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Instrumentation and monitoring of a nailed mine-waste slope

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ABSTRACT: Surface mine operations in the southern Appalachian mountains of the USA have left numerous unstable or marginally stable waste-rock slopes. Typical remediation measures include reducing the slope angle or constructing expensive retaining structures. An investigation was conducted to evaluate the effectiveness of soil nailing in these waste rock slopes. The paper discusses the advantages of soil nailing to stabilize mine spoil, and describes the demonstration program and the instrumentation plan to measure the response of the nailed slope. When complete, the results of the study will lead to recommendations regarding the application of soil nailing to the stabilization of mine-waste slopes.

1 INTRODUCTION

Prior to 1977 when the U.S. Surface Mining Act mandated surface mine reclamation, the extraction of coal from the southern Appalachian mountains of the United States often left unstable or marginally stable waste-rock slopes. These slopes were created when waste-rock was dumped down the hillside below the mine operations. Many of these slopes are active, with down slope flow carrying trees and vegetation. This movement may occur very slowly over periods of years, or may occur rapidly corresponding to periods of high rainfall or human activities.

This waste-rock mine spoil is comprised of random size material ranging from clay size to bolder size, and generally exists at low density. The dumped fill is typically weathered shale chips, sandstone fragments, and coal (Faulkner et al. 1981). Access to these slopes is often difficult, making conventional repair methods involving movement of large volumes of material demanding and expensive. Therefore, practical, cost-effective, alternative construction techniques must be developed for the remediation of these slopes. An investigation was conducted to evaluate the effectiveness of improving the stability of these slopes using soil nailing techniques. This paper discusses the advantages of soil nailing to stabilize mine spoil, and describes the site investigation, the slope nailing schemes investigated, and the instrumentation plan to measure the response of the nailed slope.

2 SITE DESCRIPTION

The site is in Anderson County Tennessee, and is designated as Buffalo Mountain. An aerial photograph of the site taken during April 1995 is shown in Figure 1. Coal mining has taken place in this area since the 1960's. Since this time, various degrees of mine reclamation have taken place in this area, resulting in a combination of reclaimed sites, partially reclaimed bond-forfeiture sites, and pre-reclamation law sites in which little or no reclamation has taken place. The site

Figure 1 Aerial Photo of Slope

of this study is a partially reclaimed area, which experienced one or more slope failures since mining was completed. This instability and subsequent erosion has hampered reclamation activities, and the slope supported little vegetation.

3 SOIL NAILING OF MINE WASTE SLOPES

The reinforcement of slopes or cuts by inclusions or soil nails is different than that using tiebacks or anchors. Anchors act as pure tension members, with stresses transferred between soil and the end of anchor. Reinforcement by nails depends upon the transfer of stresses along the inclusion (Mitchell and Villet 1987; Byrne 1992; Schlosser et al. 1992) and often relies on the bending resistance of the nails in addition to the tensile capacity (Elias and Juran 1991). While anchor and tieback systems improve the behavior of the earth structure without improving the soil, nails or inclusions actually improve the soil properties (Christopher et al. 1990). The nails are not tensioned and the face treatment plays a minor role in the stability, although shotcrete is often applied to the face.

Nailing techniques have been economically used in a range of soil conditions. Various techniques have been used, and the choice is somewhat site and material dependent. This is a major advantage of soil nailing, since the design (inclination, spacing, and length of nail) can be easily changed during construction based on the observed performance (Mitchell and Villet 1987). Although soil nailing has been demonstrated as an effective slope stabilization method in soils, and soil nailing techniques are well established, the application to mine spoil has not been demonstrated.

Soils nails offer a number of advantages over other tieback methods (Elias and Juran 1991). When applied to mine spoil slopes, several of these advantages become even more evident:

- *Lower cost.* Compared to anchors, the rapid installation of the relatively short nails results in a cost savings. The thin shotcrete typically applied to the face is more economical than thicker precast or cast-in-place concrete facing. Since the shotcrete is usually used only to assure local stability on steep soil walls and contributes little to the reinforcement process, the remediation of mine waste slopes may not require shotcrete. This makes reinforcement with nails even more economical, and does not eliminate the vegetation on the slope.
- *Use of light construction equipment.* Many of the waste rock slopes in the Appalachian region have very poor access. Light equipment and simple gravitational grouting procedures are well suited to remote locations.
- *Applicable to heterogeneous materials.* The shorter, small diameter drill holes typically used in soil nailing are well suited to materials containing cobbles, boulders and hard rock zones. Most mine spoil waste rock is highly heterogeneous and often contains large sandstone boulders.

To evaluate the effectiveness of soil nailing in mine waste slopes, and make recommendations regarding appropriate design methods, a full-scale demonstration project was initiated at the Buffalo Mountain site.

4 SITE INVESTIGATION AND TESTING

Two vertical auger borings were advanced to a depth of about 10 meters from the surface of the road that crosses the crest of the slope. The borings were conducted to identify the subsurface materials, obtain bulk samples, and to perform nail pullout tests. The auger cuttings indicated that the spoil contains a relatively dry mixture of sandstone, shale and coal. The water table was not encountered in the borings, although hand augering at the toe of the slope revealed water at a depth of about 0.3 meters.

Information from the borings, along with data from a level survey and information from both pre-mining and post-mining topographical maps, was used to construct an idealized profile of the site as shown in Figure 2. The dumped-fill materials comprising the slope range in size from clay size to boulders. Of the material finer than 10 mm, grain size analysis suggests that 95 percent is less than a #200 sieve or 0.076 mm in diameter. Atterberg limits were determined to be: plastic limit = 26, liquid limit = 31, and plasticity index = 5. The measured material properties were consistent with those reported for nearby spoil slopes in a comprehensive investigation of eastern coal mine spoil materials (Swanson et al. 1983). In place borehole shear tests (Lutenegger 1987) yielded a friction angle of about 30 degrees. Preliminary soil nail pullout tests suggest an ultimate shear stress capacity between waste and nail of about 34 kPa.

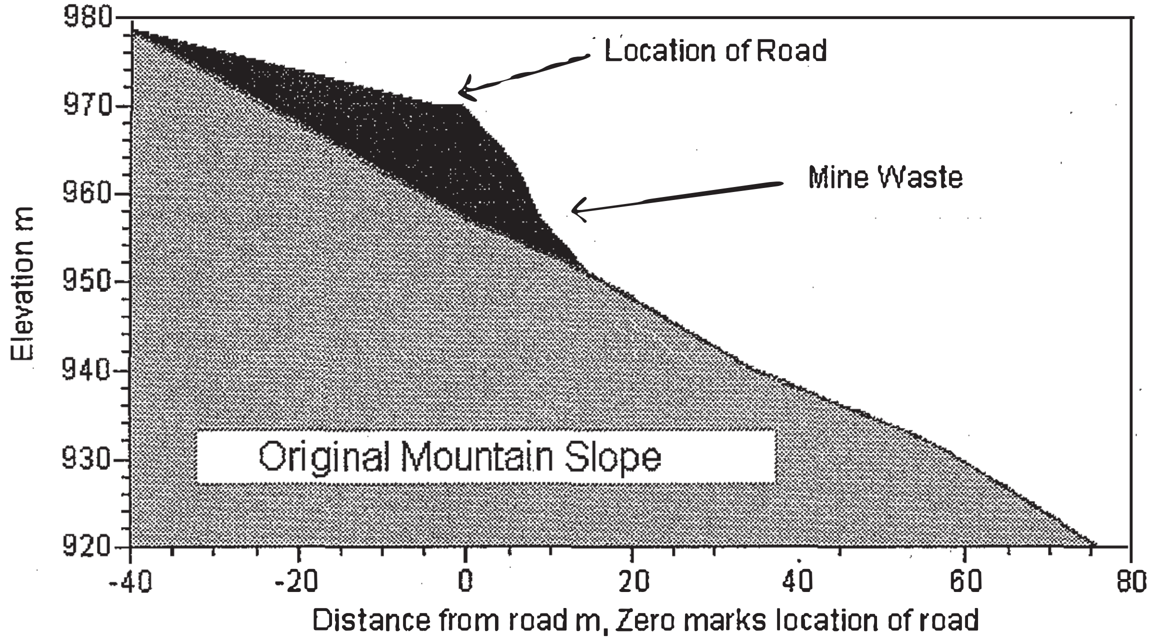

Figure 2 Schematic of Slope Profile

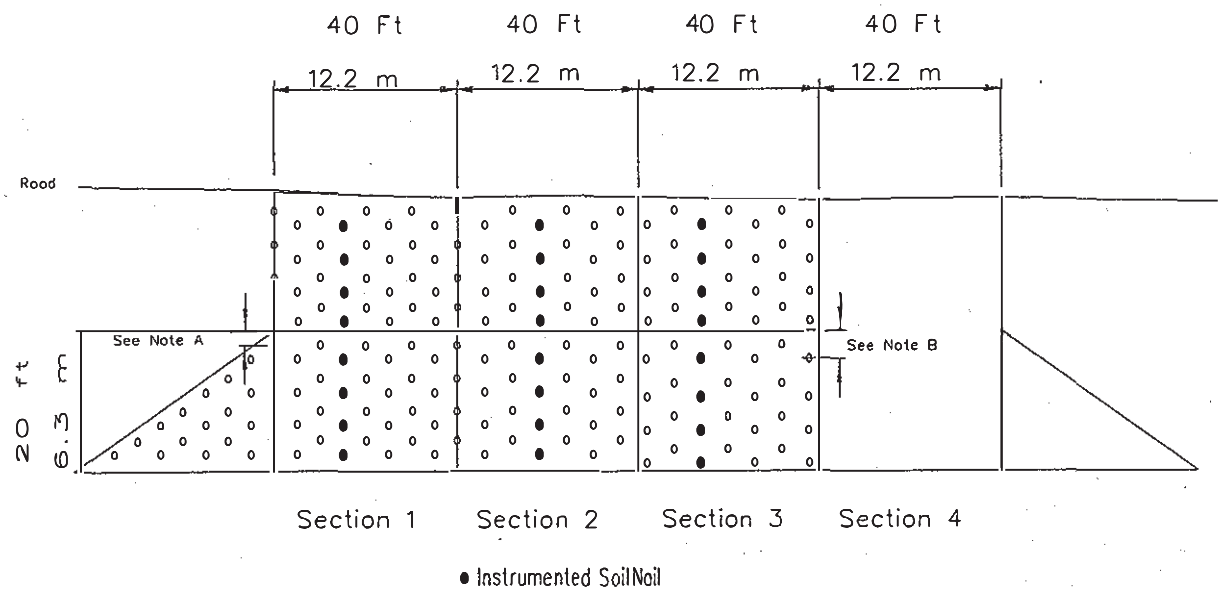

Figure 3 Elevation View of Instrumented Slope

5 PRELIMINARY ANALYSIS OF THE SLOPE

Inspection of the slope indicated that a recent failure had occurred, leaving a mass of soil and trees at the toe, Figure 1. Limit equilibrium analyses suggested that the current slope profile was in fact stable, although localized failures and erosion were prevalent. In order to reduce the stability of the unreinforced slope and determine the effectiveness of the soil nailing scheme, it was decided to steepen the lower 6.3 m from the existing 1H:1V slope to about 1H:3.7V (75 degrees), thus creating a "cut-slope" requiring support to maintain stability.

6 DESIGN OF NAILED SLOPE

The study area was divided into four sections, each about 12 m wide, as shown in Figure 3. Three of the sections were designed with different nailing schemes and thus a different computed factor of safety, while the fourth or control section was left untreated. The nails were installed from the top down in the conventional manner as the slope was cut. At the time this paper was prepared, construction was underway.

The nailed slope was designed in a manner consistent with local soil nail practice, incorporating 25.3 mm diameter steel nails of 1030 N/mm^2 ultimate strength in 200 mm diameter grout holes. However, unlike traditional soil nailing practice, shotcrete was not applied to the face. Instead, a geosynthetic reinforced erosion control mat was specified to be anchored to the slope with the nails. The properties of the erosion control mat (Erosion Control Systems 1995) are summarized in Table 1. This facing scheme eliminates the need for the shotcrete, and significantly reduces construction costs since shotcrete is difficult to apply in remote sites lacking significant water sources. More importantly, the mat will promote the establishment of vegetative cover to prevent further erosion of the slope. Restoring vegetation to the slope is a significant component of mine lands reclamation practice. All nails were finished with a 460 mm by 460 mm facing plate 6 mm thick.

In the lower cut slope sections, four rows of nails were specified with lengths and vertical and horizontal spacings as shown in Table 2. The steepening of the lower slope resulted in computed factors of safety of slightly greater than one for the nailed sections, and less than one for the untreated section. In the upper sections, four rows of 3 m nails with a vertical spacing of 1.5 m were specified. The

Table 1 Physical Properties of Erosion Control Mat

Geosynthetic Reinforcement	
Material	polyester geogrid
Weight (ASTM D3776)	0.07 N/m^2
Thickness (ASTM D1777)	1.5 mm
Aperture Size	20 mm x 20 mm
Wide Width Tensile Strength @Ultimate (ASTM D4595)	23 kN/m (warp) 13 kN/m (fill)
Elongation at break (ASTM D4595)	12 %
Erosion Control Mat	
Material	Bio-degradable curled wood excelsior mulch

(Erosion Control Systems 1995)

horizontal spacing was consistent with that of the cut-slope section immediately below.

7 SLOPE INSTRUMENTATION

Each of the four sections was instrumented with a slope inclinometer, and the nails in a vertical line within each of the three nailed sections were instrumented with strain gages. The instrumentation layout in Section 1 of the slope is typical, and is shown in Figure 4. The strain gages were placed to obtain a good indication of the stress distribution along the nails.

The gages were embedded concrete resistance strain gages, model EGP-350 manufactured by Micro-Measurements Group (Measurements Group 1995). Optical survey methods will be used to monitor movement of a number of strategic locations over each of the four sections of the slope.

8. MONITORING

The slope will be monitored throughout the construction period and into the service life. As the lower cut slope is excavated and the nails installed, the nail strains will be measured. Slope inclinometer measurements will be taken in the three nailed sections,

Table 2 Nailing Scheme

		Section			
		1	2	3	4
Nail spacing, upper (natural) slope	horizontal vertical	S_h = 1.5m S_v = 1.5 m	S_h = 1.8m S_v = 1.5 m	S_h = 1.8m S_v = 1.5 m	None
Nail length, upper (natural) slope	row 1: row 2: row 3: row 4:	L = 3 m L = 3 m L = 3 m L = 3 m	L = 3 m L = 3 m L = 3 m L = 3 m	L = 3 m L = 3 m L = 3 m L = 3 m	None
Nail spacing, lower (cut) slope	horizontal vertical	S_h = 1.5 m S_v = 1.5 m	S_h = 1.8m S_v = 1.5 m	S_h = 1.8m S_v = 1.8 m	None
Nail lengths, lower (cut) slope	row 1: row 2: row 3: row 4:	L = 6 m L = 6 m L = 6 m L = 6 m	L = 4.4 m L = 4.4 m L = 4.4 m L = 3 m	L = 4.4 m L = 3 m L = 3 m L = 3 m	None

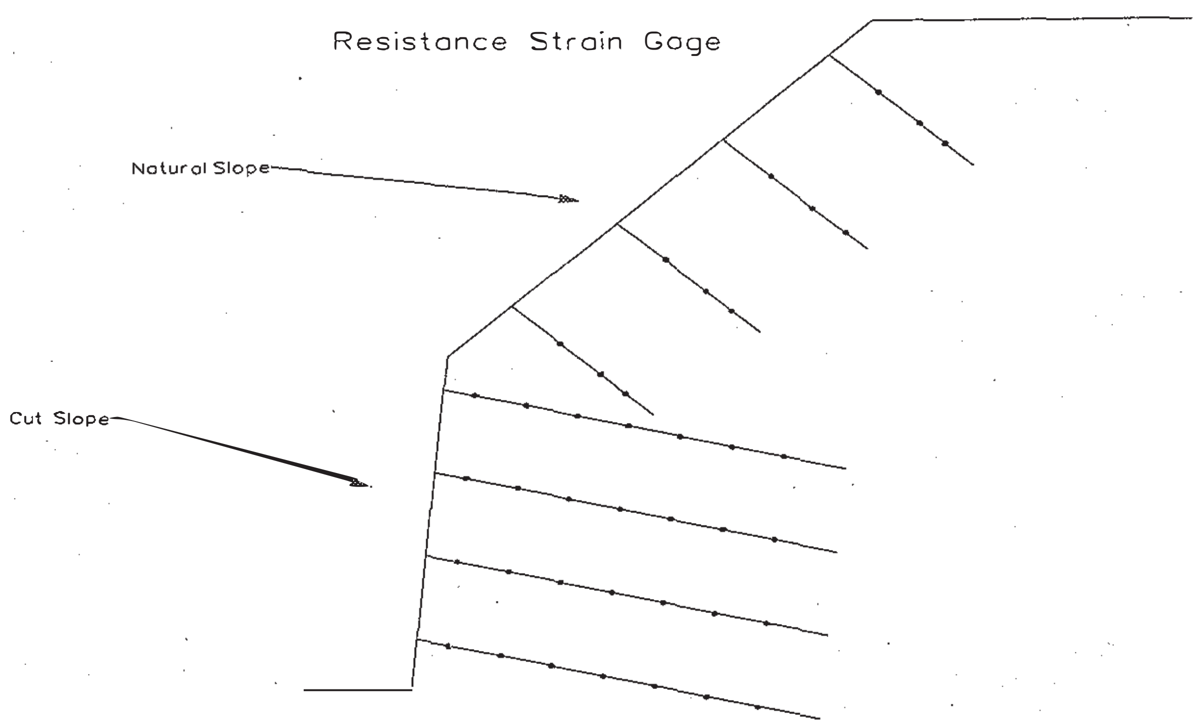

Figure 4 Section through Nailed Slope Showing Typical Soil Nail Instrumentation

as well as in the un-nailed control section. In addition, total station measurements of survey points fixed to strategic locations on the slope will be obtained over time. The observed response of the four slopes will be compared with the stability as predicted by several analysis methods.

9 CONCLUSIONS

Although soil nailing has been demonstrated as an effective slope stabilization method in soils, and soil nailing techniques are well established, the application to mine spoil has not been demonstrated. An investigation is underway in which an unstable cut slope in mine waste was stabilized with nails. The slope was divided into four sections, with three different nailing schemes and an un-nailed or control section. Instrumentation located along a number of the soil nails will provide the distribution of stress in the nails, and survey data and slope inclinometers will be used to measure the deformations of the slope. The observed response of the four slope sections will be compared with the stability as predicted by several analysis methods. The results of the study will lead to recommendations regarding the application of soil nailing to the stabilization of mine-waste slopes, and aid the development of design guidelines.

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