FIELD INVESTIGATION OF BEST PRACTICES FOR STEEP SLOPE MINE RECLAMATION EMPLOYING THE FORESTRY RECLAMATION APPROACH[1]

Dr. Richard J. Sweigard[2], Dharmendra Kumar

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 four feet deep and free of compaction. However, most of the prior reforestation research has been conducted on land that was flat or gently rolling. Some concern has 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 evaluation was based upon operational efficiency, economics, slope stability, and reforestation potential. Specifically, a 4.7 acres area was reclaimed with a combination of loaders, trucks, and dozers. Final grading was completed using single pass of a CAT-D11 dozer. Slope movement was monitored periodically by surveying 70 steel rebars. Soil bulk density, penetration resistance, and tree survival were also measured. As the project nears its end, the slope has not exhibited any appreciable instability and the FRA appears to have been effective in reclaiming the land to a forested condition.

Additional key words: Forestry reclamation, loose grading, bulk density, penetration resistance, growing media

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Introduction

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 Surface Mining Reclamation and Control Act (SMCRA), attempts to reforest the reclaimed mine sites have largely been unsuccessful. Similar to the problem of reclaiming prime farmland, researchers learned that excessive compaction negatively impacts tree survival and growth. Much of the recent works have 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 have 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 four feet(Burger, et al., 2005), of the replaced rooting medium. 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 community, 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. This is a progress report on a project that is not yet completed.

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 that employ FRA and by assessing the effectiveness from the stability, operational, economical, and reforestation potential respective. 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 listing of more specific project objectives:

- ❖ 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 of 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 reclamation practice;

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. The visit sites were accomplished by the research team from University of Kentucky, regulatory personnel from Office of Surface Mining, state regulatory personnel, and company representatives. A variety of different highwall elimination processes (e.g., contour haulback, combination of haulback and dozer push, shoot and dozer push, and gravity feed) were observed. By far the most common method (shown in Fig.1) in the Central Appalachian region is truck haulback in which a ramp is constructed on the contour bench and spoil is hauled up the ramp and dumped over the edge. In the case of combination of haulback and dozer push method, part of the highwall is eliminated by pushing material from upper benches to lower benches and other part is backfilled with truck and loader combination. Some of the sites were using the shoot and dozer push method to eliminate highwall. In this method, the highwall is blasted and dozed from top to bottom. In three sites in Virginia, the spoil was hauled by trucks up to the top of the highwall and dumped. It moved from top to bottom due to gravity and eliminated the exposed highwall. Fig.1 describes the different highwall elimination methods used in both North Appalachian (e.g., PA, OH, MD) and Central Appalachian (e.g., KY, WV, VA, TN).

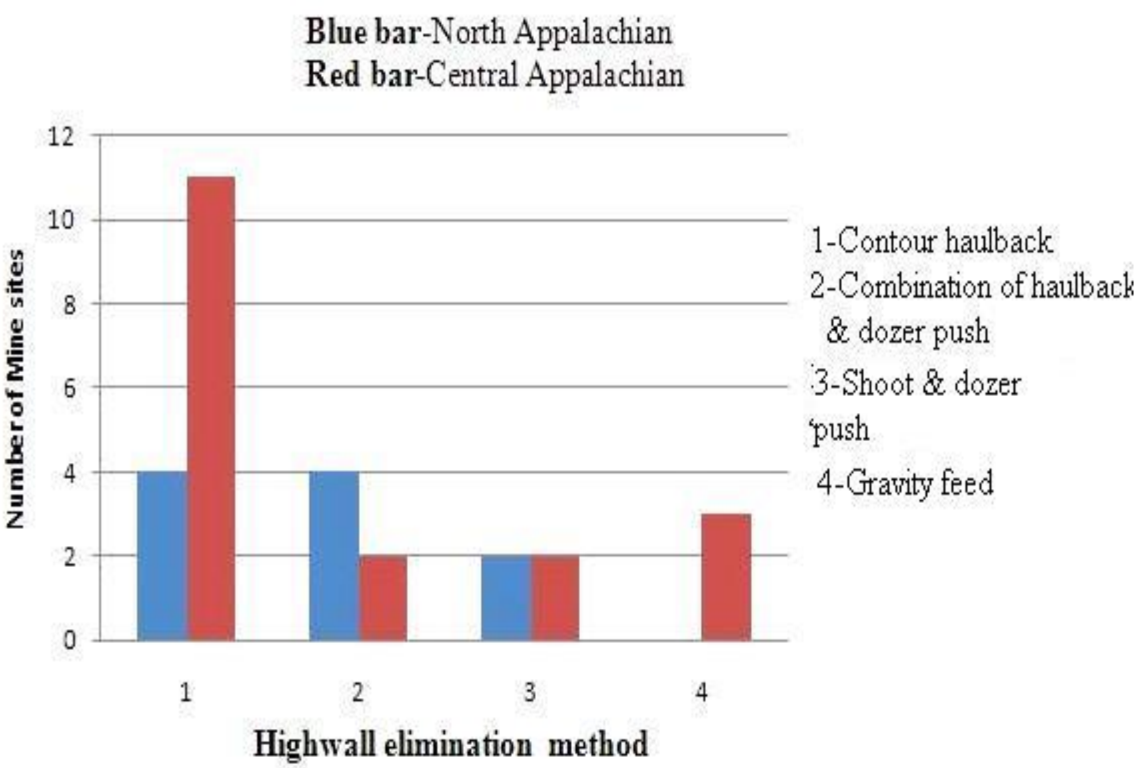

Figure 1: Plot of highwall elimination practices in Appalachian region

Field Investigation

Experimental site:

Based on the regional inventory, the Peel Poplar Mine of ICG was selected for the detailed field investigations. The site is located in Pike County in eastern Kentucky. The contour haulback mining method is used for highwall elimination. The overburden is comprised of gray and brown sand stone, shale and fireclay. Fig. 2 shows the experimental site before highwall elimination. The process of highwall elimination is described in the following section.

Figure 2**:** Experimental site (exposed highwall)

Site Preparation:

The highwall elimination was done by a combination of truck haul back and lateral dozer push. In this case, a ramp was constructed on the contour bench and spoil was hauled up the ramp and dumped over the edge. Then lateral pushing was in horizontal passes. Approximately 760,000 yd$^{\wedge 3}$ of loose materials were backfilled to eliminate the highwall by a combination of Caterpillar-992D loader, 777D trucks and a D11R dozer.

The first step of the process was to load the truck with the 992D loader and the haul the spoil up the ramp along contour. Fig. 3 and 4 shows the hauling and dumping activities

Figure 3: Hauling of spoil material

Figure 4: Dumping of spoil material

Secondly, the dumped material was pushed in horizontal passes by the CAT D-11R dozer. Fig. 5 shows the lateral pushing activity.

Figure 5: Lateral pushing of spoil material

The last step was grading of the slope from top to bottom using the D-11R dozer in a single pass method (Sweigard et al., 2007a) following FRA recommendations. After final grading, the area of approximately 4.7 acres was divided into two parts (shown in Fig. 6) based on spoil material. One part consists almost entirely of gray sandstone with some shale mixed in. The other part was a mixture of sandstone, shale, and some topsoil dozed down from above the highwall (giving material its brown color). The gray spoil accounts for around 40% of total area and the brown spoil accounts for the remaining.

Figure 6: Site after final grading

Planting:

The FRA guidelines for proper planting techniques were followed. A total of 4327 tree seedlings were planted in a 6-ft by 6-ft pattern in Spring, 2009. Ten different species were planted. Table 1 provides the inventory of seedlings. Fig. 7 shows the planting activities in both the gray spoil area and the brown spoil area. The tree growth at the end of Summer and Fall of 2009 is shown in Fig.8.

Table 1: Trees 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	GrayDogwood	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**

Figure 7**:** Planting Activities

Figure 8: Growth of trees

Slope Movement Monitoring

Some have expressed concern that loose-dumping of the top 4 feet of material with minimal grading, as recommended by FRA, could compromise the stability of the slope. In this project, prime concern is for mass movement. There are some expectations for vertical settlement and frost heave; however it is primarily horizontal movement down the hill that is the focus of the investigation.

Both the gray spoil area and the brown spoil area were instrumented with ½-inch diameter steel rebars that are 4 feet in length. A total of 70 rebars were driven up to 3 feet into the ground. To measure the total area of the slope and fix the position of the monuments, an extensive field survey was done using a Topcon total station. A regular rectangular pattern of 80-ft by 45-ft was used to fix the location of monuments (e.g., Fig.9). Detail of the monuments is shown in Table 2.

Table 2: Number of monuments survey line wise

No	Line	Gray spoil area	Brown spoil area
		No of bars	No of bars
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

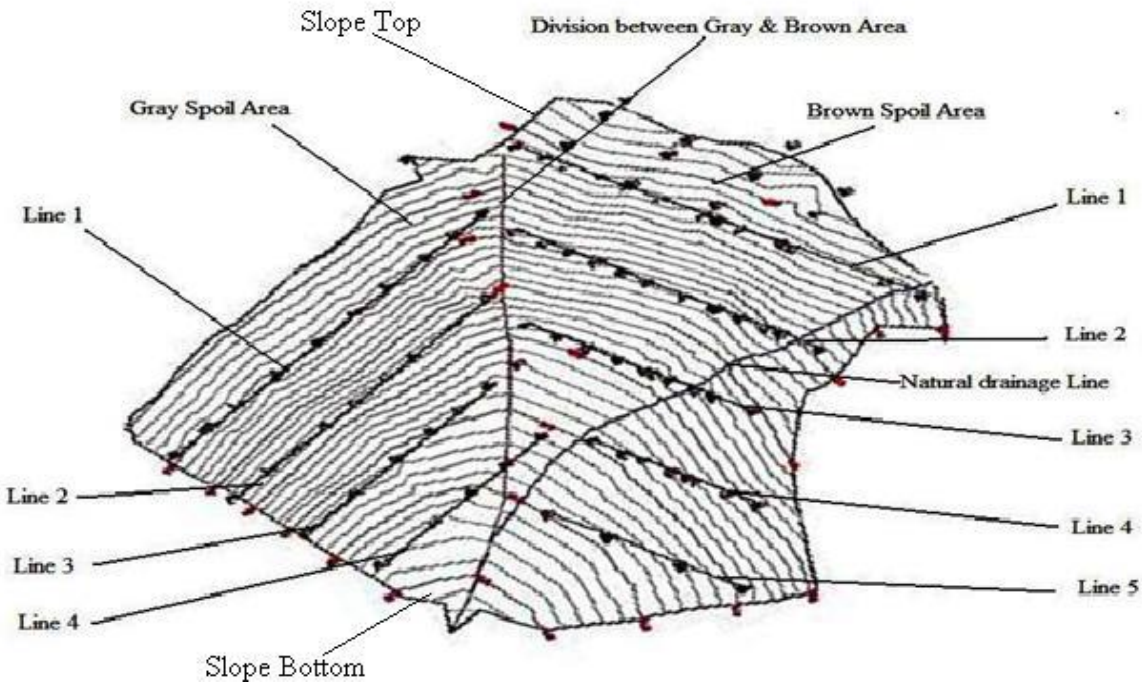

Figure 9: Top view of reclaimed slope area with orientation of monuments

<u>Monitoring Process:</u> To monitor slope movement, a regular survey of the tops of the monuments using a Topcon GTS-229 total station is done every 3 months. The accuracy for this equipment is up to 3mm for distances and 5 seconds for angle measurements. After each survey, plots to measure horizontal and vertical mass movement will be drawn and compared from previous survey plots. Fig.10 shows the plot of easting versus northing of all the monuments in line 1 and Fig.11 shows the plot of elevation at the top of monuments. These plots are from baseline survey data. Plots of eastings versus northings are used to measure any horizontal movement along the slope whereas plots of distance versus elevation are used to measure any type of settlement or vertical movement of the monuments.

Figure 10: Plot for horizontal movement monitoring

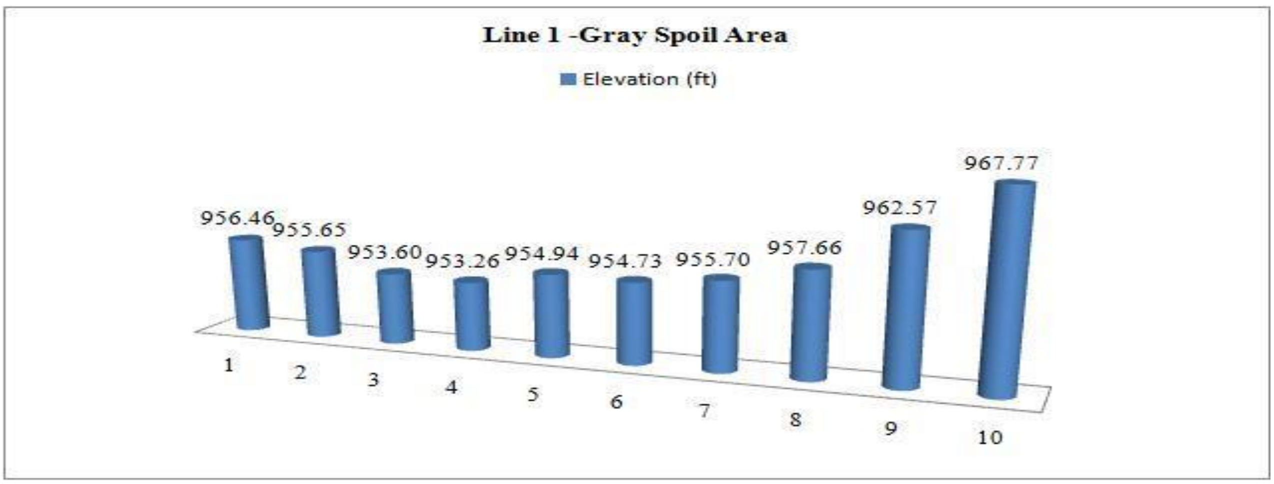

Figure 11: Plot for vertical movement monitoring

Compaction Measurement of the Growing Media

Compaction of the growing media 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 levels 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, backfilling method, equipment type and number of passes. Bulk density and penetration resistance are good predictors of root system performance in newly constructed growing media (Thompson, et al., 1987). Maximum penetration depth to refusal and bulk density display a strong correlation with tree survival rate (Conrad, 2002). An investigation of bulk density, maximum penetration depth (refusal after 30 blows), and spoil penetration resistance of growing media has been included in this research. Fig.12 describes the maximum penetration depth (depth of refusal) for both the gray spoil area and the brown spoil area by survey line. It can be observed from Fig.12 that the brown spoil area has greater depth of refusal as compared to the gray spoil area. Hence, there is expectation that trees will grow better in the brown spoil area.

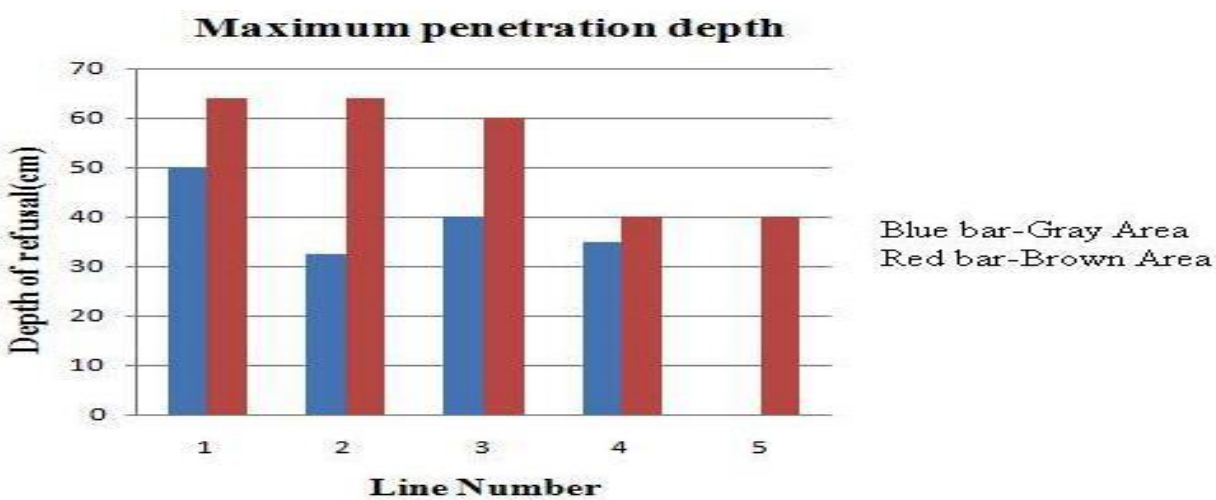

Figure 12: Plot of maximum penetration depth by survey line

<u>Bulk Density:</u> The most common measure of spoil compaction is bulk density (Dollhopf and Postle, 1988). A Troxler 3340- Nuclear density gauge was used in this study (Fig. 13). The gauge contains two isotopes- Cesium-137 for bulk density measurement and Americium-241 for moisture content measurement. There are two modes of operation for nuclear density gauges, the backscatter mode and direct transmission. In direct transmission, the total or wet density is determined by attenuation of gamma particles. A source is placed at a known depth up to 12 inches and the detector remains at the surface. The moisture content is determined by the backscatter method. It is measured by using fast neutrons emitted from the Americium-241

isotope. In this method the source of neutrons and the detector remain on the surface. A total of 70 readings were taken in a pattern of approximately a 1-m radius of the monument locations.

Figure 13: Troxler 3340-Nuclear Density Gauge

Penetration Resistance: In this study, the Wildcat Dynamic Cone Penetrometer from Trigg's Technology was used to measure spoil penetration resistance. The field set up of the penetrometer is shown in Fig.14. The equipment is lightweight and easy to transport and one person can measure strength properties in the field. It can measure resistance up to 5-m depth. Equipment set up includes of a hammer, connecting rods and a cone tip. A 3.5-gallon fluid injection system pumps a cellulose and water mixture through the rods to minimize friction on the rod.

A total of 35 field reading were recorded in a 1-m radius of alternate bar location (Fig. 9). The number of blows per 4-inch advance of the rod was recorded and the rod was driven up to depth of refusal. Undiminished kinetic energy transfer from the hammer to the cone allows using the Dutch formula (Bolamey, 1974) for calculation of penetration resistance. The Dutch formula is given as:

$$R_d = \frac{(\mathbf{M^2 * H * N})}{(\mathbf{Ap * (M + M' + Pa) * 100})}$$

Where, Rd= Dynamic cone resistance (psi)

M = Fixed mass of hammer (35 lbs)

M'= Fixed mass of driven portion of hammer (5.5 lbs)

H = Fixed height of hammer drop (15 inches)

N = Number of blows per 4 inches

Ap= Fixed projected area of cone (4 inch$^{\wedge 2}$)

Pa= Mass of rod string (7.19 lbs)

Cone apex angle = 90°

The penetration resistance for all 35 readings is calculated using above Dutch formula and results are plotted for gray and brown spoil areas separately.

Figure 14: Wildcat Dynamic Cone Penetrometer field set up

Stability Analysis

The slope stability analysis of both areas of the slope will be done using the Rotational Equilibrium Analysis of Multilayered Earthworks (REAME) software, which is widely used by most regulatory authorities in the Appalachian region. Even though the slope on the test site seems to be stable over the course of the study, the use of a computational analysis tool, such as REAME, will facilitate a comparison of relative stability of each test site and allow different scenarios to be investigated that could possibly lead to a slope failure without actually experiencing a slope failure in the field.

Conclusion

Up to this point of the project even after a period of very heavy rainfall that resulted in serious flooding in the summer, 2009, the slope did not experience any significant mass movement. At one area in brown spoil, there has some localized slumping with a maximum vertical displacement of 15 to 18 inches. The trees in the reclaimed area are performing well (shown in Fig.8). The project is still in progress. A survey of the monuments is taken every 3 months for monitoring of slope movement. The bulk density and the penetration resistance were measured at the beginning and will be measured at the end of the project. The stability analysis and economic analysis for applicability of FRA are in progress. The entire duration of project is two years, however only one year was provided for slope monitoring. An additional two years of slope monitoring would be advisable.

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