of Embedment :	3.95	ft
Average diameter over length :	2.34	in

Pole 11-2:

Deflection (ft)	Load (lbs)
0	0
0.1	212
0.2	283
0.3	304
0.4	320
0.5	300
0.6	291
0.7	218
0.8	220
0.9	208
1	201
1.1	198
1.2	173
1.3	205
1.4	182
1.5	174
1.6	165
1.7	149
1.8	123
1.9	89
2	60
2.1	57

Maximum Load = 320 lb

Top Diameter :	1.53	in
Bottom Diameter :	2.22	in
Total Length :	4.55	ft
Depth of Embedment :	3.65	ft
Average diameter over length :	1.875	in

Muskingum County - I70/SR83 - Vertical Pullout Tests
Date: 4/8/06 - 4/9/06

Pole 11-3:

Deflection (ft)	Load (lbs)
0	0
0.1	187
0.2	187
0.3	160
0.4	148
0.5	129
0.6	117
0.7	110
0.8	105
0.9	72
1	99
1.1	103
1.2	98
1.3	91
1.4	81
1.5	74
1.6	67
1.7	51
1.8	55
1.9	57
2	52
2.1	50

Maximum Load = 187 lb

Top Diameter :	1.64	in
Bottom Diameter :	2.04	in
Total Length :	4.95	ft
Depth of Embedment :	4	ft
Average diameter over length :	1.84	in

Pole 10-4:

Deflection (ft)	Load (lbs)
0	0
0.1	370
0.2	287
0.3	300
0.4	238
0.5	200
0.6	207
0.7	156
0.8	120
0.9	93
1	66
1.1	56
1.2	34
1.3	25

Maximum Load = 370 lb

Top Diameter :	2.01	in
Bottom Diameter :	2.67	in
Total Length :	4.66	ft
Depth of Embedment :	3.95	ft
Average diameter over length :	2.34	in

Pole 9-4:

Deflection (ft)	Load (lbs)
0	0
0.1	178
0.2	171
0.3	137
0.4	90
0.5	79
0.6	74
0.7	45
0.8	51
0.9	56
1	55
1.1	30

Maximum Load = 178 lb

Top Diameter :	1.39	in
Bottom Diameter :	1.87	in
Total Length :	5.18	ft
Depth of Embedment :	3.99	ft
Average diameter over length :	1.63	in

Muskingum County - I70/SR83 - Vertical Pullout Tests
Date: 4/8/06 - 4/9/06

Pole 9-5:	Deflection (ft)	Load (lbs)			
	0	0	Top Diameter :	1.66	in
	0.1	66	Bottom Diameter :	2.31	in
	0.2	62	Total Length :	4.64	ft
	0.3	63	Depth of Embedment :	3.5	ft
	0.4	60	Average diameter over length :	1.985	in
	0.5	57			
	0.6	51			
	0.7	49			
	0.8	27			
	Maximum Load =	66 lb			

Pole 10-5:	Deflection (ft)	Load (lbs)			
	0	0	Top Diameter :	1.67	in
	0.1	250	Bottom Diameter :	2	in
	0.2	243	Total Length :	5.02	ft
	0.3	216	Depth of Embedment :	4.3	ft
	0.4	150	Average diameter over length :	1.835	in
	0.5	103			
	0.6	44			
	0.7	33			
	0.8	31			
	0.9	30			
	1	22			
	Maximum Load =	250 lb			

Pole 11-3:	Deflection (ft)	Load (lbs)			
	0	0	Top Diameter :	1.73	in
	0.1	187	Bottom Diameter :	2.19	in
	0.2	187	Total Length :	5.21	ft
	0.3	160	Depth of Embedment :	4.23	ft
	0.4	148	Average diameter over length :	1.96	in
	0.5	129			
	0.6	117			
	0.7	110			
	0.8	105			
	0.9	72			
	1	99			
	1.1	103			
	1.2	98			
	1.3	91			
	1.4	81			
	1.5	74			
	1.6	67			
	1.7	51			
	1.8	55			
	1.9	57			
	2	52			
	2.1	50			
	Maximum Load =	187 lb			

Muskingum County - I70/SR83 - Vertical Pullout Tests
Date: 4/8/06 - 4/9/06

Pole 11-4:

Deflection (ft)	Load (lbs)
0	0
0.1	58
0.2	71
0.3	75
0.4	70
0.5	66
0.6	44
0.7	36
0.8	37
0.9	38
1	37
1.1	30

Maximum Load = 75 lb

Top Diameter :	1.31	in
Bottom Diameter :	1.96	in
Total Length :	5	ft
Depth of Embedment :	4.04	ft
Average diameter over length :	1.635	in

Pole 12-4:

Deflection (ft)	Load (lbs)
0	0
0.1	700
0.2	480
0.3	468
0.4	456
0.5	429
0.6	491
0.7	476
0.8	507
0.9	480
1	442
1.1	391
1.2	366
1.3	330
1.4	326
1.5	304
1.6	283
1.7	250
1.8	239
1.9	201
2	220
2.1	194
2.2	122

Maximum Load = 700 lb

Top Diameter :	2.07	in
Bottom Diameter :	2.68	in
Total Length :	5.66	ft
Depth of Embedment :	4.78	ft
Average diameter over length :	2.375	in

Pole 12-3:

Deflection (ft)	Load (lbs)
0	0
0.1	385
0.2	306
0.3	235
0.4	190
0.5	152
0.6	113
0.7	111
0.8	94
0.9	84
1	44
1.1	43
1.2	24

Maximum Load = 385 lb

Top Diameter :	1.77	in
Bottom Diameter :	2.59	in
Total Length :	5.2	ft
Depth of Embedment :	4.39	ft
Average diameter over length :	2.18	in

Muskingum County - I70/SR83 - Vertical Pullout Tests
Date: 4/8/06 - 4/9/06

Pole 13-3:

Deflection (ft)	Load (lbs)
0	0
0.1	316
0.2	250
0.3	169
0.4	146
0.5	139
0.6	114
0.7	109
0.8	108
0.9	95
1	80
1.1	74
1.2	74
1.3	73
1.4	70
1.5	57

Maximum Load = 316 lb

Top Diameter : 1.86 in
Bottom Diameter : 2.55 in
Total Length : 5.27 ft
Depth of Embedment : 4.32 ft
Average diameter over length : 2.205 in

Pole 13-2:

Deflection (ft)	Load (lbs)
0	0
0.1	148
0.2	182
0.3	235
0.4	290
0.5	480
0.6	155
0.7	149
0.8	133
0.9	112
1	94
1.1	98
1.2	99
1.3	101
1.4	96
1.5	84
1.6	69
1.7	60
1.8	55
1.9	48

Maximum Load = 480 lb

Top Diameter : 1.09 in
Bottom Diameter : 1.84 in
Total Length : 5.17 ft
Depth of Embedment : 4.17 ft
Average diameter over length : 1.465 in

Pole 13-4:

Deflection (ft)	Load (lbs)
0	0
0.1	68
0.2	63
0.3	56
0.4	39
0.5	34
0.6	20

Maximum Load = 68 lb

Top Diameter : 1.62 in
Bottom Diameter : 1.87 in
Total Length : 5.34 ft
Depth of Embedment : 1.03 ft
Average diameter over length : 1.745 in

Muskingum County - I70/SR83 - Vertical Pullout Tests
Date: 4/8/06 - 4/9/06

Pole 10-9:

Deflection (ft)	Load (lbs)
0	0
0.1	129
0.2	156
0.3	147
0.4	153
0.5	158
0.6	154
0.7	165
0.8	189
0.9	185
1	163
1.1	154
1.2	155
1.3	157
1.4	148
1.5	134
1.6	142
1.7	117
1.8	100
1.9	78
2	58
2.1	55

Maximum Load = 189 lb

Top Diameter :	1.61	in
Bottom Diameter :	2.29	in
Total Length :	5.12	ft
Depth of Embedment :	4	ft
Average diameter over length :	1.95	in

Pole 10-10:

Deflection (ft)	Load (lbs)
0	0
0.1	367
0.2	304
0.3	295
0.4	286
0.5	236
0.6	235
0.7	233
0.8	231
0.9	217
1	190
1.1	180
1.2	83
1.3	78
1.4	58
1.5	49
1.6	44
1.7	50
1.8	55
1.9	63
2	37
2.1	28

Maximum Load = 367 lb

Top Diameter :	1.83	in
Bottom Diameter :	2.48	in
Total Length :	5.25	ft
Depth of Embedment :	4.26	ft
Average diameter over length :	2.155	in

Muskingum County - I70/SR83 - Vertical Pullout Tests
Date: 4/8/06 - 4/9/06

Pole 8-9:

Deflection (ft)	Load (lbs)
0	0
0.1	207
0.2	193
0.3	165
0.4	150
0.5	140
0.6	133
0.7	120
0.8	86
0.9	133
1	100
1.1	81
1.2	63
1.3	50
1.4	38
1.5	31

Maximum Load = 207 lb

Top Diameter :	2.18	in
Bottom Diameter :	2.83	in
Total Length :	4.29	ft
Depth of Embedment :	3.8	ft
Average diameter over length :	2.505	in

Pole 8-10:

Deflection (ft)	Load (lbs)
0	0
0.1	190
0.2	186
0.3	151
0.4	144
0.5	171
0.6	180
0.7	188
0.8	177
0.9	163
1	128
1.1	136
1.2	135
1.3	138
1.4	137
1.5	138
1.6	143
1.7	125
1.8	80
1.9	81
2	77
2.1	78

Maximum Load = 190 lb

Top Diameter :	1.63	in
Bottom Diameter :	2.22	in
Total Length :	4.84	ft
Depth of Embedment :	3.96	ft
Average diameter over length :	1.925	in

Muskingum County - I70/SR83 - Vertical Pullout Tests
Date: 4/8/06 - 4/9/06

Pole 8-11:

Deflection (ft)	Load (lbs)
0	0
0.1	286
0.2	210
0.3	186
0.4	165
0.5	108
0.6	37
0.7	38
0.8	39

Maximum Load = 286 lb

Top Diameter :	1.97	in
Bottom Diameter :	2.62	in
Total Length :	5.15	ft
Depth of Embedment :	4.39	ft
Average diameter over length :	2.295	in

Pole 8-12:

Deflection (ft)	Load (lbs)
0	0
0.1	357
0.2	294
0.3	278
0.4	262
0.5	241
0.6	237
0.7	223
0.8	146
0.9	143
1	157
1.1	177
1.2	206
1.3	145
1.4	141
1.5	131
1.6	111
1.7	93
1.8	84
1.9	65
2	60
2.1	56

Maximum Load = 357 lb

Top Diameter :	1.43	in
Bottom Diameter :	2.13	in
Total Length :	5.16	ft
Depth of Embedment :	4.34	ft
Average diameter over length :	1.78	in

Muskingum County - I70/SR83 - Vertical Pullout Tests
Date: 4/8/06 - 4/9/06

Pole 17-3:

Deflection (ft)	Load (lbs)
0	0
0.1	152
0.2	160
0.3	129
0.4	147
0.5	163
0.6	145
0.7	78
0.8	88
0.9	83
1	112
1.1	129
1.2	157
1.3	165
1.4	149
1.5	64
1.6	82
1.7	69
1.8	78
1.9	71
2	86
2.1	64

Maximum Load = 165 lb

Top Diameter :	1.13	in
Bottom Diameter :	1.62	in
Total Length :	5.09	ft
Depth of Embedment :	4.55	ft
Average diameter over length :	1.375	in

Pole 18-3:

Deflection (ft)	Load (lbs)
0	0
0.1	212
0.2	195
0.3	182
0.4	143
0.5	104
0.6	132
0.7	132
0.8	120
0.9	89
1	74
1.1	83
1.2	78
1.3	71
1.4	96
1.5	120

Maximum Load = 212 lb

Top Diameter :	0.89	in
Bottom Diameter :	1.53	in
Total Length :	5.58	ft
Depth of Embedment :	4.55	ft
Average diameter over length :	1.21	in

Muskingum County - I70/SR83 - Vertical Pullout Tests
Date: 4/8/06 - 4/9/06

Pole 11-8:

Deflection (ft)	Load (lbs)
0	0
0.1	283
0.2	308
0.3	315
0.4	272
0.5	166
0.6	281
0.7	245
0.8	212
0.9	211
1	214
1.1	250
1.2	244
1.3	255
1.4	247
1.5	236
1.6	234
1.7	217
1.8	233
1.9	229
2	226
2.1	198
2.2	189
2.3	174
2.4	181
2.5	145
2.6	134

Maximum Load = 315 lb

Top Diameter :	1.8	in
Bottom Diameter :	2.4	in
Total Length :	5.12	ft
Depth of Embedment :	4.55	ft
Average diameter over length :	2.1	in

Pole 11-9:

Deflection (ft)	Load (lbs)
0	0
0.1	299
0.2	327
0.3	326
0.4	292
0.5	243
0.6	187
0.7	144
0.8	86
0.9	61
1	49
1.1	42
1.2	35
1.3	34
1.4	31
1.5	28
1.6	30

Maximum Load = 327 lb

Top Diameter :	1.67	in
Bottom Diameter :	2.21	in
Total Length :	5.32	ft
Depth of Embedment :	4.44	ft
Average diameter over length :	1.94	in

Muskingum County - I70/SR83 - Vertical Pullout Tests
Date: 4/8/06 - 4/9/06

Pole 10-8:

Deflection (ft)	Load (lbs)
0	0
0.1	148
0.2	135
0.3	129
0.4	134
0.5	141
0.6	121
0.7	121
0.8	114
0.9	118
1	118
1.1	105
1.2	104
1.3	116
1.4	122
1.5	121
1.6	94
1.7	123
1.8	86
1.9	65
2	53
2.1	41
2.2	33
2.3	31
2.4	31
2.5	29
2.6	28

Maximum Load = 148 lb

Top Diameter :	1.69	in
Bottom Diameter :	2.39	in
Total Length :	4.81	ft
Depth of Embedment :	3.99	ft
Average diameter over length :	2.04	in

Pole 14-4:

Deflection (ft)	Load (lbs)
0	0
0.1	210
0.2	190
0.3	170
0.4	161
0.5	141
0.6	130
0.7	114
0.8	91
0.9	89
1	97
1.1	97
1.2	99
1.3	98
1.4	99
1.5	52
1.6	45

Maximum Load = 210 lb

Top Diameter :		in
Bottom Diameter :		in
Total Length :		ft
Depth of Embedment :		ft
Average diameter over length :		in

Muskingum County - I70/SR83 - Vertical Pullout Tests
Date: 4/8/06 - 4/9/06

Pole 14-3:	Deflection (ft)	Load (lbs)				
				Top Diameter :	1.88	in
	0	0		Bottom Diameter :	2.74	in
	0.1	312		Total Length :	5.1	ft
	0.2	392		Depth of Embedment :	4.03	ft
	0.3	403				
	0.4	385		Average diameter over length :	2.31	in
	0.5	355				
	0.6	331				
	0.7	282				
	0.8	221				
	0.9	212				
	1	170				
	1.1	142				
	1.2	120				
	1.3	108				
	1.4	98				
	1.5	89				
	1.6	81				
	1.7	77				
	1.8	81				
	1.9	104				
	2	127				
	Maximum Load =	403	lb			

Pole 14-2:	Deflection (ft)	Load (lbs)				
				Top Diameter :		in
	0	0		Bottom Diameter :		in
	0.1	298		Total Length :		ft
				Depth of Embedment :		ft
				Average diameter over length :		in
	Maximum Load =	298	lb	Aborted - Rotted		

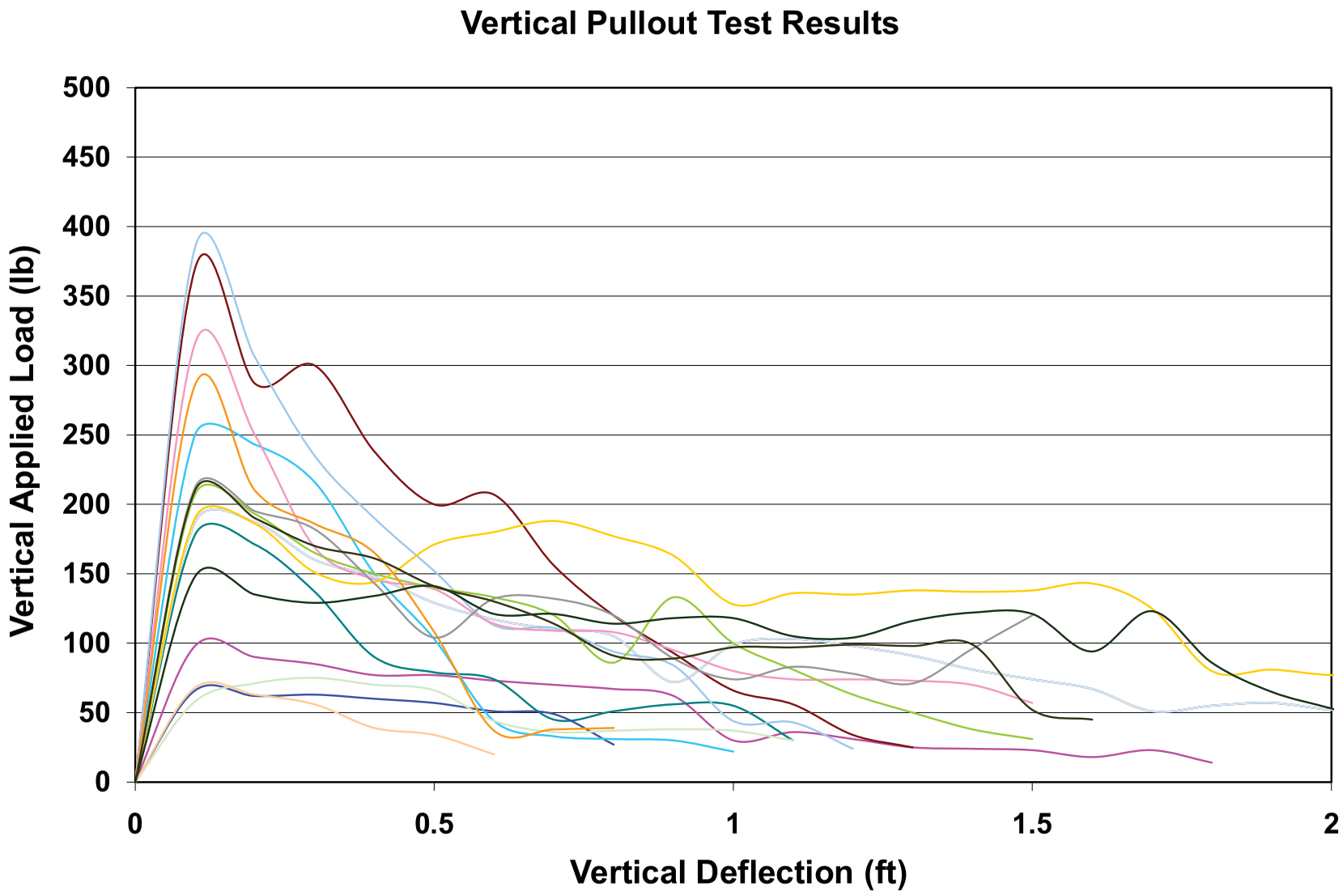
Pole 18-2:	Deflection (ft)	Load (lbs)				
				Top Diameter :	0.95	in
	0	0		Bottom Diameter :	1.33	in
	0.1	108		Total Length :	5.06	ft
	0.2	189		Depth of Embedment :	3.95	ft
	0.3	64				
	0.4	34		Average diameter over length :	1.14	in
	0.5	24				
	0.6	24				
	Maximum Load =	189	lb			

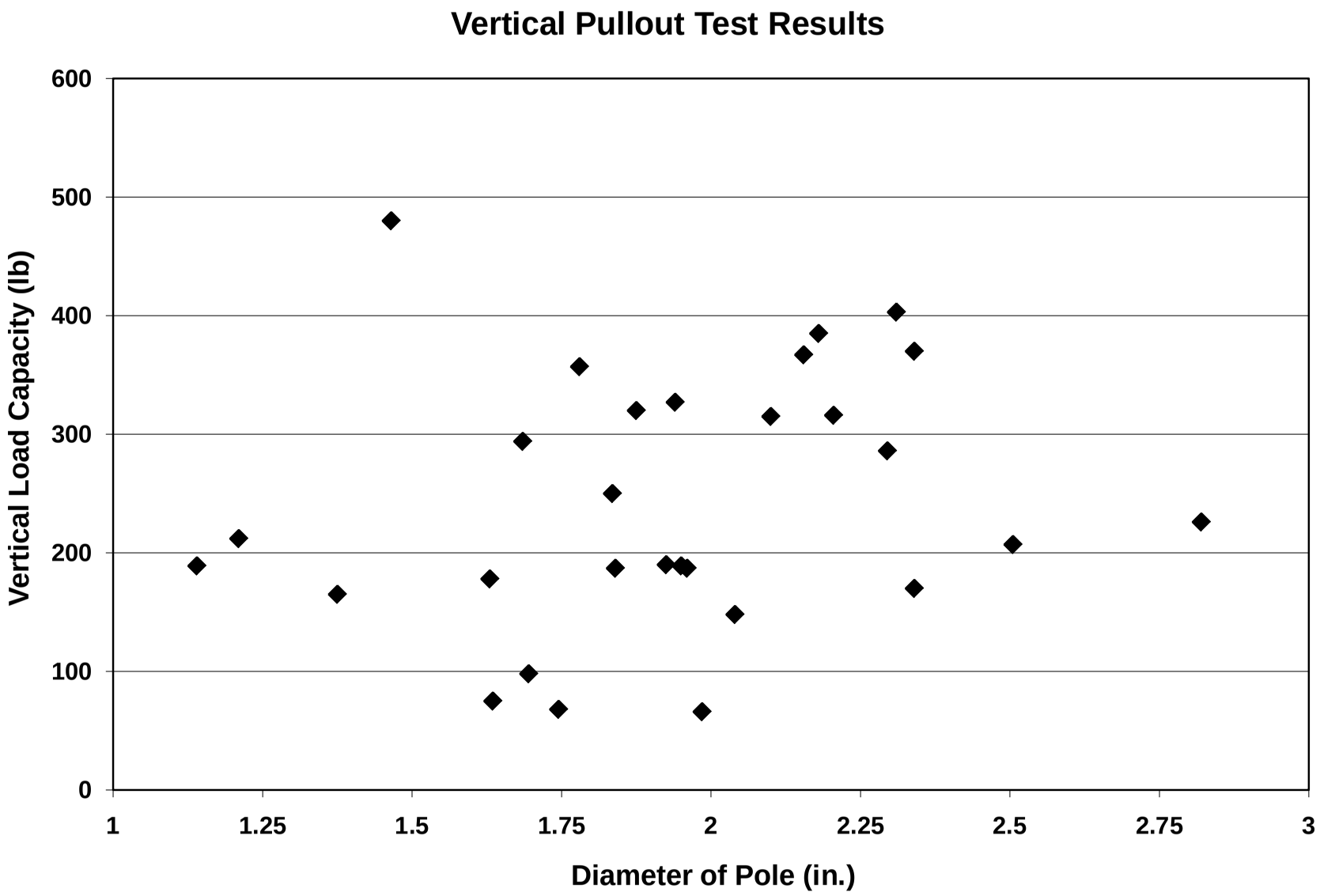
Muskingum County - I70/SR83 - Vertical Pullout Tests
Date: 4/8/06 - 4/9/06

Pole 19-2:	Deflection (ft)	Load (lbs)
	0	0
	0.1	185
	0.2	237
	0.3	294
	0.4	251
	0.5	271
	0.6	264
	0.7	239
	0.8	219
	0.9	168
	1	157
	1.1	132
	1.2	97
	1.3	85

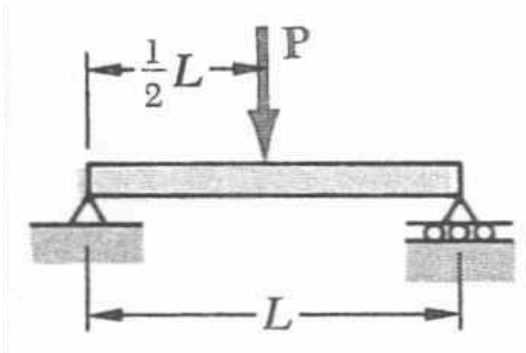
Maximum Load = 294 lb

Top Diameter :	1.45	in
Bottom Diameter :	1.92	in
Total Length :	5.07	ft
Depth of Embedment :	4.16	ft
Average diameter over length :	1.685	in


Vertical Pullout Test Results
Vertical Applied Load (lb)
500
450
400
350
300
250
200
150
100
50
0
0
0.5
1
1.5
2
Vertical Deflection (ft)


Vertical Pullout Test Results
Vertical Load Capacity (lb)
600
500
400
300
200
100
0
1
1.25
1.5
1.75
2
2.25
2.5
2.75
3
Diameter of Pole (in.)

Flexure Test: Dry (Dead) Willow Pole



$$\delta_{max} = \frac{PL^3}{48EI} \qquad M_{max} = \frac{PL}{4}$$

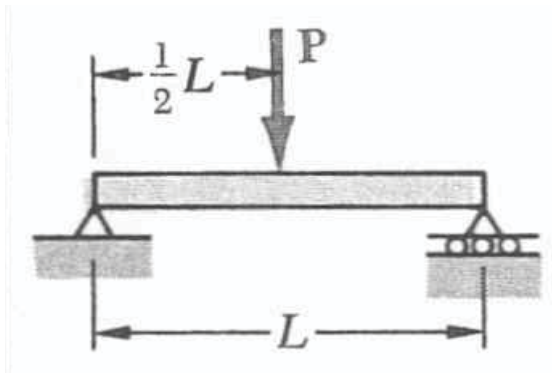
$$E = \frac{PL^3}{48I\delta_{max}} \qquad \sigma_{max} = M_{max}\left(\frac{r}{I}\right)$$

Pole 1-1 Dimensions:

L = 48.75 in
d = 1.1475 in
r = 0.57375 in
I = 0.08511 in^4

Weight		Pole Position	Deflection		E (lb/in^2)	M (lb-in)	σ (lb/in^2)
Initial	Initial	1730 mm	0 mm	0.000 in	0.00E+00	0.00	0.00
1 kg	2.205 lb	1731 mm	1 mm	0.039 in	1.59E+06	26.87	181.16
2 kg	4.41 lb	1732 mm	2 mm	0.079 in	1.59E+06	53.75	362.32
4 kg	8.82 lb	1736 mm	6 mm	0.236 in	1.06E+06	107.49	724.64
8 kg	17.64 lb	1742 mm	12 mm	0.472 in	1.06E+06	214.99	1449.29
12 kg	26.46 lb	1748 mm	18 mm	0.709 in	1.06E+06	322.48	2173.93
16 kg	35.28 lb	1756 mm	26 mm	1.024 in	9.77E+05	429.98	2898.58
20 kg	44.1 lb	1764 mm	34 mm	1.339 in	9.34E+05	537.47	3623.22
24 kg	52.92 lb	1774 mm	44 mm	1.732 in	8.66E+05	644.96	4347.87
28 kg	61.74 lb	1782 mm	52 mm	2.047 in	8.55E+05	752.46	5072.51
32 kg	70.56 lb	1798 mm	68 mm	2.677 in	7.47E+05	859.95	5797.16
36 kg	79.38 lb	1815 mm	85 mm	3.346 in	6.73E+05	967.44	6521.80
40 kg	88.2 lb	1840 mm	110 mm	4.331 in	5.78E+05	1074.94	7246.45
44 kg	97.02 lb	1890 mm	160 mm	6.299 in	4.37E+05	1182.43	7971.09
48 kg	105.84 lb	1926 mm	196 mm	7.717 in	3.89E+05	1289.93	8695.74

Flexure Test: Green (Live) Willow Pole



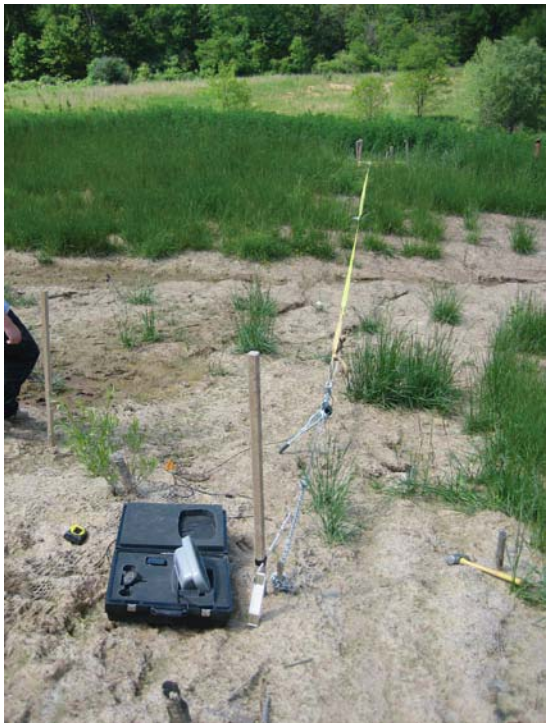
$$\delta_{max} = \frac{PL^3}{48EI} \qquad M_{max} = \frac{PL}{4}$$

$$E = \frac{PL^3}{48I\delta_{max}} \qquad \sigma_{max} = M_{max}\left(\frac{r}{I}\right)$$

Pole 8-10 Dimensions:

L =	40	in
d =	1.799	in
r =	0.8995	in
I =	0.51416	in^4

Weight		Pole Position	Deflection		E (lb/in^2)	M (lb-in)	σ (lb/in^2)
Initial	Initial	591 mm	0 mm	0.000 in	0.00E+00	0.00	0.00
18.1 kg	39.9105 lb	585 mm	6 mm	0.236 in	4.38E+05	399.11	698.22
36.2 kg	79.821 lb	580 mm	11 mm	0.433 in	4.78E+05	798.21	1396.44
54.3 kg	119.732 lb	575 mm	16 mm	0.630 in	4.93E+05	1197.32	2094.67
72.4 kg	159.642 lb	571 mm	20 mm	0.787 in	5.26E+05	1596.42	2792.89
90.5 kg	199.553 lb	566 mm	25 mm	0.984 in	5.26E+05	1995.53	3491.11
108.6 kg	239.463 lb	558 mm	33 mm	1.299 in	4.78E+05	2394.63	4189.33
126.7 kg	279.374 lb	553 mm	38 mm	1.496 in	4.84E+05	2793.74	4887.56
142.7 kg	314.654 lb	547 mm	44 mm	1.732 in	4.71E+05	3146.54	5504.77



Pictured above is the setup for the lateral pullout test. Setup includes a come-along towing wench attached to towing straps and to an s-type load cell on each end of it. One of the towing straps are wound around five willow poles and used as a reaction point. The second strap is connected to the first strap and the wench and is drawn taut. A chain is wrapped around the willow being tested and attached to the load cell. The system of straps and chains is drawn taut until a small load is maintained on the load cell. The come-along is then drawn in, pulling the willow laterally. Loads are read and recorded at constant displacement intervals by a second person.

Muskingum County - I70/SR83 - Lateral Pullout Tests

Pole 13-1: 0.65 ft exposed length

Maximum Load = 141 lbs

Deflection at Failure = 0.95 ft (Snaped at failure)

1.2 ft lenth to failure

Pole 12-1(Double): 0.70 ft exposed length

	Deflection (ft)	Load (lbs)	
	0	70	
	0.05	101	
	0.1	121	
	0.2	137	
≈ 0.40	0.4	254	Initial Failure

Maximum Load = 394 lbs

Deflection at Failure = 1.0 ft (Snaped at failure)

0.8 ft lenth to failure

Pole 11-1: 0.65 ft exposed length

	Deflection (ft)	Load (lbs)	
	0	-	
	0.05	70	
	0.1	120	
	0.15	150	
	0.2	170	
	0.25	198	
≈ 0.35	0.35	246	Initial Failure

Maximum Load = 246 lbs

Deflection at Failure = 0.35 ft (Snaped at failure - Brittle)

1.25 ft lenth to failure

Muskingum County - I70/SR83 - Lateral Pullout Tests
Muskingum County - I70/SR83 - Lateral Pullout Tests

Pole 10-1: 0.80 ft exposed length

	Deflection (ft)	Load (lbs)
	0	48
	0.05	141
	0.1	220
	0.15	262
	0.2	330
	0.25	363
	0.3	403
	0.4	435
	0.5	480
	0.55	505
	0.7	530
≈ 0.80	0.8	547

Maximum Load = 780 lbs

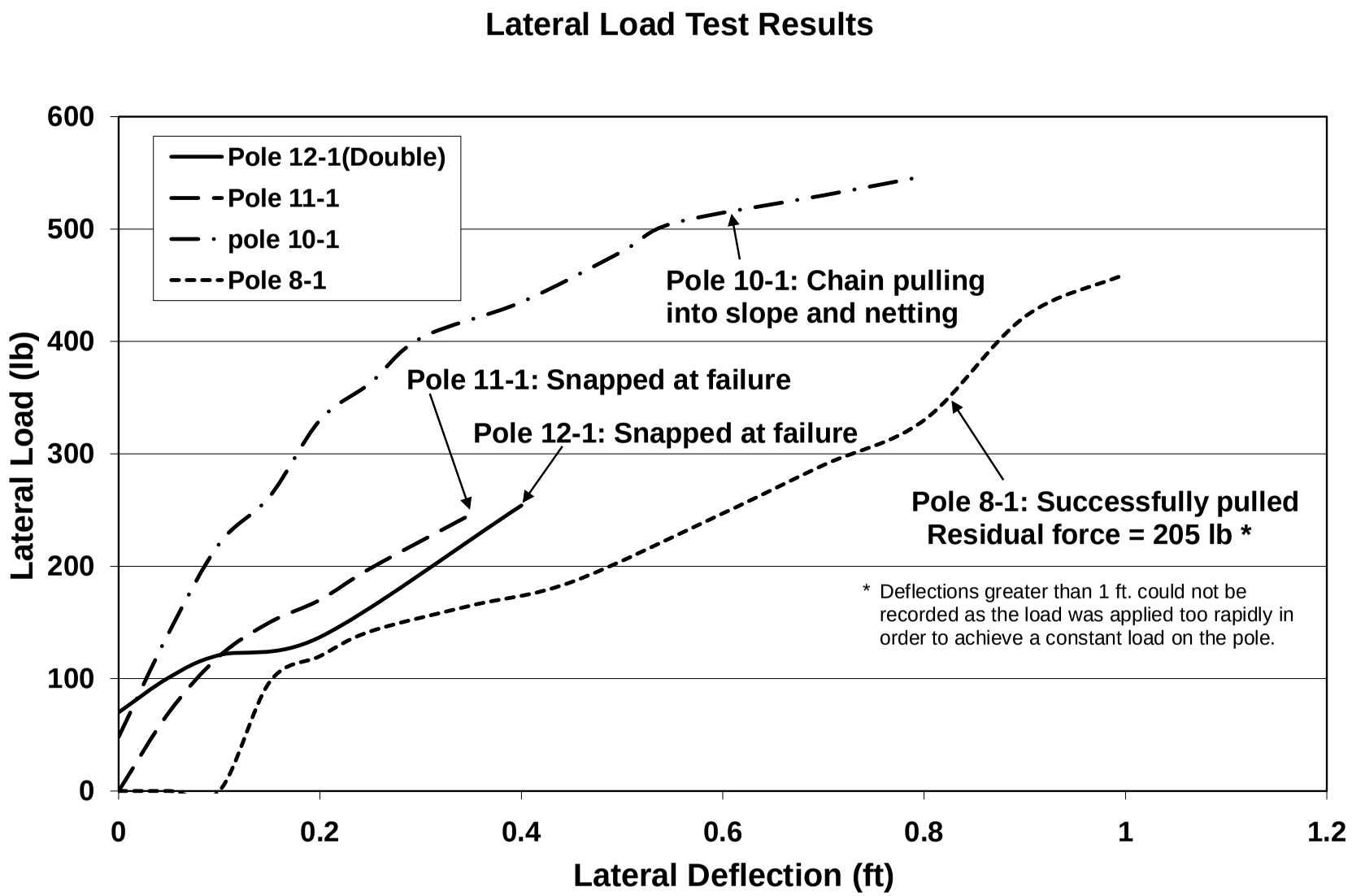
Deflection at Failure = N/A - Chain pulling into slope and netting

Pole 8-1: 0.40 ft exposed length

Deflection (ft)	Load (lbs)	
0	-	
0.05	-	
0.1	-	
0.15	97	
0.2	120	
0.25	142	
0.35	165	
0.45	186	
0.6	247	
0.7	290	
0.8	330	
0.9	422	
1	460	Initial Failure

Maximum Load = 460 lbs - (205 lbs residual force)

Deflection at Failure = N/A - Pole was pulled out of hole


Lateral Load Test Results
Pole 12-1(Double)
Pole 11-1
pole 10-1
Pole 8-1
Pole 10-1: Chain pulling into slope and netting
Pole 11-1: Snapped at failure
Pole 12-1: Snapped at failure
Pole 8-1: Successfully pulled
Residual force = 205 lb *
* Deflections greater than 1 ft. could not be recorded as the load was applied too rapidly in order to achieve a constant load on the pole.
Lateral Load (lb)
Lateral Deflection (ft)
0
100
200
300
400
500
600
0
0.2
0.4
0.6
0.8
1
1.2

Muskingum County Infinite Slope Analysis

γ_w	=	62.4	pcf			
γ	=	123	pcf			
s_u	=	400	psf	=	2.78	psi
s_u	=	800	psf	=	5.56	psi
φ_{fs}	=	26.6	deg			
c	=	0	psf			
β	=	26.6	deg			
L	=	4.5	ft	=	54	in
d	=	1.5	in	=	0.125	ft
r	=	0.75	in	=	0.0625	ft
I	=	0.2485	in^4			
E	=	1.0E+06	psi			
σ_u	=	8500	psi			
M_y	=	2816.39	lb-in			
τ_u	=	580	psi			
e/d	=	0				
s	=	3	ft			

Factor of Safety:

$$FS = A\left[\frac{\tan(\phi)}{\tan(\beta)}\right] + B\left[\frac{c + c_a}{\gamma H}\right]$$

$$A = 1 - \frac{r_u}{\cos^2(\beta)}$$

$$B = \frac{1}{\cos^2(\beta)\tan(\beta)}$$

$$r_u = \left(\frac{\gamma_w}{\gamma}\right)\left(\frac{1}{(1 + \tan(\beta)\tan(\theta))}\right)$$

Flow Mode:

$$q_y = s_u N_c$$

$$N_c = 2\left(1 + z/d\right) \leq 9$$

$$T_x = q_y d$$

Pile Mode (Long):

Dimensionless Yield Moment $(YM) = \frac{M_{yield}}{s_u d^3}$

Dimensionless Ultimate Lateral Resistance $(ULR) = \frac{T_{xu}}{s_u d^2}$

$$M_{yield} = \frac{\sigma_t I}{r}$$

$$I = \frac{\pi r^4}{4}$$

$$T_{xu} = (ULR) s_u d^2$$

		θ	H	Flow Mode				Pile Mode								Shear Mode		Limiting	FS	
									Short			Long								
				N_c	q_y	T_x	c_R	βL	L/d	ULR	T_x	YM	ULR	T_x	c_R	V_u	c_R	c_R	Reinforced	Unreinforced
A	= 1.000	90	2	34	3600	900	89.42	6.145				150	40	500	49.68	1025	101.83	49.68	1.504	1.000
B	= 2.498		2.5	42	3600	1125	111.77	6.145				150	40	500	49.68	1025	101.83	49.68	1.403	1.000
r_u	= 0.000		3	50	3600	1350	134.12	6.145				150	40	500	49.68	1025	101.83	49.68	1.336	1.000
			3.5	58	3600	1575	156.48	6.145				150	40	500	49.68	1025	101.83	49.68	1.288	1.000
			4	66	3600	1800	178.83	6.145				150	40	500	49.68	1025	101.83	49.68	1.252	1.000
			4.5	74	3600	2025	201.18	6.145				150	40	500	49.68	1025	101.83	49.68	1.224	1.000
A	= 0.493	26.6	2	34	3600	900	89.42	6.145				150	40	500	49.68	1025	101.83	49.68	0.997	0.493
B	= 2.498		2.5	42	3600	1125	111.77	6.145				150	40	500	49.68	1025	101.83	49.68	0.896	0.493
r_u	= 0.406		3	50	3600	1350	134.12	6.145				150	40	500	49.68	1025	101.83	49.68	0.829	0.493
			3.5	58	3600	1575	156.48	6.145				150	40	500	49.68	1025	101.83	49.68	0.781	0.493
			4	66	3600	1800	178.83	6.145				150	40	500	49.68	1025	101.83	49.68	0.745	0.493
			4.5	74	3600	2025	201.18	6.145				150	40	500	49.68	1025	101.83	49.68	0.717	0.493

APPENDIX B

SUPPORTING DOCUMENTS FOR LOGAN COUNTY FIELD DEMONSTRATION SITE

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Logan County 30 Year Data

Climate Data for Station: 330563 BELLEFONTAINE, OH - Source: MRCC, NCDC, ODNR

Temperature Summary
1971-2000 NCDC Normals

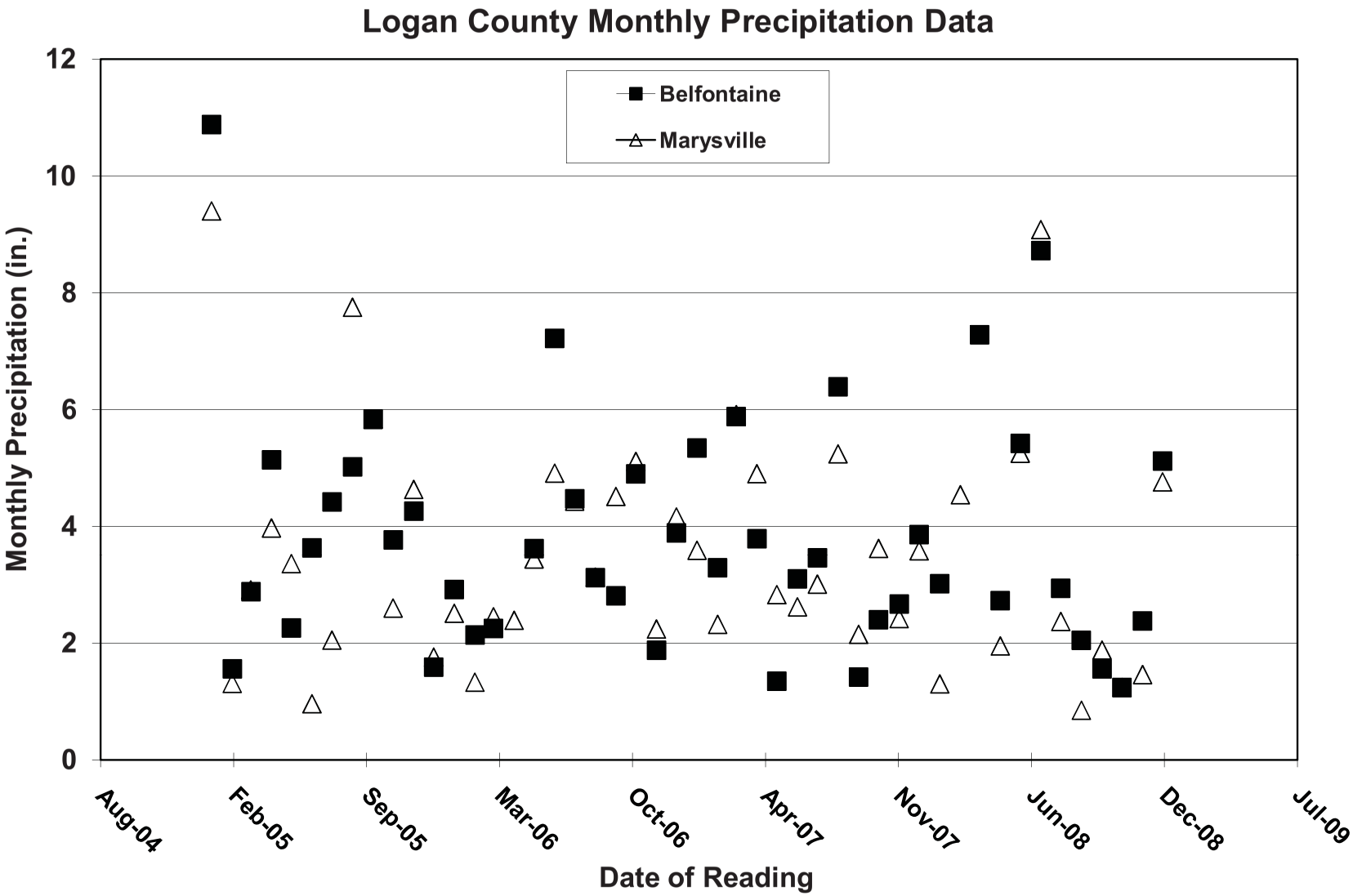
Element	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Max °F	32.2	37	47.9	59.6	70.8	79.3	83.1	81	75.2	63.2	49.4	37.6	59.7
Min °F	15.4	19.1	28.1	38.2	49.6	58.4	62.2	60.5	53.3	41.6	32	21.6	40
Mean °F	23.8	28.1	38	48.9	60.2	68.9	72.7	70.8	64.3	52.4	40.7	29.6	49.9

Precipitation Summary
1971-2000 NCDC Normals

Element	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Precip (in)	2.28	2.02	2.7	3.46	4.02	4.11	3.93	3.64	2.78	2.46	3.08	2.94	37.42

Growing Season Summary
Derived from 1971-2000 Averages

	Date of Last Spring Occurrence					Date of First Fall Occurrence				
Base Temp °F	Median	Early	90%	10%	Late	Median	Early	90%	10%	Late
32	5/1	4/8	4/11	5/15	5/26	10/10	9/23	9/27	10/25	11/4
30	4/23	4/6	4/9	5/8	5/13	10/19	9/22	10/2	11/3	11/6
28	4/11	3/23	4/3	5/1	5/7	10/22	10/2	10/7	11/12	11/22
24	4/7	3/18	3/23	4/16	4/23	11/6	10/14	10/18	11/22	11/29
20	3/25	2/28	3/10	4/11	4/18	11/18	10/24	11/4	12/11	12/18
16	3/17	2/7	2/25	4/2	4/9	11/30	11/4	11/9	12/17	12/22


Logan County Monthly Precipitation Data
Belfontaine
Marysville
Monthly Precipitation (in.)
0
2
4
6
8
10
12
Aug-04
Feb-05
Sep-05
Mar-06
Oct-06
Apr-07
Nov-07
Jun-08
Dec-08
Jul-09
Date of Reading

Logan County Monthly Precipitation Data

Climate Data for Station: 330563 BELLEFONTAINE, OH - Source: MRCC, NCDC, ODNR
Climate Data for Station: 334979 MARYSVILLE, OH - Source: MRCC, NCDC, ODNR

Precipitation Summary
NCDC

2005 Monthly Precipitation and Departure From Normal (inches)

Location	January		February		March		April		May		June	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Bellefontaine	10.88	8.60	1.56	-0.46	2.88	0.18	5.14	1.68	2.26	-1.76	3.63	-0.48
Marysville	9.40	7.10	1.31	-0.66	2.91	0.31	3.97	0.61	3.36	-0.53	0.96	-3.39

Location	July		August		September		October		November		December	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Bellefontaine	4.42	0.49	5.02	1.38	5.84	3.06	3.77	1.31	4.26	1.18	1.59	-1.35
Marysville	2.05	-1.99	7.75	4.38	5.83	3.10	2.60	0.19	4.63	1.67	1.76	-0.88

Location	Annual	
	Precip.	Depart.
Bellefontaine	51.25	13.83
Marysville	46.53	9.91

Logan County Monthly Precipitation Data

Climate Data for Station: 330563 BELLEFONTAINE, OH - Source: MRCC, NCDC, ODNR
Climate Data for Station: 334979 MARYSVILLE, OH - Source: MRCC, NCDC, ODNR

Precipitation Summary
NCDC

2006 Monthly Precipitation and Departure From Normal (inches)

Location	January		February		March		April		May		June	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Bellefontaine	2.92	0.64	2.14	0.12	2.25	-0.45	M 2.46	M -1.00	3.62	-0.40	7.22	3.11
Marysville	2.51	0.21	1.33	-0.64	2.45	-0.15	2.39	-0.97	3.44	-0.45	4.91	0.56

Location	July		August		September		October		November		December	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Bellefontaine	4.47	0.54	3.12	-0.52	2.81	0.03	4.90	2.44	1.88	-1.20	3.89	0.95
Marysville	4.43	0.39	3.13	-0.24	4.51	1.78	5.11	2.70	2.24	-0.72	4.16	1.52

Location	Annual	
	Precip.	Depart.
Bellefontaine	M 41.68	M 4.26
Marysville	40.61	3.99

Logan County Monthly Precipitation Data

Climate Data for Station: 330563 BELLEFONTAINE, OH - Source: MRCC, NCDC, ODNR
Climate Data for Station: 334979 MARYSVILLE, OH - Source: MRCC, NCDC, ODNR

Precipitation Summary
NCDC

2007 Monthly Precipitation and Departure From Normal (inches)

Location	January		February		March		April		May		June	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Bellefontaine	5.34	3.06	3.29	1.27	5.88	3.18	3.79	0.33	1.35	-2.67	3.10	-1.01
Marysville	3.59	1.29	2.32	0.35	5.91	3.31	4.90	1.54	2.83	-1.06	2.62	-1.73

Location	July		August		September		October		November		December	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Bellefontaine	3.46	-0.47	6.39	2.75	1.42	-1.36	2.40	-0.06	2.67	-0.41	3.86	0.92
Marysville	3.01	-1.03	5.24	1.87	2.15	-0.58	3.62	1.21	2.42	-0.54	3.58	0.94

Location	Annual	
	Precip.	Depart.
Bellefontaine	42.95	5.53
Marysville	42.19	5.57

Logan County Monthly Precipitation Data

Climate Data for Station: 330563 BELLEFONTAINE, OH - Source: MRCC, NCDC, ODNR
Climate Data for Station: 334979 MARYSVILLE, OH - Source: MRCC, NCDC, ODNR

Precipitation Summary
NCDC

2008 Monthly Precipitation and Departure From Normal (inches)

Location	January		February		March		April		May		June	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Bellefontaine	3.02	0.74	M 5.38	M 3.10	7.28	4.58	2.73	-0.73	5.42	1.40	8.72	4.61
Marysville	1.30	-1.00	4.54	2.75	M 5.99	M 3.39	1.95	-1.41	5.25	1.36	9.08	4.73

Location	July		August		September		October		November		December	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Bellefontaine	2.94	-0.99	2.05	-1.59	1.56	-1.22	1.24	-1.22	2.38	-0.70	5.12	2.18
Marysville	2.37	-1.67	0.85	-2.52	1.88	-0.85	1.24	-1.17	1.46	-1.50	4.76	2.12

Location	Annual	
	Precip.	Depart.
Bellefontaine	M 47.84	M 10.42
Marysville	M 40.67	M 4.05

Logan County Monthly Precipitation Data

Climate Data for Station: 330563 BELLEFONTAINE, OH - Source: MRCC, NCDC, ODNR
Climate Data for Station: 334979 MARYSVILLE, OH - Source: MRCC, NCDC, ODNR

Precipitation Summary
NCDC

2009 Monthly Precipitation and Departure From Normal (inches)

Location	January		February		March		April		May		June	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Bellefontaine	2.24	-0.04	1.84	-0.18	1.21	-1.49	4.22	0.76				
Marysville	2.03	-0.27	1.38	-0.59	1.48	-1.12	3.97	0.61				

Location	July		August		September		October		November		December	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Bellefontaine												
Marysville												

Location	Annual	
	Precip.	Depart.
Bellefontaine		
Marysville		

Logan County

March 2007 Daily Precipitation (inches)

Location	Day of the Month																															Tot
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Bellefontaine	0.23	1.13	-	0.01	-	-	0.03	-	-	T	-	-	-	0.19	1.45	0.05	0.01	-	-	0.51	-	-	1.48	0.81	-	-	-	-	-	-	-	5.90
Marysville	0.06	1.05	-	T	-	-	0.02	0.20	-	-	0.07	-	-	0.05	1.05	0.07	T	-	-	0.48	-	-	1.35	1.30	0.14	-	-	-	0.01	-	0.06	5.91

March 2007 Daily Temperatures (°F)

Location		Day of the Month																															Avg
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Bellefontaine	Max	38	47	45	45	28	40	26	30	40	59	56	54	54	74	72	38	33	40	41	48	44	72	62	58	68	76	74	78	52	65	72	52.5
	Min	22	34	27	20	21	10	11	14	18	35	24	24	24	48	31	28	25	18	18	32	34	37	56	48	53	55	58	48	44	47	47	32.6
Marysville	Max	48	49	36	29	37	27	30	41	61	55	53	52	75	72	61	33	37	41	49	49	72	64	64	70	77	76	80	64	69	75	59	55.0
	Min	35	34	23	21	23	12	19	15	24	37	31	26	38	57	32	28	26	24	30	35	32	58	47	53	53	56	62	46	46	38	48	35.8

April 2007 Daily Precipitation (inches)

Location	Day of the Month																														Tot
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Bellefontaine	0.61	-	-	0.12	-	-	-	0.10	-	-	0.06	1.26	0.03	-	0.55	-	-	-	-	-	-	-	-	-	0.09	0.54	0.37	0.05	-	0.01	3.79
Marysville	0.59	T	-	0.11	T	T	T	T	-	-	-	1.85	0.02	-	0.57	-	-	-	-	-	-	-	-	0.26	0.38	0.46	0.54	0.06	0.06	-	4.90

April 2007 Daily Temperatures (°F)

Location		Day of the Month																														Avg
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Bellefontaine	Max	60	69	71	76	33	33	34	30	35	39	48	50	41	52	40	49	56	65	54	57	67	73	77	77	71	52	69	54	68	75	55.8
	Min	48	50	48	32	25	20	19	22	24	24	25	35	32	33	30	32	30	32	36	38	35	45	54	51	47	46	52	47	43	50	36.8
Marysville	Max	73	73	80	58	33	34	34	35	41	50	51	46	52	42	49	56	63	58	59	71	74	81	81	71	55	70	58	69	75	75	58.9
	Min	58	53	47	28	27	24	22	24	31	25	36	35	35	32	32	36	38	37	37	39	38	43	58	43	47	48	49	49	51	61	39.4

Logan County

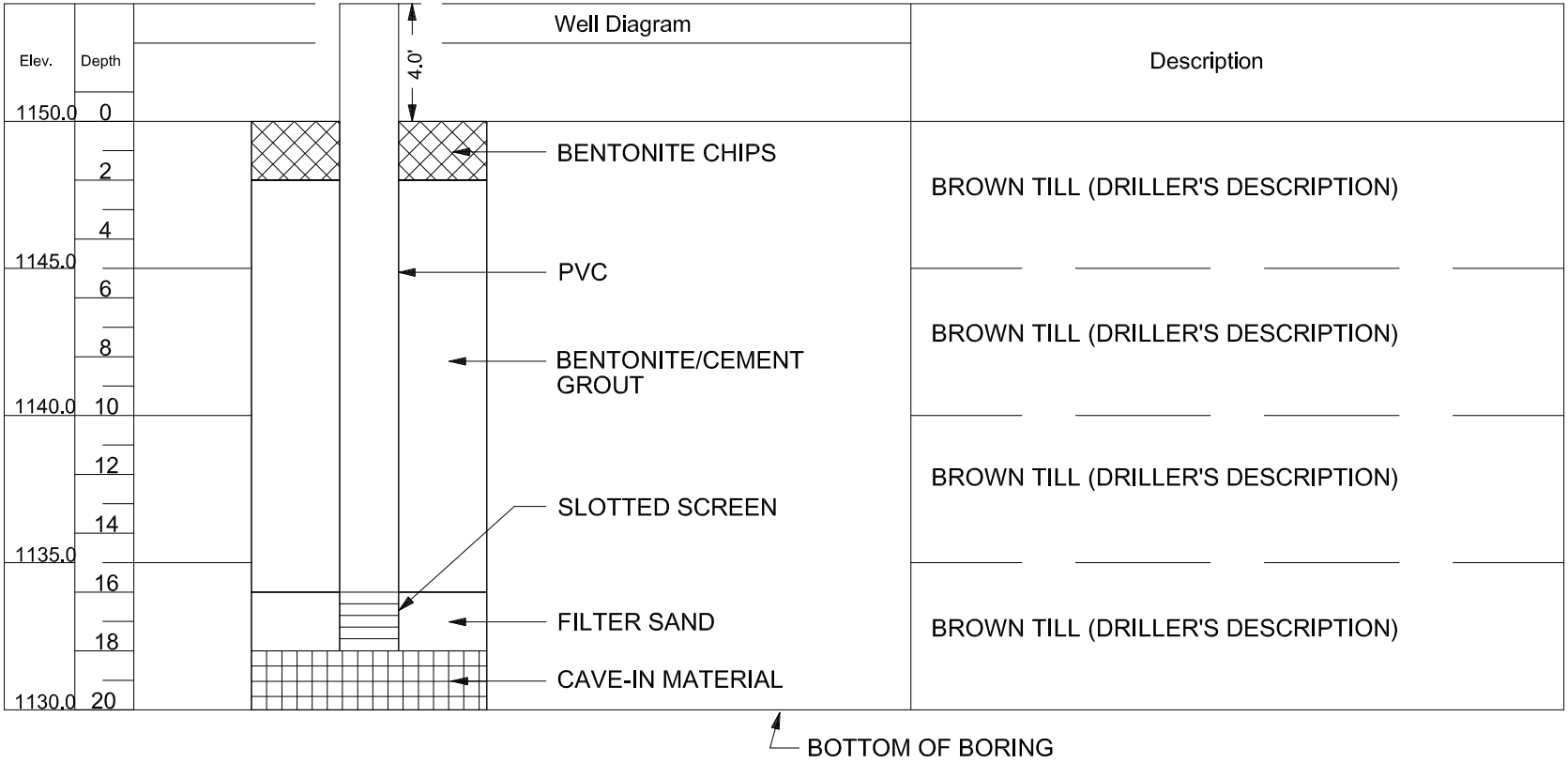
May 2007 Daily Precipitation (inches)																																
Location	Day of the Month																															Tot
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Bellefontaine	-	-	-	-	-	0.10	-	-	-	-	-	-	-	-	-	0.55	0.22	0.02	-	-	-	-	-	-	-	0.02	0.27	-	0.17	-	-	1.35
Marysville	-	T	-	-	-	0.37	-	-	-	T	-	-	-	-	-	1.48	0.10	0.03	-	T	T	-	-	-	-	-	0.23	0.06	0.19	-	0.37	2.83

May 2007 Daily Temperatures (°F)																																	
Location		Day of the Month																															Avg
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Bellefontaine	Max	77	84	66	71	74	64	64	73	82	83	82	83	76	69	80	85	58	56	64	71	79	76	83	87	85	83	83	80	78	85	87	76.4
	Min	56	51	46	46	46	44	46	49	49	57	57	54	39	45	57	57	41	39	40	49	46	49	63	63	63	62	59	58	60	65	64	52.3
Marysville	Max	85	75	75	78	65	67	75	85	88	85	76	74	72	84	87	66	57	65	71	79	76	85	88	89	86	82	82	80	87	90	88	78.8
	Min	55	52	45	47	55	45	43	48	56	57	50	45	41	43	64	48	46	42	41	53	48	55	60	61	64	62	60	63	60	64	61	52.7

State of Ohio
Department of Transportation
Office of Geotechnical Engineering

LOG OF BORING/WELL CONSTRUCTION

Date Started 10/26/04 Sampler: Type - Dia. - Water Elev. DRY Project Identification: LOGAN
Date completed 10/26/04 LOG-347- 0.00
Boring No. B-1 Station & Offset NORTHEAST LOCATION APPROX. Surface Elev. 1150.0' LANDSLIDE INVESTIGATION
Drilling Method HOLLOW STEM AUGER DRILLING Rock Coring Method
Crew Chief LEWIS Drilling Party WILLIS, VALINE



State of Ohio
Department of Transportation
Office of Geotechnical Engineering

LOG OF BORING

Date Started 10/26/04 Sampler: Type SS Dia. _____ Water Elev. 1123.0' Project Identification: LOGAN
Date completed 10/26/04 Approx. LOG-347- 0.00
Boring No. B-2 Station & Offset 2+00, CL Surface Elev. 1150.0' LANDSLIDE & MONITORING WELL INSTALL.

Elev.	Depth	Std. Pen./ R.Q.D.	Rec. ft	Loss ft	Description	Sample No.	Physical Characteristics % Agg	% C.S.	% F.S.	% Silt	% Clay	L.L.	P.I.	W.C.	ODOT Class
1150.0	0														
	2														
	4														
1145.0	6	12/15/17			BROWN GRAVELLY CLAY	16	15	4	7	29	45	34	13	15	A-6a
	8														
1140.0	10														
	12	8/11/17			BROWN GRAVELLY CLAY	17	22	4	6	25	43	32	12	16	A-6a
	14														
1134.9	16	P.S.			BROWN TILL (DRILLER'S DESCRIPTION) NOTE: SAMPLE TESTED BY OSU	18-P	-	-	-	-	-	-	-	-	VISUAL
	18														
1130.0	20														
	22	11/13/19			BROWN GRAVELLY CLAY	19	20	5	7	28	40	32	12	13	A-6a
	24														
1125.0	26	P.S.			GRAY CLAY (DRILLER'S DESCRIPTION) NOTE: SAMPLE TESTED BY OSU	20-P	-	-	-	-	-	-	-	-	VISUAL
	28														
1120.0	30														
1118.5		8/11/8			BROWN GRAVELLY SANDY SILT	21	22	14	11	44	9	18	2	12	A-4a

BOTTOM OF BORING

Particle Sizes: Agg= >2.00mm, Coarse Sand= 2.00-0.42mm, Fine Sand= 0.42-0.074mm, Silt= 0.074-0.005mm, Clay= <0.005mm

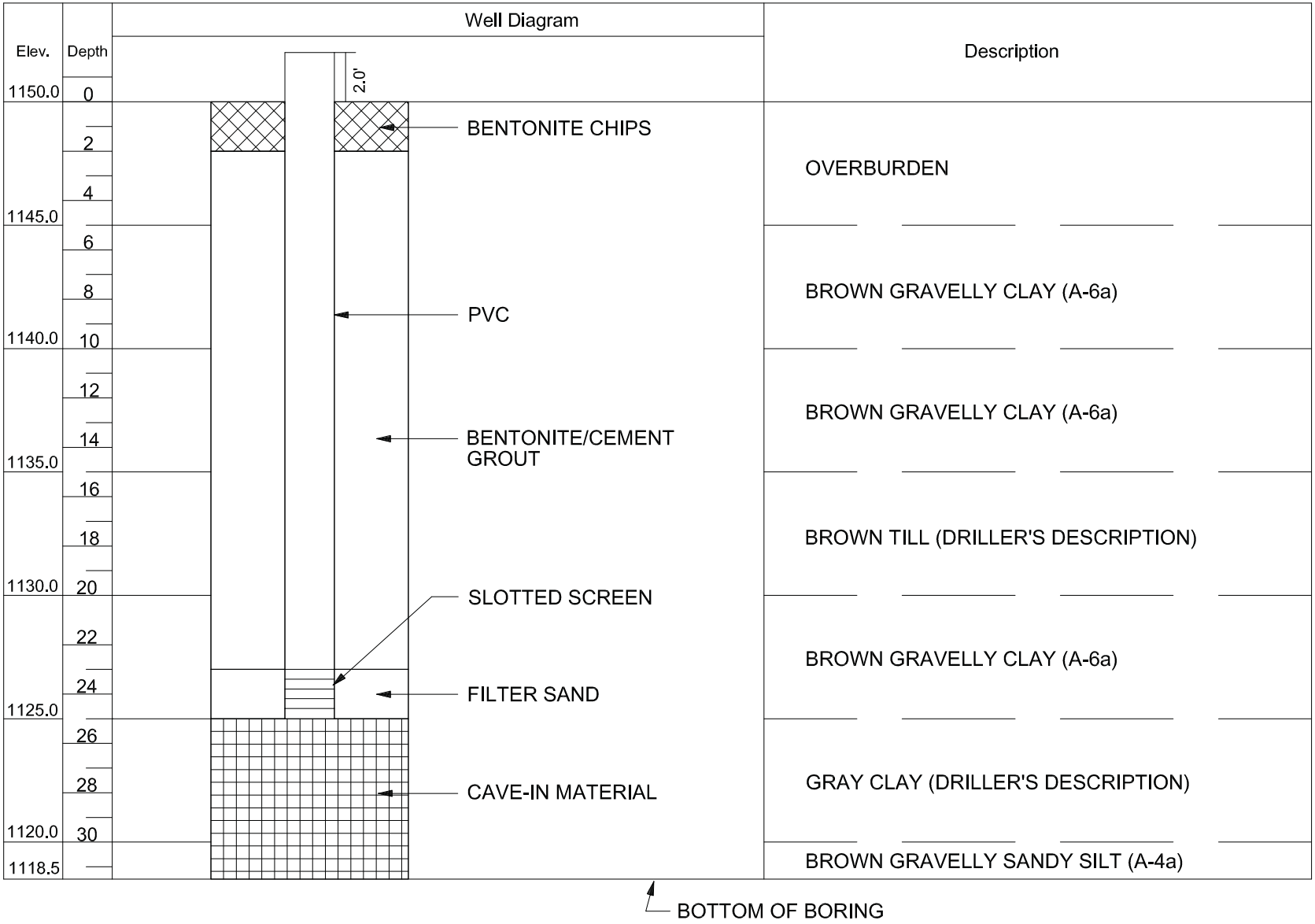
Form TE-151 Revised 9/95

State of Ohio
Department of Transportation
Office of Geotechnical Engineering

LOG OF BORING/WELL CONSTRUCTION

Date Started	10/26/04	Sampler: Type	SS	Dia.		Water Elev.	1123.0'
Date completed	10/26/04					APPROX. Surface Elev.	1150.0'
Boring No.	B-2	Station & Offset	NORTHEAST LOCATION				
Drilling Method	HOLLOW STEM AUGER DRILLING					Rock Coring Method	
Crew Chief	LEWIS	Drilling Party	WILLIS, VALINE				

Project Identification: LOGAN
LOG-347- 0.00
LANDSLIDE INVESTIGATION

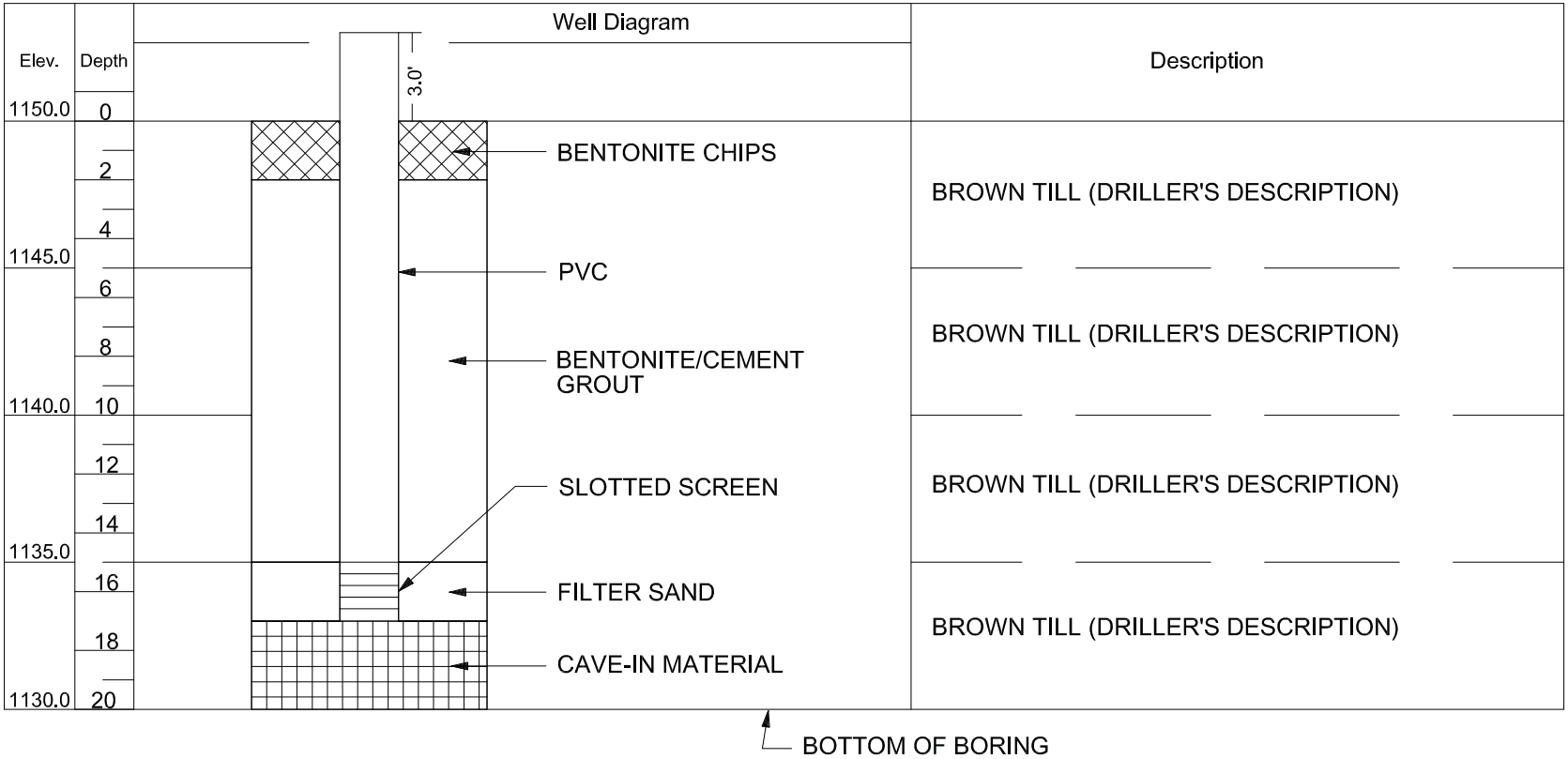


State of Ohio
Department of Transportation
Office of Geotechnical Engineering

LOG OF BORING/WELL CONSTRUCTION

Date Started	10/26/04	Sampler: Type	-	Dia.	-	Water Elev.	DRY
Date completed	10/26/04					APPROX.	
Boring No.	B-3	Station & Offset	SOUTHEAST LOCATION			Surface Elev.	1150.0'
Drilling Method	HOLLOW STEM AUGER DRILLING					Rock Coring Method	
Crew Chief	LEWIS	Drilling Party	WILLIS, VALINE				

Project Identification: LOGAN
LOG-347- 0.00
LANDSLIDE INVESTIGATION



State of Ohio
Department of Transportation
Office of Geotechnical Engineering

LOG OF BORING

Date Started 10/26/04 Sampler: Type SS Dia. _____ Water Elev. 1124.0' Project Identification: LOGAN
Date completed 10/26/04 Approx. LOG-347- 0.00
Boring No. B-4 Station & Offset 4+00, CL Surface Elev. 1150.0' LANDSLIDE & MONITORING WELL INSTALL.

Elev.	Depth	Std. Pen./ R.Q.D.	Rec. ft	Loss ft	Description	Sample No.	Physical Characteristics % Agg	% C.S.	% F.S.	% Silt	% Clay	L.L.	P.I.	W.C.	ODOT Class
1150.0	0														
	2														
	4														
1145.0	6	12/16/21			BROWN GRAVELLY CLAY	10	12	4	7	30	47	32	12	14	A-6a
	8														
1140.0	10														
	12	9/15/17			BROWN GRAVELLY CLAY	11	19	3	6	28	44	35	15	18	A-6a
	14														
1135.0	16	10/12/13			BROWN GRAVELLY CLAY	12	15	6	8	29	42	33	13	18	A-6a
	18														
1130.0	20														
	22	7/12/14			BROWN AND GRAY GRAVELLY CLAY	13	15	6	8	29	42	30	11	16	A-6a
	24														
1125.0	26	3/3/3			GRAY GRAVELLY SANDY SILT	14	26	11	16	29	18	21	5	13	A-4a
	28														
1120.0	30														
1118.5		4/8/9			GRAY SANDY GRAVELLY SILT	15	29	14	12	28	17	20	4	10	A-4a

BOTTOM OF BORING

Particle Sizes: Agg= >2.00mm, Coarse Sand= 2.00-0.42mm, Fine Sand= 0.42-0.074mm, Silt= 0.074-0.005mm, Clay= <0.005mm

Form TE-151 Revised 9/95

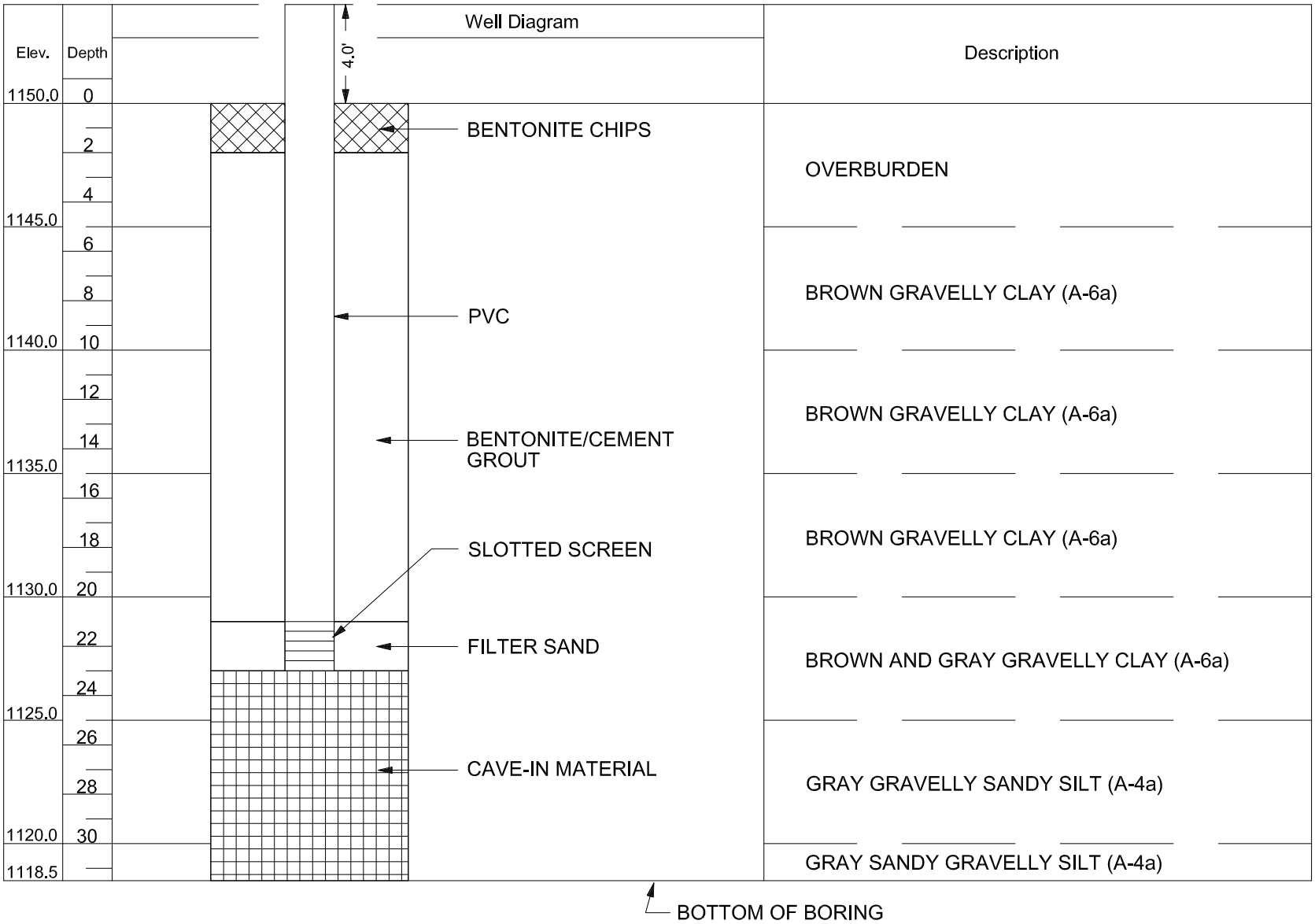
State of Ohio
Department of Transportation
Office of Geotechnical Engineering

LOG OF BORING/WELL CONSTRUCTION

6/12

Date Started	10/26/04	Sampler: Type	SS	Dia.		Water Elev.	1124.0'
Date completed	10/26/04					APPROX.	
Boring No.	B-4	Station & Offset	SOUTHEAST LOCATION			Surface Elev.	1150.0'
Drilling Method	HOLLOW STEM AUGER DRILLING					Rock Coring Method	
Crew Chief	LEWIS	Drilling Party	WILLIS, VALINE				

Project Identification: LOGAN
LOG-347- 0.00
LANDSLIDE INVESTIGATION



State of Ohio
Department of Transportation
Office of Geotechnical Engineering

LOG OF BORING/WELL CONSTRUCTION

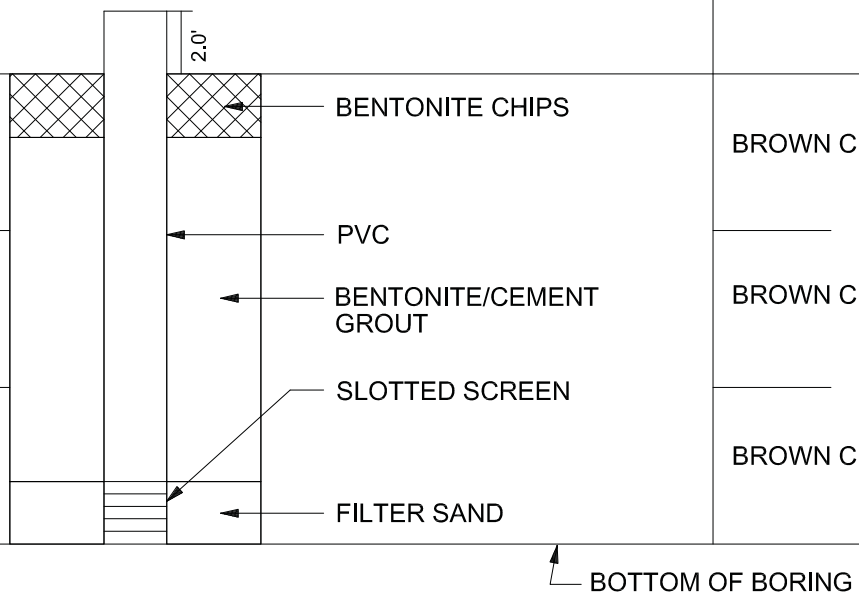
7/12

Date Started	10/25/04	Sampler: Type	-	Dia.	-	Water Elev.	DRY
Date completed	10/25/04					APPROX.	
Boring No.	B-5	Station & Offset	NORTHWEST LOCATION			Surface Elev.	1155.0'
Drilling Method	HOLLOW STEM AUGER DRILLING					Rock Coring Method	
Crew Chief	LEWIS	Drilling Party	WILLIS, VALINE				

Project Identification: LOGAN
LOG-347- 0.00
LANDSLIDE INVESTIGATION

Elev.	Depth	Description
1155.0	0	
	2	BROWN CLAY (DRILLER'S DESCRIPTION)
	4	
1150.0		
	6	BROWN CLAY (DRILLER'S DESCRIPTION)
	8	
1145.0	10	
	12	BROWN CLAY (DRILLER'S DESCRIPTION)
	14	
1140.0		

Well Diagram



State of Ohio
Department of Transportation
Office of Geotechnical Engineering

LOG OF BORING

Date Started 10/25/04 Sampler: Type SS Dia. _____ Water Elev. 1129.5' Project Identification: LOGAN
Date completed 10/25/04 Approx. LOG-347- 0.00
Boring No. B-6 Station & Offset 6+00,CL Surface Elev. 1155.0' LANDSLIDE & MONITORING WELL INSTALL.

Elev.	Depth	Std. Pen./ R.Q.D.	Rec. ft	Loss ft	Description	Sample No.	Physical Characteristics % Agg	% C.S.	% F.S.	% Silt	% Clay	L.L.	P.I.	W.C.	ODOT Class
1155.0	0														
	2														
	4														
1150.0	6	11/14/16			BROWN SILT AND CLAY	1	8	4	7	30	51	34	14	18	A-6a
	8														
1145.0	10														
	12	7/12/13			BROWN SANDY CLAY	2	11	5	7	31	46	31	12	17	A-6b
	14														
1140.0	16	5/7/11			BROWN AND GRAY SANDY CLAY	3	13	5	8	30	44	30	12	16	A-6a
	18														
1135.0	20														
	22	10/8/8			BROWN AND GRAY GRAVELLY CLAY W/BOULDERS	4	39	4	6	21	30	30	12	17	A-6a
	24														
1130.0	26	9/6/4			BROWN AND GRAY GRAVELLY SANDY SILT	5	16	4	13	41	26	20	4	24	A-4a
	28				SAND (DRILLER'S DESCRIPTION)	-	-	-	-	-	-	-	-	-	VISUAL
1125.0	30														

BOTTOM OF BORING

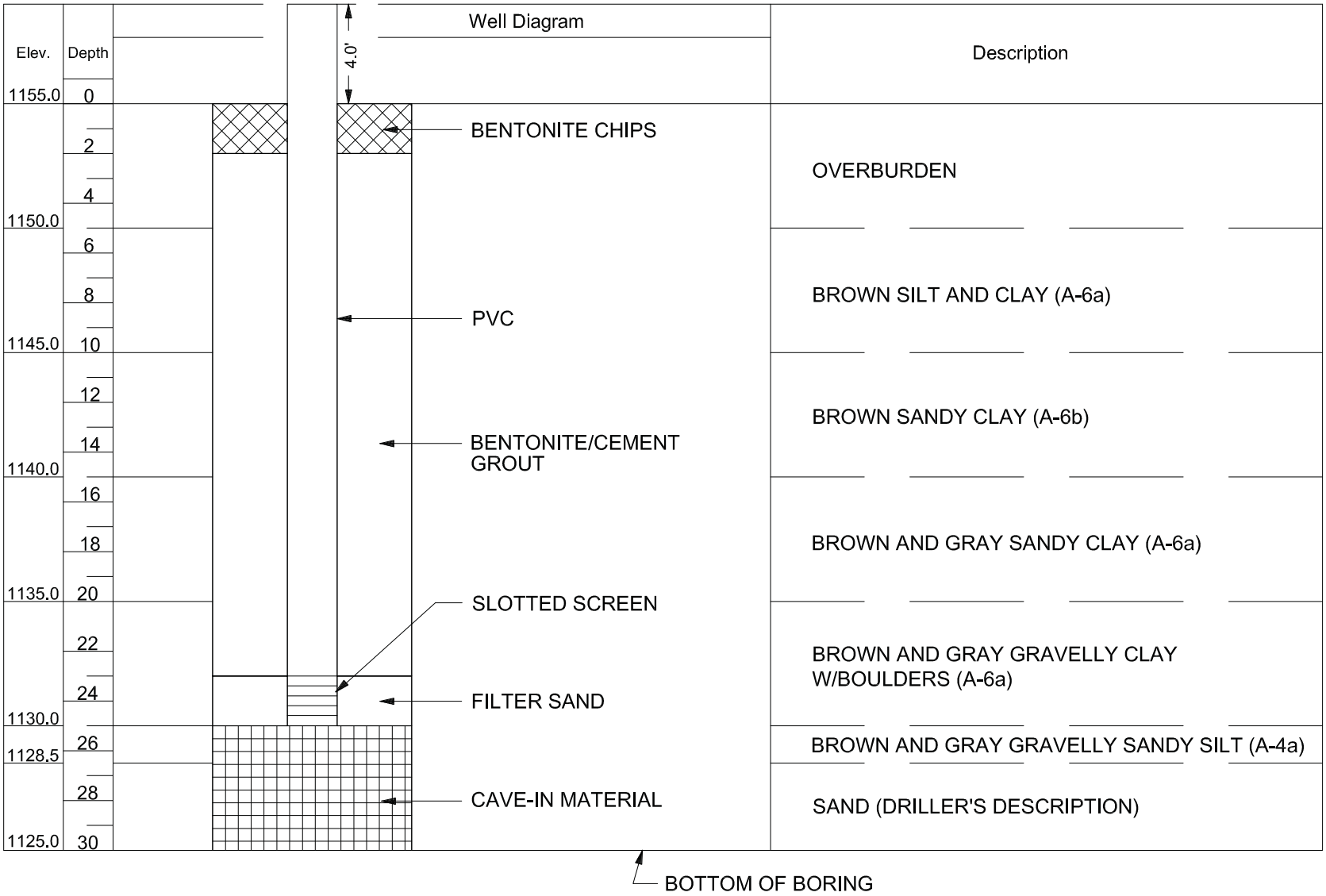
Particle Sizes: Agg= >2.00mm, Coarse Sand= 2.00-0.42mm, Fine Sand= 0.42-0.074mm, Silt= 0.074-0.005mm, Clay= <0.005mm

Form TE-151 Revised 9/95

State of Ohio
Department of Transportation
Office of Geotechnical Engineering

LOG OF BORING/WELL CONSTRUCTION

Date Started 10/25/04 Sampler: Type SS Dia. Water Elev. 1129.5' Project Identification: LOGAN
Date completed 10/25/04 APPROX. LOG-347- 0.00
Boring No. B-6 Station & Offset NORTHWEST LOCATION Surface Elev. 1155.0' LANDSLIDE INVESTIGATION
Drilling Method HOLLOW STEM AUGER DRILLING Rock Coring Method
Crew Chief LEWIS Drilling Party WILLIS, VALINE



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Department of Transportation
Office of Geotechnical Engineering

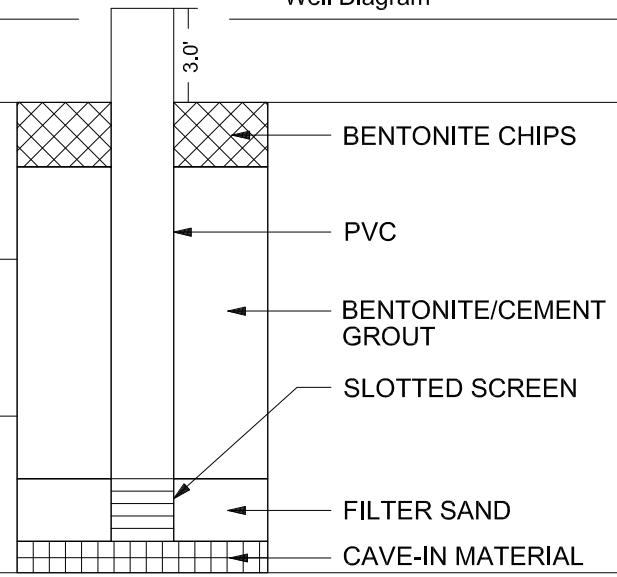
LOG OF BORING/WELL CONSTRUCTION

10/12

Date Started 10/25/04 Sampler: Type - Dia. - Water Elev. DRY Project Identification: LOGAN
Date completed 10/25/04 APPROX. LOG-347- 0.00
Boring No. B-7 Station & Offset SOUTHWEST LOCATION Surface Elev. 1155.0' LANDSLIDE INVESTIGATION
Drilling Method HOLLOW STEM AUGER DRILLING Rock Coring Method
Crew Chief LEWIS Drilling Party WILLIS, VALINE

Elev.	Depth	Description
1155.0	0	
	2	BROWN TILL (DRILLER'S DESCRIPTION)
	4	
1150.0		
	6	BROWN TILL (DRILLER'S DESCRIPTION)
	8	
1145.0	10	
	12	GRAY CLAY (DRILLER'S DESCRIPTION)
	14	
1140.0		

Well Diagram



BOTTOM OF BORING

State of Ohio
Department of Transportation
Office of Geotechnical Engineering

11/12

LOG OF BORING

Date Started 10/25/04 Sampler: Type SS Dia. _____ Water Elev. 1135.0' Project Identification: LOGAN
Date completed 10/25/04 Approx. LOG-347- 0.00
Boring No. B-8 Station & Offset 8+00, CL Surface Elev. 1155.0' LANDSLIDE & MONITORING WELL INSTALL.

Elev.	Depth	Std. Pen./ R.Q.D.	Rec. ft	Loss ft	Description	Sample No.	Physical Characteristics % Agg	% C.S.	% F.S.	% Silt	% Clay	L.L.	P.I.	W.C.	ODOT Class
1155.0	0														
	2														
	4														
1150.0	6	P.S.			BROWN CLAY (DRILLER'S DESCRIPTION) NOTE: SAMPLE TESTED BY OSU	6-P	-	-	-	-	-	-	-	-	VISUAL
	8														
1145.0	10														
	12	7/10/13			GRAY GRAVELLY CLAY	7	14	5	7	30	44	31	14	17	A-6a
	14														
1140.0	16														
	18	7/8/10			GRAY GRAVELLY CLAY	8	14	5	7	33	41	30	12	16	A-6a
	20														
1135.0	22	P.S.			BROWN CLAY (DRILLER'S DESCRIPTION) NOTE: SAMPLE TESTED BY OSU	9-P	-	-	-	-	-	-	-	-	VISUAL
	24														
1130.0															

BOTTOM OF BORING

Particle Sizes: Agg= >2.00mm, Coarse Sand= 2.00-0.42mm, Fine Sand= 0.42-0.074mm, Silt= 0.074-0.005mm, Clay= <0.005mm

Form TE-151 Revised 9/95

State of Ohio
Department of Transportation
Office of Geotechnical Engineering

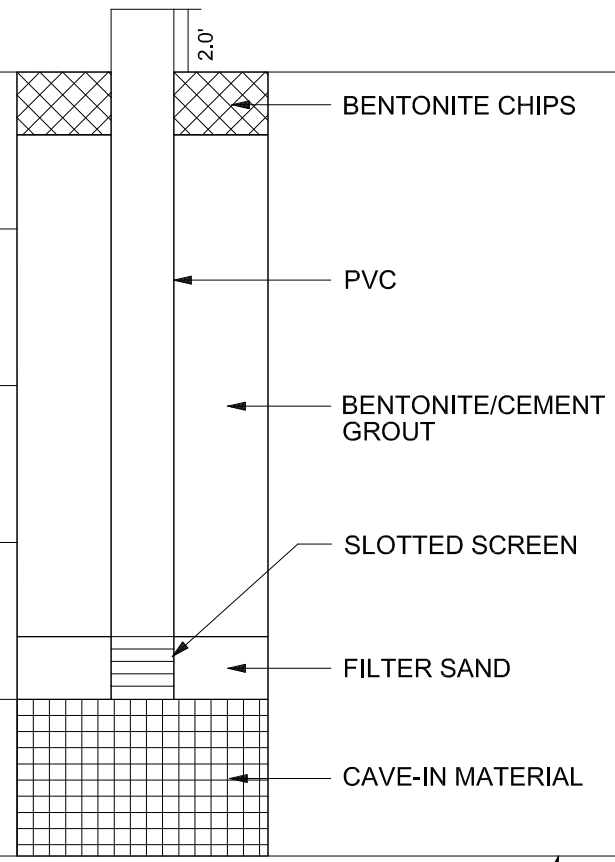
LOG OF BORING/WELL CONSTRUCTION

12/12

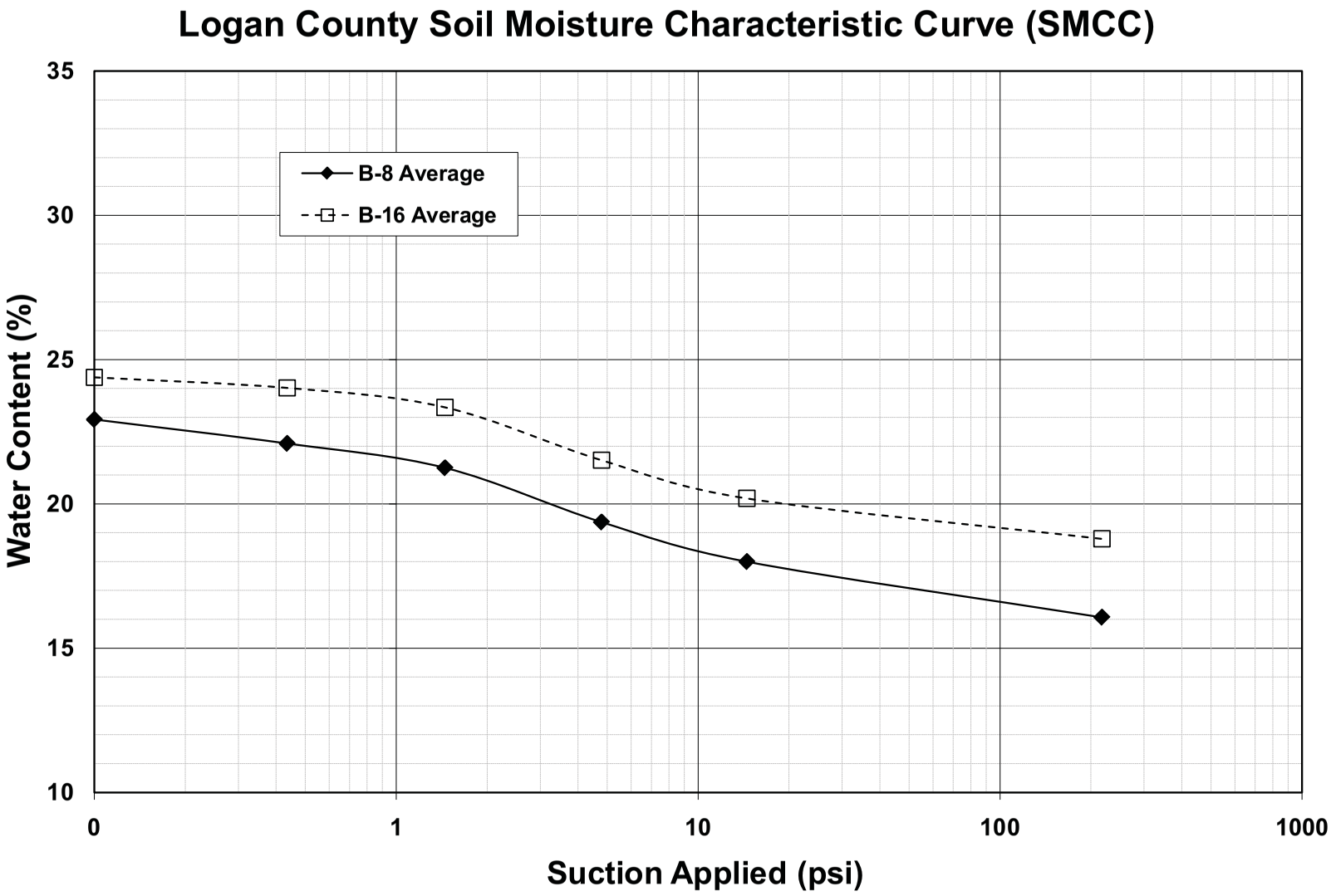
Date Started 10/25/04 Sampler: Type SS Dia. _____ Water Elev. 1135.0' Project Identification: LOGAN
Date completed 10/25/04 APPROX. LOG-347- 0.00
Boring No. B-8 Station & Offset SOUTHWEST LOCATION Surface Elev. 1155.0' LANDSLIDE INVESTIGATION
Drilling Method HOLLOW STEM AUGER DRILLING Rock Coring Method _____
Crew Chief LEWIS Drilling Party WILLIS, VALINE

Elev.	Depth	Description
1155.0	0	
	2	OVERBURDEN
	4	
1150.0		
	6	BROWN CLAY (DRILLER'S DESCRIPTION)
	8	
1145.0	10	
	12	GRAY GRAVELLY CLAY (A-6a)
	14	
1140.0		
	16	GRAY GRAVELLY CLAY (A-6a)
	18	
1135.0	20	
	22	BROWN CLAY (DRILLER'S DESCRIPTION)
	24	
1130.0		

Well Diagram

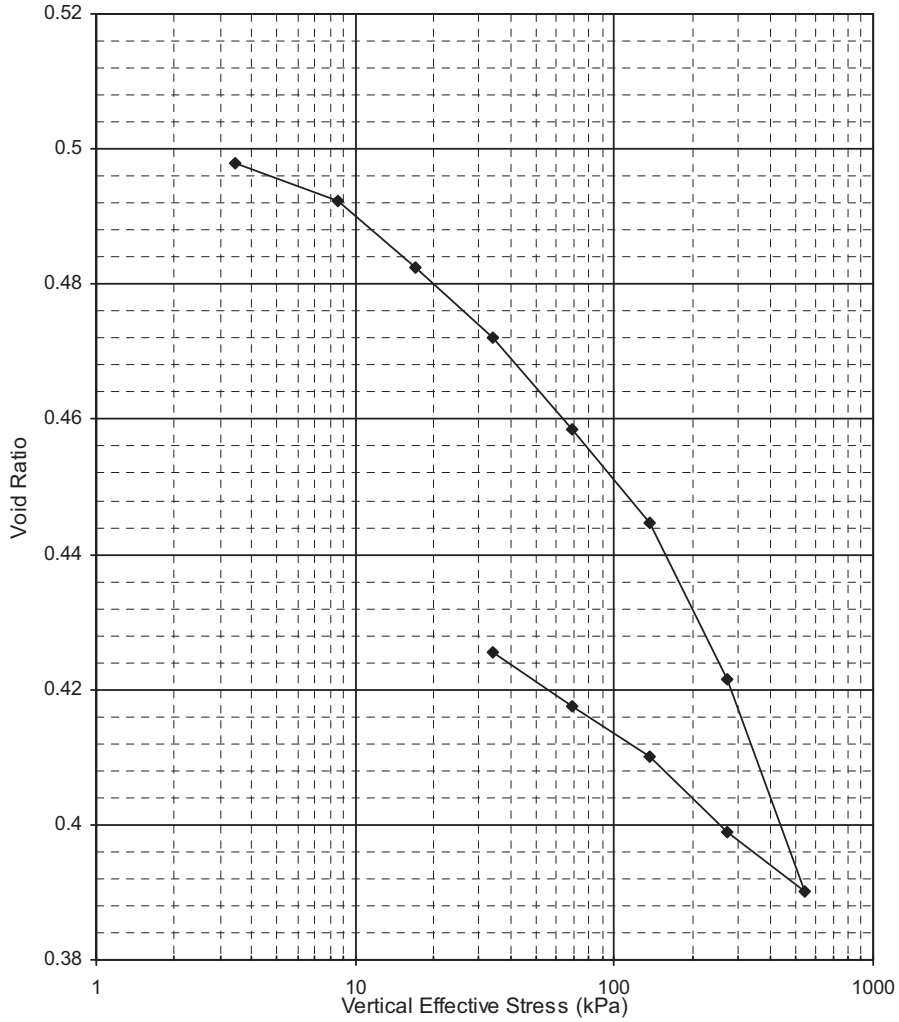


BOTTOM OF BORING


Logan County Soil Moisture Characteristic Curve (SMCC)
B-8 Average
B-16 Average
Water Content (%)
35
30
25
20
15
10
0
1
10
100
1000
Suction Applied (psi)

Determination of Soil Water Retention Characteristics							
Protocol: Each core was partitioned in three slices for the determination of soil water retention at six different potentials. Each slice was used as a replication.							
Soil Sample	**REPLICATE (slice)**	**Gravimetric Water Content (%)**					
		0 bar	**0.03 bar**	**0.10 bar**	**0.33 bar**	**1 bar**	**15 bar**
BH-8	1	22.18	21.98	21.40	19.70	18.31	16.07
BH-8	2	22.83	22.29	21.20	19.31	17.99	16.16
BH-8	3	23.76	22.00	21.14	19.10	17.69	15.97
	Average	22.92	22.09	21.25	19.37	18.00	16.07
BH-16	1	24.83	24.71	23.87	21.86	20.38	18.71
BH-16	2	24.55	24.33	23.69	21.78	20.46	19.35
BH-16	3	23.77	23.01	22.48	20.90	19.73	18.31
	Average	24.38	24.02	23.35	21.51	20.19	18.79

THE OHIO STATE UNIVERSITY SOIL MECHANICS LABORATORY

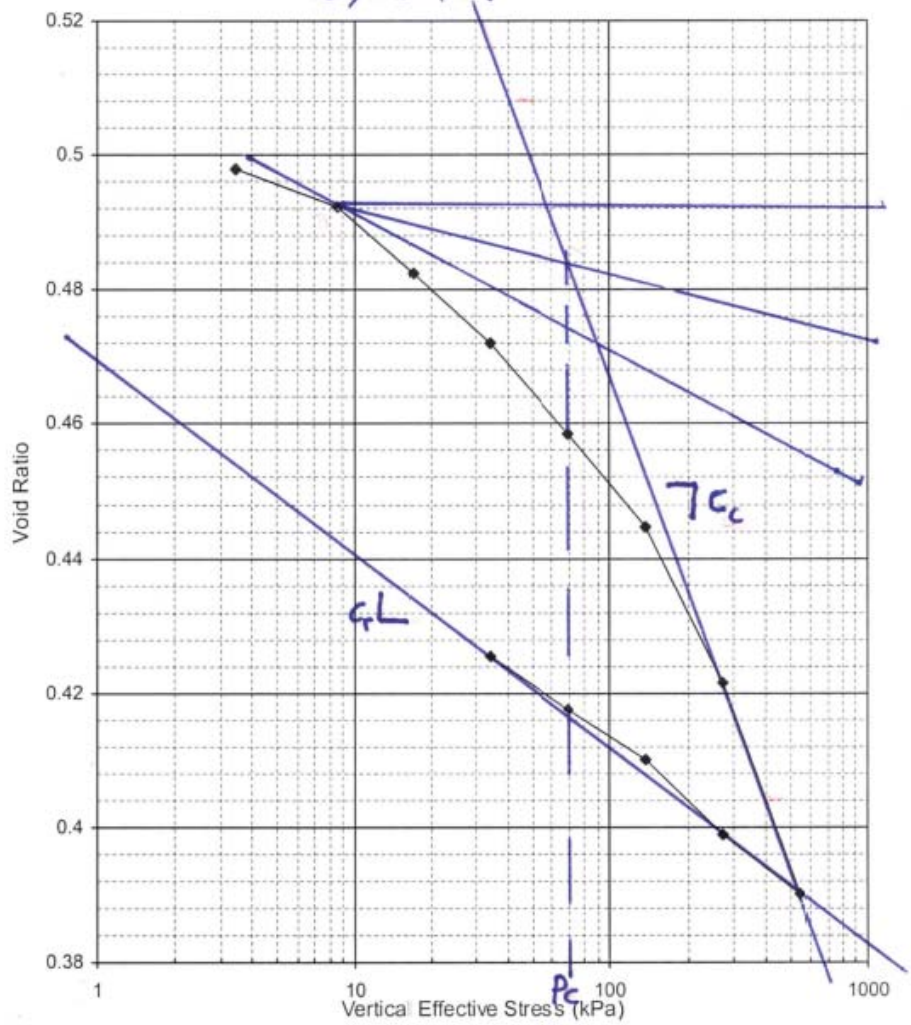


DESCRIPTION	Brown/gray clay w/ trace sand (visual)				
CLASSIFICATION	-			TYPE OF SPECIMEN	undisturbed
LL -	PL -	PI -	w [%] 18	CONSOLIDOMETER	

REMARKS	PROJECT	Bio-Engineering for Land Stabilization	
	AREA	Logan County—SR33/SR347	
	BORING ID	BH 16	SAMPLE NO. 3-top
	DEPTH/ELEV.	(6.0-8.0) ft	DATE February 24, 2005
	TECH	CMK, CHB, TM	CHECKED
1 of 1	**CONSOLIDATION TEST REPORT**		

THE OHIO STATE UNIVERSITY SOIL MECHANICS LABORATORY

Determination of P_c, C_c & C_r



DESCRIPTION	Brown/gray clay w/ trace sand (visual)				
CLASSIFICATION	-			TYPE OF SPECIMEN	undisturbed
LL -	PL -	PI -	w [%] 18	CONSOLIDOMETER	

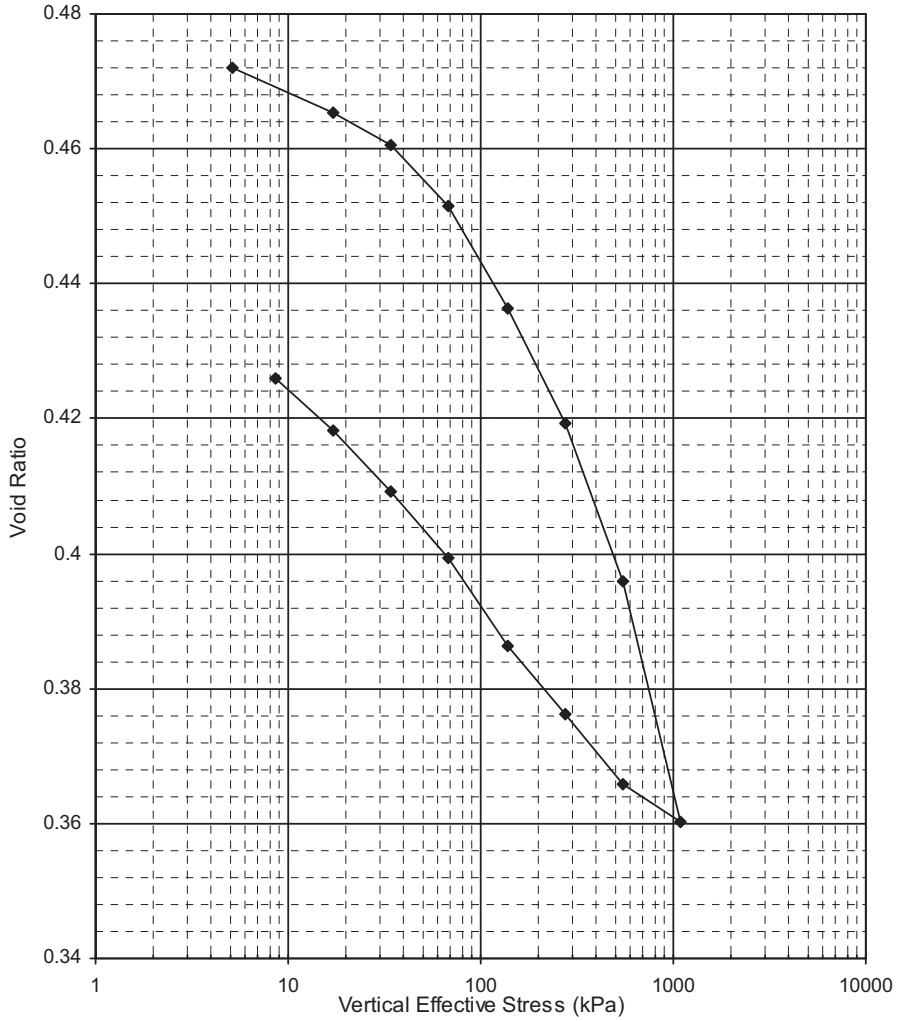
REMARKS	PROJECT	Bio-Engineering for Land Stabilization	
P_c = 70 kPa	AREA	Logan County—SR33/SR347	
C_c = 0.104	BORING ID	BH 16	SAMPLE NO. 3-top
C_r = 0.028	DEPTH/ELEV.	(6.0-8.0) ft	DATE February 24, 2005
	TECH	CMK, CHB, TM	CHECKED
1 of 1	**CONSOLIDATION TEST REPORT**		

Determination of OCR from Consolidation Test Results

Sample B-16 (6 ft.)

P_c = 1462.0 psf
γ_d = 111.0 pcf
S = 100%
H = 6 ft
H_w = 3 to 7 ft (piezo readings at P-15 range from -1 to 3 ft. bgs)
w = 18.0%
$\gamma = \gamma_d (1+w)$ = 111.0 pcf ·1.18 = 131.0 pcf
$\sigma_v = H \cdot \gamma$ = 6 ft · 131.0 pcf = 786.0 psf
$u = H_w \cdot \gamma_w$ = 3 ft · 62.4 pcf = 187.2 psf
= 7 ft · 62.4 pcf = 436.8 psf
$\sigma'_v = \sigma_v - u$ = 786.0 psf – 187.2 psf = 598.8 psf
= 786.0 psf – 436.8 psf = 349.2 psf
$OCR = P_c/\sigma'_v$ = 1462.0 psf/598.8 psf = 2.4
= 1462.0 psf/349.2 psf = 4.2

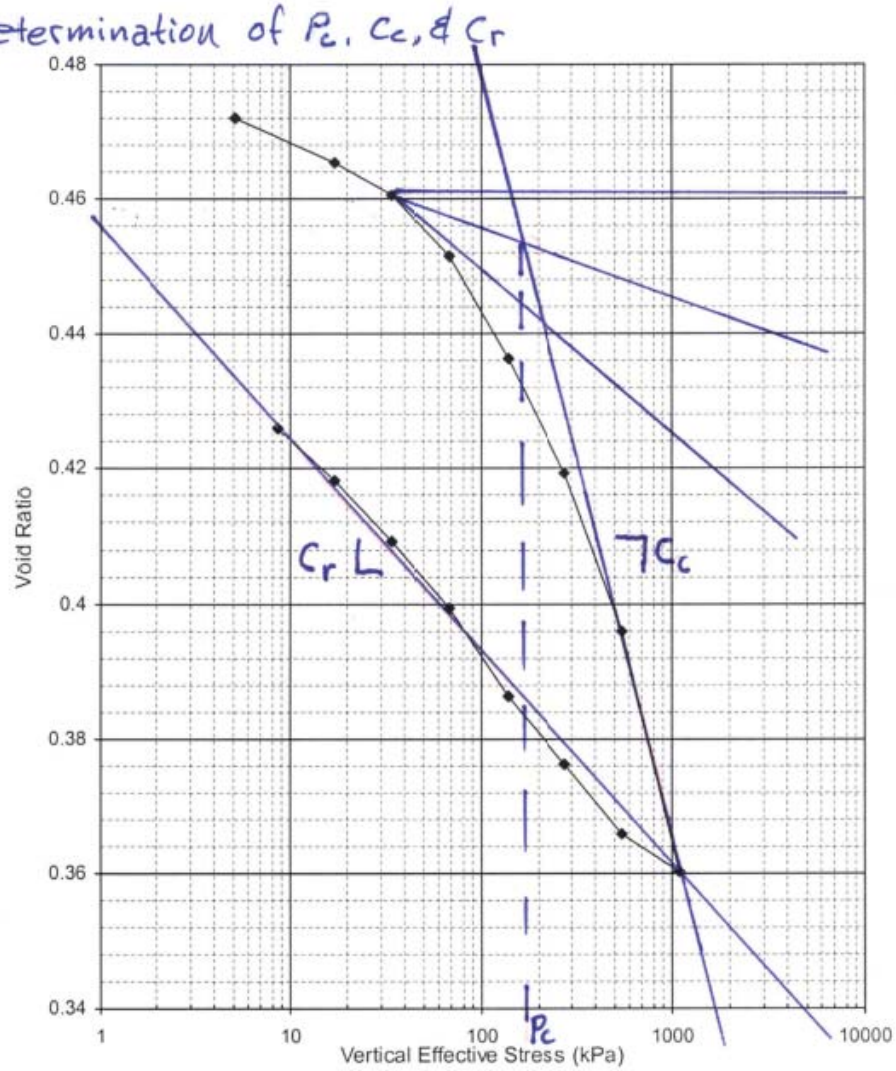
THE OHIO STATE UNIVERSITY SOIL MECHANICS LABORATORY



DESCRIPTION	Brown/gray clay (visual)				
CLASSIFICATION	-			TYPE OF SPECIMEN	undisturbed
LL -	PL -	PI -	w [%] 20	CONSOLIDOMETER	13

REMARKS	PROJECT	Bio-Engineering for Land Stabilization	
	AREA	Logan County—SR33/SR347	
	BORING ID	BH 10	SAMPLE NO. 1-bottom
	DEPTH/ELEV.	(4.0-6.0) ft	DATE June 24, 2005
	TECH	CMK, CHB	CHECKED
1 of 1	**CONSOLIDATION TEST REPORT**		

THE OHIO STATE UNIVERSITY SOIL MECHANICS LABORATORY



DESCRIPTION	Brown/gray clay (visual)				
CLASSIFICATION	-			TYPE OF SPECIMEN	undisturbed
LL -	PL -	PI -	w [%] 20	CONSOLIDOMETER	13

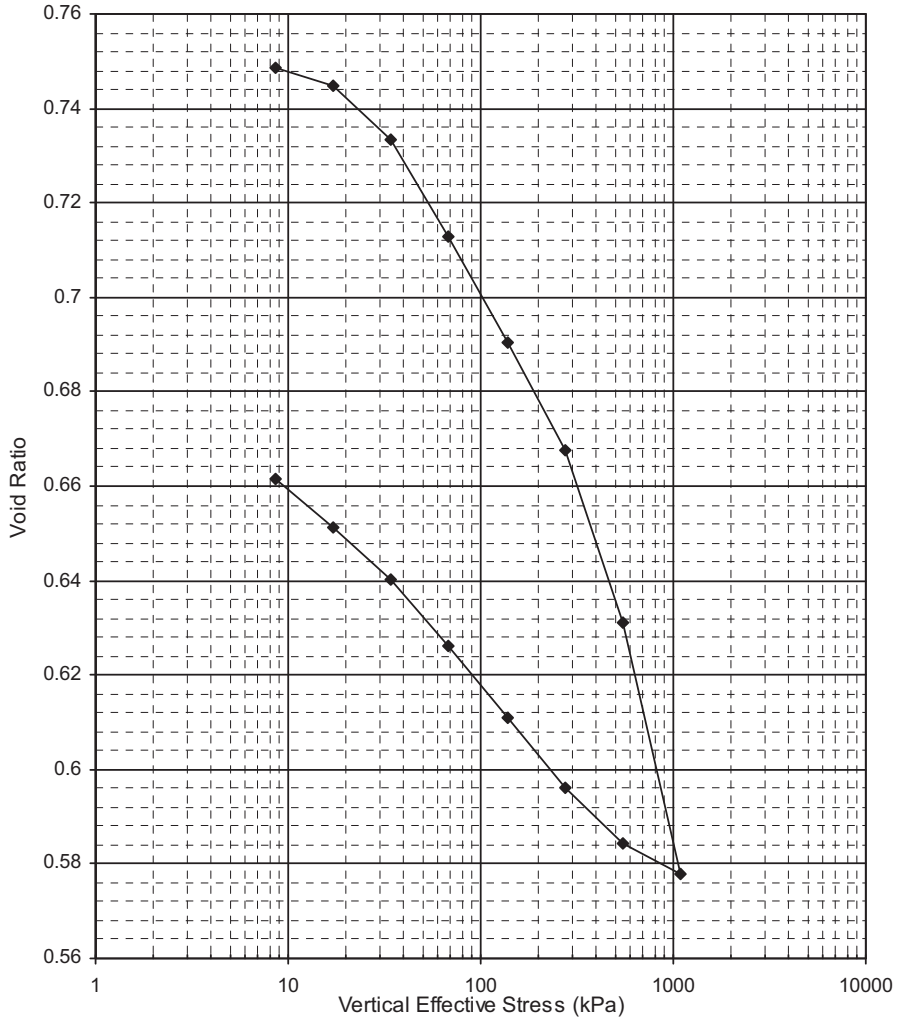
REMARKS	PROJECT	Bio-Engineering for Land Stabilization	
P_c = 168 kPa	AREA	Logan County—SR33/SR347	
C_c = 0.114	BORING ID	BH 10	SAMPLE NO. 1-bottom
C_r = 0.032	DEPTH/ELEV.	(4.0-6.0) ft	DATE June 24, 2005
	TECH	CMK, CHB	CHECKED
1 of 1	**CONSOLIDATION TEST REPORT**		

Determination of OCR from Consolidation Test Results

Sample B-10 (6 ft.) – consolidometer 13

P_c = 3508.8 psf
γ_d = 105.0 pcf
S = 100%
H = 6 ft
H_w = 0.5 to 6 ft (piezo readings at P-9 range from 0 to 5.5 ft. bgs)
w = 20.0%
$\gamma = \gamma_d (1+w)$ = 105.0 pcf ·1.20 = 126.0 pcf
$\sigma_v = H \cdot \gamma$ = 6 ft · 126.0 pcf = 756.0 psf
$u = H_w \cdot \gamma_w$ = 0.5 ft · 62.4 pcf = 31.2 psf
= 6 ft · 62.4 pcf = 374.4 psf
$\sigma'_v = \sigma_v - u$ = 756.0 psf – 31.2 psf = 724.8 psf
= 756.0 psf – 374.4 psf = 381.6 psf
OCR = P_c/σ'_v = 3508.8 psf/724.8 psf = 4.8
= 3508.8 psf/381.6 psf = 9.2

THE OHIO STATE UNIVERSITY SOIL MECHANICS LABORATORY

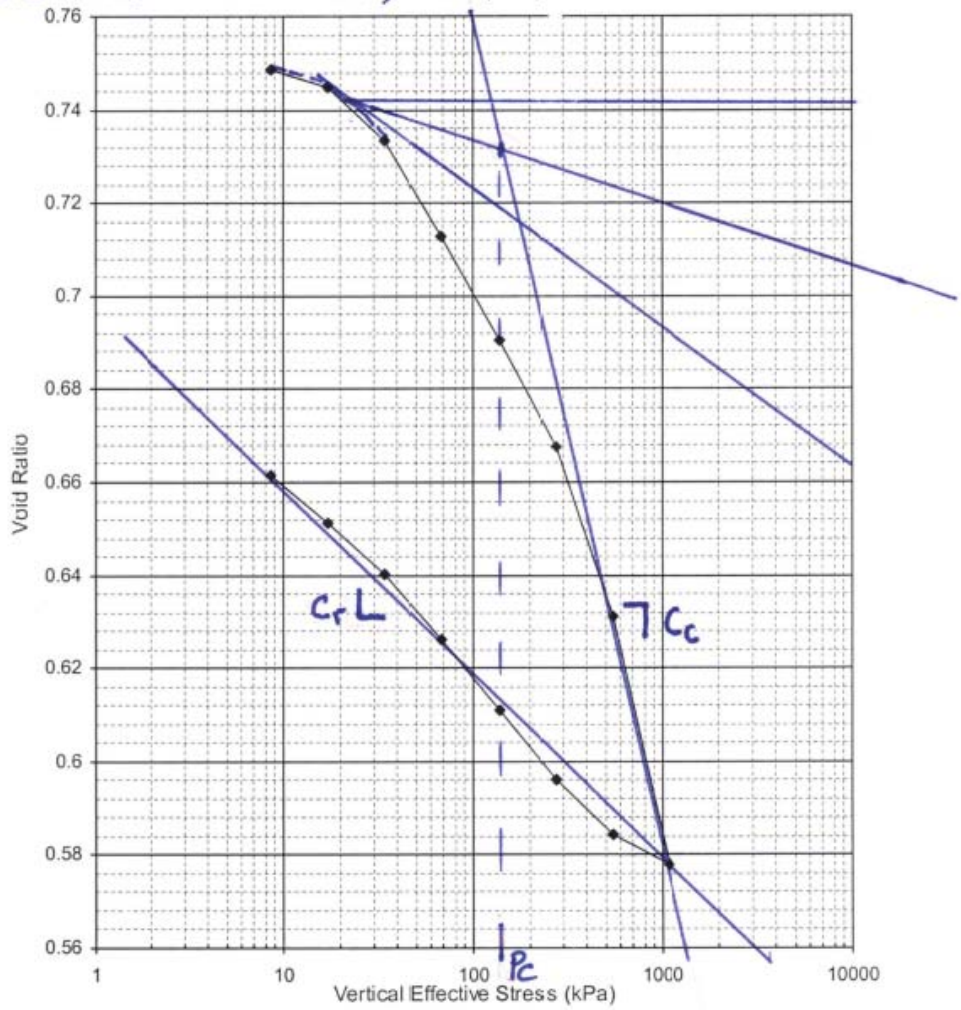


DESCRIPTION	Brown/gray clay (visual)				
CLASSIFICATION	-			TYPE OF SPECIMEN	undisturbed
LL -	PL -	PI -	w [%] 17	CONSOLIDOMETER	21

REMARKS	PROJECT	Bio-Engineering for Land Stabilization	
	AREA	Logan County—SR33/SR347	
	BORING ID	BH 10	SAMPLE NO. 1-bottom
	DEPTH/ELEV.	(4.0-6.0) ft	DATE June 24, 2005
	TECH	CMK, CHB	CHECKED
1 of 1	**CONSOLIDATION TEST REPORT**		

THE OHIO STATE UNIVERSITY SOIL MECHANICS LABORATORY

Determination of P_c, C_c & C_r



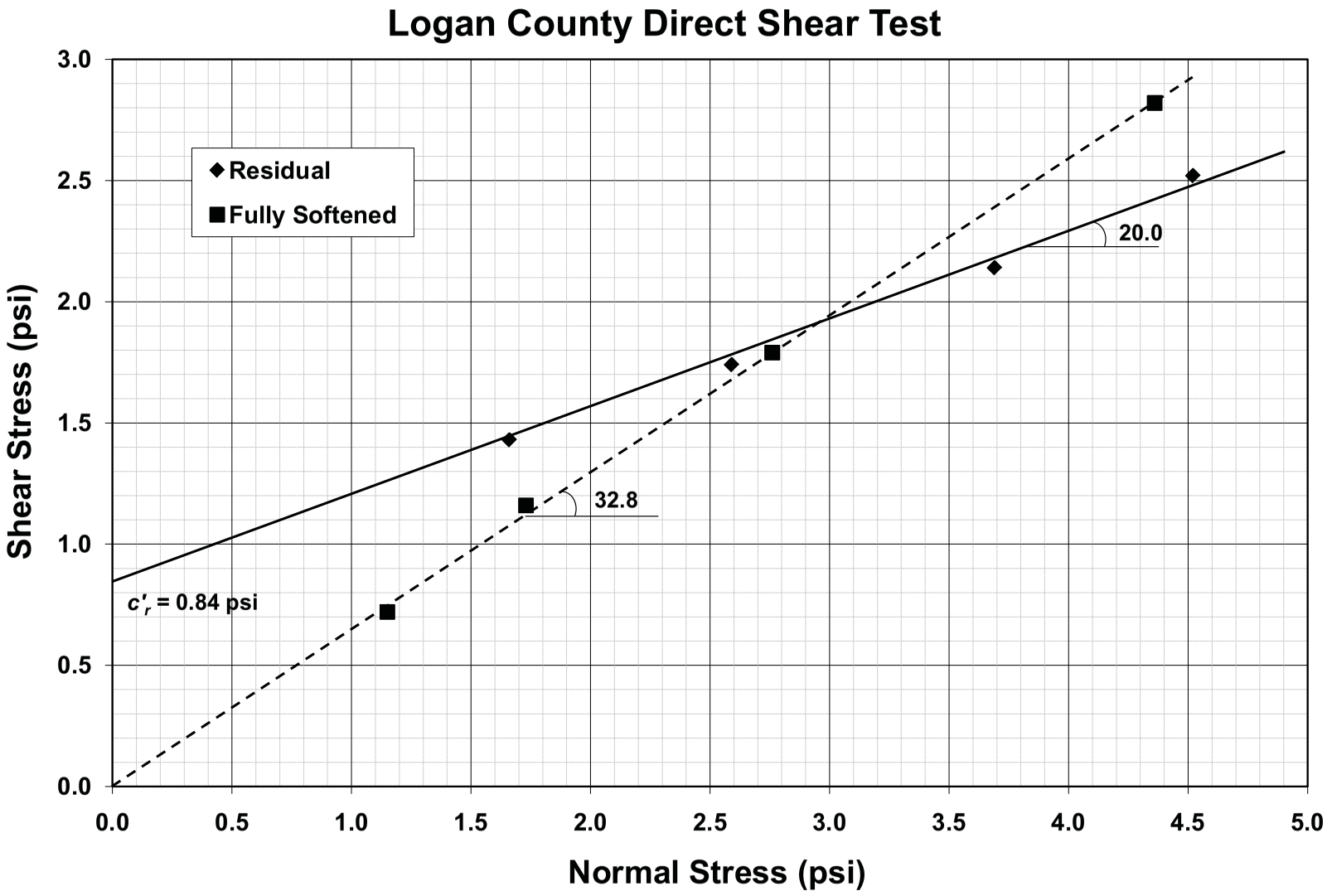
DESCRIPTION	Brown/gray clay (visual)				
CLASSIFICATION	-			TYPE OF SPECIMEN	undisturbed
LL -	PL -	PI -	w [%] 17	CONSOLIDOMETER	21

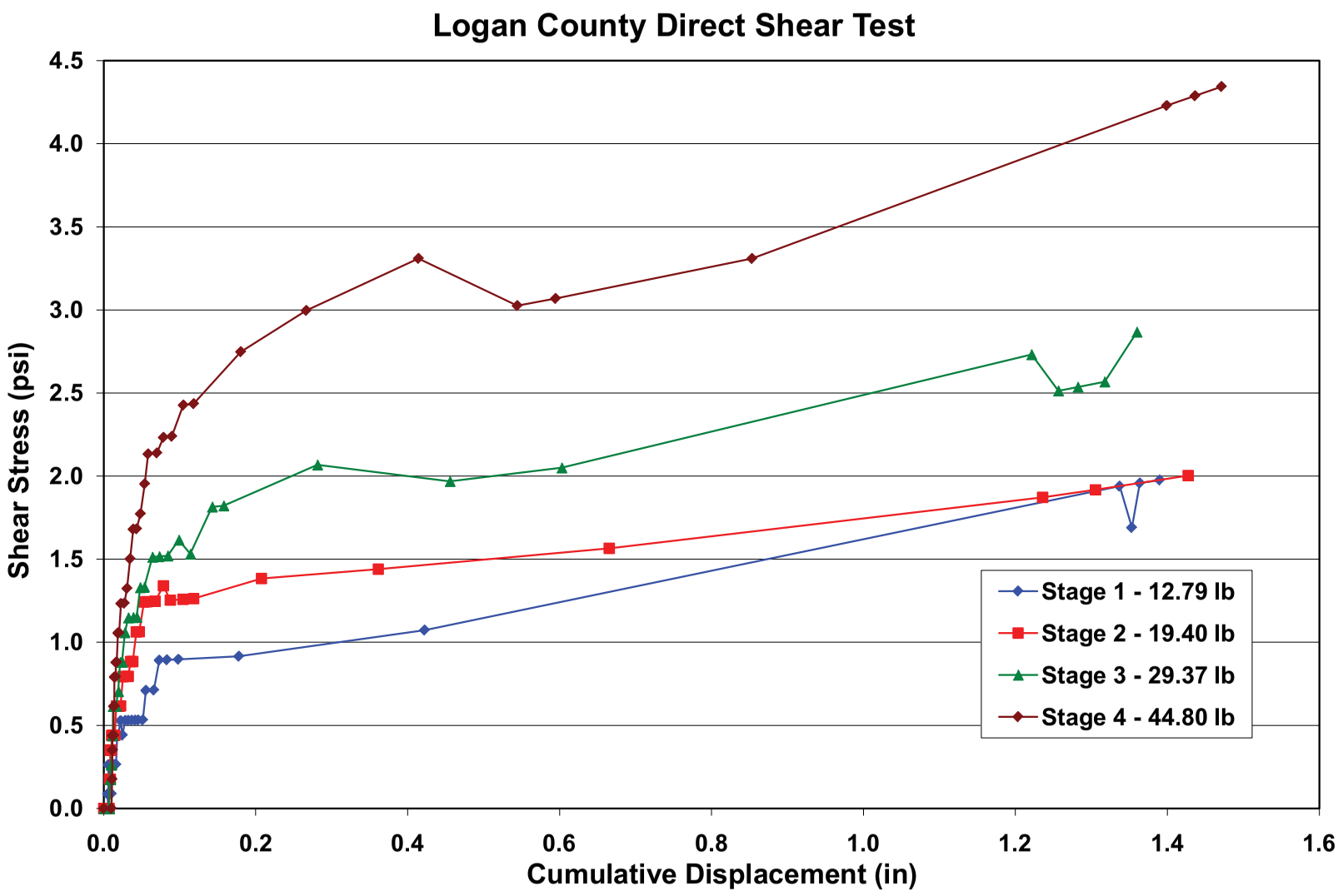
REMARKS	PROJECT	Bio-Engineering for Land Stabilization	
P_c = 145 kPa	AREA	Logan County—SR33/SR347	
C_c = 0.176	BORING ID	BH 10	SAMPLE NO. 1-bottom
C_r = 0.042	DEPTH/ELEV.	(4.0-6.0) ft	DATE June 24, 2005
	TECH	CMK, CHB	CHECKED
1 of 1	CONSOLIDATION TEST REPORT		

Determination of OCR from Consolidation Test Results

Sample B-10 (6 ft.) – consolidometer 21

P_c = 3028.4 psf
γ_d = 105.0 pcf
S = 100%
H = 6 ft
H_w = 0.5 to 6 ft (piezo readings at P-9 range from 0 to 5.5 ft. bgs)
w = 17%
$\gamma = \gamma_d (1+w)$ = 113.0 pcf ·1.17 = 132.2 pcf
$\sigma_v = H \cdot \gamma$ = 6 ft · 132.1 pcf = 792.6 psf
$u = H_w \cdot \gamma_w$ = 0.5 ft · 62.4 pcf = 31.2 psf
= 6 ft · 62.4 pcf = 374.4 psf
$\sigma'_v = \sigma_v - u$ = 792.6 psf – 31.2 psf = 761.4 psf
= 792.3 psf – 374.4 psf = 418.2 psf
OCR = P_c/σ'_v = 3028.4 psf/761.4 psf = 4.0
= 3028.4 psf/418.2 psf = 7.2


Logan County Direct Shear Test
Residual
Fully Softened
20.0
32.8
c'_r = 0.84 psi
Shear Stress (psi)
Normal Stress (psi)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0


Logan County Direct Shear Test
Shear Stress (psi)
Cumulative Displacement (in)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Stage 1 - 12.79 lb
Stage 2 - 19.40 lb
Stage 3 - 29.37 lb
Stage 4 - 44.80 lb

Logan County - Direct Simple Shear Test - Stage 1

Normal Load:	5.8	kg
	12.79	lb
Friction Force:	2	lb
Initial Area:	11.41	in^2
Initial Length:	4.15	in
Initial Width:	2.75	in

Time	Load (LED)	Displacement Reading (LVDT)	Displacement Reading (in)	Cumulative Displacement (in)	Corrected Area (in^2)	Relative Strain (in/in)	Corrected Shear Load (lb)	Shear Load Applied (lb)	Shear Stress (lb/in^2)	Normal Stress (lb/in^2)	Strain Rate (in/min)	Incremental Strain Rate (in/min)
Initial (zero)	42	76.48	3.8546	0.0000	11.4125	0.00000	42	-	0.00000	1.12042	-	-
Initial (after seating)	44	76.40	3.8506	0.0040	11.4014	0.00097	44	0	0.00000	1.12151	-	-
0.25	44	76.37	3.8490	0.0055	11.3973	0.00134	44	0	0.00000	1.12192	0.02218	-
0.5	45	76.37	3.8490	0.0055	11.3973	0.00134	45	1	0.08774	1.12192	0.01109	0.0000
1	45	76.37	3.8490	0.0055	11.3973	0.00134	45	1	0.08774	1.12192	0.00554	0.0000
1.5	45	76.37	3.8490	0.0055	11.3973	0.00134	45	1	0.08774	1.12192	0.00370	0.0000
2	45	76.36	3.8485	0.0060	11.3959	0.00146	45	1	0.08775	1.12206	0.00302	0.0010
2.5	45	76.36	3.8485	0.0060	11.3959	0.00146	45	1	0.08775	1.12206	0.00242	0.0000
3	47	76.36	3.8485	0.0060	11.3959	0.00146	47	3	0.26325	1.12206	0.00202	0.0000
3.5	45	76.33	3.8470	0.0076	11.3917	0.00182	45	1	0.08778	1.12247	0.00216	0.0030
4	45	76.33	3.8470	0.0076	11.3917	0.00182	45	1	0.08778	1.12247	0.00189	0.0000
4.5	45	76.33	3.8470	0.0076	11.3917	0.00182	45	1	0.08778	1.12247	0.00168	0.0000
5	45	76.31	3.8460	0.0086	11.3889	0.00206	45	1	0.08780	1.12274	0.00171	0.0020
6	47	76.31	3.8460	0.0086	11.3889	0.00206	47	3	0.26341	1.12274	0.00143	0.0000
7	47	76.28	3.8445	0.0101	11.3848	0.00243	47	3	0.26351	1.12315	0.00144	0.0015
8	45	76.28	3.8445	0.0101	11.3848	0.00243	45	1	0.08784	1.12315	0.00126	0.0000
9	47	76.27	3.8440	0.0106	11.3834	0.00255	47	3	0.26354	1.12329	0.00118	0.0005
10	47	76.24	3.8425	0.0121	11.3792	0.00291	47	3	0.26364	1.12370	0.00121	0.0015
12	47	76.21	3.8410	0.0136	11.3751	0.00328	47	3	0.26373	1.12411	0.00113	0.0008
14	47	76.19	3.8400	0.0146	11.3723	0.00352	47	3	0.26380	1.12438	0.00104	0.0005
16	47	76.16	3.8385	0.0161	11.3681	0.00389	47	3	0.26390	1.12479	0.00101	0.0008
18	49	76.13	3.8370	0.0176	11.3640	0.00425	49	5	0.43999	1.12520	0.00098	0.0008
20	49	76.10	3.8354	0.0192	11.3598	0.00461	49	5	0.44015	1.12561	0.00096	0.0008
24	50	76.04	3.8324	0.0222	11.3515	0.00534	50	6	0.52856	1.12644	0.00092	0.0008
28	49	75.99	3.8299	0.0247	11.3446	0.00595	49	5	0.44074	1.12713	0.00088	0.0006
32	50	75.92	3.8264	0.0282	11.3349	0.00680	50	6	0.52934	1.12809	0.00088	0.0009
36	50	75.84	3.8223	0.0323	11.3238	0.00777	50	6	0.52986	1.12920	0.00090	0.0010
40	50	75.75	3.8178	0.0368	11.3113	0.00887	50	6	0.53044	1.13044	0.00092	0.0011
45	50	75.66	3.8133	0.0413	11.2988	0.00996	50	6	0.53103	1.13169	0.00092	0.0009
50	50	75.58	3.8092	0.0454	11.2878	0.01093	50	6	0.53155	1.13280	0.00091	0.0008
55	50	75.46	3.8032	0.0514	11.2711	0.01239	50	6	0.53233	1.13447	0.00093	0.0012
60	52	75.38	3.7992	0.0554	11.2600	0.01336	52	8	0.71048	1.13559	0.00092	0.0008
70	52	75.17	3.7886	0.0660	11.2309	0.01591	52	8	0.71232	1.13853	0.00094	0.0011
80	54	75.03	3.7815	0.0731	11.2115	0.01761	54	10	0.89194	1.14050	0.00091	0.0007
90	54	74.83	3.7714	0.0832	11.1838	0.02004	54	10	0.89415	1.14333	0.00092	0.0010
105	54	74.53	3.7563	0.0983	11.1422	0.02368	54	10	0.89749	1.14760	0.00094	0.0010
185	54	72.95	3.6767	0.1779	10.9232	0.04287	54	10	0.91548	1.17060	0.00096	0.0010
432	55	68.10	3.4322	0.4224	10.2510	0.10177	55	11	1.07306	1.24737	0.00098	0.0010
1357	59	49.95	2.5175	1.3371	7.7354	0.32220	59	15	1.93913	1.65301	0.00099	0.0010
1373	57	49.63	2.5014	1.3532	7.6911	0.32608	57	13	1.69027	1.66255	0.00099	0.0010
1380	59	49.42	2.4908	1.3638	7.6620	0.32863	59	15	1.95772	1.66886	0.00099	0.0015
1410	59	48.90	2.4646	1.3900	7.5899	0.33495	59	15	1.97631	1.68471	0.00099	0.0009

Logan County - Direct Simple Shear Test - Stage 2

Normal Load:	8.8	kg
	19.40	lb
Friction Force:	2	lb

Initial Area:	11.41	in^2
Initial Length:	4.15	in
Initial Width:	2.75	in

Time	Load (LED)	Displacement Reading (LVDT)	Displacement Reading (in)	Cumulative Displacement (in)	Corrected Area (in^2)	Relative Strain (in/in)	Corrected Shear Load (lb)	Shear Load Applied (lb)	Shear Stress (lb/in^2)	Normal Stress (lb/in^2)	Strain Rate (in/min)	Incremental Strain Rate (in/min)
Initial (zero)	40	75.96	3.8284	0.0000	11.4125	0.00000	40	-	0.00000	1.69995	-	-
Initial (after seating)	45	75.82	3.8213	0.0071	11.3931	0.00170	45	0	0.00000	1.70284	-	-
0.166666667	45	75.82	3.8213	0.0071	11.3931	0.00170	45	0	0.00000	1.70284	0.04234	-
0.5	47	75.81	3.8208	0.0076	11.3917	0.00182	47	2	0.17557	1.70305	0.01512	0.0015
1	47	75.81	3.8208	0.0076	11.3917	0.00182	47	2	0.17557	1.70305	0.00756	0.0000
1.5	47	75.79	3.8198	0.0086	11.3889	0.00206	47	2	0.17561	1.70346	0.00571	0.0020
2	49	75.79	3.8198	0.0086	11.3889	0.00206	49	4	0.35122	1.70346	0.00428	0.0000
2.5	49	75.78	3.8193	0.0091	11.3876	0.00219	49	4	0.35126	1.70367	0.00363	0.0010
3	49	75.78	3.8193	0.0091	11.3876	0.00219	49	4	0.35126	1.70367	0.00302	0.0000
3.5	49	75.76	3.8183	0.0101	11.3848	0.00243	49	4	0.35135	1.70409	0.00288	0.0020
4	50	75.75	3.8178	0.0106	11.3834	0.00255	50	5	0.43924	1.70429	0.00265	0.0010
4.5	50	75.75	3.8178	0.0106	11.3834	0.00255	50	5	0.43924	1.70429	0.00235	0.0000
5	50	75.75	3.8178	0.0106	11.3834	0.00255	50	5	0.43924	1.70429	0.00212	0.0000
6	50	75.73	3.8168	0.0116	11.3806	0.00279	50	5	0.43934	1.70471	0.00193	0.0010
7	50	75.72	3.8163	0.0121	11.3792	0.00291	50	5	0.43940	1.70492	0.00173	0.0005
8	50	75.70	3.8153	0.0131	11.3765	0.00316	50	5	0.43950	1.70533	0.00164	0.0010
9	50	75.69	3.8148	0.0136	11.3751	0.00328	50	5	0.43956	1.70554	0.00151	0.0005
10	50	75.67	3.8138	0.0146	11.3723	0.00352	50	5	0.43966	1.70596	0.00146	0.0010
12	52	75.63	3.8118	0.0166	11.3668	0.00401	52	7	0.61583	1.70679	0.00139	0.0010
14	52	75.60	3.8102	0.0181	11.3626	0.00437	52	7	0.61606	1.70741	0.00130	0.0008
16	52	75.58	3.8092	0.0192	11.3598	0.00461	52	7	0.61621	1.70783	0.00120	0.0005
18	52	75.55	3.8077	0.0207	11.3557	0.00498	52	7	0.61643	1.70845	0.00115	0.0008
20	52	75.52	3.8062	0.0222	11.3515	0.00534	52	7	0.61666	1.70908	0.00111	0.0008
24	54	75.46	3.8032	0.0252	11.3432	0.00607	54	9	0.79343	1.71033	0.00105	0.0008
28	54	75.40	3.8002	0.0282	11.3349	0.00680	54	9	0.79401	1.71159	0.00101	0.0008
32	54	75.32	3.7961	0.0323	11.3238	0.00777	54	9	0.79479	1.71326	0.00101	0.0010
36	55	75.26	3.7931	0.0353	11.3155	0.00850	55	10	0.88375	1.71452	0.00098	0.0008
40	55	75.20	3.7901	0.0383	11.3072	0.00923	55	10	0.88440	1.71578	0.00096	0.0008
45	57	75.11	3.7855	0.0428	11.2947	0.01032	57	12	1.06245	1.71768	0.00095	0.0009
50	57	75.03	3.7815	0.0469	11.2836	0.01129	57	12	1.06349	1.71937	0.00094	0.0008
55	59	74.91	3.7755	0.0529	11.2670	0.01275	59	14	1.24257	1.72191	0.00096	0.0012
60	59	74.83	3.7714	0.0570	11.2559	0.01372	59	14	1.24379	1.72360	0.00095	0.0008
70	59	74.62	3.7608	0.0675	11.2268	0.01627	59	14	1.24702	1.72807	0.00096	0.0011
80	60	74.40	3.7498	0.0786	11.1963	0.01895	60	15	1.33973	1.73278	0.00098	0.0011
90	59	74.22	3.7407	0.0877	11.1713	0.02113	59	14	1.25321	1.73665	0.00097	0.0009
107	59	73.89	3.7241	0.1043	11.1256	0.02514	59	14	1.25836	1.74379	0.00098	0.0010
120	59	73.61	3.7099	0.1184	11.0868	0.02854	59	14	1.26276	1.74989	0.00099	0.0011
210	60	71.84	3.6207	0.2076	10.8415	0.05004	60	15	1.38358	1.78949	0.00099	0.0010
367	60	68.79	3.4670	0.3614	10.4187	0.08708	60	15	1.43971	1.86209	0.00098	0.0010
673	60	62.76	3.1631	0.6653	9.5830	0.16031	60	15	1.56528	2.02449	0.00099	0.0010
1247	60	51.44	2.5926	1.2358	8.0140	0.29779	60	15	1.87172	2.42084	0.00099	0.0010
1320	60	50.06	2.5230	1.3054	7.8228	0.31454	60	15	1.91748	2.48003	0.00099	0.0010
1444	60	47.64	2.4011	1.4273	7.4873	0.34393	60	15	2.00338	2.59113	0.00099	0.0010

Logan County - Direct Simple Shear Test - Stage 3

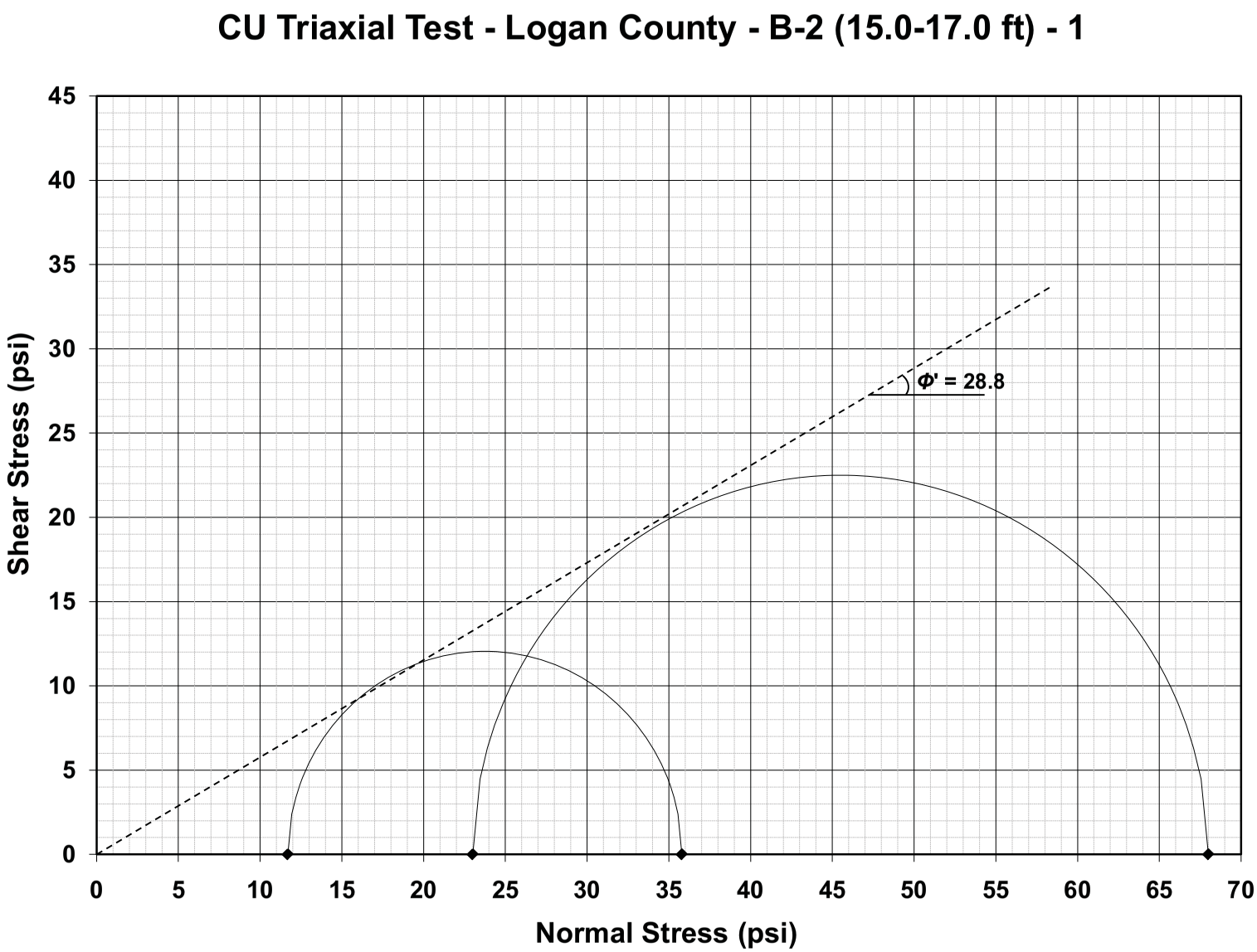
Normal Load:	13.32	kg
	29.37	lb
Friction Force:	3	lb
Initial Area:	11.41	in^2
Initial Length:	4.15	in
Initial Width:	2.75	in

Time	Load (LED)	Displacement Reading (LVDT)	Displacement Reading (in)	Cumulative Displacement (in)	Corrected Area (in^2)	Relative Strain (in/in)	Corrected Shear Load (lb)	Shear Load Applied (lb)	Shear Stress (lb/in^2)	Normal Stress (lb/in^2)	Strain Rate (in/min)	Incremental Strain Rate (in/min)
Initial (zero)	34	75.98	3.8294	0.0000	11.4125	0.00000	35	-	0.00000	2.57310	-	-
Initial (after seating)	47	75.87	3.8238	0.0055	11.3973	0.00134	47	0	0.00000	2.57655	-	-
0.5	47	75.85	3.8228	0.0066	11.3945	0.00158	47	0	0.00000	2.57717	0.01310	-
1	47	75.84	3.8223	0.0071	11.3931	0.00170	47	0	0.00000	2.57749	0.00706	0.0010
1.5	47	75.84	3.8223	0.0071	11.3931	0.00170	47	0	0.00000	2.57749	0.00470	0.0000
2	49	75.82	3.8213	0.0081	11.3903	0.00194	49	2	0.17559	2.57811	0.00403	0.0020
2.5	49	75.82	3.8213	0.0081	11.3903	0.00194	49	2	0.17559	2.57811	0.00323	0.0000
3	49	75.81	3.8208	0.0086	11.3889	0.00206	49	2	0.17561	2.57843	0.00286	0.0010
3.5	49	75.81	3.8208	0.0086	11.3889	0.00206	49	2	0.17561	2.57843	0.00245	0.0000
4	49	75.81	3.8208	0.0086	11.3889	0.00206	49	2	0.17561	2.57843	0.00214	0.0000
4.5	49	75.81	3.8208	0.0086	11.3889	0.00206	49	2	0.17561	2.57843	0.00190	0.0000
5	49	75.81	3.8208	0.0086	11.3889	0.00206	49	2	0.17561	2.57843	0.00171	0.0000
6	50	75.79	3.8198	0.0096	11.3862	0.00231	50	3	0.26348	2.57905	0.00160	0.0010
7	50	75.78	3.8193	0.0101	11.3848	0.00243	50	3	0.26351	2.57937	0.00144	0.0005
8	50	75.78	3.8193	0.0101	11.3848	0.00243	50	3	0.26351	2.57937	0.00126	0.0000
9	50	75.78	3.8193	0.0101	11.3848	0.00243	50	3	0.26351	2.57937	0.00112	0.0000
10	52	75.76	3.8183	0.0111	11.3820	0.00267	52	5	0.43929	2.58000	0.00111	0.0010
12	52	75.74	3.8173	0.0121	11.3792	0.00291	52	5	0.43940	2.58062	0.00101	0.0005
14	54	75.74	3.8173	0.0121	11.3792	0.00291	54	7	0.61516	2.58062	0.00086	0.0000
16.66666667	54	75.70	3.8153	0.0141	11.3737	0.00340	54	7	0.61546	2.58188	0.00085	0.0008
18	54	75.69	3.8148	0.0146	11.3723	0.00352	54	7	0.61553	2.58220	0.00081	0.0004
20	54	75.66	3.8133	0.0161	11.3681	0.00389	54	7	0.61576	2.58314	0.00081	0.0008
24	55	75.60	3.8102	0.0192	11.3598	0.00461	55	8	0.70424	2.58503	0.00080	0.0008
28	57	75.55	3.8077	0.0217	11.3529	0.00522	57	10	0.88083	2.58661	0.00077	0.0006
32	57	75.50	3.8052	0.0242	11.3460	0.00583	57	10	0.88137	2.58819	0.00076	0.0006
36	59	75.43	3.8017	0.0277	11.3363	0.00668	59	12	1.05855	2.59041	0.00077	0.0009
40	60	75.34	3.7971	0.0323	11.3238	0.00777	60	13	1.14802	2.59326	0.00081	0.0011
45	60	75.21	3.7906	0.0388	11.3058	0.00935	60	13	1.14985	2.59739	0.00086	0.0013
50	60	75.12	3.7860	0.0433	11.2933	0.01044	60	13	1.15112	2.60026	0.00087	0.0009
55	62	75.03	3.7815	0.0479	11.2808	0.01154	62	15	1.32969	2.60314	0.00087	0.0009
60	62	74.92	3.7760	0.0534	11.2656	0.01287	62	15	1.33149	2.60666	0.00089	0.0011
70	64	74.71	3.7654	0.0640	11.2365	0.01542	64	17	1.51293	2.61341	0.00091	0.0011
80	64	74.53	3.7563	0.0731	11.2115	0.01761	64	17	1.51630	2.61923	0.00091	0.0009
90	64	74.31	3.7452	0.0842	11.1810	0.02028	64	17	1.52043	2.62637	0.00094	0.0011
105	65	74.02	3.7306	0.0988	11.1408	0.02380	65	18	1.61568	2.63585	0.00094	0.0010
122	64	73.72	3.7155	0.1139	11.0993	0.02745	64	17	1.53163	2.64572	0.00093	0.0009
150	67	73.15	3.6868	0.1426	11.0203	0.03437	67	20	1.81484	2.66469	0.00095	0.0010
165	67	72.85	3.6716	0.1578	10.9787	0.03801	67	20	1.82171	2.67478	0.00096	0.0010
290	69	70.40	3.5482	0.2812	10.6391	0.06777	69	22	2.06784	2.76015	0.00097	0.0010
465	67	66.94	3.3738	0.4556	10.1596	0.10979	67	20	1.96859	2.89044	0.00098	0.0010
615	67	64.02	3.2266	0.6028	9.7548	0.14525	67	20	2.05026	3.01035	0.00098	0.0010
1235	69	51.75	2.6082	1.2212	8.0542	0.29426	69	22	2.73149	3.64598	0.00099	0.0010
1272	67	51.05	2.5729	1.2565	7.9572	0.30276	67	20	2.51345	3.69044	0.00099	0.0010
1300	67	50.54	2.5472	1.2822	7.8865	0.30896	67	20	2.53597	3.72351	0.00099	0.0009
1335	67	49.84	2.5119	1.3175	7.7895	0.31746	67	20	2.56756	3.76989	0.00099	0.0010
1380	69	49.00	2.4696	1.3598	7.6731	0.32766	69	22	2.86717	3.82709	0.00099	0.0009

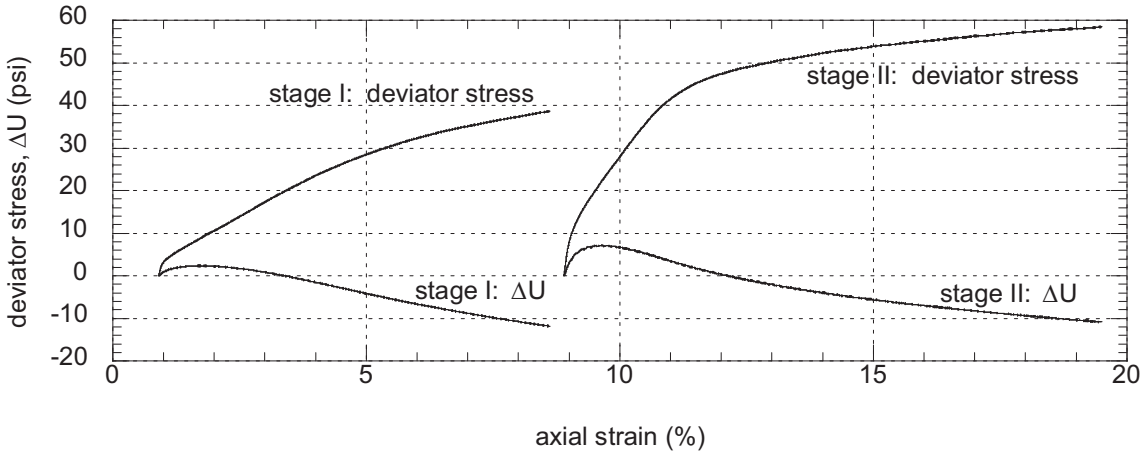
Logan County - Direct Simple Shear Test - Stage 4

Normal Load:	20.32	kg
	44.80	lb
Friction Force:	5	lb
Initial Area:	11.41	in^2
Initial Length:	4.15	in
Initial Width:	2.75	in

Time	Load (LED)	Displacement Reading (LVDT)	Displacement Reading (in)	Cumulative Displacement (in)	Corrected Area (in^2)	Relative Strain (in/in)	Corrected Shear Load (lb)	Shear Load Applied (lb)	Shear Stress (lb/in^2)	Normal Stress (lb/in^2)	Strain Rate (in/min)	Incremental Strain Rate (in/min)
Initial (zero)	30	75.98	3.8294	0.0000	11.4125	0.00000	39	-	0.00000	3.92533	-	-
Initial (after seating)	45	75.78	3.8193	0.0101	11.3848	0.00243	45	0	0.00000	3.93489	-	-
0.5	47	75.76	3.8183	0.0111	11.3820	0.00267	47	2	0.17572	3.93585	0.02218	-
1	49	75.75	3.8178	0.0116	11.3806	0.00279	49	4	0.35147	3.93633	0.01159	0.0010
1.5	49	75.75	3.8178	0.0116	11.3806	0.00279	49	4	0.35147	3.93633	0.00773	0.0000
2	50	75.75	3.8178	0.0116	11.3806	0.00279	50	5	0.43934	3.93633	0.00580	0.0000
2.5	50	75.73	3.8168	0.0126	11.3779	0.00304	50	5	0.43945	3.93729	0.00504	0.0020
3	50	75.73	3.8168	0.0126	11.3779	0.00304	50	5	0.43945	3.93729	0.00420	0.0000
3.5	50	75.73	3.8168	0.0126	11.3779	0.00304	50	5	0.43945	3.93729	0.00360	0.0000
4	50	75.73	3.8168	0.0126	11.3779	0.00304	50	5	0.43945	3.93729	0.00315	0.0000
4.5	50	75.72	3.8163	0.0131	11.3765	0.00316	50	5	0.43950	3.93777	0.00291	0.0010
5	50	75.72	3.8163	0.0131	11.3765	0.00316	50	5	0.43950	3.93777	0.00262	0.0000
6	52	75.72	3.8163	0.0131	11.3765	0.00316	52	7	0.61531	3.93777	0.00218	0.0000
7	52	75.70	3.8153	0.0141	11.3737	0.00340	52	7	0.61546	3.93873	0.00202	0.0010
8	52	75.70	3.8153	0.0141	11.3737	0.00340	52	7	0.61546	3.93873	0.00176	0.0000
9	54	75.70	3.8153	0.0141	11.3737	0.00340	54	9	0.79130	3.93873	0.00157	0.0000
10	54	75.69	3.8148	0.0146	11.3723	0.00352	54	9	0.79140	3.93921	0.00146	0.0005
12	54	75.67	3.8138	0.0156	11.3695	0.00376	54	9	0.79159	3.94017	0.00130	0.0005
14	55	75.66	3.8133	0.0161	11.3681	0.00389	55	10	0.87965	3.94065	0.00115	0.0003
16	55	75.64	3.8123	0.0171	11.3654	0.00413	55	10	0.87987	3.94161	0.00107	0.0005
18	57	75.61	3.8107	0.0186	11.3612	0.00449	57	12	1.05622	3.94305	0.00104	0.0008
20	57	75.58	3.8092	0.0202	11.3571	0.00486	57	12	1.05661	3.94450	0.00101	0.0008
24	59	75.53	3.8067	0.0227	11.3501	0.00547	59	14	1.23347	3.94690	0.00095	0.0006
28	59	75.44	3.8022	0.0272	11.3377	0.00656	59	14	1.23482	3.95125	0.00097	0.0011
32	60	75.37	3.7986	0.0307	11.3280	0.00741	60	15	1.32416	3.95463	0.00096	0.0009
36	62	75.29	3.7946	0.0348	11.3169	0.00838	62	17	1.50218	3.95851	0.00097	0.0010
40	64	75.21	3.7906	0.0388	11.3058	0.00935	64	19	1.68056	3.96239	0.00097	0.0010
45	64	75.12	3.7860	0.0433	11.2933	0.01044	64	19	1.68241	3.96676	0.00096	0.0009
50	65	75.02	3.7810	0.0484	11.2794	0.01166	65	20	1.77314	3.97164	0.00097	0.0010
55	67	74.91	3.7755	0.0539	11.2642	0.01299	67	22	1.95309	3.97701	0.00098	0.0011
60	69	74.82	3.7709	0.0585	11.2517	0.01409	69	24	2.13301	3.98142	0.00097	0.0009
70	69	74.59	3.7593	0.0701	11.2198	0.01688	69	24	2.13907	3.99274	0.00100	0.0012
80	70	74.42	3.7508	0.0786	11.1963	0.01895	70	25	2.23288	4.00114	0.00098	0.0009
90	70	74.20	3.7397	0.0897	11.1658	0.02162	70	25	2.23898	4.01206	0.00100	0.0011
105	72	73.90	3.7246	0.1048	11.1242	0.02526	72	27	2.42714	4.02706	0.00100	0.0010
120	72	73.63	3.7110	0.1184	11.0868	0.02854	72	27	2.43533	4.04065	0.00099	0.0009
180	75	72.40	3.6490	0.1804	10.9163	0.04348	75	30	2.74818	4.10376	0.00100	0.0010
270	77	70.69	3.5628	0.2666	10.6793	0.06424	77	32	2.99645	4.19483	0.00099	0.0010
420	79	67.76	3.4151	0.4143	10.2732	0.09983	79	34	3.30958	4.36065	0.00099	0.0010
547	75	65.18	3.2851	0.5443	9.9156	0.13116	75	30	3.02553	4.51791	0.00100	0.0010
600	75	64.18	3.2347	0.5947	9.7770	0.14331	75	30	3.06842	4.58196	0.00099	0.0010
860	75	59.05	2.9761	0.8533	9.0660	0.20561	75	30	3.30907	4.94130	0.00099	0.0010
1413	77	48.22	2.4303	1.3991	7.5650	0.33713	77	32	4.23003	5.92176	0.00099	0.0010
1447	77	47.48	2.3930	1.4364	7.4624	0.34612	77	32	4.28816	6.00315	0.00099	0.0011
1488	77	46.79	2.3582	1.4712	7.3668	0.35450	77	32	4.34383	6.08108	0.00099	0.0008


CU Triaxial Test - Logan County - B-2 (15.0-17.0 ft) - 1
Shear Stress (psi)
Normal Stress (psi)
Φ' = 28.8
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70

THE OHIO STATE UNIVERSITY SOIL MECHANICS LABORATORY



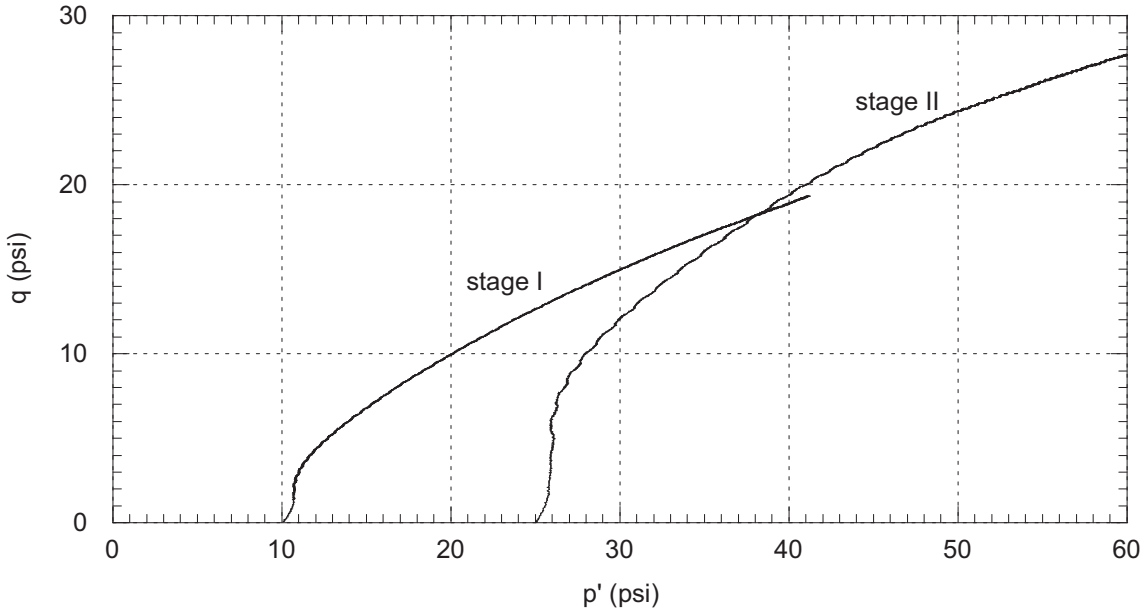
INITIAL	SPECIMEN WEIGHT	W_0 [g]	195.77	MULTI STAGE LOADING		I	II
	SPECIMEN HEIGHT	H_0 [in]	3.25	CELL PRESSURE	σ_{cell} [psi]	25	40
	SPECIMEN DIAMETER	D_0 [in]	1.46	BACK PRESSURE	u_0 [psi]	15	15
	WATER CONTENT	w_0 [%]	15.9	AXIAL STRAIN RATE	[in/min]	0.002	0.002
FINAL	SPECIMEN WEIGHT	W_f [g]	198.23	MAX DEVIATOR STRESS	$(\sigma_1 - \sigma_3)_{max}$ [psi]	38.68	58.51
	SPECIMEN HEIGHT	H_f [in]	2.81	AXIAL STRAIN, $(\sigma_1 - \sigma_3)_{max}$	ε_f [%]	8.62	19.50
	SPECIMEN DIAMETER	D_f [in]	1.54	MAX EFF. STRESS RATIO	$(\sigma_1'/\sigma_3')_{max}$	3.06	2.96
	WATER CONTENT	w_f [%]	17.3	AXIAL STRAIN, $(\sigma_1'/\sigma_3')_{max}$	ε_f [%]	4.10	11.46

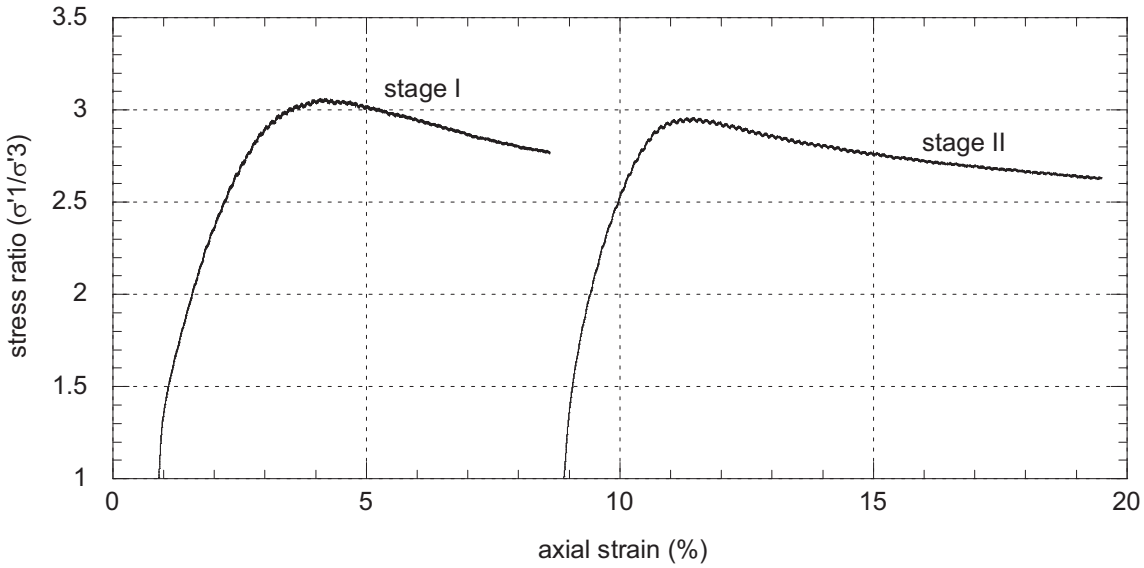
		STAGE I			STAGE II		
		INITIAL	AFTER CONSOLID.	AFTER SHEAR	INITIAL	AFTER CONSOLID.	AFTER SHEAR
DRY UNIT WEIGHT	γ_d [pcf]	118.23	121.50	←	121.50	122.49	←
VOID RATIO	e	0.4303	0.3918	←	0.3918	0.3805	←
WATER CONTENT	w [%]	15.9	14.46	←	14.46	14.04	←
SATURATION	S [%]	100.1	100.0	←	100.0	100.0	←

DESCRIPTION	brown clay with stones (visual)				
CLASSIFICATION	A-6a (ODOT class.)			TYPE OF SPECIMEN	undisturbed
LL 33	PL 19	PI 14	G_s 2.71*	TYPE OF TEST	CU

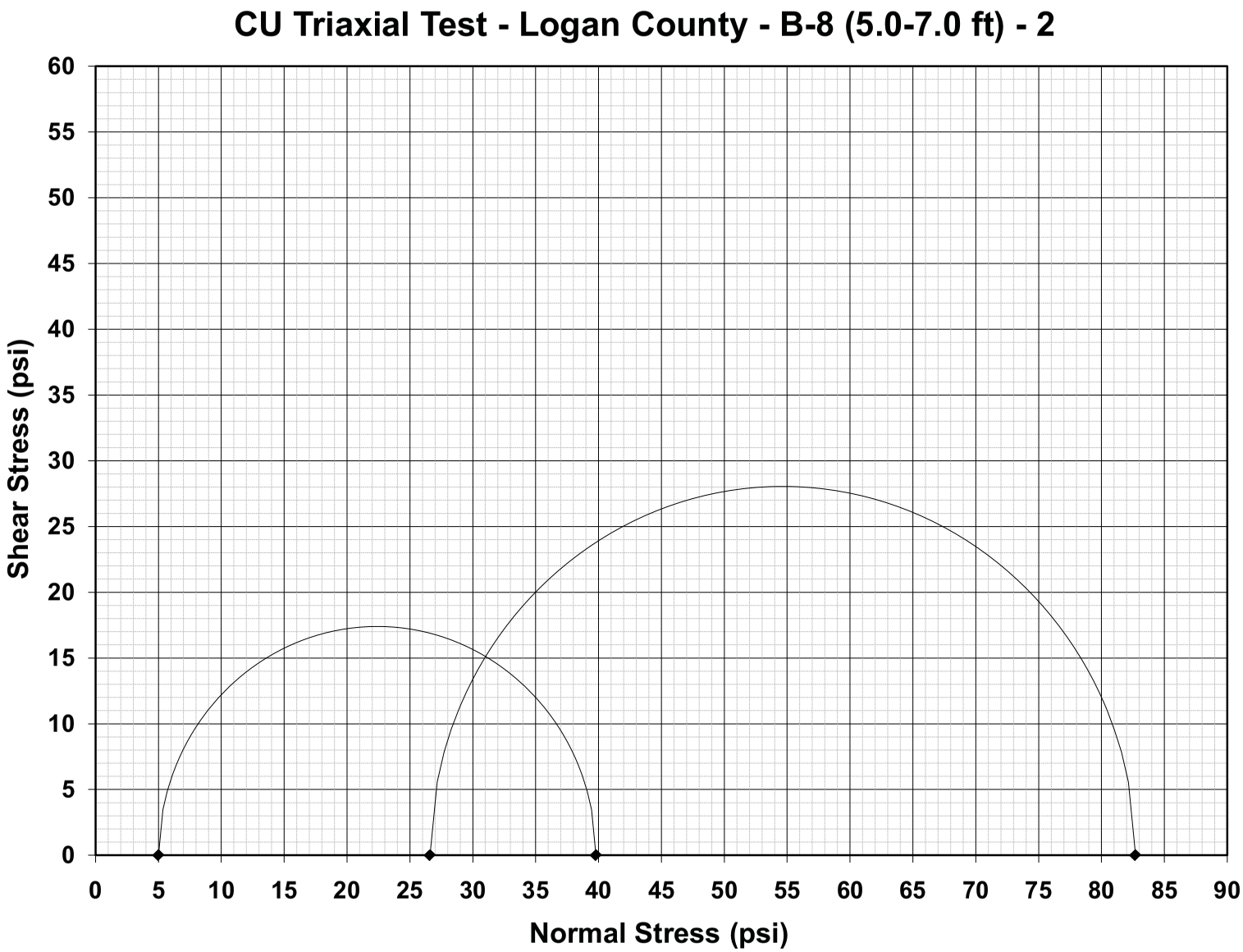
REMARKS	PROJECT Bio-Engineering for Land Stabilization	
*G_s assumed	AREA Logan County—SR33/SR347	
B-value = 0.89	BORING ID BH 2	SAMPLE NO. 18-P 1 bottom
	DEPTH/ELEV. (15.0-17.0) ft	DATE May 4, 2005
	TECH CMK	CHECKED
1 of 2	**TRIAXIAL COMPRESSION TEST REPORT**	

THE OHIO STATE UNIVERSITY SOIL MECHANICS LABORATORY

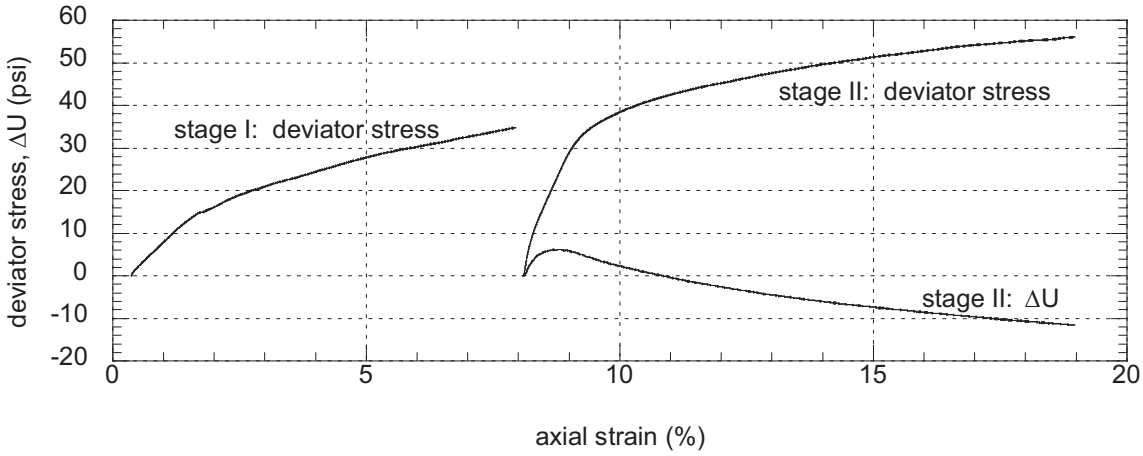




REMARKS	PROJECT	Bio-Engineering for Land Stabilization	
	AREA	Logan County—SR33/SR347	
	BORING ID	BH 2	SAMPLE NO. 18-P 1 bottom
	DEPTH/ELEV.	(15.0-17.0) ft	DATE May 4, 2005
	TECH	CMK	CHECKED
2 of 2	**TRIAXIAL COMPRESSION TEST REPORT**		


CU Triaxial Test - Logan County - B-8 (5.0-7.0 ft) - 2
Shear Stress (psi)
0
5
10
15
20
25
30
35
40
45
50
55
60
Normal Stress (psi)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90

THE OHIO STATE UNIVERSITY SOIL MECHANICS LABORATORY



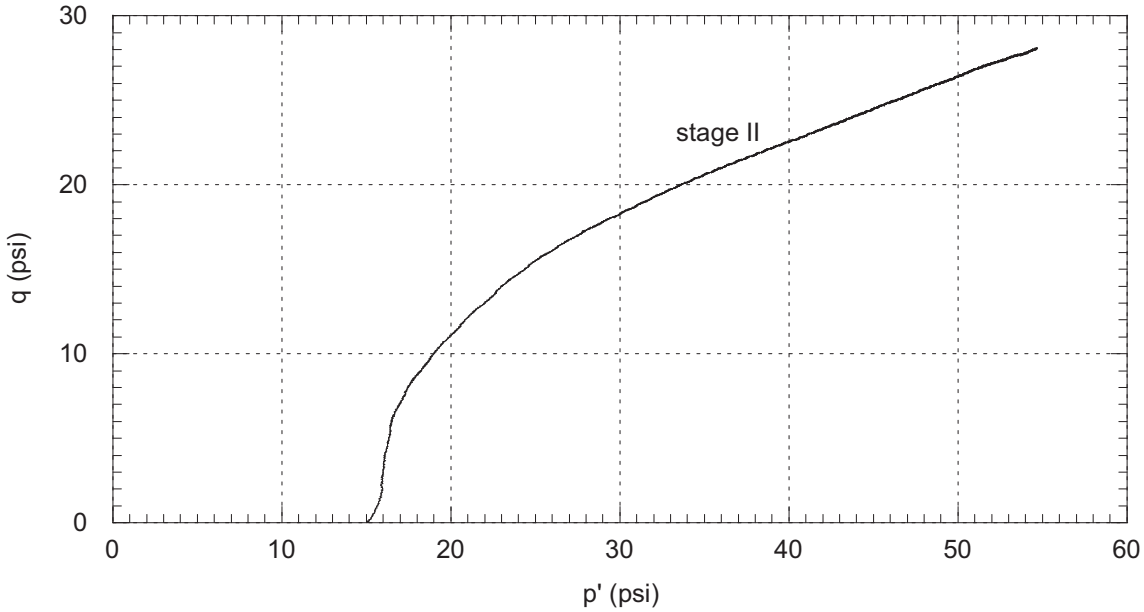
INITIAL	SPECIMEN WEIGHT	W_0 [g]	165.16	MULTI STAGE LOADING		I	II
	SPECIMEN HEIGHT	H_0 [in]	2.75	CELL PRESSURE	σ_{cell} [psi]	25	35
	SPECIMEN DIAMETER	D_0 [in]	1.46	BACK PRESSURE	u_0 [psi]	20	20
	WATER CONTENT	w_0 [%]	16.23	AXIAL STRAIN RATE	[in/min]	0.002	0.002
FINAL	SPECIMEN WEIGHT	W_f [g]	165.16	MAX DEVIATOR STRESS	$(\sigma_1 - \sigma_3)_{max}$ [psi]	34.81	56.15
	SPECIMEN HEIGHT	H_f [in]	2.25*	AXIAL STRAIN, $(\sigma_1 - \sigma_3)_{max}$	ε_f [%]	7.93	18.96
	SPECIMEN DIAMETER	D_f [in]	1.60*	MAX EFF. STRESS RATIO	$(\sigma_1'/\sigma_3')_{max}$	**	4.29
	WATER CONTENT	w_f [%]	16.2	AXIAL STRAIN, $(\sigma_1'/\sigma_3')_{max}$	ε_f [%]	**	9.24

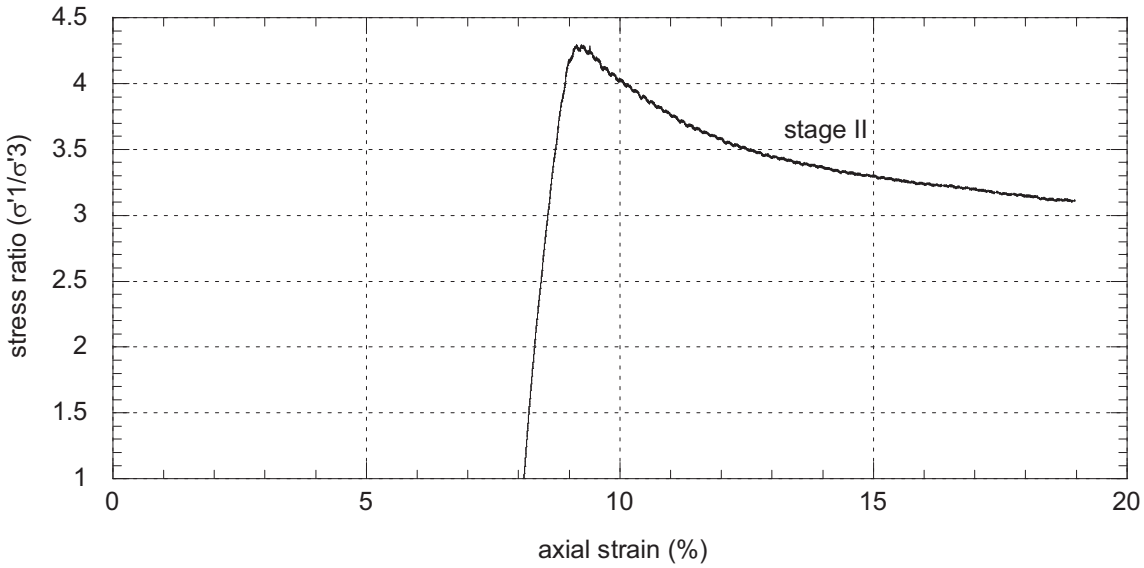
		STAGE I			STAGE II		
		INITIAL	AFTER CONSOLID.	AFTER SHEAR	INITIAL	AFTER CONSOLID.	AFTER SHEAR
DRY UNIT WEIGHT	γ_d [pcf]	117.55	118.81	←	118.81	119.62	←
VOID RATIO	e	0.4385	0.4233	←	0.4233	0.4175	←
WATER CONTENT	w [%]	16.23	15.62	←	15.62	15.41	←
SATURATION	S [%]	100.3	100.0	←	100.0	100.0	←

DESCRIPTION	brown clay with some stones—till (visual)				
CLASSIFICATION	A-6b (ODOT class.)			TYPE OF SPECIMEN	undisturbed
LL 36	PL 19	PI 19	G_s 2.71†	TYPE OF TEST	CU

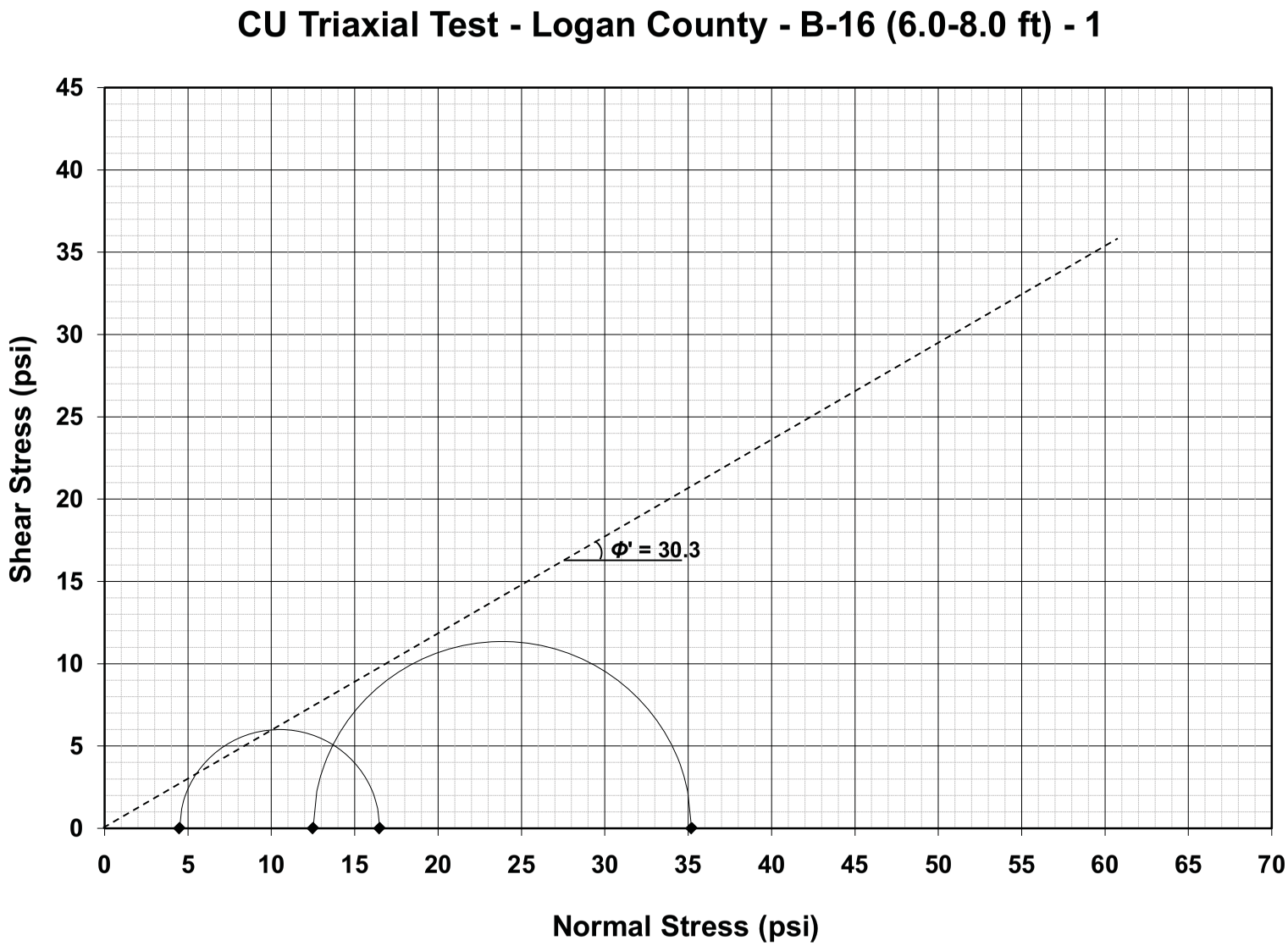
REMARKS	PROJECT	Bio-Engineering for Land Stabilization	
*value calculated not measured	AREA	Logan County—SR33/SR347	
**pore pressure data lost	BORING ID	BH 8	SAMPLE NO. 2
†G_s assumed	DEPTH/ELEV.	(5.0-7.0) ft	DATE March 22, 2005
B-value = 1	TECH	CMK	CHECKED
1 of 2	**TRIAXIAL COMPRESSION TEST REPORT**		

THE OHIO STATE UNIVERSITY SOIL MECHANICS LABORATORY

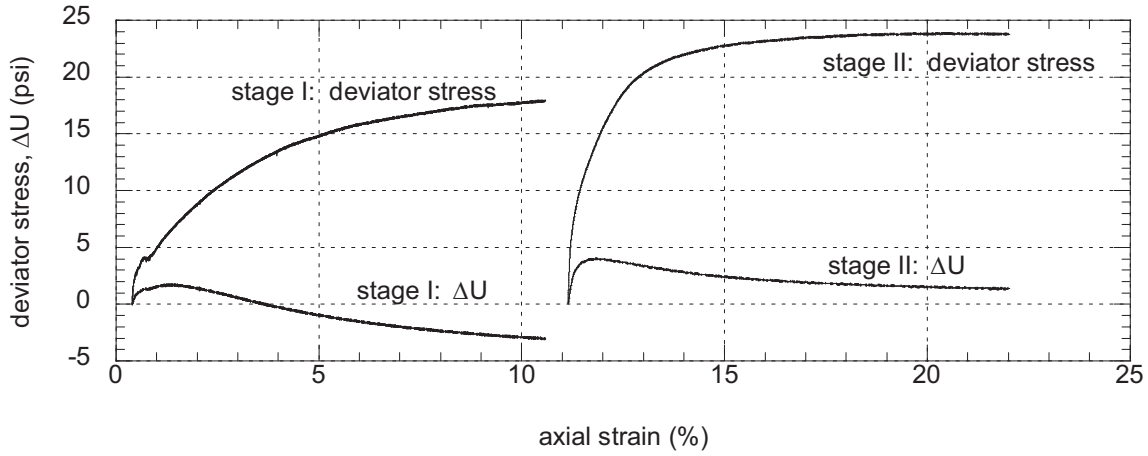




REMARKS	PROJECT	Bio-Engineering for Land Stabilization	
	AREA	Logan County—SR33/SR347	
	BORING ID	BH 8	SAMPLE NO. 2
	DEPTH/ELEV.	(5.0-7.0) ft	DATE March 22, 2005
	TECH	CMK	CHECKED
2 of 2	**TRIAXIAL COMPRESSION TEST REPORT**		


CU Triaxial Test - Logan County - B-16 (6.0-8.0 ft) - 1
Shear Stress (psi)
Normal Stress (psi)
Φ' = 30.3
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70

THE OHIO STATE UNIVERSITY SOIL MECHANICS LABORATORY



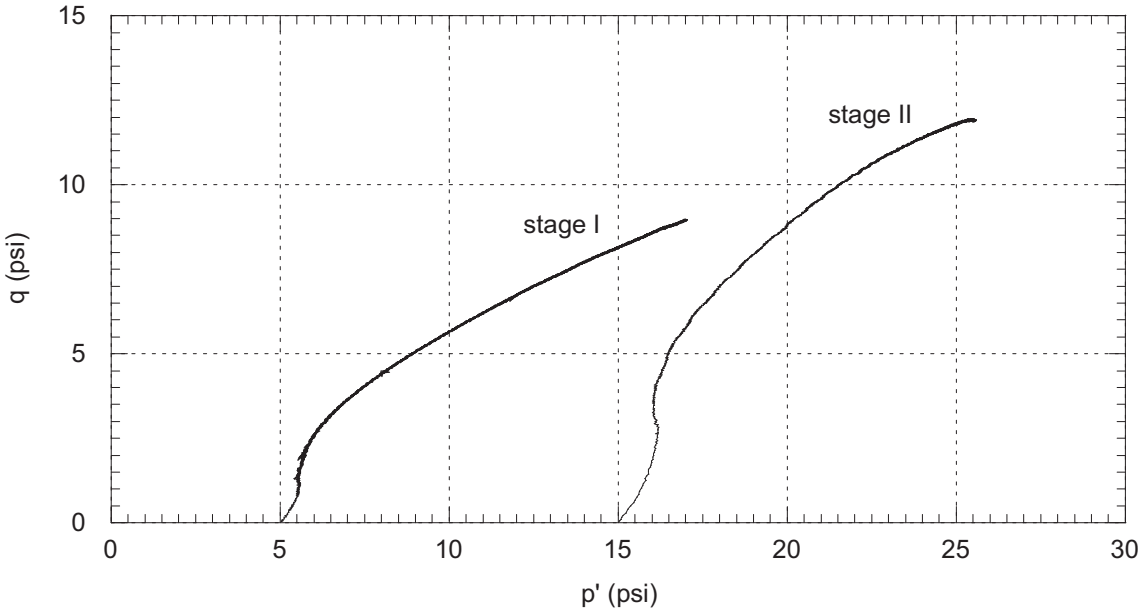
INITIAL	SPECIMEN WEIGHT	W_0 [g]	158.11	MULTI STAGE LOADING		I	II
	SPECIMEN HEIGHT	H_0 [in]	3.0	CELL PRESSURE	σ_{cell} [psi]	19	29
	SPECIMEN DIAMETER	D_0 [in]	1.4	BACK PRESSURE	u_0 [psi]	14	14
	WATER CONTENT	w_0 [%]	23.30*	AXIAL STRAIN RATE	[in/min]	0.0010	0.0025
FINAL	SPECIMEN WEIGHT	W_f [g]	155.45	MAX DEVIATOR STRESS	$(\sigma_1 - \sigma_3)_{max}$ [psi]	17.93	23.89
	SPECIMEN HEIGHT	H_f [in]	2.68	AXIAL STRAIN, $(\sigma_1 - \sigma_3)_{max}$	ε_f [%]	10.58	20.75
	SPECIMEN DIAMETER	D_f [in]	1.47	MAX EFF. STRESS RATIO	$(\sigma_1'/\sigma_3')_{max}$	3.62	2.82
	WATER CONTENT	w_f [%]	23.2	AXIAL STRAIN, $(\sigma_1'/\sigma_3')_{max}$	ε_f [%]	3.17	14.88

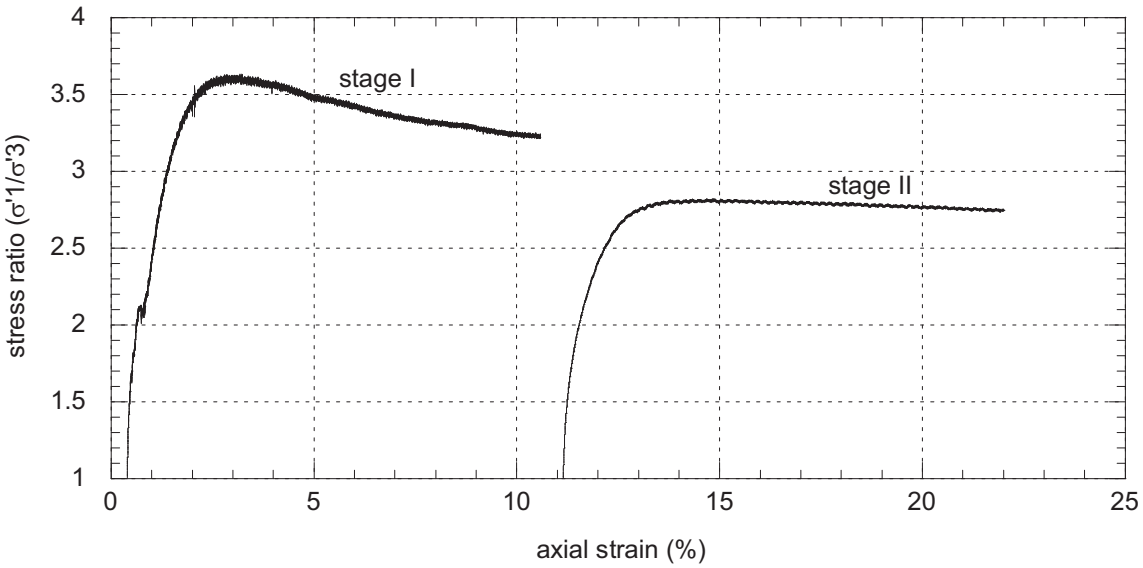
		STAGE I			STAGE II		
		INITIAL	AFTER CONSOLID.	AFTER SHEAR	INITIAL	AFTER CONSOLID.	AFTER SHEAR
DRY UNIT WEIGHT	γ_d [pcf]	104.07	105.32	←	105.32	107.11	←
VOID RATIO	e	0.6250	0.6057	←	0.6057	0.5788	←
WATER CONTENT	w [%]	23.30	22.35	←	22.35	21.36	←
SATURATION	S [%]	101.0	100.0	←	100.0	100.0	←

DESCRIPTION	gray clay (visual)				
CLASSIFICATION	A-4a (ODOT class.)			TYPE OF SPECIMEN	undisturbed
LL 32	PL 28	PI 4	G_S 2.71**	TYPE OF TEST	CU

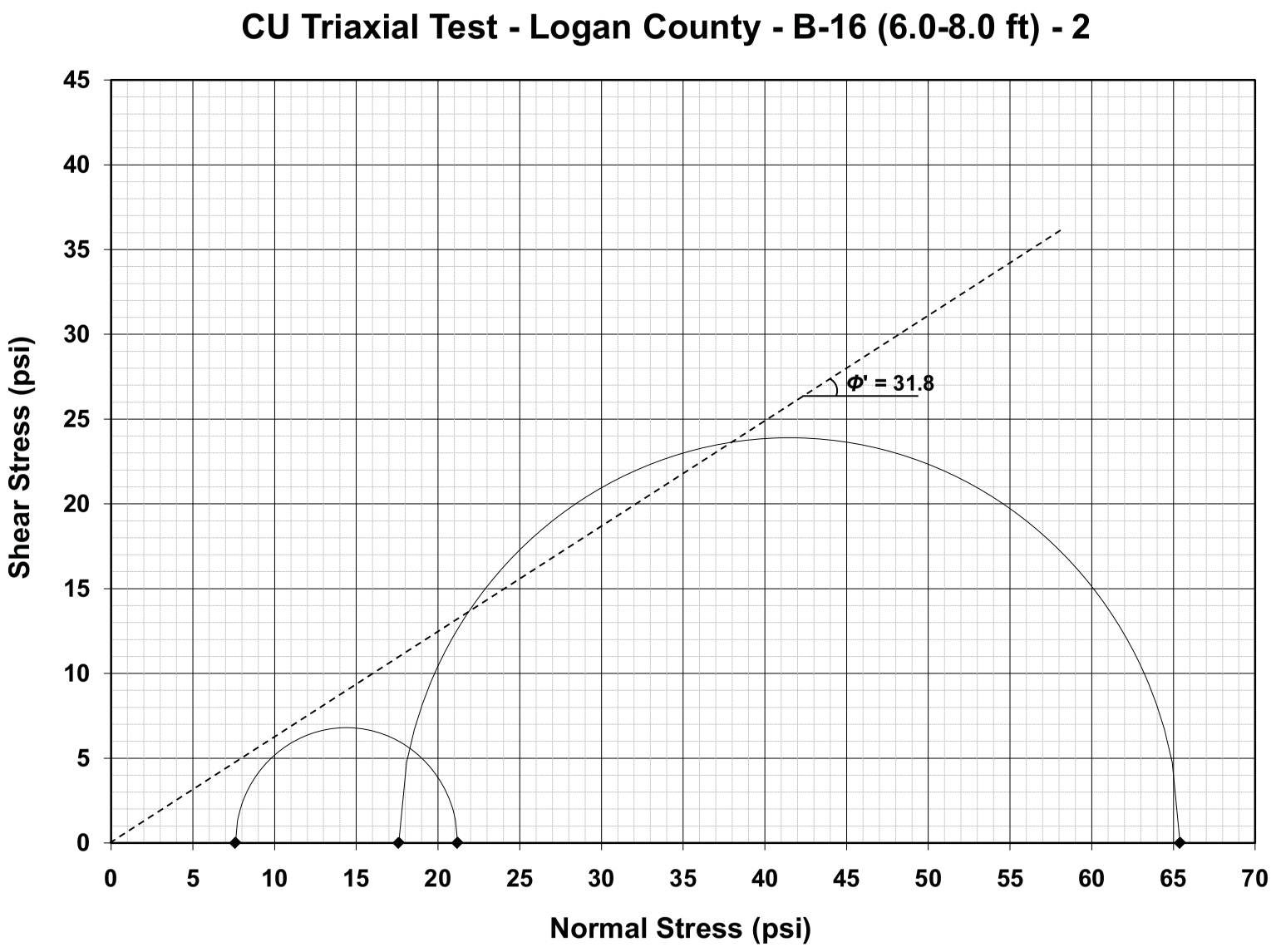
REMARKS	PROJECT	Bio-Engineering for Land Stabilization	
*w_0(%) from trimmings	AREA	Logan County—SR33/SR347	
**G_s assumed	BORING ID	BH 16	SAMPLE NO. 1-bottom
B-value = 0.95	DEPTH/ELEV.	(6.0-8.0) ft	DATE February 11, 2005
	TECH	CMK	CHECKED
1 of 2	**TRIAXIAL COMPRESSION TEST REPORT**		

THE OHIO STATE UNIVERSITY SOIL MECHANICS LABORATORY

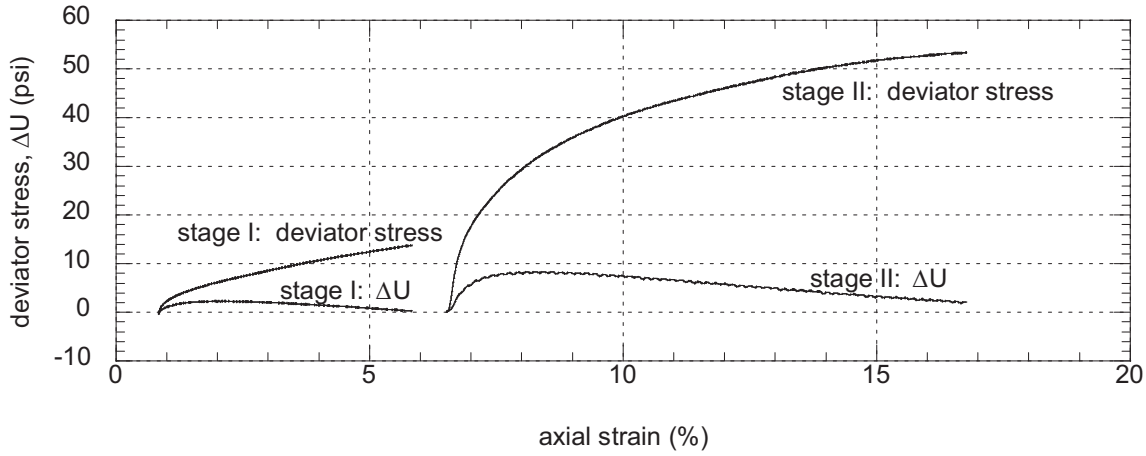




REMARKS	PROJECT	Bio-Engineering for Land Stabilization	
	AREA	Logan County—SR33/SR347	
	BORING ID	BH 16	SAMPLE NO. 1-bottom
	DEPTH/ELEV.	(6.0-8.0) ft	DATE February 11, 2005
	TECH	CMK	CHECKED
2 of 2	**TRIAXIAL COMPRESSION TEST REPORT**		


CU Triaxial Test - Logan County - B-16 (6.0-8.0 ft) - 2
Shear Stress (psi)
Normal Stress (psi)
Φ' = 31.8
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70

THE OHIO STATE UNIVERSITY SOIL MECHANICS LABORATORY



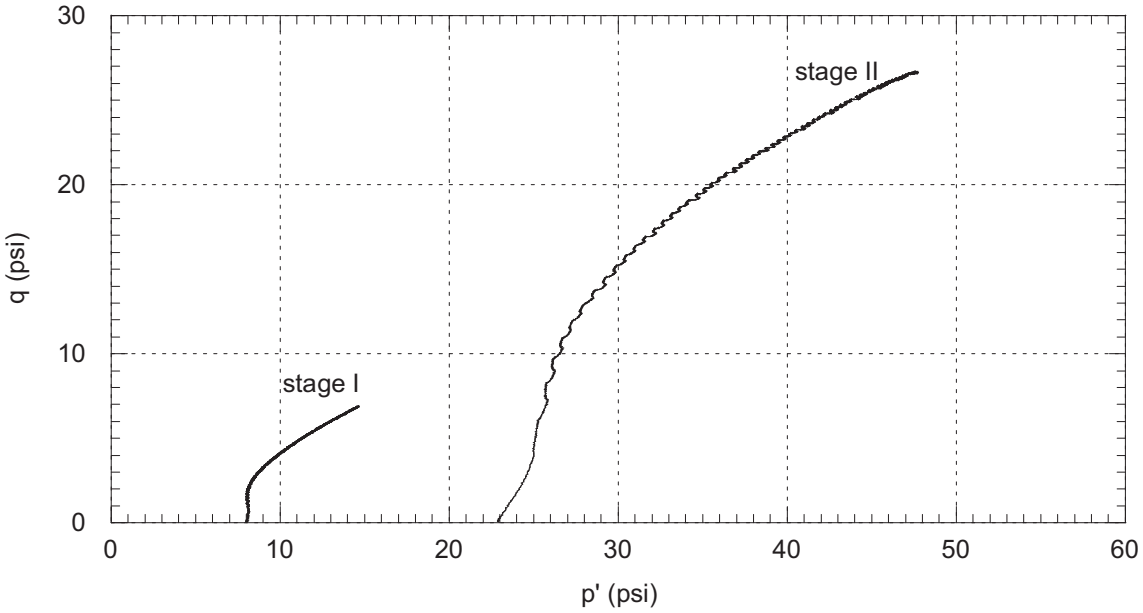
INITIAL	SPECIMEN WEIGHT	W_0 [g]	156.56*	MULTI STAGE LOADING		I	II
	SPECIMEN HEIGHT	H_0 [in]	3.0	CELL PRESSURE	σ_{cell} [psi]	22	41
	SPECIMEN DIAMETER	D_0 [in]	1.4	BACK PRESSURE	u_0 [psi]	14	18
	WATER CONTENT	w_0 [%]	21.87**	AXIAL STRAIN RATE	[in/min]	0.0001	0.0025
FINAL	SPECIMEN WEIGHT	W_f [g]	157.80	MAX DEVIATOR STRESS	$(\sigma_1 - \sigma_3)_{max}$ [psi]	13.79	53.59
	SPECIMEN HEIGHT	H_f [in]	2.80	AXIAL STRAIN, $(\sigma_1 - \sigma_3)_{max}$	ε_f [%]	5.81	16.77
	SPECIMEN DIAMETER	D_f [in]	1.43	MAX EFF. STRESS RATIO	$(\sigma_1'/\sigma_3')_{max}$	2.79	3.70
	WATER CONTENT	w_f [%]	22.83	AXIAL STRAIN, $(\sigma_1'/\sigma_3')_{max}$	ε_f [%]	5.68	12.70

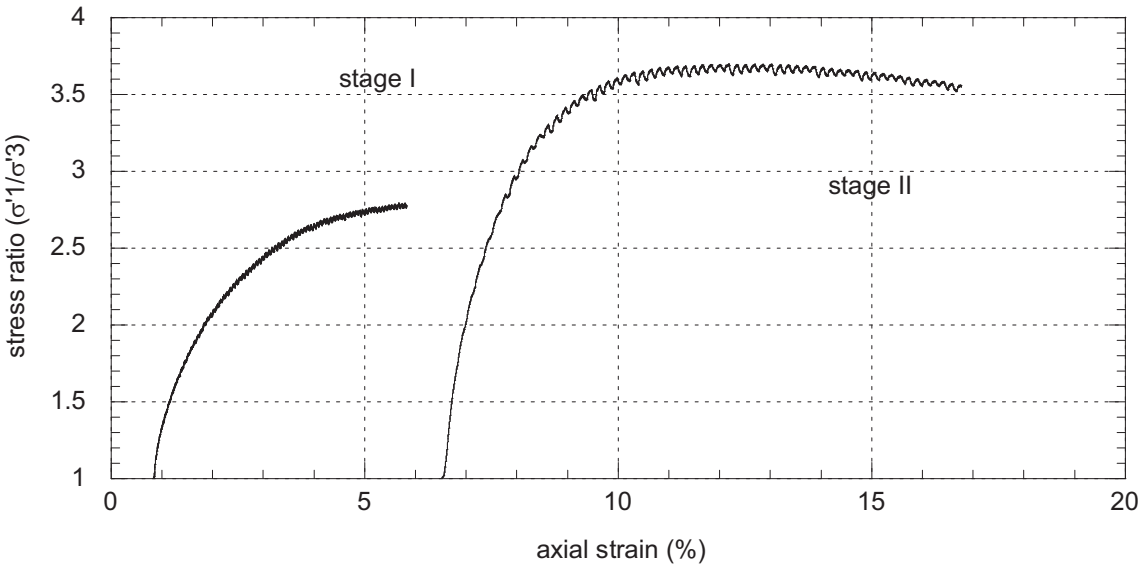
		STAGE I			STAGE II		
		INITIAL	AFTER CONSOLID.	AFTER SHEAR	INITIAL	AFTER CONSOLID.	AFTER SHEAR
DRY UNIT WEIGHT	γ_d [pcf]	105.93	108.66	←	108.66	110.91	←
VOID RATIO	e	0.5964	0.5563	←	0.5563	0.5247	←
WATER CONTENT	w [%]	21.87	20.53	←	20.53	19.36	←
SATURATION	S [%]	99.4	100.0	←	100.0	100.0	←

DESCRIPTION	gray clay (visual)				
CLASSIFICATION	A-6b (ODOT class.)			TYPE OF SPECIMEN	undisturbed
LL 33	PL 20	PI 13	G_S 2.71†	TYPE OF TEST	CU

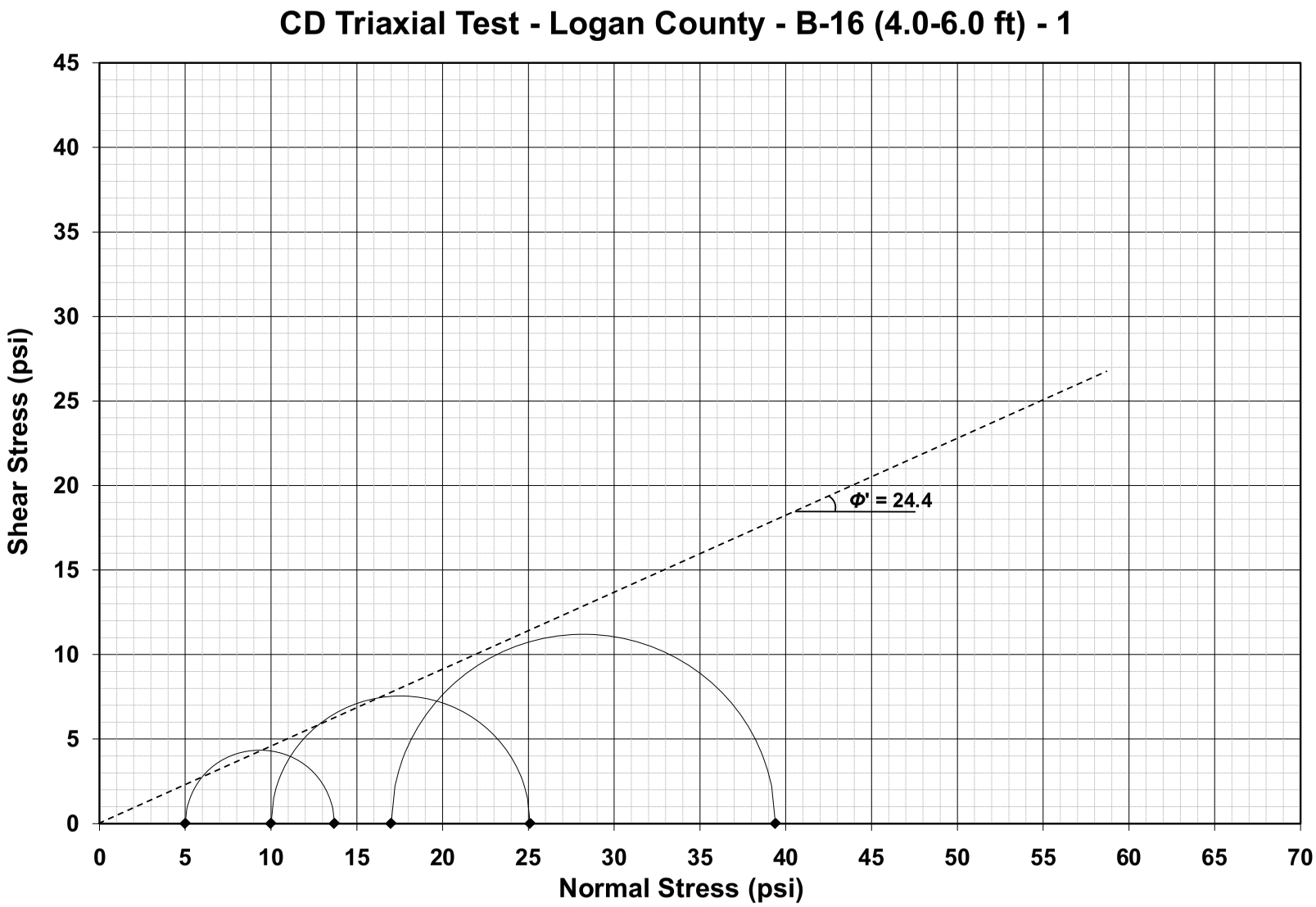
REMARKS	PROJECT	Bio-Engineering for Land Stabilization	
*W_0 calc. from w_0(%)	AREA	Logan County—SR33/SR347	
**w_0(%) calc. from trimmings	BORING ID	BH 16	SAMPLE NO. 2
†G_s assumed	DEPTH/ELEV.	(6.0-8.0) ft	DATE February 11, 2005
B-value = 0.88	TECH	CMK	CHECKED
1 of 2	**TRIAXIAL COMPRESSION TEST REPORT**		

THE OHIO STATE UNIVERSITY SOIL MECHANICS LABORATORY

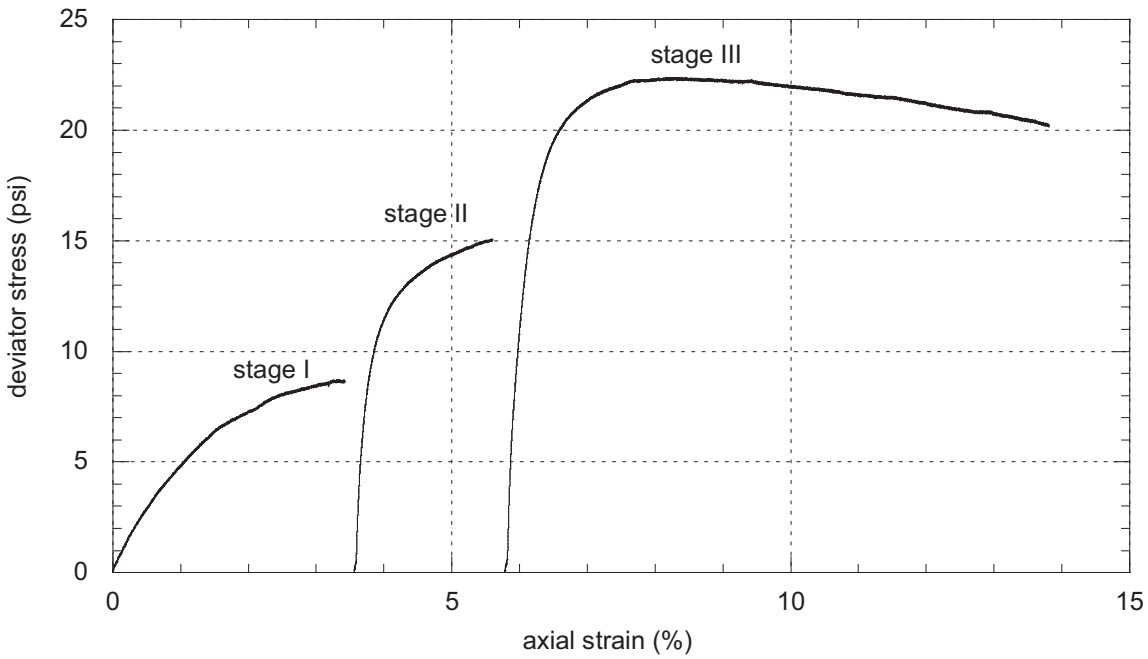




REMARKS	PROJECT	Bio-Engineering for Land Stabilization	
	AREA	Logan County—SR33/SR347	
	BORING ID	BH 16	SAMPLE NO. 2
	DEPTH/ELEV.	(6.0-8.0) ft	DATE February 11, 2005
	TECH	CMK	CHECKED
2 of 2	**TRIAXIAL COMPRESSION TEST REPORT**		


CD Triaxial Test - Logan County - B-16 (4.0-6.0 ft) - 1
Shear Stress (psi)
Normal Stress (psi)
Φ' = 24.4
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70

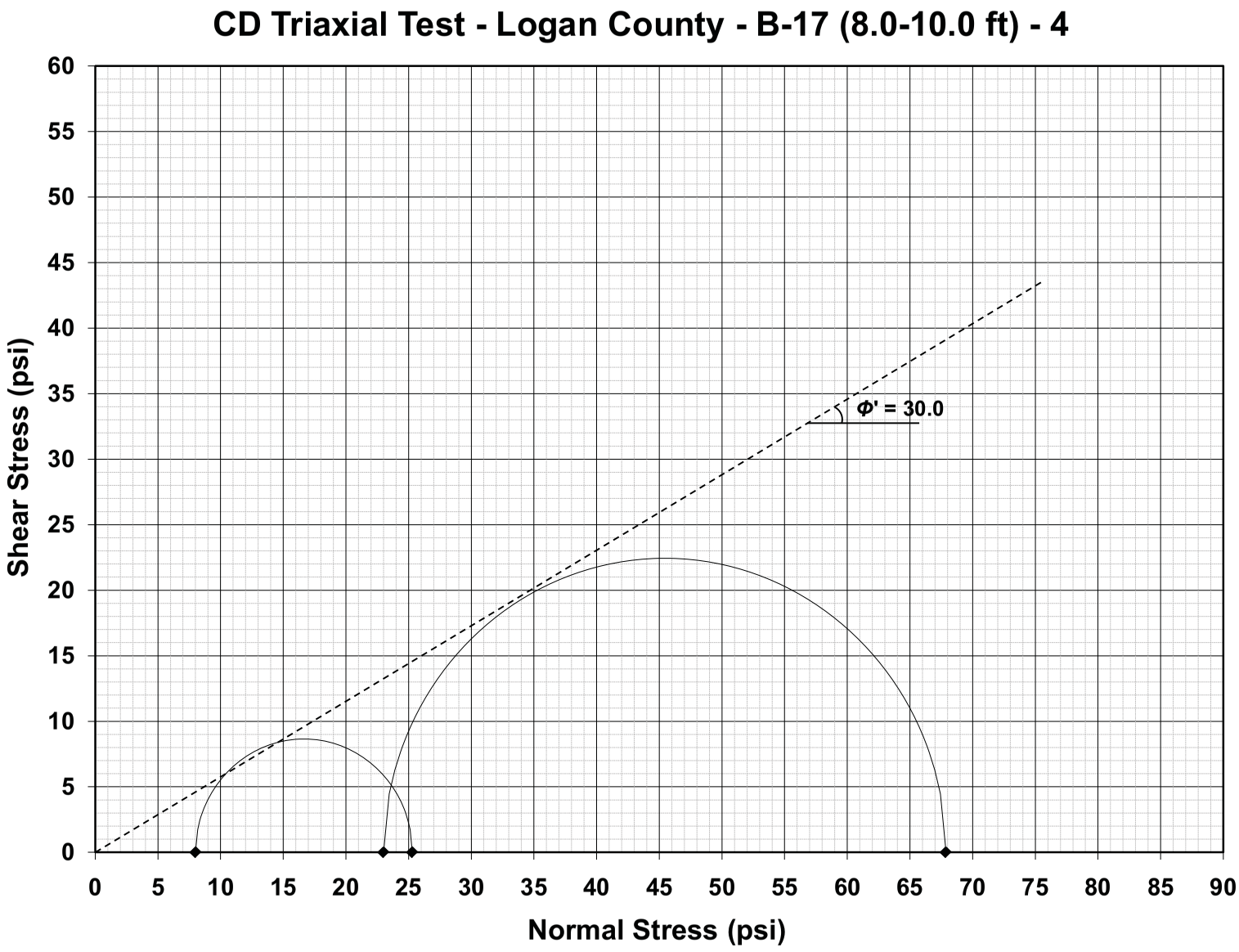
THE OHIO STATE UNIVERSITY SOIL MECHANICS LABORATORY



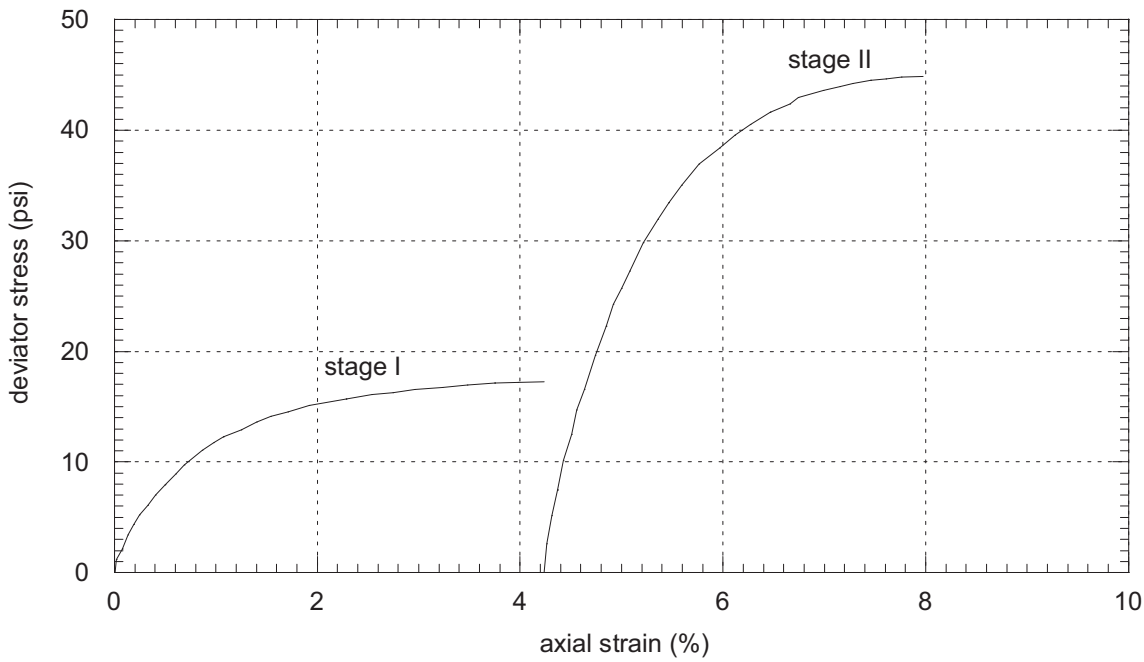
	INITIAL		FINAL		MULTISTAGE LOADING		I	II	III
SPECIMEN WEIGHT	W_0 [g]	181.0	W_f [g]	178.46	CELL PRESSURE	σ_3 [psi]	18	18	25
SPECIMEN HEIGHT	H_0 [in]	3.23	H_f [in]	2.75	PORE AIR PRESSURE	u_a [psi]	15	15	15
SPECIMEN DIAMETER	D_0 [in]	1.45	D_f [in]	1.51	PORE WATER PRESSURE	u_w [psi]	13	8	8
WATER CONTENT	w_0 [%]	17.18*	w_f [%]	16.2	NET CONFINING PRESSURE	$(\sigma_3 - u_a)$ [psi]	3	3	10
DRY UNIT WEIGHT	γ_{d0} [pcf]	109.35	γ_{df} [pcf]	118.43	MATRIC SUCTION	$(\sigma_a - u_w)$ [psi]	2	7	7
SATURATION	S_0 [%]	85.19	S_f [%]	102.60	MAXIMUM DEVIATOR STRESS	$(\sigma_1 - \sigma_3)_{max}$ [psi]	8.70	15.05	22.37
VOID RATIO	e_0	0.5465	e_f	0.4279	MAXIMUM STRESS RATIO	$(\sigma_1 / \sigma_3)_{max}$	1.48	1.84	1.89

DESCRIPTION	gray clay (visual)
CLASSIFICATION	A-6a (ODOT class.)
AXIAL STRAIN RATE	0.001 mm/min
TYPE OF SPECIMEN	undisturbed
LL 30	PL 17	PI 13	G_S 2.71**
TYPE OF TEST	CD - unsaturated

REMARKS	PROJECT	Bio-Engineering for Land Stabilization	
*w_0(%) from trimmings	AREA	Logan County—SR33/SR347	
**G_s assumed	BORING ID	BH 16	SAMPLE NO. 1-bottom
	DEPTH/ELEV.	(4.0-6.0) ft	DATE February 5, 2006
	TECH	CMK	CHECKED
1 of 1	**TRIAXIAL COMPRESSION TEST REPORT**		


CD Triaxial Test - Logan County - B-17 (8.0-10.0 ft) - 4
Shear Stress (psi)
Normal Stress (psi)
Φ' = 30.0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90

THE OHIO STATE UNIVERSITY SOIL MECHANICS LABORATORY



	INITIAL		FINAL		MULTISTAGE LOADING		I	II
SPECIMEN WEIGHT	W_0 [g]	170.47	W_f [g]	177.01	CELL PRESSURE	σ_3 [psi]	18	33
SPECIMEN HEIGHT	H_0 [in]	3.2	H_f [in]	-	PORE AIR PRESSURE	u_a [psi]	15	20
SPECIMEN DIAMETER	D_0 [in]	1.4	D_f [in]	-	PORE WATER PRESSURE	u_w [psi]	10	10
WATER CONTENT	w_0 [%]	11.36*	w_f [%]	16.25	NET CONFINING PRESSURE	$(\sigma_3 - u_a)$ [psi]	3	13
DRY DENSITY	γ_{d0} [pcf]	118.38	γ_{df} [pcf]	-	MATRIC SUCTION	$(\sigma_a - u_w)$ [psi]	5	10
SATURATION	S_0 [%]	71.86	S_f [%]	-	MAXIMUM DEVIATOR STRESS	$(\sigma_1 - \sigma_3)_{max}$ [psi]	17.24	44.87
VOID RATIO	e_0	0.4284	e_f	-	MAXIMUM STRESS RATIO	$(\sigma_1 / \sigma_3)_{max}$	1.96	3.49

DESCRIPTION	brown clay w/ few stones (visual)
CLASSIFICATION	A-4a (ODOT class.)
AXIAL STRAIN RATE	0.001 $^{mm}/_{min}$
TYPE OF SPECIMEN	undisturbed
LL 22 / PL 16 / PI 6 / G_S 2.71**	
TYPE OF TEST	CD - unsaturated

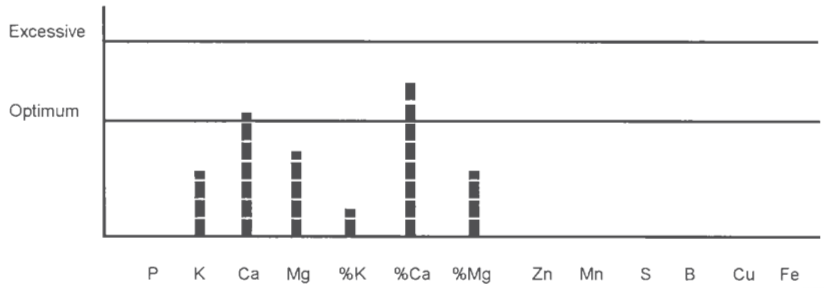
REMARKS	PROJECT	Bio-Engineering for Land Stabilization	
*w_0(%) from trimmings	AREA	Logan County—SR33/SR347	
**G_s assumed	BORING ID	BH 17	SAMPLE NO. 4
	DEPTH/ELEV.	(8.0-10.0) ft	DATE November 9, 2005
	TECH	CMK	CHECKED
1 of 1	**TRIAXIAL COMPRESSION TEST REPORT**		

EAL MAR
SOIL TESTING LABS

Sample Submitted By	Grower	Date of Report	Report Number	Record Number	Lab #	Field	Sample
CHRISTOPHER KOKESH 6893 MEADOW OAK DR. COLUMBUS, OH 43235	LOGAN CO SR 33/SR 347	02/13/06	278.013	20183	02233A		

Organic Matter %	Phosphorus Bray P1	Potassium K	Magnesium Mg	Calcium Ca	pH		Cation Exchange Capacity	Percent Base Saturation			Sulfur S	Zinc Zn	Manganese Mn	Boron B	Copper Cu	Iron Fe
					Soil	Buffer		%K	%Mg	%Ca						
1.5	4	191	788	10624	7.5		30.6	0.8	10.7	87						

Crop/Yield	Previous Crop	Nitrogen Lbs/A	P_2O_5 Lbs/A	K_2O Lbs/A	Lime		Magnesium Mg Lbs/A	Sulfur S Lbs/A	Zinc Zn Lbs/A	Manganese Mn Lbs/A	Boron B Lbs/A	Copper Cu Lbs/A	Iron Fe Lbs/A
					T/A	Type							
SHRUBS/BUSHES 1 NA		120	150	200	0.0								
HARDWOOD TREES 1 NA		120	150	200	0.0								



Comments:

Test results reported in pounds per acre

Soluble salts: 1.280 mmhos/cm

Na #/A = 218
% Na = 1.6

130 South State Street
Westerville, OH 43081
614-523-1005

CAL MAR
SOIL TESTING LABS

02/13/06
LOGAN CO
SR 33/SR 347

Sample submitted by:
CHRISTOPHER KOKESH

6893 MEADOW OAK DR.
COLUMBUS, OH 43235

Test Results

Results are in pounds per acre except pH or as noted

LAB NUMBER 278.013 SAMPLE ID	pH Soil	pH Buffer	Phosphorus (P)	Potassium (K)	Magnesium (Mg)	Calcium (Ca)
2233	7.5		4	191	788	10624

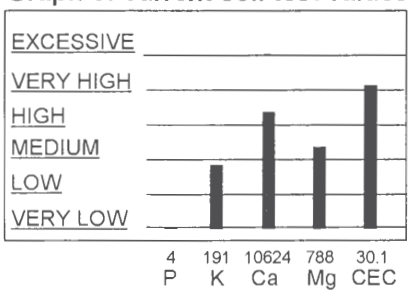
% Organic Matter	Cation Exchange Capacity	PERCENT BASE SATURATION			
		%Potassium	%Magnesium	%Calcium	%Hydrogen
1.5	30.1	0.8	10.9	88	

Recommendations

For optimum growth of your shrubs/bushes we recommend adding the following

NITROGEN (N)	PHOSPHORUS (P205)	POTASSIUM (K2O)	Sulfur- Lbs/1000 Sq.Ft.		
POUNDS / 1000 Sq. Ft. per season	POUNDS / 1000 Sq. Ft. per season	POUNDS / 1000 Sq. Ft. per season	SOIL DEPTH (inches)		
2.8	3.4	4.6	3	3	
			6	5	
			9	8	
			12	11	
			Type		

Graph of current soil test values



Please see notes on page two
page 1

CAL MAR SOIL TESTING LABS, 130 SOUTH STATE STREET, WESTERVILLE, OH 43081
PH: 614-523-1005 FAX: 614.523.1004

CAL MAR
SOIL TESTING LABS

02/13/06
LOGAN CO
SR 33/SR 347

Sample submitted by:
CHRISTOPHER KOKESH

6893 MEADOW OAK DR.
COLUMBUS, OH 43235

Notes

Soil pH

The pH level indicated by your soil test is above the optimum for your requested plant type. It will be necessary to apply sulfur in order to lower the current pH to the target pH level for your plant type. If practical, incorporate the sulfur in the soil to the rooting depth of your plant type. Recommendations have been made to assist you in applying the correct amount of sulfur depending on the expected rooting depth.

Nitrogen

Your nitrogen recommendation is based upon the plants to be grown and the soil organic matter. Your nitrogen recommendation has been increased slightly due to a low soil organic matter percentage. Nitrogen should be worked into the soil prior to planting when possible. For established plants, apply only a portion of the recommended nitrogen throughout the growing season. Be very cautious about applying nitrogen in very warm or dry weather, since this can damage the plant tissue.

Phosphorus

Your phosphorus value is very low and it may be affecting plant growth. It will be necessary to apply phosphorus in order to raise the soil phosphorus level. Phosphorus applications should be worked into the soil prior to planting if possible. If the plant material is already established, apply one-half of the recommended phosphorus to the soil surface, for now. The next time soil and phosphorus can be mixed thoroughly, apply the remaining amount recommended.

Potassium

The potassium level indicated on this sample is below the optimum for the indicated plant type. It is necessary to apply potassium in order to raise the level in the soil to the optimum range for your plant type. The best way to apply the potassium is to thoroughly mix the it in the soil to the rooting depth of your plants. Recommendations have been made to assist you in applying the correct amount of potassium. Plant injury can be minimized if you water after applying potassium.

These notes refer to the recommendations and results on page one. Additional general information is enclosed.

CAL MAR SOIL TESTING LABS, 130 SOUTH STATE STREET, WESTERVILLE, OH 43081
PH: 614-523-1005 FAX: 614.523.1004

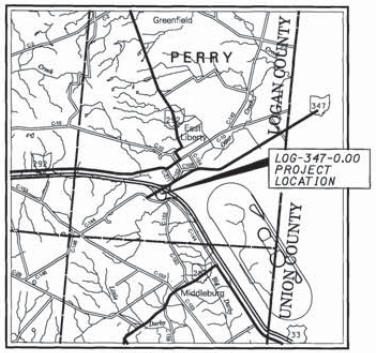
STATE OF OHIO

DEPARTMENT OF TRANSPORTATION

LOG/UNI-347/33-0.00/8.36

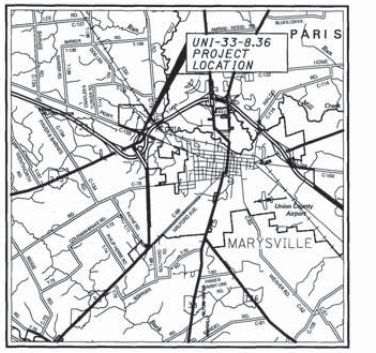
PERRY TOWNSHIP

LOGAN COUNTY



LOCATION MAP

LATITUDE: 40°19'44" N LONGITUDE: 83°35'09" W



LOCATION MAP

LATITUDE: 40°14'19" N LONGITUDE: 83°24'06" W

INDEX OF SHEETS:

TITLE SHEET	1
SCHEMATIC PLAN	2-2A
GENERAL NOTES	3-3A
GENERAL SUMMARY	4
PLAN DETAILS	5-8B
DETAIL NOTES	9

SCALE IN MILES

0 1 2 3 4

N

PORTION TO BE IMPROVED.....

INTERSTATE & DIVIDED HIGHWAY.....

UNDIVIDED STATE & FEDERAL ROUTES.....

OTHER ROADS.....

UNDERGROUND UTILITIES

TWO WORKING DAYS

BEFORE YOU DIG

CALL 1-800-362-2764 (TOLL FREE)

OHIO UTILITIES PROTECTION SERVICE

NON-MEMBERS

MUST BE CALLED DIRECTLY

PLAN PREPARED BY:

OHIO DEPT. OF TRANSPORTATION

DISTRICT SEVEN

PRODUCTION DEPARTMENT

ENGINEERS SEAL:

STATE OF OHIO PAUL ROBERT HARTMAN No. 47388 PROFESSIONAL ENGINEER

SIGNED: Paul Robert Hartman

DATE: 7-17-06

STANDARD CONSTRUCTION DRAWINGS						SUPPLEMENTAL SPECIFICATIONS	
DM-4.3	7-19-02					800	8-9-06
DM-4.4	7-19-02					832	4-25-06
						SPECIAL PROVISIONS	

PROJECT DESCRIPTION

LOGAN COUNTY

ENVIRONMENTAL MITIGATION - STABILIZATION OF SLOPE AREA (DITCH EMBANKMENT) AT THE INTERCHANGE OF US33 AND SR347 INFIELD AREA CARRYING DRAINAGE FROM WEST TO EAST THROUGH THE LOOP RAMP "B".

UNION COUNTY

ENVIRONMENTAL MITIGATION - STABILIZATION OF SLOPE AREA AT THE INTERCHANGE OF US33, US 36, SR 4 , AND COUNTY ROAD 133.

PROJECT EDA - N/A (MAINTENANCE PROJECT)
CONTRACTOR EDA - N/A (MAINTENANCE PROJECT)
NOI EDA - N/A (MAINTENANCE PROJECT)

2005 SPECIFICATIONS

THE STANDARD SPECIFICATIONS OF THE STATE OF OHIO, DEPARTMENT OF TRANSPORTATION, INCLUDING CHANGES AND SUPPLEMENTAL SPECIFICATIONS LISTED IN THE PROPOSAL SHALL GOVERN THIS IMPROVEMENT.

APPROVED William L. Harrison/PAN
DATE 7-17-06 DISTRICT DEPUTY DIRECTOR

APPROVED Gordon Parker
DATE 8-30-06 DIRECTOR, DEPARTMENT OF TRANSPORTATION

FEDERAL PROJECT NO. NON-FEDERAL

PID NO. 78581

CONSTRUCTION PROJECT NO.

RAILROAD INVOLVEMENT NONE

LOG/UNI-347/33-0.00/8.36

1/9

LOG SR 347/33 0.00/8.36
060404 PID 78581
DRT 7 10/18/2006

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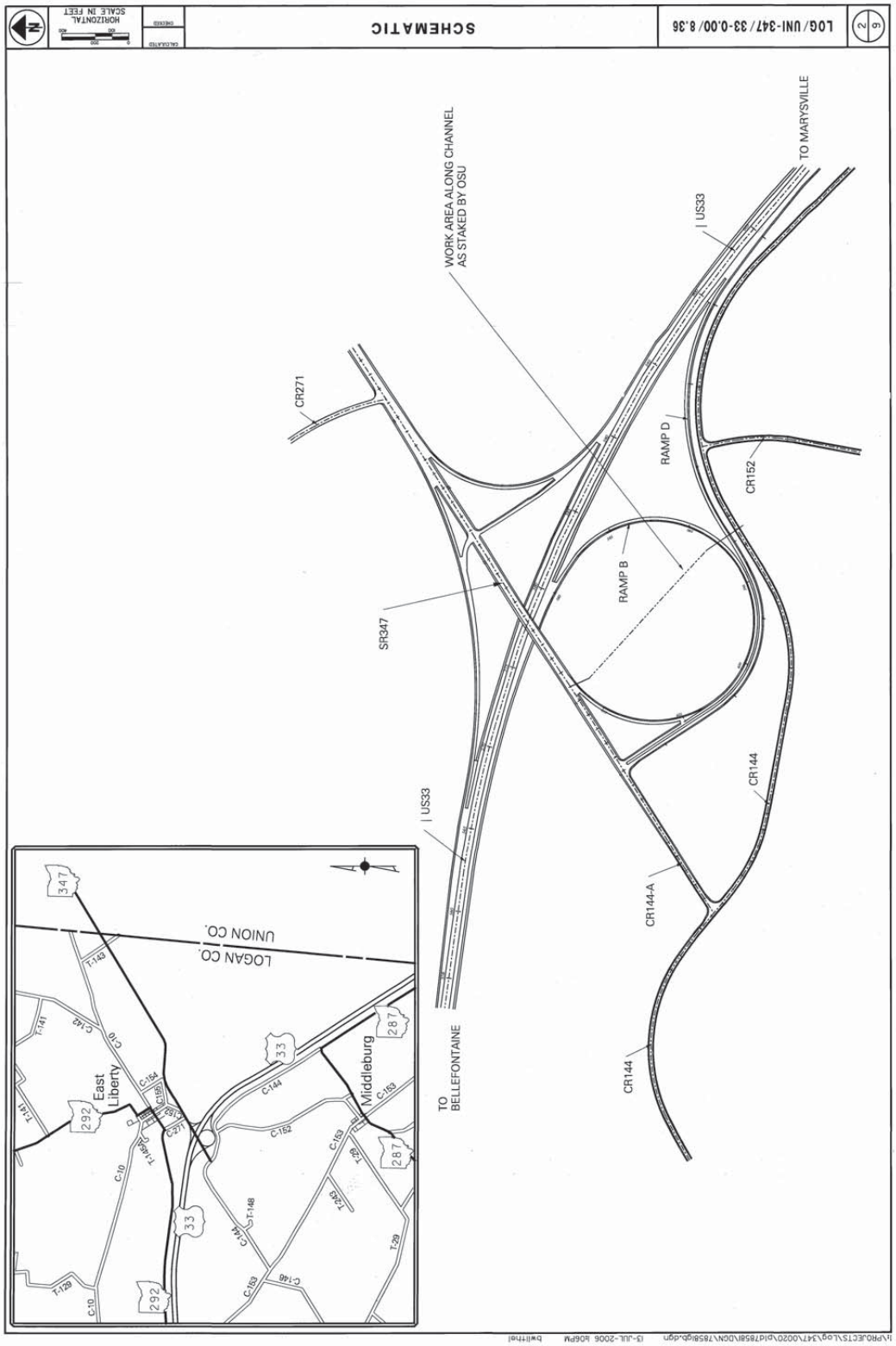
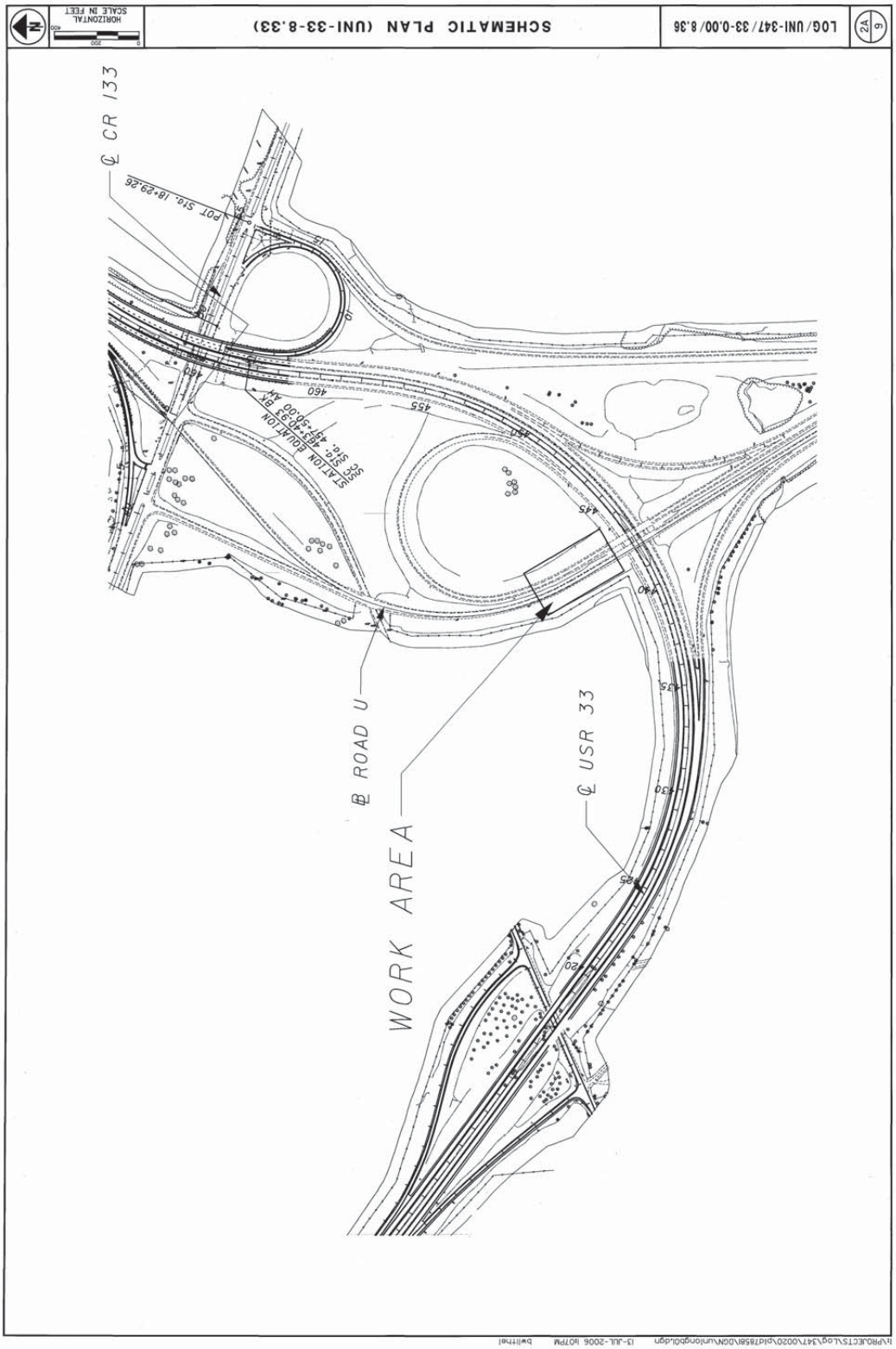

LOG/UNI-347/33-0.00/8.36
2/9
SCHEMATIC
HORIZONTAL
SCALE IN FEET
TO MARYSVILLE
I US33
WORK AREA ALONG CHANNEL
AS STAKED BY OSU
CR271
RAMP D
CR152
RAMP B
SR347
CR144
I US33
CR144-A
CR144
TO
BELLEFONTAINE
LOGAN CO.
UNION CO.
East
Liberty
Middleburg
347
292
33
287
C-10
C-144
C-152
C-153
C-154
T-143
T-141
T-147
T-148
T-149
T-129
C-142
C-146
C-27


LOG/UNI-347/33-0.00/8.36
2A
9
SCHEMATIC PLAN (UNI-33-8.33)
HORIZONTAL
SCALE IN FEET
0
200
400
℄ CR 133
Pot Sta. 18+29.26
℄ ROAD U
℄ USR 33
WORK AREA
STATION EQUATION
Sta. 457+91 BK
Sta. 457+50.02 AH
455
460
450
445
440
435
430
425
420
415
410

CONTACT FOR THE OHIO STATE UNIVERSITY

THE CONTRACTOR SHALL CONTACT THE OHIO STATE UNIVERSITY 2 WEEKS BEFORE ANY WORK IS TO BEGIN.

LISTED BELOW ARE THE CONTACTS FOR THE OHIO STATE UNIVERSITY:

PATRICK J. FOX, PROFESSOR
DEPT. OF CIVIL AND ENVIRONMENTAL ENGINEERING AND GEODETIC SCIENCE
495A HITCHCOCK HALL
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COLUMBUS, OHIO 43210

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483C HITCHCOCK HALL
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COLUMBUS, OHIO 43210

TEL. (614) 292-1071
E-MAIL: WU.26@OSU.EDU

BORROW MATERIAL

IDENTIFICATION OF BORROW AREAS ON THE PLANS DOES NOT INDICATE THAT THE MATERIAL AVAILABLE FROM THESE AREAS MEETS THE REQUIREMENTS OF CMS 203.

SEEDING AND MULCHING

THE FOLLOWING QUANTITIES ARE PROVIDED TO PROMOTE GROWTH AND CARE OF PERMANENT SEEDED AREAS:

THE SEED MIXTURE SHALL BE CLASS-TYPE 3A, SLOPE MIXTURES PER 2005 CMS TABLE 659.09-1 PLUS 20 LB/ACRE OF WINTER WHEAT.

659, SEEDING AND MULCHING 1875 SQ. YD.

659, COMMERCIAL FERTILIZER 0.25 TON

659, WATER 10 M. GAL.

SEEDING AND MULCHING SHALL BE APPLIED TO ALL AREAS OF EXPOSED SOIL OR AS DIRECTED BY THE PROJECT ENGINEER. QUANTITY CALCULATIONS FOR SEEDING AND MULCHING ARE BASED ON THESE LIMITS.

ITEM 601 - SLOPE PROTECTION, MISC: GEOCELL

THIS ITEM SHALL CONSIST OF FURNISHING AND INSTALLING GEOCELLS FOR SLOPE PROTECTION AS SHOWN IN THESE PLANS. THE GEOCELL SHALL BE A VIRGIN, NON-THERMALLY DEGRADED POLYETHYLENE POLYMER WHICH IS CLEAN AND FREE OF ANY CONTAMINANTS. THE GEOCELL SHALL BE FREE OF DEFECTS INCLUDING TEARS, NODULES OR ANY OTHER DEFECT THAT WOULD AFFECT ITS SERVICEABILITY.

CONSTRUCTION AND PLACEMENT OF THE GEOCELL SLOPE PROTECTION SHALL BE AS DESCRIBED IN THESE PLANS, OR AS DIRECTED BY THE PROJECT ENGINEER.

PAYMENT FOR THE ABOVE WORK SHALL BE MADE AT THE UNIT PRICE BID FOR ITEM 601 - SLOPE PROTECTION, MISC.: GEOCELL, FEET, AND SHALL INCLUDE ALL LABOR, TOOLS, EQUIPMENT, AND MATERIALS NECESSARY TO CONSTRUCT THE GEOCELL SLOPE PROTECTION.

ITEM 610 - SPECIAL - RETAINING WALL MISC: GEOCELL GRAVITY WALL

THIS ITEM SHALL CONSIST OF FURNISHING AND INSTALLING A GEOCELL GRAVITY WALL AS SHOWN IN THE PLANS. THE GEOCELL SHALL BE A VIRGIN, NON-THERMALLY DEGRADED POLYETHYLENE POLYMER WHICH IS CLEAN AND FREE OF ANY CONTAMINANTS. THE GEOCELL SHALL BE FREE OF DEFECTS INCLUDING TEARS, NODULES OR ANY OTHER DEFECT THAT WOULD AFFECT ITS SERVICEABILITY.

CONSTRUCTION OF THE GEOCELL GRAVITY WALL SHALL BE AS DESCRIBED IN THESE PLANS, OR AS DIRECTED BY THE PROJECT ENGINEER.

PAYMENT FOR THE ABOVE WORK SHALL BE MADE AT THE UNIT PRICE BID FOR ITEM 610 - SPECIAL - RETAINING WALL MISC: GEOCELL GRAVITY WALL, LUMP, AND SHALL INCLUDE ALL LABOR, TOOLS, EQUIPMENT, AND MATERIALS NECESSARY TO CONSTRUCT THE GEOCELL GRAVITY WALL.

ITEM 661 - PLANTING, MISC.: WILLOW POLE INSTALLATION AND PROTECTION

THIS ITEM SHALL CONSIST OF CUTTING, PREPARING, AND PLANTING WILLOW POLES, AS DESCRIBED IN THESE PLANS. THE LOCATION OF THE LIVE POLES IS THE ODNR DELAWARE WILDLIFE AREA WHICH IS WITHIN A 40 MILE RADIUS OF THE JOB SITE AND MORE SPECIFICALLY, EIGHT MILES NORTH OF DELAWARE, 10 MILES SOUTH OF MARION, AND BETWEEN U.S. ROUTES 42 AND 23. THE WILDLIFE AREA IS ADJACENT TO THE DELAWARE RESERVOIR AND DELAWARE STATE PARK AND CAN BE REACHED FROM THE EAST AND WEST BY STATE ROUTE 229 AND FROM THE SOUTH AND NORTH BY U.S. ROUTE 23 AND COUNTY ROAD 220. CONTACT TIM DAVIS AT LEAST TWO DAYS PRIOR TO PICKING UP THE LIVE POLES (CELL # 740-360-7615 OR OFFICE # 740-499-3019). PLACEMENT OF THE WILLOW POLES SHALL BE AS DESCRIBED IN THESE PLANS OR AS DIRECTED BY THE OSU PERSONNEL.

THE PROVISION IN CMS 661.20, FOR 20 PERCENT ADDITIONAL COMPENSATION FOR LIVING PLANTS AT THE END OF THE ESTABLISHED PERIOD, SHALL NOT APPLY.

PAYMENT FOR THE ABOVE WORK SHALL BE MADE AT THE UNIT PRICE BID FOR ITEM 661 - PLANTING, MISC.: WILLOW POLE INSTALLATION AND PROTECTION, LUMP, AND SHALL INCLUDE ALL LABOR, TOOLS, EQUIPMENT, AND MATERIALS NECESSARY TO CUT, INSTALL, AND PROTECT THE WILLOW POLES.

WORK PERIOD

ALL WORK TO INSTALL WILLOW POLES AND BRUSH SHALL BE PERFORMED BETWEEN NOVEMBER 1 AND APRIL 2. DELAYS DUE TO WEATHER DURING THIS PERIOD SHALL NOT BE CONSIDERED FOR EXTENSION OF THE CONTRACT.

ITEM 203 EXCAVATION, AS PER PLAN

THIS ITEM SHALL CONSIST OF REMOVING THE MATERIAL IN THE AREAS STAKED AND SPECIFIED BY O.S.U. PERSONNEL. EXCAVATION SHALL BE AS PER CMS 203 OR AS DIRECTED BY THE ENGINEER. ALL MATERIALS, LABOR, AND INCIDENTALS NEEDED TO PERFORM THE EXCAVATION, AS DETAILED IN THESE PLANS, SHALL BE INCLUDED IN THE CONTRACT PRICE FOR ITEM 203 EXCAVATION, AS PER PLAN

ITEM 203 EMBANKMENT, AS PER PLAN

THIS ITEM SHALL INCLUDE PREPARING THE AREAS UPON WHICH THE PROPOSED BERM IS TO BE CONSTRUCTED, PLACING AND COMPACTING APPROVED MATERIAL FOR THE PROPOSED BERM, "AREA 10", PER CMS 203, OR AS DIRECTED BY THE PROJECT ENGINEER. ALL MATERIALS LABOR, AND INCIDENTALS NEEDED TO PERFORM THE WORK, AS DETAILED IN THESE PLANS SHALL BE INCLUDED IN THE CONTRACT PRICE FOR ITEM 203 EMBANKMENT, AS PER PLAN.

COORDINATION WITH OTHER CONTRACTORS

THE CONTRACTOR SHOULD BE AWARE THAT DISTRICT 6 HAS AN EMERGENCY EMBANKMENT STABILIZATION PROJECT (UNI-33-8.36/12.13, PID80442) SCHEDULED TO SELL IN THE JUNE21, 2006 BID LETTING. THE LOCATIONS FOR THE PROJECT ARE AT THE US 33 AND US 36/SR 4/ SR 245 INTERCHANGE AND AT THE US 33 AT US 36 EAST.

ITEM 614 - MAINTAINING TRAFFIC

AT NO TIME ARE ANY ROADS TO BE CLOSED TO TRAFFIC. ROAD WORK AHEAD SIGNS, W20-1-48, SHALL BE POSTED WHEN VEHICLES WILL BE MOVING IN AND OUT OF THE WORK AREA. SIGN LOCATIONS SHALL BE AS PER CMS 614.04 OR AT THE DISCRETION OF THE PROJECT ENGINEER.

PAYMENT FOR THE ABOVE WORK SHALL BE MADE AT THE UNIT PRICE BID FOR ITEM 614 - MAINTAINING TRAFFIC, LUMP, AND SHALL INCLUDE ALL LABOR, TOOLS, EQUIPMENT, AND MATERIALS NECESSARY TO MAINTAIN TRAFFIC.

CONTACT FOR THE OHIO STATE UNIVERSITY

THE CONTRACTOR SHALL CONTACT THE OHIO STATE UNIVERSITY TWO (2) WEEKS BEFORE ANY WORK IS TO BEGIN.

LISTED BELOW ARE THE CONTACTS FOR THE OHIO STATE UNIVERSITY:

PATRICK J. FOX, PROFESSOR
DEPT. OF CIVIL AND ENVIRONMENTAL ENGINEERING AND
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GEODETIC SCIENCE
483C HITCHCOCK HALL
THE OHIO STATE UNIVERSITY
COLUMBUS, OHIO 43210

TEL. (614) 292-1071
E-MAIL: WU.26@OSU.EDU

ITEM 661 - PLANTING, MISC.: WILLOW POLE INSTALLATION AND PROTECTION

THE CONTRACTOR WILL COORDINATE WITH THE OHIO STATE UNIVERSITY FOR THE LOCATION OF THE LIVE POLES. THE CONTRACTOR SHALL SUPPLY LABOR TO CUT THE LIVE POLES AND TRANSPORT THE POLES TO THE JOBSITE. THE LOCATION WILL BE WITHIN A 40 MILE RADIUS OF THE JOB SITE. DEER REPELLANT TABLETS (REPELLEX OR EQUIVALENT AS APPROVED BY THE OSU REPRESENTATIVE AND THE ENGINEER) AND PROTECTIVE SPRAY (DEER AWAY, TREE GUARD, OR EQUIVALENT AS APPROVED BY OSU AND THE ENGINEER) SHALL BE APPLIED AS PER THESE PLANS. INCLUDED FOR PAYMENT IN THIS ITEM SHALL BE THE HOLE, DEER PROTECTION, PEA GRAVEL, NON-WOVEN GEOTEXTILE FABRIC, AND PVC PIPE, ALL AS DETAILED IN THESE PLANS.

ALL LABOR, MATERIALS, AND INCIDENTALS NEEDED TO INSTALL THE WILLOW POLES AND PROTECTION, AS PER THESE PLANS, SHALL BE PAID FOR UNDER LUMP SUM ITEM 661, PLANTING, MISC.: WILLOW POLE INSTALLATION AND PROTECTION FOR UNI-33-8.33

ITEM 614 MAINTAINING TRAFFIC

AT NO TIME ARE ANY ROADS TO BE CLOSED TO TRAFFIC. ROAD WORK AHEAD SIGN, W20-1-48, WILL BE POSTED WHEN VEHICLES WILL BE MOVING IN AND OUT OF THE WORK AREA. SIGN LOCATION SHALL BE AS PER CMS 614.04 OR AT THE DISCRETION OF THE ENGINEER.

CONSTRUCTION PROCEDURES

1. EARTHWORK

1.1 GENERAL

CONSTRUCTION EQUIPMENT IS NOT PERMITTED ON SLOPE FACES. ALL EARTHWORKS SHALL BE PERFORMED IN A MANNER AS NOT TO DISTURB THE SLOPE FACES WITH THE EXCEPTION TO CONSTRUCTION INSTALLATION SPECIFICALLY REQUIRING LABOR AND/OR EQUIPMENT ON SLOPE FACE. EXTENT OF CONSTRUCTION ACTIVITY WILL BE MARKED WITH STAKES AND OSU AND/OR ODOT PERSONNEL SHALL BE ONSITE TO SUPERVISE CONSTRUCTION. NO ACTIVITY SHALL INTERFERE WITH ONSITE INSTRUMENTATION. (PIEZOMETERS, TENSIOMETE, INCLINOMETERS, ETC.)

1.2 SCRAPING OF SLOPES

AREAS ON SLOPE FACES WHERE INDICATED SHALL BE SMOOTHED WITH A LOW-IMPACT TRACTOR, DOZER, OR EQUIVALENT PRIOR TO THE INSTALLATION OF VEGETATIVE MATERIAL.

2. WILLOW POLES

2.1 CUTTING, TRANSPORTATION, AND STORAGE

WILLOW POLES ARE TO BE CUT AT THE LOCATION (S) SPECIFIED BY OSU AND TRANSPORTED TO THE CONSTRUCTION SITE THE SAME DAY. THE CUTTING SITE (S) MAY BE UP TO 40 MILES AWAY FROM THE PROJECT SIE. WILLOW POLES ARE TO BE 1 - 2 1/2 INCHES IN DIAMETER AND CUT TO 6 1/2 TO 7 1/2 FEET IN LENGTH. WILLOW POLES ARE TO BE RELATIVELY STRAIGHT AND FREE OF LARGE BENDS, DAMAGE, AND DISEASE. WILLOW POLES ARE TO BE KEPT DAMP DURING TRANSPORT IF TEMPERATURES ARE ABOVE FREEZING BY MEANS OF BURLAP, TARPS, ETC. ONCE AT THE SITE, POLES ARE TO BE KEPT UNDER WATER IF TEMPERATURES ARE ABOVE FREEZING. THE CONTRACTOR IS TO MAINTAIN A MINIMUM OF TWO CATTLE WATE TROUGHS ON SITE TO KEEP POLES WET PRIOR TO INSTALLATION. WATER IN TROUGHS SHOULD BE CHANGED EVERY 2-3 DAYS. WILLOW POLES ARE TO BE INSTALLED WITHIN FIVE (5) DAYS OF CUTTING.

2.2 PREPARATION AND INSTALLATION

WILLOW POLES MTERIALS WILL BE PREPARED AND INSTALLED BY THE CONTRACTOR AS INSTRUCTED BY OSU PERSONNEL.

WILLOW POLES WILL BE PREPARED BY USING A CHAIN SAW, LOPPERS, PRUNERS, ETC., TO TRIM OFF KNOBS ON EACH POLE TO MAKE THE POLE SMOOTH ALONG ITS LENGTH.

WILLOW POLES WILL BE INSTALLED IN PRE-AUGERED HOLES THAT 3 INCHES IN DIAMETER. HOLES MAY BE MADE UNING AN AUGER, A SPIKE, OR OTHER APPROVED METHODS IN THE AREAS DESIGNATED BY THE OHIO STATE UNIVERSITY. THE HOLES WILL BE MADE 3 FEET ON CENTER IN A GRID PATTERN AND 4 1/2 FEET DEEP. LOCATION OF HOLES WILL BE DETERMINED BY THE OSU REPRESENTATIVE.

ONE WILLOW POLE WILL BE DROPPED INTO EACH HOLE WITH THE LARGER DIAMETER END PLACED IN FIRST. THE POLE SHOULD STICK OUT OF THE HOLE 1- 1 1/2 FEET AFTER PLACEMENT. LIMITED HAMMERING MAY BE REQUIRED IN SOME CASES AND, IF NEEDED SHOULD BE DONE WITH A DEAD-BLOW OR RUBBER MALLET. HOLES ARE TO BE BACKFILLED WITH COARSE SAND AND THE LAST 4- 6 INCHES OF EACH HOLE SHALL BE FILLED WITH GRANULAR BENTONITE.

THE TWELVE INCH LONG BREATHER TUBE (1/2" DIAMETER PVC OR EQUIVALENT) SHALL BE INSTALLED IN EACH HOLE PRIOR TO THE PLACEMENT OF BENTONITE. THE BREATHER TUBE SHALL EXTEND 4 INCHES INTO THE COARSE SAND BACKFILL, MUST STICK ABOVE THE GROUND SURFACE A MINIMUM OF 2 INCHES, AND SHOULD BE NOTICEABLY FREE OF OBSTRUCTIONS.

AN 18 INCH SQUARE OF BIODEGRADABLE WEED CONTROL FABRIC WITH A SLIT IN THE MIDDLE SHALL BE PLACED OVER EACH POLE AND SECURED BY PINS TO THE GROUND SURFACE.

FOLLOWING THE INSTALLATION AND BACK FILL OF THE LIVE WILLOW POLES, EACH POLE SHALL PROTRUDE FROM THE GROUND SURFACE APPROXIMATELY 1 FOOT. TRIMMING MAY BE REQUIRED FOR EXCESSIVELY LONG POLES. EACH POLE SHALL BE TREATED TO PREVENT SPLITTING AND DRYING BY APPLYING TREEKOTE TREE WOUND DRESSING OR EQUIVALENT TO THE EXPOSED TOP SURFACE. MANUFACTURER'S RECOMMENDATIONS SHALL BE FOLLOWED FOR THE APPLICATION OF TREE WOUND DRESSING.

2.3 REPELLEX

PLACE TWO (2) TABLETS OF REPELLEX, OR EQUIVALENT PRODUCT, IN EACH HOLE APPROXIMATELY ONE FOOT FROM THE TOP.

2.4 PROTECTIVE SPRAY

SPRAY POLES AFTER INSTALLATION WITH DEER AWAY, TREE GUARD, OR EQUIVALENT PRODUCT (APPROXIMATELY ON GALLON FOR 600 POLES OR AS PER MANUFACTURERS RECOMMENDATIONS).

3. EROSION CONTROL MAT, TYPE F

3.1 INSTALLATION

JUTE MAT SHALL BE INSTALLED IN ACCORDANCE TO MANUFACTURER'S RECOMMENDATIONS PLACED PRIOR TO WILLOW POLE INSTALLATION OVER MARKED AREA.

4. HYDROSEEDING

4.1 INSTALLATION

HYDROSEEDING WILL BE PROVIDED FOR INDICATED AREAS ACCORDING TO ODOT SPECIFICATIONS. SEED MIX WILL BE CLASS-TYPE 3A, SLOPE MIXTURES PER 2005 CMS TABLE 659.09-1 PLUS 20 LB/ACRE OF WINTER WHEAT. THE FOLLOWING QUANTITIES ARE CARRIED TO THE GENERAL SUMMARY.

ITEM 659 SEEDING AND MULCHING	792 SQ YD
ITEM 659 COMMERCIAL FERTILIZER	0.15 TON
ITEM 659 WATER	5 MGAL
ITEM 671 EROSIN CONTROL MAT, TYPE F	790 SQ YD

GENERAL NOTES (UNI-33-8.33)

LOG/UNI-347/33-0.00/8.36

3A
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SHEET NUMBER											ITEM	ITEM EXT.	GRAND TOTAL	UNIT	DESCRIPTION	SEE SHEET NO.
						3	3A	5								
															ROADWAY	
								250			203	10001	250	CU YD	EXCAVATION, AS PER PLAN	
								93			203	20001	93	CU YD	EMBANKMENT, AS PER PLAN	3
								250			204	50000	250	SQ YD	GEOTEXTILE FABRIC	3
															EROSION CONTROL	
								33			601	21100	33	SQ YD	SLOPE PROTECTION, MISC.: GEOCELL	
								8			653	10000	8	CU YD	TOPSOIL FURNISHED AND PLACED	3
						1875	792				659	10000	2667	SQ YD	SEEDING AND MULCHING	
						0.25	0.15				659	20000	0.40	TON	COMMERCIAL FERTILIZER	
						10	5				659	35000	15	M GAL	WATER	
							790	916			671	15050	1706	SQ YD	EROSION CONTROL MAT, TYPE F	
															LANDSCAPING	
						LUMP					661	99940	LUMP		PLANTING, MISC.: WILLOW POLE INSTALLATION AND PROTECTION	3
							LUMP				661	99940	LUMP		PLANTING, MISC.: WILLOW POLE INSTALLATION AND PROTECTION (UNI-33-8.36)	3A
															RETAINING WALLS	
																3
								100			SPECIAL	61050020	100	FT	RETAINING WALL, MISC.: GEOCELL GRAVITY WALL	
											614	11000	LUMP		MAINTAINING TRAFFIC	
											624	10000	LUMP		MOBILIZATION	

CALCULATED BCW
CHECKED

GENERAL SUMMARY

LOG/UNI-347/33-0.00/8.36

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9

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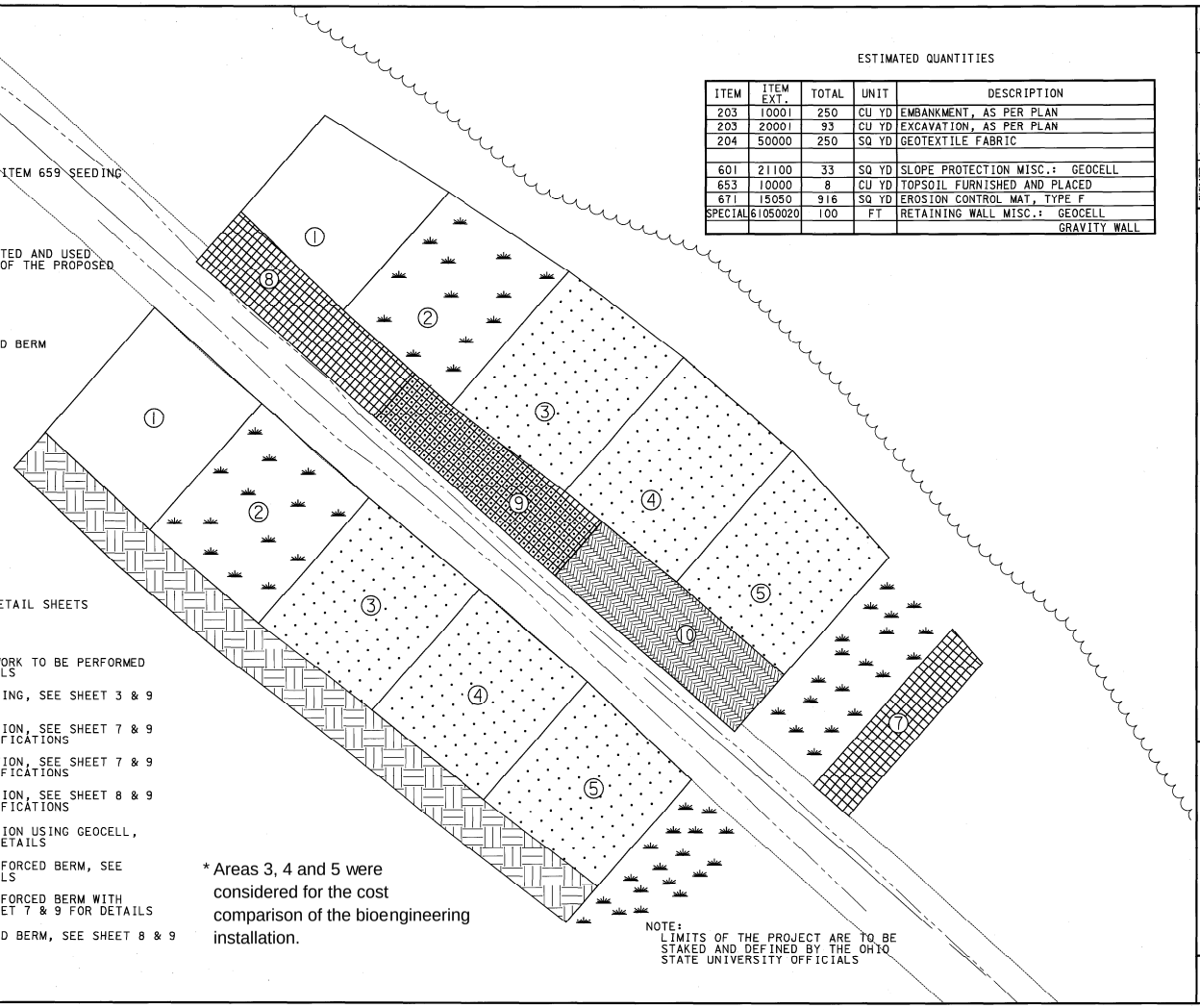
LEGEND:

- SEEDING ACCORDING TO ITEM 659 SEEDING AND MULCHING
- WILLOW POLE
- MATERIAL TO BE EXCAVATED AND USED FOR THE CONSTRUCTION OF THE PROPOSED BERM
- GEOCELLS
- PROPOSED BRUSH LAYERED BERM

FOR DIMENSIONS SEE DETAIL SHEETS

1. CONTROL SECTION, NO WORK TO BE PERFORMED SEE SHEET 6 FOR DETAILS
2. O.D.O.T STANDARD SEEDING, SEE SHEET 3 & 9 FOR DETAILS
3. WILLOW POLE INSTALLATION, SEE SHEET 7 & 9 FOR DETAILS AND SPECIFICATIONS
4. WILLOW POLE INSTALLATION, SEE SHEET 7 & 9 FOR DETAILS AND SPECIFICATIONS
5. WILLOW POLE INSTALLATION, SEE SHEET 8 & 9 FOR DETAILS AND SPECIFICATIONS
7. SLOPE EROSION PROTECTION USING GEOCELL, SEE SHEET 8 & 9 FOR DETAILS
8. PROPOSED GEOCELL REINFORCED BERM, SEE SHEET 6 & 9 FOR DETAILS
9. PROPOSED GEOCELL REINFORCED BERM WITH WILLOW POLES, SEE SHEET 7 & 9 FOR DETAILS
10. PROPOSED BRUSH LAYERED BERM, SEE SHEET 8 & 9 FOR DETAILS



* Areas 3, 4 and 5 were considered for the cost comparison of the bioengineering installation.

NOTE:
LIMITS OF THE PROJECT ARE TO BE STAKED AND DEFINED BY THE OHIO STATE UNIVERSITY OFFICIALS

ESTIMATED QUANTITIES

ITEM	ITEM EXT.	TOTAL	UNIT	DESCRIPTION
203	10001	250	CU YD	EMBANKMENT, AS PER PLAN
203	20001	93	CU YD	EXCAVATION, AS PER PLAN
204	50000	250	SQ YD	GEOTEXTILE FABRIC
601	21100	33	SQ YD	SLOPE PROTECTION MISC.: GEOCELL
653	10000	8	CU YD	TOPSOIL FURNISHED AND PLACED
671	15050	916	SQ YD	EROSION CONTROL MAT, TYPE F
SPECIAL	61050020	100	FT	RETAINING WALL MISC.: GEOCELL GRAVITY WALL

N

HORIZONTAL SCALE IN FEET 0 10 20

CALCULATED BCW CHECKED

PLAN
RAMP B INFIELD

LOG/UNI-347/33-0.00/8.36

5/9

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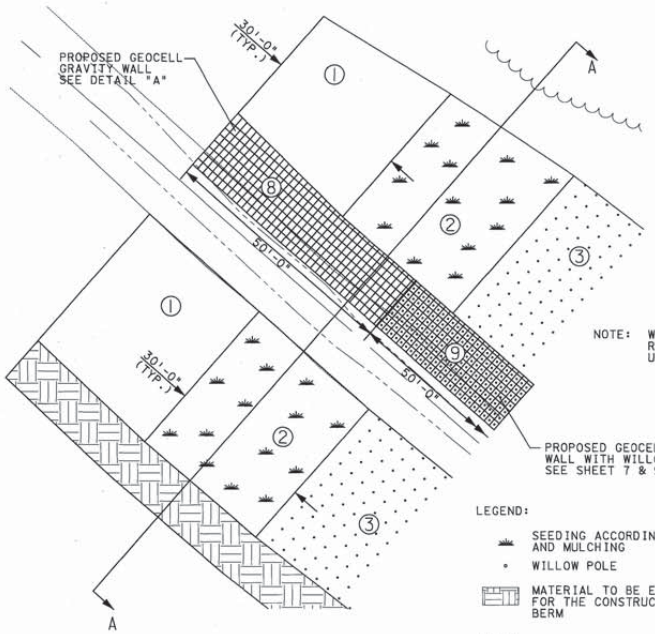


NOTE: WILLOW POLES ARE FOR GRAPHICAL REPRESENTATION AND NOT TO BE USED FOR CALCULATING QUANTITIES

LEGEND:

- SEEDING ACCORDING TO ITEM 659 SEEDING AND MULCHING
- WILLOW POLE
- MATERIAL TO BE EXCAVATED AND USED FOR THE CONSTRUCTION OF THE PROPOSED BERM
- PROPOSED GEOCELL GRAVITY WALL

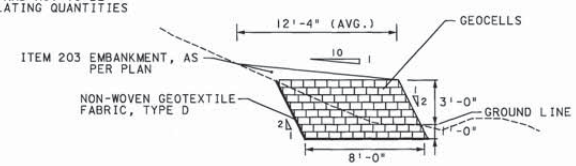
AREA "1"
WORK TO BE PERFORMED

1. THIS AREA IS TO BE CONSIDERED THE CONTROL AREA, AND THE CONTRACTOR SHALL NOT PERFORM ANY WORK ON THIS SECTION OF THE PROJECT. EQUIPMENT IS NOT PERMITTED ON THIS PORTION OF THE SLOPE FACE AT ANY TIME.

AREA "2"
WORK TO BE PERFORMED

1. THE CONTRACTOR SHALL SCRAPE AND SMOOTH THE SLOPE FACE BY USING A LOW-IMPACT TRACTOR, DOZER, OR EQUIVALENT. EQUIPMENT IS ONLY PERMITTED ON THE SLOPE FACE WHILE THE SCRAPING AND SMOOTHING OPERATION IS BEING PERFORMED.
2. THE CONTRACTOR SHALL HYDROSEED THE AREA. THE SEED MIXTURE SHALL BE CLASS-TYPE 3A, SLOPE MIXTRES PER 2005 CMS TABLE 659.09-1 PLUS 20 LB/ACRE OF WINTER WHEAT.

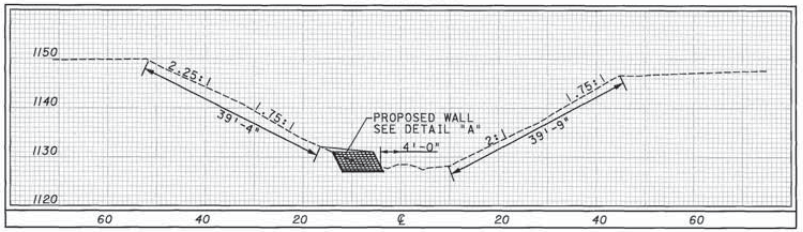
DETAIL "A"
PROPOSED GEOCELL GRAVITY WALL



GEOCELL GRAVITY WALL

NOTE: FOR A DESCRIPTION OF WORK SEE SHEET 9

SECTION A-A



SECTION 1 & 2 DETAILS

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CALCULATED BCW CHECKED

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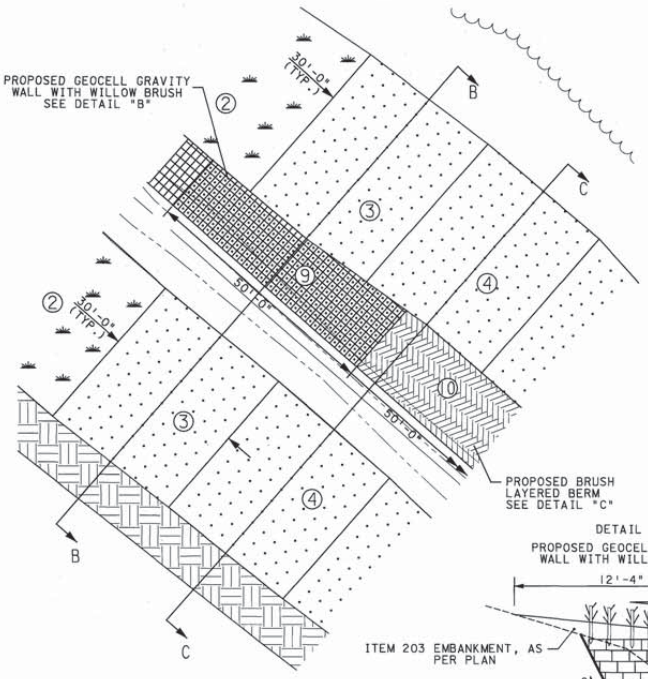
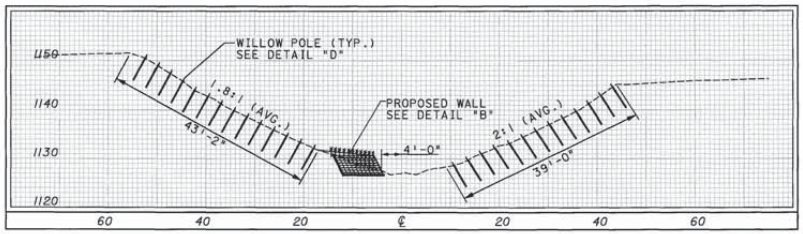
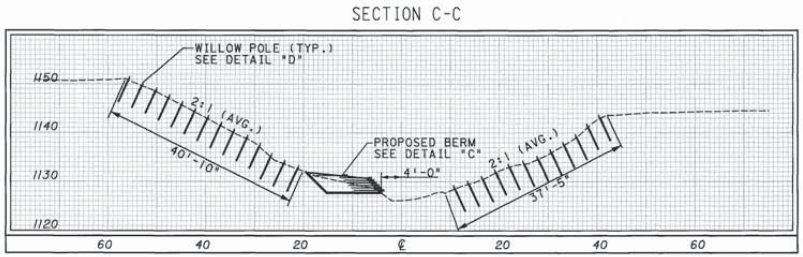
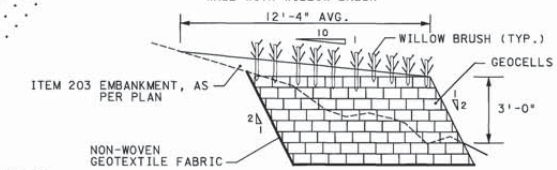




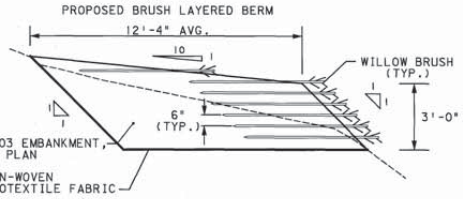


NOTE: FOR A DESCRIPTION OF WORK TO BE PERFORMED SEE SHEET 9

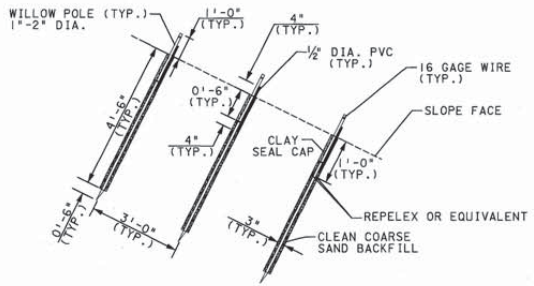
DETAIL "B"
PROPOSED GEOCELL GRAVITY WALL WITH WILLOW BRUSH



DETAIL "C"
PROPOSED BRUSH LAYERED BERM



DETAIL "D"
WILLOW POLE INSTALLATION



LEGEND:

- SEEDING ACCORDING TO ITEM 659 SEEDING AND MULCHING
- WILLOW POLE
- MATERIAL TO BE EXCAVATED AND USED FOR THE CONSTRUCTION OF THE PROPOSED BERM
- PROPOSED GEOCELL
- PROPOSED BRUSH LAYERED BERM

NOTE: WILLOW POLES ARE FOR GRAPHICAL REPRESENTATION AND NOT TO BE USED FOR CALCULATING QUANTITIES

CALCULATED BCW
CHECKED

SECTION 3 & 4 DETAILS

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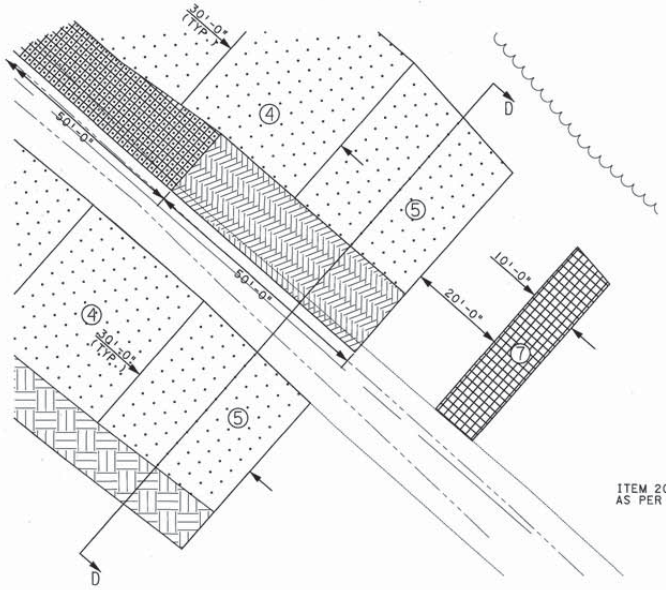
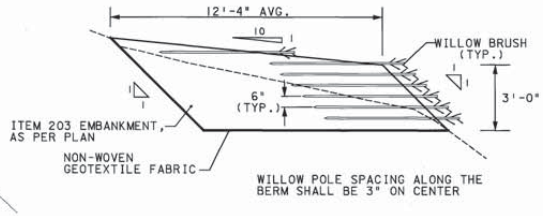


LEGEND:

- * WILLOW POLE
- MATERIAL TO BE EXCAVATED AND USED FOR THE CONSTRUCTION OF THE PROPOSED BERM
- PROPOSED GEOCELL REINFORCED BERM
- PROPOSED BRUSH LAYERED BERM

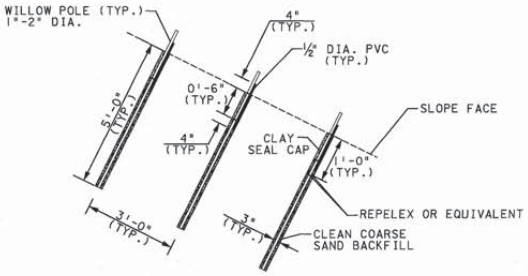
NOTE: WILLOW POLES ARE FOR GRAPHICAL REPRESENTATION AND NOT TO BE USED FOR CALCULATING QUANTITIES

DETAIL "C"
PROPOSED BRUSH LAYERED BERM

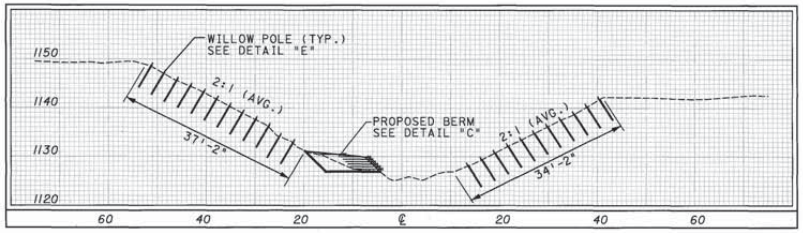


NOTE: FOR A DESCRIPTION OF WORK TO BE PERFORMED SEE SHEET 9

DETAIL "E"
WILLOW POLE INSTALLATION



SECTION D-D



CALCULATED BCW
CHECKED

SECTION 5 & 6 DETAILS

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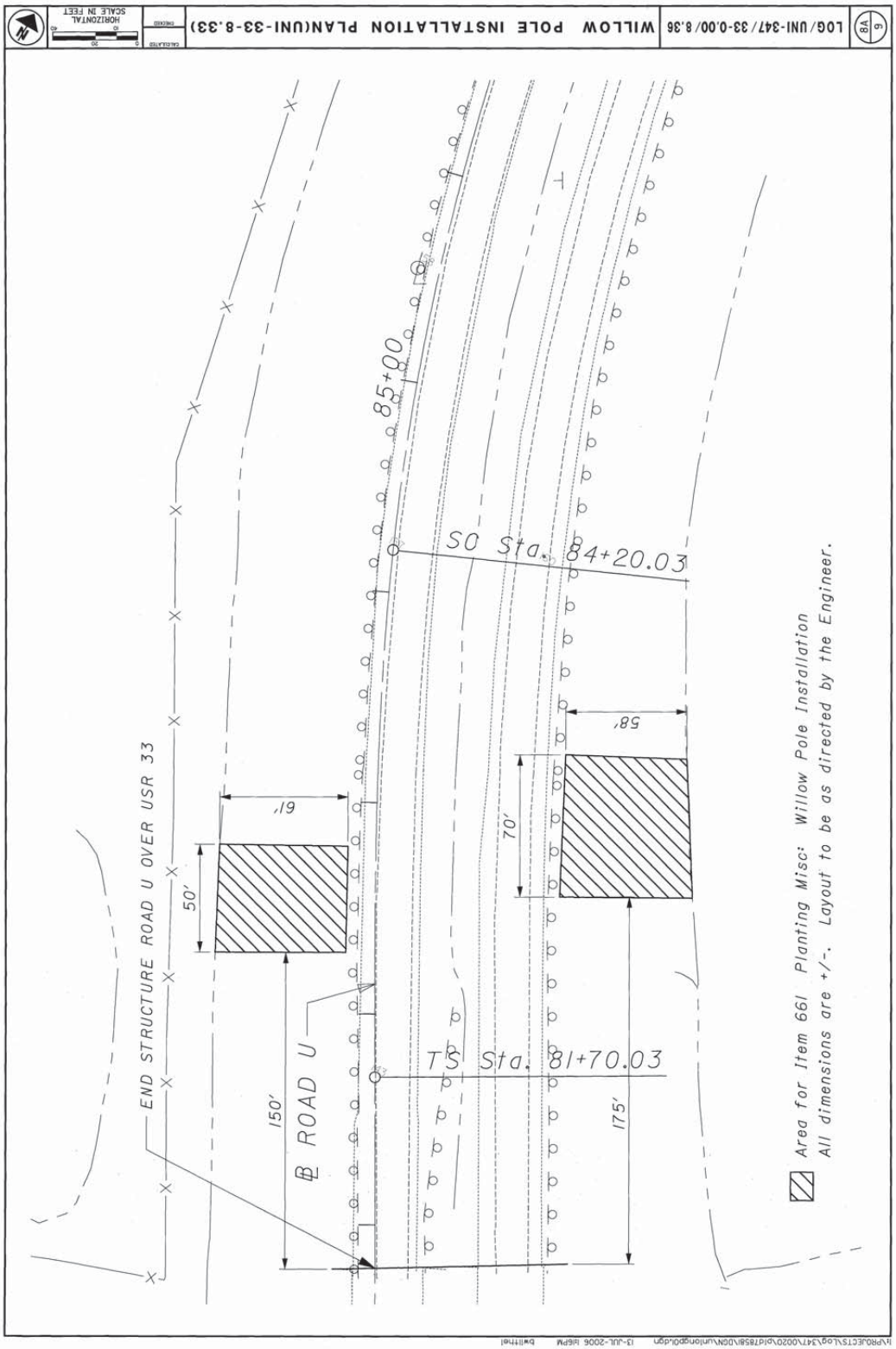
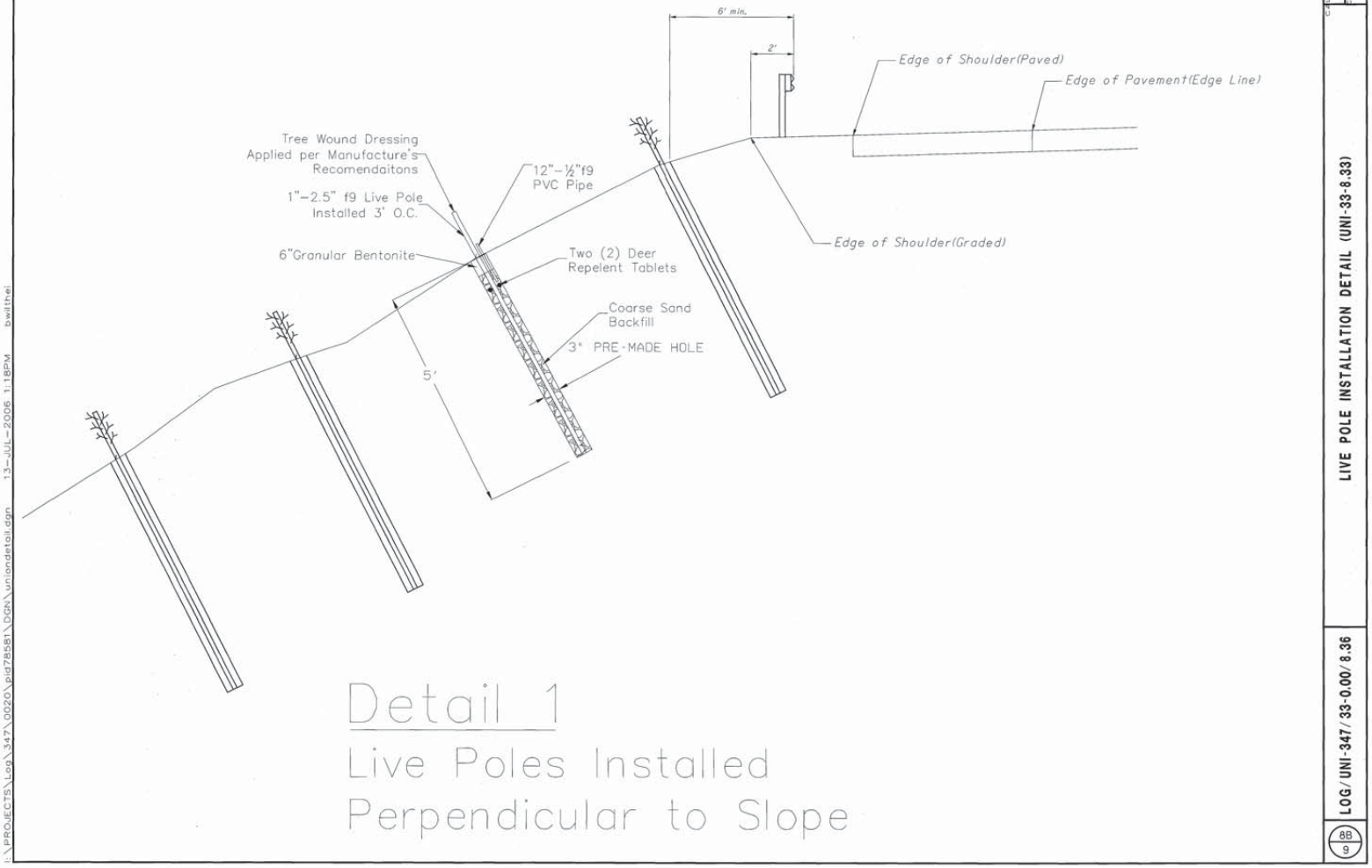

LOG/UNI-347/33-0.00/8.36
WILLOW POLE INSTALLATION PLAN(UNI-33-8.33)
HORIZONTAL
SCALE IN FEET
85+00
SO Sta. 84+20.03
58'
70'
61'
50'
END STRUCTURE ROAD U OVER USR 33
150'
℄ ROAD U
TS Sta. 81+70.03
175'
Area for Item 661 Planting Misc: Willow Pole Installation
All dimensions are +/-. Layout to be as directed by the Engineer.



Detail 1

Live Poles Installed
Perpendicular to Slope

CALCULATED
CHECKED

LIVE POLE INSTALLATION DETAIL (UNI-33-8.33)

LOG/UNI-347/33-0.00/8.36

8B
9

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AREA "3"
WORK TO BE PERFORMED

1. THE CONTRACTOR SHALL SCRAPE AND SMOOTH THE SLOPE FACE BY USING A LOW-IMPACT TRACTOR, DOZER, OR EQUIVALENT. EQUIPMENT IS ONLY PERMITTED ON THE SLOPE FACE WHILE THE SCRAPING AND SMOOTHING OPERATION IS BEING PERFORMED.

2. THE CONTRACTOR SHALL COORDINATE WITH THE OSU PERSONNEL ON THE LOCATION OF THE WILLOW POLES. THE CONTRACTOR SHALL CUT AND TRIM EACH POLE AND ENSURE THEY ARE STRAIGHT. THE ENDS OF EACH POLE SHALL BE CUT WITH A TAPERED END. 16 GAGE WIRE SHALL BE TIED AROUND THE TOP OF EACH POLE A MINIMUM OF TWO (2) TURNS TO AVOID SPLITTING.

3. THE CONTRACTOR SHALL MAKE HOLES VERTICALLY, OR PERPENDICULAR TO THE SLOPE FACE. THE HOLES SHALL BE 0'-3" IN DIAMETER AND 4'-6" DEEP. THEY SHALL BE PLACED 3'-0" APART FORMING A GRID PATTERN AS SHOWN IN THE PLAN VIEW. HOLES WILL BE MADE BY AUGER AND SPIKE METHODS, OR OTHER APPROVED METHODS IN A MANNER AS TO NOT DISTURB THE SLOPE FACE.

4. THE CONTRACTOR SHALL PLACE ONE (1) WILLOW POLE INTO EACH HOLE. THE POLE SHALL THEN BE HAMMERED FIRMLY INTO THE BASE OF THE HOLE USING A DEAD BLOW OR RUBBER MALLET. THE CONTRACTOR SHALL BACKFILL EACH HOLE WITH COURSE SAND IN 0'-6" LIFTS, AND TAMPED TO ENSURE ALL VOIDS ARE FILLED. THE TOP 0'-6" SHALL BE BACKFILLED WITH A CLAY SEAL. A ½" PVC PIPE SHALL BE PLACED IN THE HOLE, EXTENDING 0'-4" INTO THE COURSE SAND LAYER AND 0'-4" ABOVE THE SURFACE AS SHOWN IN DETAIL D. THE INSTALLATION SHALL BE COMPLETED BY TRIMMING THE TOP OF EACH WILLOW POLE SUCH THAT THERE IS APPROX. 1'-0" REMAINING ABOVE THE SLOPE FACE. THE CONTRACTOR SHALL THEN PLACE AN 0'-18" SQUARE OF BIODEGRADEABLE LANDSCAPE FABRIC OR EQUIVALENT SUCH THAT THE FABRIC RESTS ON THE GROUND SURFACE AROUND EACH POLE.

5. EACH POLE SHALL BE TREATED TO PREVENT SPLITTING AND DRYING BY APPLYING TREEKOTE TREE WOUND DRESSING OR EQUIVALENT TO THE EXPOSED TOP SURFACE. MANUFACTURER'S RECOMMENDATIONS SHALL BE FOLLOWED FOR THE APPLICATION OF TREE WOUND DRESSING

6. THE CONTRACTOR SHALL PLACE TWO (2) TABLETS OF REPELLEX, OR EQUIVALENT PRODUCT IN EACH HOLE APPROXIMATELY 1'-0" FROM THE TOP. THE CONTRACTOR SHALL ALSO APPLY THE WILLOW POLES, AFTER SPROUTING, WITH DEER AWAY PROTECTIVE SPRAY, TREE GUARD, OR EQUIVALENT. THE SPRAY SHALL BE APPLIED PER THE MANUFACTURE'S SPECIFICATIONS.

7. THE CONTRACTOR SHALL HYDROSEED THE AREA ACCORDING TO ITEM 659 SEEDING AND MULCHING. THE SEED MIXTURE SHALL BE TYPE 3A + 20 LB/AC WINTER WHEAT.

8. THE CONTRACTOR SHALL PLACE THE EROSION CONTROL MAT, TYPE F ACCORDING TO CMS 671 OVER THE AREA.

AREA "4"
WORK TO BE PERFORMED

THIS AREA SHALL BE CONSTRUCTED FOLLOWING STEPS 2 - 8 FOR AREA "3"

AREA "5"
WORK TO BE PERFORMED

1. THE CONTRACTOR SHALL COORDINATE WITH THE OSU PERSONNEL ON THE LOCATION OF THE WILLOW POLES. THE CONTRACTOR SHALL CUT AND TRIM EACH POLE AND ENSURE THEY ARE STRAIGHT. THE ENDS OF EACH POLE SHALL BE CUT WITH A BLUNT END.

2. THE CONTRACTOR SHALL MAKE HOLES VERTICALLY, OR PERPENDICULAR TO THE SLOPE FACE. THE HOLES SHALL BE 0'-3" IN DIAMETER AND 5'-0" DEEP. THEY SHALL BE PLACED 3'-0" APART FORMING A GRID PATTERN AS SHOWN IN THE PLAN VIEW. HOLES WILL BE MADE BY AUGER AND SPIKE METHODS, OR OTHER APPROVED METHODS IN A MANNER AS TO NOT DISTURB THE SLOPE FACE.

3. THE CONTRACTOR SHALL PLACE ONE (1) WILLOW POLE INTO EACH HOLE. THE CONTRACTOR SHALL BACK FILL EACH HOLE WITH COURSE SAND IN 0'-6" LIFTS, AND TAMPED TO ENSURE ALL VOIDS ARE FILLED. THE TOP 0'-6" SHALL BE BACKFILLED WITH A CLAY SEALER. A ½" PVC PIPE SHALL BE PLACED IN THE HOLE, EXTENDING 0'-4" INTO THE COURSE SAND LAYER AND 0'-4" ABOVE THE SURFACE AS SHOWN IN DETAIL "E". THE CONTRACTOR SHALL THEN PLACE AN 0'-18" SQUARE OF BIODEGRADEABLE LANDSCAPE FABRIC OR EQUIVALENT SUCH THAT THE FABRIC RESTS ON THE GROUND SURFACE AROUND EACH POLE.

4. EACH POLE SHALL BE TREATED TO PREVENT SPLITTING AND DRYING BY APPLYING TREEKOTE TREE WOUND DRESSING OR EQUIVALENT TO THE EXPOSED TOP SURFACE. MANUFACTURER'S RECOMMENDATIONS SHALL BE FOLLOWED FOR THE APPLICATION OF TREE WOUND DRESSING

5. THE CONTRACTOR SHALL PLACE TWO (2) TABLET OF REPELLEX, OR EQUIVALENT PRODUCT IN EACH HOLE APPROXIMATELY 1'-0" FROM THE TOP. THE CONTRACTOR SHALL ALSO APPLY THE WILLOW POLES, AFTER SPROUTING, WITH DEER AWAY PROTECTIVE SPRAY, TREE GUARD, OR EQUIVALENT. THE SPRAY SHALL BE APPLIED PER THE MANUFACTURE'S SPECIFICATIONS.

6. THE CONTRACTOR SHALL HYDROSEED THE AREA ACCORDING TO ITEM 659 SEEDING AND MULCHING. THE SEED MIXTURE SHALL BE TYPE 3A + 20 LB/AC WINTER WHEAT.

7. THE CONTRACTOR SHALL PLACE THE EROSION CONTROL MAT, TYPE F ACCORDING TO CMS 671 OVER THE AREA.

AREA "7"
WORK TO BE PERFORMED

1. THE CONTRACTOR SHALL PLACE AND STRETCH THE GEOCELL TO THE SPECIFIC PANEL DIMENSIONS. ANCHOR THE GEOCELL AS PER THE MANUFACTURE'S RECOMMENDATIONS AND SPECIFICATIONS. INFILL EACH CELL WITH TOPSOIL. COMPACT AND REMOVE ANY EXCESS SOIL SUCH THAT THE INFILL IS FLUSH WITH THE TOP OF THE GEOCELL.

2. THE CONTRACTOR SHALL HYDROSEED THE AREA ACCORDING TO ITEM 659 SEEDING AND MULCHING. THE SEED MIXTURE SHALL BE TYPE 3A + 20 LB/AC WINTER WHEAT.

AREA "8"
WORK TO BE PERFORMED

1. THE CONTRACTOR SHALL REMOVE ALL VEGETATIVE COVER, DEBRIS, AND SOIL FROM THE SITE WHERE THE GEOCELL GRAVITY WALL IS TO BE PLACED, THROUGH THE USE OF A LOW IMPACT TRACTOR, HAND LABOR (SHOVELS), OR EQUIVALENT. THE BASE MATERIAL SHALL THEN BE LEVELED AND COMPACTED TO A MINIMUM 95% STANDARD PROCTOR DENSITY.

2. UPON PREPARING THE SITE FOR CONSTRUCTION OF THE GRAVITY WALL, THE CONTRACTOR SHALL INSTALL THE NON-WOVEN GEOTEXTILE FABRIC, TYPE D PER CMS 204.07

3. THE CONTRACTOR SHALL THEN PLACE AND STRETCH THE GEOCELL TO THE SPECIFIC PANEL DIMENSIONS. INFILL EACH CELL WITH THE SOIL FROM THE BORROW SITE AS DESCRIBED IN THESE PLANS. PLACEMENT SHALL BE PLACED SUCH THAT WHEN COMPACTED A MINIMUM OF 95% STANDARD PROCTOR MAY BE REACHED. EXCESS MATERIAL SHALL BE REMOVED SO THAT THE SOIL IS FLUSH WITH THE TOP OF THE GEOCELL, INSURING AN EVEN SURFACE FOR THE PLACEMENT OF THE NEXT GEOCELL LAYER. CONTINUE UNTIL THE WALL IS CONSTRUCTED AS SHOWN IN THE PLANS.

4. THE CONTRACTOR SHALL HYDROSEED THE AREA ACCORDING TO ITEM 659 SEEDING AND MULCHING. THE SEED MIXTURE SHALL BE TYPE 3A + 20 LB/AC WINTER WHEAT.

AREA "9"
WORK TO BE PERFORMED

1. THE CONTRACTOR SHALL REMOVE ALL VEGETATIVE COVER, DEBRIS, AND SOIL FROM THE SITE WHERE THE GEOCELL GRAVITY WALL IS TO BE PLACED, THROUGH THE USE OF A LOW IMPACT TRACTOR, HAND LABOR (SHOVELS), OR EQUIVALENT. THE BASE MATERIAL SHALL THEN BE LEVELED AND COMPACTED TO A MINIMUM 95% STANDARD PROCTOR DENSITY.

2. UPON PREPARING THE SITE FOR CONSTRUCTION OF THE GRAVITY WALL, THE CONTRACTOR SHALL INSTALL THE NON-WOVEN GEOTEXTILE FABRIC, TYPE D PER CMS 204.07

3. THE CONTRACTOR SHALL THEN PLACE AND STRETCH THE GEOCELL TO THE SPECIFIC PANEL DIMENSIONS. INFILL EACH CELL WITH THE SOIL FROM THE BORROW SITE AS DESCRIBED IN THESE PLANS. PLACEMENT SHALL BE PLACED SUCH THAT WHEN COMPACTED A MINIMUM OF 95% STANDARD PROCTOR MAY BE REACHED. EXCESS MATERIAL SHALL BE REMOVED SO THAT THE SOIL IS FLUSH WITH THE TOP OF THE GEOCELL, INSURING AN EVEN SURFACE FOR THE PLACEMENT OF THE NEXT GEOCELL LAYER. CONTINUE UNTIL THE WALL IS CONSTRUCTED AS SHOWN IN THE PLANS.

4. THE CONTRACTOR SHALL USE WILLOW BRUSH 1/2" TO 1" IN DIAMETER THE CONTRACTOR SHALL THEN PLACE THE WILLOW BRUSH INTO THE TOP OF THE GRAVITY WALL. THE DEPTH SHALL BE BETWEEN 0'-6" TO 1'-0". THE INSTALLATION OF THE WILLOW POLES SHALL BE COMPLETED BY TRIMMING THE TOP OF ALL WILLOW BRUSH SUCH THAT THERE IS 0'-6" TO 0'-9" REMAINING ABOVE THE PROPOSED GROUND SURFACE.

5. THE CONTRACTOR SHALL HYDROSEED THE AREA ACCORDING TO ITEM 659 SEEDING AND MULCHING. THE SEED MIXTURE SHALL BE TYPE 3A + 20 LB/AC WINTER WHEAT.

AREA "10"
WORK TO BE PERFORMED

1. THE CONTRACTOR SHALL REMOVE ALL VEGETATIVE COVER, DEBRIS, AND SOIL FROM THE SITE WHERE THE GEOCELL GRAVITY WALL IS TO BE PLACED, THROUGH THE USE OF A LOW IMPACT TRACTOR, HAND LABOR (SHOVELS), OR EQUIVALENT. THE BASE MATERIAL SHALL THEN BE LEVELED AND COMPACTED TO A MINIMUM 95% STANDARD PROCTOR DENSITY.

2. THE CONTRACTOR SHALL PLACE THE BORROW MATERIAL ACCORDING TO CMS 203 IN 0'-6" LIFTS. AFTER EACH LIFT THE CONTRACTOR SHALL PREPARE AND PLACE WILLOW BRUSH HORIZONTALLY AS SHOWN IN DETAIL "C".

3. THE CONTRACTOR SHALL HYDROSEED THE AREA ACCORDING TO ITEM 659 SEEDING AND MULCHING. THE SEED MIXTURE SHALL BE TYPE 3A + 20 LB/AC WINTER WHEAT.

CALCULATED BCW
CHECKED

DETAIL NOTES

LOG/UNI-347/33-0.00/8.36

9/9

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Live Pole Installation

Scraped slope

Spiking holes

Sharpening Pole (Best Method)

Live Pole Installation

Installing breather tubes

Backfilling live pole holes

Wiring live pole tops (best method)

Visual log of construction activities at the Logan County demonstration site.

Live Pole Installation

Bentonite backfill

Installing biodegradable weed control mats

Finished pole (best method)

Geocell Wall Construction

Geocell section stretched across form

Backfilling geocell section

Compacting after filling each lift

Visual log of construction activities at the Logan County demonstration site.

Brushlayer Construction

Placing willow brush

Backfilling over willow brush

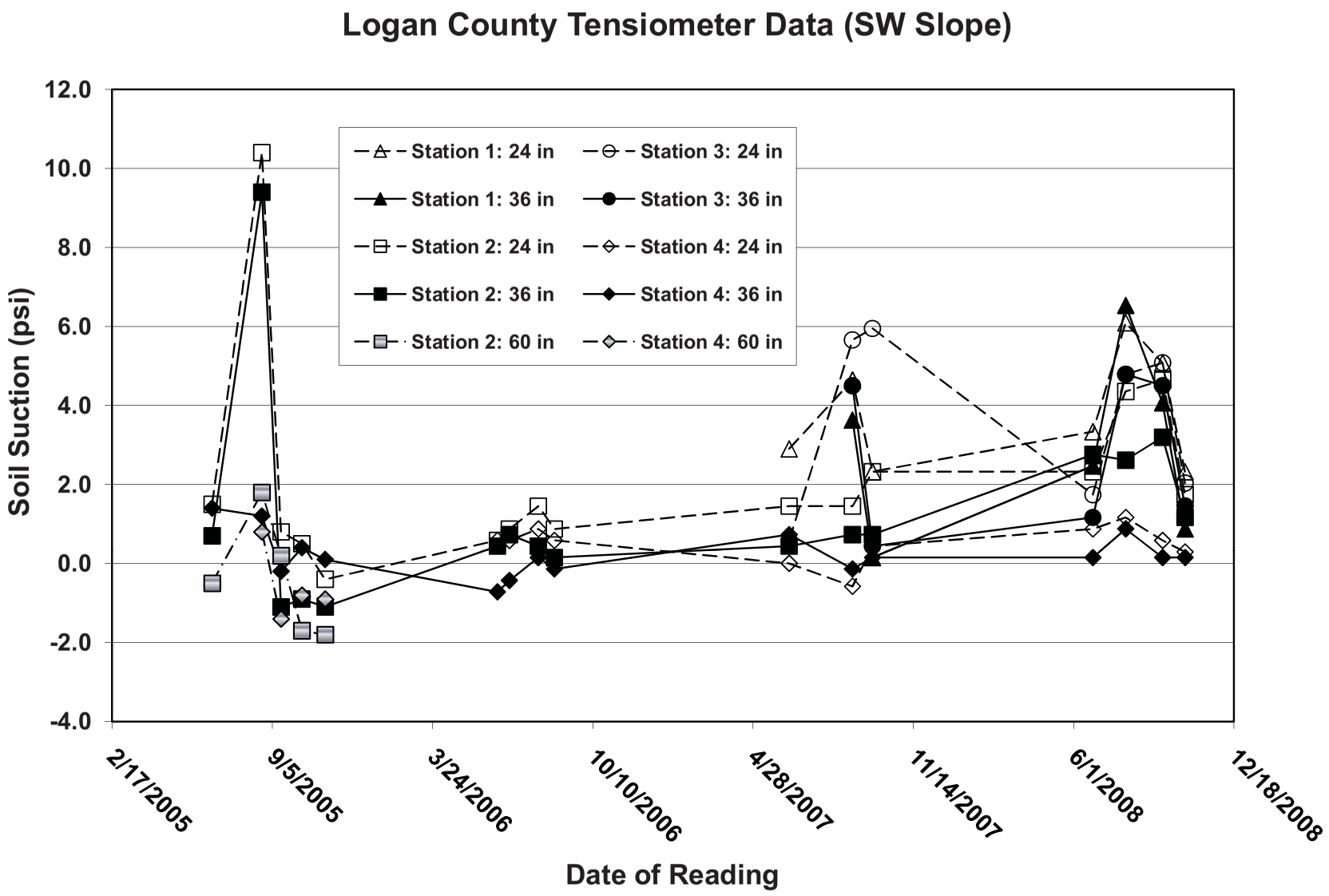
Compacting after filling each lift

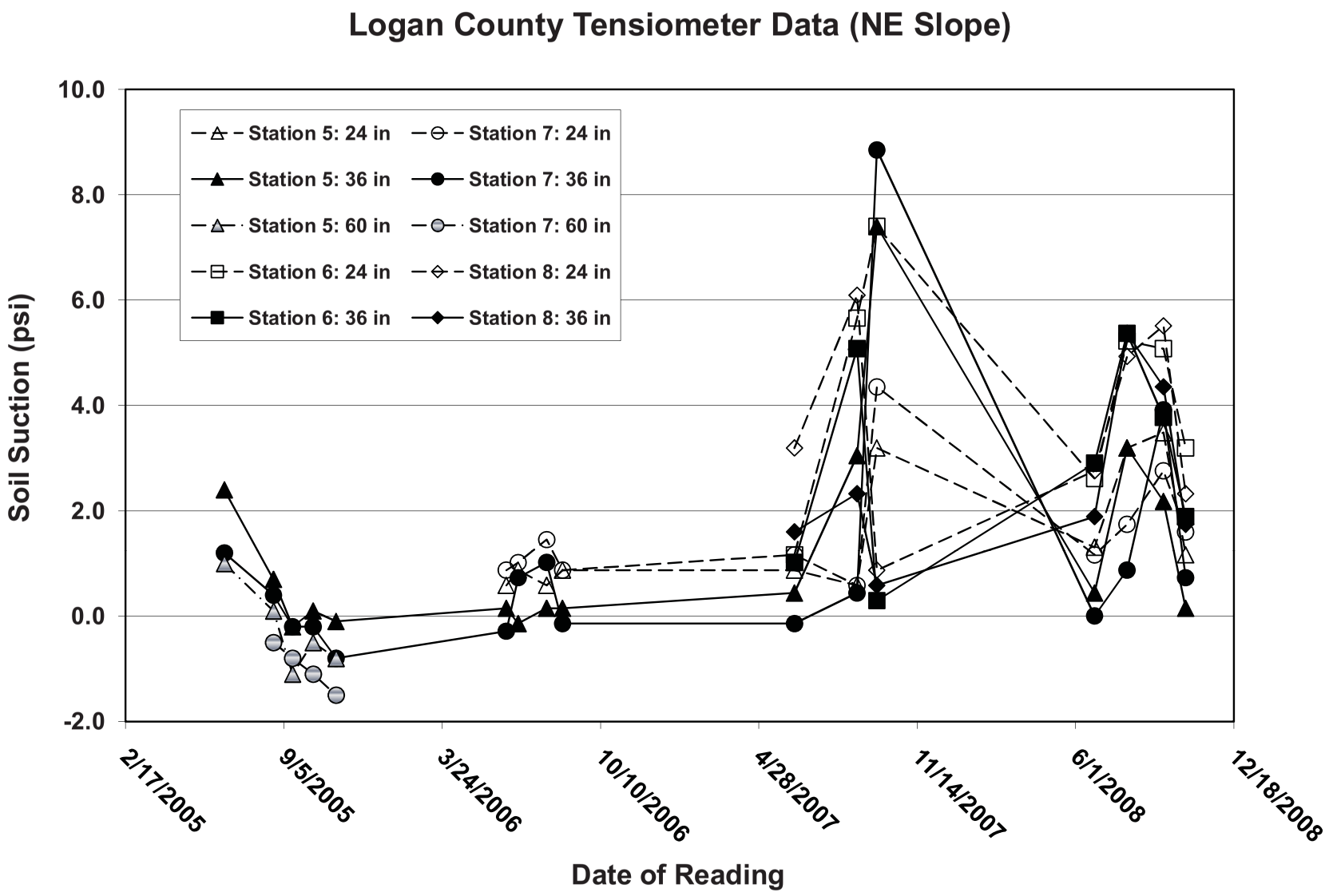
Visual log of construction activities at the Logan County demonstration site.

Logan County Tensiometer Data

ID	Depth	Soil Suction (psi)*															
		Date of Reading															
		6/22/2005	8/23/2005	9/16/2005	10/12/2005	11/10/2005	6/13/2006	6/28/2006	8/3/2006	8/23/2006	6/12/2007	8/30/2007	9/24/2007	6/25/2008	8/5/2008	9/20/2008	10/18/2008
#1	24 in	-	-	-	-	-	-	-	-	-	2.90	4.64	2.32	3.34	6.09	5.08	2.32
	36 in	-	-	-	-	-	-	-	-	-	-	3.63	0.15	2.47	6.53	4.07	0.88
#2	24 in	1.50	10.40	0.80	0.50	-0.40	0.58	0.87	1.45	0.87	1.45	1.45	2.32	2.32	4.35	4.64	1.74
	36 in	0.70	9.40	-1.10	-0.90	-1.10	0.44	0.73	0.44	0.15	0.44	0.73	0.73	2.76	2.62	3.20	1.17
	60 in	-0.50	1.80	0.20	-1.70	-1.80	-	-	-	-	-	-	-	-	-	-	-
#3	24 in	-	-	-	-	-	-	-	-	-	0.58	5.66	5.95	1.74	4.79	5.08	2.03
	36 in	-	-	-	-	-	-	-	-	-	-	4.50	0.44	1.17	4.79	4.50	1.46
#4	24 in	-	-	-	-	-	0.58	0.58	0.87	0.58	0.00	-0.58	0.44	0.87	1.16	0.58	0.29
	36 in	1.40	1.20	-0.20	0.40	0.10	-0.72	-0.43	0.15	-0.14	0.73	-0.14	0.15	0.15	0.88	0.15	0.15
	60 in	-	0.80	-1.40	-0.80	-0.90	-	-	-	-	-	-	-	-	-	-	-
#5	24 in	-	-	-	-	-	0.58	0.87	0.58	0.87	0.87	0.58	3.19	1.31	3.19	3.48	1.16
	36 in	2.40	0.70	-0.20	0.10	-0.10	0.15	-0.14	0.15	0.15	0.44	3.05	7.40	0.44	3.20	2.18	0.15
	60 in	1.00	0.10	-1.10	-0.50	-0.80	-	-	-	-	-	-	-	-	-	-	-
#6	24 in	-	-	-	-	-	-	-	-	-	1.16	5.66	7.40	2.61	5.22	5.08	3.19
	36 in	-	-	-	-	-	-	-	-	-	1.02	5.08	0.30	2.91	5.37	3.78	1.89
#7	24 in	-	-	-	-	-	0.87	1.02	1.45	0.87	1.16	0.58	4.35	1.16	1.74	2.76	1.60
	36 in	1.20	0.40	-0.20	-0.20	-0.80	-0.28	0.73	1.02	-0.14	-0.14	0.44	8.85	0.01	0.88	3.92	0.73
	60 in	-	-0.50	-0.80	-1.10	-1.50	-	-	-	-	-	-	-	-	-	-	-
#8	24 in	-	-	-	-	-	-	-	-	-	3.19	6.09	0.87	2.76	4.93	5.51	2.32
	36 in	-	-	-	-	-	-	-	-	-	1.60	2.33	0.59	1.89	5.37	4.36	1.75

* All values have also been corrected for elevation corresponding to the water column in the tensiometer.


Logan County Tensiometer Data (SW Slope)
Station 1: 24 in
Station 1: 36 in
Station 2: 24 in
Station 2: 36 in
Station 2: 60 in
Station 3: 24 in
Station 3: 36 in
Station 4: 24 in
Station 4: 36 in
Station 4: 60 in
Soil Suction (psi)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
2/17/2005
9/5/2005
3/24/2006
10/10/2006
4/28/2007
11/14/2007
6/1/2008
12/18/2008
Date of Reading

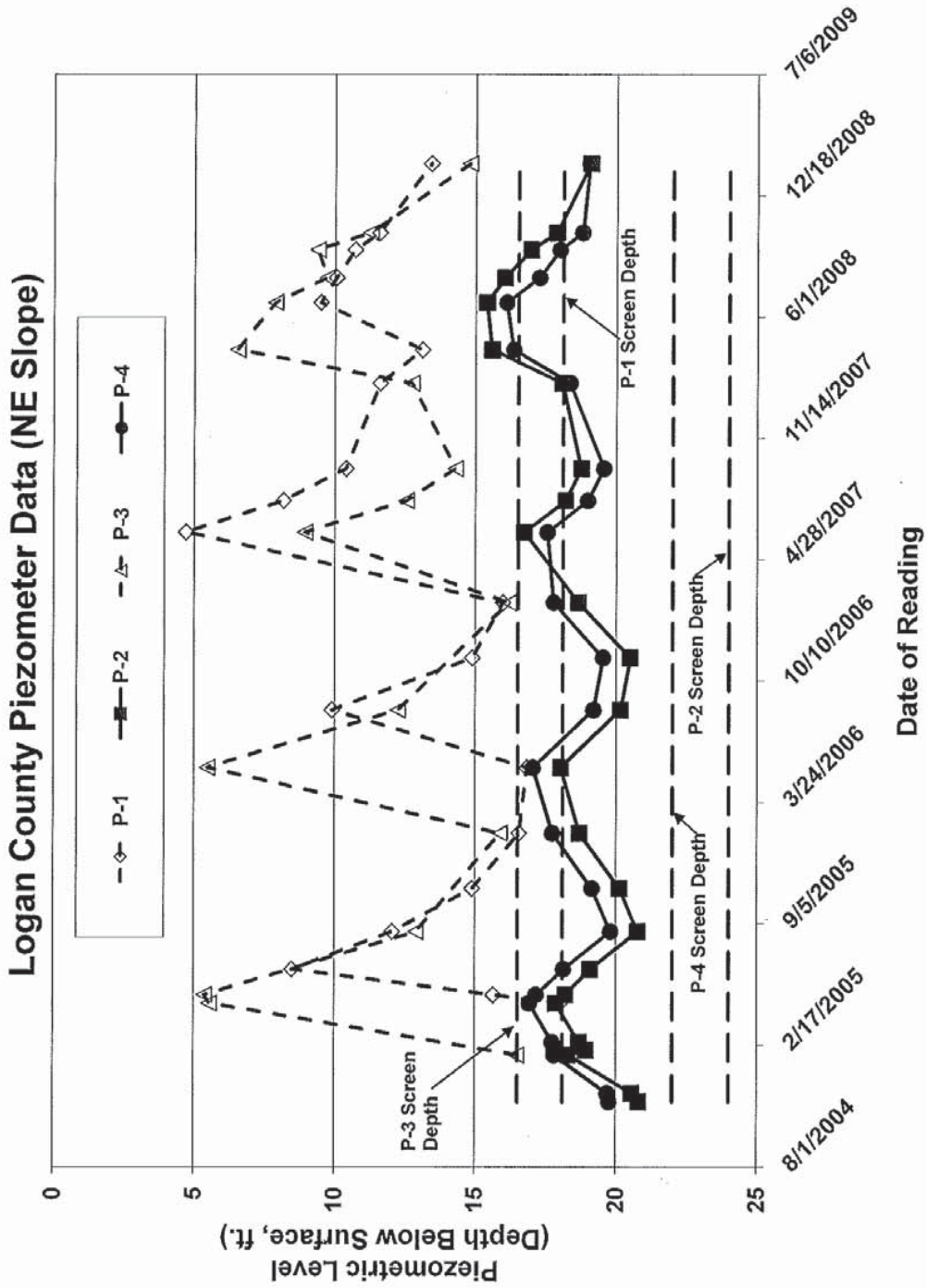

Logan County Tensiometer Data (NE Slope)
Station 5: 24 in
Station 7: 24 in
Station 5: 36 in
Station 7: 36 in
Station 5: 60 in
Station 7: 60 in
Station 6: 24 in
Station 8: 24 in
Station 6: 36 in
Station 8: 36 in
Soil Suction (psi)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
2/17/2005
9/5/2005
3/24/2006
10/10/2006
4/28/2007
11/14/2007
6/1/2008
12/18/2008
Date of Reading

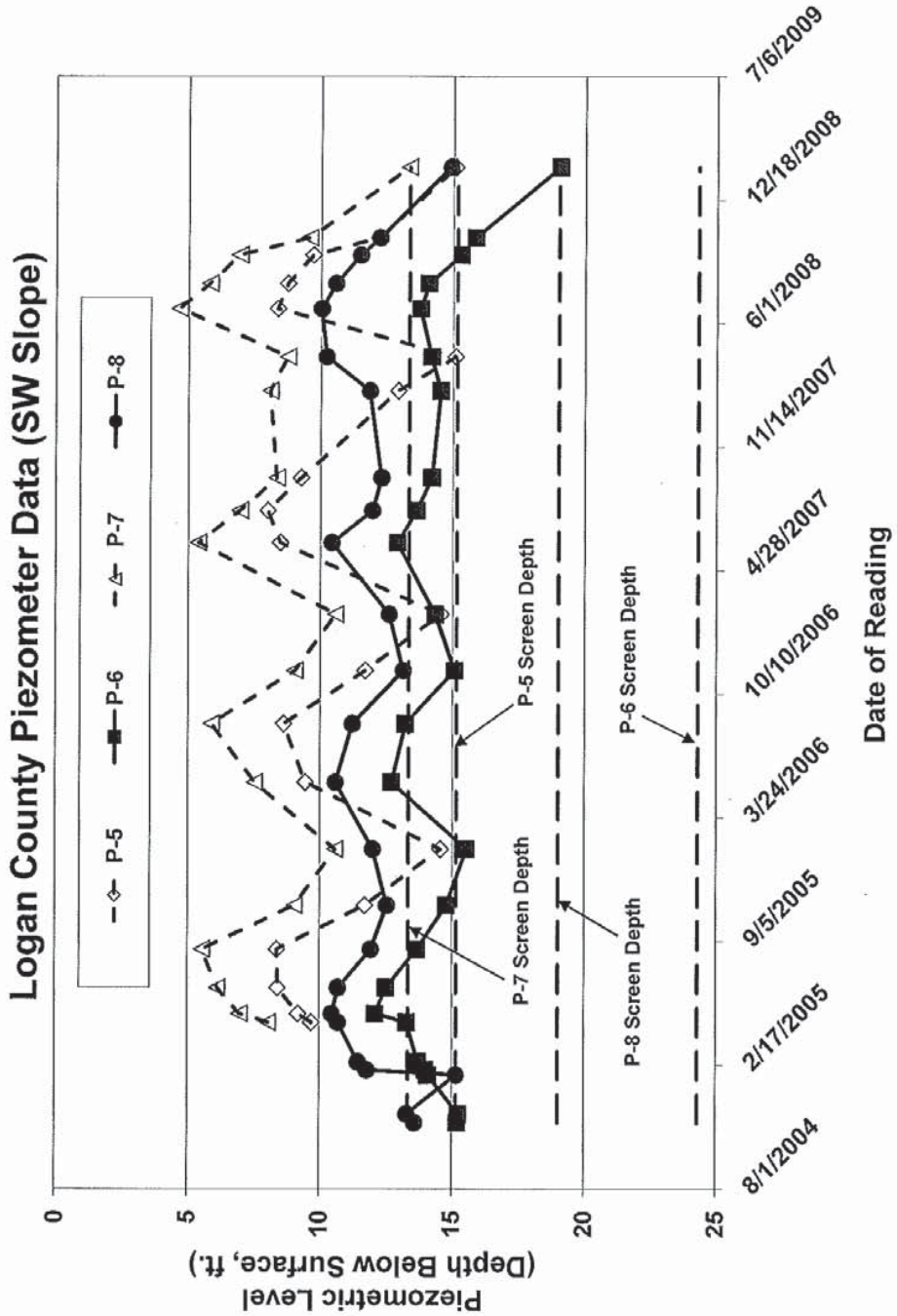
Logan County Piezometer Data

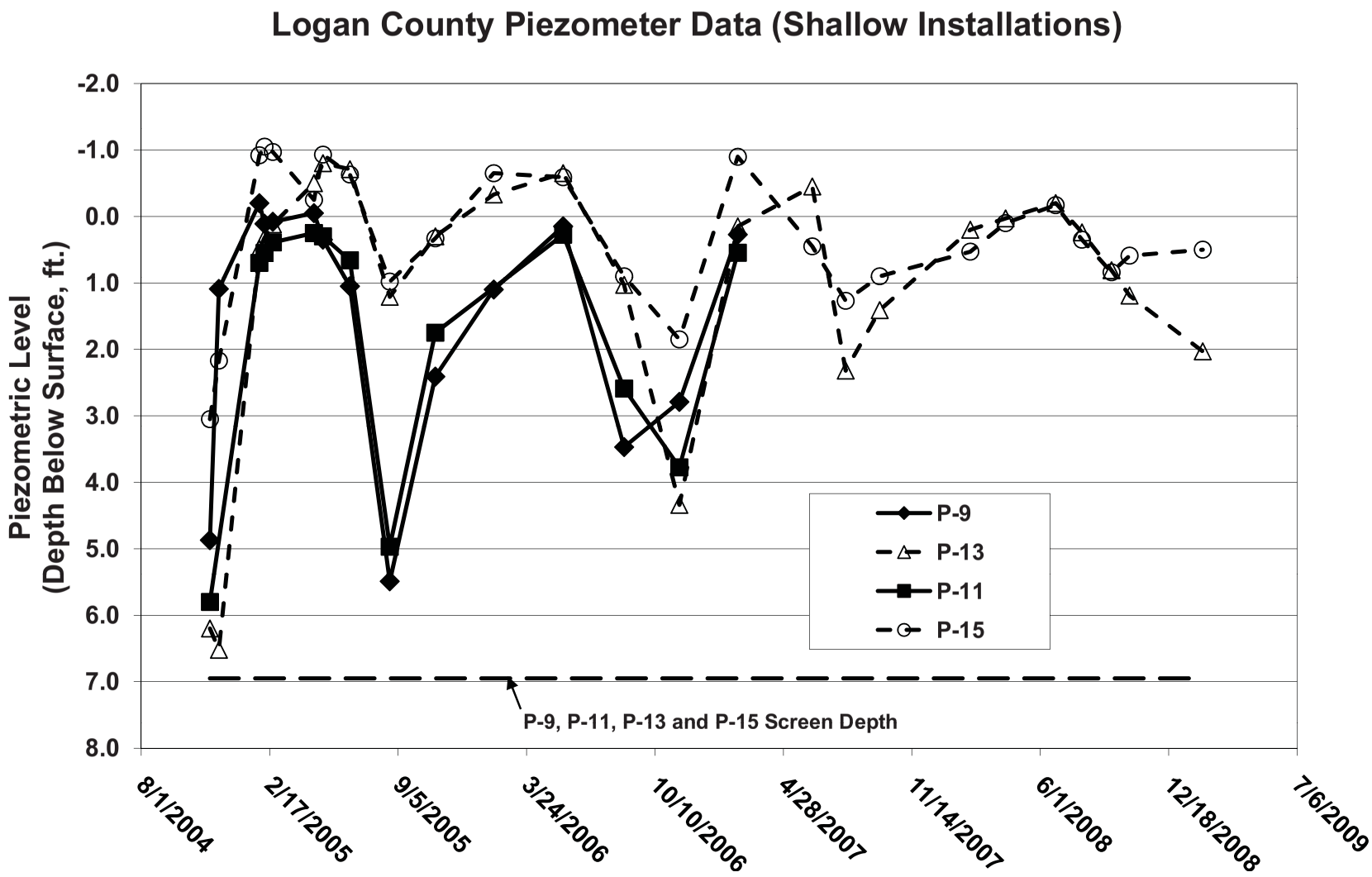
Piezometer/Well ID	D.T.B.	H.O.G.	D.B.G.	Date of Reading												
				11/16/2004	11/30/2004	2/1/2005	2/9/2005	2/22/2005	4/27/2005	5/11/2005	6/22/2005	8/23/2005	11/2/2005	2/1/2006	5/20/2006	8/23/2006
1	22.00	3.90	18.10	-	-	-	-	-	18.00	15.64	8.48	12.04	14.89	16.54	16.82	9.90
2	25.70	2.70	23.00	20.80	20.55	18.30	18.93	18.69	17.85	18.20	19.08	20.76	20.12	18.70	18.03	20.15
3	17.00	0.50	16.50	-	-	16.47	-	-	5.55	5.37	-	12.89	-	15.87	5.46	12.24
4	26.90	1.00	25.90	19.75	19.69	17.80	17.81	17.73	16.92	17.16	18.13	19.80	19.14	17.73	17.04	19.19
5	16.95	1.80	15.15	-	-	-	-	-	9.70	9.20	8.42	8.39	11.70	14.55	9.45	8.63
6	27.90	3.60	24.30	15.20	15.24	14.10	14.00	13.73	13.30	12.10	12.50	13.68	14.77	15.54	12.70	13.23
7	16.95	3.60	13.35	-	-	-	-	-	8.05	6.97	6.12	5.54	9.05	10.57	7.51	5.88
8	21.95	1.30	20.65	13.60	13.30	15.15	11.79	11.46	10.70	10.46	10.70	11.93	12.53	12.00	10.58	11.22
9	8.60	1.70	6.90	4.87	1.09	-0.20	0.11	0.08	-0.05	0.35	1.05	5.49	2.41	1.10	0.15	3.47
11	8.15	1.20	6.95	5.80	-	0.70	0.55	0.39	0.25	0.30	0.66	4.97	1.75	-	0.28	2.59
13	11.95	5.00	6.95	6.20	6.52	0.49	0.32	0.12	-0.50	-0.80	-0.71	1.21	0.30	-0.33	-0.65	1.03
15	11.95	4.95	7.00	3.05	2.17	-0.92	-1.05	-0.97	-0.25	-0.93	-0.63	0.98	0.33	-0.65	-0.59	0.90

Logan County Piezometer Data (*Continued*)

Piezometer/Well ID	D.T.B.	H.O.G.	D.B.G.	Date of Reading											
				11/17/2006	2/16/2007	6/12/2007	8/3/2007	9/25/2007	2/13/2008	4/8/2008	6/25/2008	8/5/2008	9/20/2008	10/18/2008	2/9/2009
1	22.00	3.90	18.10	14.89	15.96	4.70	8.15	10.39	11.59	13.10	9.48	10.04	10.70	11.56	13.40
2	25.70	2.70	23.00	20.49	18.66	16.72	18.19	18.75	18.07	15.57	15.39	16.01	16.94	17.85	19.07
3	17.00	0.50	16.50	-	16.17	8.92	12.53	14.28	12.73	6.52	7.85	9.71	9.37	11.24	14.78
4	26.90	1.00	25.90	19.53	17.77	17.54	18.98	19.55	18.35	16.33	16.08	17.24	17.97	18.78	19.03
5	16.95	1.80	15.15	11.70	14.55	8.49	8.01	9.27	12.93	15.09	8.37	8.75	9.70	12.19	15.08
6	27.90	3.60	24.30	15.07	14.34	12.92	13.64	14.20	14.53	14.19	13.77	14.08	15.30	15.84	19.04
7	16.95	3.60	13.35	9.05	10.57	5.38	6.95	8.35	8.09	8.76	4.65	5.80	6.92	9.56	13.33
8	21.95	1.30	20.65	13.14	12.60	10.43	11.96	12.30	11.85	10.21	10.02	10.56	11.49	12.22	14.90
9	8.60	1.70	6.90	2.79	0.27	-	-	-	-	-	-	-	-	-	-
11	8.15	1.20	6.95	3.78	0.55	-	-	-	-	-	-	-	-	-	-
13	11.95	5.00	6.95	4.34	0.15	-0.45	2.32	1.41	0.20	0.03	-0.20	0.24	0.81	1.19	2.03
15	11.95	4.95	7.00	1.85	-0.90	0.45	1.27	0.90	0.53	0.10	-0.17	0.35	0.84	0.59	0.50


Logan County Piezometer Data (NE Slope)
P-1
P-2
P-3
P-4
P-3 Screen Depth
P-4 Screen Depth
P-2 Screen Depth
P-1 Screen Depth
Piezometric Level (Depth Below Surface, ft.)
0
5
10
15
20
25
8/1/2004
2/17/2005
9/5/2005
3/24/2006
10/10/2006
4/28/2007
11/14/2007
6/1/2008
12/18/2008
7/6/2009
Date of Reading


Logan County Piezometer Data (SW Slope)
P-5
P-6
P-7
P-8
P-5 Screen Depth
P-6 Screen Depth
P-7 Screen Depth
P-8 Screen Depth
Piezometric Level
(Depth Below Surface, ft.)
0
5
10
15
20
25
8/1/2004
2/17/2005
9/5/2005
3/24/2006
10/10/2006
4/28/2007
11/14/2007
6/1/2008
12/18/2008
7/6/2009
Date of Reading


Logan County Piezometer Data (Shallow Installations)
Piezometric Level
(Depth Below Surface, ft.)
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
8/1/2004
2/17/2005
9/5/2005
3/24/2006
10/10/2006
4/28/2007
11/14/2007
6/1/2008
12/18/2008
7/6/2009
P-9
P-13
P-11
P-15
P-9, P-11, P-13 and P-15 Screen Depth

Survival Statistics June 12, 2007

NE Slope

Overall Survival: 49.8%

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
14	1	1	1	1	2	2	2	2	3	2	2	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	3	2	2	3
13	1	1	1	1	2	2	2	2	2	2	2	1	1	1	1	2	1	2	2	1	1	1	1	1	1	1	3	3	3	1
12	1	1	1	1	3	2	2	1	2	2	2	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	3	3	2	2
11	1	1	1	2	3	2	2	2	3	3	2	1	1	1	1	1	1	3	1	2	3	3	3	2	2	1	1	2	3	1
10	1	1	1	1	3	2	2	2	3	2	2	1	1	1	1	1	1	2	1	1	2	2	3	2	2	1	3	1	1	1
9	1	1	1	2	3	2	2	2	2	2	3	1	1	1	3	3	1	2	3	2	2	2	2	3	2	1	1	1	1	1
8	1	1	1	1	2	3	3	3	3	2	3	1	1	1	1	1	1	3	1	2	1	1	1	1	1	2	2	3	2	1
7	1	1	1	1	3	3	2	2	2	2	1	1	1	1	2	1	3	2	1	3	1	1	1	3	2	1	2	1	1	1
6	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	1	3	1	2	1	1	1	1	1	1	1	1	1	1	1
5	2	2	1	1	3	3	3	3	3	3	3	2	2	2	1	1	2	3	3	2	1	1	2	1	1	3	3	2	3	2
4	1	1	2	2	2	2	2	2	1	1	1	2	1	2	1	2	2	1	3	2	2	2	3	1	2	3	2	2	3	2
3	3	1	1	1	1	1	1	1	1	2	3	3	2	2	2	1	2	1	2	2	3	2	1	1	1	1	3	3	3	3
2	2	1	1	1	1	1	2	1	2	1	2	2	3	3	1	1	2	1	3	2	1	3	2	1	1	1	3	3	3	
1	2	2	1	1	1	1	2	1	2	1	3	2	2																	

(Survival: 43.6%)
Panel 3
Scraped Slope/Best Method
(76.4%)

(57.1%)
Panel 4
No Scraping/Best Method
(72.8%)

(51.9%)
Panel 5
No Scraping/Minimal Method
(64.6%)

	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	1	1	1	1	1	1	3	1	1	3	1	1	1		1															
2	1	1	1	2	3	1	1	1	3	1	1	1	1	3	1	1	1	3	3	1	1	1	3							
3	2	1	3	1	3	1	1	1	1	3	1	1	1	1	3	1	1	3	1	2	3	3	3	1	1	1	1	3	1	3
4	3	1	1	1	1	1	2	1	2	1	3	1	1	3	1	1	3	3	3	1	1	1	3	1	1	3	1	3	1	1
5	1	1	2	1	1	2	3	2	2	1	1	1	3	3	3	1	1	1	2	1	1	1	2	1	1	1	1	3	1	3
6	1	1	3	1	1	1	3	1	1	1	2	1	1	1	1	3	2	1	1	2	1	2	3	1	3	1	1	3	1	1
7	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2	1	2	1	1	1	1	2	3	1	3	1
8	1	1	2	3	1	2	1	1	3	1	1	1	1	1	1	2	1	1	3	1	1	1	1	1	3	1	3	1	1	3
9	1	2	1	2	1	1	3	2	1	1	1	1	1	1	1	1	1	1	3	1	3	1	2	3	1	3	1	3	3	1
10	1	3	1	1	1	1	1	1	1	2	1	1	1	3	3	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1
11	1	1	1	1	1	1	1	3	1	1	1	2	1	1	1	1	1	1	1	1	3	1	1	1	1	3	3	1	1	1
12	1	1	1	1	1	1	1	1	3	1	1	2	3	1	3	1	1	3	1	1	2	1	1	1	1	1	1	3	3	1
13	1	1	1	1	1	1	1	1	2	1	1	1	1	1	3	3	2	1	1	1	3	2	1	3	1	1	2	1	1	1
14	1	1	3	1	1	1	1	1	1	1	1																			

SW Slope

Overall Survival: 71.7%

1 Willow survived 2 Willow sprouted, then died 3 Willow died

Graphical representation of survival of the NE and SW live pole plots at the Logan County demonstration site on June 12, 2007.

Survival Statistics August 7, 2007

NE Slope

Overall Survival: 27.6%

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
14	1	2	2	2	2	2	2	2	3	2	2	1	1	2	2	3	2	2	2	2	2	2	2	2	2	1	3	2	2	3
13	1	2	1	1	2	2	2	2	2	2	2	1	1	1	1	2	1	2	2	2	2	2	2	1	1	1	3	3	3	2
12	1	1	1	1	3	2	2	1	2	2	2	1	1	1	1	1	1	1	3	2	1	1	1	1	1	1	3	3	2	2
11	1	1	1	2	3	2	2	2	3	3	2	1	1	1	1	1	1	3	1	2	3	3	3	2	2	1	2	2	3	1
10	1	1	1	1	3	2	2	2	3	2	2	1	1	1	1	1	1	2	1	1	2	2	3	2	2	2	3	2	1	1
9	1	1	1	2	3	2	2	2	2	2	3	1	1	1	3	3	1	2	3	2	2	2	2	3	2	1	1	1	1	1
8	1	1	1	1	2	3	3	3	3	2	3	1	1	2	1	2	1	3	2	2	1	1	1	2	1	2	2	3	2	2
7	1	1	1	1	3	3	2	2	2	2	2	1	2	2	2	1	3	2	1	3	1	1	1	3	2	1	2	1	1	2
6	1	1	1	3	3	3	3	3	3	3	3	2	2	2	1	2	3	2	2	2	1	1	1	2	1	1	2	1	1	1
5	2	2	1	1	3	3	3	3	3	3	3	2	2	2	2	2	2	3	3	2	2	2	2	2	2	3	3	2	3	2
4	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	2	2	2	3	2	2	3	2	2	3	2
3	3	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	3	2	2	2	2	2	3	3	3	3
2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	3	2	2	3	2	2	2	2	3	3	3	
1	2	2	2	2	2	1	2	2	2	2	3	2	2																	

(Survival: 23.6%)
Panel 3
Scraped Slope/Best Method
(37.1%)

(30.8%)
Panel 4
No Scraping/Best Method
(17.6%)

(28.7%)
Panel 5
No Scraping/Minimal Method
(26.6%)

	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	1	2	1	2	1	1	3	1	2	3	2	2	2		2															
2	1	2	1	2	3	2	2	2	3	2	2	2	2	3	2	2	2	3	3	2	2	2	3							
3	2	1	3	2	3	1	1	2	2	3	2	2	2	2	3	2	2	3	2	2	3	3	3	2	1	1	1	3	1	3
4	3	2	2	2	2	2	2	2	2	2	3	2	2	3	2	2	3	3	3	2	2	2	3	2	2	3	1	3	1	1
5	2	2	2	2	2	2	3	2	2	2	2	2	3	3	3	2	2	2	2	2	2	2	2	2	2	1	1	3	1	3
6	2	2	3	2	2	2	3	2	2	2	2	2	2	2	2	3	2	2	2	2	2	2	3	1	3	1	1	3	2	1
7	2	2	1	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	1	3	1
8	1	1	2	3	2	2	2	1	3	2	2	2	2	2	2	2	1	2	3	2	2	2	2	1	3	1	3	1	1	3
9	1	2	1	2	2	2	3	2	2	1	2	2	1	2	1	2	2	2	3	2	3	2	2	3	1	3	1	3	3	2
10	1	3	1	2	1	1	1	1	1	2	1	1	1	3	3	1	2	1	1	1	1	1	2	1	1	2	3	2	2	2
11	1	1	1	2	1	1	2	3	1	1	2	2	2	1	1	1	1	1	1	1	3	2	1	1	1	3	3	1	2	2
12	1	1	1	1	1	1	1	1	3	1	1	2	3	1	3	1	2	3	1	2	2	2	2	2	2	2	2	3	3	2
13	1	1	1	2	1	1	1	2	2	1	2	1	2	2	3	3	2	2	2	2	3	2	2	3	2	2	2	2	2	2
14	1	2	3	1	1	1	2	2	2	2	2																			

SW Slope

Overall Survival: 27.5%

1 Willow survived 2 Willow sprouted, then died 3 Willow died

Graphical representation of survival of the NE and SW live pole plots at the Logan County demonstration site on August 7, 2007.

Survival Statistics September 25, 2007

NE Slope

Overall Survival: 25.9%

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
14	1	2	2	2	2	2	2	2	3	2	2	1	1	2	2	3	2	2	2	2	2	2	2	2	2	1	3	2	2	3
13	1	2	1	1	2	2	2	2	2	2	2	1	1	1	1	2	1	2	2	2	2	2	2	1	1	1	3	3	3	2
12	1	1	1	1	3	2	2	1	2	2	2	1	1	1	1	2	1	1	3	2	1	1	1	1	1	1	3	3	2	2
11	1	1	1	2	3	2	2	2	3	3	2	1	1	1	1	1	1	3	1	2	3	3	3	2	2	1	2	2	3	1
10	1	1	1	1	3	2	2	2	3	2	2	1	1	1	1	1	1	2	1	1	2	2	3	2	2	1	3	2	1	1
9	1	1	2	2	3	2	2	2	2	2	3	1	1	2	3	3	1	2	3	2	2	2	2	3	2	1	1	1	1	1
8	1	1	1	1	2	3	3	3	3	2	3	1	1	2	1	2	2	3	2	2	1	1	1	2	1	2	2	3	2	2
7	1	1	2	1	3	3	2	2	2	2	2	2	2	2	2	1	3	2	1	3	1	1	1	3	2	1	2	1	1	2
6	1	1	1	3	3	3	3	3	3	3	3	2	2	2	1	2	3	2	2	2	1	1	1	2	1	1	2	1	1	1
5	2	2	2	2	3	3	3	3	3	3	3	2	2	2	2	2	2	3	3	2	2	2	2	2	2	3	3	2	3	2
4	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	2	2	2	3	2	2	3	2	2	3	2
3	3	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	3	2	2	2	2	2	3	3	3	3
2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	3	2	2	3	2	2	2	2	3	3	3	
1	2	2	2	2	2	1	2	2	2	2	3	2	2																	

(Survival: 20.7%)
Panel 3
Scraped Slope/Best Method
(32.1%)

(27.8%)
Panel 4
No Scraping/Best Method
(16.8%)

(29.5%)
Panel 5
No Scraping/Minimal Method
(21.2%)

	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	2	2	1	2	1	1	3	1	2	3	2	2	2		2															
2	2	1	2	2	3	1	1	1	3	1	2	2	2	3	2	2	2	3	3	2	2	2	3							
3	2	2	3	2	3	1	1	2	2	3	2	2	2	2	3	2	2	3	2	2	3	3	3	2	1	2	2	3	1	3
4	3	2	2	2	2	2	2	2	2	2	3	2	2	3	2	2	3	3	3	2	2	2	3	2	2	3	1	3	2	1
5	2	2	2	2	2	2	3	2	2	2	2	2	3	3	3	2	2	2	2	2	2	2	2	2	2	1	1	3	1	3
6	2	2	3	2	2	2	3	2	2	2	2	2	2	2	2	3	2	2	2	2	2	2	3	2	3	1	1	3	2	1
7	2	2	1	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	1	1	1
8	1	1	2	3	2	2	2	1	3	2	2	2	2	2	2	2	2	2	3	2	2	2	2	1	3	1	3	1	1	3
9	1	2	1	2	2	2	3	2	2	1	2	2	2	2	1	2	2	2	3	2	3	2	2	3	2	3	1	3	3	2
10	1	3	1	2	1	1	1	2	1	2	1	1	1	3	3	1	2	1	1	1	1	1	2	1	1	2	3	2	2	2
11	2	2	1	2	1	1	2	3	1	2	2	2	2	1	1	1	1	1	1	1	3	2	2	2	1	3	3	1	2	2
12	1	2	1	1	1	1	1	1	3	1	1	2	3	1	3	1	2	1	1	2	2	2	2	2	2	2	2	3	3	2
13	2	1	1	2	1	1	1	2	2	1	2	1	2	2	3	3	2	2	2	2	3	2	2	3	2	2	2	2	2	2
14	2	2	3	1	1	2	2	2	2	2	2																			

SW Slope

Overall: 27.5%

1 Willow survived 2 Willow sprouted, then died 3 Willow died

Graphical representation of survival of the NE and SW live pole plots at the Logan County demonstration site on September 25, 2007.

Survival Statistics June 12, 2008

NE Slope

Overall Survival: 22.4%

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
14	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3	3
13	1	3	1	1	3	3	3	3	3	3	3	1	3	3	1	3	1	3	3	3	3	3	3	1	1	1	3	3	3	3
12	1	1	1	1	3	3	3	3	3	3	3	1	1	1	1	3	1	3	3	3	3	1	1	1	1	1	3	3	3	3
11	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	1	1	3	1	3	3	3	3	3	3	1	3	3	3	1
10	1	1	1	1	3	3	3	3	3	3	3	1	1	1	1	1	1	3	1	1	3	3	3	3	3	1	3	3	1	1
9	3	1	3	3	3	3	3	3	3	3	3	1	1	3	3	3	1	3	3	3	3	3	3	3	3	1	1	1	1	1
8	1	1	1	1	3	3	3	3	3	3	3	3	3	3	1	3	3	3	3	3	1	1	1	3	1	3	3	3	3	3
7	1	3	3	1	3	3	3	3	3	3	3	3	3	3	3	1	3	3	1	3	1	1	3	3	3	1	3	1	1	3
6	1	1	1	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3	3	3	1	3	1	3	1	1	3	1	1	1
5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
1	3	3	3	3	3	3	3	3	3	3	3	3	3																	

(Survival: 17.9%)
Panel 3
Scraped Slope/Best Method
(22.9%)

(22.6%)
Panel 4
No Scraping/Best Method
(15.2%)

(27.1%)
Panel 5
No Scraping/Minimal Method
(15.9%)

	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	3	3	3	3	3	3	3	3	3	3	3	3	3		3															
2	3	3	3	3	3	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3							
3	3	3	3	3	3	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3	1	3
4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	3	1
5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3
6	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	3	3	1
7	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1
8	3	1	3	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	1	3	1	1	3
9	3	3	1	3	3	3	3	3	3	1	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
10	3	3	1	3	1	1	1	3	1	3	1	1	1	3	3	1	3	1	1	1	3	1	3	1	3	3	3	1	3	3
11	3	3	1	3	1	1	3	3	1	3	3	3	3	1	1	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3
12	3	3	1	1	1	1	1	1	3	1	1	3	3	1	3	1	3	1	1	3	3	3	3	3	3	3	3	3	3	3
13	3	3	1	3	1	1	1	3	3	1	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
14	3	3	3	1	1	3	3	3	3	3	3																			

SW Slope

Overall: 18.3%

1 Willow survived 3 Willow died

Graphical representation of survival of the NE and SW live pole plots at the Logan County demonstration site on June 12, 2008.

Survival Statistics September 20, 2008

NE Slope

Overall Survival: 18.4%

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
14	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
13	3	3	3	1	3	3	3	3	3	3	3	1	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
12	3	1	1	1	3	3	3	3	3	3	3	1	1	1	1	3	1	3	3	3	3	3	1	3	1	1	3	3	3	3
11	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	1
10	1	1	1	1	3	3	3	3	3	3	3	1	1	1	1	1	1	3	1	1	3	3	3	3	3	3	3	3	1	1
9	3	1	3	3	3	3	3	3	3	3	3	1	1	3	3	3	1	3	3	3	3	3	3	3	3	3	1	1	1	1
8	1	1	1	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3	3	3	1	1	1	3	1	3	3	3	3	3
7	1	3	3	1	3	3	3	3	3	3	3	3	3	3	3	1	3	3	1	3	1	1	3	3	3	1	3	1	1	3
6	1	1	1	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3	3	3	1	3	1	3	1	1	3	1	1	1
5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
1	3	3	3	3	3	3	3	3	3	3	3	3	3																	

(Survival: 14.3%)
Panel 3
Scraped Slope/Best Method
(22.1%)

(20.3%)
Panel 4
No Scraping/Best Method
(13.6%)

(20.2%)
Panel 5
No Scraping/Minimal Method
(15.9%)

	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	3	3	3	3	3	3	3	3	3	3	3	3	3		3															
2	3	3	3	3	3	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3							
3	3	3	3	3	3	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3	1	3
4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	3	1
5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3
6	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	3	3	1
7	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1
8	3	1	3	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	1	3	1	1	3
9	3	3	1	3	3	3	3	3	3	1	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
10	3	3	1	3	1	1	1	3	1	3	1	1	1	3	3	1	3	1	1	3	3	1	3	1	3	3	3	1	3	3
11	3	3	1	3	1	1	3	3	1	3	3	3	3	1	1	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3
12	3	3	1	1	1	1	1	1	3	1	1	3	3	1	3	1	3	1	3	3	3	3	3	3	3	3	3	3	3	3
13	3	3	3	3	1	1	1	3	3	1	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
14	3	3	3	1	1	3	3	3	3	3	3																			

SW Slope

Overall: 17.2%

1 Willow survived 3 Willow died

Graphical representation of survival of the NE and SW live pole plots at the Logan County demonstration site on September 20, 2008.

Survival Statistics June 15, 2009

NE Slope

Overall Survival: 12.2%

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
14	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
13	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
12	3	1	3	3	3	3	3	3	3	3	3	1	1	1	1	3	1	3	3	3	3	3	1	3	1	3	3	3	3	3
11	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
10	1	1	1	1	3	3	3	3	3	3	3	3	1	3	3	3	1	3	1	1	3	3	3	3	3	3	3	3	1	1
9	3	1	3	3	3	3	3	3	3	3	3	1	1	3	3	3	1	3	3	3	3	3	3	3	3	3	1	1	1	1
8	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
7	1	3	3	1	3	3	3	3	3	3	3	3	3	3	3	1	3	3	1	3	1	1	3	3	3	3	3	1	3	3
6	1	1	1	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3	3	3	3	3	1	3	3	3	3	3	3	3
5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
1	3	3	3	3	3	3	3	3	3	3	3	3	3																	

(Survival: 12.1%)
Panel 3
Scraped Slope/Best Method
(16.4%)

(15.0%)
Panel 4
No Scraping/Best Method
(12.8%)

(9.3%)
Panel 5
No Scraping/Minimal Method
(16.8%)

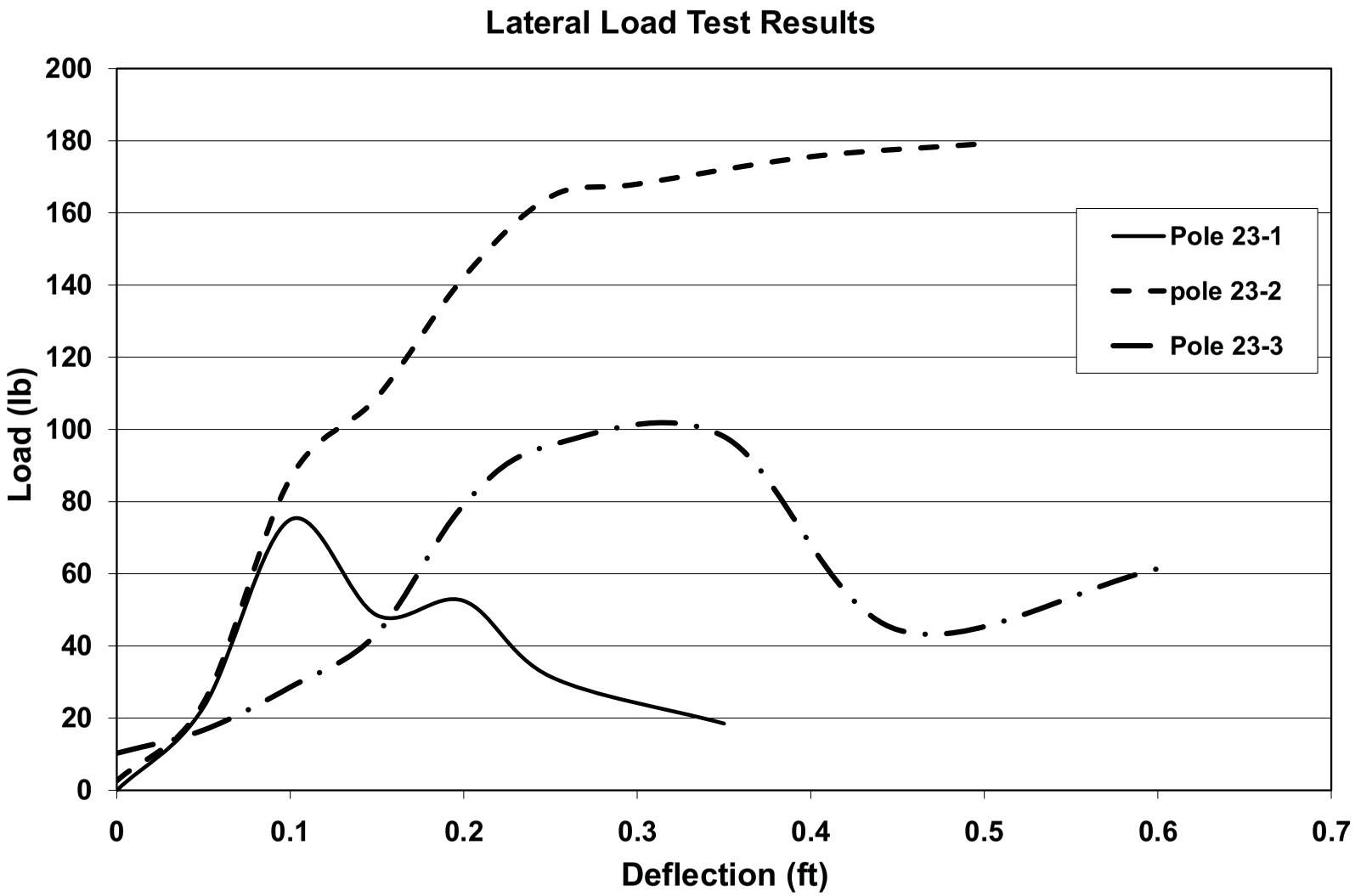
	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	3	3	3	3	3	3	3	3	3	3	3	3	3		3															
2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3							
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3	1	3
4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	3	1
5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3
6	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	3	3	1
7	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1
8	3	1	3	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	1	3	1	1	3
9	3	3	3	3	3	3	3	3	3	1	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3
10	3	3	3	3	1	1	1	3	1	3	1	1	1	3	3	1	3	1	3	3	3	1	3	1	3	3	3	1	3	3
11	3	3	3	3	1	1	3	3	1	3	3	3	3	1	1	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3
12	3	3	3	1	1	1	1	1	3	1	1	3	3	1	3	1	3	1	3	3	3	3	3	3	3	3	3	3	3	3
13	3	3	3	3	1	1	1	3	3	1	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
14	3	3	3	1	1	3	3	3	3	3	3																			

SW Slope

Overall: 15.3%

1 Willow survived 3 Willow died

Graphical representation of survival of the NE and SW live pole plots at the Logan County demonstration site on June 15, 2009.


Lateral Load Test Results
Load (lb)
200
180
160
140
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Deflection (ft)
Pole 23-1
pole 23-2
Pole 23-3

Logan County - US33/SR347 - Lateral Pullout Tests

Pole 23-1: 0.85 ft exposed length

	Deflection (ft)	Load (lbs)	
	0	-	
	0.05	23	
	0.1	75	
	0.15	48.5	Initial Failure
	0.2	52.5	
	0.25	31.5	
≈ 0.35	0.35	18.5	Pole Broke

Maximum Load = 75 lbs

Deflection at Failure = 0.35 ft (Snaped at failure - Brittle)

1.2 ft length to failure

Pole 23-2: 0.80 ft exposed length

Deflection (ft)	Load (lbs)	
0	2.6	
0.05	24.3	
0.1	86.4	
0.15	108.9	
0.2	142.2	
0.25	164.5	
0.3	168	
0.4	175.6	
0.5	179.2	Failure - Snapped off

Maximum Load = 180 lbs

Deflection at Failure = 0.50 ft

1.33 ft length to failure

Logan County - US33/SR347 - Lateral Pullout Tests

Pole 23-3: 0.83 ft exposed length

Deflection (ft)	Load (lbs)	
0	10.3	
0.05	16.7	
0.1	28.6	
0.15	43.5	
0.2	79.1	
0.25	95.6	
0.35	98	Snapped
0.45	44.5	
0.6	61.4	Broke Off

Maximum Load = 98 lbs - (205 lbs residual force)

Deflection at Failure = .6 ft

1.39 ft length to failure

Logan County Infinite Slope Analysis

γ_w	=	62.4	pcf			
γ	=	136	pcf			
s_u	=	300	psf	=	2.08	psi
s_u	=	450	psf	=	3.13	psi
φ_{fs}	=	29	deg			
c	=	0	psf			
β	=	26.6	deg			
L	=	5	ft	=	60	in
d	=	1.25	in	=	0.10417	ft
r	=	0.625	in	=	0.05208	ft
I	=	0.1198	in^4			
E	=	1.0E+06	psi			
σ_u	=	8500	psi			
M_y	=	1629.85	lb-in			
τ_u	=	580	psi			
e/d	=	0				
s	=	3	ft			

Factor of Safety:

$$FS = A\left[\frac{\tan(\phi)}{\tan(\beta)}\right] + B\left[\frac{c + c_R}{\gamma H}\right]$$

$$A = 1 - \frac{r_u}{\cos^2(\beta)}$$

$$B = \frac{1}{\cos^2(\beta)\tan(\beta)}$$

$$r_u = \left(\frac{\gamma_w}{\gamma}\right)\left(\frac{1}{(1 + \tan(\beta)\tan(\theta))}\right)$$

Flow Mode:

$$q_y = s_u N_c$$

$$N_c = 2\left(1 + z/d\right) \le 9$$

$$T_x = q_y d$$

Pile Mode (Long):

$$\text{Dimensionless Yield Moment } (YM) = \frac{M_{yield}}{s_u d^3}$$

$$\text{Dimensionless Ultimate Lateral Resistance } (ULR) = \frac{T_{xu}}{s_u d^2}$$

$$M_{yield} = \frac{\sigma_y I}{r}$$

$$I = \frac{\pi r^4}{4}$$

$$T_{xu} = (ULR) s_u d^2$$

			Flow Mode				Pile Mode								Shear Mode		Limiting	FS	
								Short			Long								
	θ	H	N_c	q_y	T_x	c_R	βL	L/d	ULR	T_x	YM	ULR	T_x	c_R	V_u	c_R	c_R	Reinforced	Unreinforced
A = 1.000	90	2	40.4	2700	562.5	55.88	7.095				267	55	269	26.68	712	70.71	26.68	1.352	1.107
B = 2.498		2.5	50	2700	703.125	69.86	7.095				267	55	269	26.68	712	70.71	26.68	1.303	1.107
r_u = 0.000		3	59.6	2700	843.75	83.83	7.095				267	55	269	26.68	712	70.71	26.68	1.270	1.107
		3.5	69.2	2700	984.375	97.80	7.095				267	55	269	26.68	712	70.71	26.68	1.247	1.107
		4	78.8	2700	1125	111.77	7.095				267	55	269	26.68	712	70.71	26.68	1.229	1.107
		4.5	88.4	2700	1265.625	125.74	7.095				267	55	269	26.68	712	70.71	26.68	1.216	1.107
A = 0.541	26.6	2	40.4	2700	562.5	55.88	7.095				267	55	269	26.68	712	70.71	26.68	0.844	0.599
B = 2.498		2.5	50	2700	703.125	69.86	7.095				267	55	269	26.68	712	70.71	26.68	0.795	0.599
r_u = 0.367		3	59.6	2700	843.75	83.83	7.095				267	55	269	26.68	712	70.71	26.68	0.762	0.599
		3.5	69.2	2700	984.375	97.80	7.095				267	55	269	26.68	712	70.71	26.68	0.739	0.599
		4	78.8	2700	1125	111.77	7.095				267	55	269	26.68	712	70.71	26.68	0.722	0.599
		4.5	88.4	2700	1265.625	125.74	7.095				267	55	269	26.68	712	70.71	26.68	0.708	0.599

Logan County Cost Analysis

	Unit Cost	Quantities	Cost
Excavation	$72.00	250	$18,000.00
Embankment	$100.00	93	$9,300.00
Geotextile	$5.00	250	$1,250.00
Slope Protection/Geocell	$250.00	33	$8,250.00
Topsoil	$150.00	8	$1,200.00
Seeding and Mulching	$2.50	1875	$4,687.50
Commercial Fertilizer	$325.00	0.25	$81.25
Water	$50.00	10	$500.00
Erosion Control Mat	$6.00	838	$5,028.00
Planting, Misc.	LS	1	$64,500.00
Retaining Wall	$233.00	100	$23,300.00
Contract Performance Bond	$4,000.00	1	$4,000.00
Maintaining Traffic	$3,000.00	0.5	$1,500.00
Mobilization	$3,000.00	0.5	$1,500.00
			$143,096.75

Logan County Bioengineering Cost Analysis

	Unit Cost	Quantities	Cost
Excavation	$72.00	0	$0.00
Embankment	$100.00	0	$0.00
Geotextile	$5.00	0	$0.00
Slope Protection/Geocell	$250.00	0	$0.00
Topsoil	$150.00	0	$0.00
Seeding and Mulching	$2.50	720	$1,800.00
Commercial Fertilizer	$325.00	0.25	$81.25
Water	$50.00	10	$500.00
Erosion Control Mat	$6.00	838	$5,028.00
Planting, Misc.	LS	1	$64,500.00
Retaining Wall	$233.00	0	$0.00
Contract Performance Bond	$4,000.00	1	$4,000.00
Maintaining Traffic	$3,000.00	0.5	$1,500.00
Mobilization	$3,000.00	0.5	$1,500.00
			$78,909.25

APPENDIX C

SUPPORTING DOCUMENTS FOR UNION COUNTY FIELD DEMONSTRATION SITE

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Union County 30 Year Data

Climate Data for Station: 334979 MARYSVILLE, OH - Source: MRCC, NCDC, ODNR

Temperature Summary
1971-2000 NCDC Normals

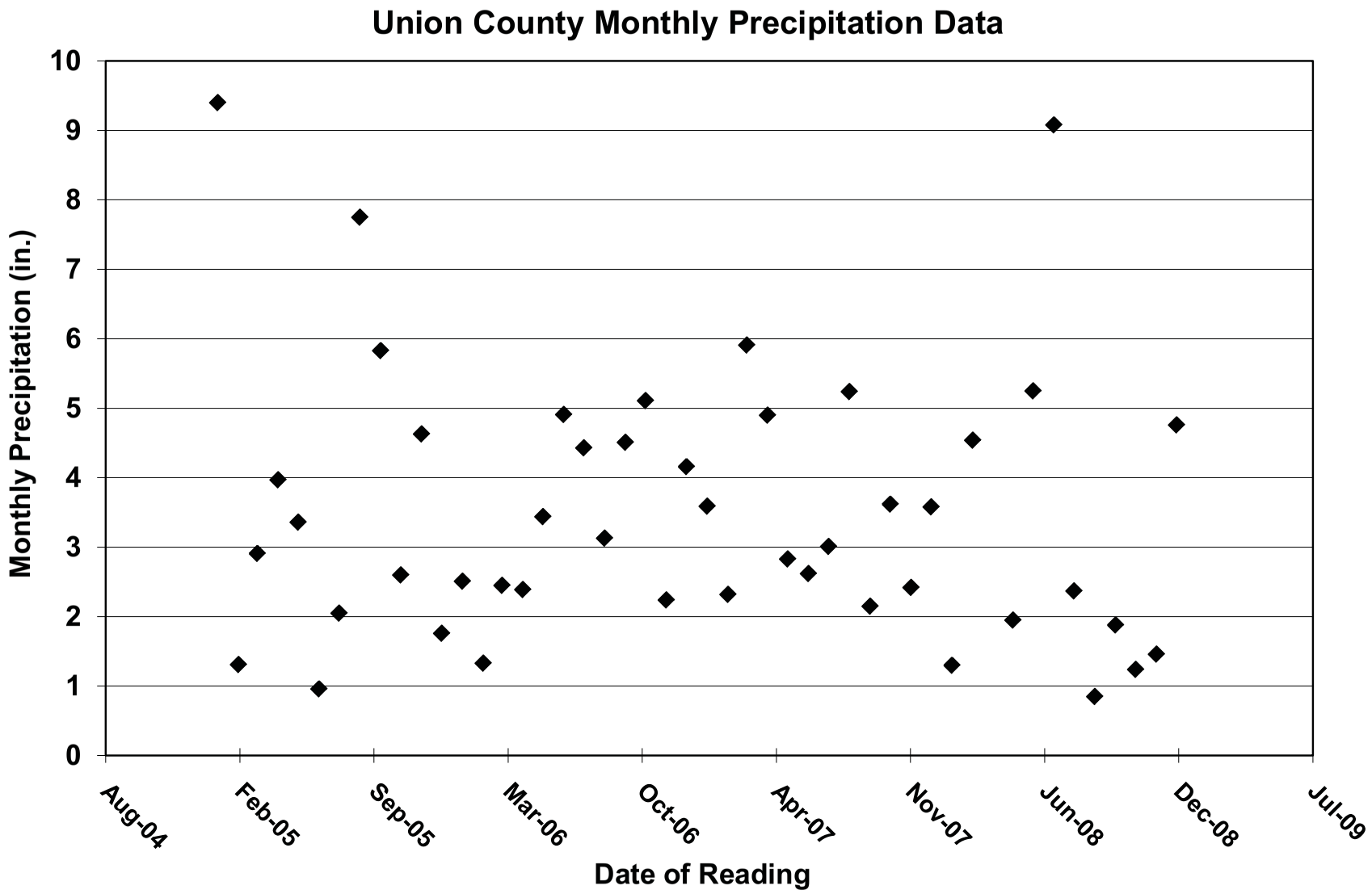
Element	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Max °F	33.5	38.0	49.4	61.3	72.1	80.5	84.2	82.2	75.6	63.6	49.9	38.3	60.7
Min °F	18.1	21.1	29.9	39.4	50.2	59.3	63.5	61.4	54.0	42.7	33.5	24.0	41.4
Mean °F	25.8	29.6	39.7	50.4	61.2	69.9	73.9	71.8	64.8	53.2	41.7	31.2	51.1

Precipitation Summary
1971-2000 NCDC Normals

Element	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Precip (in)	2.3	1.97	2.6	3.36	3.89	4.35	4.04	3.37	2.73	2.41	2.96	2.64	36.62

Growing Season Summary
Derived from 1971-2000 Averages

	Date of Last Spring Occurrence					Date of First Fall Occurrence				
Base Temp °F	Median	Early	90%	10%	Late	Median	Early	90%	10%	Late
32	4/25	4/8	4/11	5/7	5/9	10/16	9/23	9/28	11/4	11/20
30	4/16	3/28	4/5	4/30	5/8	10/24	10/2	10/12	11/5	11/20
28	4/10	3/24	3/28	4/24	4/29	11/3	10/14	10/18	11/15	11/20
24	4/3	3/13	3/16	4/12	4/18	11/13	10/17	10/22	11/28	12/11
20	3/19	2/8	3/1	4/7	4/10	11/22	10/24	11/4	12/18	1/2
16	3/11	2/8	2/17	3/23	4/7	12/8	11/4	11/15	12/25	1/2


Union County Monthly Precipitation Data
Monthly Precipitation (in.)
0
1
2
3
4
5
6
7
8
9
10
Aug-04
Feb-05
Sep-05
Mar-06
Oct-06
Apr-07
Nov-07
Jun-08
Dec-08
Jul-09
Date of Reading

Union County Monthly Precipitation Data

Climate Data for Station: 334979 MARYSVILLE, OH - Source: MRCC, NCDC, ODNR

Precipitation Summary
NCDC

2005 Monthly Precipitation and Departure From Normal (inches)

Location	January		February		March		April		May		June	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Marysville	9.40	7.10	1.31	-0.66	2.91	0.31	3.97	0.61	3.36	-0.53	0.96	-3.39

Location	July		August		September		October		November		December	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Marysville	2.05	-1.99	7.75	4.38	5.83	3.10	2.60	0.19	4.63	1.67	1.76	-0.88

Location	Annual	
	Precip.	Depart.
Marysville	46.53	9.91

Union County Monthly Precipitation Data

Climate Data for Station: 334979 MARYSVILLE, OH - Source: MRCC, NCDC, ODNR

Precipitation Summary
NCDC

2006 Monthly Precipitation and Departure From Normal (inches)

Location	January		February		March		April		May		June	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Marysville	2.51	0.21	1.33	-0.64	2.45	-0.15	2.39	-0.97	3.44	-0.45	4.91	0.56

Location	July		August		September		October		November		December	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Marysville	4.43	0.39	3.13	-0.24	4.51	1.78	5.11	2.70	2.24	-0.72	4.16	1.52

Location	Annual	
	Precip.	Depart.
Marysville	40.61	3.99

Union County Monthly Precipitation Data

Climate Data for Station: 334979 MARYSVILLE, OH - Source: MRCC, NCDC, ODNR

Precipitation Summary
NCDC

2007 Monthly Precipitation and Departure From Normal (inches)

Location	January		February		March		April		May		June	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Marysville	3.59	1.29	2.32	0.35	5.91	3.31	4.90	1.54	2.83	-1.06	2.62	-1.73

Location	July		August		September		October		November		December	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Marysville	3.01	-1.03	5.24	1.87	2.15	-0.58	3.62	1.21	2.42	-0.54	3.58	0.94

Location	Annual	
	Precip.	Depart.
Marysville	42.19	5.57

Union County Monthly Precipitation Data

Climate Data for Station: 334979 MARYSVILLE, OH - Source: MRCC, NCDC, ODNR

Precipitation Summary
NCDC

2008 Monthly Precipitation and Departure From Normal (inches)

Location	January		February		March		April		May		June	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Marysville	1.30	-1.00	4.54	2.75	M 5.99	M 3.39	1.95	-1.41	5.25	1.36	9.08	4.73

Location	July		August		September		October		November		December	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Marysville	2.37	-1.67	0.85	-2.52	1.88	-0.85	1.24	-1.17	1.46	-1.50	4.76	2.12

Location	Annual	
	Precip.	Depart.
Marysville	M 40.67	M 4.05

Union County Monthly Precipitation Data

Climate Data for Station: 334979 MARYSVILLE, OH - Source: MRCC, NCDC, ODNR

Precipitation Summary
NCDC

2009 Monthly Precipitation and Departure From Normal (inches)

Location	January		February		March		April		May		June	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Marysville	2.03	-0.27	1.38	-0.59	1.48	-1.12	3.97	0.61				

Location	July		August		September		October		November		December	
	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.	Precip.	Depart.
Marysville												

Location	Annual	
	Precip.	Depart.
Marysville		

Union County Daily Precipitation and Temerature

March 2007 Daily Precipitation (inches)

Location	Day of the Month																															Tot
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Marysville	0.06	1.05	-	T	-	-	0.02	0.20	-	-	0.07	-	-	0.05	1.05	0.07	T	-	-	0.48	-	-	1.35	1.30	0.14	-	-	-	0.01	-	0.06	5.91

March 2007 Daily Temperatures (°F)

Location		Day of the Month																														Avg
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Marysville	Max	48	49	36	29	37	27	30	41	61	55	53	52	75	72	61	33	37	41	49	49	72	64	64	70	77	76	80	64	69	75	59	55.0
	Min	35	34	23	21	23	12	19	15	24	37	31	26	38	57	32	28	26	24	30	35	32	58	47	53	53	56	62	46	46	38	48	35.8

April 2007 Daily Precipitation (inches)

Location	Day of the Month																														Tot
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Marysville	0.59	T	-	0.11	T	T	T	T	-	-	-	1.85	0.02	-	0.57	-	-	-	-	-	-	-	-	0.26	0.38	0.46	0.54	0.06	0.06	-	4.90

April 2007 Daily Temperatures (°F)

Location		Day of the Month																													Avg
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Marysville	Max	73	73	80	58	33	34	34	35	41	50	51	46	52	42	49	56	63	58	59	71	74	81	81	71	55	70	58	69	75	75	58.9
	Min	58	53	47	28	27	24	22	24	31	25	36	35	35	32	32	36	38	37	37	39	38	43	58	43	47	48	49	49	51	61	39.4

May 2007 Daily Precipitation (inches)

Location	Day of the Month																															Tot
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Marysville	-	T	-	-	-	0.37	-	-	-	T	-	-	-	-	-	1.48	0.10	0.03	-	T	T	-	-	-	-	-	0.23	0.06	0.19	-	0.37	2.83

May 2007 Daily Temperatures (°F)

Location		Day of the Month																														Avg
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Marysville	Max	85	75	75	78	65	67	75	85	88	85	76	74	72	84	87	66	57	65	71	79	76	85	88	89	86	82	82	80	87	90	88	78.8
	Min	55	52	45	47	55	45	43	48	56	57	50	45	41	43	64	48	46	42	41	53	48	55	60	61	64	62	60	63	60	64	61	52.7

State of Ohio
Department of Transportation
Office of Geotechnical Engineering

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LOG OF BORING

Date Started 9/15/05 Sampler: Type SS Dia. _____ Water Elev. - Project Identification: UNION
Date completed 9/15/05 UNI-33-8.35
Boring No. B-1 Station & Offset 81+50, 62' LT. Surface Elev. 1034.0' RESEARCH PROJECT-SLIP

Elev.	Depth	Std. Pen./ R.Q.D.	Rec. ft	Loss ft	Description	Sample No.	Physical Characteristics % Agg	% C.S.	% F.S.	% Silt	% Clay	L.L.	P.I.	W.C.	ODOT Class
1034.0	0														
1033.5		AUGERED			SOD	-	-	-	-	-	-	-	-	-	VISUAL
1033.0	2	3/4/6			BROWN CLAY (REC. 1.5')	37	0	1	2	37	60	52	31	23	A-7-6
1030.5	4	7/9/11			BROWN SILTY CLAY (REC. 1.5')	38	0	0	1	41	58	36	17	19	A-6b
1028.0	6	9/12/17			BROWN SILT AND CLAY (REC. 1.5')	39	0	0	0	45	55	34	14	18	A-6a
1025.5	8	5/10/15			BROWN SILT AND CLAY (REC. 1.5')	40	0	0	0	48	52	32	14	18	A-6a
1023.0	10	16/22/26			BROWN SILT AND CLAY (REC. 1.5')	41	0	1	1	44	54	32	13	18	A-6a
1020.5	12	5/9/14			BROWN SILT AND CLAY (REC. 1.5')	42	0	6	2	38	54	34	15	21	A-6a
1019.0	14														

BOTTOM OF BORING

Particle Sizes: Agg= >2.00mm, Coarse Sand= 2.00-0.42mm, Fine Sand= 0.42-0.074mm, Silt= 0.074-0.005mm, Clay= <0.005mm

Form TE-151 Revised 9/95

State of Ohio
Department of Transportation
Office of Geotechnical Engineering

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LOG OF BORING

Date Started 9/13/05 Sampler: Type SS Dia. ____ Water Elev. - Project Identification: UNION
Date completed 9/13/05 UNI-33-8.35
Boring No. B-2* Station & Offset 81+50, 12' LT. Surface Elev. 1059.5' RESEARCH PROJECT-SLIP

Elev.	Depth	Std. Pen./ R.Q.D.	Rec. ft	Loss ft	Description	Sample No.	Physical Characteristics % Agg	% C.S.	% F.S.	% Silt	% Clay	L.L.	P.I.	W.C.	ODOT Class
1059.5	0														
1059.0 1058.5		AUGERED			SOD	-	-	-	-	-	-	-	-	-	VISUAL
	2	2/3/3			BROWN SILTY CLAY (REC. 1.3')	7	0	1	3	32	64	42	20	24	A-7-6
1056.0	4	3/5/6			BROWN CLAY W/TRACE OF ROOTS (REC. 1.5')	8	0	1	2	30	67	48	27	23	A-7-6
1053.5	6	3/5/9			BROWN SILTY CLAY (REC. 1.5')	9	0	3	5	37	55	36	16	24	A-6b
1051.0	8	7/10/15			BROWN SILTY CLAY (REC. 1.5')	10	0	0	3	42	55	35	16	17	A-6b
1048.5	10	7/14/17			BROWN SILTY CLAY (REC. 1.5')	11	0	1	2	38	59	38	18	21	A-6b
1046.0	12	7/9/14			BROWN GRAVELLY CLAY (REC. 1.5')	12	20	2	3	31	44	36	16	17	A-6b
1043.5	14	11/14/23			BROWN SILTY CLAY (REC. 1.5')	13	0	5	8	38	49	35	16	18	A-6b
1041.0	16	4/7/14			BROWN SILTY CLAY (REC. 1.5')	14	0	2	5	38	55	40	19	21	A-6b
1038.5	18	12/17/31			BROWN GRAVELLY CLAY (REC. 1.5')	15	19	2	4	30	45	36	16	21	A-6b
1034.5	20	7/11/16			BROWN GRAVELLY CLAY (REC. 1.5')	16	37	1	2	25	35	37	19	15	A-6b
1029.5	22	8/12/23			BROWN CLAY (REC. 1.5')	17	0	4	5	28	63	46	23	20	A-7-6
1024.5	24	8/11/17			BROWN GRAVELLY CLAY (REC. 1.5')	18	26	0	1	20	53	39	18	21	A-6b
1023.0	26														
	28														
	30														
	32														
	34														
	36														

BOTTOM OF BORING

Particle Sizes: Agg= >2.00mm, Coarse Sand= 2.00-0.42mm, Fine Sand= 0.42-0.074mm, Silt= 0.074-0.005mm, Clay= <0.005mm

Form TE-151 Revised 9/95

* NOTE: WATER MONITORING WELL INSTALLED IN THIS HOLE.

State of Ohio
Department of Transportation
Office of Geotechnical Engineering

LOG OF BORING

Date Started 9/14/05 Sampler: Type SS Dia. _____ Water Elev. - Project Identification: UNION
Date completed 9/14/05 UNI-33-8.35
Boring No. B-3* Station & Offset 81+50, 84' RT. Surface Elev. 1058.7' RESEARCH PROJECT-SLIP

Elev.	Depth	Std. Pen./ R.Q.D.	Rec. ft	Loss ft	Description	Sample No.	Physical Characteristics % Agg	% C.S.	% F.S.	% Silt	% Clay	L.L.	P.I.	W.C.	ODOT Class
1058.7	0														
1058.2		AUGERED			TOPSOIL	-	-	-	-	-	-	-	-	-	VISUAL
1057.7	2	2/3/4			BROWN SILTY CLAY (REC. 1.3')	19	0	3	3	34	60	37	17	23	A-6b
1055.2	4	3/4/6			BROWN SILT AND CLAY (REC. 1.5')	20	11	4	5	32	48	32	13	18	A-6a
1052.7	6	5/5/8			BROWN SILTY CLAY (REC. 1.5')	21	0	1	2	35	62	39	19	23	A-6b
1050.2	8	2/4/6			BROWN SILTY CLAY (REC. 1.5')	22	0	2	3	34	61	37	16	20	A-6b
1047.7	10	5/8/8			BROWN SILTY CLAY (REC. 1.5')	23	13	2	3	30	52	37	16	20	A-6b
1045.2	12	5/9/12			BROWN SANDY CLAY (REC. 1.5')	24	11	4	7	31	47	38	18	17	A-6b
1042.7	14	5/7/9			BROWN CLAY (REC. 1.5')	25	0	1	2	34	63	45	23	20	A-7-6
1040.2	16	3/7/8			BROWN CLAY (REC. 1.5')	26	0	1	3	32	64	51	28	20	A-7-6
1037.7	18	6/8/12			BROWN SILTY CLAY W/ORGANIC (REC. 1.5')	27	0	2	4	36	58	42	20	21	A-7-6
1033.7	20	5/7/10			BROWN CLAY (REC. 1.5')	28	0	1	4	34	61	52	30	24	A-7-6
1028.7	22	4/8/14			GRAY SILTY CLAY W/TRACE OF ORGANIC (REC. 1.5')	29	0	1	4	36	59	44	20	22	A-7-6
1023.7	24	5/9/16			BROWN AND GRAY CLAY (REC. 1.5')	30	0	1	2	28	69	56	30	27	A-7-6
1022.2	26														
	28														
	30														
	32														
	34														
	36														

BOTTOM OF BORING

Particle Sizes: Agg= >2.00mm, Coarse Sand= 2.00-0.42mm, Fine Sand= 0.42-0.074mm, Silt= 0.074-0.005mm, Clay= <0.005mm

Form TE-151 Revised 9/95

* NOTE: WATER MONITORING WELL INSTALLED IN THIS HOLE.

State of Ohio
Department of Transportation
Office of Geotechnical Engineering

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LOG OF BORING

te Started 9/15/05 Sampler: Type SS Dia. _____ Water Elev. - Project Identification: UNION
te completed 9/15/05 UNI-33-8.35
ring No. B-4 Station & Offset 81+50, 141' RT. Surface Elev. 1031.0' RESEARCH PROJECT-SLIP

lev.	Depth	Std. Pen./ R.Q.D.	Rec. ft	Loss ft	Description	Sample No.	Physical Characteristics % Agg	% C.S.	% F.S.	% Silt	% Clay	L.L.	P.I.	W.C.	ODOT Class
31.0	0														
30.5		AUGERED			SOD	-	-	-	-	-	-	-	-	-	VISUAL
30.0	2	5/3/4			BROWN SILTY GRAVELLY SAND (REC. 1.5')	43	22	32	8	23	15	22	4	17	A-4a
27.5	4	3/4/6			BROWN CLAY W/TRACE OF ORGANIC (REC. 1.5')	44	0	1	3	29	67	58	33	27	A-7-6
25.0	6	5/10/14			BROWN CLAY (REC. 1.5')	45	0	2	2	25	71	46	22	21	A-7-6
22.5	8	5/10/15			BROWN SILTY CLAY (REC. 1.5')	46	0	1	1	28	70	43	20	20	A-7-6
20.0	10	10/15/22			BROWN SILTY CLAY (REC. 1.5')	47	0	3	5	32	60	39	17	22	A-6b
17.5	12	5/10/14			BROWN GRAVELLY CLAY (REC. 1.5')	48	21	2	4	29	44	38	18	19	A-6b
16.0	14														

BOTTOM OF BORING

Particle Sizes: Agg= >2.00mm, Coarse Sand= 2.00-0.42mm, Fine Sand= 0.42-0.074mm, Silt= 0.074-0.005mm, Clay= <0.005mm

Form TE-151 Revised 9/95

State of Ohio
Department of Transportation
Office of Geotechnical Engineering

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LOG OF BORING

Date Started 9/13/05 Sampler: Type SS Dia. _____ Water Elev. - Project Identification: UNION
Date completed 9/13/05 UNI-33-8.35
Boring No. B-5* Station & Offset 82+50, 11' LT. Surface Elev. 1059.1' RESEARCH PROJECT-SLIP

Elev.	Depth	Std. Pen./ R.Q.D.	Rec. ft	Loss ft	Description	Sample No.	Physical Characteristics % Agg	% C.S.	% F.S.	% Silt	% Clay	L.L.	P.I.	W.C.	ODOT Class
1059.1	0														
1058.5		AUGERED			SOD & TOPSOIL	-	-	-	-	-	-	-	-	-	VISUAL
	2														
	4														
1054.1															
	6														
		P.S.			SAMPLE GIVEN TO OSU	1-P	-	-	-	-	-	-	-	-	VISUAL
	8														
1049.1	10														
	12	4/6/9			BROWN GRAVELLY CLAY	2	18	1	3	32	46	36	17	16	A-6b
	14														
1044.1															
	16														
		P.S.			SAMPLE GIVEN TO OSU	3-P	-	-	-	-	-	-	-	-	VISUAL
	18														
1039.1	20														
	22	6/11/18			BROWN GRAVELLY CLAY	4	20	2	5	29	44	37	17	17	A-6b
	24														
1034.1															
	26														
		P.S.			SAMPLE GIVEN TO OSU	5-P	-	-	-	-	-	-	-	-	VISUAL
	28														
1029.1	30														
1027.6		7/14/26			BROWN SILTY CLAY	6	0	4	3	30	63	40	20	21	A-6b

P.S. = PRESS SAMPLE

BOTTOM OF BORING

Particle Sizes: Agg= >2.00mm, Coarse Sand= 2.00-0.42mm, Fine Sand= 0.42-0.074mm, Silt= 0.074-0.005mm, Clay= <0.005mm

Form TE-151 Revised 9/95

* NOTE: WATER MONITORING WELL INSTALLED IN THIS HOLE.

State of Ohio
Department of Transportation
Office of Geotechnical Engineering

6/6

LOG OF BORING

Date Started 9/14/05 Sampler: Type SS Dia. _____ Water Elev. - Project Identification: UNION
Date completed 9/14/05 UNI-33-8.35
Boring No. B-6* Station & Offset 82+75, 84' RT. Surface Elev. 1058.5' RESEARCH PROJECT-SLIP

Elev.	Depth	Std. Pen./ R.Q.D.	Rec. ft	Loss ft	Description	Sample No.	Physical Characteristics % Agg	% C.S.	% F.S.	% Silt	% Clay	L.L.	P.I.	W.C.	ODOT Class
1058.5	0														
1058.0		AUGERED			TOPSOIL	-	-	-	-	-	-	-	-	-	VISUAL
	2														
	4														
1053.5	6														
	8	P.S.			SAMPLE GIVEN TO OSU	31-P	-	-	-	-	-	-	-	-	VISUAL
1048.5	10														
	12	6/8/11			BROWN SILT AND CLAY (REC. 1.5')	32	0	3	5	41	51	34	15	17	A-6a
	14														
1043.5	16														
	18	P.S.			SAMPLE GIVEN TO OSU	33-P	-	-	-	-	-	-	-	-	VISUAL
1038.5	20														
	22	6/11/15			BROWN SILTY CLAY W/ORGANIC (REC. 1.5')	34	0	2	5	36	57	39	19	22	A-6b
	24														
1033.5	26														
	28	P.S.			SAMPLE GIVEN TO OSU	35-P	-	-	-	-	-	-	-	-	VISUAL
1028.5	30														
1027.0		3/7/14			GRAY CLAY W/TRACE OF ORGANIC (REC. 1.5')	36	0	1	4	29	66	51	26	24	A-7-6

BOTTOM OF BORING

P.S. = PRESS SAMPLE

Particle Sizes: Agg= >2.00mm, Coarse Sand= 2.00-0.42mm, Fine Sand= 0.42-0.074mm, Silt= 0.074-0.005mm, Clay= <0.005mm

Form TE-151 Revised 9/95

* NOTE: WATER MONITORING WELL INSTALLED IN THIS HOLE.

WILDCAT DYNAMIC CONE LOG

The Ohio State University
CEEGS
Columbus, Ohio

PROJECT NUMBER: OSURF #: 746483
DATE STARTED: 01-06-2005
DATE COMPLETED: 01-06-2005

HOLE #: sta 82+85, elev 1055
CREW: Kokesh, Trenner
PROJECT: OSU/ODOT Bioengineering
ADDRESS: Union County - 33-8.33
LOCATION: Marysville, Ohio

SURFACE ELEVATION: 1055
WATER ON COMPLETION:
HAMMER WEIGHT: 35 lbs.
CONE AREA: 10 sq. cm

DEPTH	BLOWS PER 10 cm	RESISTANCE Kg/cm²	GRAPH OF CONE RESISTANCE 0 50 100 150	N'	TESTED CONSISTENCY NON-COHESIVE	COHESIVE
-	2	8.9	••	2	VERY LOOSE	SOFT
-	3	13.3	•••	3	VERY LOOSE	SOFT
- 1 ft	3	13.3	•••	3	VERY LOOSE	SOFT
-	2	8.9	••	2	VERY LOOSE	SOFT
-	2	8.9	••	2	VERY LOOSE	SOFT
- 2 ft	3	13.3	•••	3	VERY LOOSE	SOFT
-	4	17.8	•••••	5	LOOSE	MEDIUM STIFF
-	6	26.6	•••••••	7	LOOSE	MEDIUM STIFF
- 3 ft	8	35.5	••••••••••	10	LOOSE	STIFF
- 1 m	8	35.5	••••••••••	10	LOOSE	STIFF
-	7	27.0	•••••••	7	LOOSE	MEDIUM STIFF
- 4 ft	6	23.2	••••••	6	LOOSE	MEDIUM STIFF
-	6	23.2	••••••	6	LOOSE	MEDIUM STIFF
-	7	27.0	•••••••	7	LOOSE	MEDIUM STIFF
- 5 ft	8	30.9	••••••••	8	LOOSE	MEDIUM STIFF
-	6	23.2	••••••	6	LOOSE	MEDIUM STIFF
-	8	30.9	••••••••	8	LOOSE	MEDIUM STIFF
- 6 ft	8	30.9	••••••••	8	LOOSE	MEDIUM STIFF
-	12	46.3	••••••••••••	13	MEDIUM DENSE	STIFF
- 2 m	13	50.2	•••••••••••••	14	MEDIUM DENSE	STIFF
- 7 ft	10	34.2	•••••••••	9	LOOSE	STIFF
-	10	34.2	•••••••••	9	LOOSE	STIFF
-	10	34.2	•••••••••	9	LOOSE	STIFF
- 8 ft	10	34.2	•••••••••	9	LOOSE	STIFF
-	15	51.3	••••••••••••••	14	MEDIUM DENSE	STIFF
-	12	41.0	••••••••••••	11	MEDIUM DENSE	STIFF
- 9 ft	9	30.8	••••••••	8	LOOSE	MEDIUM STIFF
-	10	34.2	•••••••••	9	LOOSE	STIFF
-	8	27.4	•••••••	7	LOOSE	MEDIUM STIFF
- 3 m 10 ft	9	30.8	••••••••	8	LOOSE	MEDIUM STIFF
-	12	36.7	••••••••••	10	LOOSE	STIFF
-	12	36.7	••••••••••	10	LOOSE	STIFF
-	11	33.7	•••••••••	9	LOOSE	STIFF
- 11 ft	11	33.7	•••••••••	9	LOOSE	STIFF
-	11	33.7	•••••••••	9	LOOSE	STIFF
-	18	55.1	••••••••••••••••	15	MEDIUM DENSE	STIFF
- 12 ft	15	45.9	••••••••••••••	13	MEDIUM DENSE	STIFF
-	13	39.8	••••••••••••	11	MEDIUM DENSE	STIFF
-	16	49.0	•••••••••••••••	13	MEDIUM DENSE	STIFF
- 4 m 13 ft	15	45.9	••••••••••••••	13	MEDIUM DENSE	STIFF

Marysville - Upper Hole - Wildcat Data

HOLE #: sta 82+85, elev 1055

WILDCAT DYNAMIC CONE LOG

PROJECT: OSU/ODOT Bioengineering

PROJECT NUMBER: OSURF #: 746483

DEPTH	BLOWS PER 10 cm	RESISTANCE Kg/cm²	GRAPH OF CONE RESISTANCE 0 50 100 150	N'	TESTED CONSISTENCY NON-COHESIVE	COHESIVE
-	16	44.3	••••••••••••	12	MEDIUM DENSE	STIFF
-	18	49.9	•••••••••••••••	14	MEDIUM DENSE	STIFF
- 14 ft	16	44.3	••••••••••••	12	MEDIUM DENSE	STIFF
-	16	44.3	••••••••••••	12	MEDIUM DENSE	STIFF
-	16	44.3	••••••••••••	12	MEDIUM DENSE	STIFF
- 15 ft	20	55.4	••••••••••••••••••	15	MEDIUM DENSE	STIFF
-	18	49.9	•••••••••••••••	14	MEDIUM DENSE	STIFF
-	14	38.8	••••••••••••	11	MEDIUM DENSE	STIFF
- 16 ft						
- 5 m						
-						
- 17 ft						
-						
-						
- 18 ft						
-						
-						
- 19 ft						
-						
- 6 m						
- 20 ft						
-						
-						
- 21 ft						
-						
-						
- 22 ft						
-						
-						
- 7 m 23 ft						
-						
-						
- 24 ft						
-						
-						
- 25 ft						
-						
-						
- 26 ft						
- 8 m						
-						
- 27 ft						
-						
-						
- 28 ft						
-						
-						
- 29 ft						
-						
- 9 m						

Marysville - Upper Hole - Wildcat Data

WILDCAT DYNAMIC CONE LOG

The Ohio State University
CEEGS
Columbus, Ohio

PROJECT NUMBER: OSURF #: 746483
DATE STARTED: 01-06-2005
DATE COMPLETED: 01-06-2005

HOLE #: sta 82+85, elev 1046
CREW: Kokesh, Trenner
PROJECT: OSU/ODOT Bioengineering
ADDRESS: Union County - 33-8.33
LOCATION: Marysville, Ohio

SURFACE ELEVATION: 1046
WATER ON COMPLETION:
HAMMER WEIGHT: 35 lbs.
CONE AREA: 10 sq. cm

DEPTH	BLOWS PER 10 cm	RESISTANCE Kg/cm²	GRAPH OF CONE RESISTANCE 0 50 100 150	N'	TESTED CONSISTENCY NON-COHESIVE	COHESIVE
-	2	8.9	••	2	VERY LOOSE	SOFT
-	3	13.3	•••	3	VERY LOOSE	SOFT
- 1 ft	3	13.3	•••	3	VERY LOOSE	SOFT
-	3	13.3	•••	3	VERY LOOSE	SOFT
-	4	17.8	•••••	5	LOOSE	MEDIUM STIFF
- 2 ft	6	26.6	•••••••	7	LOOSE	MEDIUM STIFF
-	4	17.8	•••••	5	LOOSE	MEDIUM STIFF
-	4	17.8	•••••	5	LOOSE	MEDIUM STIFF
- 3 ft	6	26.6	•••••••	7	LOOSE	MEDIUM STIFF
- 1 m	5	22.2	••••••	6	LOOSE	MEDIUM STIFF
-	5	19.3	•••••	5	LOOSE	MEDIUM STIFF
- 4 ft	5	19.3	•••••	5	LOOSE	MEDIUM STIFF
-	7	27.0	•••••••	7	LOOSE	MEDIUM STIFF
-	8	30.9	••••••••	8	LOOSE	MEDIUM STIFF
- 5 ft	9	34.7	•••••••••	9	LOOSE	STIFF
-	9	34.7	•••••••••	9	LOOSE	STIFF
-	8	30.9	••••••••	8	LOOSE	MEDIUM STIFF
- 6 ft	9	34.7	•••••••••	9	LOOSE	STIFF
-	9	34.7	•••••••••	9	LOOSE	STIFF
- 2 m	15	57.9	••••••••••••••••	16	MEDIUM DENSE	VERY STIFF
- 7 ft	14	47.9	••••••••••••••	13	MEDIUM DENSE	STIFF
-	15	51.3	•••••••••••••••	14	MEDIUM DENSE	STIFF
-	11	37.6	•••••••••••	10	LOOSE	STIFF
- 8 ft	10	34.2	••••••••••	9	LOOSE	STIFF
-	9	30.8	••••••••	8	LOOSE	MEDIUM STIFF
-	20	68.4	••••••••••••••••••••	19	MEDIUM DENSE	VERY STIFF
- 9 ft	14	47.9	••••••••••••••	13	MEDIUM DENSE	STIFF
-	11	37.6	•••••••••••	10	LOOSE	STIFF
-	13	44.5	••••••••••••	12	MEDIUM DENSE	STIFF
- 3 m 10 ft	20	68.4	••••••••••••••••••••	19	MEDIUM DENSE	VERY STIFF
-	15	45.9	••••••••••••••	13	MEDIUM DENSE	STIFF
-	12	36.7	••••••••••••	10	LOOSE	STIFF
-	15	45.9	••••••••••••••	13	MEDIUM DENSE	STIFF
- 11 ft	21	64.3	••••••••••••••••••••	18	MEDIUM DENSE	VERY STIFF
-	18	55.1	••••••••••••••••	15	MEDIUM DENSE	STIFF
-	12	36.7	••••••••••••	10	LOOSE	STIFF
- 12 ft	11	33.7	•••••••••••	9	LOOSE	STIFF
-	10	30.6	••••••••	8	LOOSE	MEDIUM STIFF
-	10	30.6	••••••••	8	LOOSE	MEDIUM STIFF
- 4 m 13 ft	10	30.6	••••••••	8	LOOSE	MEDIUM STIFF

Marysville - Middle Hole

HOLE #: sta 82+85, elev 1046 **WILDCAT DYNAMIC CONE LOG**

PROJECT: OSU/ODOT Bioengineering PROJECT NUMBER: OSURF #: 746483

DEPTH	BLOWS PER 10 cm	RESISTANCE Kg/cm²	GRAPH OF CONE RESISTANCE 0 50 100 150	N'	TESTED CONSISTENCY NON-COHESIVE	COHESIVE
-	13	36.0	••••••••••	10	LOOSE	STIFF
-	12	33.2	•••••••••	9	LOOSE	STIFF
- 14 ft	12	33.2	•••••••••	9	LOOSE	STIFF
-	12	33.2	•••••••••	9	LOOSE	STIFF
-	13	36.0	••••••••••	10	LOOSE	STIFF
- 15 ft	18	49.9	••••••••••••••	14	MEDIUM DENSE	STIFF
-	19	52.6	•••••••••••••••	15	MEDIUM DENSE	STIFF
-	23	63.7	••••••••••••••••••	18	MEDIUM DENSE	VERY STIFF
- 16 ft						
- 5 m						
-						
- 17 ft						
-						
-						
- 18 ft						
-						
-						
- 19 ft						
-						
- 6 m						
- 20 ft						
-						
-						
- 21 ft						
-						
-						
- 22 ft						
-						
-						
- 7 m 23 ft						
-						
-						
- 24 ft						
-						
-						
- 25 ft						
-						
-						
- 26 ft						
- 8 m						
-						
- 27 ft						
-						
-						
- 28 ft						
-						
-						
- 29 ft						
-						
- 9 m						

Marysville - Middle Hole

WILDCAT DYNAMIC CONE LOG

The Ohio State University
CEEGS
Columbus, Ohio

PROJECT NUMBER: OSURF #: 746483
DATE STARTED: 01-06-2005
DATE COMPLETED: 01-06-2005

HOLE #: sta 82+85, elev 1039
CREW: Kokesh, Trenner
PROJECT: OSU/ODOT Bioengineering
ADDRESS: Union County - 33-8.33
LOCATION: Marysville, Ohio

SURFACE ELEVATION: 1039
WATER ON COMPLETION:
HAMMER WEIGHT: 35 lbs.
CONE AREA: 10 sq. cm

DEPTH	BLOWS PER 10 cm	RESISTANCE Kg/cm²	GRAPH OF CONE RESISTANCE 0 50 100 150	N'	TESTED CONSISTENCY NON-COHESIVE	COHESIVE
-	2	8.9	••	2	VERY LOOSE	SOFT
-	2	8.9	••	2	VERY LOOSE	SOFT
- 1 ft	2	8.9	••	2	VERY LOOSE	SOFT
-	5	22.2	••••••	6	LOOSE	MEDIUM STIFF
-	4	17.8	•••••	5	LOOSE	MEDIUM STIFF
- 2 ft	4	17.8	•••••	5	LOOSE	MEDIUM STIFF
-	6	26.6	•••••••	7	LOOSE	MEDIUM STIFF
-	8	35.5	••••••••••	10	LOOSE	STIFF
- 3 ft	8	35.5	••••••••••	10	LOOSE	STIFF
- 1 m	8	35.5	••••••••••	10	LOOSE	STIFF
-	10	38.6	•••••••••••	11	MEDIUM DENSE	STIFF
- 4 ft	14	54.0	••••••••••••••••	15	MEDIUM DENSE	STIFF
-	14	54.0	••••••••••••••••	15	MEDIUM DENSE	STIFF
-	9	34.7	••••••••••	9	LOOSE	STIFF
- 5 ft	9	34.7	••••••••••	9	LOOSE	STIFF
-	6	23.2	••••••	6	LOOSE	MEDIUM STIFF
-	6	23.2	••••••	6	LOOSE	MEDIUM STIFF
- 6 ft	8	30.9	••••••••	8	LOOSE	MEDIUM STIFF
-	7	27.0	•••••••	7	LOOSE	MEDIUM STIFF
- 2 m	8	30.9	••••••••	8	LOOSE	MEDIUM STIFF
- 7 ft	8	27.4	•••••••	7	LOOSE	MEDIUM STIFF
-	8	27.4	•••••••	7	LOOSE	MEDIUM STIFF
-	9	30.8	••••••••	8	LOOSE	MEDIUM STIFF
- 8 ft	12	41.0	•••••••••••	11	MEDIUM DENSE	STIFF
-	20	68.4	••••••••••••••••••••	19	MEDIUM DENSE	VERY STIFF
-	25	85.5	••••••••••••••••••••••••	24	MEDIUM DENSE	VERY STIFF
- 9 ft	28	95.8	••••••••••••••••••••••••••••	25+	MEDIUM DENSE	VERY STIFF
-	32	109.4	••••••••••••••••••••••••••••••••	25+	DENSE	HARD
-	26	88.9	••••••••••••••••••••••••••	25	MEDIUM DENSE	VERY STIFF
- 3 m 10 ft	26	88.9	••••••••••••••••••••••••••	25	MEDIUM DENSE	VERY STIFF
-	25	76.5	••••••••••••••••••••••	21	MEDIUM DENSE	VERY STIFF
-	25	76.5	••••••••••••••••••••••	21	MEDIUM DENSE	VERY STIFF
-	22	67.3	••••••••••••••••••••	19	MEDIUM DENSE	VERY STIFF
- 11 ft	22	67.3	••••••••••••••••••••	19	MEDIUM DENSE	VERY STIFF
-	23	70.4	•••••••••••••••••••••	20	MEDIUM DENSE	VERY STIFF
-	25	76.5	••••••••••••••••••••••	21	MEDIUM DENSE	VERY STIFF
- 12 ft	23	70.4	•••••••••••••••••••••	20	MEDIUM DENSE	VERY STIFF
-	24	73.4	••••••••••••••••••••••	20	MEDIUM DENSE	VERY STIFF
-	24	73.4	••••••••••••••••••••••	20	MEDIUM DENSE	VERY STIFF
- 4 m 13 ft	25	76.5	••••••••••••••••••••••	21	MEDIUM DENSE	VERY STIFF

Marysville - Lower Hole - Wildcat Data

HOLE #: sta 82+85, elev 1039

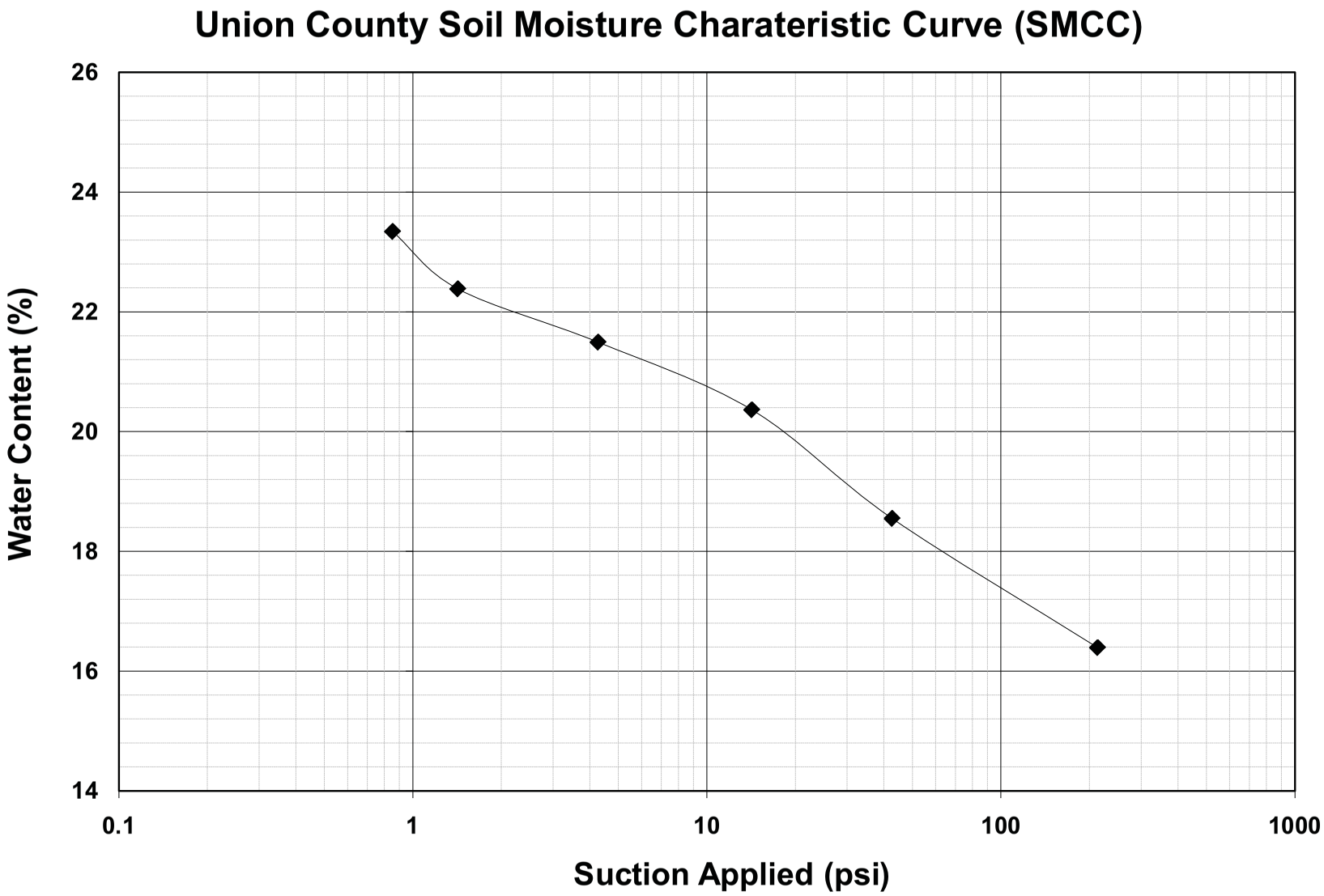
WILDCAT DYNAMIC CONE LOG

PROJECT: OSU/ODOT Bioengineering

PROJECT NUMBER: OSURF #: 746483

DEPTH	BLOWS PER 10 cm	RESISTANCE Kg/cm²	GRAPH OF CONE RESISTANCE 0 50 100 150	N'	TESTED CONSISTENCY NON-COHESIVE	COHESIVE
-	25	69.3	••••••••••••••••••••	19	MEDIUM DENSE	VERY STIFF
-	26	72.0	••••••••••••••••••••	20	MEDIUM DENSE	VERY STIFF
- 14 ft	25	69.3	••••••••••••••••••••	19	MEDIUM DENSE	VERY STIFF
-	21	58.2	••••••••••••••••	16	MEDIUM DENSE	VERY STIFF
-	18	49.9	••••••••••••••	14	MEDIUM DENSE	STIFF
- 15 ft	19	52.6	••••••••••••••••	15	MEDIUM DENSE	STIFF
-	17	47.1	••••••••••••••	13	MEDIUM DENSE	STIFF
-	16	44.3	••••••••••••	12	MEDIUM DENSE	STIFF
- 16 ft						
- 5 m						
-						
- 17 ft						
-						
-						
- 18 ft						
-						
-						
- 19 ft						
-						
- 6 m						
- 20 ft						
-						
-						
- 21 ft						
-						
-						
- 22 ft						
-						
-						
- 7 m 23 ft						
-						
-						
- 24 ft						
-						
-						
- 25 ft						
-						
-						
- 26 ft						
- 8 m						
-						
- 27 ft						
-						
-						
- 28 ft						
-						
-						
- 29 ft						
-						
- 9 m						

Marysville - Lower Hole - Wildcat Data


Union County Soil Moisture Charateristic Curve (SMCC)
Water Content (%)
26
24
22
20
18
16
14
0.1
1
10
100
1000
Suction Applied (psi)

Soil Moisture Retention at Different Suctions

Date: 12/10/2007

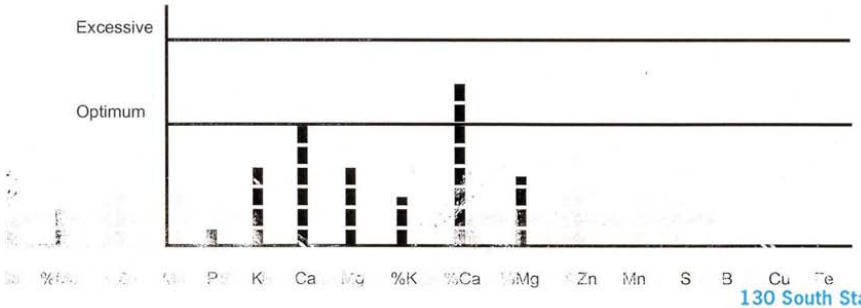
Sample:1(Union county)		
Suction applied		Moisture content
(cm)	(psi)	(%)
60	0.85	23.3
100	1.42	22.4
300	4.27	21.5
1000	14.22	20.4
3000	42.67	18.5
15000	213.35	16.4

CALMAR SOIL TESTING LABS

Sample Submitted By	Grower	Date of Report	Report Number	Record Number	Lab #	Field	Sample
BRIAN TRENNER 2070 NEIL AVE;470 HITCHCOCK HL COLUMBUS, OH 432103	UNION COUNTY US 33 & US 36,4	09/10/07	745.035	66905	10658C	TP1	

Organic Matter %	Phosphorus Bray P1	Potassium K	Magnesium Mg	Calcium Ca	pH		Cation Exchange Capacity	Percent Base Saturation			Sulfur S	Zinc Zn	Manganese Mn	Boron B	Copper Cu	Iron Fe
					Soil	Buffer		%K	%Mg	%Ca						
1.4	6	242	568	9204	8.1		25.7	1.2	9.2	90						

Crop/Yield	Previous Crop	Nitrogen Lbs/A	P_2O_5 Lbs/A	K_2O Lbs/A	Lime		Magnesium Mg Lbs/A	Sulfur S Lbs/A	Zinc Zn Lbs/A	Manganese Mn Lbs/A	Boron B Lbs/A	Copper Cu Lbs/A	Iron Fe Lbs/A
					T/A	Type							
HARDWOOD TREES 1 NA	HARDWOOD TREES	120	150	200	0.0								



Comments:

Test results reported in pounds per acre

Recommendations give are annual plus build-up

130 South State Street
Westerville, OH 43081
614-523-1005

Live Pole Installation

Live poles soaking

Spiking holes

Placing willows in holes

Live Pole Installation

Bentonite backfill

Backfilling live pole holes

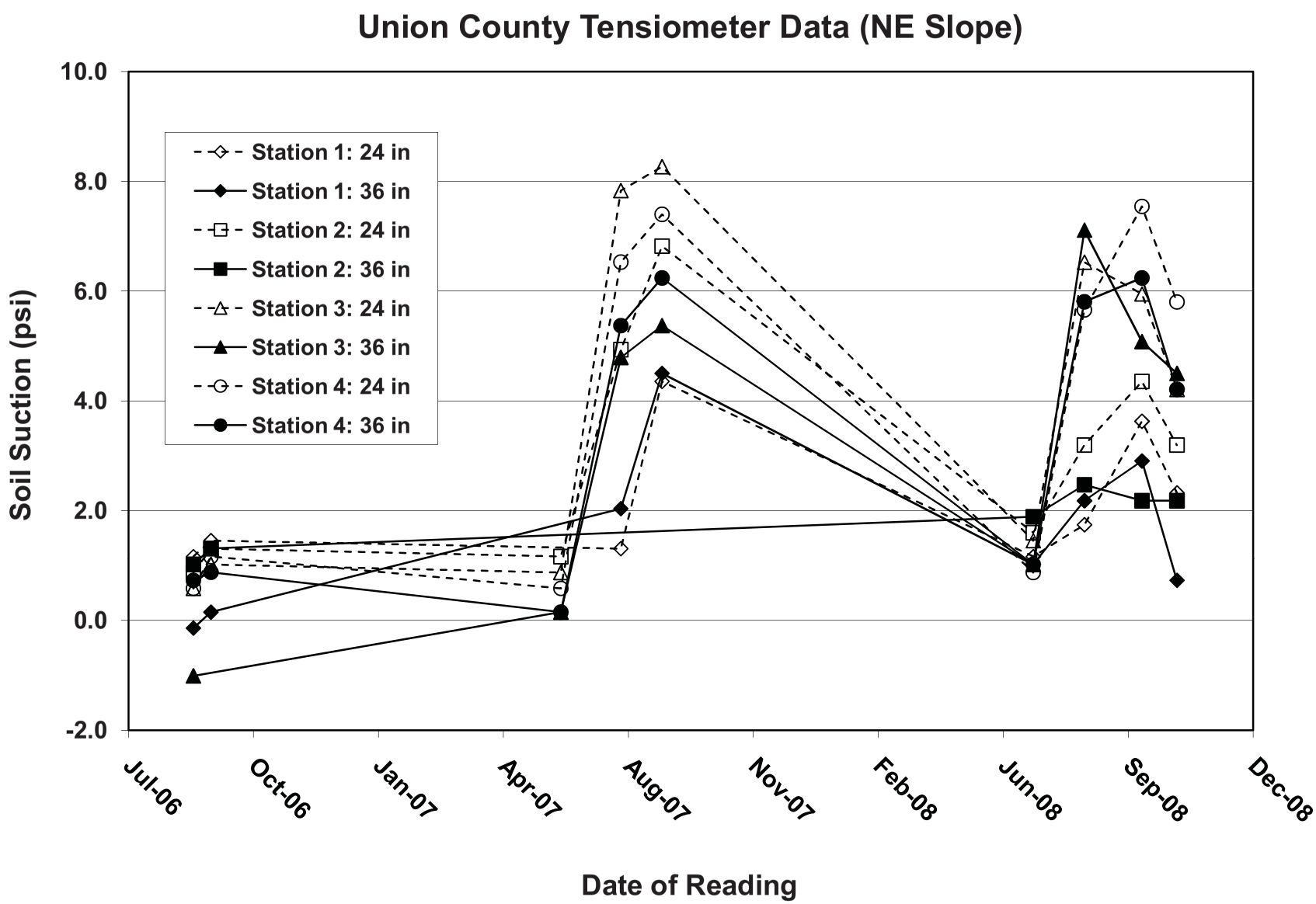
Trimming poles to specified height

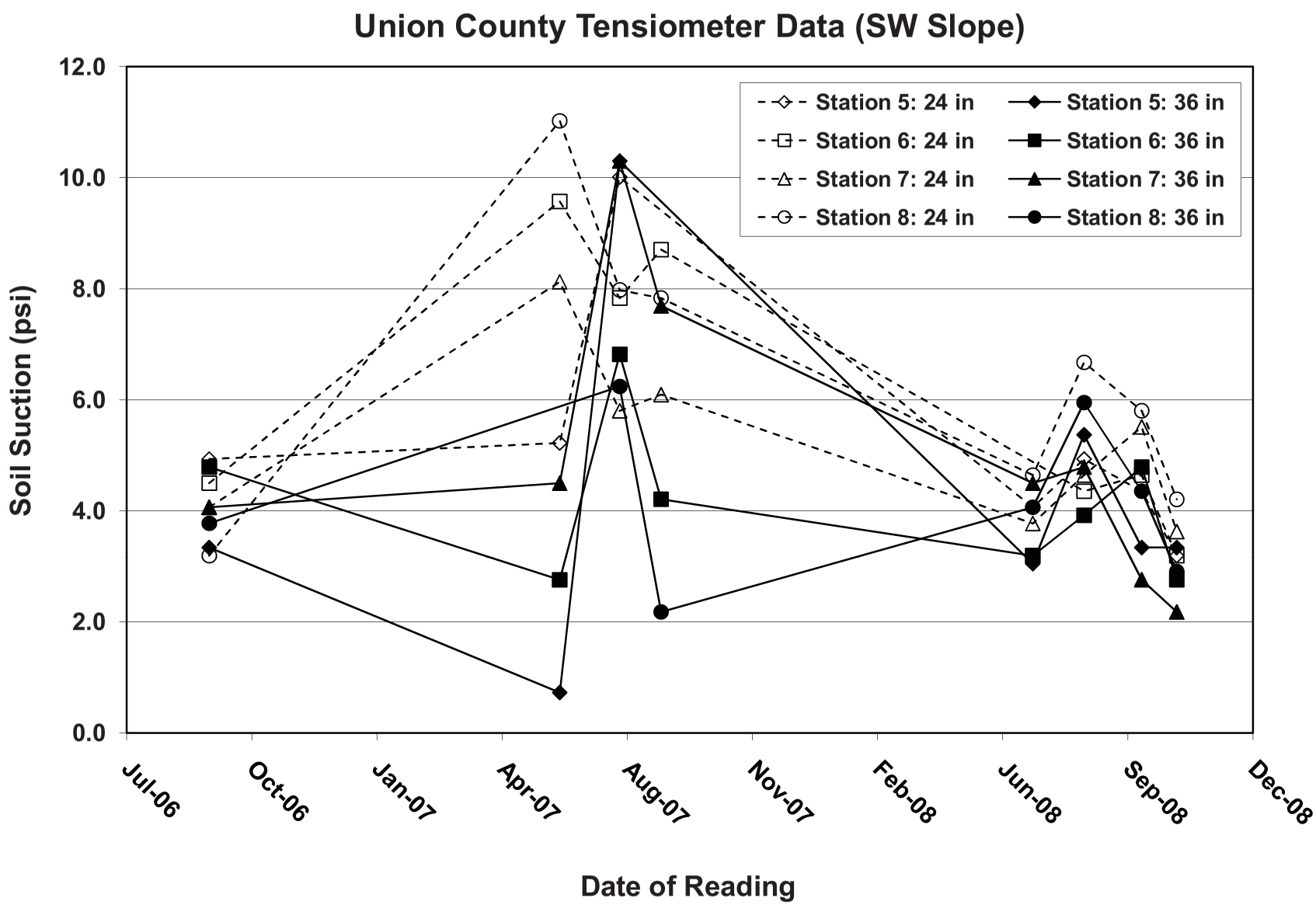
Visual log of construction activities at the Union County demonstration site.

Union County Tensiometer Data

ID	Depth	Soil Suction (psi)*								
		Date of Reading								
		8/23/2006	9/6/2006	6/13/2007	7/31/2007	9/2/2007	6/25/2008	8/5/2008	9/20/2008	10/18/2008
# 1	24 in	1.16	1.45	-	1.31	4.35	1.16	1.74	3.63	2.32
	36 in	-0.14	0.15	-	2.04	4.50	1.02	2.18	2.91	0.73
# 2	24 in	0.87	1.31	1.16	4.93	6.82	1.60	3.19	4.35	3.19
	36 in	1.02	1.31	-	-	-	1.89	2.47	2.18	2.18
# 3	24 in	0.58	1.02	0.87	7.83	8.27	1.45	6.53	5.95	4.21
	36 in	-1.01	-	0.15	4.79	5.37	1.02	7.11	5.08	4.50
# 4	24 in	0.58	1.16	0.58	6.53	7.40	0.87	5.66	7.54	5.80
	36 in	0.73	0.88	0.15	5.37	6.24	1.02	5.81	6.24	4.21
# 5	24 in	-	4.93	5.22	10.01	-	4.06	4.93	4.35	3.19
	36 in	-	3.34	0.73	10.30	-	3.05	5.37	3.34	3.34
# 6	24 in	-	4.50	9.57	7.83	8.70	-	4.35	4.64	3.19
	36 in	-	4.79	2.76	6.82	4.21	3.20	3.92	4.79	2.76
# 7	24 in	-	4.06	8.12	5.80	6.09	3.77	4.64	5.51	3.63
	36 in	-	4.07	4.50	10.30	7.69	4.50	4.79	2.76	2.18
# 8	24 in	-	3.19	11.02	7.98	7.83	4.64	6.67	5.80	4.21
	36 in	-	3.78	-	6.24	2.18	4.07	5.95	4.36	2.91

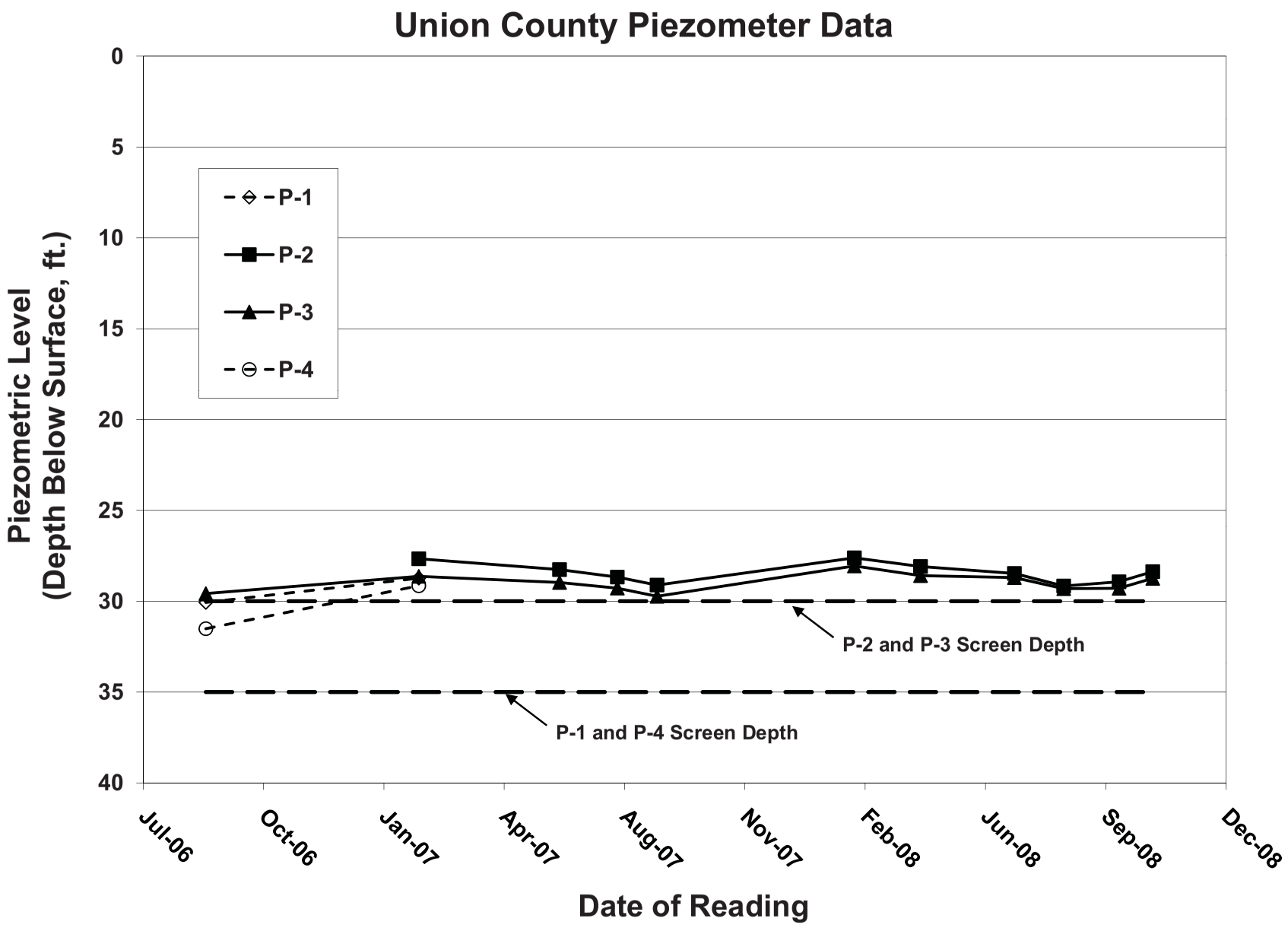
* Negative values indicate positive pore pressure. All values have also been corrected for elevation corresponding to the water column in the tensiometer.


Union County Tensiometer Data (NE Slope)
Station 1: 24 in
Station 1: 36 in
Station 2: 24 in
Station 2: 36 in
Station 3: 24 in
Station 3: 36 in
Station 4: 24 in
Station 4: 36 in
Soil Suction (psi)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
Jul-06
Oct-06
Jan-07
Apr-07
Aug-07
Nov-07
Feb-08
Jun-08
Sep-08
Dec-08
Date of Reading


Union County Tensiometer Data (SW Slope)
Station 5: 24 in
Station 5: 36 in
Station 6: 24 in
Station 6: 36 in
Station 7: 24 in
Station 7: 36 in
Station 8: 24 in
Station 8: 36 in
Soil Suction (psi)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Jul-06
Oct-06
Jan-07
Apr-07
Aug-07
Nov-07
Feb-08
Jun-08
Sep-08
Dec-08
Date of Reading

Union County Piezometer Data

Piezometer ID	D.T.B.	H.O.G.	D.B.G.	Date of Reading										
				8/23/2006	2/16/2007	6/13/2007	7/31/2007	9/2/2007	2/13/2008	4/8/2008	6/25/2008	8/5/2008	9/20/2008	10/18/2008
1	35.00	0.00	35.00	30.07	28.73	-	-	-	-	-	-	-	-	-
2	30.00	0.00	30.00	-	27.66	28.26	28.67	29.58	27.89	28.09	28.47	29.16	28.93	28.37
3	30.00	0.00	30.00	29.58	28.63	28.97	29.28	29.73	28.06	28.59	28.7	29.31	29.29	28.74
4	35.00	0.00	35.00	31.51	29.15	-	-	-	-	-	-	-	-	-


Union County Piezometer Data
Piezometric Level
(Depth Below Surface, ft.)
0
5
10
15
20
25
30
35
40
P-1
P-2
P-3
P-4
P-2 and P-3 Screen Depth
P-1 and P-4 Screen Depth
Jul-06
Oct-06
Jan-07
Apr-07
Aug-07
Nov-07
Feb-08
Jun-08
Sep-08
Dec-08
Date of Reading

Survival Statistics June 12, 2007

SW Slope
Overall Survival: 94.5%

	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Bottom
2	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	1	
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
5	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	2	
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
7	1	1	1	1	1	2	2	1	1	1	1	1	1	1	1	1	3	
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
10	1	1	1	3	1	1	1	1	1	1	1	1	1	3	1	1	1	
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
12	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
14	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	
15	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	
16	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	Top

1	Willow survived
2	Willow sprouted, then died
3	Willow died

US-33/SR-36,4 Interchange

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
20	1	1	1	2	1	2	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	2	Top
19	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2	1	1	1	1	3	3	
18	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
17	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	
16	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	
15	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	
13	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	3	1	1	1	1	1	1	1	1	
12	1	1	1	1	1	1	1	1	3	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	1	
10	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	3	1	1	3	3	3	
9	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	1	1	3	1	1	1	3	1	
8	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	
7	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	
6	1	1	1	1	1	1	1	1	1	3	1	3	1	1	1	1	1	1							
5	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1								
4	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1									
3	1	1	1	1	1	1	1	1	1	1	1	3	1	3	1										
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1											
1	1	1	1	1	1	1	1	1	1	1	1	1	1												Bottom

NE Slope
Overall Survival: 90.9%

Graphical representation of survival of the NE and SW live pole plots at the Union County demonstration site as of June 12, 2007.

Survival Statistics July 31, 2007

SW Slope
Overall Survival: 60.3%

	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Bottom
2	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	2	
3	1	2	1	2	2	2	2	2	1	2	2	1	2	2	3	3	2	
4	2	2	2	2	1	1	1	2	1	1	1	2	1	1	1	2	2	
5	2	1	1	2	3	1	2	2	1	1	2	1	2	1	1	2	2	
6	2	2	2	2	1	2	2	2	1	2	2	1	2	2	2	2	1	
7	2	2	1	2	2	2	2	2	2	2	1	2	2	2	2	2	3	
8	1	1	1	2	1	1	1	1	1	1	1	1	1	2	2	2	2	
9	1	1	1	2	2	1	1	1	1	1	2	1	1	1	1	2	2	
10	1	1	1	3	1	1	1	1	1	2	1	1	1	3	2	2	2	
11	1	2	1	1	2	1	1	1	1	1	1	1	1	1	1	1	2	
12	1	2	1	1	2	1	1	2	1	1	1	2	1	2	1	1	1	
13	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	
14	1	1	1	1	1	1	1	3	2	2	1	1	1	1	1	1	2	
15	1	1	2	2	1	1	3	2	1	1	2	1	1	1	2	1	1	
16	1	1	2	2	2	2	1	2	2	3	1	2	2	2	2	2	2	Top

1 Willow survived

2 Willow sprouted, then died

3 Willow died

US-33/SR-36,4 Interchange

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
20	1	2	2	2	2	2	2	1	2	2	1	1	1	2	1	2	2	2	2	2	2	2	1	2	Top
19	1	1	2	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2	1	1	1	1	3	3	
18	1	1	1	1	1	1	1	1	2	3	1	1	1	1	1	2	1	1	1	1	1	1	1	1	
17	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	3	1	1	1	1	
16	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	
15	1	1	1	1	1	1	1	2	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
14	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	3	1	
13	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	3	1	1	1	1	1	1	1	1	
12	1	1	1	1	1	1	1	1	3	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	
11	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	1	
10	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	2	2	1	3	1	1	3	3	3	
9	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	1	1	3	2	1	1	3	1	
8	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	3	2	2	1	2	2	1	
7	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	
6	1	1	1	1	1	1	1	1	1	3	1	3	1	1	1	1	1	1							
5	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1								
4	1	1	1	1	1	1	3	1	1	2	2	1	1	1	1	1									
3	1	1	1	1	1	1	2	1	1	1	1	3	1	3	1										
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1											
1	1	1	1	1	1	2	2	1	1	1	1	1	1												Bottom

NE Slope
Overall Survival: 83.4%

Graphical representation of survival of the NE and SW live pole plots at the Union County demonstration site as of July 31, 2007.

Survival Statistics September 20, 2007

SW Slope
Overall Survival: 46.2%

	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Bottom
2	1	1	1	1	1	2	1	3	1	1	1	1	1	1	2	2	2	
3	1	2	1	2	2	2	2	2	1	2	2	1	2	2	3	3	2	
4	2	2	2	2	2	1	2	2	1	1	2	2	1	2	2	2	2	
5	2	2	1	2	3	1	2	2	1	1	2	1	2	2	2	2	2	
6	2	2	2	2	1	2	2	2	1	2	2	2	2	2	2	2	2	
7	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	
8	2	1	2	2	2	1	2	1	1	1	1	1	1	2	2	2	2	
9	2	1	2	2	2	2	2	1	2	1	2	1	1	1	1	2	2	
10	1	1	1	3	1	1	1	1	2	2	1	2	1	3	2	2	2	
11	2	2	1	2	2	1	1	1	2	1	1	1	1	2	2	2	2	
12	1	2	1	1	2	1	1	2	1	1	1	2	2	2	1	2	1	
13	1	1	1	1	1	2	2	1	1	1	1	2	1	2	1	1	2	
14	1	1	1	1	1	1	1	1	2	2	2	2	1	1	1	2	2	
15	1	1	2	2	1	1	1	2	2	1	2	1	1	2	2	1	1	
16	2	1	2	2	2													Top

1 Willow survived

2 Willow sprouted, then died

3 Willow died

Willow destroyed from mowing

US-33/SR-36,4 Interchange

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
20	2	2	2	2	2	2	2	1	2	2	2	1	1	2	2	2	2	2	2	2	2	2	1	2	Top
19	1	1	2	1	1	1	1	1	2	2	1	1	1	1	1	1	1	2	1	1	2	1	3	3	
18	1	1	1	1	1	1	1	1	2	3	1	1	1	1	2	2	1	1	1	1	1	1	2	1	
17	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	3	1	1	1	1	
16	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	2	1	1	3	3	
15	1	1	2	1	1	1	1	2	3	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	
14	1	1	2	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	3	1	
13	1	2	1	1	1	1	1	1	1	2	2	2	1	1	1	3	1	1	1	1	2	1	1	1	
12	1	1	1	1	1	1	1	1	3	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	
11	1	1	2	1	1	1	1	2	1	1	1	1	1	1	2	1	1	1	1	1	1	3	3	1	
10	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	2	2	1	3	1	1	3	3	3	
9	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	1	1	3	2	1	1	3	1	
8	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	3	2	2	1	2	2	1	
7	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	
6	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1							
5	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1								
4	1	1	1	1	1	1	3	1	1	2	2	1	1	1	1	1									
3	1	1	1	1	1	1	2	1	1	1	1	3	1	3	1										
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1											
1	1	1	1	1	1	2	2	1	1	1	1	1	1												Bottom

NE Slope
Overall Survival: 79.5%

Graphical representation of survival of the NE and SW live pole plots at the Union County demonstration site as of September 20, 2007.

Survival Statistics June 12, 2008

SW Slope
Overall Survival: 39.6%

	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Bottom
2	1	1	1	3	3	3	1	3	1	1	1	1	3	1	3	3	3	
3	1	3	1	3	3	3	3	3	1	3	3	3	3	3	3	3	3	
4	3	3	3	3	3	1	3	3	1	1	3	3	3	3	3	3	3	
5	3	3	1	3	3	1	3	3	1	1	3	3	3	3	3	3	3	
6	3	3	3	3	1	3	3	3	1	3	3	3	3	3	3	3	3	
7	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
8	3	1	3	3	3	1	3	1	1	1	1	1	3	3	3	3	3	
9	1	1	1	3	3	3	3	1	3	1	3	1	1	3	3	3	3	
10	1	1	1	3	1	1	1	1	3	3	1	3	3	3	3	3	3	
11	3	3	1	3	3	1	1	1	3	1	1	3	1	3	3	3	3	
12	1	3	1	1	3	3	3	3	3	1	3	3	3	3	1	3	1	
13	1	1	1	1	1	1	1	1	1	3	3	3	1	3	1	3	3	
14	1	1	1	1	1	1	3	3	3	3	3	3	1	1	1	3	3	
15	1	1	3	3	1	1	1	3	3	3	3	1	1	3	3	1	1	
16	3	1	3	3	3													Top

1 Willow survived

3 Willow died

Willow destroyed from mowing

US-33/SR-36,4 Interchange

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
20																									Top
19	1	1	3	3	3	3	1	1	3	3	1	3	1	3	1	3	1	3	1	1	3	3	3	3	
18	3	1	3	3	3	1	1	1	3	3	1	1	1	3	3	3	1	1	3	1	1	3	3	1	
17	3	1	1	3	1	1	3	1	1	3	1	1	1	3	3	3	1	1	3	3	3	3	1	3	
16	1	1	3	3	1	1	3	3	3	3	3	1	1	3	1	1	1	1	3	3	1	1	3	3	
15	3	3	3	1	1	3	1	3	3	1	3	3	3	1	1	1	1	1	1	1	1	1	1	1	
14	3	1	3	1	1	1	1	3	3	3	1	3	1	1	1	1	1	1	1	1	1	1	3	1	
13	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	3	1	1	1	1	1	1	1	1	
12	1	1	1	1	1	1	1	1	3	1	3	1	1	1	1	1	1	3	1	1	1	1	1	3	
11	1	1	3	3	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	1
10	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	3	3	1	3	1	1	3	3	3	
9	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	3	3	1	1	3	1	
8	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	
7	1	1	1	1	3	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	
6	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1							
5	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1								
4	1	1	1	1	1	1	3	1	1	3	3	1	1	1	1	1									
3	1	1	1	1	1	1	3	1	1	1	1	3	1	3	1										
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1											
1	1	1	1	1	1	3	3	1	1	1	1	1	1												Bottom

NE Slope
Overall Survival: 74.4%

Graphical representation of survival of the NE and SW live pole plots at the Union County demonstration site as of June 12, 2008.

Survival Statistics September 20, 2008

SW Slope
Overall Survival: 33.8%

	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Bottom
2	1	1	1	3	3	3	1	3	1	1	1	1	3	1	3	3	3	
3	1	3	1	3	3	3	3	3	1	3	3	3	3	3	3	3	3	
4	3	3	3	3	3	1	3	3	1	1	3	3	3	3	3	3	3	
5	3	3	1	3	3	1	3	3	1	1	3	3	3	3	3	3	3	
6	3	3	3	3	1	3	3	3	1	3	3	3	3	3	3	3	3	
7	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
8	3	1	3	3	3	1	3	1	1	1	1	1	3	3	3	3	3	
9	1	1	1	3	3	3	3	1	3	1	3	1	1	3	3	3	3	
10	1	1	1	3	1	1	1	1	3	3	1	3	3	3	3	3	3	
11	3	3	1	3	3	3	1	1	3	1	1	3	1	3	3	3	3	
12	1	3	1	1	3	3	3	3	3	1	3	3	3	3	3	3	1	
13	1	1	1	1	1	3	3	1	1	3	3	3	1	3	1	3	3	
14	3	1	1	1	1	3	3	3	3	3	3	3	3	1	1	3	3	
15	3	3	3	3	3	3	1	3	3	3	3	3	3	3	3	3	1	
16	3	3	3	3	3	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	Top

1 — Willow survived

3 — Willow died

☒ — Willow destroyed from mowing

US-33/SR-36,4 Interchange

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
20	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	Top
19	1	1	3	3	3	3	1	1	3	3	1	3	1	3	1	3	1	3	1	1	3	3	3	3	
18	3	1	3	3	3	1	1	1	3	3	1	3	3	3	3	3	1	1	3	1	1	3	3	1	
17	3	1	1	3	1	1	3	1	1	3	1	1	3	3	3	3	1	1	3	3	3	3	1	3	
16	1	1	3	3	1	1	3	3	3	3	3	1	3	3	1	1	1	1	3	3	1	1	3	3	
15	3	3	3	1	1	3	1	3	3	1	3	3	3	1	1	1	1	1	1	1	1	1	1	1	
14	3	1	3	1	1	1	1	3	3	3	1	3	1	1	1	1	1	1	1	1	1	1	3	1	
13	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	3	1	1	1	1	1	1	1	1	
12	1	1	1	1	1	1	1	1	3	1	3	1	1	1	1	1	1	3	1	1	1	1	1	3	
11	1	1	3	3	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	1	
10	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	3	3	1	3	1	1	3	3	3	
9	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	3	3	1	1	3	1	
8	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	
7	1	1	1	1	3	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	
6	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1							
5	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1								
4	1	1	1	1	1	1	3	1	1	3	3	1	1	1	1	1									
3	1	1	1	1	1	1	3	1	1	1	1	3	1	3	1										
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1											
1	1	1	1	1	1	3	3	1	1	1	1	1	1												Bottom

NE Slope
Overall Survival: 73.4%

Graphical representation of survival of the NE and SW live pole plots at the Union County demonstration site as of September 20, 2008.

Survival Statistics June 15, 2009

SW Slope
Overall Survival: 27.3%

	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Bottom
2	1	1	1	3	3	3	1	3	1	1	1	1	3	1	3	3	3	
3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
5	3	3	1	3	3	1	3	3	3	1	3	3	3	3	3	3	3	
6	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	
7	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
8	3	3	3	3	3	3	3	3	3	3	1	1	3	3	3	3	3	
9	1	1	1	3	3	3	3	1	3	1	3	1	1	3	3	3	3	
10	1	1	3	3	1	1	3	3	3	3	1	3	3	3	3	3	3	
11	3	3	3	3	3	3	1	1	3	1	1	3	1	3	3	3	3	
12	1	3	1	1	3	3	3	3	3	1	3	3	3	3	3	3	3	
13	1	1	1	1	1	3	3	1	1	3	3	3	1	3	1	3	3	
14	3	1	1	1	1	3	3	3	3	3	3	3	3	1	1	3	3	
15	3	3	3	3	3	3	1	3	3	3	3	3	3	3	3	3	1	
16	3	3	3	3	3													Top

1 Willow survived

3 Willow died

Willow destroyed from mowing

US-33/SR-36,4 Interchange

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
20																									Top
19	1	1	3	3	3	3	1	1	3	3	1	3	1	3	1	3	1	3	1	1	3	3	3	3	
18	3	1	3	3	3	1	1	1	3	3	1	3	3	3	3	3	1	1	3	1	1	3	3	1	
17	3	1	1	3	1	1	3	1	1	3	1	3	3	3	3	3	1	1	3	3	3	3	1	3	
16	1	1	3	3	1	1	3	3	3	3	3	3	3	3	1	1	1	1	3	3	1	1	3	3	
15	3	3	3	1	1	3	1	3	3	1	3	3	3	1	1	1	1	1	1	1	1	1	1	1	
14	3	1	3	1	1	1	1	3	3	3	1	3	1	1	1	1	1	1	1	1	1	1	3	1	
13	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	3	1	1	1	1	1	1	1	1	
12	1	1	1	1	1	1	1	1	3	1	3	1	1	1	1	1	1	3	1	1	1	1	1	3	
11	1	1	3	3	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	1	
10	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	3	3	1	3	1	1	3	3	3	
9	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	3	3	1	1	3	1	
8	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	
7	1	1	1	1	3	1	1	1	1	1	3	1	1	3	1	1	1	1	1	1	1	1	1	1	
6	1	1	1	1	1	1	1	1	1	3	1	1	1	3	3	1	1	1							
5	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1								
4	1	1	1	1	1	1	3	1	1	3	3	1	1	1	1	1									
3	1	1	1	1	1	1	3	1	1	1	1	3	1	3	1										
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1											
1	1	1	1	1	1	3	3	1	1	1	1	1	1												Bottom

NE Slope
Overall Survival: 72.1%

Graphical representation of survival of the NE and SW live pole plots at the Union County demonstration site as of June 15, 2009.

Union County Conventional Construction Cost Analysis

	Unit Cost	Quantities	Cost
Clearing and Grubbing	$5,000.00	0.47	$2,350.00
Headwall Removed	$500.00	1	$500.00
Pipe Removed	$22.00	70	$1,540.00
Guardrail Removed	$1.00	320	$320.00
Excavation	$7.50	5608	$42,060.00
Embankment	$8.80	7564	$66,563.20
Subgrade Compaction	$5.60	225.4	$1,262.24
Guardrail, Type 5	$11.20	557.25	$6,241.20
Bridge Term. Assy, Type 1	$1,120.00	2	$2,240.00
Bridge Term. Assy, Type 2	$375.00	1	$375.00
Impact Att, T 1-98 (Bidirectional)	$3,475.00	1	$3,475.00
Rock Ch Prot, C W/Filter	$50.00	1	$50.00
Soil Analysis Test	$30.00	1	$30.00
Topsoil	$25.00	428.64	$10,716.00
Commercial Fertilizer	$450.00	0.5217	$234.77
Lime	$50.00	0.799	$39.95
Water	$10.00	20.68	$206.80
Sodding Reinforced	$11.00	161	$1,771.00
Slope Erosion Protection	$1.90	3104	$5,897.60
Storm Water Pollution Prevention Plan	$3,000.00	0.47	$1,410.00
Erosion Control	$1.00	4700	$4,700.00
Concrete Masonry	$3,500.00	0.3	$1,050.00
6" Conduit, Type F	$14.00	174	$2,436.00
15" Conduit, Type F, 707.05 Type C	$77.00	84	$6,468.00
Catch Basin Recon To Grade	$1,100.00	1	$1,100.00
Precast Reinforced Conc. Outlet	$315.00	2	$630.00
6" Shallow Pipe UD	$13.50	236	$3,186.00
6" Base Pipe UD	$13.70	246	$3,370.20
Asphalt Concrete Base, PG64-22	$99.00	66	$6,534.00
Aggregate Base	$56.00	37	$2,072.00
Tack Coat	$4.00	12	$48.00
Asph. Conc. Surf., 12.5mm, Type A (448)	$135.00	8	$1,080.00
Barrier Reflector, Type A	$5.00	11	$55.00
Edge Line, Type 1	$1,100.00	0.62	$682.00
Object Marker, One Way	$17.50	15	$262.50
Work Zone Edge Line, Class I	$2,520.00	0.61	$1,537.20
Water	$25.00	31.02	$775.50
Portable Conc. Barrier, 32"	$21.85	737	$16,103.45
Barrier Reflector, Type B	$5.00	15	$75.00
Contract Performance Bond	$5,300.00	1	$5,300.00
Maintaining Traffic	$15,500.00	0.5	$7,750.00
Field Office, Type B	$3,250.00	2	$6,500.00
Construction Layout Stakes	$15,000.00	0.5	$7,500.00
Mobilization	$20,000.00	0.75	$15,000.00

Total Cost of Conventional Construction: $241,497.61

Union County Bioengineering Cost Analysis

	Unit Cost	Quantities	Cost
Excavation	$72.00	0	$0.00
Embankment	$100.00	0	$0.00
Geotextile Fabric	$5.00	0	$0.00
Slope Protection/Geocell	$250.00	0	$0.00
Topsoil	$150.00	0	$0.00
Seeding and Mulching	$2.50	790	$1,975.00
Commercial Fertilizer	$325.00	0.15	$48.75
Water	$50.00	5	$250.00
Erosion Control Mat	$6.00	790	$4,740.00
Planting, Misc.	LS	0	$47,000.00
Retaining Wall	$233.00	0	$0.00
Contract Performance Bond	$4,000.00	1	$4,000.00
Maintaining Traffic	$3,000.00	0.5	$1,500.00
Mobilization	$3,000.00	0.5	$1,500.00
			$61,013.75

Cost Comparison between Conventional and Bioengineering Methods

Construction Limits:

	Conventional	Bioengineering
Linear feet of construction:	290 LFT	120 LFT
Square yards of contstruction:	2159 SY	790 SY

Method	Total Cost ($)	$/LFT	$/SY
Conventional	241,500	833	112
Bioenginering	61,000	508	77