Field Investigation of Best Practices for Steep-Slope Mine Reclamation Employing the Forestry Reclamation Approach

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FORM FP-1

OFFICE OF SURFACE MINING NATIONAL TECHNOLOGY TRANSFER TEAM FACE PAGE

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PROPOSERS ORGANIZATION

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Richard J. Sweigard / 12/21/07

SIGNATURE OF PRINCIPAL INVESTIGATOR/DATE

PI Assurance: I agree to accept responsibility for the scientific conduct of the project, to provide the required reports, to acknowledge OSM in any presentations and publications wherein the results of this project are used, and to provide copies of presentation abstracts and publications to OSM. I also agree to allow this proposal to be reviewed by industry and/or academia and that proprietary information which has been properly identified will be used solely for proposal evaluation.

Richard J. Sweigard / 12-21-07

SIGNATURE OF ORGANIZATION'S CERTIFYING REPRESENTATIVE/DATE

JH Certification & Acceptance: I certify that to the best of my knowledge, the statements contained herein are complete and true and I accept the obligation to comply with OSM terms and conditions provided an award is made as a result of this submission.

DISCLAIMER

ACKNOWLEDGEMENT

The authors acknowledge the support of Office of Surface Mining (OSM) and University of Kentucky for the steep slope mine reclamation project. Special thanks go to International Coal Group (ICG) for allowing and assisting with the experimental work at Peel Poplar Mine. The authors are also thankful to mine personnel and regulatory authorities for assisting in field visits throughout the Appalachian region. Special recognition is due to Dr. Patrick Angel of OSM for his help and suggestions throughout this project.

ABSTRACT

Previous research has demonstrated that excessive compaction of reclaimed surface-mined land is a major deterrent to successful reforestation. The five-step Forestry Reclamation Approach (FRA) was developed, in part, to address this problem. In particular, the FRA emphasizes the need for creating a suitable rooting medium that is at least 1.22 M (4 ft.) deep and free of compaction. However, most of the prior reforestation research has been conducted on land that was flat or gently rolling. Some concerns have been expressed about applying the FRA to steep-slope mines, such as those found throughout the Appalachian region. A field study was conducted at ICG's Peel Poplar Mine in eastern Kentucky to evaluate the applicability of the FRA to steep-slope mining. The evaluations were based upon operational efficiency, economics, slope stability, and reforestation potential. Specifically, a 1.9 hectare (4.7 acre) area was reclaimed with a combination of loaders, trucks, and dozers. Final grading was completed using only a single pass by a CAT-D11R dozer. Slope movement was monitored periodically by surveying 70 steel rebars. The stability analysis was done using the computer programs REAME and Geo-Slope (W). Soil bulk density, penetration resistance, and tree survival were also measured and compared with the earlier works on flat or rolling surfaces. An economic analysis was done considering equipment ownership and operating costs, final grading costs, and planting cost. The slope has not exhibited any appreciable instability and the FRA appears to have been effective in reclaiming the land to a condition suitable for reforestation.

KEYWORDS: Forestry Reclamation Approach, Soil resistance, Bulk density, Loose grading, Depth of refusal

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

1.1 Background

Over the past decade and a half, a considerable amount of work has been done on improving reclamation practices to enhance reforestation success on surface-mined land. For many years following the passage of the Surface Mining Reclamation and Control Act (SMCRA, 1977), attempts to reforest the reclaimed mine sites have largely been unsuccessful due to excessive compaction. Similar to the problem of reclaiming prime farmland, researchers learned that excessive compaction negatively impacts tree survival and growth. Much of the recent work has concentrated on minimizing or alleviating soil compaction, but it has also addressed selection of the rooting medium, planting methods, and the selection of tree and herbaceous species. There have been many positive results from this work, not the least of which is heightened realization on the part of industry, regulators, and the general public of the importance of reforesting surface-mined land and the technical path to success in this area.

One of the specific results that has been realized from the recent studies is the formation of the Appalachian Regional Reforestation Initiative (ARRI), (Angel et al., 2005) and the formalization of the Forestry Reclamation Approach (FRA), which recommends only minimal grading of the upper 1.22 m (4 ft.) of the replaced rooting medium (Burger et al., 2005). However, the vast majority of research sites that were used to develop and test these minimal grading practices have been either mountaintop removal operations or area stripping operations where the final surface was flat or rolling. Very few sites even considered minimal or loose grading on steep slopes and none have actually studied the best practices for implementing the Forestry Reclamation Approach on steep-slope highwall elimination operations.

Certainly, one of the driving forces behind the passage of SMCRA was the problem of unstable slopes caused by unregulated conventional contour mining that was practiced widely in the Appalachian region. The problems of exposed highwalls and unstable outslopes have effectively been resolved by enforcement of the regulations derived from SMCRA. By necessity, successful highwall elimination requires a considerable amount of compaction, which has negative impacts on tree growth. Tree planting also suffers, because it is difficult to properly plant trees in compacted soil (Torbert and Burger, 2000). There has been concern expressed by some, both from industry and the regulatory authorities, that the application of FRA on steep slopes may be either impractical or even, under some circumstances, deleterious to the stability of the slope in question.

Successful application of FRA in flat or rolling surfaces is the motivating force behind this research in steep slopes. Mined lands are drastically disturbed by surface mining due to removal of native vegetation, soil and exposed overburden (Conrad, 2002). To minimize these environmental and ecological disturbances, SMCRA requires that a coal mining operation "restore the land affected to a condition capable of supporting the uses which it was capable of supporting prior to any mining, or higher or better uses". After two decades of experience with SMCRA, Kentucky Department of Surface Mining Reclamation and Enforcement (KDSMRE) realized that the implementation of SMCRA was not performing affectively for reforestation. Through several field visits, KDSMRE determined that excessive compaction of growing media, inappropriate growing media, and excessive competition from herbaceous ground cover are the main causes of unsuccessful reforestation in mine-lands. In 1997, KDSMRE issued Reclamation Advisory Memorandum (RAM#124), a forerunner of the FRA.

The University of Kentucky conducted a detailed field study on the applicability of the RAM#124 at the Starfire Mine located near Hazard, Kentucky. The Starfire project produced relationships between tree survival rates and spoils characteristics and provided very visual proof of the impact of minimal grading on tree growth.

1.2 Objectives

The overall objective of this research is to facilitate the broader application of FRA on steep-slope operations throughout the Appalachian region. This is accomplished by conducting a thorough evaluation of the current regional practices that are used for highwall elimination in steep-slope mines where reforestation is practiced and by assessing the effectiveness from the stability, operational, economical, and reforestation potential perspective. Slope stability is a major focus of this investigation and is being evaluated through field monitoring and analysis of a reclaimed slope. Following is a list of more specific project objectives which included conducting:

- ❖ A regional inventory documenting the current practices throughout the Appalachian region that are used for highwall elimination at steep-slope operations where reforestation is the intended postmining land use.
- ❖ A comprehensive field evaluation of the most common practices at a test site in eastern Kentucky. The evaluation is focused on the following characteristics for the reclamation practices selected:
    - Slope stability of the reclaimed mine where the highwall has been eliminated.

- Operational efficiency in terms of equipment, labor, time, and material required to implement FRA for reclamation.
- Study of reforestation potential in terms of selected spoil characteristics such as bulk density and maximum penetration depth, which have been proven to correlate to reforestation success.
- The cost associated with the implementation of the reclamation practices.

1.3 Scope of Work

The Office of Surface Mining (OSM), Applied Science Program has established a goal of developing "technical tools that improve the efficiency and accuracy of the state regulatory authorities in permitting coal mines and enforcing their federally approved state regulatory programs." The program also seeks projects that will improve "the efficiency with which the coal industry conducts surface coal mining and reclamation activities". Both objectives of OSM have been taken into account in this project.

The project was needed because there is a reluctance of the mining industry to implement FRA on steep-slope operations due to a concern about future reclamation liability. There is also a need for a clear understanding among regulatory personnel concerning the best practices for applying FRA to steep-slope operations. The project addresses an application of FRA that has received little attention; the analytical techniques that were employed are well established and are drawn from years of experience. The primary issues addressed in this investigation are based on the concern shared by industry representatives and regulators associated with applying FRA to steep-slope operations requiring highwall elimination in the Appalachian region. The principles outlined in the FRA have been primarily developed and demonstrated on mine sites where the final surface is the flat or rolling, for example, the research conducted by the University of Kentucky at the Starfire Mine. The Starfire project was successful for a number of reasons. First of all, it produced volumes of data relating tree survival and growth to spoil characteristics and hydrologic characteristics. Secondly, and probably most important, it provided very visual proof of the impact of minimal grading on tree growth.

Although FRA has performed well on flat or rolling surfaces, it is necessary to test its applicability on steep-slope reclamation and to determine what constraints, if any, affect its use in that setting. Successful implementation of FRA on steep slopes will help to ease the concerns of industry personnel and regulators about the potential slope stability impact and lead to greater numbers of trees established on reclaimed lands.

Chapter 2

EXECUTIVE SUMMARY

The primary objectives of this project were to document the current practices for highwall elimination throughout the Appalachian region where the reforestation was the intended post-mining land use and to conduct a comprehensive field evaluation of the most common practices at a test site in eastern Kentucky that was reclaimed following the Forestry Reclamation Approach (FRA). The field evaluation was focused on the stability of the reclaimed steep slope, the operational efficiency of reclamation process, costs associated with reclaiming the steep slope, and the reforestation potential in terms of the selected spoil characteristics such as bulk density and maximum penetration depth, which have been shown to correlate to reforestation success on flat or rolling surfaces.

A total of 28 mine sites were visited in both the Northern Appalachian region (PA, OH, and MD) and the Central Appalachian region (KY, WV, VA, and TN). Mainly four types of highwall practices were observed: contour haulback, combination of haulback and dozer push, shoot and dozer push, and gravity methods. The most common method to eliminate highwall was contour haulback with varying degree of dozer push.

Based on the field visits, the Peel Poplar Mine of the International Coal Group (ICG) was selected for a detailed field investigation. The site is located on Left Fork of Blackberry Creek in Pike County, Kentucky. The site can be found on the Matewan Quadrangle of the United States Geological Survey with latitude 37° 30’ 40” and longitude 82° 13’ 36”. The topography of the Peel Poplar Mine is consistent with the Kentucky portion of the Cumberland Plateau. The area consists of valleys, narrow ridges, and steep slopes. The coal seams were mined using the contour haulback mining method. The highwall was eliminated using a combination of haulback and dozer push. The final grading was done by a Cat-D11R dozer following FRA guidelines. The final surface consists of two types of material: brown spoil area (brown weathered sandstone and soil mixture) and gray spoil area (gray sandstone).

For slope movement monitoring, a total of 70 steel rebars (1.27 cm diameter and 1.22 m length) were driven in a regular pattern in both areas. Quarterly surveys of the monuments were done using a total station and prism combination. The survey results from the baseline survey and the final survey were plotted and analyzed by line for movement of monuments horizontally down the slope and vertical settlement or heaving. To study the stability of the slope, computer analyses were conducted for both areas using the Rotational Equilibrium Analysis of Multilayered Earthworks (REAME) and Geo-Slope (W) programs. The scope of the project did not provide for seepage monitoring. Therefore, seepage conditions were not a part of the analyses that were performed. Both the computer modeling results (REAME and Geo-Slope) for the brown and the gray spoil areas indicated that overall the slopes were stable with only the upper part of the slopes where the slope inclination is highest (near 30°) showing any signs of instability. The minor instances of instability were confined to the upper 1.2 m of the spoil and did not compromise the integrity of the entire slope. These findings were verified by the survey results of slope movement monitoring.

Spoil characterization was done collecting dry bulk density measurements (using Troxler-3440 nuclear density gauge) and spoil penetration resistance (using Wildcat Dynamic Cone Penetrometer) in June, 2009 and May, 2010. It was observed the spoil characteristics on this steep slope site were similar to those observed in the earlier work on flat or rolling surfaces at the Starfire Mine by Conrad (2002).

Total reclamation costs for both methods, complete haulback and the combination of haulback and dozer push, were calculated considering highwall elimination cost, final grading cost and planting cost. It was observed that total reclamation cost for a combination of haulback and varying amounts of dozer pushing was less than that for complete haulback cost. Based on the economic analysis in this study, it was determined that the application of FRA in steep slopes does not have a significant economic impact on reclamation cost.

A total of 4327 tree seedlings were planted in April, 2009, just after final grading of the experimental site. Although, the primary focus of this project was on operational factors and slope stability considerations, the survival of the trees planted on both the gray and the brown spoil areas was monitored one year after the planting, at which time 71.2% of the trees on the brown spoil and 62.9% on the gray spoil survived. The survival rates provided additional data to verify the relationships previously developed between spoil characteristics and tree survival rates.

For the duration of the investigation, it can be concluded that the Forestry Reclamation Approach performed satisfactorily. The spoil characteristics and tree survival were similar to those observed on earlier reclaimed flatter surfaces. There were no major stability problems encountered and minor instability in the slopes can be avoided by careful attention to final grading so that local over-steepened areas are avoided.

Chapter 3

EXPERIMENTAL INVESTIGATION

3.1 Regional Inventory

A comprehensive study of regional practices of highwall elimination on steep-slope operations that are compatible with the application of FRA was conducted throughout the Appalachian region (i.e., Kentucky, Virginia, West Virginia, Ohio, Maryland, Tennessee and Pennsylvania). A total of 28 field visits were completed in these seven states as shown in Figure 3.1. The site visits were conducted by the research team from University of Kentucky, regulatory personnel from the Office of Surface Mining, state regulatory personnel, and company representatives. A variety of different highwall elimination processes were observed. These processes include contour haulback, combination of haulback and dozer push, shoot and dozer push, and gravity feed. By far the most common method in the Central Appalachian region is contour haulback. The common highwall elimination methods observed throughout the Appalachian region are discussed in Sec. 3.1. Some of the highwall elimination stages (i.e. exposed highwall, active elimination, final graded site, and reforested highwall) observed during field visits are shown in Figure 3.3 to Figure 3.9. Complete documentation of all 28 mine visits is included in Appendix A.

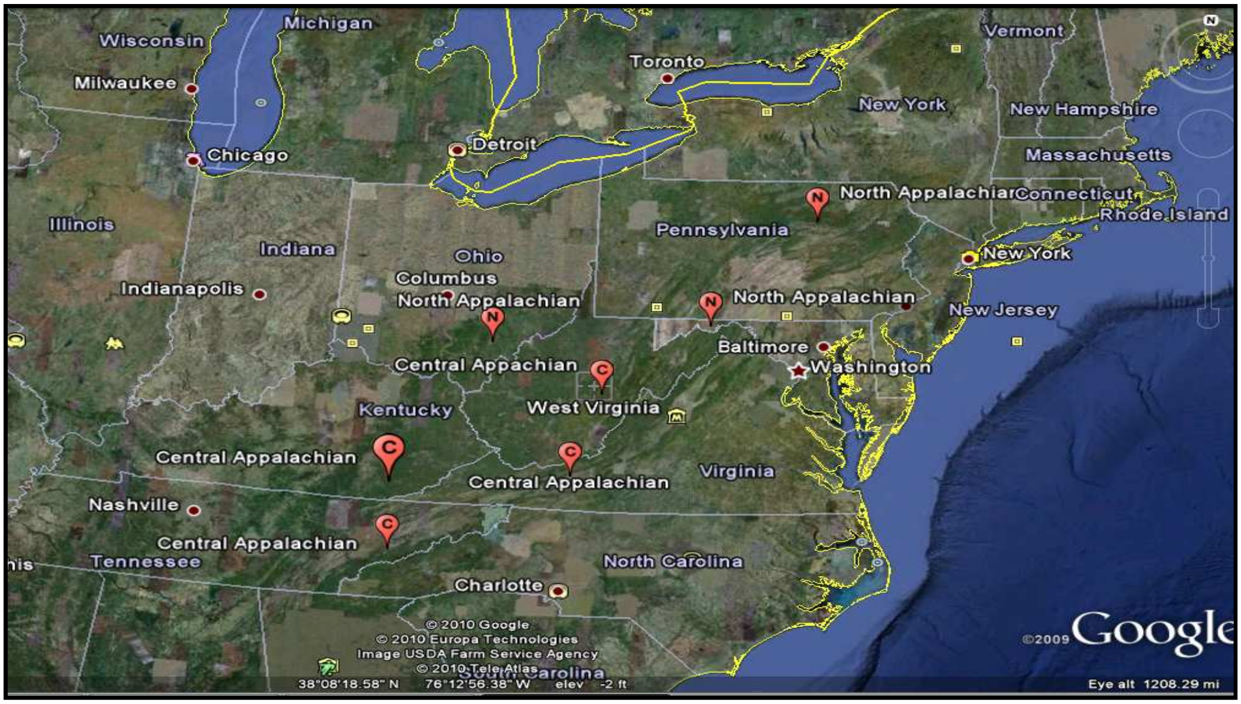


Figure 3.1: Location map showing the field visit states in the Appalachian region (N flags-North Appalachian region and C flags-Central Appalachian region), (Source: Google Earth)

3.1.1 Highwall Elimination Methods

After the coal is mined, backfilling of the highwall achieves AOC as required by SMCRA. As a result of field visits for inventoring highwall elimination practices throughout the Appalachian region, four main different types of elimination methods were observed. These methods are described below.

3.1.1.1 Contour Haulback

The contour haulback method involves haulage of spoil material laterally along the bench, where it is dumped on the pit floor. This method is widely used to comply with the regulations that prohibit downslope placement of spoil and require that the final highwall be completely eliminated. In this method, a ramp is made up to the top of the highwall and spoil material is hauled up the ramp and dumped over the edge. Then, the materials is graded with the help of dozers. In some cases, the overburden is hauled over the contour bench and then dumped into fairly horizontal lifts. In this case, each lift can be compacted, if needed as shown in Figure 3.2.

Figure 3.2: Contur haulback with horizontal lifts

3.1.1.2 Combinatin of Haulback and Dozer Push

In this method the highwall is eliminated using both the haulback method and dozer pushing. This is especially useful when more than one coal seamed is mined. The lower bench can be reclaimed by pushing blasted spoil down from the upper bench and then hauling spoil back to reclaim the upper bench.

3.1.1.3 Shoot and Dozer Push

In this method of highwall elimination, cast blasting of the overburden is used. This is found most commonly in block-cut mining operations of Norhtern Appalachia where the terrain is less steep. The blasted overburden is pushed laterally by dozers into the pit where coal has been removed. Sometimes hydraulic excavators are also used to give final shape to the reclaimed highwall.

3.1.1.4 Gravity Feed

In the gravity feed method, the spoil materials are dumped using trucks from the top of the highwall and gravity is allowed to deposit the spoil on the bench below. Dozers are still used for final grading. This method is most commonly used as part of remining operations or AML reclamation sites where an existing unreclaimed highwall must be eliminated.

Figure 3.3: Exposed highwall (Copley Fork Surface Mine, Near Logan, WV)

Figure 3.4: Active highwall elimination process using haulback at Brink Mine (B&M Energy), Pennsylvania

Figure 3.5: Active haulback process (North & South Surface Mine, Logan County, WV)

Figure 3.6: Final graded highwall (North and South Surface Mine Logan County, WV)

Figure 3.7: Reclaimed steep-slope highwall (Right Fork and Hardway Branch, near Drennan, WV)

Figure 3.8: Successful reforestation in reclaimed mine (Bent Mountain, KY)

Figure 3.9: Recently planted reclaimed highwall (King Mountain Surface Mine, near Jellico, TN)

3.2 Field Investigation

3.2.1 Site Description

3.2.1.1 Location

Based on the field visits for the regional inventory of highwall elimination processes, the Peel Poplar Mine of ICG was selected for the detailed field investigation. The site is located on Left Fork of Blackberry Creek (Figure 3.10) in Pike County, Kentucky. The site can be found on the Matewan Quadrangle of the United States Geological Survey with latitude 37° 30’ 40” and longitude 82° 13’ 36”.

Figure 3.10: Experimental site location (Source: Google Earth)

3.2.1.2 Topography

The topography of the Peel Poplar Mine is consistent with the Kentucky portion of the Cumberland Plateau. The area consists of valleys, narrow ridges, and steep slopes. The area is well drained and connects to the Licking River, Big and Little Sandy Rivers, the Cumberland River and the Kentucky River waterways. The average elevation of the ridges is 1053 ft. above sea level.

3.2.1.3 Geology

The coal deposit at Peel Poplar is exposed along the contour. The strata consist of layers of sandstone, shale, coal and underclays. A typical cross section is shown in Figure 3.11.

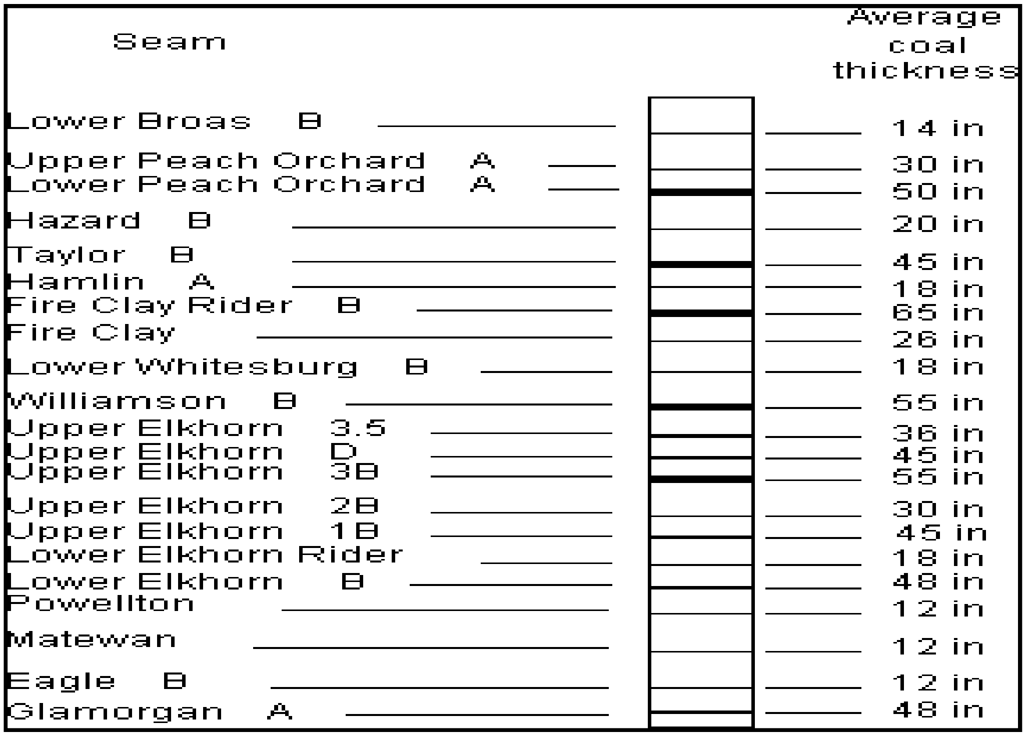


Figure 3.11: Matewan quadrangle coal stratigraphy (Source: USGS, 2003)

3.2.1.4 Climate

The climate of the region is temperature humid continental with average precipitation of 114 cm (44.9 in.), and an average monthly precipitation of 10 cm (3.9 in.), which ranges from 6-12 cm (2.4-4.7 in.) (Angel et al., 2008). Average temperature is 13°C (55.4^0), with a mean daily maximum and minimum of 31°C (87.8^0F) and 18°C (64.4^0F) in July and 8°C (46.4^0F) and -4°C (24.8^0 F) in January.

3.2.2 Mining Method

The coal seams are mined using the contour haulback mining method. The mining is done using a combination of hydraulic excavators, front end loaders, trucks, and dozers. The detailed highwall elimination process is discussed in the next section. Figure 3.12 shows the experimental site, before the highwall was eliminated.

Figure 3.12: Experimental site at the Peel Poplar Mine (before highwall elimination)

3.2.3 Highwall Elimination

The contour haulback mining method is most commonly used throughout the Appalachian region in the mountainous terrain where the coal seams are exposed along the contours. In this method, a first cut is made into the hillside above the coal seam, and a portion of the coal seam is exposed after removal of the overburden. The mining process advances following the coal seams by a succession of cuts along the contour. As a result of these mining activities, highwalls are exposed along contour as shown in Figure 3.13. Commonly used methods to eliminate exposed highwall and to achieve approximate original contour are described in Sec. 3.1.1.

Figure 3.13: Exposed highwall at ICG Peel Poplar Mine (Pike County, Kentucky)

3.2.3.1 Regulations for Highwall Elimination

At the time SMCRA was signed into law in August of 1977 the event was hailed as a victory for environmental interests (Zipper et al., 1989). SMCRA established several rules and restrictions for spoil handling procedures used by coal surface mining operations and it resulted in substantial improvements in overall reclamation practices in surface mining.

SMCRA, Sec. 515, 30 U.S.C. 1265. Subsection 515(b)(3), requires that all surface coal mining operations backfill, compact, and grade "in order to restore the approximate original contour of the land with all highwalls, spoil plies, and depressions eliminated (unless small depressions are needed in order to retain moisture to assist revegetation)". Subsection, 515(b)-(16), requires that reclamation occur as "contemporaneously as practicable" with mining operations. The issue of returning mined land to the approximate original contour (AOC) was debated in nearly every session of Congress leading to the passage of P.L. 95-87. Environmental groups called for complete highwall elimination and return to AOC, while industry and most state government representatives urged flexible requirements and local responsibility. This issue was resolved in 95th Congress with some allowance for variance from the requirement to return land to AOC.

According to SMCRA, Sec.701(2), the approximate original contour means that surface configuration achieved by backfilling and grading of the mined area so that the reclaimed area, including any terracing or access roads, closely resembles the general surface configuration of the land prior to mining and the drainage pattern of the surrounding terrain, with highwalls and spoil piles eliminated. Throughout the Appalachian region, as well as the entire nation, AOC must be achieved, unless a variance is granted to accommodate a proposed postmining land use.

3.2.3.2 Steep Slopes

SMRCA, Sec 515 (subsection c (4)) , defines the term "Steep slope" as any slope above 20 ° or such lesser slope as may be defined by the regulatory authority after consideration of soil, climate, and other characteristics of a region or state. For this project, steep-slope mining refers to slopes that are at least 20° and may include slopes in excess of 26° or 2:1.

3.2.3.3 Experimental Site Design

The highwall elimination was done by using a combination of truck haulback and lateral dozer push. For this, a ramp was constructed along the contour bench and spoil was hauled up the ramp and dumped over the edge. Then lateral pushing was done in horizontal passes. Approximately 581,000 m^3 (760,000 yd^3) of loose material was backfilled to eliminate the highwall by a combination of a Caterpillar 992D loader, 777D trucks, and a D11R dozer.

The first step of the process was to load the trucks using the 992D loader and then haul the spoil up the ramp along contour. Figure 3.14 and 3.15 shows the hauling and dumping activities.

Figure 3.14: Hauling of spoil material

Figure 3.15: Dumping of spoil material

Next, the dumped material was pushed in horizontal passes by the CAT D-11R dozer. Figure 3.16 shows the lateral pushing of spoil.

Figure 3.16: Lateral pushing of spoil material

3.2.3.4 Final Grading

The last step was grading of the slope from top to bottom using the D11R dozer in a single pass following FRA recommendations (Sweigard et al., 2007). The grading was done moving downslope as suggested in Forestry Reclamation Advisory #3. It was done by leaving small ridges of rocks on the surface between passes. After final grading, the area of approximately 1.9 hectare (4.7 acres) was naturally divided into two parts (Figure 3.17) based on spoil material. One part consists almost entirely of gray sandstone mixed with some shale. The other part was a mixture of sandstone, shale, and some topsoil dozed down from above the highwall (giving the material its brown color). The gray spoil accounts for around 40% of total area and the brown spoil accounts for the remaining portion.

Figure 3.17: Experimental site after final grading

3.2.4 Slope Movement Monitoring

3.2.4.1 Field Monitoring

Reclamation scientists and industry personnel have expressed concern that loose dumping of the top 1.22 m (4 ft.) of material with minimal grading, as recommended by FRA, could compromise the stability of the slope. Hence, it necessitates the close monitoring of this loose spoil in steep slopes for any type of mass movement. In this study, the focus was on monitoring for mass movement, not minor slumping. There were some expectations for vertical settlement and frost heave; however, it was primarily horizontal movement down the slope that was the focus of this investigation. To measure mass movement, a well-defined survey network was created.

(1) Survey Work

A detailed survey of the experimental site was conducted to locate the boundaries of the site, to plot the topographic contours, to fix the location of the survey monuments, and to find the area, slope angle, and volume of the backfilled spoil. A combination of a Topcon GTS-229 (total station) and prism was used for the survey work as shown in Figure 3.18. The total station can measure with a precision up to 3 mm (0.12 in.) for distances and up to 5 seconds for angles (Topcon Instruction Manual). It is also incorporated with a data collector, which can store the field readings in text files.

The locations of the reference points were chosen in such a manner that the relative movement of any unstable area could be monitored. The permanent control points (reference points) were located on stable ground outside the slope area and within view of the targets. Two permanent reference points were grouted in an undisturbed part of the slope: one above the gray spoil area and other above the brown spoil area. The AutoCAD drawing of reclaimed area with monument orientation is shown in Figure 3.19. To fix the location of survey monuments, a survey network was developed so that each point could be seen easily from the permanent stations. After plotting the surface survey results in SurvCADD software, it was determined that the area of the site is 1.9 hectare (4.7 acre). It is divided in two parts, the gray spoil area (average slope 31°) and the brown spoil area (average slope 26°).

Figure 3.18: Combination of total station and prism for survey work

(2) Monument Installation

After fixing the locations of the monuments by surveying, both the gray spoil and the brown spoil areas were instrumented with 1.25 cm (1/2 in.) diameter and 1.22 m (4 ft.) length steel rebars. A typical monument orientation is shown in Figure 3.20. A total of 70 rebars were driven up to a depth of 0.92 m (3 ft.) into the ground as shown in Figure 3.19. A regular rectangular pattern of approximately 25 m by 15 m (82.0 ft. by 49.2 ft.) was used in locating the monuments. The monuments in each line are listed in Table 3.1.

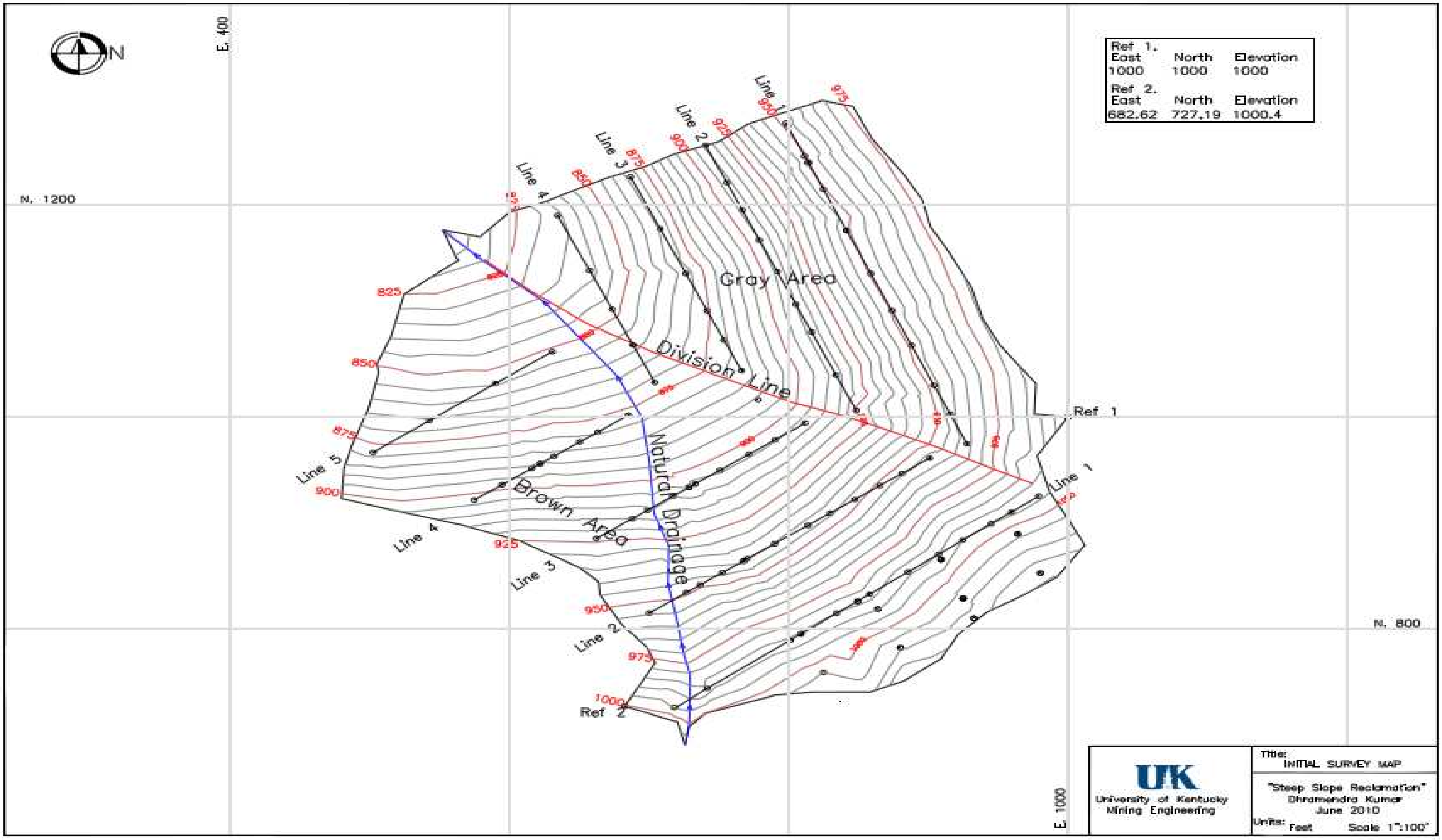


Figure 3.19: Map of the site with orientation of survey monuments

Table 3.1: Number of monuments per survey line

No.	Line	No of bars (Gray area)	No of bars (Brown area)
1	Line 1	10	10
2	Line 2	9	11
3	Line 3	7	8
4	Line 4	5	6
5	Line 5	-	4
	Total	31	39

Figure 3.20: A typical survey monument

(c) Monitoring Program

In order to monitor slope movement, a regular survey of the tops of the monuments using a Topcon GTS-229 total station was done approximately quarterly (June 2009, August 2009, March 2010, and May 2010). One survey, which was scheduled for December, 2009, was missed due to inclement weather conditions in December, 2009 and January, 2010. After each survey, plots to measure horizontal and vertical movement were drawn and compared with previous survey plots. Figure 3.21 shows the plot of easting versus northing of all the monuments in line-1 and Figure 3.22 shows the plot of elevation at the top of the monuments. Plots of eastings versus northings are used to measure any horizontal movement along the slope. Plots of elevations are used to measure any type of settlement or vertical movement of the monuments.

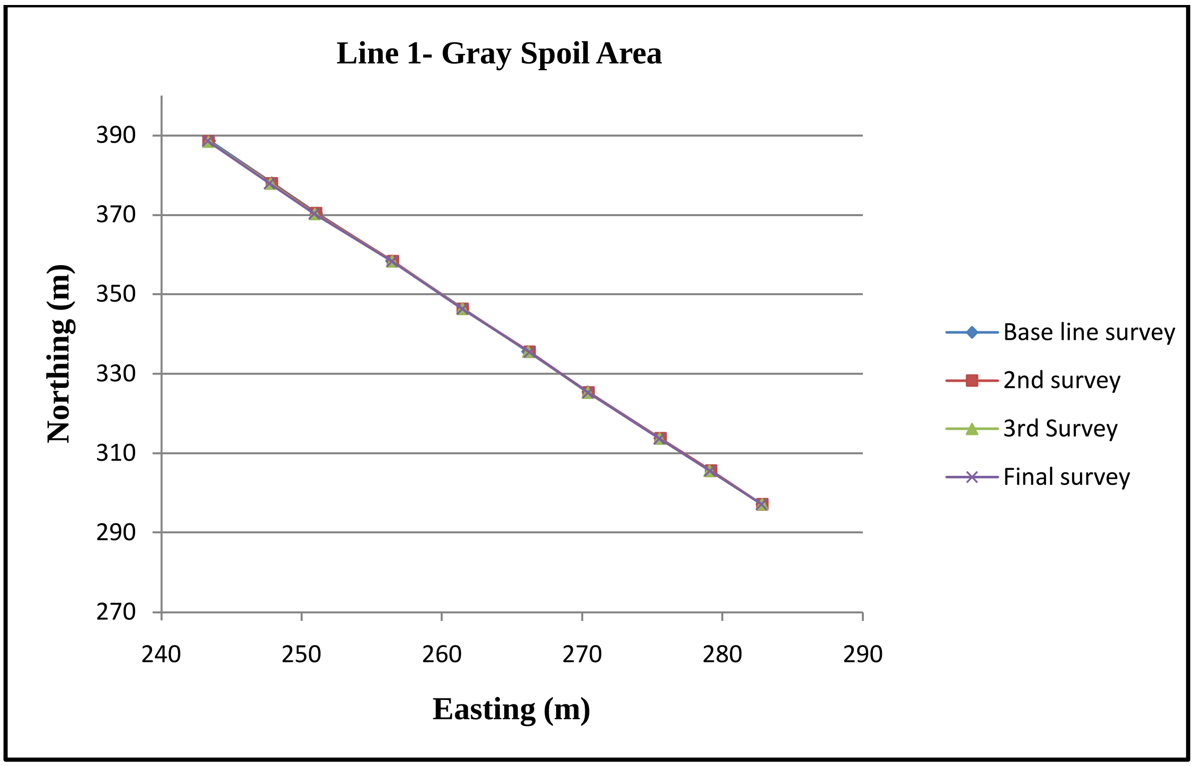


Figure 3.21: Plot to measure mass movement down the slope

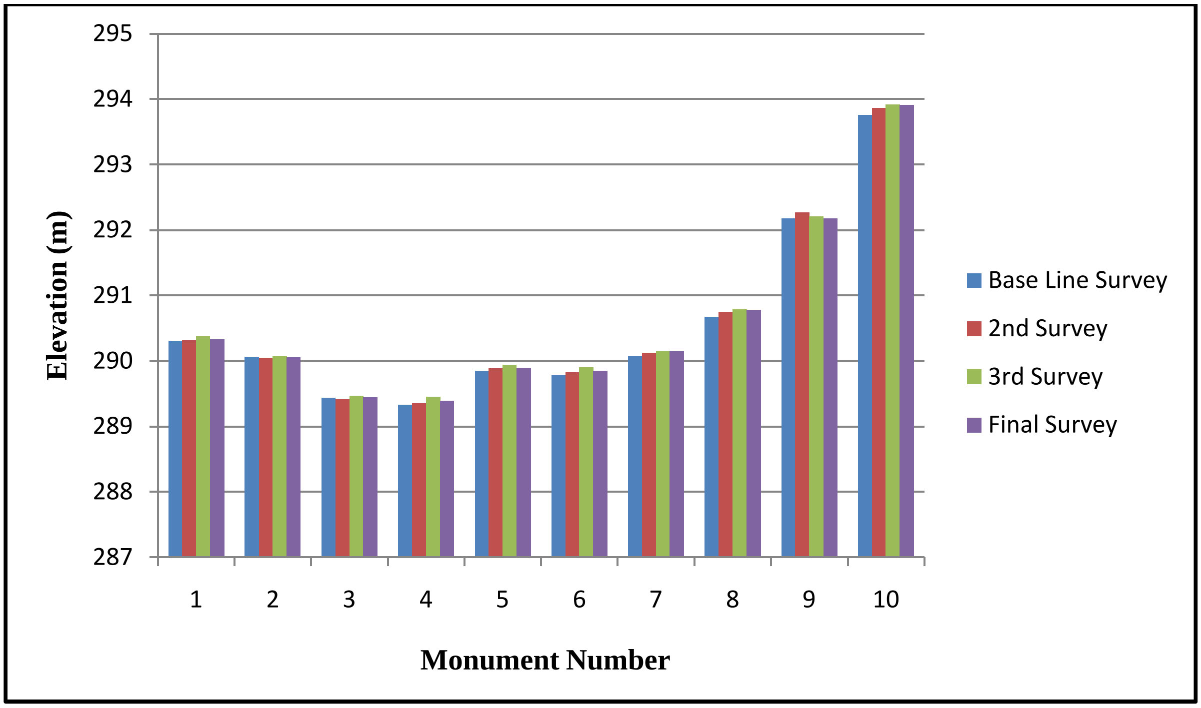


Figure 3.22: Plot to measure vertical settlement or heaving of the monuments (Line 1 –Gray spoil area)

(d) Slope Movement Analysis

The survey results from the baseline survey and the final survey are plotted and analyzed by line for movement of monuments down the slope and vertical settlement or heaving. The results of maximum downward horizontal and vertical movement for the brown and the gray spoil area are listed in Tables 3.2 and 3.3, respectively.

Table 3.2: Slope movement for the brown spoil area in one year

Downward Horizontal Movement			
No.	**Line**	**Max. Movement**	
		(m)	**(ft.)**
1	Line 1	0.227	0.74
2	Line 2	0.194	0.64
3	Line 3	0.173	0.57
4	Line 4	0.157	0.52
5	Line 5	0.19	0.62
Vertical Movement			
1	Line 2	0.155	0.51
2	Line 2	0.244	0.80
3	Line 3	0.160	0.53
4	Line 4	0.130	0.43
5	Line 5	0.16	0.54

Table 3.3: Slope movements for the gray spoil area in one year

Downward Horizontal Movement			
No.	**Line**	**Max. Movement**	
		(m)	**(ft.)**
1	Line 1	0.294	0.96
2	Line 2	0.189	0.62
3	Line 3	0.139	0.46
4	Line 4	0.158	0.52
Vertical Movement			
No.	**Line**	**Max. Movement**	
		(m)	**(ft.)**
1	Line 2	0.103	0.34
2	Line 2	0.155	0.51
3	Line 3	0.133	0.43
4	Line 4	0.154	0.51

3.2.4.2 Slope Stability Analysis

One of the strongest driving forces behind the passage of SMCRA was the problem of unregulated conventional contour mining operations that were most common throughout the Appalachian region. The problems associated with exposed highwalls and unstable slopes have been minimized after implementation of SMCRA. However, to maintain stability of slopes as required by SMCRA, the mine operators do a considerable amount of compaction of loose spoil, which can have negative effects on tree growth. The successful implementation of FRA in flat or rolling ground has led to the possible application of FRA on steep slopes, which is the subject of this investigation. There have been concerns expressed by both industry and the regulatory authorities, that the application of FRA on steep slopes may be either impractical or even, under some circumstances, deleterious to the stability of the slope. The stability concern arises due to the top 1.22 m (4 ft.) of loose material on steep slopes.

Field measurement of slope movement has been done using the slope monitoring network and computer modeling of slope stability has been performed. Several approaches for the analysis of the slope stability problem could be used. However, in this particular study, the static equilibrium (limit equilibrium) method was used for slope stability analysis.

The main objective of any type of stability analysis is the prediction of the accurate slope factor of safety. Stresses, gravity loading, rock mass strength, geology, and pore pressure are the main factors contributing to slope failure problems (Girard et al., 2000). A number of failure criteria have been suggested for slope stability modeling (Griffiths, 2001), but Mohr-Coulomb's criteria is still most widely used for geotechnical practices. A Mohr-Coulomb failure criterion is a function of the cohesion and internal friction angle of material (Al-Awad, 2000). The Mohr-Coulomb failure criterion is expressed mathematically in Eq. 3.1.

$$\tau = C + \sigma_n * \tan\emptyset \qquad (3.1)$$

Where, τ is the shear stress and σ_n is the normal stress at failure plane. The C and Φ are the cohesion and friction angle of the material.

The evaluation of the Mohr-Coulomb failure envelope requires at least three triaxial tests on soil samples at various confining pressures to determine the shear strength parameters. For these tests a series of Mohr circles can be plotted. Then the locus of the tangent points of the circles is drawn, developing the failure envelope for the soil, which defines the boundary between stable and unstable stress states (Al-Awad, 2000). Figure 3.23 shows the Mohr-Coulomb criterion.

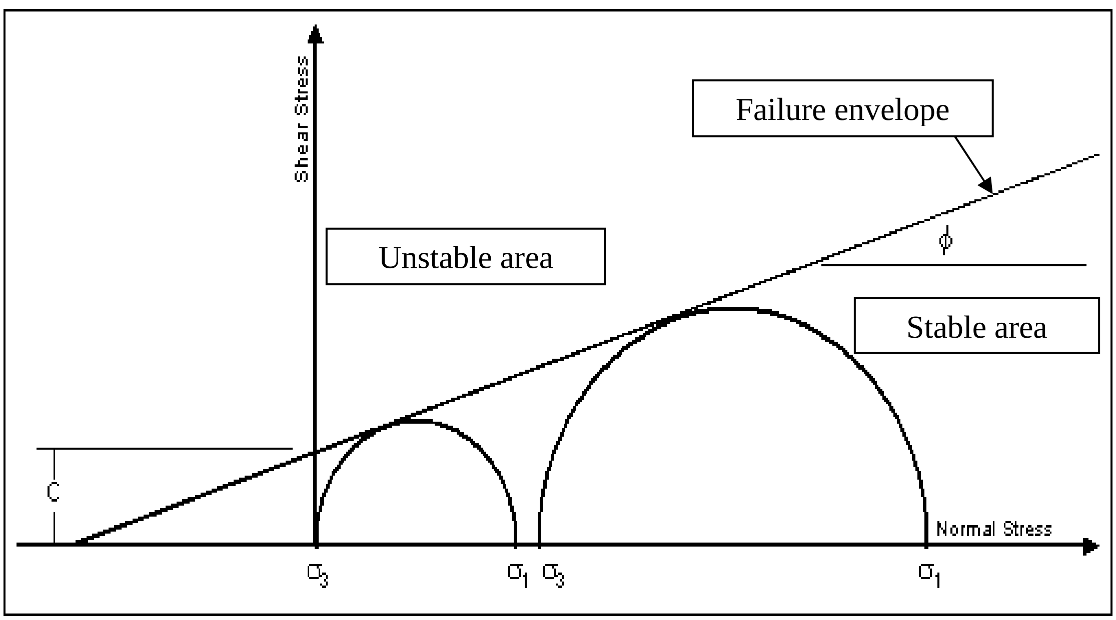


Figure 3.23: Mohr-Coulomb failure criterion

(1) Limit Equilibrium Method

The limit equilibrium methods are the most commonly used approach for analyzing the stability of slopes. The fundamental assumption of this method is that failure occurs through sliding of a block or mass along a slip surface (RocNews, 2004). The limit equilibrium methods are popular in geotechnical practice due to their relative simplicity and ability to evaluate the sensitivity of stability to various input parameters.

At the condition of limit equilibrium, all points on a failure plane are on the verge of failure (Charles, 1999). At the failure point, the driving forces (stresses or moments) are just equal to the resisting forces (stresses or moments). Hence, the factor of safety is equal to unity. If the resisting forces of a slope are greater than the driving forces, the factor of safety is greater than unity and the slope is stable. However, when the resisting forces are less than the driving forces, the slope becomes unstable. The main shortcoming of limit equilibrium methods is the assumption that the slide mass can be divided into slices, which necessitates further assumptions considering side force directions between slices, with consequent implications for equilibrium.

In limit equilibrium methods, a failure surface is assumed and a state of limit equilibrium is said to exist. The stress along the failure surface is obtained from Eq. 3.2:

$$\tau = \frac{S}{F} \tag{3.2}$$

Where, τ is the shear stress on failure plane and S is the shear strength of material. F is the safety factor.

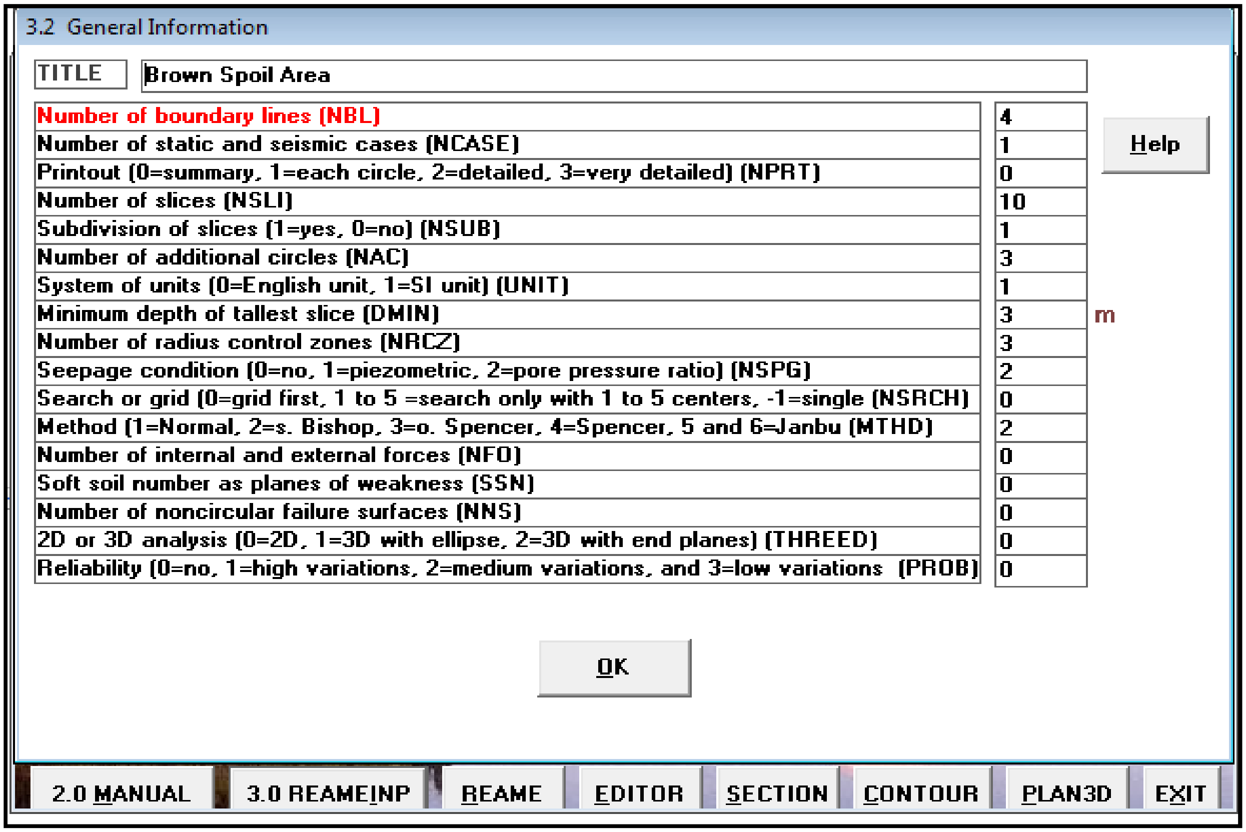
(2) Computer Models

In this study, 2D computer models of the slopes for stability analysis were developed using Rotational Equilibrium Analysis of Multilayered Earthworks (REAME) and Geo-Slope/W computer programs.

(a) REAME Model

The slope stability analyses for the brown and the gray spoil areas were performed using REAME (2008 Version). The 2D analysis was done using the Simplified Bishop Method for both areas. Three different soil layers: bedrock, gray spoil, and top gray or top brown (loose 1.22 m) were used in the analysis. General soil input parameters for the model are shown in Table 3.4. Two types of REAME analysis for each spoil area were done: the first considering the top 1.22 m (4 ft.) of loose material (with and without fixing minimum depth of tallest slice) and the second considering total backfilled material all with the same properties. The use of a curved envelope has proven that these shallow circles are not critical and should be eliminated by using a DMIN (minimum depth of tallest slice), (Huang, 1983). The gray spoil area is completely dry and no seepage was found in any part of the slope, hence the assumption of zero pore pressure was justified. A natural drainage passes through upper part of the brown spoil area, but this drainage is affecting only the small area of the slope. Monitoring of pore pressure was not included in the scope of the investigation. For stability analysis purposes, the brown area was also analyzed without consideration of pore pressure.

Table 3.4: General information for REAME model



3.2 General Information

TITLE: Brown Spoil Area

Number of boundary lines (NBL)	4
Number of static and seismic cases (NCASE)	1
Printout (0=summary, 1=each circle, 2=detailed, 3=very detailed) (NPRT)	0
Number of slices (NSLI)	10
Subdivision of slices (1=yes, 0=no) (NSUB)	1
Number of additional circles (NAC)	3
System of units (0=English unit, 1=SI unit) (UNIT)	1
Minimum depth of tallest slice (DMIN)	3 m
Number of radius control zones (NRCZ)	3
Seepage condition (0=no, 1=piezometric, 2=pore pressure ratio) (NSPG)	2
Search or grid (0=grid first, 1 to 5 =search only with 1 to 5 centers, -1=single (NSRCH)	0
Method (1=Normal, 2=s. Bishop, 3=o. Spencer, 4=Spencer, 5 and 6=Janbu (MTHD)	2
Number of internal and external forces (NFO)	0
Soft soil number as planes of weakness (SSN)	0
Number of noncircular failure surfaces (NNS)	0
2D or 3D analysis (0=2D, 1=3D with ellipse, 2=3D with end planes) (THREED)	0
Reliability (0=no, 1=high variations, 2=medium variations, and 3=low variations (PROB)	0

(b) Geo-Slope Model

Limit equilibrium models for the brown and the gray spoil areas were developed using the Geo-Slope/W (2007) computer program. The Simplified Bishop Method was again used for this analysis. The spoil physical properties and boundaries are the same as those used for the REAME model. Two types of Geo-Slope analyses for each spoil area were done: the first considered the top 1.22 m (4 ft.) of loose material (with and without fixing minimum depth of tallest slice) and the second considered the total backfilled material with the same properties.

(3) Spoil Physical Properties

To get spoil physical properties (friction angle, Poisson's ratio, and Young's modulus) consolidated undrained triaxial tests were performed on each spoil sample in a laboratory at the University of Kentucky, Department of Civil Engineering. For the cohesion values of spoil, at least two triaxial tests on each spoil sample would be required. Due to time and resource limitations, cohesion values were assumed as suggested by Huang (1983). For the coarse spoil with very few fines, cohesion should theoretically be zero (Huang, 1983). However, for analysis purposes, a small cohesion value was desirable to eliminate the formation of very shallow circles. In this analysis, a cohesion value of 0.0479 kN/m^2 (1 psf) was assumed for the top gray, the top brown, and the gray spoils. Bulk density values were taken from the results of nuclear density measurements at a depth of 15 cm (6 in.). The spoil physical properties used for analysis are listed in Table 3.5.

Table 3.5: Spoil physical properties used for stability analysis

Soil Type	**Unit Weight pcf**	**Unit Weight kN/m^3**	**Cohesion kN/m^2**	**Friction Angle(°)**	**Poisson's Ratio**	**Young's Modulus psi**	**Young's Modulus kN/m^2**
	(γ)	**(γ)**	**(C)**	**(Φ)**	**(ν)**	**(E)**	**(E)**
Top Brown	98.68	15.5	0.0479	36	0.3	7.89E+04	5.44E+05
Top Gray	105.81	16.7	0.0479	37	0.3	8.46E+04	5.83E+05
Gray	125	19.62	0.0479	38	0.3	1.00E+05	6.89E+05
Rock	225	35.316	9.58	42	0.1	1.00E+10	6.89E+10

(4) Stability Analysis for Brown Spoil Area

(a) Profile for Analysis

A cross sectional view of the profile for the brown spoil area is shown in Figure 3.24. This is a representative profile almost in the middle of slope with an average angle of 21°. However the local inclination of the upper part of the slope approaches or even exceeds 30^0 in some locations.

(b) REAME Models for Brown Spoil Area

Three models were developed using the REAME program for the brown spoil area. First, without fixing the depth of the tallest circle, the top 1.22 m (4 ft.) was considered loose material. In this case a factor of safety of 1.287 was found and the very shallow failure circle is touching the upper part of the slope as shown in Figure 3.25. Secondly, the model was run by fixing the depth of the tallest slice at 3 m (9.8 ft.) and it resulted in safety factor of 1.490. The failure circle is touching the spoil materials below the top 1.22 m (4 ft.) of the loose material, as shown in Figure 3.26. Finally, the model was run without consideration for loose top material and this resulted in a safety factor of 1.507. The failure circle is passing through the upper part of the slope as shown in Figure 3.27. The contours of safety factors for the REAME models are shown in appendix C.

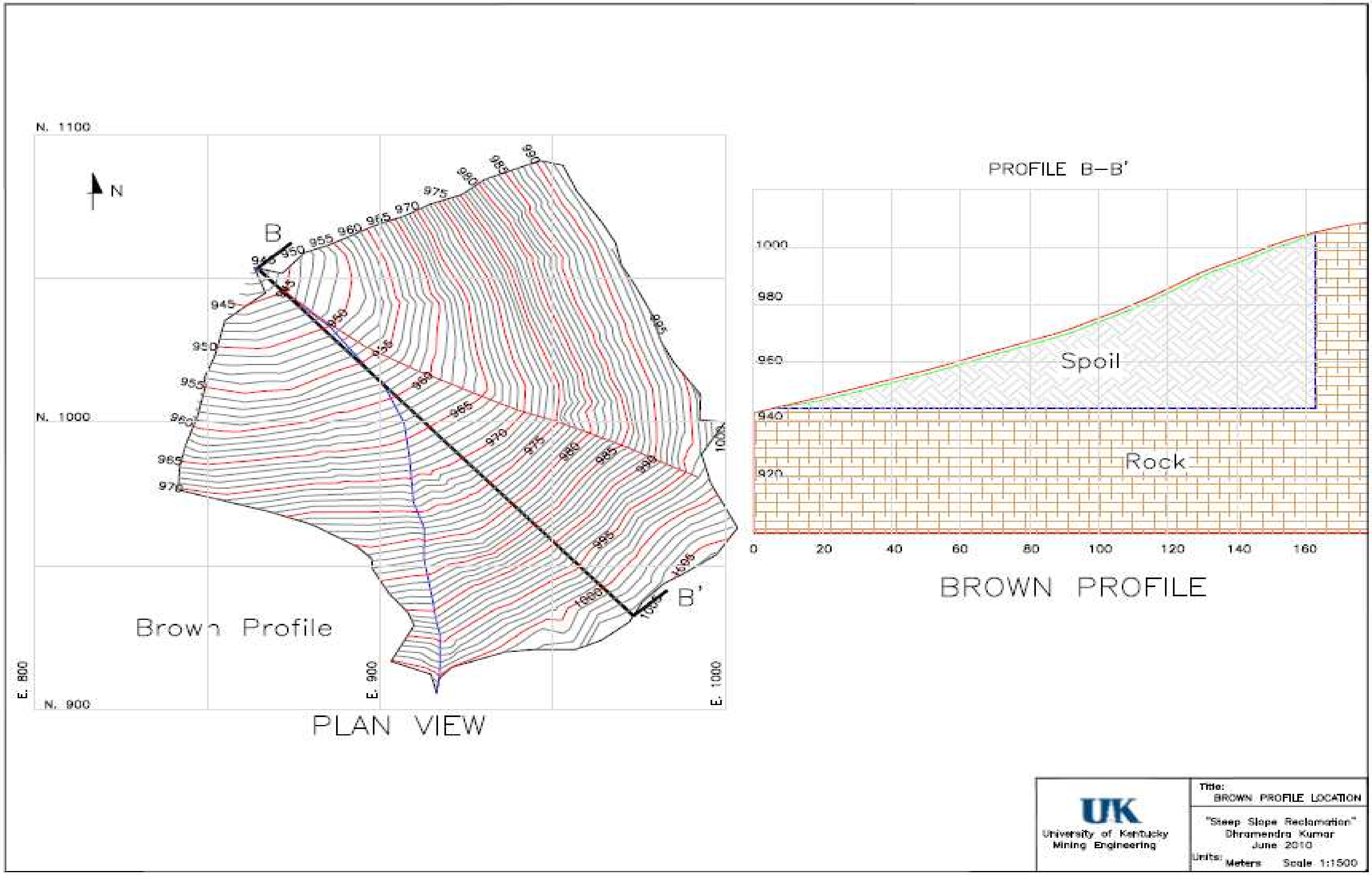


Figure 3.24: Profile used for stability analysis of brown area

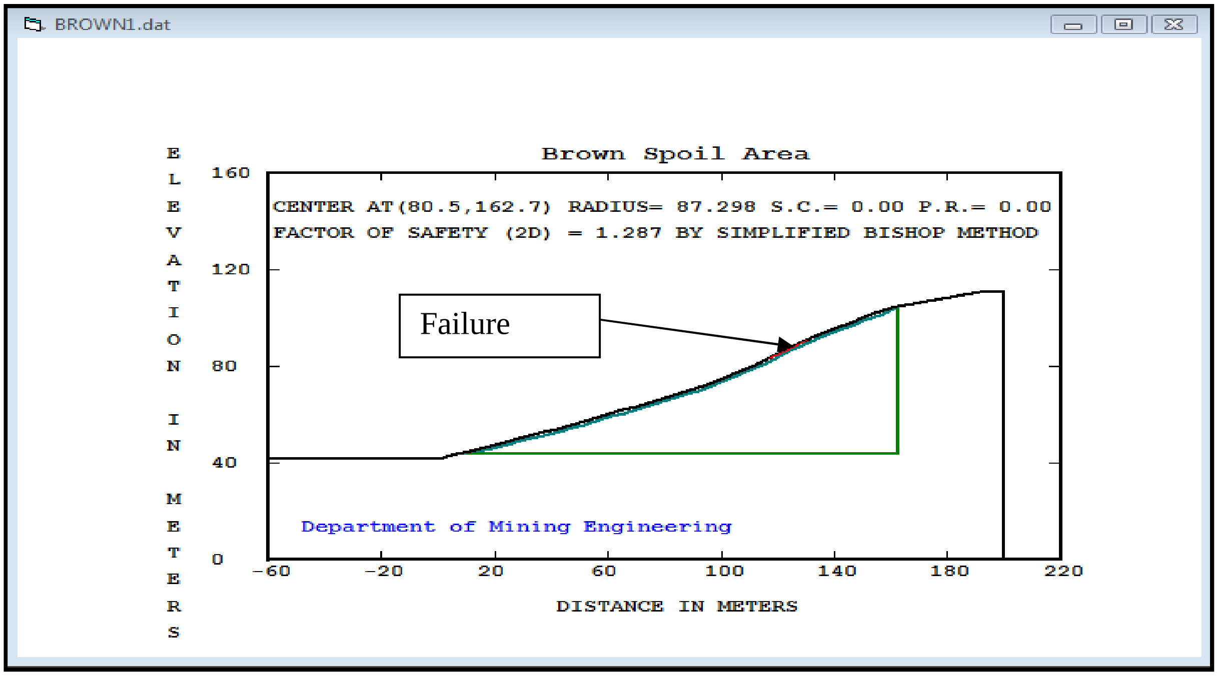


Figure 3.25: REAME model for the brown area (with loose top 1.22 m of material)

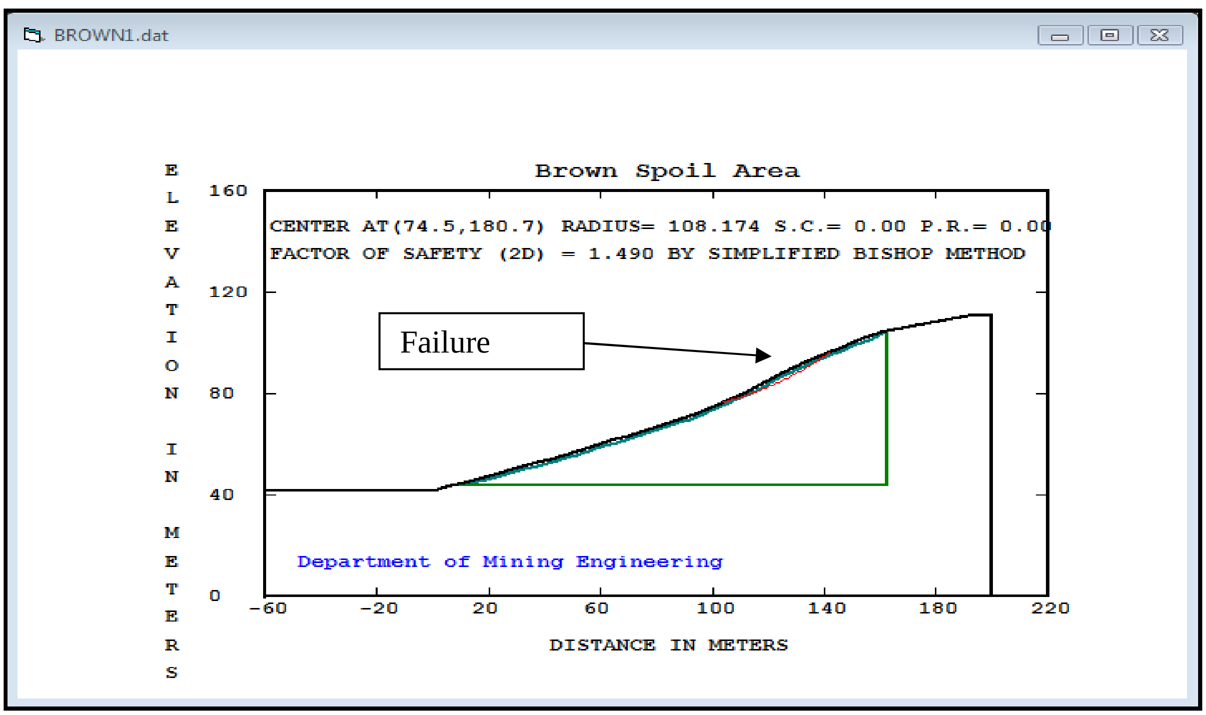


Figure 3.26: REAME model for the brown area (with loose top 1.22 m of material) and minimum depth of tallest slice

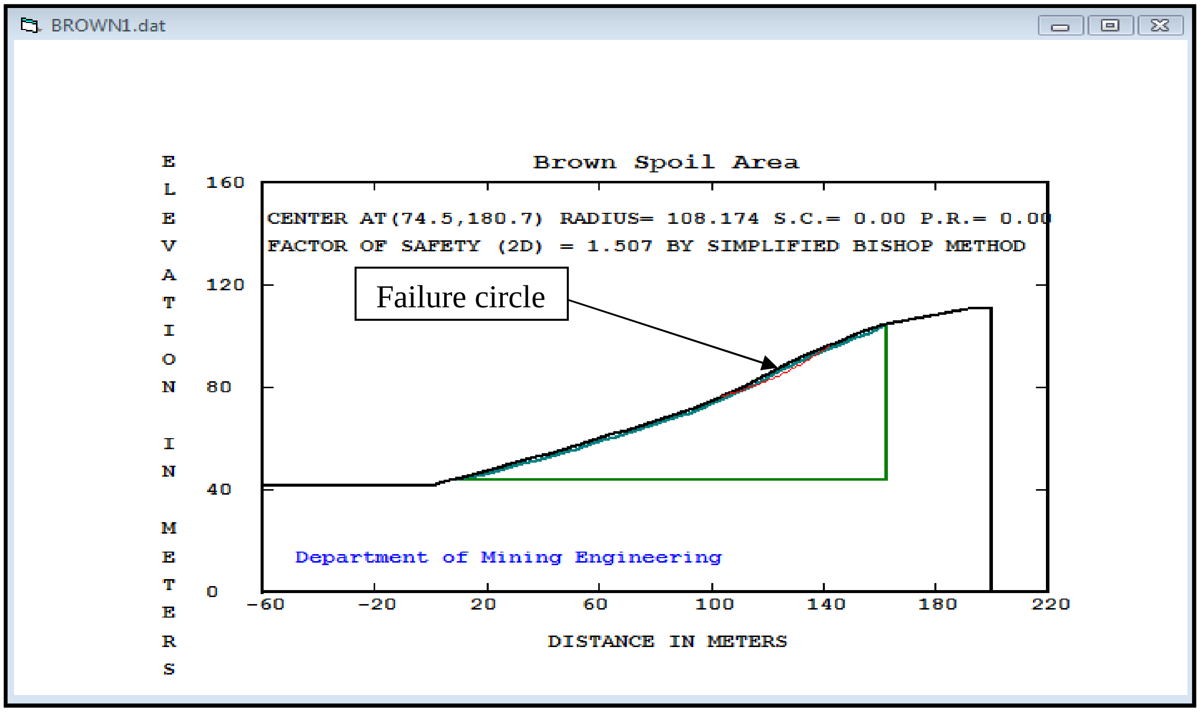


Figure 3.27: REAME model for the brown area (without loose top 1.22 m of material) and fixing depth of tallest slice

(c) GEO-SLOPE Model for Brown Spoil Area

Similar to the REAME models, three models were developed using the Geo-Slope (W) program. Initially, considering the top 1.22 m (4 ft.) of loose material, a factor of safety of 1.298 was found and the failure circle is touching the upper part of the slope as shown in Figure 3.28. Secondly, considering a slightly deeper circle touching the lower part of the top 1.22 m (4 ft.) of loose material resulted in a safety factor of 1.50, as shown in Figure 3.29. Finally, the model was run without consideration of the loose material and resulted in a safety factor of 1.393. The failure circle is passing through the upper part of the slope as shown in Figure 3.30.

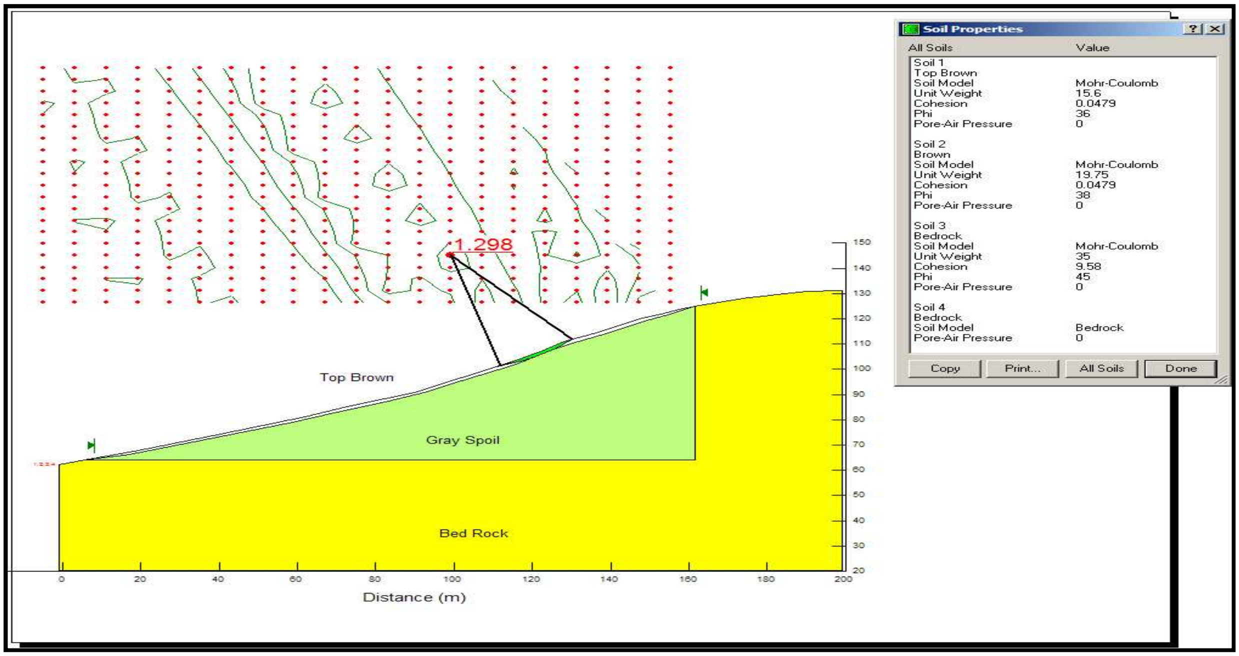


Figure 3.28: Geo-Slope model for the brown area (with loose top 1.22 m of material)

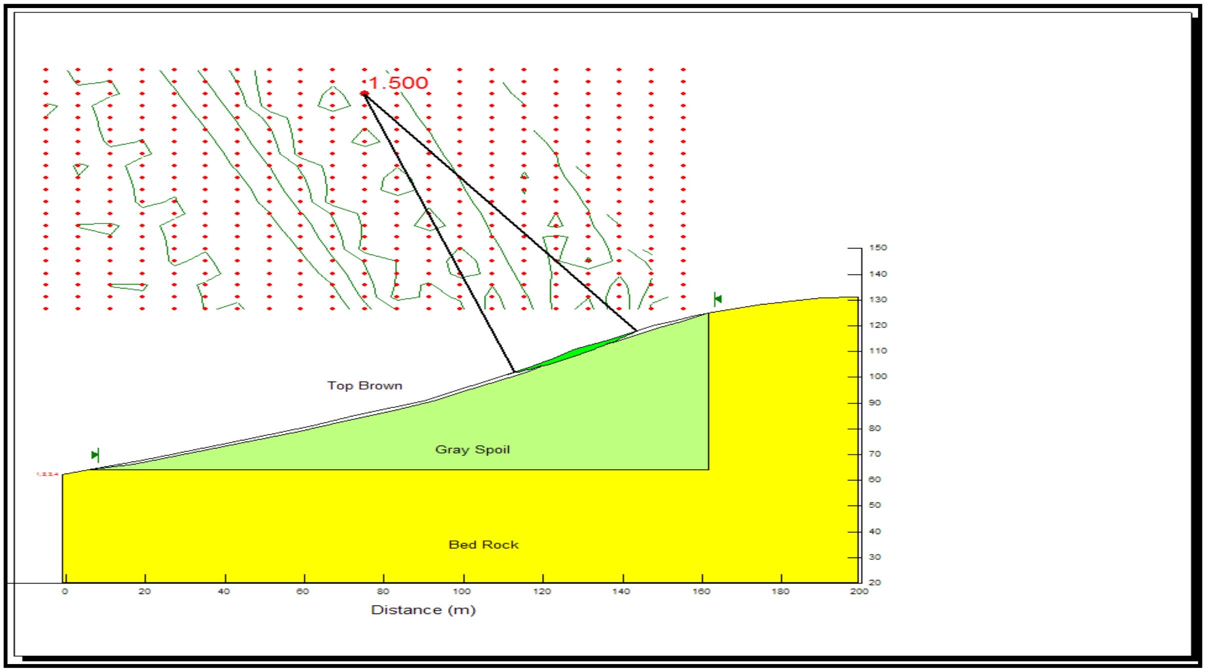


Figure 3.29: Geo-Slope model for the brown area (circle touching lower part of loose material)

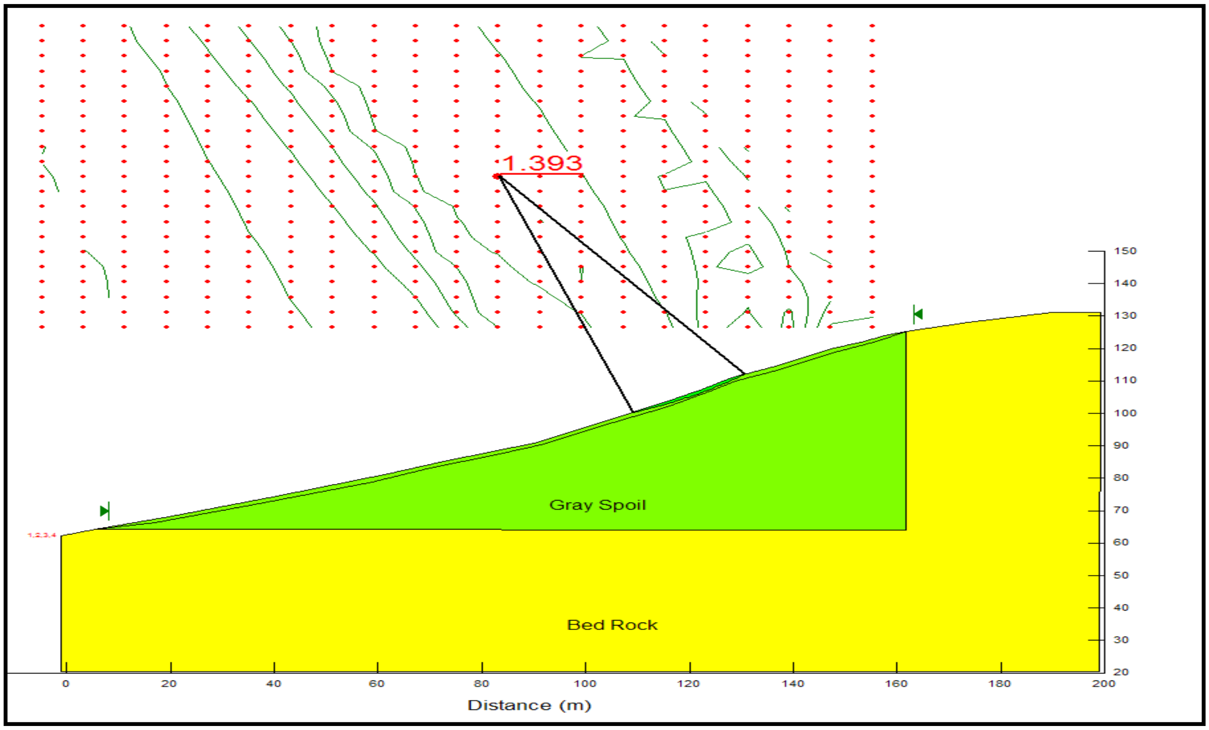


Figure 3.30: Geo-Slope model for the brown area (without loose top 1.22 m of material)

(5) Stability Analysis for the Gray Spoil Area

(a) Profile for Analysis

A cross sectional view of the profile used for stability analysis of the gray spoil is shown in Figure 3.31. This is a representative profile almost in the middle of slope with an average angle of 26°. However, the local inclinations of the upper part of the slope range from 31° to 35°.

(b) REAME Model for Gray Spoil Area

The REAME models for the gray area were developed similar to the models for the brown area. In the first case, with 1.22 m of loose top material and without fixing the depth of the tallest slice, the factor of safety was found to be 1.00. The failure circle is passing through upper part of the slope as shown in Figure 3.32. In the second case, after fixing the minimum depth of the tallest slice, the factor of safety was found to be 1.292. The failure circle is passing below the loose materials as shown in Figure 3.33. In the last model, without consideration of top loose material, the factor of safety was found to be 1.302 as shown in Figure 3.34. The contours of safety factor for REAME models are shown in appendix C.

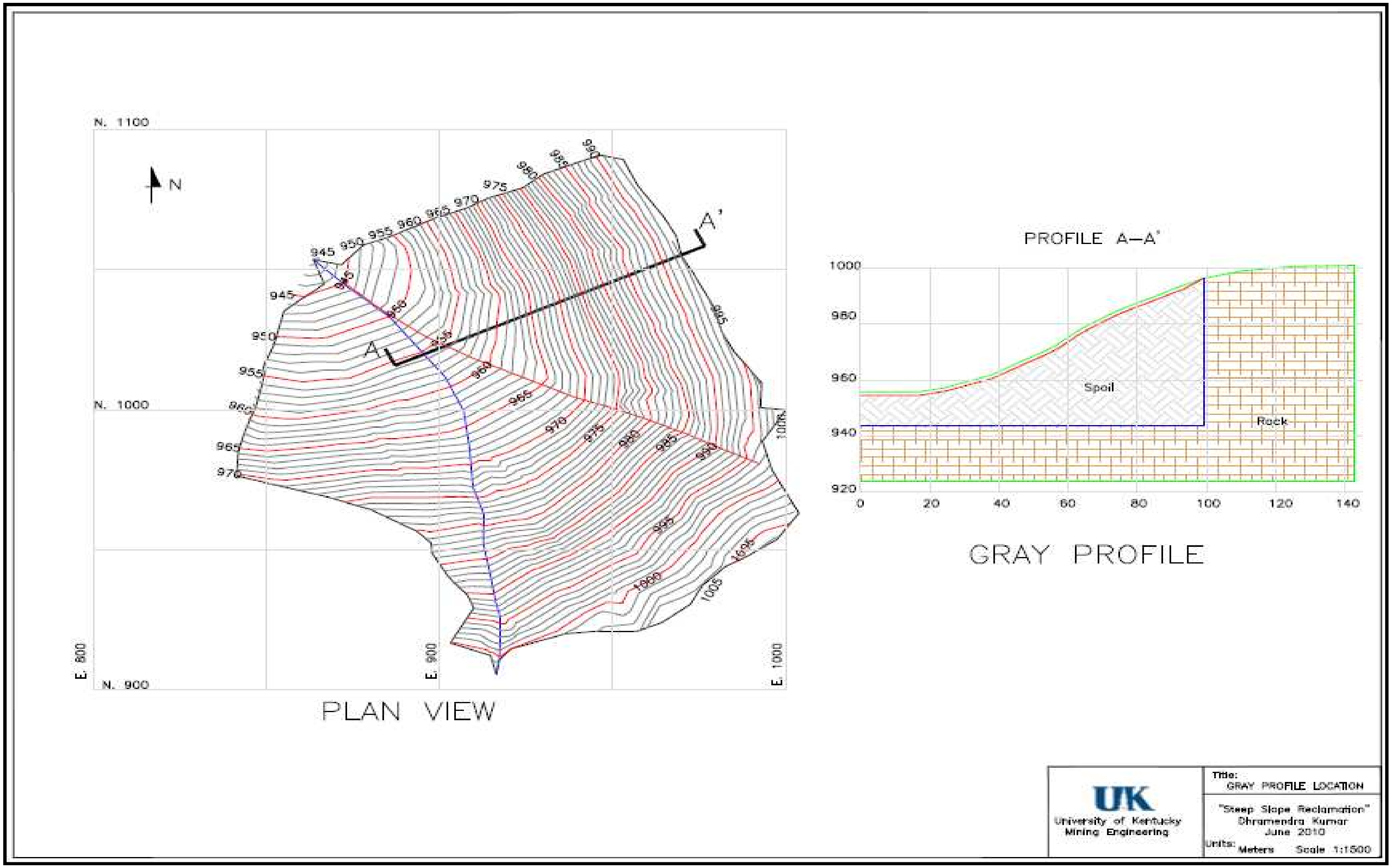


Figure 3.31: Profile used for stability analysis of the gray area

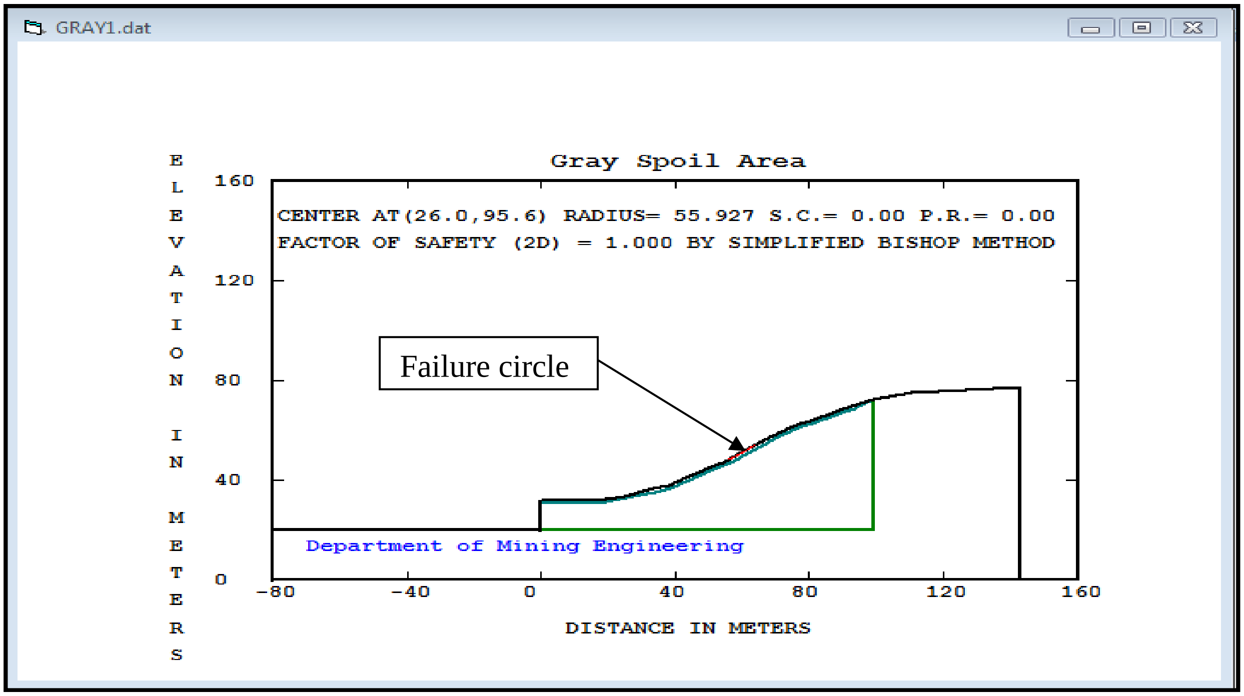


Figure 3.32: REAME model for the gray area (with loose top 1.22 m of material)

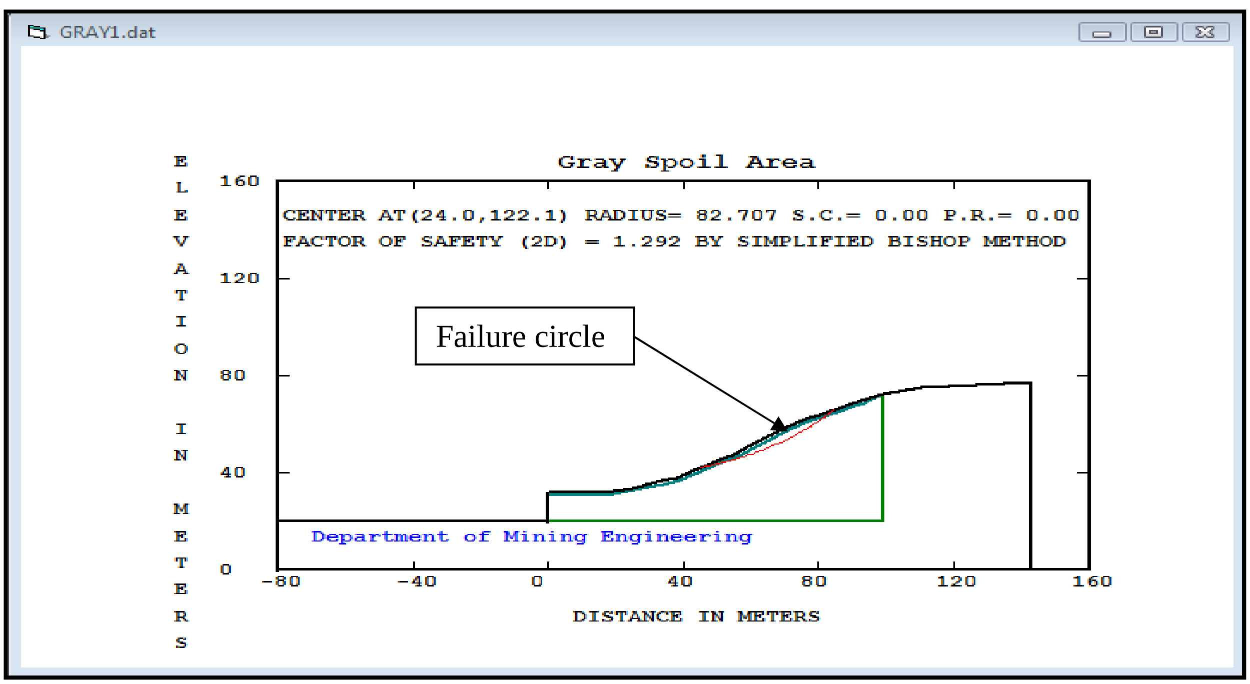


Figure 3.33: REAME model for the gray area (with loose top 1.22 m of material) and minimum depth of tallest slice

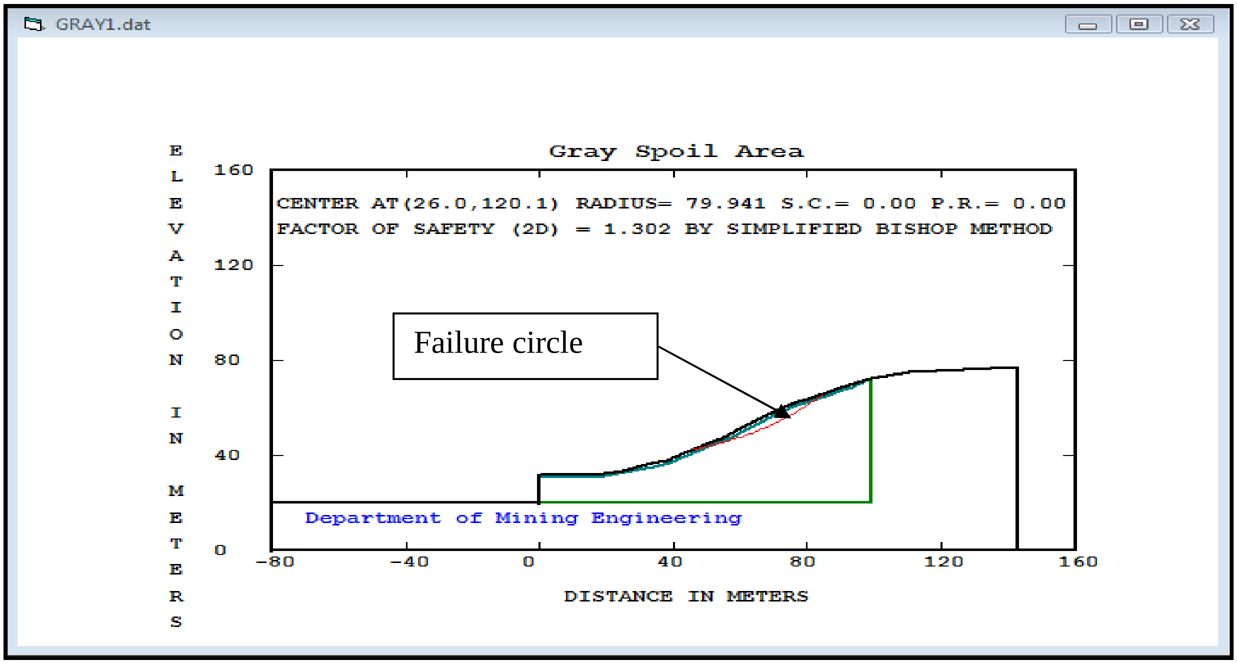


Figure 3.34: REAME model for the gray area (without loose top 1.22 m of material) and fixing depth of tallest slice

(c) GEO-SLOPE Model for the Gray spoil area

Similar to the Geo-Slope models for the brown spoil area, three models were developed for the gray spoil area. Considering the top 1.22 m (4 ft.) as loose material, the factor of safety was found to be 1.121 as shown in Figure 3.35. In the second case with a deeper circle, the factor of safety was found to be 1.154 as shown in Figure 3.36. In the last case, without the top 1.22 m (4 ft.) of loose materials, the safety factor was found to be 1.158 as shown in Figure 3.37.

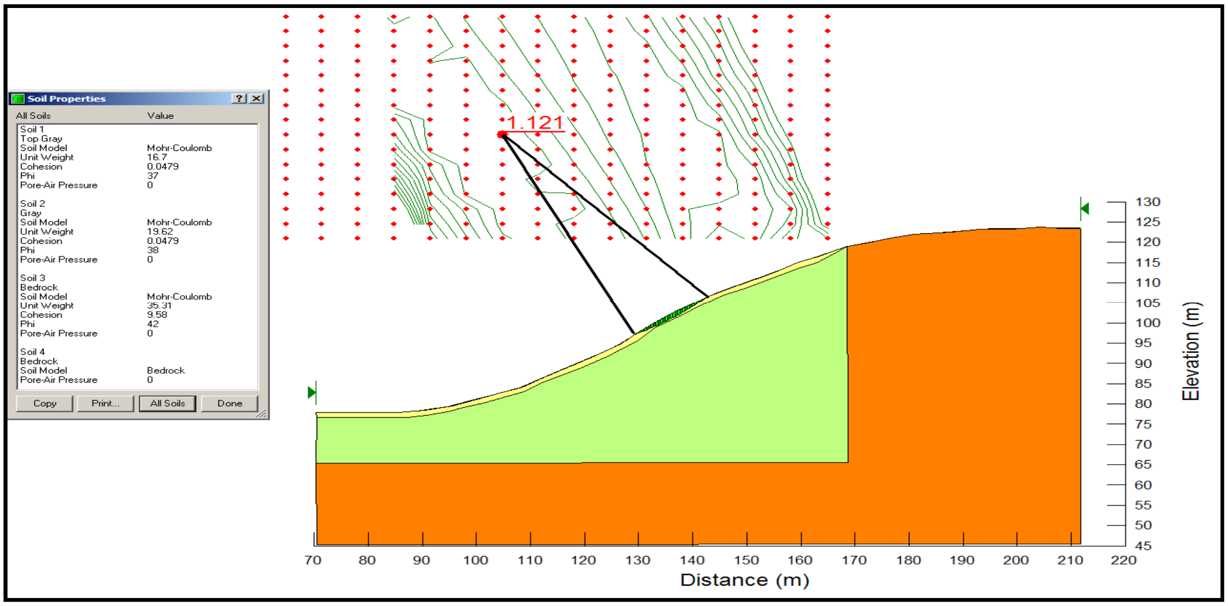


Figure 3.35: Geo-Slope model for the gray area (with loose top 1.22 m of material)

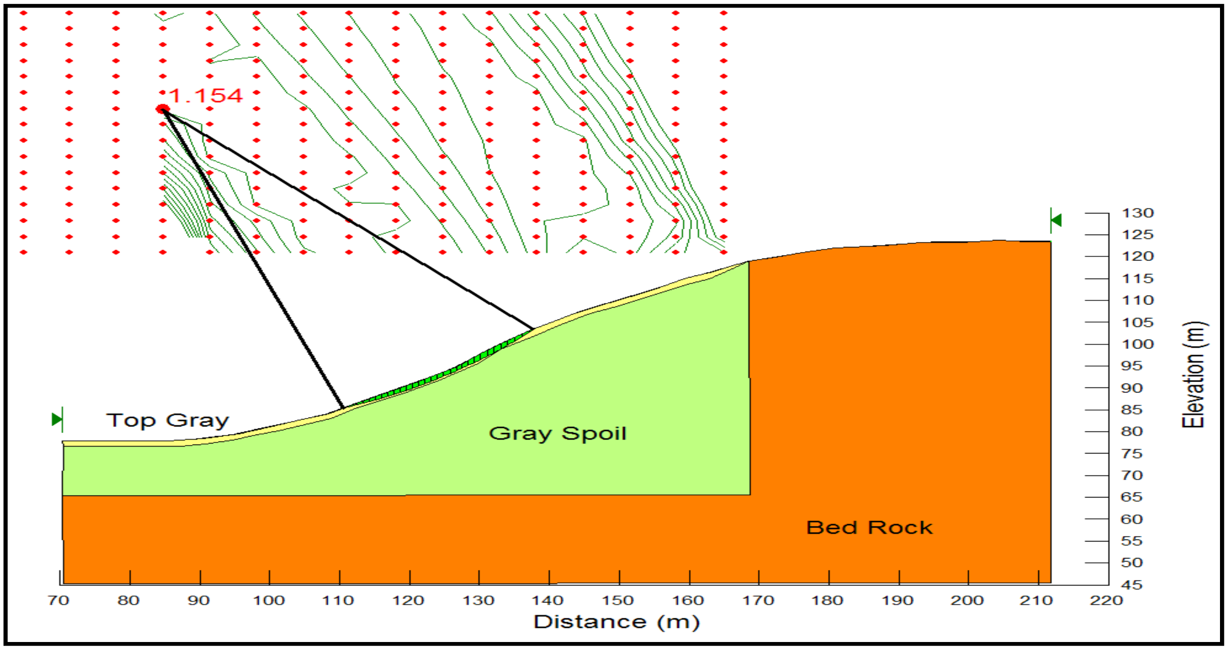


Figure 3.36: Geo-Slope model for the gray area (with loose top 1.22 m of material considering deeper circle)

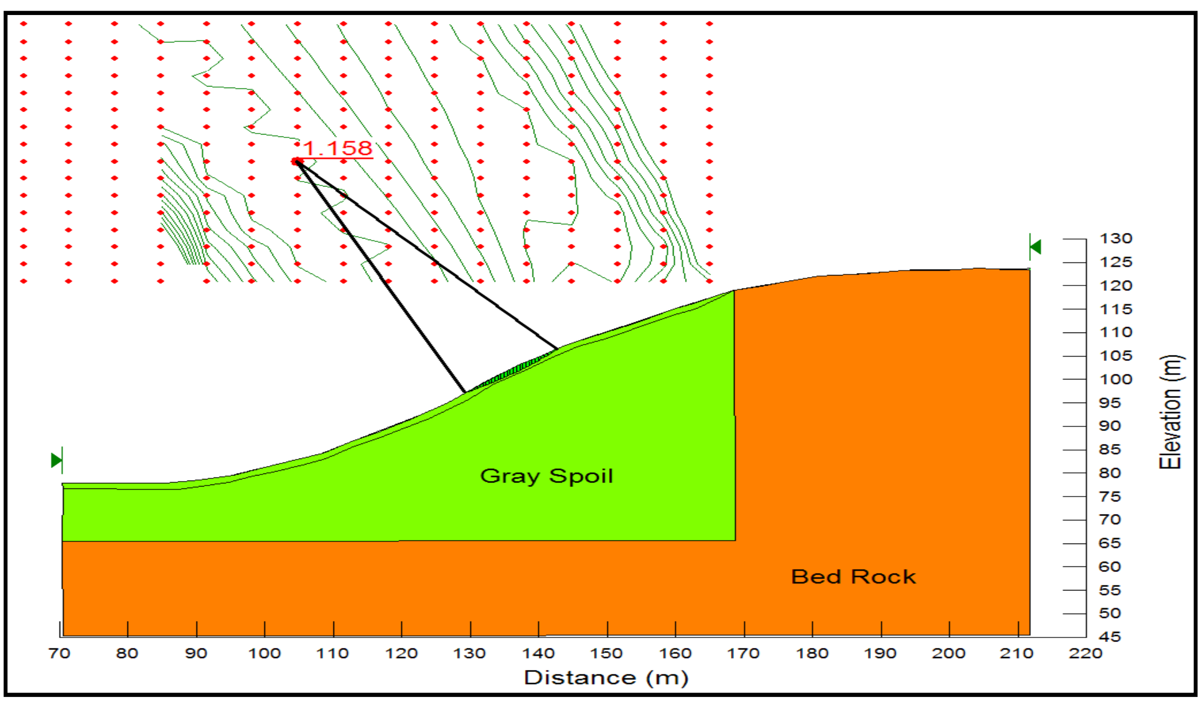


Figure 3.37: Geo-Slope model for the gray area (without loose top 1.22 m of material)

(5) Slope Stability Analysis Results

A summary of the results from the REAME and the Geo-Slope models for the brown and the gray spoil areas is listed in Table 3.6. In none of the cases evaluated do the computer models predict a deep failure surface that would threaten the stability of the entire slope.

Table 3.6: Summary of results for stability analysis

		Brown Spoil Area		Gray Spoil Area	
No.	Analysis Type	REAME	GEO-SLOPE	REAME	GEO-SLOPE
		F.S	F.S	F.S	F.S
1	With top 1.22 m loose material	1.287	1.298	1	1.21
2	Without loose material	1.505	1.393	1.302	1.158

3.2.5 Spoil Characterization

3.2.5.1 Compaction of Growing Media

From many years of research on reforestation of surface-mined land, it is known that any attempt to regrade surface mines results in soil compaction (Lyle, 1987). Ashby from Southern Illinois University-Carbondale was one of the first researchers to recognize the impact that excessive compaction was having on reforestation of surface-mined lands (Ashby, 1978). The causes for soil compaction are classified as natural or human causes. For mine reclamation, reclamationists are mainly concerned with the compaction caused by humans activities through topsoil removal, overburden regarding and topsoil replacement. Activities responsible for compaction of growing media in reclaimed mined lands are movement of the equipment and the type of equipment (tire or crawler mounted).

In compacted soils, the particles are packed closely together and few macropores exist. Soil compaction causes loss of pore space in soil. The loss of pore space results in less movement of water. There may be less water storage space in the soil and less space for air movement. As a result, the compacted soil is harder for roots to penetrate. Reduction of pore space causes decreased soil physical fertility and it requires additional fertilizer application and increased production cost. It was reported by Hamza and Anderson (2005) that, "A detrimental sequence then occurs of reduced plant growth leading to lower inputs of fresh organic matter in the soil, reduced nutrients recycling and mineralization, reduced activities of micro-organisms, and increased wear and tear on cultivation machinery."

Soil compaction occurs when soil particles are pressed together reducing pore space between them. Compacted soils have few large pores and have a reduced rate of both water infiltration and drainage from the compacted layer. This occurs because large pores are the most effective in moving water through the soil (Sikora, 2009). Compaction also reduces exchange of gases resulting in aeration related problems.

Compaction of the growing medium has one of the greatest impacts on the success of reforestation on reclaimed mined lands (Conrad et al., 2001). It produces undesirable physical properties. Compaction increases bulk density and resistance to mechanical penetration (Barnhisel, 1988). It has been recognized that excessive alteration of these physical properties tend to reduce root growth, lowering the potential for successfully growing trees on reclaimed sites (Graves et al., 1995). Hydraulic conductivity of the growing medium is also reduced due to compaction, hence resulting in restriction for roots from getting nutrients and water for growth and survival (Barnhisel, 1988). The level of compaction of the growing medium is a function of physical properties, its moisture content and the method of backfilling. Bulk density and penetration resistance are good predictors of root system performance in newly constructed growing media (Thompson, et al., 1987). Penetration depth to refusal and bulk density display a strong correlation with tree survival rate (Conrad, 2002).

3.2.5.2 Impact of Soil Compaction on Trees Survival and Growth Rate

Survival and growth of trees on reclaimed mined lands are often limited by a physical effect rather than chemical problems (Dollhopf and Postle, 1988). Unfavorable soil physical conditions have been proven to be the most severe and difficult factors in the reclamation of prime farmland soil (Dunker et al., 1991). Years of research have demonstrated that soil compaction is the single most limiting factor in returning prime farmland soils to their original levels of productivity.

Soil compaction has both desirable and undesirable effects on plant growth (Hunt, 2007). Slightly compacted soils can speed up the rate of seed germination because it promotes good contact between the seeds and soil. Moderate compaction reduces water loss from soil due to evaporation and, hence, prevents the soil around the growing seed from drying out. However, excessive soil compaction impedes root growth and, therefore, limits the amount of soil explored by roots. This results in a decrease of the plants' ability to take up nutrients and water. For tree growth, the adverse effect of soil compaction on water flow and storage may be more serious than the direct effect of soil compaction on root growth.

Research at Southern Illinois University has shown that there is a negative correlation between root weight, plant development, and bulk density (Vance et al., 1987). As bulk density increases, root development, and plant growth decreases (Conrad et al, 2002). Soil compaction indirectly affects root development through changes in soil structural arrangement and cracking patterns, soil strength, total porosity, number of large pores, volumetric water content, hydraulic conductivity, air filled porosity, gas diffusion rate, and nutrient availability (Taylor and Brar, 1991).

3.2.5.3 Compaction Evaluation Methodology and Equipment Background

Thompson et al., (1987), demonstrated that bulk density and penetration resistance are good predicators of root system performance in reclaimed mined lands. As a result of reforestation research at Starfire Mine by the University of Kentucky, it was found that maximum penetration depth (depth of refusal) and bulk density display a strong correlation with tree survival rate (Conrad, 2002). There is less evidence of a correlation between soil resistance and tree survival rate (Conrad, 2002). A number of different methods such as core sampling, sand cone, excavation or volumetric determination, and radiation methods can be used to evaluate the bulk density of growing media. A nuclear density gauge (radiation method) is the appropriate choice for bulk density measurement when numerous measurements are required as in reclaimed surface mines (Jansen, 1990).

Soil resistance to deformation or penetration gives an indirect measurement of soil strength (Jansen, 1990). Dunker et al., (1994) found that severe root impendence occurs when penetration resistance exceeds 2000 kPa (290 psi) and root elongation is severely restricted at

2620 kPa (380 psi). Barnhisel (2001) found that in farmland soils root penetration stopped with penetration resistance more 2069 kPa (300 psi).

(1) Nuclear Density Gauge

To measure in-situ bulk density, nuclear density gauges are most widely used in civil construction, agriculture, and the mining industries. Nuclear density gauges determine bulk density and moisture content of spoil using a small amount of Cesium-137 and Americium-241 (Regimand and Gilbert, 1999). It can work in two modes: direct transmission mode and backscatter mode.

(a) Direct Transmission Mode

The field dry density is determined by the nuclear gauge method using the direct transmission procedure. In this procedure, the total or wet density is determined by attenuation of gamma radiation. A hole is formed in the material to be tested and the source is placed into the material to a predetermined depth, while the detector remains at the surface (Figure 3.38). The total number of gamma particles detected is representative of the density of material in the path between the source and the detector. Material density is inversely proportional to the number of gamma particles detected. In the case of a dual probe strata gauge, the detector is in the second probe and allows measuring the density of the material between the two probes, at a constant depth below the surface.

(b) Backscatter Mode

In backscatter mode, the source and the detector are placed in the same plane on the material to be tested (Figure 3.39). Gamma particles from the source penetrate the material and a fraction of them are scattered back to the detector. The number of gamma particles scattered back to the detector is inversely proportional to the material density.

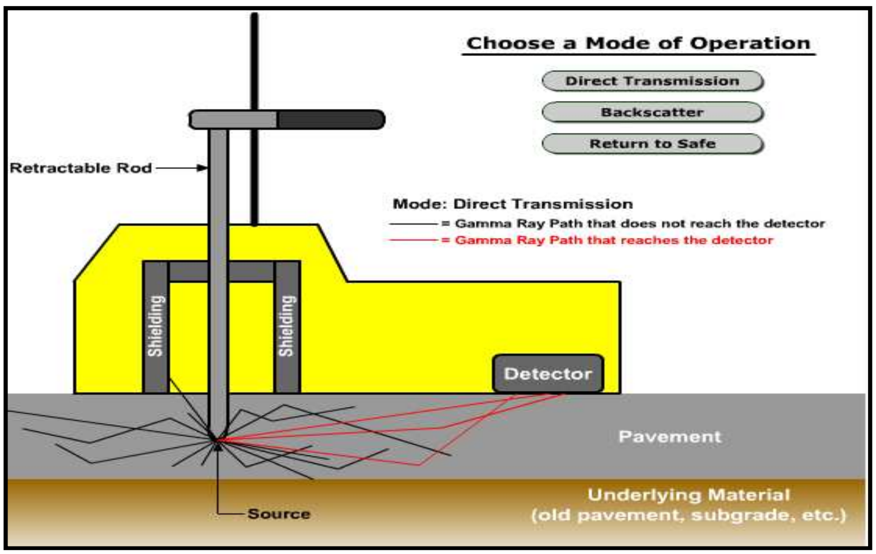


Figure 3.38: Direct transmission mode of measurement (Source: training.ce.washington.edu)

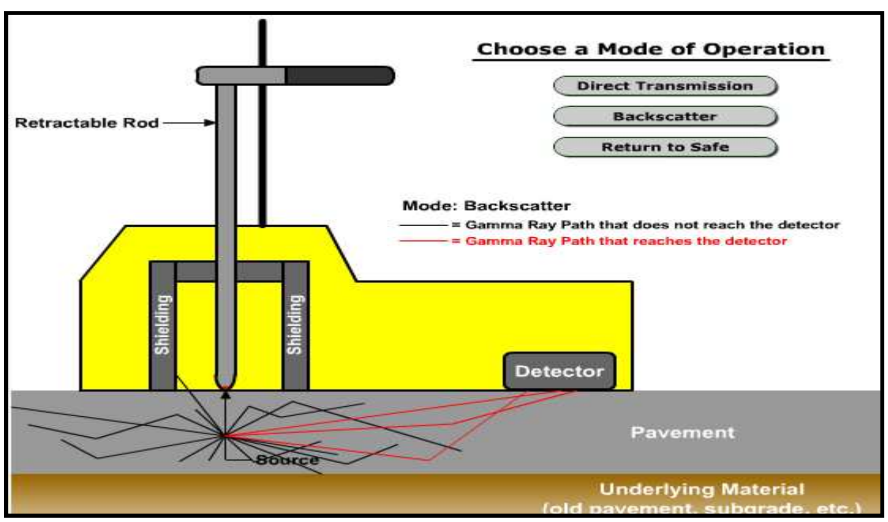


Figure 3.39: Backscatter mode of measurement (Source: training.ce.washington.edu)

It can also measure the moisture content of the material simultaneously to density measurement (CPN Corporation, 1989). Fast neutron sources are used for moisture determination as Americium-241 and a thermal neutron detector such as Helium-3. Moisture content is determined by the interaction of fast neutron and the hydrogen nucleus in water. Standard counts must be taken before testing to compensate source decay over time. The gauge should be calibrated periodically.

(2) Cone Penetrometer

The cone penetrometer has been used to identify soil type, stratigraphy, and variability for more than 60 years. The cone penetrometer has evolved from an original mechanical cone to an electric cone and a piezocone that are currently used for in-situ testing in civil engineering applications. The cone penetrometer is useful in accessing the level of compaction and in-situ strength of growing media (Dunker et al., 1994). The location of compacted layers in soil can be detected using a penetrometer without excavating the soil (Hooks and Jansen, 1986). Two types of penetrometers, static cone penetrometer (SCP) and dynamic cone penetrometer (DCP), are most commonly used in the United States. The cone penetrometer can measure soil compaction in areas where soil is likely to inhibit root system development (Conrad, 2002). Both static and dynamic penetrometers have been proven to yield useful information in regards to soil penetration and resistance measurement (Hunt, 2007). Dynamic cone penetrometers tend to yield much more consistent results and have a greater range of repeatability because these are not subjected to operator's variability (Herrick and Jones, 2002).

A static cone penetrometer was developed for use on reclaimed mined lands at the University of Illinois by Hooks and Jansen (1986). This equipment can be used to get soil strength and penetration resistance in mine soils where the amount and depth of compaction varies as a function of the reclamation method used (Hooks and Jansen, 1986). Static cone penetrometers apply a constant hydraulic, mechanical, or electric power (via truck, tractor, or other motorized source in Figure 3.40) and record data deep into the soil profile using digital data acquisition (Jones et al., 2004). It measures the force required to push a metal cone through the soil at a constant velocity. A load cell or strain gauges attached with an analog dial or pressure transducer are used to measure force applied by the cone. The American Society of Agricultural Engineers (ASAE) has recommended a cone penetrometer with cone angle 30° as a standard measuring device for charactering penetration resistance (compaction) of soils.

Herrick and Jones (2002) introduced a modified dynamic cone penetrometer (DCP) to determine penetration resistance based on the number of hammer blows required to obtain a depth of refusal. In order to move the penetrometer through the soil, a known amount of kinetic energy is applied to the cone by the hammer (Herrick and Jones, 2002). The weight of the hammer, slide distance, and cone angle influence the amount of energy delivered and can be adjusted to local soil conditions for soft or hard soils (Jones et al., 2004).

Figure 3.40: Static cone penetrometer used to collect data at the Starfire Mine (Source: Conrad, 2002)

The Wildcat Dynamic Cone Penetrometer, manufactured by Trigg's Technology, is used to measure in-situ strength (penetration resistance and maximum penetration depth) of the growing media. A Wildcat Dynamic Cone Penetrometer is shown in Figure 3.41. It is lightweight and one person can handle it to test soil strength properties. This penetrometer can measure penetration resistance normally up to 5 m (16.4 ft.). Standard penetration test (SPT) method is used by this equipment to measure soil resistance. It applies a known amount of kinetic energy to the cone, which causes the penetrometer to move a distance through the soil (Herrick and Jones, 2002). Either number of blows required to penetrate a specified depth, or the depth of penetration per blow are recorded to calculate penetration resistance. The number of blows required is an indication of the density of the ground (Hunt, 2007). The weight of the hammer, slide distance, and cone angle influence the energy delivered and these can be adjusted to local conditions.

Figure 3.41: Wildcat Dynamic Cone Penetrometer

A hammer weighing 16 kg (35 lbs.) is attached to a rod (Figure 3.44). It can be raised up to a height of 38.1 cm (15 in.). At the top of the hammer, a plate is attached to indicate the maximum height of raise. To minimize the energy loss, hammer and plate should not be rammed together. Rods of 1m (3 ft.) length and 2.8 cm (1.1 in.) diameter are attached to a cone with an area of 10 cm^2 (1.55 $in.^2$). The rods are designed with hollow centers to allow flow of fluid just above the cone tip. Lines are etched at each 10 cm (4 in.) increment on the rods. A 13.25 l (3.5 gal.) fluid injection system is attached (Figure 3.44). It pumps a mixture of cellulose and water through the rods to minimize the friction.

The undiminished kinetic energy from the hammer is transmitted to the cone. The Dutch formula is used to determine cone resistance values, which is also defined as the ultimate bearing resistance of the cone (Triggs and Simpson, 2005). The Dutch formula is given in Eq.3.4,

$$\mathrm{Rd} = \frac{M^2 * H * N}{Ap * (M + M' + Pa) * 10} \tag{3.4}$$

where, Rd is the dynamic cone resistance in kg/cm^2 or lb/in^2. M is the mass of the hammer. M is the mass of the driving portion of the hammer (2.49 kg or 5.5 lbs.). Pa is the mass of the rod, which is 3.2 kg or 7.19 lbs. H is the hammer drop height. Ap is the projected area of the cone and N is the number of blows per 10 cm (4 in.) of penetration.

3.2.5.4 Field Data Collection for Spoil Characterization

Previous work by Conrad (2002) at the Starfire Mine and by other researchers has demonstrated that there is a good correlation between specific parameters that reflect the level of compaction and tree growth characteristics. In this study, considerations have been given to evaluate the effect of spoil compaction on survival and growth rate of trees in the case of steep slopes. Shortly after final preparation of the site, dry bulk density was recorded in June, 2009. At the same time, penetration resistance and maximum penetration depth or depth of refusal were also measured. These parameters were again evaluated approximately after one year in May, 2010.

(1) Bulk Density Measurement

The dry bulk density, wet density, and moisture content of the brown and the gray spoil areas were recorded using a Troxler 3440 single probe nuclear density gauge. The field set-up of the nuclear density gauge is shown in Figure 3.42. A total of 70 readings were recorded (near each monument). The locations of the measurement points are shown in Figure 3.43. Readings were recorded at depths of 5 cm (2 in.), 15 cm (6 in.), and 30 cm (12 in.).

Surface preparation for spoil testing is important for gauge performance and test results. A hole of 30.5 cm (12 in.) depth is made using the rod provided with the gauge and the surface is smoothed using a scraper plate as shown in Figure 3.42. The purpose of smoothing the surface is to fill small voids, cracks or holes with sand or fine particles to avoid scattering of radiation. Due to operational difficulties and accuracy concerns, the bulk density at 15 cm (6 in.) depth is considered for all further analyses in this investigation. The bulk density readings for the brown and the gray spoil area recorded in June, 2009 and May, 2010 measurements are listed in appendix D.

Figure 3.42: Field set up of nuclear density gauge

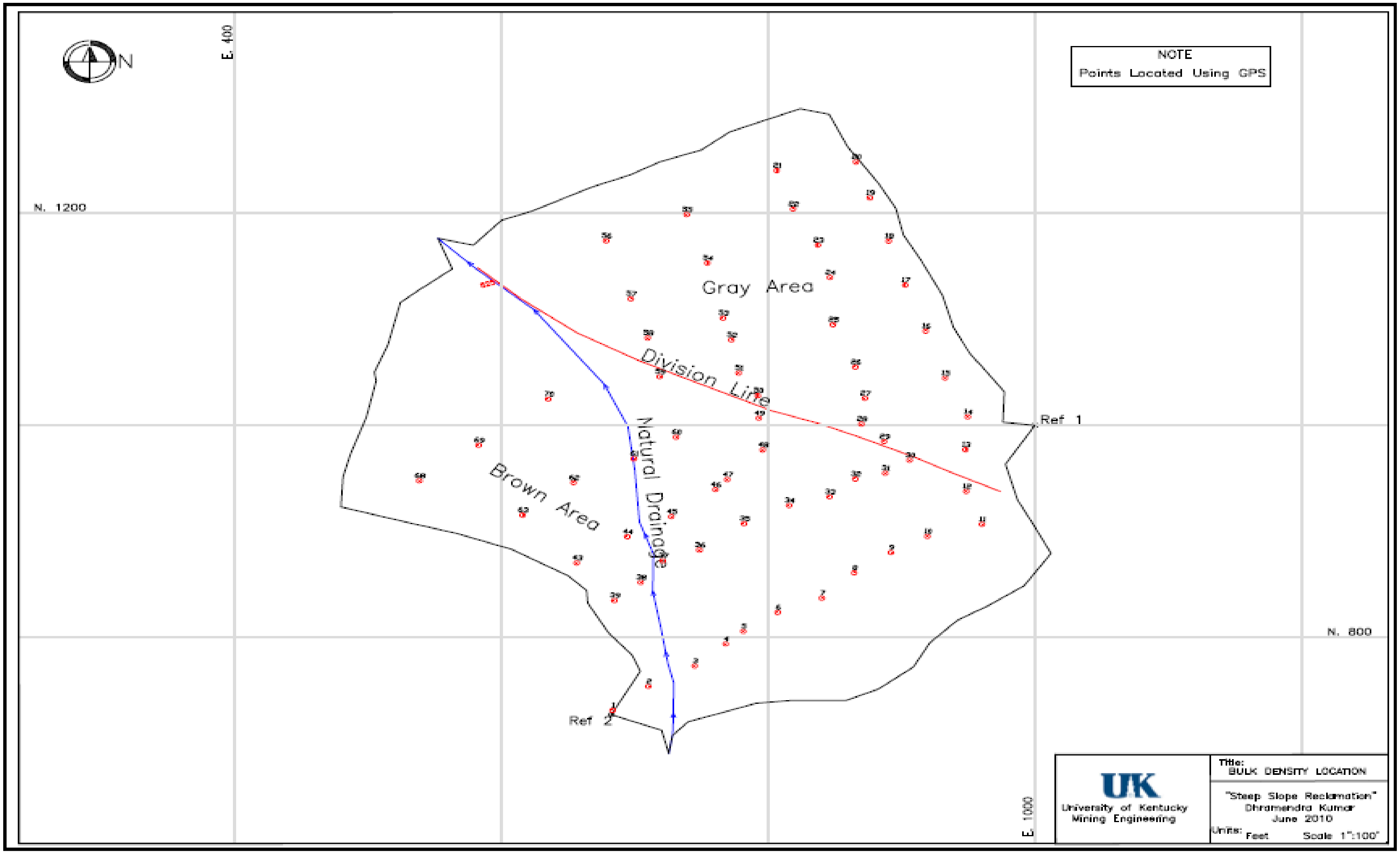


Figure 3.43: Bulk density measurement points

The dry bulk density results for both the brown and the gray spoil areas at 15 cm (6 in.) for June, 2009 and May, 2010 measurements are listed in Table 3.7.

Table 3.7: Dry bulk density

No.	Area	June, 2009		May, 2010	
		(pcf)	(g/cm^3)	(pcf)	(g/cm^3)
1	Brown spoil	90.38	1.45	98.48	1.58
2	Gray spoil	99.98	1.6	106.69	1.71

(2) Spoil Penetration Resistance

To measure spoil resistance for growth and development of roots in the growing medium, the following two parameters were evaluated for both the brown and the gray spoil: average penetration resistance and maximum penetration depth. If the number of blows per increment with the penetrometer exceeded 35, this was taken as an indication of refusal or maximum penetration depth. A total of 35 readings were recorded near alternating monuments located in both the gray and the brown spoil areas. A field set up of the dynamic cone penetrometer measurements is shown in Figure 3.44. The measurement locations are shown in Figure 3.45.

Figure 3.44: Field set up of the Wildcat Dynamic Cone Penetrometer

(a) Average of Penetration Resistance

The penetration resistance results for the brown and the gray spoil areas are listed in Table 3.8.

Table 3.8: Average penetration resistance

No.	**Area**	**June, 2009**		**May, 2010**	
		(kg/cm^2)	**(psi)**	**(kg/cm^2)**	**(psi)**
1	Brown spoil	63.69	905.86	74.68	1062.17
2	Gray spoil	72.13	1025.90	68.44	973.42

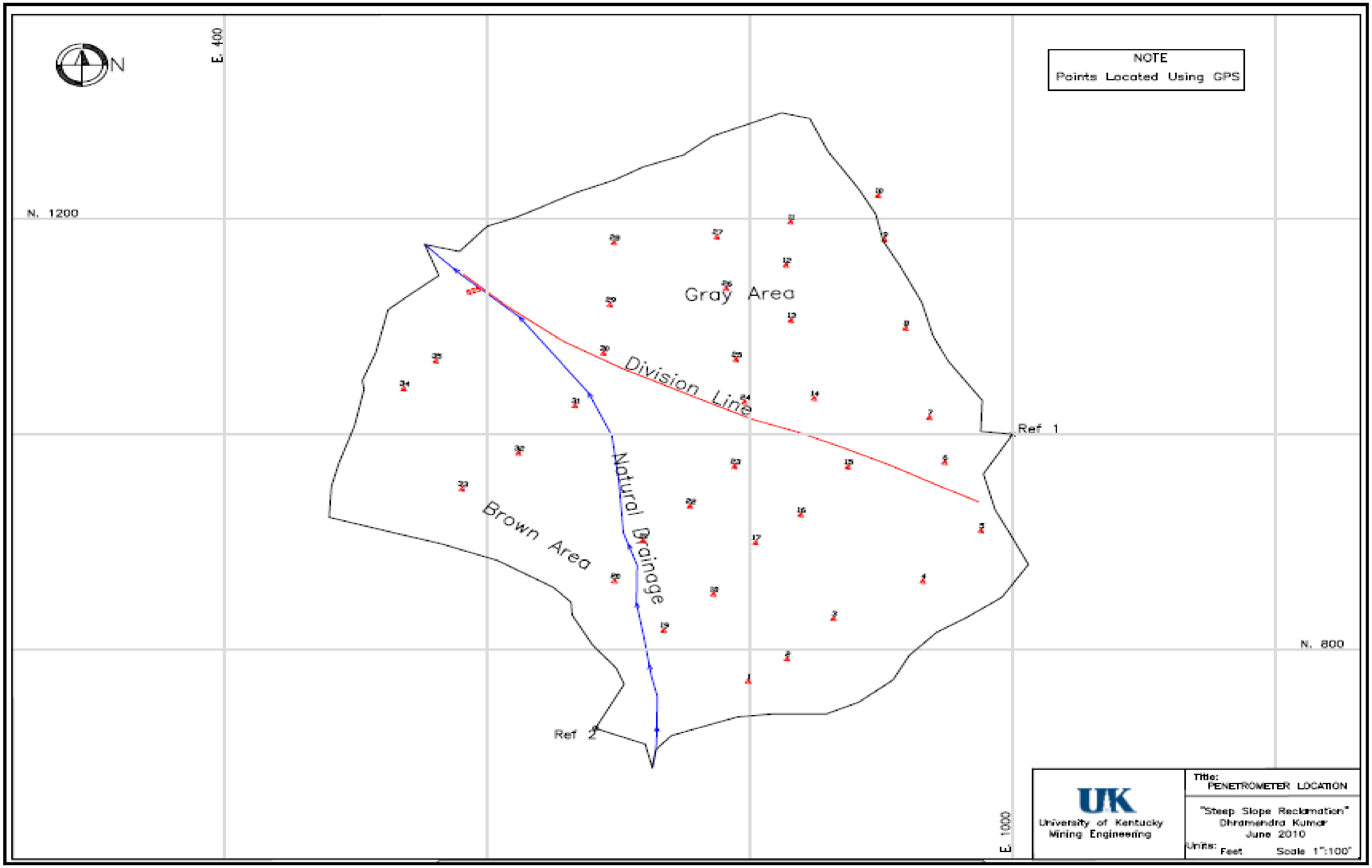


Figure 3.45: Penetrometer measurement points

(b) Maximum Penetration Depth

The maximum penetration depth (depth of refusal) results for the brown and the gray spoil areas are listed in Table 3.9.

Table 3.9: Maximum penetration depth

No.	Area	June, 2009		May, 2010	
		(in.)	(cm)	(in.)	(cm)
1	Brown spoil	22.24	55.61	23.80	59.5
2	Gray spoil	15.50	38.76	23.10	57.76

3.2.6 Tree Planting

Tree planting was done following the FRA guidelines for proper planting techniques. Planting was done by a professional contractor, Williams Forestry Services. It was done using hoedads as shown in Figure 3.46. A total of 4327 tree seedlings of ten different species were planted in a 1.8 m by 1.8 m (6 ft. by 6 ft.) pattern in the spring of 2009. Table 3.10 provides the inventory of seedlings planted. Figure 3.46 shows the planting activities in the brown spoil area. Based on the chemical analysis of spoil samples by University of Kentucky Regulatory Service, recommended grass seeding and fertilizers are listed in Table 3.11.

Table 3.10: Tree inventory

No.	Common Name	Scientific Name	No. of Trees
1	White Oak	Quercus Alba	713
2	Black Oak	Quercus Velutina	713
3	Black Cherry	Prunus Serotina	713
4	Sugar Maple	Acer Saccharum	713
5	Yellow Poplar	Liriodendron Tulipifera	400
6	Northern Red Oak	Quercus Rubra	297
7	Gray Dogwood	Cornus Racemosa Lam	236
8	Eastern Redbud	Cercis Canadensis	236
9	White Pine	Pinus Strobes	281
10	American Chestnut	Castanea Dentata	25
Total number of trees			4327

Table 3.11: Recommended grass seeding

Grass Seeding		
No.	**Type of Grass Seeding**	**Quantity (kg/acre)**
1	Perennial ryegrass	4.54
2	Orchard grass (steep slope only)	2.27
3	Timothy	0.00
4	Foxtail	4.54
5	Birds foot (steep slope only)	2.27
6	Ladino or white clover	1.36
Fertilizer		
	Type of fertilizer	**Quantity (kg/acre)**
1	Nitrogen	22.68-34.02
2	Phosphorous (as P)	36.29-45.36
3	Phosphorous (as P_2O_5)	81.65-104.33

Figure 3.46: Professional crew planting the tree seedlings

3.2.7 Economic Analysis

The objectives of the economic analysis in this study were to develop an estimate of the cost involved in steep-slope reclamation and determine the economic impacts of using FRA on steep slopes as compared to flat or rolling surfaces. The main goal was to determine if the highwall elimination method makes any significant difference in the overall cost involved in steep-slope reclamation.

The construction of the experimental site was monitored closely to evaluate the operational efficiency of the highwall elimination process and reclamation practices including the subsequent application of FRA. The analysis process includes the productivity and cost estimation for each major piece of equipment (i.e. loader, truck, and dozer). A detailed cost analysis for the highwall elimination process, final grading, and planting was done. The cost analysis includes the cost of machinery on an hourly basis, labor cost, materials, and supplies needed to bring the site to the point of eligibility of Phase I bond release. The productivity of equipment depends on the type and capacity of the equipment, operational conditions, and operator's skill. A time and motion study of each piece of equipment was conducted in the analysis. The average cost of final grading was calculated based on the site area. The planting cost was taken from cost estimates provided by Williams Forestry Services. The overall time involved in the reclamation process is also important, because it has an economic impact on the bond liability.

Half of the highwall was eliminated by dozer push method and the other half by the conventional contour haulback method. A combination of a Caterpillar 992 D loader and 777 D trucks were used for haulback and Caterpillar D10 and D11R dozers were used for material pushing and final grading. For highwall elimination costs, the analysis was divided into four steps:

Step 1. Estimation of backfilled spoil volume required to bring the highwall up to AOC,

Step 2. Estimation of the production rate per hour for individual equipment (i.e. loader, truck, and dozer),

Step 3. Estimation of hourly ownership and operating cost involved for individual equipment,

Step 4. Estimation of total cost associated with haulback materials and dozer push materials.

3.2.7.1 Estimation of Backfilled Spoil Volume

Approximately half of the slope was backfilled by dozer push using a CAT D11 R dozer and the other half by the haulback method using a combination of a CAT 992D loader and 777D trucks. The backfill volume of spoil was calculated using SurvCADD software and the result was 581,922 m^3 (761,124 yd^3). Using the sectional method, the volume of each individual section was calculated using Eq. 3.4:

$$V = ((A_1+A_2)/2)*D \quad (3.4)$$

where, V is the volume of a particular section. A_1 and A_2 are the areas of a section and subsequent section. D is the distance between the sections. Using the summation of sectional volumes, the total backfilled spoil volume was 581,580.23 m^3 (760,678.26 yd^3). This spoil volume was approximately the same as the volume obtained from SurvCADD software. Detailed calculations of spoil volume are listed in appendix E. For economic analysis, the total volume handled (581,922 m^3) was divided in two parts: dozer push and haulback volume, which are shown in Table 3.12.

Table 3.12: Backfilled volume

No.	Method	Volume (yd^3)	Volume (m^3)
1	Dozer push	380,562	290,961
2	Haulback	380,562	290,961

3.2.7.2 Estimation of Production Rate

(1) Loader Production Rate

A Caterpillar 992D loader was used for excavation of loose spoil. General parameters of the 992D loader are listed in Table 3.13. Figure 3.47 shows the 992D model front end loader.

Table 3.13: Details of 992D loader

No.	Parameter	Detail
1	Loader model	992D
2	Make	Caterpillar
3	Bucket capacity	11.5 m^3 (15 yd^3)
5	Rated payload	21.7 tonne (23.9 T.)
6	Bucket payload	33,100 kg (73,000 lb.)

Figure 3.47: Caterpillar 992 D loader (Source: Emeco Equipment)

Loader productivity is defined as the effective volume of loose spoil handled per hour. Generally, it is expressed in terms of bank cubic meters per hour (cubic yards per hr). The important factor in determining the production rate of a wheel loader is the operating load (bucket load) rather than bucket capacity as is the case for mining shovels. If a loader operates at maximum load when handling a light material, it will be under-sized and unstable if transferred to handling dense material. Bucket capacity is a function of operating load, loose density of the material and fillibility of the bucket. The loader production rate was calculated using the formula below in Eq. 3.5 **(**Sweigard, 1992),

$$Q = \frac{Bc \times \quad \times O \times Bf \times \quad \times C}{S} \qquad (3.5)$$

where Q is the loader productivity per hour in m^3/hr (yd^3/hr). Bc is the bucket capacity of loader in m^3 (yd^3). C is the loading cycles completed by the loader per hour. A and O are the availability of loader and job operating factor respectively. Bf, P, and S are the bucket fill factor, loader propel factor and swing factor, respectively. Factors affecting the productivity of the loader are described below.

(a) Cycle Time (C)

The skill of the operator, degree of fragmentation of spoil, and condition of the loading area are the main factors affecting cycle time of the loader. The operating cycle is a summation of loading, hauling, dumping, and returns times. In most cases, the loading and dumping times are considered as fixed times, whereas hauling and return times are variable times, because these times depend on haul distances, condition of the haul roads, and gradient of the roads. For one complete loading cycle, spotting time of the truck should be also considered. Based on field observations, the time cycle is divided into spotting time and loading time (combination of loading, hauling, dumping, and returns times). Each loading of the truck requires four bucket loads, hence for the average cycle time per bucket, the total time taken to fill one truck is divided by four. The observed cycle times for the 992 D are listed in Table 3.14.

Table 3.14: Cycle time for 992 D loader

Obs. No.	**Spotting Time (sec)**	**Loading Time (sec)**	**Total Time (tc) (sec)**
1	25	170	190
2	20	165	190
3	25	170	192
4	22	160	180
5	20	165	187
6	22	170	194
7	24	160	185
8	25	165	187
9	22	160	180
10	20	170	170
Average time per bucket(sec)			46

(b) Effective Cycle Time

For effective cycle time, the machine availability and operators efficiency were taken into account. For the observed job conditions, the operator's efficiency was taken as 0.9. The effective cycle time for the loader is listed in Table 3.15.

Table 3.15: Effective cycle time for loader

No.	Detail	Value
1	Cycle time (sec)	46
2	No. of cycle per hr	78
3	Operator skill/efficiency	0.9
4	Machine availability	0.95
5	Gen operational efficiency	0.83
6	Effective cycle per hr	55

(c) Swell

Swell is defined as percentage of the original volume that a material increases when it is removed from the natural state. When excavated, the material breaks up into different size particles that do not fit together, causing air pockets or voids to reduce the weight per volume. Swell is generally expressed in percentage. A swell factor of 80% was taken in this analysis (Hartman et al., 1992).

(d) Fill Factor (Bf)

The percentage of available volume in a body, bucket, or bowl that is actually used is defined as the fill factor. A fill factor of 87% for a loader bucket means that 13% of the rated volume is not being used to carry material.

(e) Swing Factor (S)

The angle of swing required for a loader in order to dump material in a truck, affects the productivity of the loader. Based on field observations, a swing factor 0.8 was used (Hartman et al., 1992).

Assumed factors for productivity calculation for loader are listed in Table 3.16.

Table 3.16: Assumed factors for loader production

No.	Detail	Value
1	Bucket fill factor (Bf)	0.8
2	Swing factor (S)	0.8
3	Job operating factor (O)	0.9
4	Propel time factor (P)	0.85
5	Availability (A)	0.75

Production per hour is calculated as:

$$Q = \frac{.5 * \ .75 * \ .9 * \ .8 * \ .85 * 55}{.8}$$

$$= 289.52 \text{ m}^3/\text{hr}.$$

(2) Truck Production Rate

Caterpillar 777D trucks were used as haulage units. There were two trucks in the fleet for the highwall elimination process. Table 3.17 shows general details of the truck. A 777D model truck is shown in Figure 3.48.

Table 3.17: Details of Caterpillar 777D truck

No.	Parameter	Value
1	Truck model	777D
2	Make	Caterpillar
3	Targeted payload	90725 Kg (200015 lb)
4	Capacity struck	42.1 m^3 (55 yd^3)
5	Capacity heaped	60.1 m^3 (78.6 yd^3)

Figure 3.48: Caterpillar 777D truck (Source: Caterpillar.com)

(a) Cycle Time (t)

The cycle time of the haulage units is determined from field measurements or from reasonable estimates in similar situations. The cycle times are generally divided into two common elements (fixed time and variable time) and each element is estimated separately. The field observations from the time study for the trucks are listed in Table 3.18. In this study, wait and spotting times at the dump were combined with dumping time (td). The cycle times for a truck are given in Eq. 3.6 (Hartman & Mutmansky, 2002):

$$\text{tc} = \text{tte} + \text{twe} + \text{tse} + \text{tl} + \text{ttl} + \text{twd} + \text{tsd} + \text{td} \tag{3.6}$$

where tc is the total time taken by a truck in one trip. The parameters twe, tse, and tl are waiting, spotting, and loading times at the loader site. The ttl and tte are the load and empty travel times, respectively. The twd, tsd, and td are the waiting, spotting, and dumping times at the dump site.

Table 3.18: Cycle times for 777D trucks

No.	Activity	Obs. 1 (sec)	Obs. 2 (sec)	Obs. 3 (sec)	Obs. 4 (sec)	Obs. 5 (sec)
1	Spotting (tse)	25	20	25	22	20
2	Loading (tl)	170	165	170	160	165
3	Load travel (ttl)	190	185	190	200	190
4	Dumping (td)	45	50	50	45	40
5	Empty travel (tte)	150	150	145	140	140
6	Wait at loader (twe)	120	110	125	120	115
7	Total (tc)	700	680	705	687	670
Average cycle time (sec)					688	

(b) Effective Cycles per Hour

For effective or actual trips per hour, the average cycle times were multiplied by the correction factors considering operator's skill and machine availability. The effective cycles per hour for 777D trucks are listed in Table 3.19.

Table 3.19: Effective cycles per hour for truck

No.	Parameter	Value
1	Cycle time(sec)	688
2	No. of trips per hr	5
3	Operator skill/efficiency (O)	0.9
4	Machine availability (A)	0.95
5	Gen operational efficiency (O*A)	0.83
6	Effective cycles per hr	4

(a) Calculation of Production Rate of Trucks

The truck production rate is given in Eq. 3.7:

$$\text{Production rate(Pt)} = \text{Payload} * \text{cycle per hr} * \text{Fill factor} \quad (3.7)$$

Pt= 42.1*4*0.86

= 144.65 m^3 per hr.

The total truck fleet production was obtained by multiplying the production rate by the number of trucks in the fleet, which was two in this case, in Eq. 3.8:

Truck fleet production (Pf) = Pt*K (number of trucks) (3.8)

=144.65*2

= 289.31 m^3 per hr.

(3) Dozer Production Rate

A Caterpillar D11R dozer was used for dozing and final grading work. General parameters of the dozer are listed in Table 3.20. The D11R dozer is shown in Figure 3.49.

Table 3.20: Details of D11R dozer

No.	Parameter	Detail
1	Make	Caterpillar
2	Model	D11R
3	Blade capacity	13 m^3 (17 yd^3)
4	Gross power	698 kW (935 hp)
5	Flywheel Power	634 KW (850 hp)
6	Operating weight	104,400 kg (230100 lb)
7	Speed (Forward)	11.7 km/hr (7.3 mph)
8	Speed (Reverse)	14 km/hr (8.7 mph)

Figure 3.49: Caterpillar D11R dozer (Source: Emeco Equipment)

(a) Cycle Time

The cycle time for dozer operation is the summation of the time taken for pushing material and reverse traveling for the next push. Field observations of the D11R dozer for the time study are listed in Table 3.21.

Table 3.21: Cycle time for dozer

No.	Push Time (sec)	Reverse Time (sec)	Cycle Time (sec)
1	150	40	190
2	180	60	240
3	165	60	225
4	180	70	250
5	170	40	210
6	145	40	185
7	150	40	190
8	180	50	230
9	170	45	215
10	160	55	215
Average time per push (sec)			215

(b) Effective Cycle Time

For effective or actual time per push, the average time per push was multiplied by the correction factors considering the operator's skill and machine availability. The effective cycle times per hour for the D11R dozer are listed in Table 3.22.

Table 3.22: Effective cycle times for dozer

No.	Parameter	Value
1	Average time per push (sec)	215
2	Dozing technique (slot dozing)	1.20
3	Operator skill/efficiency (O)	0.75
4	Job efficiency	0.84
5	Grade correction	1.15
6	Effective time per push (sec)	187

(a) Calculation of Production Rate of Dozer

The hourly production rate is the amount of spoil volume a dozer moves under ideal conditions in one hour.

The estimated production rate or the material actually pushed per hour by a dozer was obtained using Eq. 3.8:

$$\text{Bank volume per hr} = \frac{\text{Bl de c city} * 60 * \text{Job efficency}}{\text{CycleTime (min)}} \tag{3.8}$$

$$= (13*60*60*0.84) / 187$$

$$= 210.25 \text{ m}^3 \text{ per hr.}$$

(4) Summary of Production Results

The result of hourly production rate calculations for the 992D loader, the 777D trucks, and the D11R dozer are shown in Figure 3.50.

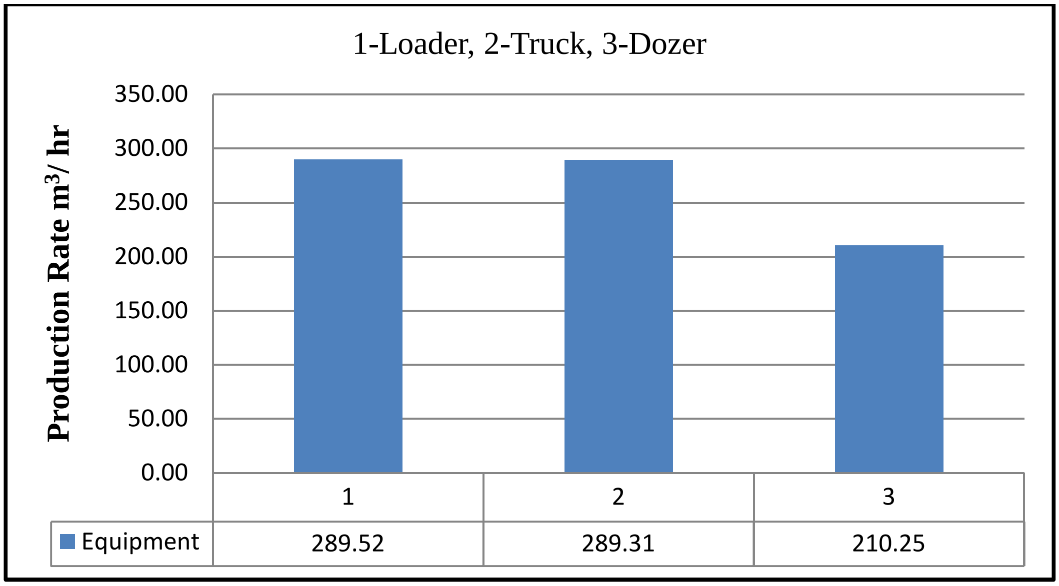


Figure 3.50: Observed hourly production rates of the equipment

3.2.7.3 Estimation of Operating Cost

The first step in the optimization process begins with cost analysis of the equipment. Cost analysis can be done using two different approaches, static and dynamic cost analysis. The static cost analysis method does not consider time value of money. However, in the dynamic cost analysis method, time value of money is considered. In this study, the dynamic method of analysis is used. The equipment costs can be broken down into two classes, ownership cost and operating cost. Hourly owning and operating costs for a given machine can vary widely because they are influenced by many factors as such type of machine, the ownership period, local price of fuel and labor, the repair and maintenance costs, shipping costs from the factory, interest rate, etc.

(1) Ownership Cost

To recover some part of the initial investment in equipment and be able to replace it, the owner must recover, over the ownership period, an amount equal to the loss in resale value and the other costs of owning the equipment including interest, insurance, and taxes. The machine owner, for accounting purposes, estimates resale loss in advance, and recovers their original equipment investment by establishing depreciation schedules according to the various uses of the equipment. The ownership period in years, the hours per year, and the total number of hours on a machine, are significant factors in determining owning and operating costs. Factors to be considered for owning costs are described below (Caterpillar, 2007).

(a) Delivery Price to Customer (P)

Delivered price should include all costs incurred to put a machine on the job including transportation and any applicable sale taxes. For rubber tire equipment, tires are considered a wear item and covered as an operating expense (Caterpillar, 2007).

(b) Residual Value at Replacement (S)

Any piece of earthmoving machinery will have some residual value at trade-in. While many owners prefer to depreciate their equipment to zero, others recognize the residual resale or trade-in value. For many owners, potential resale or trade-in value is a key factor in their purchasing decisions, since this is a means of reducing the investment they must recover through depreciation charges (Caterpillar, 2007).

(c) Value to be Recovered through Work

The delivered price (P) less the estimated residual value (S) results in the value to be recovered through work. If it is divided by the total usage hours, it gives the hourly cost to protect the asset value (Caterpillar, 2007).

(d) Interest (I)

Interest is the cost of using capital. If the machine will be used for N years, one can calculate the average annual investment during the use period and apply the interest rate and expected annual usage using Eq. 3.9 (Caterpillar, 2007):

$$\text{Interest} = \frac{\left[\frac{P(N+1)+S(N-1)}{N}\right]}{\text{our/yr}} * \text{Simple int. \% rate} \quad (3.9)$$

where P is the principle amount invested on the equipment and N is the life of the equipment.

(e) Insurance and Taxes

Insurance and property taxes can be calculated in one of two ways. If the specific annual cost is known, it should be divided by the estimated usage.   However, when the specific interest and tax costs for each machine are not known, the following formulas given in Eq. 3.10 and Eq.3.11 can be applied (Caterpillar,2007):

$$\text{Insurance} = \frac{\left[\frac{P(N+1)+S(N-1)}{2N}\right]}{\text{Hour/yr}} * \text{Insurance rate \%} \quad (3.10)$$

$$\text{Property tax} = \frac{\left[\frac{P(N+1)+S(N-1)}{2N}\right]}{\text{Hour/yr}} * \text{Tax rate \%} \quad (3.11)$$

(2) Operating Cost

The operating cost is the cost associated with the field operation of the equipment. It includes fuel cost, operator wages, maintenance cost (both planned and operational maintenance), tire replacement cost, and spare parts cost. The main components of operating cost are described below.

(a) Fuel Cost

Actual fuel consumption is measured in the field during operation of the equipment. Equipment application determines engine load factor, which in turn controls engine fuel consumption. An engine continuously producing full-rated horsepower is operating at a load factor of 1.0. The period of the spent at idle, dozer travel in reverse, haul units traveling empty, close maneuvering at part throttle, and operating downhill are examples of conditions which reduce load factor. Based on field experience, the fuel consumption for various pieces of equipment at Peel Poplar Mine are listed in Table 3.23. The hourly fuel cost is determined using Eq.3.12 (Caterpillar, 2007):

$$\text{Hourly fuel cost} = \text{hourly consumption} * \text{local unit price of fuel} \tag{3.12}$$

Table 3.23: Diesel fuel consumption of equipment at Peel Poplar Mine

No.	Equipment	Fuel Consumption in l/hr (gal/hr)
1	992D Loader	53.0 (14)
2	777D Truck	83.3 (22)
3	D11R Dozer	87.1 (23)

(b) Planned Maintenance

Planned maintenance costs include parts and labor at the intervals specified in the operation and maintenance manuals provided for each machine. Maintenance costs for each machine may vary slightly depending upon factors required or specified by the customer (Caterpillar, 2007).

(c) Tires

Tire cost is an important part of the hourly cost of any wheel equipment. The best estimate for tire costs are obtained when tire life estimates are based upon actual operator experience, and are used with prices the machine owner actually pays for the replacement tires. Tire hourly cost can be calculated by using the formula in Eq. 3.13 (Caterpillar, 2007):

$$\text{Hourly tire cost} = (\text{Tires replacement cost})/(\text{Estimated tire life}) \qquad (3.13)$$

(d) Repair Costs

Repair cost per hour should be developed by the equipment dealer, with customer input for the specific machine application and requirement. Machine applications, operating conditions, ownership periods, component life, and maintenance attention determine repair costs. Repair and component lives are normally the largest single item in operating costs and include all parts and direct labor (Caterpillar, 2007).

(e) Special Wear Items

All costs for high-wear items such as cutting edges, bucket teeth, body liners, etc. should be included here. These costs vary widely depending on applications, material and operating conditions (Caterpillar, 2007).

(f) Operator's Hourly Wage

The operator's wages are based on local wages scales and should include the hourly cost of fringe benefits; these can vary from company to company (Caterpillar, 2007). For ICG, the average wage of the operators was $25 per hour.

(g) Inflation Factor

The cost data were taken from Mine and Mill Equipment Costs (An Estimator's Guide) of Western Mine Engineering, Inc, 2006, and Reclamation Cost Estimator's Guide (North Dakota Public Service Commission, Reclamation Division, 2006). Since all cost data are taken from the year 2006, for present cost, an inflation factor (t) from 2006 to 2010 was considered. The inflation factor for converting 2006 dollar value to 2010 dollar value is 1.075.

3.2.7.4 Estimation of Hourly Ownership and Operating Cost

The hourly ownership and operating cost for all equipment was calculated based on the parameters discussed in the above section. The fixed parameters for equipment life, usage, and financial rates are listed in Table 3.24. Detailed cost calculations are listed in Appendix E. Figure 3.51 shows the resulting hourly costs.

Table 3.24: Fixed parameters for cost calculations

No.	Parameter	Value
1	Estimated ownership period (N yr)	7
2	Estimated usage (hr/yr)	3,000
3	Ownership usage (total hr=B*C)	20,000
4	Interest (r %)	10.25
5	Insurance (I %)	0.75
6	Sales tax (s %)	5
7	Fuel charge ($/gal)	2.60

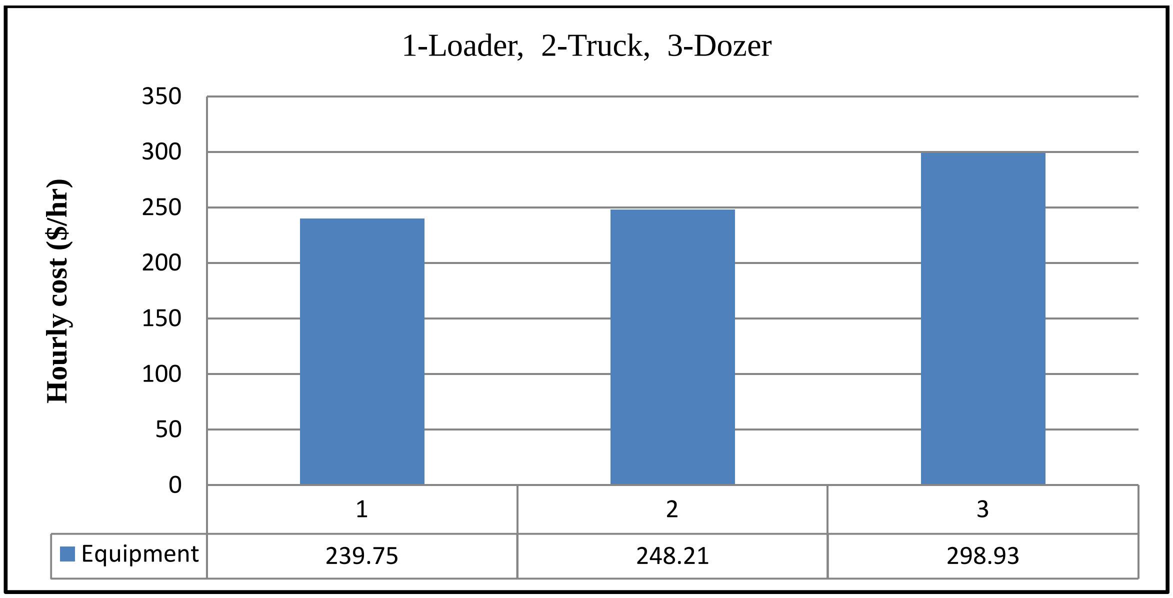


Figure 3.51: Equipment hourly ownership and operating cost

3.2.7.5 Estimation of Highwall Elimination Cost

The highwall elimination cost is divided into two parts: haulback cost and dozer push cost. Haulback cost is the cost of handling spoil with the combination of loader and trucks, whereas dozer push cost is the cost for pushing material by the dozer. The cost calculation procedure is outlined in the following sections.

Step 1. Volume to be handled

Total volume to be handled by each method is taken from Table 3.12.

Step 2. Equipment productivity and number of days required

The calculations to find the number of total working days required to handle material necessary for highwall elimination are listed in Table 3.25. Two shifts (effective 9 hr. per shift) were considered.

Table 3.25: Number of days required to eliminate highwall

No.	Parameter	Loader	Truck	Dozer
1	Volume to be handled(m^3)	290,960.53	290,960.53	290,960.53
2	Productivity (m^3/hr.)	289.52	289.31	210.25
3	No. of hours	1004.97	1005.71	1383.86
4	No. of days	56	56	77

Step 3. Total cost of highwall elimination (half haulback and half dozer push):

Total cost for highwall elimination is the summation of haulback cost and dozer push cost. It is obtained using Eq. 3.14.

$$\text{Total cost (\$)} = \text{Total volume to handled}(\text{m}^3) * \text{Cost per m}^3 \quad (3.14)$$

Cost per m^3 for loader, truck, and dozer are listed in Table 3.26. A comparison of the cost per m^3 is shown in Figure 3.52. The total highwall elimination cost is listed in Table 3.27.

Table 3.26: Equipment operating cost per m^3 of spoil handled

No.	Equipment	Productivity (m^3/hr)	Hourly cost ($/hr)	Cost per m^3 ($)
1	Loader	289.52	239.75	0.83
2	Truck	289.31	248.21	0.86
3	Dozer	210.25	298.93	1.42

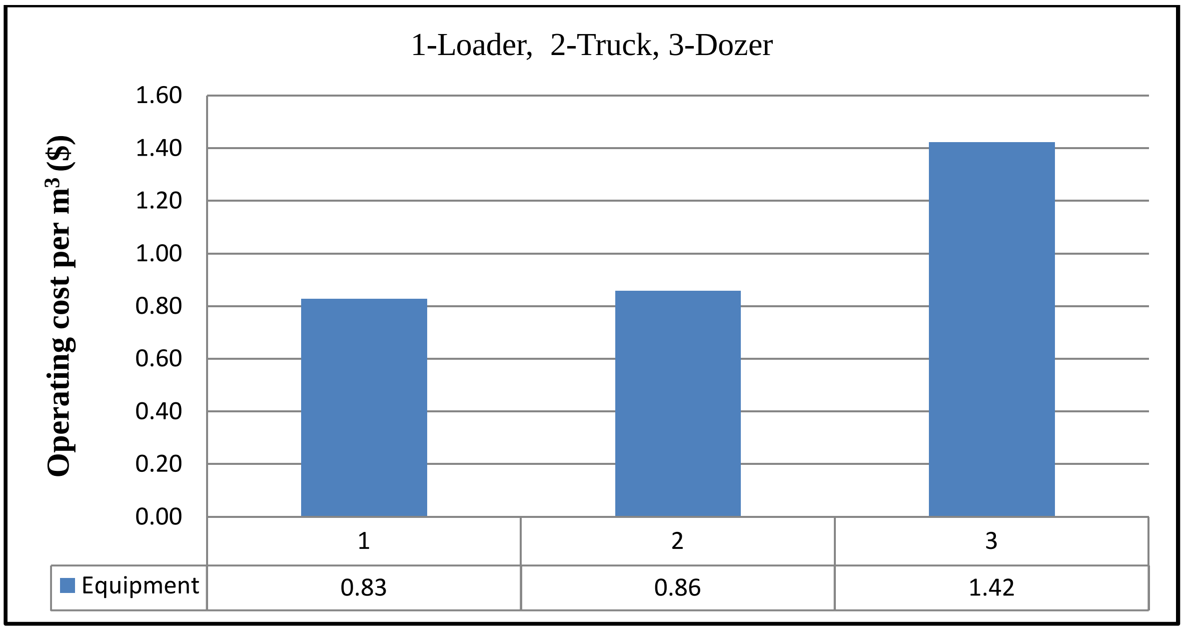


Figure 3.52: Equipment operating cost per m^3 of spoil handled

Table 3.27: Total highwall elimination cost for half haulback and half dozer push method

No.	Method	Cost per m^3 ($)	Volume (m^3)	Highwall elimination cost($)
1	Haulback	1.69	290,960.76	490,570.07
2	Dozer push	1.42	290,960.76	413,678.14
		Total cost($)		904,248.21

Step 4: Total cost of highwall elimination considering complete haulback method is listed in Table 3.28.

Table 3.28: Total highwall elimination cost for complete haulback method

No.	**Method**	**Cost per m^3 ($)**	**Volume (m^3)**	**Highwall elimination cost ($)**
1	Haulback	1.69	581,921.5105	981,140.15
Total cost($)				981,140.15

3.2.7.6 Final Grading Cost

The final grading was done using the D11R dozer following the FRA guidelines. To estimate the final grading cost by the D11R dozer on steep slopes, the dozer cost per hour was multiplied by the total working hours required for final grading. In this investigation, a total of two shifts of 9 working hours were required. A comparison of final grading cost using the conventional grading method and FRA method was performed in this study.

3.2.8 Comparison of Conventional Final Grading with FRA Final Grading

For conventional final grading, the dozer moves material down the slope (top to bottom) in overlapping passes. Approximately, one third of the dozer blade width is covered in one pass. Then it comes back to the top of slope and starts a new grading pass. However, in the case of FRA grading, the dozer moves along the slope without overlapping the passes. In this case a ramp is made near the slope and the dozer uses this ramp back to the top to avoid the over compaction of spoil. In the case of FRA grading, the full width of the dozer blade and some additional area (2 ft. in this study) of the slope is covered in one pass. A comparison of costs associated with both methods is done is this analysis. The horizontal distance and vertical distances along the slope are taken from the final map of the experimental site. The dozer speed data are taken from the Caterpillar Handbook, Volume 37, which are 11.7 km/hr (7.3 mph) for forward movement and 14.0 km/hr (8.7 mph) for reverse movement. Due to operational difficulties in the steep slope grading, 50% of these speeds are assumed in this analysis. The detailed procedure for comparison of costs is described below.

(1) Dozer Details

Dozer blade and speed data are listed in Table 3.29.

Table 3.29: Fixed parameters for D11R dozer

No.	Model	Blade Width		Speed		Adjusted Speed	
		(m)	(ft)	Forward (km/hr)/ (ft./min)	Reverse (km/hr)/ (ft./min)	Forward (km/hr)/ (ft./min)	Reverse (km/hr)/ (ft./min)
1	D11R	6.34	20.8	11.7 (640)	14 (766)	5.85 (320)	7 (383)

(2) Highwall Details

The distances to be covered for final grading are listed in Table 3.30. These distances are taken from profiles near the middle of both slopes.

Table 3.30: Distances to be covered in final grading

No.	Area	Horizontal Distance		Vertical Distance	
		(ft)	(m)	(ft)	(m)
1	Brown Area	338.00	103.02	493.19	150.32
2	Gray Area	416.71	127.01	331.79	101.13

(3) Number of Passes Required

The total number of dozer passes required for the brown and the gray area are listed in Table 3.31.

Table 3.31: Total number of dozer passes required for brown and gray area

No.	Area	Conventional Grading		FRA Grading	
		Effective Width per Pass (m)/(ft.)	**Total Passes**	**Effective Width per Pass (m)/(ft.)**	**Total Passes**
1	Brown Area	2.11 (6.92)	49	6.95 (22.80)	15
2	Gray Area	2.11 (6.92)	61	6.95 (22.80)	19
		Summation	110	Summation	34

(4) Time Required in Grading

For the FRA grading a ramp was made adjacent to the gray area. After each pass, the dozer followed this ramp to reach the top of slope and started a new pass. It took approximately 10 min per pass for the gray area and 15 min per pass for the brown area. The effective working time of the dozer is considered to be 45 min per hour. Total time required in final grading of the brown and the gray areas are listed in Table 3.32.

Table 3.32: Total time required for final grading

No	Area	Conventional Grading			FRA Grading		
		Time per Pass (min)	**Adjusted time per pass (min)**	**Total Time (min)**	**Time per Pass (min)**	**Adjusted time per pass (min)**	**Total Time (min)**
1	Brown Area	2.83	6	294	16.54	20	300
2	Gray Area	1.47	5	305	11.04	15	285
			Summation	599		Summation	585

(5) Total Final Grading Cost

To get the total final grading cost, per hour operating cost for the D11R was taken from the economic analysis section of this study. A total estimate of the final grading cost for the brown and the gray area is listed in Table 3.33. A comparison of final grading cost is shown in Figure 3.53.

Table 3.33: Total final grading cost

No.	Method	Effective Working Time (hr)	Cost per hr ($)	Total Cost ($)
1	Conventional Grading	17	298.93	5035.31
2	FRA Grading	13	298.93	3886.09

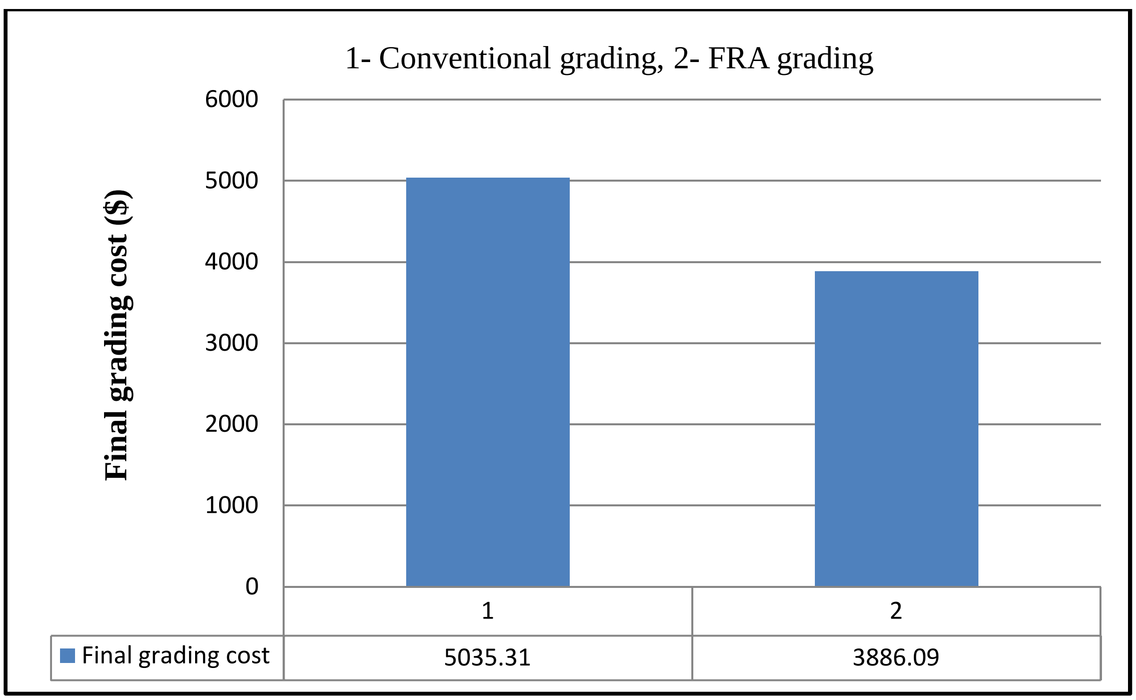


Figure 3.53: Comparison of final grading cost

3.3 Planting Cost

The tree planting was done by Williams Forestry Service. The total cost for 4327 tree seedlings and labor charges was $ 2570 for this 4.7 acre steep-slope research plot.

3.4 Total Reclamation Cost

The total reclamation costs for both the haulback and the combination of haulback and dozer push methods are listed in Table 3.34. A comparison of reclamation cost using complete haulback and a combination of haulback and dozer push method is shown in Figure 3.54.

Table 3.34: Total reclamation cost

No.	**Activity**	**Method of Highwall Elimination**	
		Haulback Cost ($)	**Combination of Haulback & Dozer Push Cost ($)**
1	Highwall Elimination	981,139.38	904,247.50
2	Final Grading	3,886.09	3,886.09
3	Planting	2,570	2,570
4	Total Cost ($)	987,596.24	910,704.30

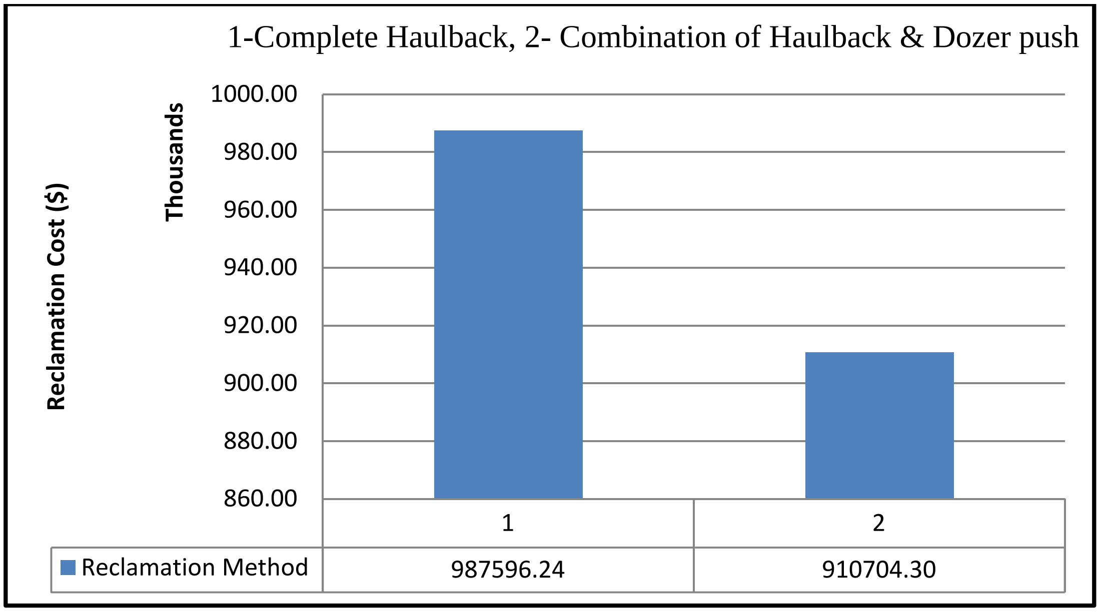


Figure 3.54: Comparison of total reclamation cost

3.5 Summary of Economic Analysis

Total reclamation cost represents the costs involved to bring the steep slope operations to Phase I bond release conditions. Based on the detailed economic analysis for reclaiming the steep slope in this study, it is observed that the application of FRA in steep slopes does not have a significant economic impact on the reclamation cost as compared to FRA applications in flat or rolling surfaces. The cost of the eliminating highwall using only the haulback method was somewhat higher as compared to the cost for the combination of haulback and dozer push method. This difference in costs is explained by above analysis, since the cost per m^3 for the combination of loader and truck was $ 0.27 higher as compared to dozer pushing cost. The final grading cost using the FRA guidelines is somewhat less in this example as compared to the conventional grading cost. The saving in final grading cost is balanced somewhat by relatively higher cost of planting in steep slopes as compared to flat or rolling surfaces. The conclusion of the economic analysis is that, in this case, the application of FRA had almost no impact on the overall reclamation cost.

Chapter 4

RESULTS AND DISCUSSION

4.1 Summary of Field Visits

The summary of the different highwall elimination methods used in both the Northern Appalachian region (e.g., PA, OH, and MD) and the Central Appalachian region (e.g., KY, WV, VA, and TN) is shown in Figure 4.1. It was observed that the most common method in both regions was the contour haulback. A more detailed report for each mine visit is included in Appendix A.

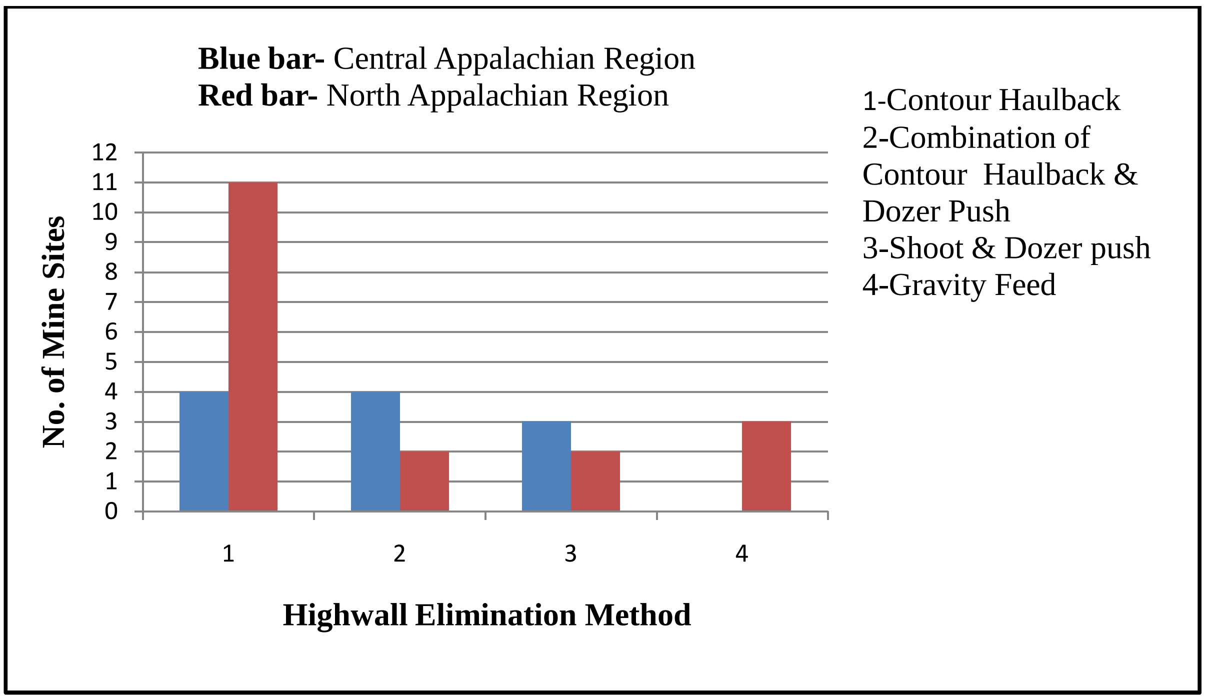


Figure 4.1: Plot of highwall elimination practices throughout the Appalachian region

4.2 Summary of Slope Movement Monitoring Results

Survey results from the baseline survey and the final survey are plotted and analyzed by monument line for movement of monuments down the slope and vertical settlement or heaving. The results of maximum downward horizontal and vertical movement for the brown and the gray spoil area are shown in Figure 4.2 and 4.3, respectively. Maximum downward horizontal and vertical slope movements are shown in Figure 4.5. By the end of the project, even after a period of very heavy rainfall (6.1 cm in a day, May, 2009 and 6.2 cm in a day, August, 2009) that resulted in serious flooding in the region, the slope did not experience any significant mass movement. At one area in the brown spoil, there has some localized slumping with a maximum vertical displacement of 37.5 cm (15 in.) to 45 cm (18 in.) as shown in Figure 4.4. In some parts of the slope, heaving of the monuments was recorded possibly due to consolidation of loose spoil and the freezing and thawing cycle. Maximum horizontal slope movements of 0.227 m (0.74 ft.) in the brown area (Line 1) and 0.294 m (0.96 ft.) in the gray area (Line 1) were recorded. Maximum vertical displacements of monument of 0.244 m (0.84 ft.) in the brown area (Line 2) and 0.155 m (0.51 ft.) in the gray area (Line 2) were recorded. These small slope movements are consistent with the computer model analyses in the slope stability section, which did not predict any massive slope failure.

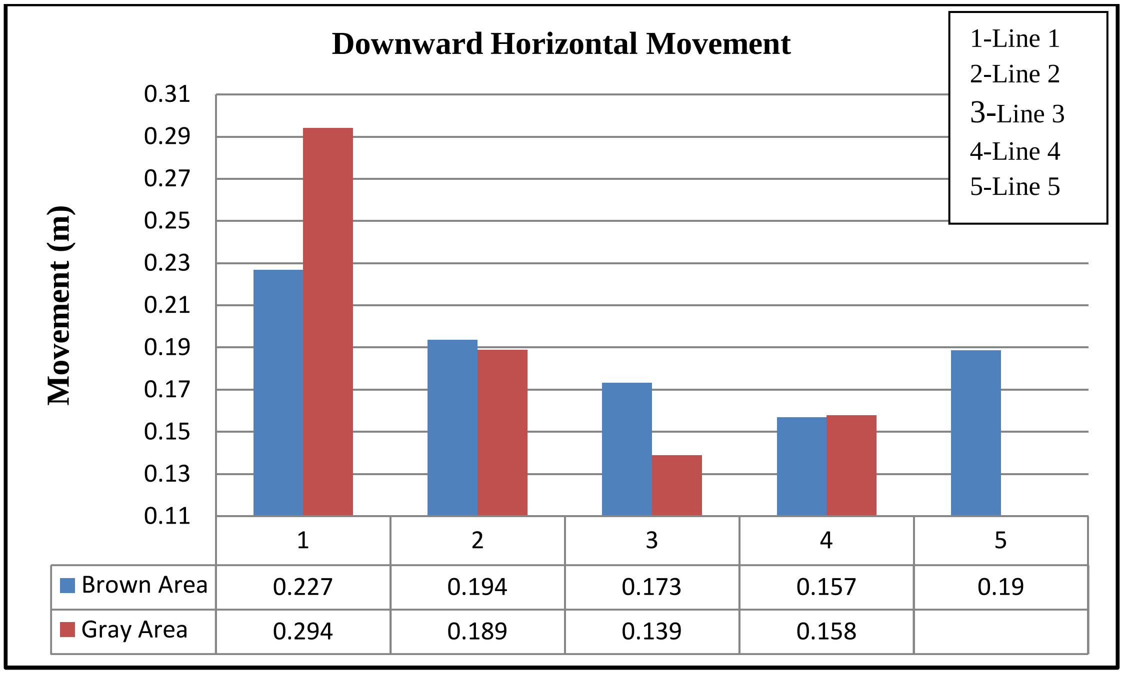


Figure 4.2: Maximum downward horizontal movement of brown and gray area

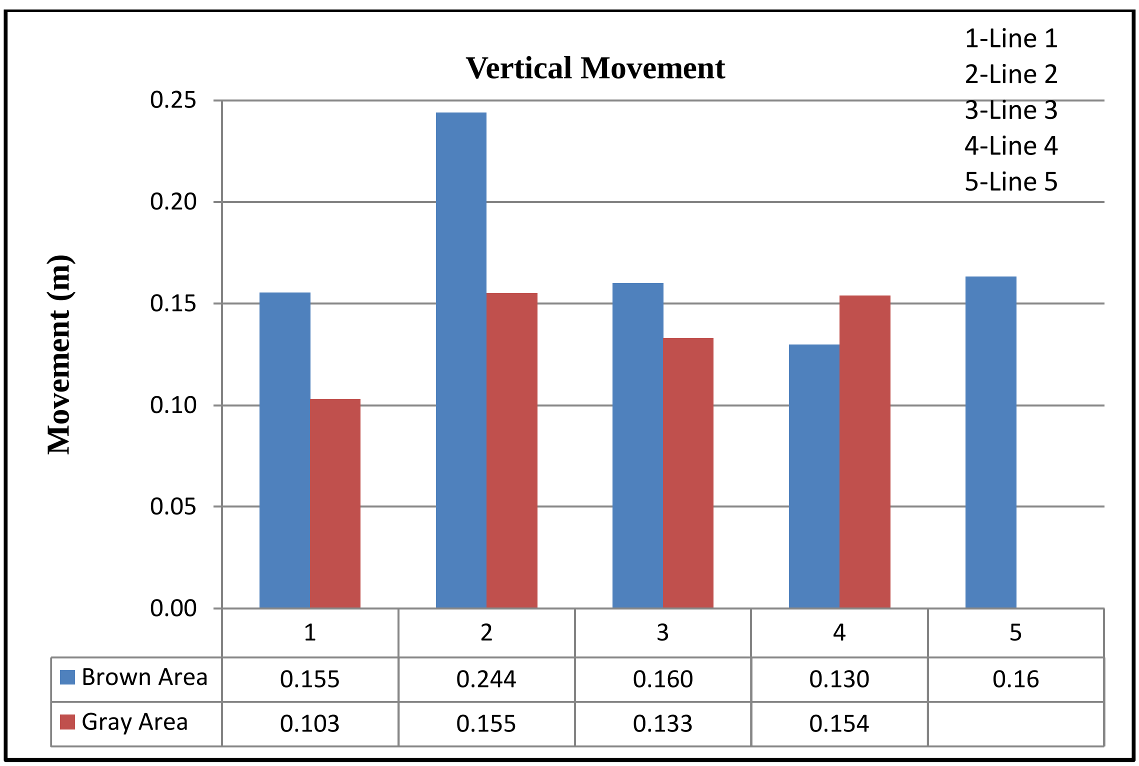


Figure 4.3: Maximum vertical movement of brown and gray area

Figure 4.4: Small slumping in the brown spoil area after two heavy rains

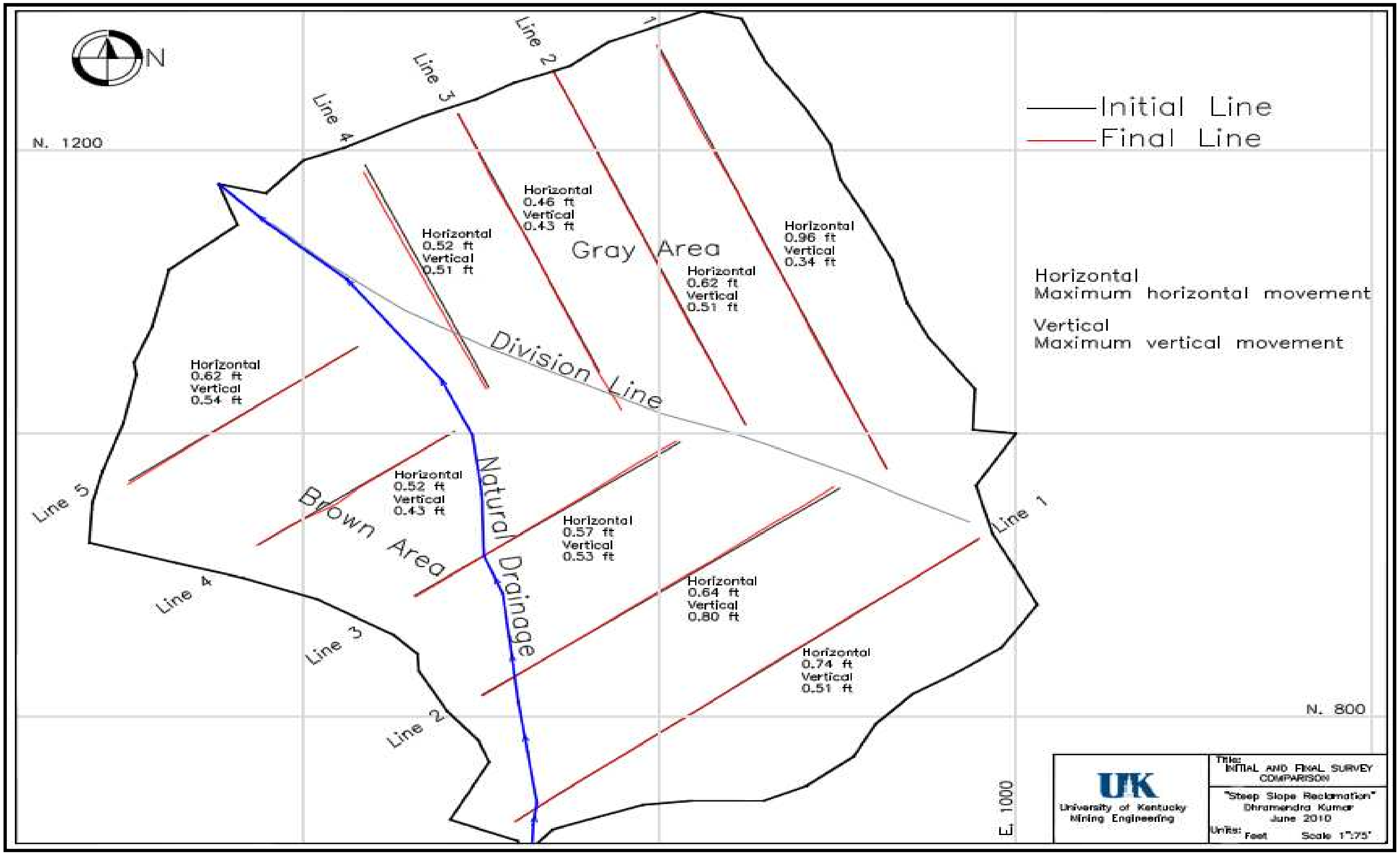


Figure 4.5: Maximum horizontal and vertical movement during one year monitoring

4.3 Summary of Slope Stability Analysis Results

The computer modeling results using REAME and Geo-Slope for both the brown and the gray spoil areas predicted only minor amounts of instability in the upper part of the slope where the slope inclination is highest (near 30°). In addition the results without 1.22 m (4 ft.) of loose material were similar to the results obtained when considering 1.22 m (4 ft.) of loose top material. This would seem to indicate that the application of FRA in steep slopes does not cause any additional stability problems that would not otherwise exist for very steep (more than 26°) slopes. These results are verified by the survey results of slope movement monitoring. Furthermore, any minor slumping issues associated with the loose material were isolated to the upper 1.22 m (4 ft.) and did not contribute to any mass instability. A comparison of profiles used for the stability analysis over a one year time duration is shown in Figure 4.6. This profile comparison also shows only a small amount of movement in the upper part of slope. These minor instability conditions can be prevented through careful final grading of slopes to eliminate local over-steepened spots.

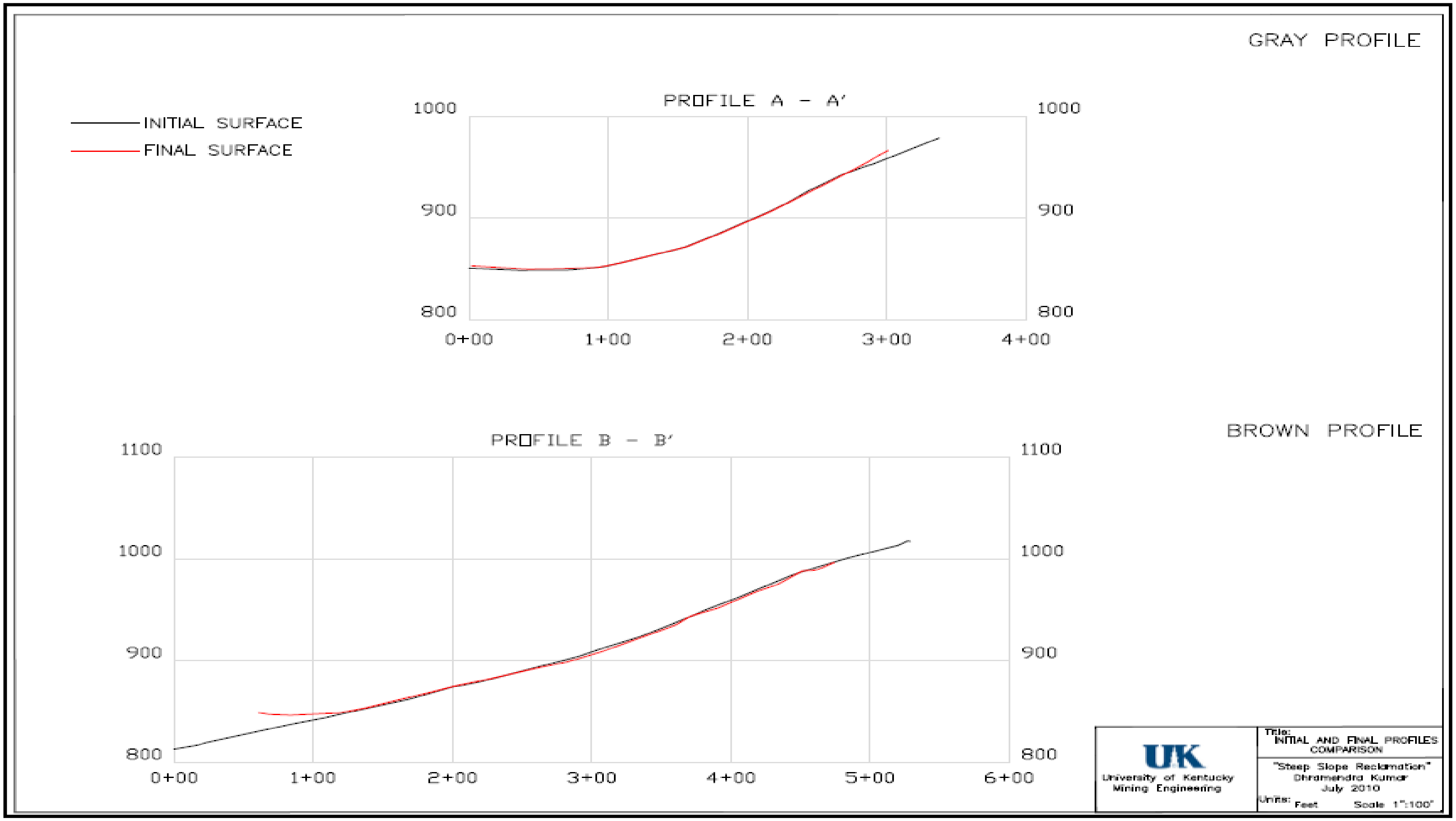


Figure 4.6: Comparison of profiles to locate area of mass movement

4.4 Spoil Characterization Results

4.4.1 Bulk Density

A comparison of bulk density results at a depth of 15 cm (6 in.) depth for the brown and the gray areas is shown in Figure 4.7. It is observed that the bulk density values have increased slightly in one year, which is consistent with research results by Conrad (2002) at the Starfire Mine. Conrad (2002) stated that initially the growing medium in loose dumped areas consolidates and hence, results in an increase of dry bulk density.

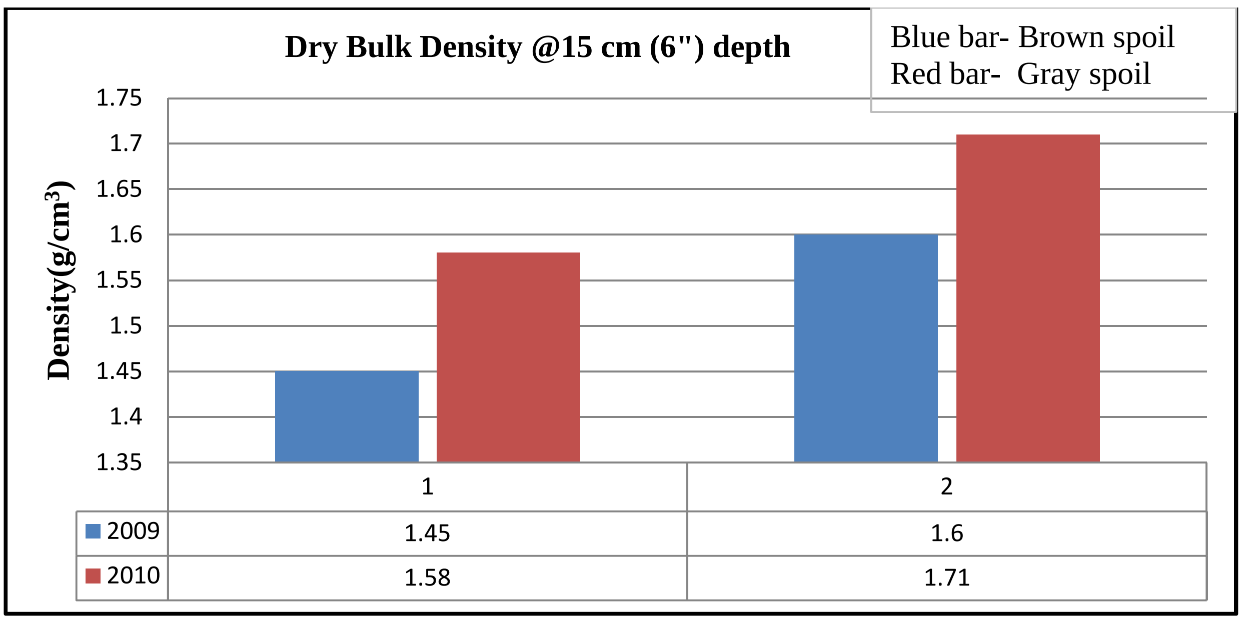


Figure 4.7: Comparison of dry bulk density at 15 cm (6 inches) depth

4.4.1.1 Comparison of Results with Earlier Work

The average dry bulk density and tree survival rates one year after reclamation for the brown and the gray spoil areas are compared with one year results obtained at Starfire Mine on three different plots: loose-dumped, struck-off, and compacted (Conrad, 2002). The results from these investigation are similar to the results at the Starfire Mine as shown in Table 4.1. The bulk density values were somewhat less compared to the loose-dumped and struck-off plots at Starfire. Tree survival rates were also lower, but still within a reasonable range.

Table 4.1: Comparison of bulk density and survival rate with earlier works at Starfire Mine

No.	Parameter	Starfire Mine (1997)			Peel Poplar Mine (2010)	
		Loose-Dumped	**Struck-Off**	**Compacted**	**Brown-Spoil Area**	**Gray-Spoil Area**
1	Bulk Density (pcf)	109.2	108.9	119.1	90.38	99.98
	Bulk Density (g/cm^3)	1.75	1.75	1.91	1.45	1.60
2	Survival Rate (%)	86.1	89.9	71	71.2	62.9

4.4.2 Spoil Penetration Resistance

4.4.2.1 Average Penetration Resistance

A comparison of average penetration resistance for June, 2009 and May, 2010 is presented in Figure 4.8. Figure 4.8 indicates the penetration resistance increased slightly for the brown spoil area, whereas it decreased slightly for the gray spoil area. To correlate trees survival rate and penetration resistance at least two more years of data are required. The variation of penetration resistance with the depth for the brown spoil in June, 2009 is shown in Figure 4.9. The variation of penetration resistance with depth for the gray spoil area in June, 2009 and May, 2010 and the brown area in May, 2010 are shown in appendix D. From the Figure 4.9, it is obvious that the penetration resistance increases with the depth. The high penetration resistance at a depth greater than 1 m (3.28 ft.) most likely corresponds to the top of the backfilled spoil, which is below the 1.22 m (4 ft.) of loose-dumped material.

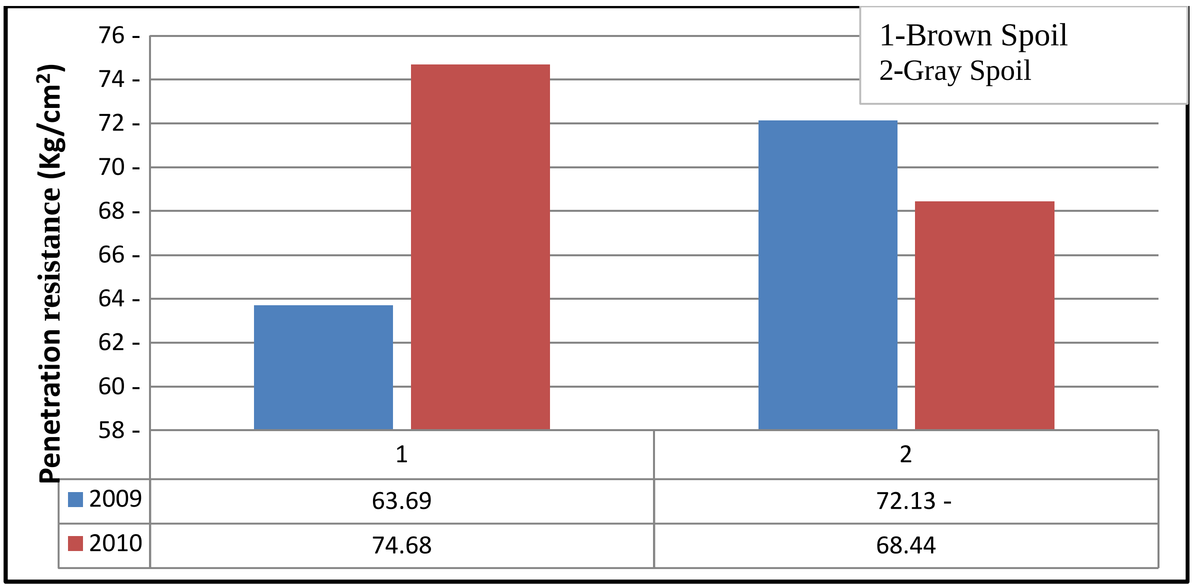


Figure 4.8: Comparison of average penetration resistance for brown and gray spoil area

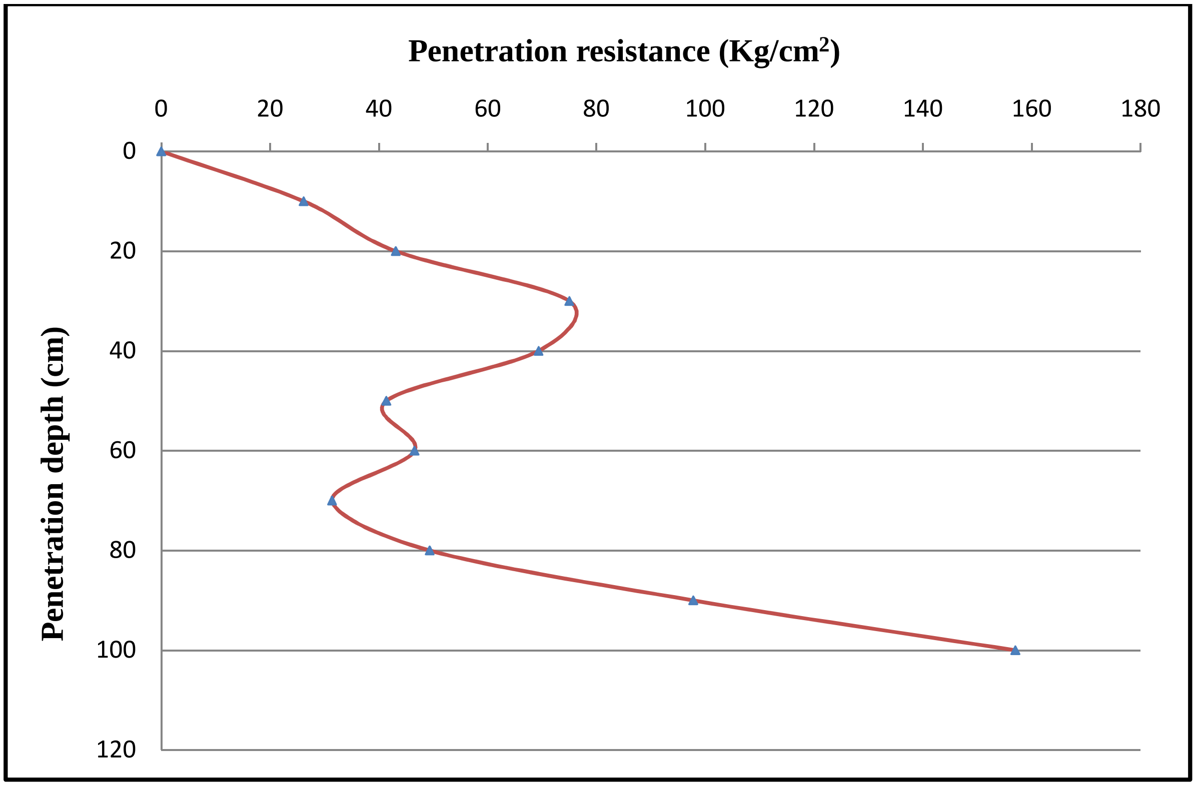


Figure 4.9: Variation of penetration resistance with depth for brown spoil area (June, 2009)

4.4.2.2 Comparison of Average Penetration Resistance Results with Earlier Work

The average penetration resistance and trees survival rates one year after reclamation for the brown and the gray spoil areas are compared with one year results obtained at Starfire Mine on three different types of plots: loose-dumped, struck-off, and compacted (Conrad, 2002). The results of this research are similar to the previous results at Starfire Mine as shown in Table 4.2. However, the penetration resistances for this investigation are significantly greater than those observed on the loose-dumped plots at Starfire Mine, which experienced no final grading by a dozer.

Table 4.2: Comparison of penetration resistance and survival rate with earlier work at Starfire Mine

No.	Parameter	Starfire Mine (1997)			Peel Poplar Mine (2010)	
		Loose-Dumped	Struck-Off	Compacted	Brown-Spoil Area	Gray-Spoil Area
1	Penetration Resistance (psi)	665.7	806.3	1043.7	905.86	1025.9
	Penetration Resistance (kg/cm^2)	46.81	56.70	73.40	63.70	72.14
2	Survival Rate (%)	86.1	89.9	71	71.2	62.9

4.4.2.3 Maximum Penetration Depth

A comparison of maximum penetration depth for the brown and the gray area is shown in Figure 4.10. To correlate properly tree survival rate and maximum penetration resistance at least two more years of data are required.

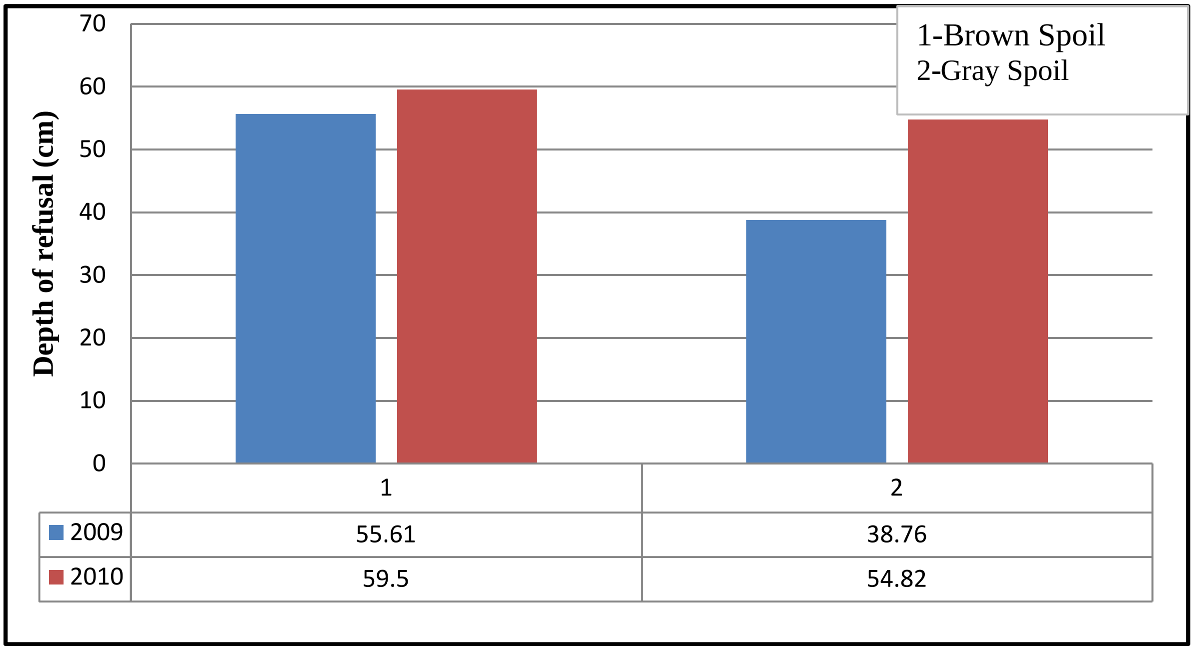


Figure 4.10: Comparison of maximum penetration depth for the brown and the gray spoil area

4.4.2.4 Comparison of Maximum Penetration Depth Results with Earlier Work

The maximum penetration resistance and trees survival rates one year after reclamation for the brown and the gray spoil areas are compared in Table 4.3 with one year results obtained at the Starfire Mine on three different types of plots: loose-dumped, struck-off, and compacted (Conrad, 2002). The results from this investigation exhibit a much greater average penetration depth as shown in Table 4.3. This is most likely due to the fact that a static recording cone penetrometer was used to measure maximum penetration depth at the Starfire Mine while a dynamic cone penetrometer was used in the current investigation. Measurements made with a static cone penetrometer are much more dependent on the skill of the technician than those made with a dynamic cone penetrometer.

Table 4.3: Comparison of maximum penetration depth and survival rate with earlier works at Starfire Mine

No.	Parameter	Starfire Mine (1997)			Peel Poplar Mine (2010)	
		Loose-Dumped	Struck-Off	Compacted	Brown-Spoil Area	Gray-Spoil Area
1	Max. Penetration Depth(inch)	11.9	10.4	9.5	22.24	15.5
	Max. Penetration Depth(cm)	29.75	26.00	23.75	55.60	38.75
2	Survival Rate (%)	86.1	89.9	71	71.2	62.9

4.5 Economic Analysis Results

4.5.1 Highwall Elimination Cost

Total highwall elimination cost for the haulback and dozer push method is listed in Table 4.4 and total highwall elimination cost using complete haulback method is listed in Table 4.5. A comparison of costs is shown in Figure 4.11.

Table 4.4: Total highwall elimination cost for half haulback and half dozer push method

No.	Method	Cost per m^3 ($)	Volume (m^3)	Highwall elimination cost($)
1	Haulback	1.69	290,960.76	490,570.07
2	Dozer push	1.42	290,960.76	413,678.14
Total cost($)				904,248.21

Table 4.5: Total highwall elimination cost for complete haulback method

No.	Method	Cost per m^3 ($)	Volume (m^3)	Highwall elimination cost ($)
1	Haulback	1.69	581,921.51	981,140.15
Total cost($)				981,140.15

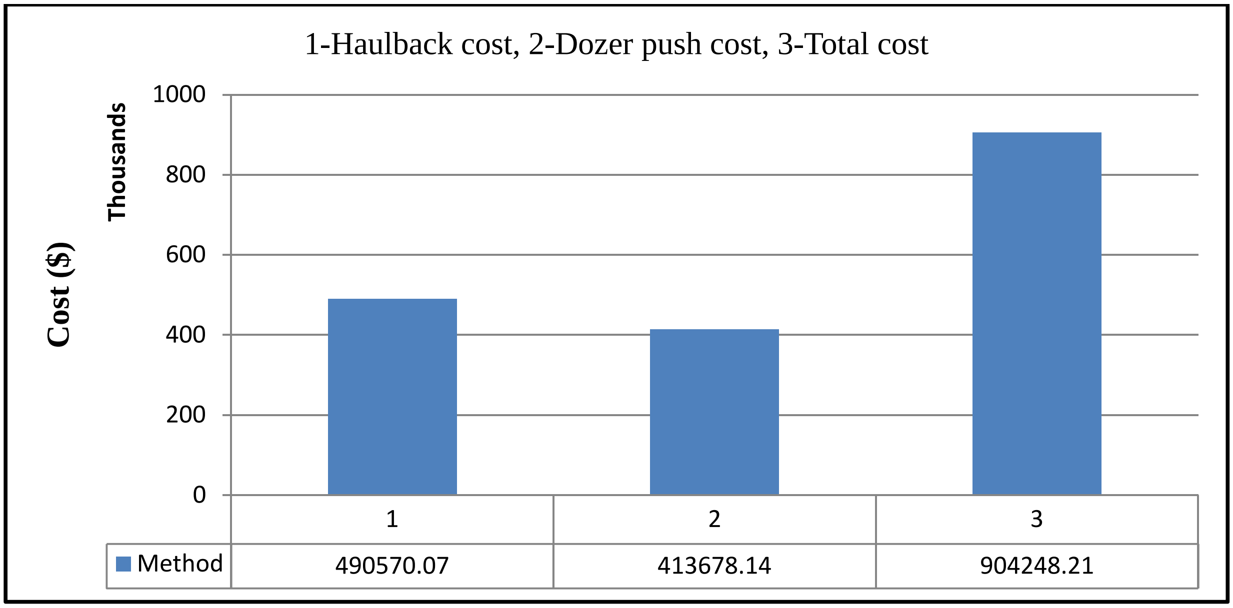


Figure 4.11: Total highwall elimination cost

4.5.2 Total Reclamation Cost

Total reclamation costs for both methods, complete haulback and a combination of haulback and dozer push, were calculated considering highwall elimination cost, final grading cost and planting cost. A comparison of costs is shown in Figure 4.12. From Figure 4.12 is clear that, for the conditions at this mine, total reclamation cost for a combination of haulback and varying amounts of dozer pushing is less as compared to complete haulback cost.

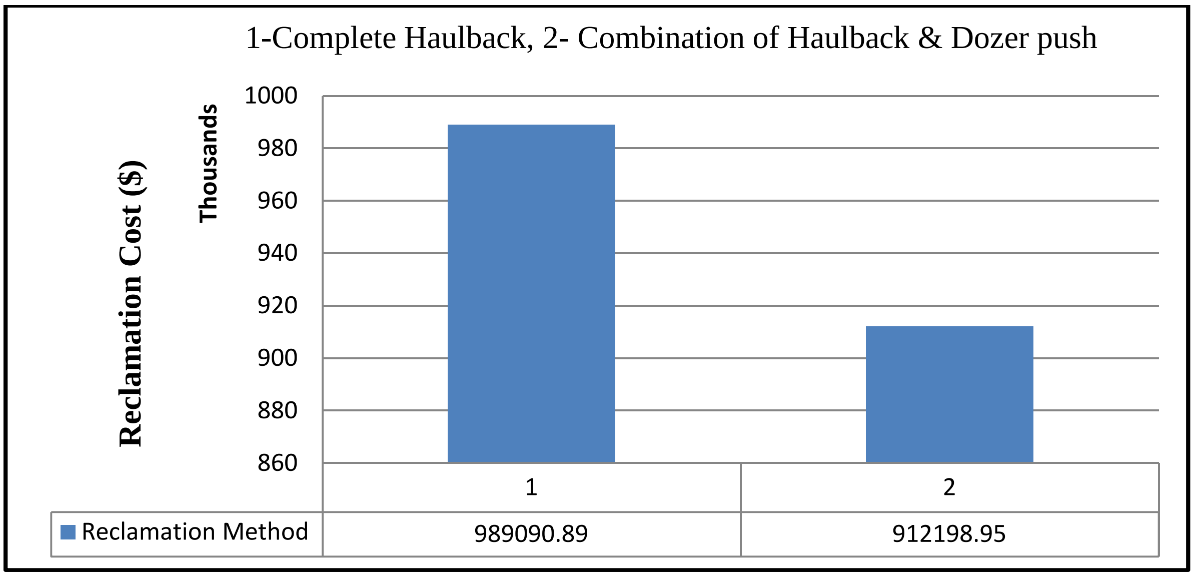


Figure 4.12: Comparison of total reclamation cost

4.5.3 Summary of Economic Analysis

Total reclamation cost represents the costs involved to bring the steep slope operations to Phase I bond release conditions. Based on the economic analysis for reclaiming the steep slope in this study, it is demonstrated that the application of FRA in steep slopes does not have a significant economic impact on reclamation cost as compared to FRA applications in flat or rolling surfaces. The cost of eliminating highwalls using only the haulback method is somewhat higher as compared to the cost for the combination of haulback and dozer push method. For this reason, it is advisable to optimize the amount of dozer push utilized at any steep-slope operation.

Regardless of which common method of highwall elimination is used, it does not appear that there is an economic deterrent to the application of FRA on steep slopes.

4.6 Assessment of Trees Survival Rate

Although, the primary focus of this project was on operational and slope stability considerations, the survival of the trees planted on both the gray and the brown spoil areas was monitored one year after the planting. The survival rates provided additional data to verify the relationships previously developed between spoil characteristics and tree survival rates. Survival rates one year after planting are shown in Table 4.6. A low survival rate was observed at two localized areas of the slope as shown in Figure 4.14 and Figure 4.15, respectively. The reason for low survival rate in this particular area of the brown spoil area could be attributed to the excessive competition between trees and the native grasses and vegetation. The lower survival rate in the particular area of the gray spoil area could be due to the very high gradient of the slope (about 35°).

Table 4.6: Tree survival rate

No.	Area	Planted Trees (April, 2009)	Survival (April, 2010)	Survival Rate (%)
1	Brown spoil	2412	1715	71.1
2	Gray spoil	1731	1088	62.9

Figure 4.13: Lower survival rate area of the gray spoil area

Figure 4.14: Lower survival rate area of the brown spoil area

Chapter 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

Site visits were conducted at 28 steep-slope surface mining operations throughout the Appalachian region to investigate the most common highwall elimination methods that could be compatible with FRA. One of these mines, the Peel Poplar Mine, in Pike County, Kentucky was selected for a detailed field investigation. The site was reclaimed using FRA standards so that slope stability, economic, operational, spoil characteristic, and tree survival factors could be evaluated. The investigation into the applicability of FRA on steep slopes can be concluded in following points:

1. The intensive field visits for inventorying steep slopes practices throughout the Appalachian region concluded that the contour haulback method coupled, in many cases, with varying amounts of dozer push, is the most common practice to eliminate highwalls both in the Northern and Central Appalachian regions.
2. Physical characteristics of the root growth medium such as bulk density and maximum penetration depth, on the steep slope reclamation site were similar to the values obtained for loosely compacted materials on flat or gently rolling surfaces.
3. The tree survival rate on steep slopes is also comparable to the survival rates on flat surfaces. However, the rates observed were somewhat lower than those obtained from earlier loose-dumped plots at the Starfire Mine. In one location of the slope, where the slope angle was very high (about 35°), a much lower survival rate was observed. This local lower survival

rate also corresponded to the gray spoil area, which had inferior characteristics compared to the brown spoil area.

4. In this investigation, it was found that the top 1.22 m (4 ft.) of loose material did not cause any significant stability problems. Lower factors of safety were observed for very steep portions of the slope (more than 30°), but these areas were not significantly affected by the upper 1.22 m (4 ft.) of loose material. Any instability associated with the loose material was negligible and resulted in only minor slumping rather than mass instability.
5. The economic analysis of the field site indicated that the application of FRA on steep slopes did not have a significant impact on the overall reclamation cost.

The results of this investigation support the conclusion that the Forestry Reclamation Approach is compatible with steep slope mining operations. It does not present a significant slope stability problem and any potential minor instability in the slopes can be avoided by careful attention to final grading so that the local over-steepened areas are avoided.

5.2 Recommendation and Future Work

The duration of this investigation was two years; however, only slightly more than one year was provided for data collection at the field site following reclamation. In previous studies on the applicability the FRA on flat or rolling surfaces, a minimum of 3-5 years of data collection was required to establish the spoil characteristics and to study the survival rate and growth rates of the trees. In this research, the one year field investigation of spoil characteristics such as bulk density, penetration resistance, and slope monitoring, represent an excellent base line to continue research at this experimental site. An additional two to three years of slope monitoring, spoil characterization investigations, and tree survival monitoring are advisable to verify the conclusions of this investigation. The following future tasks are suggested to supplement and expand the objectives of the current research:

1. Conduct at least annual evaluations of bulk density and penetration measurements and correlate these data with the survival rates of the trees.
2. Divide the area in small segments and measure the change in spoil characteristics and survival rate. Study, how the change in spoil characteristics influences the survival and growth rate of different types of trees. Also, investigate if the difference in survival rate associated with relative steepness persists.
3. For slope movement monitoring, conduct the survey of the monuments for at least two more years and investigate slope movement over time.
4. For the purpose of stability analysis, conduct more triaxial test on both the brown spoil material and the gray spoil material to get better estimates of physical properties such as friction angle, cohesion value, Young's modulus, and Poisson's ratio.
5. Investigate the applicability of existing slope stability analytical methods to the unique two-layer system created by the upper 1.22 m (4 ft.) of the loose material and determine whether modification to any of these methods would produce better results. This could result in the inclusion of three-dimensional analysis, if this proves to be more critical than the two-dimensional case used in this investigation. Three-dimensional analysis may provide better estimate of slope stability, because the slope geometry is highly variable and is not laterally extensive.
6. Expand the field investigation to include monitoring of piezometric levels in the slope so that pore pressure can be taken into account in the slope stability analysis.

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APPENDIX A

Inventory of Highwall Elimination Practices throughout the Appalachian Region

Central Appalachian Region

No.	Kentucky Mine Visit 1			
1	Mine Name	17 West	Company	Lexington Coal Company
2	Location	Near Inez, Kentucky	Date	5/29/2008
3	Mine Type	Mountain top removal	Mining Status	Reclaimed
4	Highwall Detail	Height: 150 ft. approximately 100 ft. back shot from original top, Length: 600 ft. 4 benches		
5	Type of overburden	Brown sandstone		
6	Method of H/W Elimination	The primary method of operation was to shoot the material and shove it from the top of the highwall to the toe. Generally, there were two separate shot benches (level) creating a stair-step appearance on the way down the high wall. The shoot and push method allowed the company to keep haul trucks off the material and limit the equipment.		
7	Reclamation Method	The ROM (Run of mine) material was used for reclamation. Typically, they used two dozer passes for final grading. LLC is primarily a company that performed reclamation on land that has been mined by other companies.		
8	Reforestation Effort	The grasses were planted one year prior to trees being planted on the spoil.		
9	Post Mining land use	Reforestation, fish & wildlife habitat		

Central Appalachian Region

No.	Kentucky Mine Visit 2			
1	Mine Name	Bent Mountain	Company	Appalachian Fuels
2	Location	Pikeville, Kentucky	Date	7/25/2008
3	Mine Type	Mountain top removal	Mining Status	Active
4	Highwall Detail	Height:300 ft., length: 50 ft., and 25 ft. width safety benches and slope 2:1		
5	Type of overburden	Sandstone and shale		
6	Method of H/W Elimination	Ramp haulback and one dozer pass with a D-10 is performed. One highwall was eliminated by ramping up and dumping from the top and working the way down, putting in benches as needed.		
7	Reclamation Method	Substitute material is used for reclamation and final grading is done by D-10 in single pass		
8	Reforestation Effort(if applicable)			
9	Post Mining land use	Wildlife habitat (with 30% trees)		

Central Appalachian Region

No.	Kentucky Mine Visit 3			
1	Mine Name	Bent Mountain	Company	Appalachian Fuels and Predecessors
2	Location	Pikeville, Kentucky	Date	07/25/2008
3	Mine Type	Contour operation dumped from the top	Mining Status	Reclaimed
4	Highwall Detail	Height: 100 ft., slope: 1.5:1.6 in 1		
5	Type of overburden	Sandstone and shale		
7	Method of H/W Elimination	The spoil was dumped from the top and one tractor pass was performed. The tractor would go back around the side to get back to the top. Sandstone was used in the spoil material, so there is no problem of erosion.		
8	Reclamation Method	Substitute material was used for reclamation and final grading was done by D-10 with only one pass**.**		
9	Reforestation Effort(if applicable)	Planted oaks, pines and locust		
10	Post Mining land use	Reforestation		

Central Appalachian Region

No.	Kentucky Mine Visit 4			
1	Mine Name	Hunts Branch	Company	Central Appalachian Mining
2	Location	Pikeville, Kentucky	Date	07/30/2008
3	Mine Type	Contour haul-back and mountaintop removal	Mining Status	Active (some reclaimed)
4	Highwall Detail	Height: 150 ft., Length: 600 ft., slope: 2:1, 4 benches		
5	Type of Overburden	Sandstone and shale		
6	Method of H/W Elimination	This was a single seam cut on a small area with multiple seam operation. There was an existing H/W approximately 100 ft. high. A second cut was made creating a highwall approximately 250 ft. The spoil was hauled back and dumped ¾ of the way, and then the final quarter was blasted and shot down.		
7	Reclamation Method	The substitute materials were used for reclamation. Final grading was done by using D-10 & D-11. Excessive compaction was avoided.		
8	Reforestation Effort(if applicable)			
9	Post Mining L and use	Forest land, fish & wildlife habitat		

Central Appalachian Region

No.	Kentucky Mine Visit 5			
1	Mine Name	Peel Poplar	Company	ICG group
2	Location	Near Phelps, Kentucky	Date	08/11/2008
3	Mine Type	Contour haulback	Mining Status	Active
4	Highwall Detail	Height: 100ft., Length 500 ft., slope: 2:1		
5	Type of Overburden	Sandstone and shale		
6	Method of H/W Elimination	Conventional haulback		
7	Reclamation Method	The substitute materials were used for reclamation with one dozer pass and avoiding tracking on it.		
8	Reforestation Effort(if applicable)	Mixed species of trees were planted as locust, oaks and maples.		
9	Post Mining land use	Reforestation		

Central Appalachian Region

No.	Kentucky Mine Visit 6			
1	Mine Name	Thunder Ridge	Company	ICG Group
2	Location	Hazard, Kentucky	Date	08/22/2008
3	Mine Type	Contour haul-back and area mining	Mining Status	Active
4	Highwall Detail	Height: 100 ft., Length: 300 ft., slope: 2:1, one bench		
5	Type of Overburden	Sandstone and shale		
6	Method of H/W Elimination	Conventional haulback method was used for highwall elimination.		
7	Reclamation Method	The substitute materials were used for reclamation. Final grading was done by using D-10 and compaction is minimized by avoiding tracking in reclaimed area.		
8	Reforestation Effort (if applicable)			
9	Post Mining land use	Wildlife habitat (30% trees)		

Central Appalachian Region

No.	Virginia Mine Visit 1			
1	Mine Name	Meg Lynn Land Company	Company	A& G Coal Corporation
2	Location	Near Norton, Virginia	Date	6/19/2008
3	Mine Type	Contour Mining	Status	Active
4	Highwall Detail	Height: 400 ft. approximately, length: 500 ft. approximately, Slope of backfill greater than 2:1		
5	Type of overburden	Gray sandstone and brown sandstone		
6	Method of H/W Elimination	The spoil was loaded by a 992 FEL and hauled by 785 and 789 trucks from the pit and dumped at the top of HW. This method was referred as gravity feed as mentioned previously in VA. The spoil was loose dumped and then material was dumped on top. One dozer pass was performed by a D-10.		
7	Reclamation Method	Best available topsoil and substitute material is used for reclamation. Generally one dozer pass using D-10		
8	Reforestation Effort(if applicable)			
9	Post Mining Land use	Forestry and light industrial gas-line and pipelines		

Central Appalachian Region

No.	Virginia Mine Visit 2			
1	Mine Name	Meg Lynn Land Company	Company	A& G Coal Corporation
2	Location	Near Norton, Virginia	Date	6/19/2008
3	Mine Type	Area Mining	Mining Status	Active
4	Highwall Detail	Height: 100 ft. approximately, length: huge contour cut, one bench dumped from top, Slope of backfill greater than 2:1.		
5	Type of Overburden	Sandstone with some shale		
6	Method of H/W Elimination	The gravity feed method of HW elimination was used. There were total 8 seams in this mine, separated by a couple hundred feet of overburden and interburden. The lower seam was mined first. There were preexisting HWs at this mine. The 2nd cut was taken keeping the spoil on the bench. The cut were ranging from 50 to 500 ft. All the spoil was left on the bench and pushed by D-10. The material was pushed into an adjacent cut. As mining extended up to the next seam, any adjacent spoil was pushed from the bench above to the bench below to complete the elimination process.		
7	Reclamation Method	Run of mine materials were used for reclamation. 1-2 dozer passes, go down and then go around and back to top		
8	Reforestation Effort(if applicable)	Planted locust, oaks, ash and hardwoods. Contract hydro- seeding is done in fall and spring by Big Valley.		
9	Post Mining land use	Unmanaged forest		

Central Appalachian Region

No.	Virginia Mine Visit 3			
1	Mine Name	88 Strips	Company	Paramount
2	Location	Near Davenport, Virginia	Date	6/20/2008
3	Mine Type	Contour Mining	Mining Status	Active
4	Highwall Detail	Height: 120 ft. approximately, length: 1000 ft. approximately, angle of repose for ROM		
5	Type of Overburden	Sandstone and shale		
6	Method of H/W Elimination	There are two separate techniques at this mine 1. Gravity feed: In this method almost all of the material was dumped over the top of the HW by trucks. 2. In this method the spoil was loaded by a 992 FEL and hauled by 785 and 789 trucks from the pit and dumped at the top of HW. The spoil is loose dumped and then soil is dumped on top of that. One dozer pass is performed by a D-11.		
7	Reclamation Method	Topsoil and substitute material were used for reclamation. Material was dumped over the HW and no passes currently being made, but generally, 1 or 2 pass were performed.		
8	Reforestation Effort(if applicable)	Planted hardwood, red oak, white oak, green ash, white ash, cherry and hickory.		
9	Post Mining land use	Reforestation		

Central Appalachian Region

No.	West Virginia Mine Visit 1			
1	Mine Name	North and South Surface Mine	Company	Massey Energy
2	Location	Near Logan, WV	Date	7/11/2008
3	Mine Type	Contour haulback	Mining Status	Active & reclaimed
4	Highwall Detail	Height: 100 ft., length of highwall 200 ft., one bench, slope of back fill 2:1.		
5	Type of overburden	Sandstone and shale		
6	Method of H/W Elimination	This was a multiple seam operation. First cut was made approximately 50 ft. wide for the trucks. Then dropped down and take 130 ft. cuts to operate on the HW. The spoil from the lower seam was hauled to adjacent valley fills. The mining progressed upward to the next seam and the spoils were shoved over to replace the spoil taken from the lower seam. This sequence was repeated for as many seams as mined. The material was hauled in to the main top of the points to replace the material over the top seam.		
7	Reclamation Method	Best available topsoil. Final grading is done by D-11		
8	Reforestation Effort(if applicable)			
9	Post Mining land use	Reforestation		

Central Appalachian Region

No.	West Virginia Mine Visit 2			
1	Mine Name	Copley Fork Surface Mine	Company	Argus Coal
2	Location	Near Logan, WV	Date	7/11/2008
3	Mine Type	Contour haul back practiced, but mined like mountain top removal	Status	Active
4	Highwall Detail	Height: 90 ft., length of highwall 800 ft.		
5	Type of overburden	Sandstone and shale		
6	Method of H/W Elimination	The 800 ft. section on the contour was mined out to make room for the spoil to be placed. The spoil from this initial cut was generally used to adjust the mined mountain tops to AOC. The spoil was hauled and backstacked on the bench. All the spoil was ramped up and dumped, eliminating ramps as it progressed upward in lifts. An excavator was used at the top of the HW if any settlement occurs. An excavator may also be used on steep slopes. If this occurs, the ramps were left to leave room at the top so the excavator can push it from the top of the HW and limiting its impact on compaction.		
7	Reclamation Method	Substitute materials were used for reclamation. Final grading was done by D-11 in single pass.		
8	Reforestation Effort(if applicable)			
9	Post Mining land use	Wildlife habitat , commercial light industrial for gasline, hayland and unmanaged forests		

Central Appalachian Region

No.	West Virginia Mine Visit 3			
1	Mine Name	Right Fork and Hardway Branch	Company	Nicholas Energy (Massey)
2	Location	Near Drennan, WV	Date	7/24/2008
3	Mine Type	Contour haulback	Mining Status	Reclaimed last year
4	Highwall Detail	Height: 80 ft. on Coalburg Winifred seam & 50 ft. wall on Winifred seam, length of highwall 3000 ft., Slope of backfill around 2:1, one bench.		
5	Type of Overburden	Sandstone and shale		
6	Method of H/W Elimination	This was multiple seam operation. The first cut was made on the lower seam approximately 50 ft. wide for trucks. The spoil from the lower seam (the initial cut) was hauled to adjacent valley fills. The mining progressed upward to the next seam and the spoil are shoved over to replace the spoil taken from the lower seam. This sequence is repeated for as many seams as mined. The material is hauled in to the top of the highwall to replace the material over the top seam.		
7	Reclamation Method	Dozing was done using to dozer D-5 & D-6 in yo-yo effect to get better results. At the final 10 ft. of HW, an excavator was used to eliminate highwall.		
8	Reforestation Effort(if applicable)	Planted white pine, locust and oak.		
9	Post Mining land use	Forestland and wildlife habitat		

Central Appalachian Region

No.	West Virginia Mine Visit 4			
1	Mine Name	Fola Surface Mine	Company	Fola Coal Company
2	Location	Near Summersville, WV	Date	7/25/2008
3	Mine Type	Contour and highwall mining	Mining Status	Active & reclaimed
4	Highwall Detail	Height: 200 ft., length of highwall 600 ft., Slope of backfill around 2:1		
5	Type of overburden	Sandstone and shale		
6	Method of H/W Elimination	A multiple seam operation was done by taking a 200 ft. footwall. The spoil material is hauled up and then dozed in single pass by CAT D-11 dozer. Upper part is handled by a backhoe. The outslopes from the mountains are eliminated by conventional haulback method.		
7	Reclamation Method	Substitute material. Final grading is done by D-11 one pass only		
8	Reforestation Effort(if applicable)	Planted white pine , locust and oak		
9	Post Mining land use	Commercial forestry, wildlife and pastureland, noncommercial woodland		

Central Appalachian Region

No.	West Virginia Mine Visit 5			
1	Mine Name	Birch River	Company	ICG group
2	Location	Near Drennan, WV	Date	8/8/2008
3	Mine Type	Mountaintop removal with area mining	Mining Status	Active
4	Highwall Detail	Height: 50 ft. approximately, length: 300 ft. approximately		
5	Type of overburden	White sandstone and brown sandstone		
6	Method of H/W Elimination	Trucks were dumping right up against the HW using ramping method. The dozer was blending the material at the top leaving a little material for D-10 dozer to be used for grading.		
7	Reclamation Method	The substitute materials were used for reclamation. Final grading was done in one dozer pass.		
8	Reforestation Effort(if applicable)			
9	Post Mining land use	Forestland, fish & wildlife habitat.		

Central Appalachian Region

o.	Tennessee Mine Visit 1			
1	**Mine Name**	Area 18	Company	Premium Coal
2	**Location**	Near Knoxville, TN	Date	6/10/2008
3	**Mine Type**	Contour haulback	Mining Status	Reclaimed & Active
4	**Type of Overburden**	Sandstone and shale		
5	**Method of H/W Elimination**	This was a typical contour haulback method. Two cuts were made from the existing HW. The dozer cleared off as much of the material as possible. Then spoil was shot, loaded, and hauled up to dumping location. A ramp was constructed from bench. Often the ramp begins at the base of the highwall on one side of the cut and goes up and reaches the top of the highwall.		
6	**Reclamation Method**	Composite topsoil substitute is used for reclamation with minimum grading.		
7	**Reforestation Effort(if applicable)**	Fescue and locust were seeded. Also planted valuable hardwoods on part of property two years ago, but haven't established growth to this point.		
8	**Post Mining land use**	Forestland and wildlife habitat		

Central Appalachian Region

No.	Tennessee Mine Visit 2			
1	Mine Name	King Mountain	Company	Mountainside Coal Company
2	Location	Near Jellico, TN	Date	6/11/2008
3	Mine Type	Contour haulback	Mining Status	Active & some reclaimed
4	Highwall Detail	Height: old HW 70-80 ft., New HW 159 ft., length of Highwall: Entire mine 2000 ft. Slope of backfill around 24-25°, one bench.		
5	Type of Overburden	Sandstone and shale (weathered mix)		
6	Method of H/W Elimination	The overburden was blasted approximately two to three feet above the coal seam. Then the blasted material was loaded and hauled to be backfilled. Two dozers were currently being used at this operation. One dozer was removing the material from the top of the bench and other was spreading and backfilling. A dozer was used to push the material from the top of the bench to the pit for FEL. Once this dozer had free time, it returns to the rear of the last cut with the coal extracted and backfills this pit as much as possible. The dozers were able to push the spoil from the next bench to heights of 45-50 ft. above the pit floor.		
7	Reclamation Method	They tried to take best available material directly from the bench and spread with no off bench storage two to three passes of dozer performed to smooth it little bit.		
8	Reforestation Effort(if applicable)	Using 70 lb./acre of seed mix for initial revegetation, but no trees are planted.		
9	Post Mining land use	Wildlife habitat and commercial for gas wells		

Central Appalachian Region

No.	Tennessee Mine Visit 3			
1	Mine Name	National Mine # 7	Company	National Coal Company
2	Location	Cambell County, TN	Date	6/11/2008
3	Mine Type	Contour haulback	Mining Status	Active
4	Highwall Detail	Height: 150 ft., Slope of backfill around 2:1		
5	Type of overburden	Sandstone and shale		
6	Method of H/W Elimination	Highwall was eliminated by loader 992B and truck 785 S. There were 3-4 seams at this mine. The backfill was ramped up and dumped and leveled with the dozer.		
7	Reclamation Method	The mine had variance for topsoil and could use available substitute material.		
8	Reforestation Effort	Planted chestnut, white oak, red oak, hickory, ash and short leaf pine.		
9	Post Mining Land use	Reforestation		

North Appalachian Region

No.	Ohio Mine Visit 1			
1	**Mine Name**	Stanton Mine and Big rock	Company	Sands Hill Co., LLC
2	**Location**	Near Wellston, Ohio	Date	6/30/2008
3	**Mine Type**	Area Mining (with some similarities to contour mining)	Mining Status	Reclaimed & active
4	**Highwall Detail**	100 ft. approximately, Length: 300 ft., Slope 3:1		
5	**Type of Overburden**	Sandstone (weathered) and shale		
6	**Method of H/W Elimination**	The backfilling was done in lifts using haulback. The ramps were built up and material was dumped from top. Most of the material was moved by D-11 and trucks. The company also performed the shoot and shove method.		
7	**Reclamation Method**	Topsoil material was used for reclamation, but generally B and C horizons. Final grading is done by D-9. They try not to track through it, but make it fairly smooth.		
8	**Reforestation Effort(if applicable)**	Planted ash, black locust, Virginia pine in 8 X 8 ft. pattern.		
9	**Post Mining land use**	Pastureland or all undeveloped		

North Appalachian Region

No.	Ohio Mine Visit 2			
1	**Mine Name**	Daron-Consol Site	Company	Oxford Mining
2	**Location**	Cadiz, Ohio	Date	7/1/2008
3	**Mine Type**	Area Mining	Mining Status	Active
4	**Highwall Detail**	Height: 100 ft. approximately, one working bench		
5	**Type of Overburden**	Sandstone and shale		
6	**Method of H/W Elimination**	Slices are taken back into mountain, material hauled up ramps and dumped over the top of the piles created in front of the highwall		
7	**Reclamation Method**	Substitute material is used for reclamation, but it looks like topsoil. Final grading is done by D-10 and D-7 dozer in single pass.		
8	**Reforestation Effort(if applicable)**	For initial revegetation, they use 25 lb. of seed mix in one acre. Generally, they do one or two passes.		
9	**Post Mining land use**	Pastureland		

North Appalachian Region

No.	Ohio Mine Visit 3			
1	Mine Name	Love Branch and Jockey East (2235) and West (2255)	Company	Oxford Mining
2	Location	Cadiz, Ohio	Date	07/01/2008
3	Mine Type	Area Mining	Mining Status	Reclaimed & active
4	Highwall Detail	Not available		
5	Type of overburden	Sandstone and shale		
6	Method of H/W Elimination	Cut is started through the ridge tops and a portion of it is ripped. Ripping and dozing is done from top to bottom.		
7	Reclamation Method	Alternative topsoil material is used for reclamation. This site is using full FRA application.		
8	Reforestation Effort (if applicable)	Planted chestnut, oaks and hardwoods in April 2008. The vegetation found onsite was a combination of early succession and second growth hardwoods and grasses such as fescue		
9	Post Mining land use	Forest and cropland (undeveloped)		

North Appalachian Region

No.	Ohio Mine Visit 4			
1	Mine Name	Wiesel (Evanish)	Company	Buckeye Industrial
2	Location	Minerva, Ohio	Date	7/1/2008
3	Mine Type	Contour haulback	Mining Status	Active (old HW existing)
4	Highwall Detail	Height: 60-70 ft. approximately, Length: 300ft., one bench, Slope 3:1		
5	Type of overburden	Sandstone and shale		
6	Method of H/W Elimination	There was an existing HW and they stripped in behind and brought material in to fill the existing HW. They don't usually affect the out slopes. 75 X 75 ft. blocks are cut conventionally .The space between the piles were filled in as the cut was made. Dozer pushed as much material as possible.		
7	Reclamation Method	Topsoil and substitute material is used for reclamation. Final grading is done by D-7.		
8	Reforestation Effort(if applicable)			
9	Post Mining land use	Farmland, undeveloped but basically pastures with trees		

No.	Pennsylvania Mine Visit 1			
1	Mine Name	Brink	Company	B and M Energy
2	Location	Near Mchaffey, PA	Date	6/4/2008
3	Mine Type	Block cut contour	Mining Status	Reclaimed
4	Highwall Detail	Height: 50-350 ft. approximately, Length: 300 ft., 5 benches at one time		
5	Type of overburden	Sandstone and shale		
6	Method of H/W Elimination	Typical block cut method was used. The haul trucks ramped back around to the rear of cut and dumped the material to fill the cut. The final grading was done using D-10 dozer.		
7	Reclamation Method	Topsoil is used for reclamation		
8	Reforestation Effort(if applicable)			
9	Post Mining land use	Reforestation		

No.	**Pennsylvania Mine Visit 2**			
1	Mine Name	Buterbaugh	Company	Forcey
2	Location	Near Mchaffey, PA	Date	6/4/2008
3	Mine Type	Block cut contour	Mining Status	Reclaimed
4	Highwall Detail	Height: 120 ft., Length: 600 ft., 2 benches at one time, slope nearly 30° at steepest point		
5	Type of Overburden	Browns sandstone and black shale (acidic)		
6	Method of H/W Elimination	The topsoil was typically taken off prior to previous mining so ROM material was used instead. There was an existing HW and country road went right beside the HW originally. A FEL or a loader was used to load material into 100 ton haul trucks. The spoil was ramped up to the top of the HW and dumped. A D-11 dozer was used to spread the spoil from the top to the base at the angle of repose. Only one dozer pass was made to limit compaction. When it reached the proceeding bench, the dozer would track around to the ramp and repeat the process. This was actually done for safety reasons, but it is exactly what ARRI recommends.		
7	Reclamation Method	Best available topsoil is used for reclamation. Final grading is done by D-11 with only single pass.		
8	Reforestation Effort(if applicable)	For initial revegetation 100 lb./acre of typical red top or less. Planted black locust. The trees were growing well because less competitive grasses where seeded. Implementation of valuable hardwoods would be very useful in a similar location.		
9	Post Mining land use	Reforestation		

North Appalachian Region

No.	Pennsylvania Mine Visit 3			
1	Mine Name	Huey Mine	Company	Strishock Coal
2	Location	Near Clearfield, PA	Date	6/6/2008
3	Mine Type	Block cut contour	Status	Active
4	Highwall Detail	Height: 100 ft., length: 500 ft., 4 benches, slope nearly 12°		
5	Type of Overburden	Sandstone and shale		
6	Method of H/W Elimination	There was auguring being performed in the bottom of the box cut. Overburden was being removed from two benches. End dumping of spoil was done in other side of box cut. Dozer was used for leveling.		
7	Reclamation Method	Topsoil and substitute materials are used for reclamation		
8	Reforestation Effort(if applicable)			
9	Post Mining land use	Reforestation		

North Appalachian Region

No.	Maryland Mine Visit 1			
1	Mine Name	Douglas Mine #2 (Mount Zion)	Company	G&S Coal Company
2	Location	Near Bloomington, MD	Date	6/3/2008
3	Mine Type	Block cut contour	Mining Status	Reclaimed
4	Highwall Detail	Height: 100 ft., Length: 100 ft., 3 Benches, Slope nearly 20°		
5	Type of Overburden	Sandstone and shale		
6	Method of H/W Elimination	Combination of dozer push laterally into the previous pit and FEL & truck when dozer can no longer push. Dozers are used to expose the rock. Final grading is done using dozers up and down the slope. This particular mine has three separate highwalls because they were mining three seams at once.		
7	Reclamation Method	Topsoil (saved 12-18 in.) is used for reclamation		
8	Reforestation Effort(if applicable)	For initial revegetation, grasses and legumes are used. Planted locust, dogwoods, crab apple.		
9	Post Mining land use	Reforestation		

North Appalachian Region

No.	Maryland Mine Visit 2			
1	Mine Name	Peewee Hill Mine	Company	G&S Coal Company
2	Location	Near Bloomington, MD	Date	6/3/2008
3	Mine Type	Block cut contour (dragline used for neighboring box-cut contour)	Mining Status	Active
4	Highwall Detail	Height: 100 ft., Length: 100 ft., 1 Bench, Slope nearly 10-16°		
5	Type of overburden	Sandstone and shale		
6	Method of H/W Elimination	D-11 was used to push the topsoil off the highwall originally. The spoil material was hauled back to origin of the block cut and dumped. A front end loader was used to bring down the spoil once it has been blasted. These block cuts were typically not more than 100ft. to reduce the long distance hauling costs. The spoil is cast side to side as mining advances, but in the deepest points, the spoil is hauled up and down the slope. The final grading is all performed by the dozers up and down the slope.		
7	Reclamation Method	Topsoil (save up to 12-18 in.) was used for reclamation. For initial revegetation grasses and legumes were used.		
8	Reforestation Effort(if applicable)	Planted locust, dogwoods, crab apple, saw tooth oak and spruce.		
9	Post Mining land use	Reforestation		

North Appalachian Region

No.	Maryland Mine Visit 3			
1	Mine Name	Shalimar	Company	AML reclamation
2	Location	Near Bloomington, MD	Date	6/3/2008
3	Mine Type	Abandoned	Mining Status	Reclaimed
4	Highwall Detail	Height: 30-40 ft.		
5	Type of overburden	Refuse and sandstone with shale		
6	Method of H/W Elimination	The fill material was old refuse from an abandoned mine. The material was loaded at the base with an excavator and then hauled up to the top and dumped. Two Volvo, 35 ton trucks were used to transport the material. A D-4 and John Deere 350 were used to level the spoil. The cover contained a lot of refuse material. In some spots, salvage material was used from the side of the channel.		
7	Reclamation Method	Topsoil (save up to 12-18 in.) is used for reclamation. For initial revegetation grasses and legumes are used.		
8	Reforestation Effort(if applicable)			
9	Post Mining land use	Reforestation		

North Appalachian Region

No.	Maryland Mine Visit 4			
1	Mine Name	East and West Vindex Reclamation Site	Company	AML reclamation
2	Location	Near Bloomington, MD	Date	6/3/2008
3	Mine Type	Highwall elimination	Mining Status	Reclaimed
4	Highwall Detail	Height: 40-50 ft., length of highwall 600 ft., slope of back fill 22^0		
5	Type of Overburden	Run of mine material		
6	Method of H/W Elimination	This area was deep mined in the 1950's and surface mined in the 1970's. AML is using the existing material for high wall elimination. A minimal amount of material was hauled on to the site. The spoil had been cast into the adjacent onsite stream. A shovel was used to loosen the material. The spoil was then moved from the base of the highwall by D-8 or D-9 dozers. The dozers spread the material approximately 350 ft. which is near the cut off for pushing the material. The highwall was pushed up from the bottom.		
7	Reclamation Method	Substitute material is used for reclamation		
8	Reforestation Effort(if applicable)			
9	Post Mining land use	Reforestation		

APPENDIX B

Survey Data

BASE LINE SURVEY

Gray Spoil Area

Base line survey	6/19/2009		**Location**	Peel Poplar Mine (Pike County)			
Reference points							
	Northing		**Easting**		**Elevation**		**Description**
No.	**(ft.)**	**(m)**	**(ft.)**	**(m)**	**(ft.)**	**(m)**	
1	1000	304.8	1000	304.8	1000	304.8	Fixed Point 1
2	727.07	221.61	682.48	208.02	1000.16	304.85	Fixed Point 2
Monuments							
No.	**Northing**		**Easting**		**Elevation**		**Description**
	(ft.)	**(m)**	**(ft.)**	**(m)**	**(ft.)**	**(m)**	
1	1275.06	388.64	798.76	243.46	952.46	290.31	GB11
2	1240.52	378.11	813.25	247.88	951.65	290.06	GB12
3	1215.32	370.43	823.73	251.07	949.60	289.44	GB13
4	1175.94	358.43	841.24	256.41	949.26	289.33	GB14
5	1136.55	346.42	857.95	261.50	950.94	289.85	GB15
6	1101.05	335.60	873.04	266.10	950.73	289.78	GB16
7	1067.77	325.46	887.10	270.39	951.70	290.08	GB17
8	1029.46	313.78	903.98	275.53	953.66	290.68	GB18
9	1002.59	305.59	915.97	279.19	958.57	292.17	GB19
10	974.85	297.14	927.83	282.80	963.77	293.76	GB110
11	1257.27	383.21	740.25	225.63	912.45	278.11	GB21
12	1222.16	372.51	755.84	230.38	908.96	277.05	GB22
13	1194.85	364.19	766.65	233.67	907.09	276.48	GB23
14	1167.96	355.99	778.27	237.22	906.00	276.15	GB24
15	1138.41	346.99	791.15	241.14	906.90	276.42	GB25

16	1107.13	337.45	804.91	245.34	910.89	277.64	GB26
17	1081.21	329.55	815.30	248.50	914.53	278.75	GB27
18	1033.92	315.14	835.79	254.75	913.64	278.48	GB28
19	1006.62	306.82	847.99	258.47	924.31	281.73	GB29
20	1226.77	373.92	686.91	209.37	867.20	264.32	GB31
21	1177.29	358.84	706.96	215.48	868.58	264.74	GB32
22	1133.51	345.49	727.82	221.84	870.42	265.30	GB33
23	1100.40	335.40	741.06	225.88	874.77	266.63	GB34
24	1072.70	326.96	753.06	229.53	879.53	268.08	GB35
25	1042.62	317.79	766.02	233.48	882.32	268.93	GB36
26	1016.76	309.91	778.12	237.17	891.17	271.63	GB37
27	1184.88	361.15	634.09	193.27	834.85	254.46	GB41
28	1139.40	347.29	654.28	199.42	839.42	255.85	GB42
29	1100.71	335.50	670.75	204.44	848.78	258.71	GB43
30	1065.23	324.68	686.93	209.38	859.37	261.94	GB44
31	1031.72	314.47	702.69	214.18	872.75	266.01	GB45

BASE LINE SURVEY

Brown Spoil Area

Base line Survey	6/19/2009		Location	Peel Poplar Mine (Pike County)			
Reference points							
	Northing		**Easting**		**Elevation**		**Description**
No.	**(ft.)**	**(m)**	**(ft.)**	**(m)**	**(ft.)**	**(m)**	
1	1000	304.8	1000	304.8	1000	304.8	Fixed Point 1
2	727.07	221.61	682.48	208.02	1000.16	304.85	Fixed Point 2
Monuments							
No.	**Northing**		**Easting**		**Elevation**		**Description**
	(ft.)	**(m)**	**(ft.)**	**(m)**	**(ft.)**	**(m)**	
1	725.52	221.14	718.40	218.97	999.16	304.54	BB11
2	744.63	226.96	741.68	226.06	990.21	301.81	BB12
3	789.76	240.72	801.52	244.30	989.60	301.63	BB13
4	814.85	248.37	834.47	254.35	985.97	300.52	BB14
5	833.03	253.91	857.78	261.45	983.73	299.84	BB15
6	853.75	260.22	885.53	269.91	989.42	301.57	BB16
7	870.60	265.36	906.55	276.32	992.00	302.36	BB17
8	883.86	269.40	924.56	281.81	996.99	303.88	BB18
9	899.80	274.26	945.56	288.21	996.80	303.82	BB19
10	926.42	282.37	979.62	298.59	994.26	303.05	BB110
11	814.41	248.23	700.27	213.44	954.96	291.07	BB21
12	841.21	256.40	735.82	224.28	949.01	289.26	BB22
13	852.65	259.89	751.60	229.09	943.96	287.72	BB23
14	867.21	264.32	770.89	234.97	940.61	286.70	BB24
15	880.17	268.28	788.44	240.32	940.11	286.54	BB25
16	897.72	273.62	812.24	247.57	942.84	287.38	BB26

17	909.50	277.22	828.31	252.47	945.43	288.17	BB27
18	922.65	281.22	845.43	257.69	948.25	289.03	BB28
19	936.37	285.41	863.63	263.23	952.57	290.34	BB29
20	947.87	288.91	879.44	268.05	954.20	290.84	BB210
21	962.39	293.34	898.49	273.86	956.99	291.69	BB211
22	884.52	269.60	662.09	201.81	923.44	281.47	BB31
23	911.18	277.73	697.63	212.64	911.66	277.88	BB32
24	924.50	281.79	715.27	218.02	909.80	277.31	BB33
25	936.04	285.31	730.87	222.77	906.88	276.42	BB34
26	949.25	289.33	748.88	228.26	904.83	275.79	BB35
27	965.02	294.14	769.07	234.41	904.16	275.59	BB36
28	979.38	298.51	787.89	240.15	905.11	275.88	BB37
29	994.85	303.23	808.79	246.52	907.54	276.62	BB38
30	920.46	280.56	573.55	174.82	903.56	275.41	BB41
31	935.26	285.07	593.33	180.85	898.40	273.83	BB42
32	950.08	289.58	617.87	188.33	892.58	272.06	BB43
33	961.82	293.16	630.77	192.26	887.79	270.60	BB44
34	973.13	296.61	646.36	197.01	882.81	269.08	BB45
35	1000.89	305.07	682.89	208.15	878.11	267.65	BB46
36	964.18	293.88	501.26	152.79	879.62	268.11	BB51
37	995.19	303.33	541.86	165.16	866.49	264.11	BB52
38	1030.31	314.04	587.92	179.20	855.77	260.84	BB53
39	1060.49	323.24	628.38	191.53	850.58	259.26	BB54

FINAL SURVEY

Gray Spoil Area

Final Survey	5/14/2010		Location		Peel Poplar Mine (Pike County)		
Reference points							
	Northing		**Easting**		**Elevation**		**Description**
No.	**(ft.)**	**(m)**	**(ft.)**	**(m)**	**(ft.)**	**(m)**	
1	1000	304.8	1000	304.8	1000	304.8	Fixed Point 1
2	727.07	221.61	682.48	208.02	1000.16	304.85	Fixed Point 2
Monuments							
No.	**Northing**		**Easting**		**Elevation**		**Description**
	(ft.)	**(m)**	**(ft.)**	**(m)**	**(ft.)**	**(m)**	
1	1274.72	388.53	798.28	243.31	952.51	290.33	GB11
2	1239.73	377.87	812.70	247.71	951.63	290.06	GB12
3	1214.72	370.25	823.18	250.91	949.62	289.44	GB13
4	1175.52	358.30	841.35	256.44	949.44	289.39	GB14
5	1136.21	346.32	857.80	261.46	951.11	289.90	GB15
6	1100.53	335.44	873.51	266.25	950.95	289.85	GB16
7	1066.99	325.22	887.18	270.41	951.92	290.15	GB17
8	1029.00	313.64	903.88	275.50	954.00	290.78	GB18
9	1002.52	305.57	915.67	279.10	958.58	292.18	GB19
10	974.82	297.13	927.75	282.78	964.27	293.91	GB110
11	1256.77	383.06	740.04	225.56	912.48	278.12	GB21
12	1221.71	372.38	755.41	230.25	909.17	277.12	GB22
13	1194.58	364.11	766.53	233.64	907.23	276.52	GB23
14	1167.60	355.88	778.07	237.16	906.39	276.27	GB24
15	1138.35	346.97	790.86	241.06	907.41	276.58	GB25

16	1106.73	337.33	804.91	245.34	910.89	277.64	GB26
17	1080.79	329.42	815.02	248.42	914.64	278.78	GB27
18	1033.95	315.15	836.09	254.84	914.01	278.59	GB28
19	1006.76	306.86	847.92	258.45	924.51	281.79	GB29
20	1226.31	373.78	686.87	209.36	867.61	264.45	GB31
21	1177.16	358.80	706.73	215.41	868.37	264.68	GB32
22	1133.34	345.44	727.65	221.79	870.85	265.44	GB33
23	1100.51	335.44	740.93	225.84	875.10	266.73	GB34
24	1072.49	326.89	753.03	229.52	879.96	268.21	GB35
25	1042.56	317.77	765.86	233.44	882.73	269.06	GB36
26	1016.80	309.92	778.52	237.29	891.58	271.75	GB37
27	1184.74	361.11	633.85	193.20	835.17	254.56	GB41
28	1139.17	347.22	653.96	199.33	839.77	255.96	GB42
29	1100.80	335.52	671.26	204.60	849.28	258.86	GB43
30	1065.18	324.67	687.16	209.45	859.67	262.03	GB44
31	1031.49	314.40	702.74	214.19	872.99	266.09	GB45

FINAL SURVEY

Brown Spoil Area

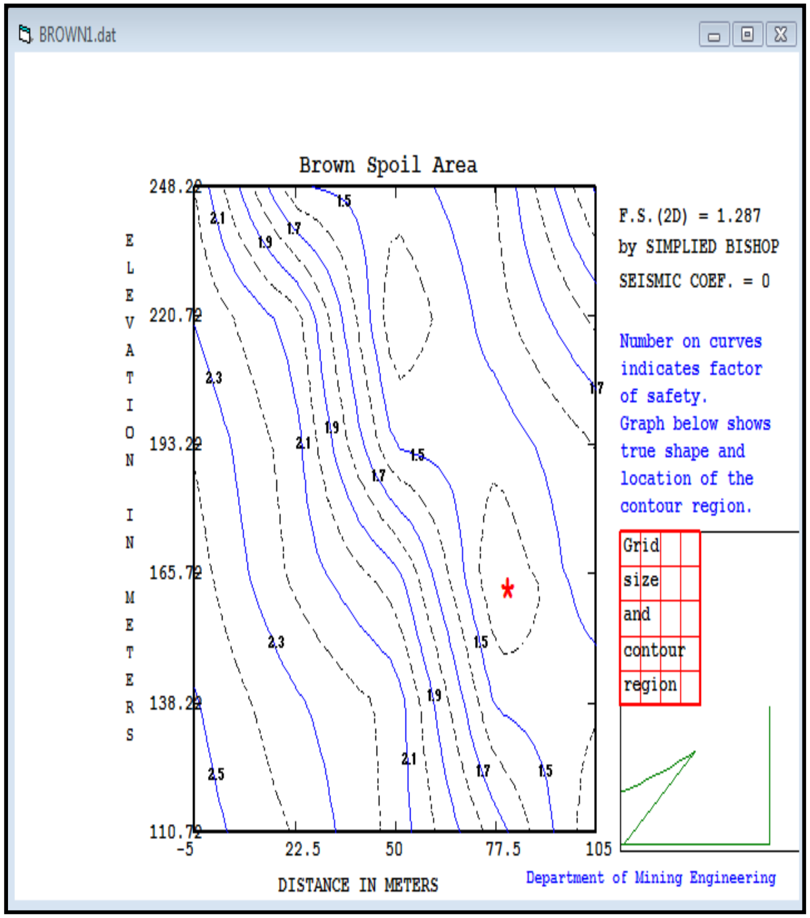
Final Survey	5/14/2010		Location	Peel Poplar Mine (Pike County)			
Reference points							
	Northing		Easting		Elevation		Description
No.	(ft.)	(m)	(ft.)	(m)	(ft.)	(m)	
1	1000	304.8	1000	304.8	1000	304.8	Fixed Point 1
2	727.07	221.61	682.48	208.02	1000.16	304.85	Fixed Point 2
Monuments							
No.	Northing		Easting		Elevation		Description
	(ft.)	(m)	(ft.)	(m)	(ft.)	(m)	
1	725.63	221.17	718.77	219.08	999.20	304.56	BB11
2	744.64	226.97	742.05	226.18	990.66	301.95	BB12
3	789.73	240.71	801.75	244.37	989.91	301.73	BB13
4	814.91	248.39	834.71	254.42	986.39	300.65	BB14
5	833.76	254.13	857.92	261.49	984.13	299.96	BB15
6	853.90	260.27	885.15	269.79	989.84	301.70	BB16
7	870.76	265.41	906.62	276.34	992.40	302.48	BB17
8	884.07	269.47	924.51	281.79	996.47	303.72	BB18
9	900.05	274.34	945.83	288.29	997.31	303.98	BB19
10	926.35	282.35	979.46	298.54	994.76	303.20	BB110
11	814.60	248.29	700.52	213.52	955.27	291.17	BB21
12	841.55	256.50	736.26	224.41	949.32	289.35	BB22
13	852.94	259.98	751.99	229.21	944.29	287.82	BB23
14	867.41	264.39	771.22	235.07	940.53	286.67	BB24
15	880.57	268.40	788.94	240.47	940.91	286.79	BB25
16	897.94	273.69	812.26	247.58	943.34	287.53	BB26

17	909.39	277.18	828.54	252.54	945.83	288.29	BB27
18	922.88	281.29	845.80	257.80	948.63	289.14	BB28
19	936.61	285.48	863.70	263.25	952.92	290.45	BB29
20	947.75	288.87	879.20	267.98	954.62	290.97	BB210
21	962.60	293.40	898.06	273.73	957.38	291.81	BB211
22	884.48	269.59	662.59	201.96	923.84	281.59	BB31
23	911.00	277.67	698.04	212.76	912.04	277.99	BB32
24	924.54	281.80	715.65	218.13	910.20	277.43	BB33
25	936.30	285.38	731.31	222.90	907.26	276.53	BB34
26	949.48	289.40	749.01	228.30	905.16	275.89	BB35
27	964.99	294.13	769.46	234.53	904.55	275.71	BB36
28	979.56	298.57	788.03	240.19	905.49	275.99	BB37
29	994.71	303.19	809.34	246.69	908.07	276.78	BB38
30	920.88	280.68	573.73	174.87	903.41	275.36	BB41
31	935.66	285.19	593.52	180.90	898.45	273.85	BB42
32	949.91	289.53	618.25	188.44	892.74	272.11	BB43
33	961.69	293.12	631.15	192.37	887.97	270.65	BB44
34	972.94	296.55	646.45	197.04	883.08	269.16	BB45
35	1000.81	305.05	683.40	208.30	878.54	267.78	BB46
36	964.10	293.86	501.45	152.84	879.48	268.07	BB51
37	995.30	303.37	541.97	165.19	866.54	264.12	BB52
38	1030.25	314.02	588.33	179.32	855.90	260.88	BB53
39	1060.17	323.14	628.92	191.69	851.12	259.42	BB54

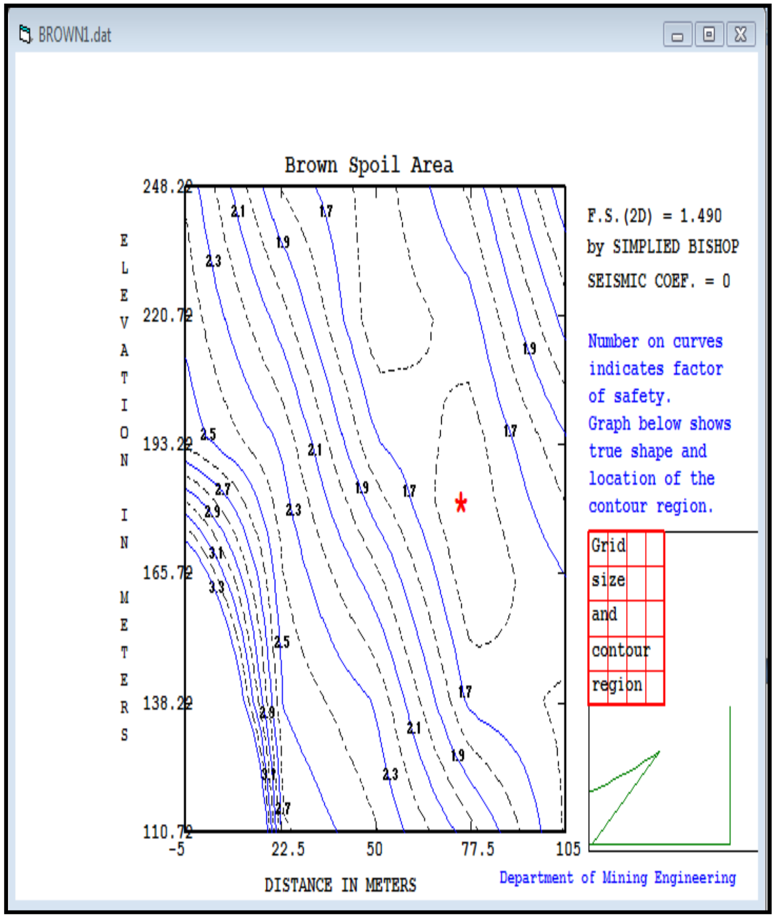
APPENDIX C

Slope Stability Analysis

Contours of Safety Factor - Brown Spoil Area

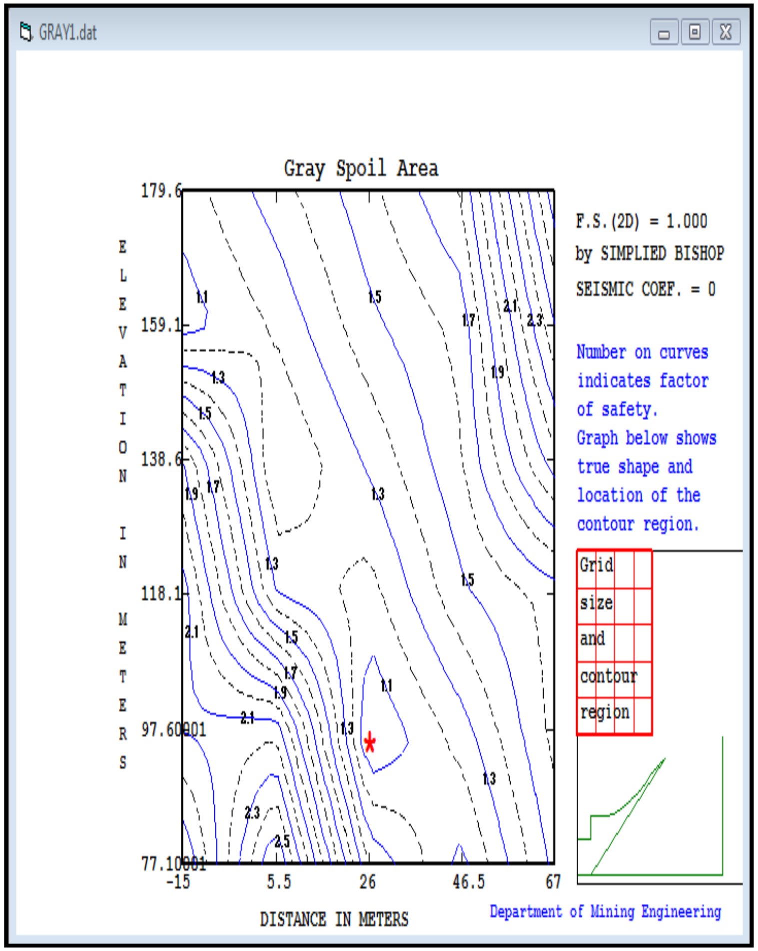


(A) Minimum safety factor

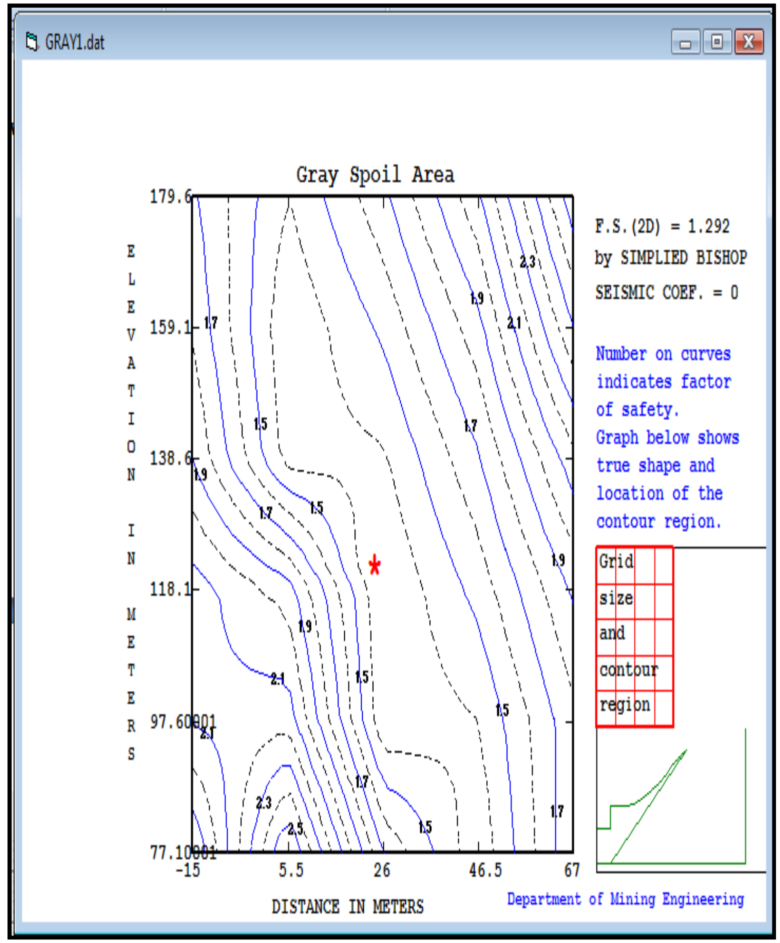


(B) With DMIN 3 m

Contours of Safety Factor- Gray Spoil Area

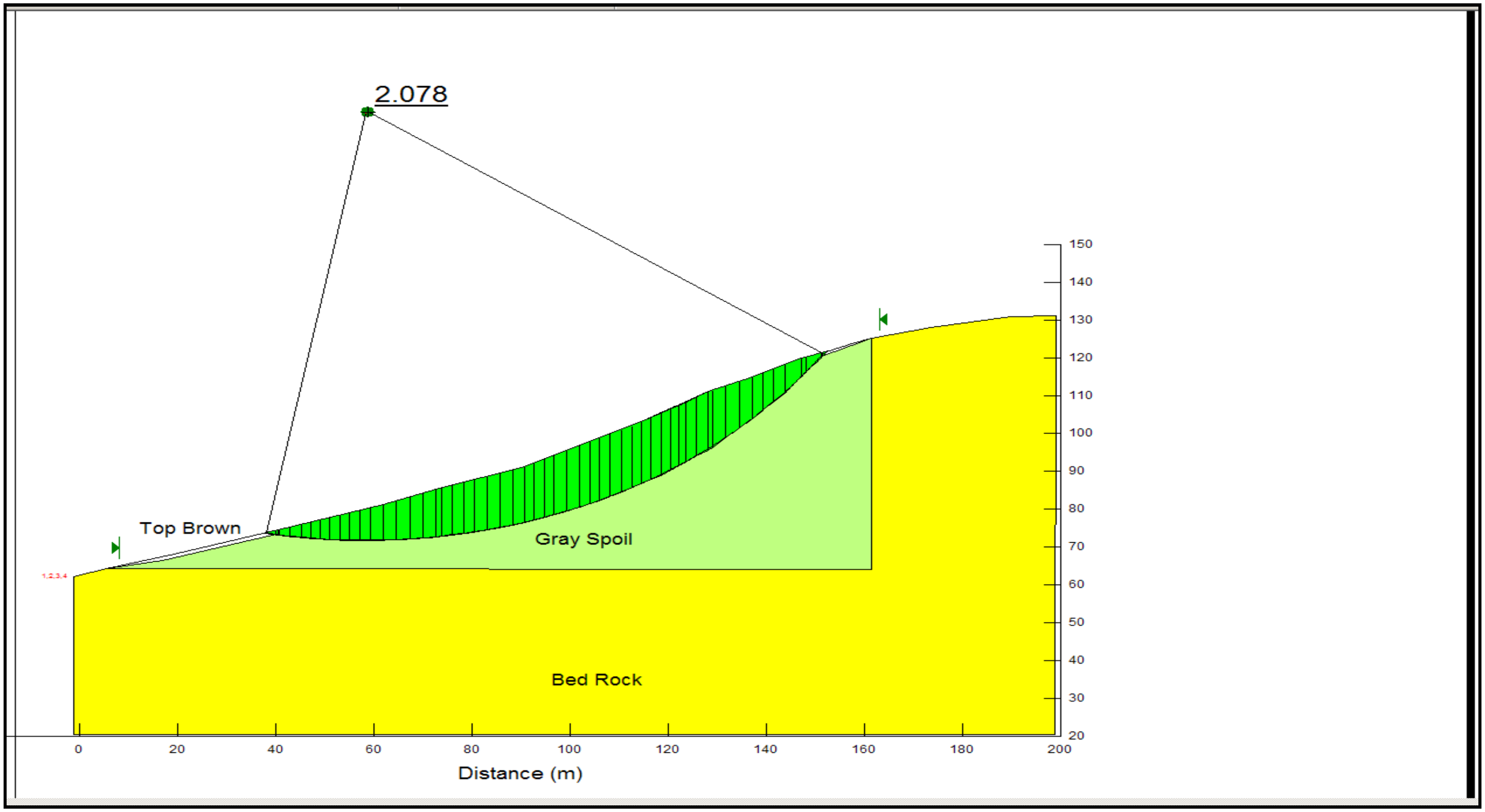


(A) Minimum safety factor

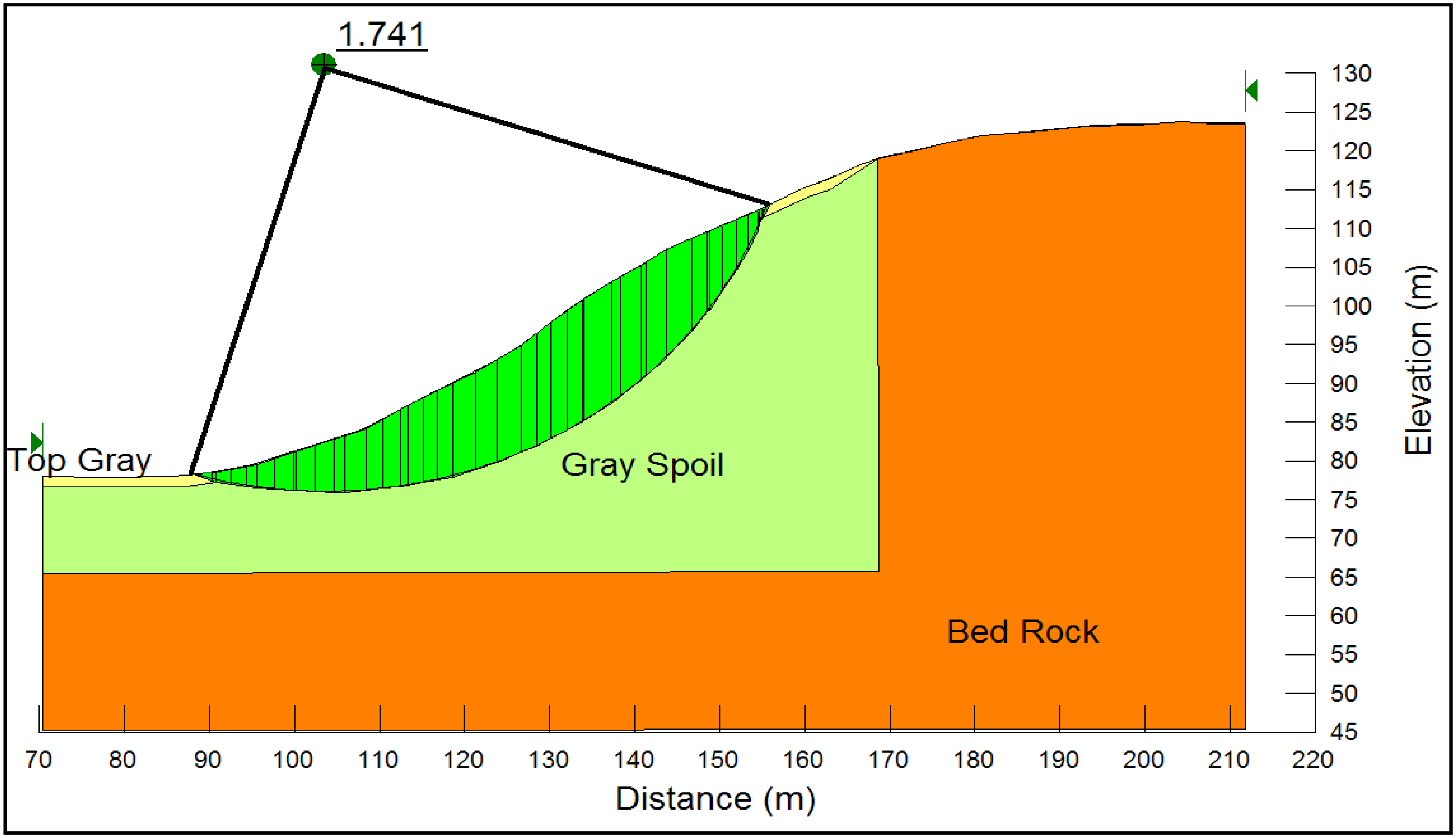


(B) With DMIN 3 m

Geo-Slope model for brown spoil area considering overall slope



Geo-Slope model for gray spoil area considering overall slope



APPENDIX D

Nuclear Density Gauge and Penetrometer Data

BULK DENSITY

Bulk Density Readings for Gray Spoil Area

Period	June, 2009		**Location**	Peel Poplar (Pike County)		
Weather	Clear		**Area**	Gray Spoil		
Sample No.	**Dry Bulk Density**					
	5.1 cm (2 in.) Depth		**15.2 cm (6 in.) Depth**		**30.5 cm (12 in.) Depth**	
	(Pcf)	**(g/cm^3)**	**(Pcf)**	**(g/cm^3)**	**(Pcf)**	**(g/cm^3)**
1	92.1	1.476	98.00	1.57	99.80	1.60
2	97.9	1.569	100.50	1.61	107.50	1.72
3	84.5	1.354	103.70	1.66	106.30	1.70
4	88.1	1.412	101.70	1.63	105.80	1.70
5	78.2	1.253	92.70	1.49	0.00	0.00
6	95.2	1.526	102.70	1.65	107.10	1.72
7	93.3	1.495	100.60	1.61	107.20	1.72
8	86.2	1.381	93.60	1.50	100.50	1.61
9	96	1.538	110.80	1.78	118.60	1.90
10	97.3	1.559	109.30	1.75	117.30	1.88
11	97.8	1.567	110.90	1.78	117.80	1.89
12	100.1	1.604	111.90	1.79	116.20	1.86
13	104.8	1.679	115.10	1.84	0.00	0.00
14	103.6	1.660	114.80	1.84	115.10	1.84
15	103.5	1.659	102.20	1.64	106.90	1.71
16	102.8	1.647	102.40	1.64	105.80	1.70
17	101.8	1.631	102.30	1.64	106.20	1.70
18	95.6	1.532	104.90	1.68	105.30	1.69
19	84.7	1.357	95.90	1.54	99.30	1.59

20	92.5	1.482	96.80	1.55	104.90	1.68
21	93.1	1.492	97.10	1.56	105.80	1.70
22	90.5	1.450	97.80	1.57	103.10	1.65
23	83.9	1.345	101.40	1.63	0.00	0.00
24	83.4	1.337	98.10	1.57	103.80	1.66
25	81.8	1.311	99.50	1.59	101.40	1.63
26	78.3	1.255	97.30	1.56	100.80	1.62
27	67.5	1.082	86.50	1.39	97.70	1.57
28	66.8	1.071	87.10	1.40	98.10	1.57
29	79.6	1.276	88.40	1.42	99.40	1.59
30	78.5	1.258	87.40	1.40	97.40	1.56
31	78.9	1.264	87.90	1.41	98.30	1.58
Average	**89.62**	**1.44**	**99.98**	**1.60**	**95.27**	**1.53**
Std dev	**10.32**	**0.17**	**7.99**	**0.13**	**32.27**	**0.52**

BULK DENSITY
Bulk Density Readings for Brown Spoil Area

Period	June, 2009		**Location**	Peel Poplar (Pike County)		
Weather	Clear		**Area**	Brown Spoil		
Sample No.	**Dry Bulk Density**					
	5.1 cm (2 in.) Depth		**15.2 cm (6 in.) Depth**		**30.5 cm (12 in.) Depth**	
	(Pcf)	**(g/cm^3)**	**(Pcf)**	**(g/cm^3)**	**(Pcf)**	**(g/cm^3)**
1	93.80	1.50	85.00	1.36	86.4	1.38
2	77.90	1.25	103.50	1.66	110.3	1.77
3	104.30	1.67	113.60	1.82	119.3	1.91
4	69.50	1.11	83.00	1.33	92.2	1.48
5	68.20	1.09	66.90	1.07	71	1.14
6	76.60	1.23	77.20	1.24	82	1.31
7	107.50	1.72	110.80	1.78	110.5	1.77
8	106.80	1.71	98.00	1.57	105.2	1.69
9	84.20	1.35	87.90	1.41	95.9	1.54
10	82.00	1.31	82.70	1.33	84.6	1.36
11	73.60	1.18	78.60	1.26	97.7	1.57
12	74.10	1.19	79.00	1.27	97.1	1.56
13	67.50	1.08	91.10	1.46	96.4	1.54
14	69.10	1.11	92.10	1.48	97	1.55
15	74.90	1.20	92.80	1.49	97.4	1.56
16	76.10	1.22	92.50	1.48	96.1	1.54
17	73.20	1.17	77.70	1.25	97.3	1.56
18	74.10	1.19	77.30	1.24	96.9	1.55
19	65.60	1.05	88.30	1.42	97.2	1.56
20	63.40	1.02	86.30	1.38	96.7	1.55

21	62.70	1.00	85.20	1.37	95.8	1.54
22	67.40	1.08	94.40	1.51	102.1	1.64
23	68.00	1.09	94.10	1.51	101.8	1.63
24	66.80	1.07	93.20	1.49	102.1	1.64
25	64.80	1.04	83.90	1.34	101.9	1.63
26	65.00	1.04	84.20	1.35	101.7	1.63
27	80.60	1.29	100.80	1.62	104.3	1.67
28	81.50	1.31	99.20	1.59	103.9	1.67
29	83.40	1.34	98.50	1.58	105.1	1.68
30	90.00	1.44	95.80	1.54	103.1	1.65
31	91.30	1.46	96.50	1.55	102.5	1.64
32	92.80	1.49	97.80	1.57	101.4	1.63
33	70.50	1.13	90.90	1.46	102.2	1.64
34	71.80	1.15	91.40	1.46	100.3	1.61
35	72.00	1.15	90.30	1.45	100.1	1.60
36	68.90	1.10	90.50	1.45	98.6	1.58
37	69.00	1.11	89.40	1.43	98.1	1.57
38	68.00	1.09	91.70	1.47	97.4	1.56
39	69.50	1.11	92.70	1.49	98.9	1.58
Average	**76.57**	**1.23**	**90.38**	**1.45**	**98.68**	**1.58**
Std dev	**11.92**	**0.19**	**9.21**	**0.15**	**8.01**	**0.13**

BULK DENSITY
Bulk Density Readings for Gray Spoil Area

Period	May , 2010		**Location**	Peel Poplar (Pike County)	
Weather	Clear		**Area**	Gray Spoil	

Sample No.	**Dry Bulk Density**					
	5.1 cm (2 in.) Depth		**15.2 cm (6 in.) Depth**		**30.5 cm (12 in.) Depth**	
	(Pcf)	**(g/cm^3)**	**(Pcf)**	**(g/cm^3)**	**(Pcf)**	**(g/cm^3)**
1	98.5	1.58	101.2	1.62	99.80	1.60
2	94.7	1.52	109.4	1.75	107.50	1.72
3	92.1	1.48	105.4	1.69	106.30	1.70
4	99.8	1.599	111.9	1.79	105.80	1.70
5	93.1	1.492	114.6	1.84	107.30	1.72
6	83.2	1.333	105.2	1.69	107.10	1.72
7	95.5	1.530	107.1	1.72	107.20	1.72
8	87.4	1.401	102.8	1.65	100.50	1.61
9	92.7	1.486	100.5	1.61	118.60	1.90
10	91.8	1.471	104.3	1.67	117.30	1.88
11	101.9	1.633	112.3	1.80	117.80	1.89
12	101.8	1.631	111.3	1.78	116.20	1.86
13	93.6	1.500	104.5	1.67	116.80	1.87
14	95.2	1.526	107.5	1.72	115.10	1.84
15	106.2	1.702	112	1.79	106.90	1.71
16	101.1	1.620	104.7	1.68	105.80	1.70
17	100.4	1.609	103.8	1.66	106.20	1.70
18	101.1	1.620	103.2	1.65	105.30	1.69
19	100.6	1.612	105.3	1.69	99.30	1.59
20	102.4	1.641	105.5	1.69	104.90	1.68

21	102.4	1.641	101.7	1.63	105.80	1.70
22	89.9	1.441	108.3	1.74	103.10	1.65
23	71.3	1.143	95.1	1.52	102.70	1.65
24	89.9	1.441	107.7	1.73	103.80	1.66
25	96.7	1.550	128.5	2.06	101.40	1.63
26	94.5	1.514	110.1	1.76	100.80	1.62
27	93.5	1.498	107.2	1.72	97.70	1.57
28	80.2	1.285	105.8	1.70	98.10	1.57
29	98.1	1.572	103.3	1.66	99.40	1.59
30	94.4	1.513	103.1	1.65	97.40	1.56
31	97.1	1.556	104.2	1.67	98.30	1.58
Average	**94.87**	**1.52**	**106.69**	**1.71**	**105.81**	**1.70**
Std dev	**7.25**	**0.12**	**5.73**	**0.09**	**6.41**	**0.10**

BULK DENSITY
Bulk Density Readings for Brown Spoil Area

Period	May , 2009	**Location**	Peel Poplar (Pike County)
Weather	Clear	**Area**	Brown Spoil

Sample No.	**Dry Bulk Density**					
	5.1 cm (2 in.) Depth		**15.2 cm (6 in.) Depth**		**50.5 cm (12 in.) Depth**	
	(Pcf)	**(g/cm^3)**	**(Pcf)**	**(g/cm^3)**	**(Pcf)**	**(g/cm^3)**
1	97.1	1.56	110.8	1.78	-	-
2	96.3	1.54	110.5	1.77	115.4	1.85
3	90.7	1.45	89.3	1.43	98.3	1.58
4	80.2	1.29	84.4	1.35	85.2	1.37
5	75	1.20	75.4	1.21	72.6	1.16
6	72.4	1.16	85.5	1.37	89.6	1.44
7	82.7	1.33	97.2	1.56	-	-
8	88.2	1.41	101.5	1.63	103.1	1.65
9	95.4	1.53	103.6	1.66	96.2	1.54
10	87.6	1.40	94.1	1.51	99.6	1.60
11	80.8	1.29	92.6	1.48	98.5	1.58
12	81.3	1.30	95.1	1.52	101.1	1.62
13	82.1	1.32	94.2	1.51	98.6	1.58
14	79.5	1.27	97.3	1.56	-	-
15	75.9	1.22	99.6	1.60	103.7	1.66
16	82.9	1.33	94.1	1.51	99.1	1.59
17	87.3	1.40	91.4	1.46	92.5	1.48
18	92.5	1.48	95.1	1.52	94.6	1.52
19	90.2	1.45	98.8	1.58	-	-
20	91.8	1.47	91.5	1.47	104.2	1.67

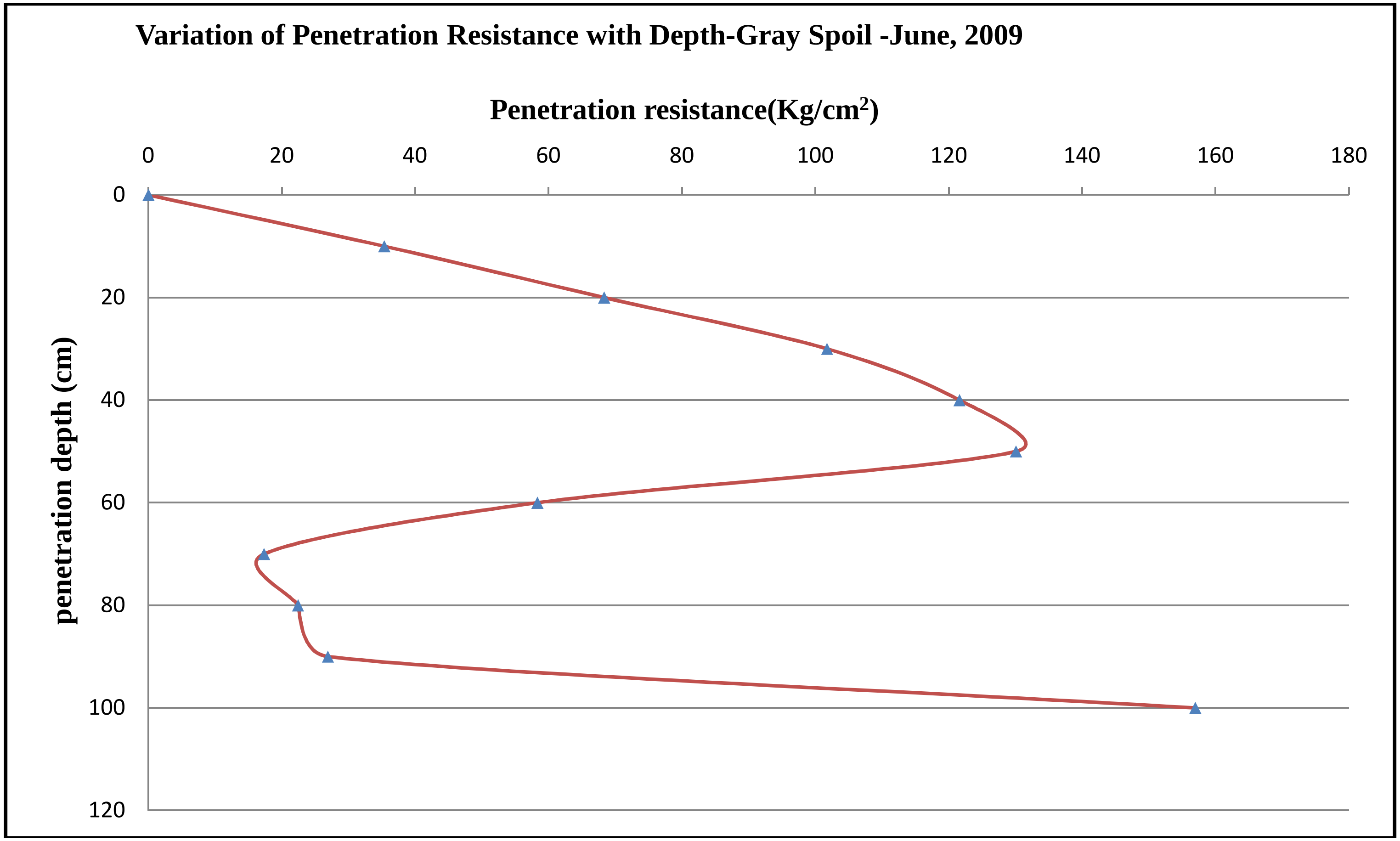
21	93.1	1.49	93.6	1.50	103.9	1.67
22	99.3	1.59	104.7	1.68	113.5	1.82
23	77.1	1.24	91.8	1.47	100.2	1.61
24	86.1	1.38	109.5	1.75	114.9	1.84
25	89.7	1.44	88.7	1.42	-	-
26	75.1	1.20	87.6	1.40	112.1	1.80
27	87.5	1.40	97.3	1.56	100.7	1.61
28	87.2	1.40	108	1.73	114.4	1.83
29	95	1.52	111.1	1.78	112.1	1.80
30	89.1	1.43	92.1	1.48	102.4	1.64
31	84.5	1.35	104.6	1.68	108.1	1.73
32	97.1	1.56	116.5	1.87	117.9	1.89
33	92.3	1.48	110.3	1.77	114.3	1.83
34	94.1	1.51	108.9	1.75	112.5	1.80
35	88.3	1.42	107.9	1.73	-	-
36	82.9	1.33	96.4	1.54	112.2	1.80
37	84.9	1.36	97.3	1.56	111.9	1.79
38	89.9	1.44	106.5	1.71	106.6	1.71
39	87.3	1.40	105.9	1.70	106.1	1.70
Average	**86.93**	**1.39**	**98.48**	**1.58**	**103.52**	**1.66**
Std dev	**6.83**	**0.11**	**9.02**	**0.14**	**9.84**	**0.16**

PENETRATION RESISTANCE
Blow Count Gray Spoil Area

Period	June, 2009					Location	Peel Poplar (Pike County)				
Weather	Clear					Area	Gray Spoil				
Sample No.	Number of Blows										Maxi. Penetration Depth (cm)
	10 (cm)	20 (cm)	30 (cm)	40 (cm)	50 (cm)	60 (cm)	70 (cm)	80 (cm)	90 (cm)	100 (cm)	
1	17	35									20
2	9	11	8	12	11	13	4	5	6	35	95
3	4	6	10	37							37
4	4	11	16	35							40
5	6	13	14	16	35						45
6	6	17	35								30
7	5	9	12	35							40
8	9	12	35								30
9	9	17	35								30
10	12	23	35								30
11	4	13	12	35							40
12	5	9	12	19	35						45
13	6	15	16	35							37
14	9	17	35								30
15	6	11	18	20	35						50
16	5	20	35								30
17	18	20	35								30

PENETRATION RESISTANCE
Penetration Resistances for Gray Spoil Area

Period	June, 2009				Location	Peel Poplar				
Weather	Clear				Area	Gray Spoil				
Sample No.	Penetration Resistance									
	10 (cm) (kg/cm^2)	20 (cm) (kg/cm^2)	30 (cm) (kg/cm^2)	40 (cm) (kg/cm^2)	50 (cm) (kg/cm^2)	60 (cm) (kg/cm^2)	70 (cm) (kg/cm^2)	80 (cm) (kg/cm^2)	90 (cm) (kg/cm^2)	100 (cm) (kg/cm^2)
1	76.24	156.95								
2	40.36	49.33	35.88	53.81	49.33	58.30	17.94	22.42	26.91	156.95
3	17.94	26.91	44.84	165.92						
4	17.94	49.33	71.75	156.95						
5	26.91	58.30	62.78	71.75	156.95					
6	26.91	76.24	156.95							
7	22.42	40.36	53.81	156.95						
8	40.36	53.81	156.95							
9	40.36	76.24	156.95							
10	53.81	103.14	156.95							
11	17.94	58.30	53.81	156.95						
12	22.42	40.36	53.81	85.20	156.95					
13	26.91	67.27	71.75	156.95						
14	40.36	76.24	156.95							
15	26.91	49.33	80.72	89.69	156.95					
16	22.42	89.69	156.95							
17	80.72	89.69	156.95							
Average	**35.35**	**68.32**	**101.74**	**121.58**	**130.05**	**58.30**	**17.94**	**22.42**	**26.91**	**156.95**
Std dev	**19.15**	**30.56**	**51.36**	**45.26**	**53.81**					


Variation of Penetration Resistance with Depth-Gray Spoil -June, 2009
Penetration resistance(Kg/cm2)
0
20
40
60
80
100
120
140
160
180
penetration depth (cm)
0
20
40
60
80
100
120

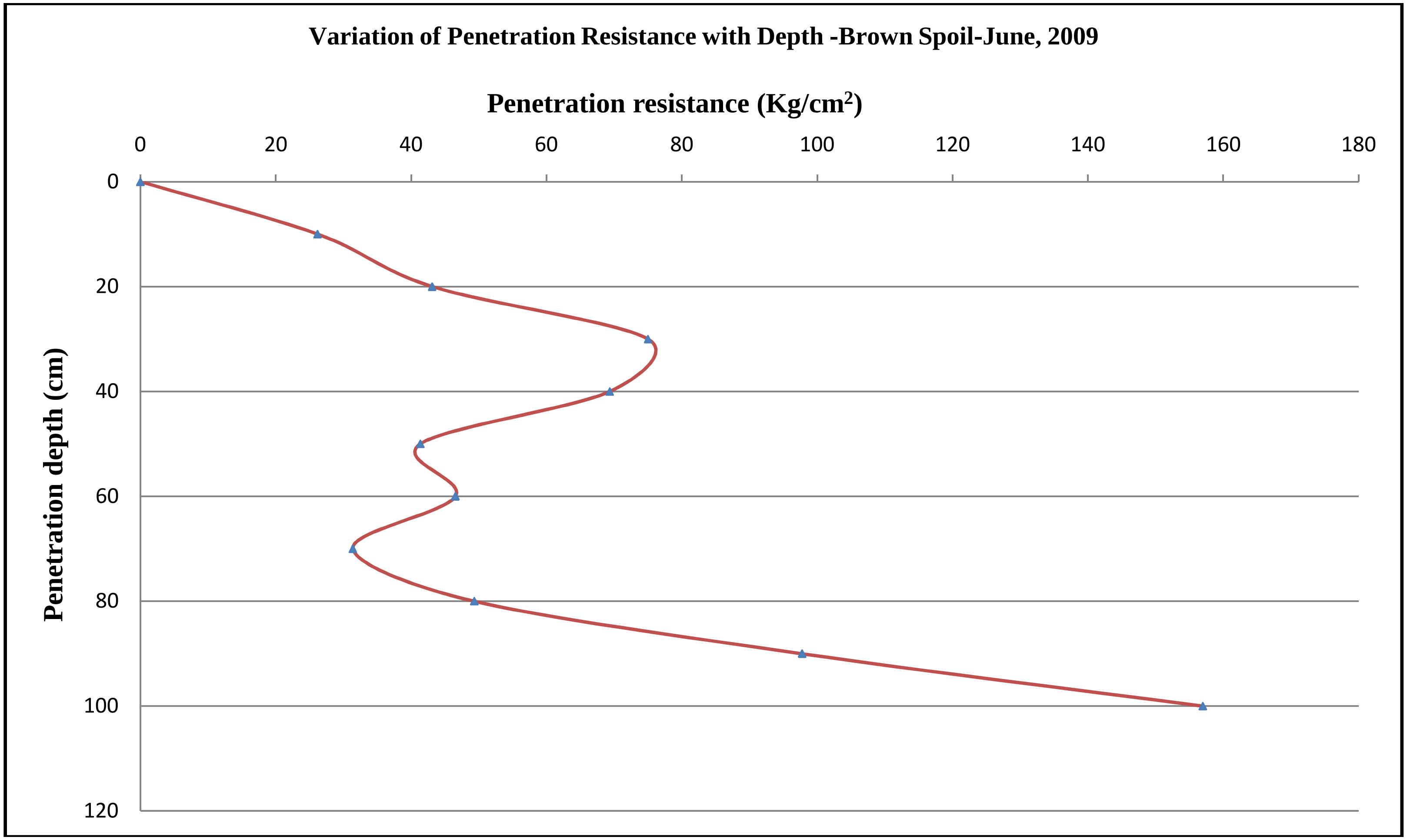
PENETRATION RESISTANCE
Blow Count-Brown Spoil Area

Period	June, 2009				Location	Peel Poplar(Pike County)				
Weather	Clear				Area	Brown Spoil				

Sample No.	Number of Blows									Max. Penetration Depth (cm)
	10 (cm)	20 (cm)	30 (cm)	40 (cm)	50 (cm)	60 (cm)	70 (cm)	80 (cm)	90 (cm)	100 (cm)	
1	10	17	35								30
2	8	10	35								30
3	4	5	4	2	2	7	1	2	2	35	95
4	9	19	15	15	14	21	35				68
5	3	4	4	1	1	1	2	10	35		90
6	3	6	5	5	7	6	6	13	35		85
7	5	7	8	10	9	6	6	35			77
8	4	20	35								30
9	4	5	3	3	2	6	5	4	35		85
10	7	15	35								30
11	3	3	5	8	4	1	1	2	2	35	95
12	4	6	37								30
13	4	3	3	4	9	35					60
14	6	7	9	13	35						50
15	6	10	13	35							35
16	11	12	13	35							33
17	5	9	18	35							38
18	9	15	24	35							40

PENETRATION RESISTANCE
Penetration Resistances for Brown Spoil Area

Period	June, 2009				Location	Peel Poplar (Pike County)				
Weather	Clear				Area	Brown Spoil				
No.	Penetration Resistance									
	10 (cm)	20 (cm)	30 (cm)	40 (cm)	50 (cm)	60 (cm)	70 (cm)	80 (cm)	90 (cm)	100 (cm)
	(kg/cm^2)	(kg/cm^2)	(kg/cm^2)	(kg/cm^2)	(kg/cm^2)	(kg/cm^2)	(kg/cm^2)	(kg/cm^2)	(kg/cm^2)	(kg/cm^2)
1	44.84	76.24	156.95							
2	35.88	44.84	156.95							
3	17.94	22.42	17.94	8.97	8.97	31.39	4.48	8.97	8.97	156.95
4	40.36	85.20	67.27	67.27	62.78	94.17	156.95			
5	13.45	17.94	17.94	4.48	4.48	4.48	8.97	44.84	156.95	
6	13.45	26.91	22.42	22.42	31.39	26.91	26.91	58.30	156.95	
7	22.42	31.39	35.88	44.84	40.36	26.91	26.91	156.95		
8	17.94	89.69	156.95							
9	17.94	22.42	13.45	13.45	8.97	26.91	22.42	17.94	156.95	
10	31.39	67.27	156.95							
11	13.45	13.45	22.42	35.88	17.94	4.48	4.48	8.97	8.97	156.95
12	17.94	26.91	165.92							
13	17.94	13.45	13.45	17.94	40.36	156.95				
14	26.91	31.39	40.36	58.30	156.95					
15	26.91	44.84	58.30	156.95						
16	49.33	53.81	58.30	156.95						
17	22.42	40.36	80.72	156.95						
18	40.36	67.27	107.63	156.95						
Average	**26.16**	**43.10**	**74.99**	**69.34**	**41.36**	**46.53**	**31.39**	**49.33**	**97.76**	**156.95**

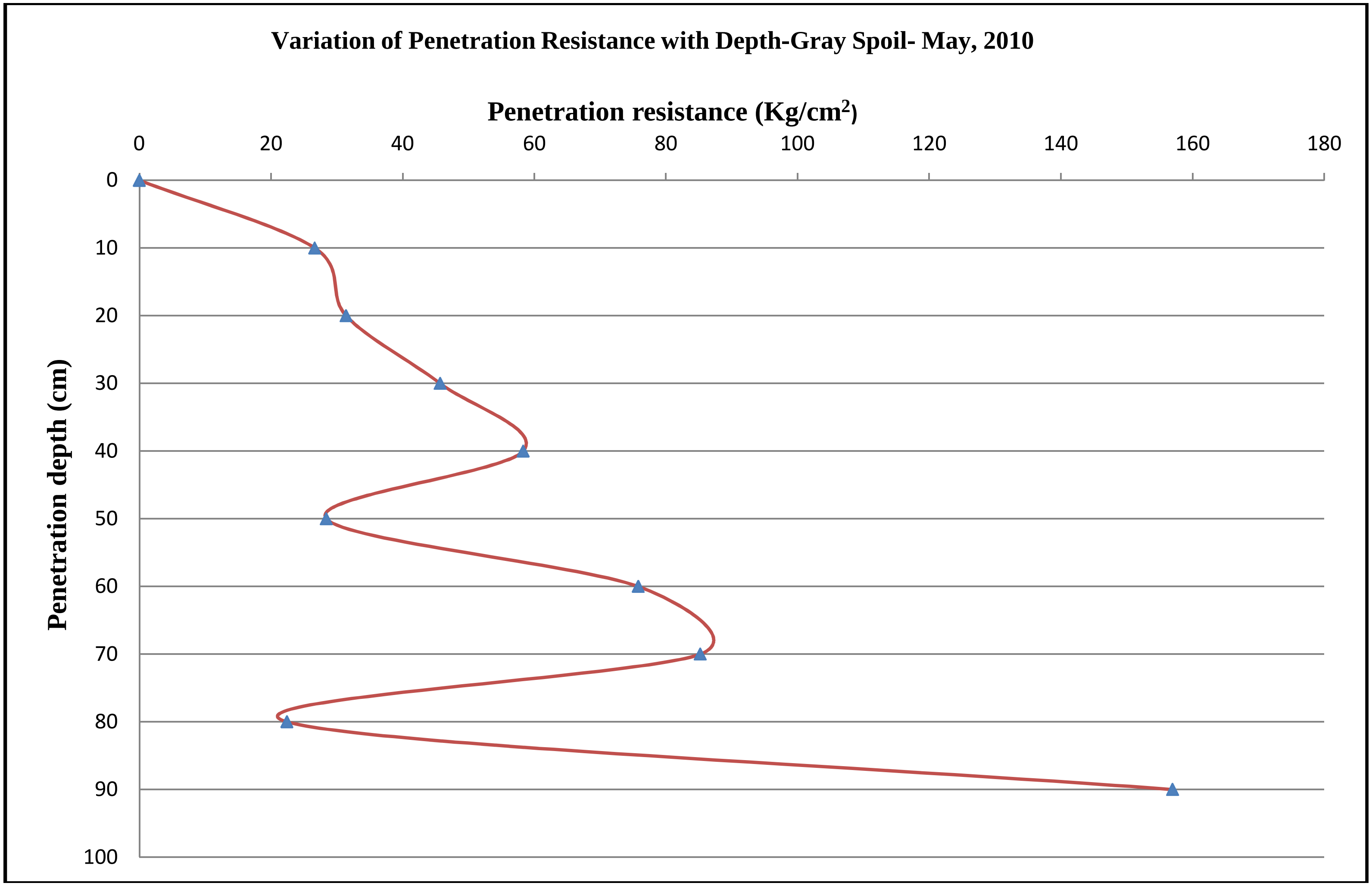

Variation of Penetration Resistance with Depth -Brown Spoil-June, 2009
Penetration resistance (Kg/cm2)
0
20
40
60
80
100
120
140
160
180
Penetration depth (cm)
0
20
40
60
80
100
120

PENETRATION RESISTANCE
Blow Count-Gray Spoil Area

Period	May, 2010						Location	Peel Poplar (Pike County)			
Weather	Clear						Area	Gray Spoil			
Sample No.	Number of Blows										Maxi. Penetration Depth (cm)
	10 (cm)	20 (cm)	30 (cm)	40 (cm)	50 (cm)	60 (cm)	70 (cm)	80 (cm)	90 (cm)	100 (cm)	
1	3	5	3	7	9	35					60
2	4	4	4	3	4	5	4	5	35		85
3	3	7	9	11	14	20	35				65
4	3	8	5	25	35	50					60
5	1	4	9	4	5	10	20	35			75
6	1	3	4	5	3	4	7	35			75
7	3	5	3	2	4	2	11	35			73
8	3	8	35								25
9	3	5	5	35							33
10	4	5	7	8	3	4	5	10	35		85
11	5	5	4	7	16	43	35				70
12	3	3	4	35							33
13	3	4	5	13	23	35					55
14	5	11	28	35							40
15	3	6	5	7	10	11	35				65
16	6	9	12	16	20	35					53
17	5	15	14	35	35						30

PENETRATION RESISTANCE
Penetration Resistances for Gray Spoil Area

Period	June, 2009				**Location**	Peel Poplar (Pike County)				
Weather	Clear				**Area**	Gray Spoil				
Sample No.	**Penetration Resistance**									
	10 (cm)	**20 (cm)**	**30 (cm)**	**40 (cm)**	**50 (cm)**	**60 (cm)**	**70 (cm)**	**80 (cm)**	**90(cm)**	**100 (cm)**
	(kg/cm^2)	**(kg/cm^2)**	**(kg/cm^2)**	**(kg/cm^2)**	**(kg/cm^2)**	**(kg/cm^2)**	**(kg/cm^2)**	**(kg/cm^2)**	**(kg/cm^2)**	**(kg/cm^2)**
1	13.45	22.42								
2	17.94	17.94	17.94	13.45	17.94	22.42	17.94	22.42	156.95	
3	13.45	31.39	40.36	49.33						
4	13.45	35.88	22.42	112.11						
5	4.48	17.94	40.36	17.94	22.42					
6	4.48	13.45	17.94							
7	13.45	22.42	13.45	8.97						
8	13.45	35.88	156.95							
9	13.45	22.42	22.42							
10	17.94	22.42	31.39							
11	22.42	22.42	17.94	31.39						
12	13.45	13.45	17.94	156.95						
13	13.45	17.94	22.42	58.30						
14	22.42	49.33	125.56							
15	13.45	26.91	22.42	31.39	44.84					
16	26.91	40.36	53.81							
17	22.42	67.27	62.78							
Average	**15.30**	**28.23**	**42.88**	**53.31**	**28.40**	**22.42**	**17.94**	**22.42**	**156.95**	
Std dev	**5.94**	**14.07**	**41.26**	**50.01**	**14.42**					


Variation of Penetration Resistance with Depth-Gray Spoil- May, 2010
Penetration resistance (Kg/cm2)
0
20
40
60
80
100
120
140
160
180
Penetration depth (cm)
0
10
20
30
40
50
60
70
80
90
100

PENETRATION RESISTANCE
Blow Count-Brown Spoil Area

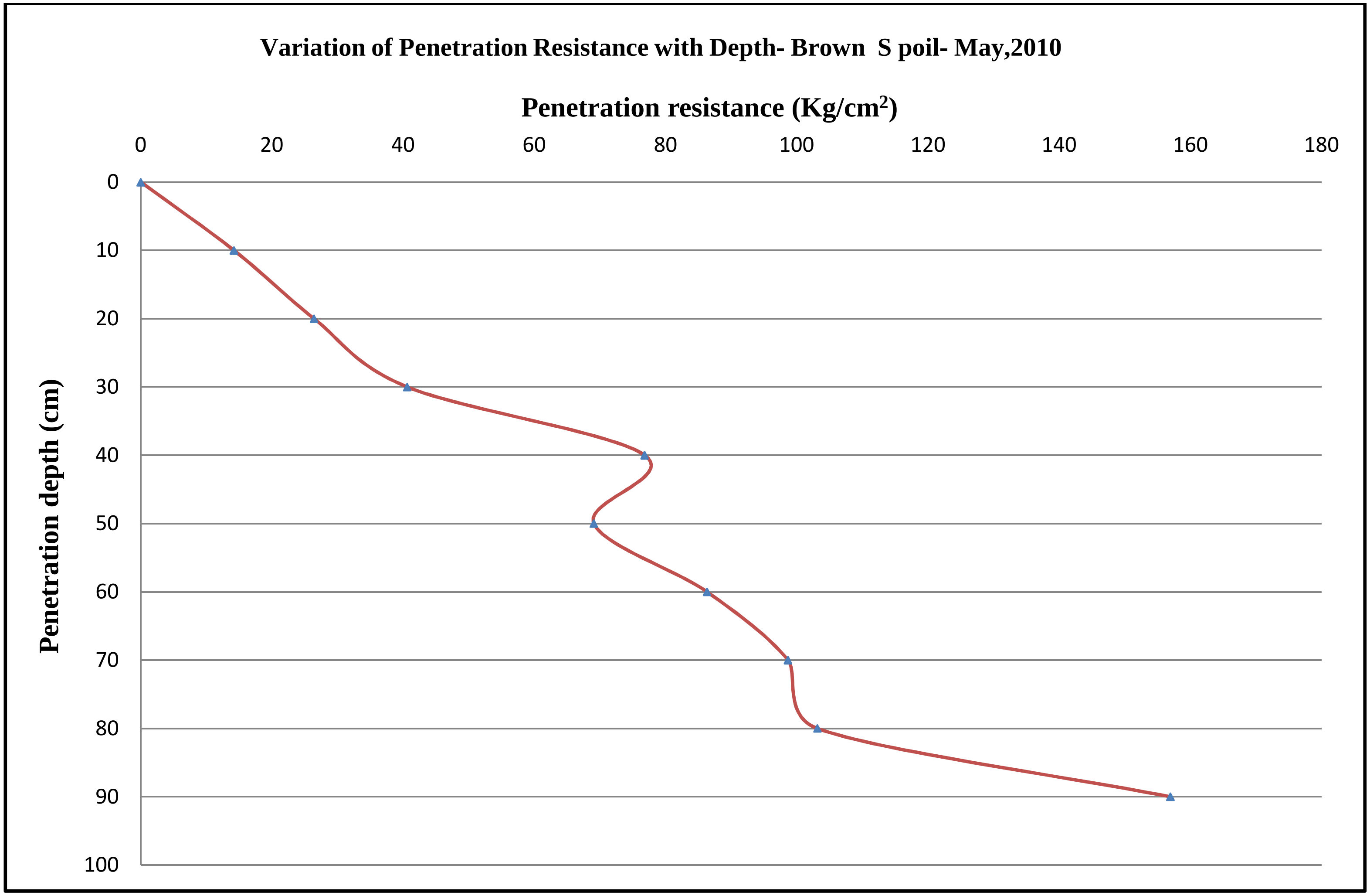
Period	May, 2010	**Location**	Peel Poplar (Pike County)
Weather	Clear	**Area**	Brown Spoil

Sample No.	**Number of Blows**										**Max. Penetration Depth (cm)**
	10 (cm)	**20 (cm)**	**30 (cm)**	**40 (cm)**	**50 (cm)**	**60 (cm)**	**70 (cm)**	**80 (cm)**	**90 (cm)**	**100 (cm)**	
1	1	6	11	16	35						43
2	1	6	7	4	8	9	12	35			75
3	1	2	2	2	5	11	10	11	35		90
4	2	4	11	35							33
5	4	11	24	35							37
6	3	5	5	5	4	8	12	35			73
7	4	9	12	35							40
8	1	1	3	10	9	11	10	14	35		85
9	3	5	7	5	35						90
10	2	9	13	12	14	14	35				63
11	2	5	11	7	15	35					55
12	4	4	4	2	3	3	35				77
13	4	11	12	19	18	23	35				70
14	5	15	14	35							40
15	4	2	4	15	20	35					55
16	7	6	18	35							40
17	5	2	3	10	35						50
18	4	3	2	12	27	35					55

PENETRATION RESISTANCE
Penetration Resistances for Brown Spoil Area

Period	May, 2010				**Location**	Peel Poplar (Pike County)				
Weather	Clear				**Area**	Brown Spoil				
Sample No.	**Penetration Resistance**									
	10 (cm)	**20 (cm)**	**30 (cm)**	**40 (cm)**	**50 (cm)**	**60 (cm)**	**70 (cm)**	**80 (cm)**	**90 (cm)**	**100 (cm)**
	(kg/cm^2)	**(kg/cm^2)**	**(kg/cm^2)**	**(kg/cm^2)**	**(kg/cm^2)**	**(kg/cm^2)**	**(kg/cm^2)**	**(kg/cm^2)**	**(kg/cm^2)**	**(kg/cm^2)**
1	4.48	26.91	49.33							
2	4.48	26.91	31.39							
3	4.48	8.97	8.97	8.97	22.42	49.33	44.84	49.33	156.95	
4	8.97	17.94	49.33	156.95						
5	17.94	49.33	107.63	156.95						
6	13.45	22.42	22.42	22.42	17.94	35.88	53.81	156.95		
7	17.94	40.36	53.81	156.95						
8	4.48	4.48	13.45	44.84						
9	13.45	22.42	31.39	22.42	156.95					
10	8.97	40.36	58.30	53.81						
11	8.97	22.42	49.33	31.39	67.27	156.95				
12	17.94	17.94	17.94	8.97						
13	17.94	49.33	53.81	85.20	80.72	103.14				
14	22.42	67.27	62.78	156.95						
15	17.94	8.97	17.94	67.27						
16	31.39	26.91	80.72	156.95						
17	22.42	8.97	13.45	44.84						
18	17.94	13.45	8.97	53.81						

Average	**14.20**	**26.41**	**40.61**	**76.80**	**69.06**	**86.32**	**98.66**	**103.14**	**156.95**	
Std dev	**7.57**	**16.91**	**27.10**	**59.20**	**56.24**	**55.33**	**6.34**	**76.10**		


Variation of Penetration Resistance with Depth- Brown S poil- May,2010
Penetration resistance (Kg/cm2)
0
20
40
60
80
100
120
140
160
180
Penetration depth (cm)
0
10
20
30
40
50
60
70
80
90
100

APPENDIX E

Economic Analysis

Calculation of Volume of Backfilled Spoil
Gray Spoil Area

No.	Distance between Slice (m)/(ft.)	Width of Slice (D) (m)/(ft.)	Area of Slice (A) (m^2)/(ft^2)	Average area (m^2)/(ft^2)	Volume (V) (m^3)/(yd^3)
	0		2,468.7 (26,573.7)		
1		7.62 (25)		2,503.9 (26,593.00)	18,826.9 (24,623.14)
	7.62 (25)		2,472.3 (26,612.29)		
2		7.62 (25)		2,480.1 (26,696.79)	18,900.3 (24,719.25)
	15.24 (50)		2,488.0 (26,781.29)		
3		7.62 (25)		2,504.3 (26,957.39)	19,084.8 (24,960.54)
	22.86 (75)		2,520.7 (27,133.48)		
4		7.62 (25)		2,524.9 (27,178.46)	10,241.3 (25,165.24)
	30.48 (100)		2,529.1 (27,223.43)		
5		7.62 (25)		2,544.3 (27,387.13)	19,389.1 (25,358.45)
	38.10 (125)		2,559.5 (27,550.83)		
6		7.62 (25)		2,558.6 (27,541.18)	19,498.1 (25,501.09)
	45.72 (150)		2,557.7 (27,531.52)		
7		7.62 (25)		2,529.5 (27,228.60)	19,276.8 (25,211.66)
	53.34 (175)		2,501.4 (26,925.67)		
8		7.62 (25)		2,461.7 (26,498.57)	18,760.0 (24,535.71)
	60.96 (200)		2,422.0 (26,071.47)		
9		7.62 (25)		2,255.9 (24,283.35)	17,191.7 (22,484.58)
	68.58 (225)		2,089.8 (22,495.22)		
10		7.62 (25)		2,135.1 (22,982.44)	16,270.7 (21,280.03)
	76.20 (250)		2,180.3 (23,469.65)		
11		7.62 (25)		2,092.1 (22,520.42)	15,943.6 (20,852.24)
	83.82 (275)		2,004.0 (21,571.18)		

12		7.62 (25)		1,910.3 (20,562.99)	14,577.8 (19,039.80)
	91.44 (300)		1,816.6 (19,554.79)		
13		7.62 (25)		1,720.5 (18,519.74)	13,111.3 (17,147.90)
	99.06 (325)		1,624.3 (17,484.68)		
14		7.62 (25)		1,513.0 (16,286.65)	11,530.3 (15,080.23)
	106.68 (350)		1,401.7 (15,088.61)		
15		7.62 (25)		1258.7 (13,548.61)	9,591.9 (12,545.01)
	114.30 (375)		1,115.6 (12,008.61)		
Total (LCM) (LCY)					**251,174.8 (328,504.88)**

Calculation of Volume of Backfilled Spoil
Brown Spoil Area

No.	Distance between Slices (m)/(ft.)	Width of Slice (D) (m)/(ft.)	Area of Slice (A) (m^2)/($ft.^2$)	Average Area (m^2)/($ft.^2$)	Volume (V) (m^3)/($yd.^3$)
1	0		3,636.6 (39,144.82)		
		7.62 (25)		3,640.4 (39,185.98)	27,742.2 (36,283.31)
2	7.62 (25)		3,644.2 (39,227.13)		
		7.62 (25)		3,623.0 (38,998.63)	27,609.6 (36,109.84)
3	15.24 (50)		3,601.7 (38,770.13)		
		7.62 (25)		3,596.6 (38,714.82)	27,408.7 (35,847.05)
4	22.86 (75)		3,591.5 (38,659.5)		
		7.62 (25)		3,600.3 (38,754.46)	27,436.7 (35,883.76)
5	30.48 (100)		3,609.1 (38,849.42)		
		7.62 (25)		3,618.4 (38,949.25)	27,574.6 (36,064.12)
6	38.10 (125)		3,627.7 (39,049.08)		
		7.62 (25)		3,625.8 (39,029.27)	27,631.3 (36,138.21)
7	45.72 (150)		3,624.0 (39,009.45)		
		7.62 (25)		3,629.2 (39,066.14)	27,657.4 (36,172.35)
8	53.34 (175)		3,634.5 (39,122.82)		
		7.62 (25)		3,591.9 (38,664.02)	27,372.7 (35,800.02)
9	60.96 (200)		2,549.3 (38,205.22)		
		7.62 (25)		3,664.5 (39,445.74)	27,926.1 (36,523.83)
10	68.58 (225)		3,779.8 (40,686.26)		

		7.62 (25)		3,632.9 (39,105.92)	27,685.5 (36,209.19)
11	76.20 (250)		3,486.1 (37,525.58)		
		7.62 (25)		3,570.9 (38,438.59)	27,213.1 (35,591.29)
12	83.82 (275)		3,655.8 (39,351.6)		
		7.62 (25)		3,566.8(38,394.46)	27,181.9 (35,550.42)
13	91.44 (300)		3,477.9 (37,437.31)		
Total volume (LCM)/ (LCY)					**330,440.0 (432,173.38)**

Hourly Equipment Cost Estimation

Ownership Costs					
No.	**Section**	**Description**	**CAT-992D Loader**	**CAT-777D Truck**	**CAT-D11R Dozer**
1	A	Delivery price (P) to the customer	1627200	1440000	1530000
	B	Less tire replacement cost if desired	66628	55668	0
	C	Adjusted price (a-b)	1560572	1384332	1530000
2	A	Less residual value at replacement (S%)	26	35	28
	B	Residual value	423072	504000	428400
3	A	Net value recovered through work	1137500	880332	1101600
	B	Cost per hr	56.88	44.02	55.08
4		Interest cost ($/hr)	31.77	28.11	29.87
5		Insurance cost ($/hr)	2.32	2.06	2.19
6		Property tax ($/hr)	4.07	3.60	3.83
7		Total hourly owning cost ($)	95.04	77.79	90.96
Operating Costs					
1	A	Fuel Consumption (gal/hr)	14	22	23
	B	Fuel cost per gal ($)	2.6	2.6	2.6
	C	Fuel cost per hr ($/hr)	36.40	57.20	59.80
2		Lube, oil, filter, grease, labor ($/hr)	7.66	6.34	8.74
3	A	Tires life (hr)	10000	10000	0
	B	Tire replacement cost ($/hr)	6.66	5.57	0

	C	Undercarriage (Dozer)	0	0	0
4		Overhaul /Repair reserve ($/ hr)	10.32	17.15	26.74
5		Repair & maintenance ($/hr)	11.68	10.55	26.88
6		Special wear items ($/hr)	1.18	1.18	3.68
7		Hourly operating costs ($/hr)	73.90	97.99	125.84
9		Operator's hourly wage ($)	25.00	25.00	25
10		Total owning and operating cost ($/ hr)	193.94	200.78	241.80
11		Overhead and profit @15%	29.09	30.12	36.27
		Estimated hourly cost ($/hr)	223.03	230.89	278.07
		Rate of inflation change% (2006-2010)	7.50	7.50	7.50
		Actual hourly cost ($/hr)	**239.75**	**248.21**	**298.93**