PHYSICAL PROPERTIES OF KENTUCKY'S AML LANDSLIDES: CASE STUDIES ANALYZED[1]

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Abstract: Once an abandoned mined land (AML) landslide occurs and is identified as an emergency, engineers must rapidly implement a slope stabilization design. Correct slope remediation solutions are generally derived from well-executed geotechnical examinations. This paper summarizes a large body of geotechnical data compiled by the U.S. Office of Surface Mining Reclamation and Enforcement (OSM) from AML landslides in eastern Kentucky. Special attention is placed on the examination of subsurface failures, phreatic water levels, soil profiles, and soil composition information from numerous borehole exploration programs. Strength properties calculated from laboratory procedures and stability analysis techniques were also reviewed. Laboratory-determined soil shear strength values were found to be higher than those inferred from stability analysis. This suggests that postfailure determinations of the phreatic surface may be largely inappropriate when used in stability analysis or that laboratory-measured shear strengths are ineffective in replicating in situ colluvium/spoil slope properties.

Additional Key Words: landslides, slope stability, coal mine spoil.

Introduction

Prior to the Federal Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87), rock, soil, organic material, coal, and even discarded mining equipment from surface and underground mines in Kentucky were simply cast over the sides of strip and adit benches. This coal mine spoil was generally poorly mixed, uncompacted, and allowed to settle at the material's angle of repose. The spoil generally rested on top of the preexisting colluvium, alluvial, and residual soil layers. Many of these slopes were already close to failing or, in some cases, had already experienced some slope instability. Weigle (1966) estimated that 12% of eastern Kentucky's strip mine spoil had failed by the mid-1960's. Often, runoff from the abandoned mines drains through the adjacent soil cover, increasing its degree of saturation. Increasing moisture contents caused by poor drainage conditions, reduces the shear strength of the soil and enhances the development of subsurface failures. This type of instability has become one of the Nation's most critical AML problems. From 1979 until February 1992, 425 landslides in 9 States were stabilized at a cost of $64,625,044. Kentucky had the most AML landslides, with a total of 268 at a cost of $41.5 million. The average cost of each stabilization project was $152,059.

Depending on the landslide's rate of movement and proximity to civil structures, different reactions are required by State and Federal agencies responsible for implementing the AML program. A landslide is classified as a "dangerous slide" if it represents an imminent hazard to humans or, if unchecked, it could inflict heavy damage on civil or residential structures. These types of landslides are managed under the AML Emergency Program. Attempts are made to remedy this type of landslide as quickly as possible (Roberts and Spadaro 1992). Approximately 10% of the AML emergency landslide remediation actions in eastern Kentucky have been designed using extensive geotechnical information. However, even with this geotechnical information, the soil's shear strength was still difficult to establish. Accurate shear strength characterization of landslide material is absolutely essential for reliable designs. Uncertainty about the range of material strengths experience from different categories of AML landslides affects the engineer's judgment. Under these conditions, the remediation effort must often be conservatively designed. Underestimating material strength leads to increased remediation cost, while overestimating could lead to inadequate slope stabilization.

Causes of AML Landslides

Characterization of AML landslides in eastern Kentucky was accomplished by analyzing 37 geotechnical reports from OSM's project data base (table 1) dispersed over much of Kentucky's eastern coalfields (fig. 1). In all of the cases analyzed, past mining activity was associated with AML landslides and generally produced what is technically referred to as a rotational

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Table 1. Characteristics of eastern Kentucky AML landslides.

Landslide name/soil layer[1]	Soil type	Description	In situ moisture	Consistency	USCS[2]
(1) Adkins/1	Spoil	Sandy lean clay	Moist to saturated	Soft	CL.
Adkins/2	Residual	. . do	Moist	Medium to stiff	CL.
Adkins/3	Colluvium	. . do	Moist to wet	Soft to medium	CL.
(2) Allen-Banner/1	–	Clay sand	–	–	SC.
Allen-Banner/2	–	Inorganic silt	–	–	ML.
Allen-Banner/3	–	Silty sand	–	–	SM.
(3) Anna Miller/1	Colluvium	Sandy silt with rock fragments and large boulders.	Moist to wet	Soft to very stiff	ML.
(4) Bear Branch/1	Spoil	Sandy lean clay with rock fragments and boulders.	Damp to moist	Stiff to very stiff	CL.
Bear Branch/2	Spoil	Clayey sand with rock fragments and boulders.	. . do	Medium dense to dense.	–
Bear Branch/3	Colluvium	Sandy lean clay with rock fragments.	Damp to moist	Stiff to very stiff	CL.
(5) Bentley/1	–	Silty sand with sandstone fragments.	–	Moderately stiff	SC-SM.
(6) Betty Trent/1	Colluvium	Clayey sand with gravel and coal.	Moist	Stiff to very stiff	SC.
Betty Trent/2	Colluvium	Clayey sand with gravel-size rock fragments.	Moist	. . do	SC.
Betty Trent/3	Spoil	Silty clayey sand with gravel.	Moist	Stiff	SC-SM.
(7) Birchfield/1	Colluvium	Sandy lean clay with rock fragments.	Damp to moist	Stiff to very stiff	CL.
Birchfield/2	Colluvium	. . do	. . do	. . do	CL.
(8) Bonnyman II/1	Colluvium	Sandy lean clay	–	–	CL.
(9) Bryant/1	Spoil	Lean clay with sand and gravel.	Moist	Soft to medium	CL.
Bryant/2	Residual	. . do	Moist	Stiff	CL.
(10) Carol Begley/1	Spoil	Sandy lean clay with gravel.	Damp to moist	Medium to stiff	CL.
Carol Begley/2	Colluvium	Sandy lean clay	Moist	Stiff to very stiff	CL.
(11) Church/1	Colluvium	. . do	Damp	Stiff	CL.
Church/2	Spoil	Sandy lean clay with gravel	Damp to wet	Medium to hard	CL.
(12) Clear Creek/1	Spoil	Sandy lean clay with rock fragments and boulders.	Moist to wet	Soft to stiff	CL.
Clear Creek/2	Colluvium	Lean clay with gravel-size rock fragments.	Moist	Medium to very stiff	CL.
Clear Creek/3	Colluvium	Clayey sand with silt	Moist to wet	Stiff to very stiff	SC-SM.
(13) Cubert Spence/1	Residual	Sandy lean clay	Damp to moist	Very stiff to hard	CL.
Cubert Spence/2	Spoil	Sandy lean clay with rock fragments.	. . do	Stiff to very stiff	–
(14) Denver Newsome/1	Spoil	Sandy with coal shale fragments.	–	Medium	SM-SC.
Denver Newsome/2	–	–	Wet	Very soft	CL.
(15) Eva Hamilton/1	Colluvium	Sandy lean clay with gravel and boulders.	Moist	Soft to very stiff	CL.
Eva Hamilton/2	Colluvium	Sandy lean clay with gravel.	Moist to wet	Medium to stiff	CL.
Eva Hamilton/3	Colluvium	Sandy lean clay with shale fragments.	Moist	Stiff	CL.
(16) Everage/1	Colluvium	Sandy silt with rock fragments.	Damp to wet	Stiff to very stiff	ML.
(17) Frazier/1	Colluvium	Sandy lean clay	Damp to moist	Medium to hard	CL.
Frazier/2	Colluvium	Lean clay with sand	. . do	Stiff to hard	CL.
Frazier/3	Residual	Clayey sand with gravel	Moist	Medium dense to dense.	SC.
(18) French III/1	–	Silty sand	–	–	ML-CL.
French III/2	Spoil	Sandy	–	–	–
(19) Grose/1	Colluvium	Sandy lean clay with rock fragments.	Damp to moist	Soft to very stiff	CL.
Grose/2	Residual	Lean clay	Moist to wet	Stiff to very stiff	CL.
(20) John Kennedy/1	Fill	Lean clay with sand	. . do	Medium to stiff	CL.
John Kennedy/2	Spoil	. . do	. . do	Soft to medium	CL.
(21) Kodak/1	–	Clayey sand with gravel and coal fragments.	Dry to wet	Loose to medium compact	SC.
Kodak/2	Spoil	Clayey sand with rock fragments and boulders.	Damp to wet	Soft to medium	–
Kodak/3	Colluvium	Sandy lean clay with gravel and coal fragments.	Damp to moist	Stiff to very stiff	CL.
Kodak/4	Colluvium	Clayey sand with sandstone fragments.	. . do	Very stiff to hard	SC.
(22) Leroy Jewell/1	–	. . do	Moist	Medium to stiff	SC.
Leroy Jewell/2	Colluvium	Sandy lean clay	Moist	. . do	–
(23) Loftis/1	Fill	Clayey sand with rock fragments and boulders.	Damp to moist	Medium to compact	SC.
Loftis/2	Fill	Sandy lean clay with rock fragments.	. . do	Medium to very stiff	CL.
Loftis/3	Colluvium	. . do	. . do	Very stiff.	CL.
Loftis/4	Residual	Silty clay with shale partings.	. . do	Medium	–
(24) Maynard/1	Spoil	Sandy clay with gravel and rock fragments.	Dry to wet	–	SC.
Maynard/2	Colluvium	. . do	. . do	–	SC.
(25) Moore II/1	Residual	Sandy lean clay	Damp to moist	Medium to very stiff	CL.
Moore II/2	Spoil	. . do	Moist to wet	Soft to medium	CL.
(26) Pinky Lee/1	Spoil	. . do	Moist	Medium	CL.
(27) Ray/1	Colluvium	Clayey sand with sandstone fragments.	Damp to moist	Stiff to very stiff	–
(28) Ritchie/1	Spoil	Silty to clayey sand with gravel and boulders.	Moist	Medium to stiff	SC-SM.
Ritchie/2	Residual	Sandy lean clay	Moist	Stiff	CL.
Ritchie/3	Colluvium	Clayey sand with gravel	Moist	Stiff	SC.
(29) Ronnie Anderson/1	Spoil	Clayey sand with gravel and boulders.	Moist to wet	Soft	SC.
Ronnie Anderson/2	Colluvium	Sandy lean clay with gravel	Moist to saturated	Very soft to medium	CL.
Ronnie Anderson/3	–	Sandy lean clay with sandstone fragments.	Moist to wet	Medium to stiff	CL.
Ronnie Anderson/4	Colluvium	Lean clay with sand and gravel.	. . do	Soft to stiff	CL.
Ronnie Anderson/5	Alluvial	Clayey sand with gravel	. . do	Medium	SC.
(30) Sanders/1	Spoil	Sandy lean clay with rock fragments.	Damp to wet	Soft to stiff	CL.
Sanders/2	Colluvium	Lean clay	Damp to moist	Stiff to very stiff	–
(31) Sharp/1	–	Sandy lean clay	Moist to wet	Soft to very stiff	CL.
(32) Spradlin Branch II/1	Spoil	Organic material and boulders.	Wet to saturated	Very soft to medium	CL.

Landslide name/soil layer[1]	Soil type	Description	In situ moisture	Consistency	USCS[2]
Spradlin Branch II/2	Residual	Gravelly lean clay with sand.	Moist to wet	Medium	CL.
Spradlin Branch II/3	Colluvium	Clayey sand with gravel	–	–	SC.
(33) Stone/1	Spoil	do	Damp to wet	Soft to stiff	SC.
Stone/2	Spoil	Sandy lean clay	Moist to wet	Soft to medium	CL.
Stone/3	Alluvial	Clayey sand	Saturated	Medium	SC.
(34) Sue Taylor/1	–	Sandy silty clay with gravel	–	–	CL-ML.
Sue Taylor/2	–	Sandy silt	–	–	ML.
(35) Wells-Pennington/1	Spoil	Sandy lean clay	Damp to moist	Soft to stiff	CL.
Wells-Pennington/2	Colluvium	Sandy lean clay with gravel	Moist	Stiff	CL.
Wells-Pennington/3	–	Sandy lean clay	Moist	Medium to stiff	CL.
(36) Winfield-Weaver/1	–	–	–	–	–
(37) Wooton/1	Spoil	Silty sands with boulders and logs.	Wet	Very soft to very stiff	SM.

do.	Same as above.
SC	Clayey sands, sand-clay mixture.
SM	Silty sands, sand-silt mixture.
SC-SM	Clayey sands and silty sands.
CL-ML	Sandy clays and sandy silts.
CL	Inorganic sandy, silty, or lean clays of low to medium plasticity.
ML	Inorganic clayey silts or clayey, very fine sands with low plasticity.

[1] Numbers in parentheses refer to landslide locations shown in fig. 1.

[2] Unified Soil Classification System.

NOTE.–Dash indicates not determined.

or translational debris flow. Typical landslide characteristics are multiple soil layers, soil thicknesses, and the position of phreatic surfaces and mined coalbeds.

Three general categories of mining-induced landslides were recognized from this data base: 1) failure of outcasted spoil material; 2) failure of natural soil slopes due to increased water saturation from mining-induced sources; and 3) failure of natural soil slopes due to increased surcharge loading from outslope spoil material. Of the three causes, the first two were much more prevalent. A more detailed description of each cause is given below.

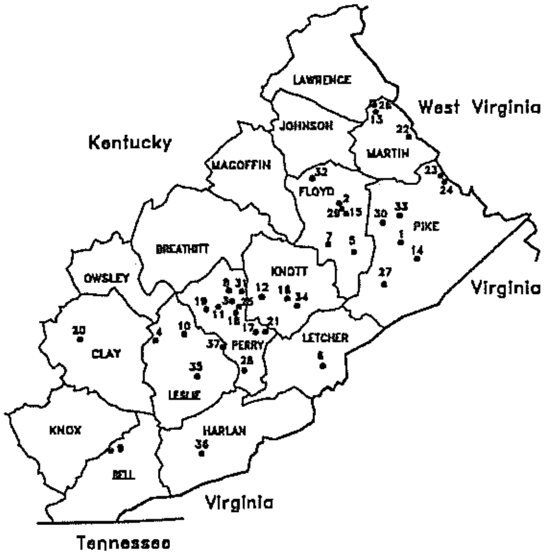

Figure 1. Eastern Kentucky counties with AML landslide locations where geotechnical data was available.

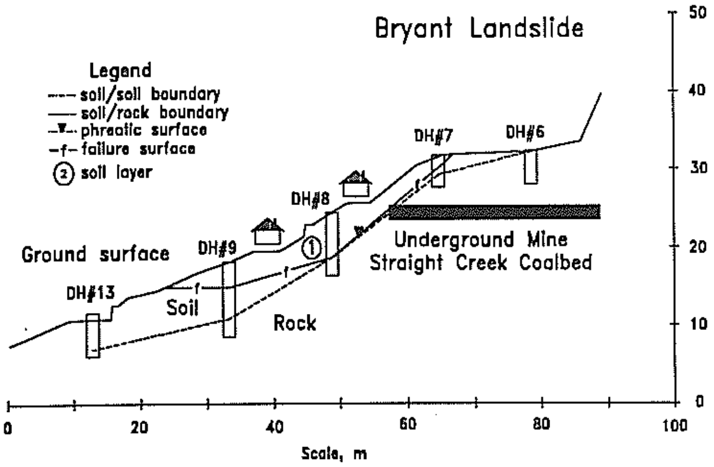

Figure 2. Typical cross-section through an eastern Kentucky AML landslide consisting primarily of spoil.

Failure of Outslope Casted Spoil Material

Considering the composition and manner of placement, it is understandable that outslope casted mine spoil has been involved in extensive slope instabilities. Spoil is the dirt and rock material overlying the coalbed that is removed to gain access to the coal. Of the 37 landslides examined, approximately one-half were attributed directly to failures within the casted spoil material with conditions similar to those shown in fig. 2. Kimball (1974) noted that prior to the Federal Surface Mining Control and Reclamation Act of 1977, almost all of eastern Kentucky's strip mines dumped or pushed the spoil over the bench with little or no compactive effort, allowing it to assume its angle of repose. Because the spoil has been placed recently in geologic terms (10 to 40 years), much of this material is still disintegrating with time, producing higher concentrations of fines. Therefore, temporary increases in porewater pressure from heavy storms and progressive deterioration of the strength of soil from weathering have caused and will continue to cause sporadic slope instabilities throughout eastern Kentucky.

Failure of Natural Soil Slopes Due to Increased Water Saturation From Mining-Induced Sources

Natural soils found on eastern Kentucky's slopes are predominantly comprised of colluvium deposits, with lesser amounts of residual and alluvial soil layers. Typically, colluvium consists of unstratified, locally derived, and randomly oriented angular blocks of bedrock in a clayey matrix. In geologic terms, colluvium is actively moving (Rahn 1986). Residual soils are the disintegrated materials above the bedrock, which have been subjected to weathering process influenced primarily by changes in moisture content and the freeze-thaw cycle (Taylor 1948). In general, eastern Kentucky's hillsides have a relatively thin layer of residual soil (0 to 7 m thick). Fills are compacted soil moved in place by mechanical means. Alluvial soil includes stratified layers of silt, sand, gravel, and clay deposited within a stream's flood plain. Alluvial soil is only found along the lowest of eastern Kentucky's hillsides and is therefore rarely found in landslide areas. Landslides were found to occur most frequently in colluvium, which is consequentially most like the spoil material in character.

When reclamation is not practiced, rainfall and/or mine water is allowed to drain directly into the natural soil (fig. 3). As noted previously, increased water saturation raises the phreatic surface, increasing the porewater pressure and lowering the shearing resistance of the soil. The shearing resistance of the soil counteracts the tendency of the soil on a slope to move downward and outward under the influence of gravity.

Failure of Natural Soil Slopes Due to Increased Surcharge Loading From Outslope Spoil Material

Sometimes landslides in the naturally steep slopes of eastern Kentucky are activated by surcharge loading from casted spoil somewhere upslope from the scarp of the resulting failure surface (head). The weight of the spoil increases the driving force exerted on the existing soil, overcoming the resistance force. Surcharge loading from outslope spoil was found to be responsible for only one landslide.

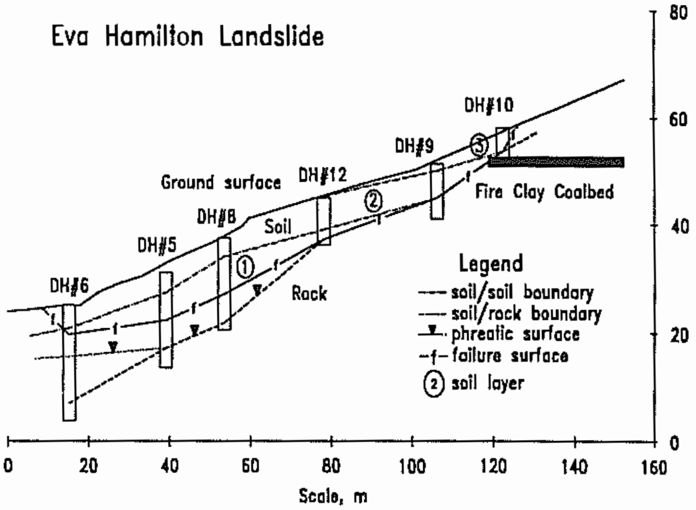

Figure 3. Cross-section of a typical eastern Kentucky AML landslide where underground mine has emitted water in the natural soil slope.

Classification of AML Landslide Material

Two to three distinct soil layers were found within each of the 37 landslides examined (table 1). Thirty-one colluvium and 24 spoil layers were identified from a total list of 83. Nine other soil layers were classified as residual, 3 as fill, 2 as alluvial, and 14 were not identified.

It is understood that the type of soil found on eastern Kentucky's slopes directly depends on the lithologic type of the subjacent rock strata (Davies 1973). In most of the slopes studied in this paper, the strata found immediately below the soil belong to the Breathitt Formation. This formation contains numerous minable coalbeds and alternating units of sandstones, siltstones, and shales. The siltstones and shales readily weather into soils, which form the colluvium and residual layers. The same weathering process takes much longer to break the resistant sandstone down to its granular components. Therefore, rock fragments ranging in size from gravel (4.75 to 75 mm) to boulders (>300 mm) are generally derived from sandstone formations. The percentage of rock debris within eastern Kentucky slopes is believed to be much higher than that of other landslide regions in Ohio, Pennsylvania, and northern West Virginia principally because of increased occurrence of sandstone strata.

Of the 31 colluvium layers examined, 20 were described as sandy lean clays or clayey sands with gravel, rock fragments, or boulders. A lean clay is one that is only slightly plastic because it contains a larger proportion of silt or sand than clay. Seven samples were simply described as sandy lean clays. Two samples were sandy silt with rock fragments or boulders. The spoil layers were described in a similar fashion. Sandy lean clay or a clayey sand with gravel, rock fragments, and boulders were the dominant descriptions. Only seven soils were designated without a larger fragments component. Spoil layers differ from colluvium in the occasional occurrences of mining machinery, topsoil and organic material such as trees and brush, and the uneven distribution of rock fragments based on the distance from the spoil dump point. Weigle (1966) and Kimball (1974) described similar occurrences of spoil in eastern Kentucky. Clearly, a significant portion of the colluvium and spoil contains large particles varying in size and shape and floating in a matrix of clay and sand mixtures. The significance of this will be discussed later in this paper.

Soils studied in this paper were classified by the Unified Soil Classification System (Casagrande 1948). Sixty-six percent of the layers were classified as either CL or ML, both fine-grained soils (table 2). The dominant classification was CL (lean clays), accounting for 65% of the colluvium, 65% of the spoil, 88% of the residual, and 67% of the fill layers. All of the fine- grained soils had low to medium plasticities. Next to the alluvial, spoil had the highest concentration of coarse-grained soils (SC to SM) with 35%, while residual had the lowest concentration with 12%. All of the coarse-grained soils were dirty (clayey or silty) sands. In another study, Weigle (1966) found that spoil varied from clayey silt (ML) to silty sand (SM) with relatively low plasticity.

Table 2. Classification of soils found in eastern Kentucky's AML landslides.

Soil Layer	Fine-grain			Coarse-grain			Not Defined
	CL	CL-ML	ML	SC	SC-SM	SM	
Colluvium	17		2	6	1		3
Spoil	13			3	3	1	4
Residual	7			1			1
Fill	2			1			
Alluvial				2			
Not determined	4	2	2	3	1	1	1

Material Properties Affecting AML Landslides

Certain material properties are important in estimating the strength of AML slopes. Two of the most critical properties are *moisture content* and *consistency/density*. In general, the rapid weathering of the shales and siltstones have produced well-graded colluvium and spoil layers. Well-graded soil is often low in permeability and variable in moisture content. Okagbue (1984) noted a correlation between spoil moisture content and the percentage of fine-grained soils, suggesting that water contributes to material degradation.

Below the ground water or phreatic surface, soils are completely saturated with water. Eastern Kentucky's AML slopes have a range of phreatic surface conditions, some of which may be associated with seasonal changes in rainfall. Swanson et al. (1983) found, however, that phreatic surface fluctuations were not directly comparable to rainfall intensity. Exploration drilling at many of the study sites found some evidence of phreatic surfaces above the soil-rock interface, especially where an abandoned mine was emitting water directly into the slope. Several geotechnical reports mentioned phreatic surfaces thought to extend close to the ground surface during periods of excessive rainfall, but none measured such a condition. This is, of course, a serious consideration because as the phreatic surface rises through the soil layers, the ability of the soil mass to resist failure is greatly diminished. Additionally, Swanson et al. (1983) noted that after the phreatic surface is lowered below a newly developed failure surface, the spoil layers may soften with a permanent loss of strength.

Most of the landslide slopes studied had phreatic surface well below the ground surface and most often occurred at or below the rock line. Soils above the phreatic surface were found to have a wide range in moisture contents. The degree to which the soil was saturated can be expressed in terms of the percentage of water filling void spaces: dry (0%), humid (1% to 25%), damp (26% to 50%), moist (51% to 75%), wet (76% to 99%), and saturated (100%). Colluvium, spoils, residuals, and fill layers within this study were found to span the entire range of saturation. However, the average saturation was in the moist category (fig. 4). Not surprisingly, the alluvial layers, which are found near the flood plains, were closer to the saturated state.

Another important material property, as it relates to slope stability, is *consistency and/or relative density*. Consistency of fine-grained soils corresponds in some respects to the relative density in coarse-grained soils (Holtz and Kovacs 1981). In most of the 37 AML landslide projects studied, the consistency/relative density characteristics were evaluated with data generated from the Standard Penetration Test (SPT). The SPT measures the resistance supplied by different soil layers as a tool is driven downward. The penetration resistance is reported as the number of blows to drive the tool 0.3 m. Lambe and Whitman (1969) discuss techniques for correlating penetration resistance with the relative density of sand and the consistency and strength of clay.

Consistency is a measure of the degree of adhesion between clay particles and the resistance offered against forces that tend to deform or rupture the soil aggregate (Terzaghi and Peck 1967). The consistency of clays can be categorized as very soft, soft, medium, stiff, very stiff, and hard. All of these consistencies were encountered in the AML landslides of eastern

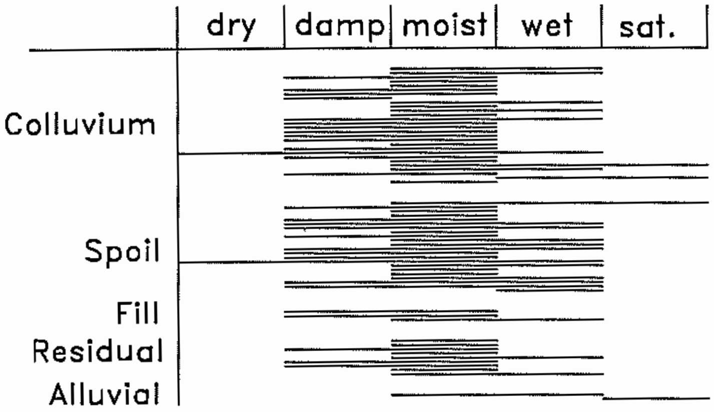

Figure 4. Saturation ranges of eastern Kentucky AML landslide soil layers.

Kentucky (fig. 5). Very soft or hard clays, which correspond to soils of little or great strength, were rarely encountered. In many cases, extremely high resistance rates (>100 blows/0.3 m) were experienced when the penetrating tool encountered large rock fragments or boulders. In general, colluvium, residual, and fill CL-ML layers have stiff consistencies, while spoil CL-ML layers are slightly less stiff, averaging medium consistency.

Coarse-grained SC-SM soils have relative density categories which are similar to those of the consistency categories of clay: very loose, loose, medium, dense, and very dense. These categories are also a crude indicator of strength in that very loose sand could be excavated by hand, while very dense sand would require power tools. Because of the inconsistencies in reporting relative density, analysis of this property was not accomplished.

Density characteristics can also be examined by weighing equal volumes of soil. It is generally assumed that increases in density of similar materials produce corresponding increases in strength. For instance, when spoil is first placed it can have a dry unit weight of 1,137 to 1,442 kg/m^3 (Weigle 1966). Over time, consolidation, which is a form of densification, can occur through dewatering or surcharge loading from overlying soil layers, increasing the dry unit weight. In eastern Kentucky, an average dry unit weight of 1,725 kg/m^3 was measured. A comparison of dry unit measurements with the optimum values as calculated by the Standard Proctor test was also performed. This analysis indicated that nonuniform consolidation is typical for both the colluvium and spoil soil layers. It was determined that colluvium had compacted an average of 92% of its optimum value and the aging spoil an average of 94%. Generally, a compaction of 95% is viewed as a minimum for mechanically compacted soils placed in civil engineering applications. These numbers compare well with Swanson et al. (1983) where the percent of compaction ranged from 81% to 107%, with a median value of 89% for spoil recently reclaimed from active strip mines.

AML Landslide Shear Strengths

The most important design input parameter needed to engineer remediation efforts is the soil's *shear strength*. Its primary use is to define the shape of the Mohr-Columb failure envelope. Soil shear strength is delimited by two parameters: the friction angle (ϕ) and the cohesion (C). These shear strength parameters were analyzed for eastern Kentucky's AML landslides by comparing laboratory-derived shear strength data with those found by performing stability analysis calculations.

Laboratory Determination

One of the most accepted techniques for determining soil shear strength parameters is by laboratory means. The two commonly used laboratory tests are the *direct shear* and the *triaxial* test. It is generally accepted that the direct shear test is simpler to perform but less accurate than the triaxial test. Thirty-eight shear strength tests were analyzed from 28 different AML landslides (table 3). The triaxial method accounted for 36 tests.

Triaxial tests are generally performed under one of three conditions: unconsolidated-undrained (UU), consolidated-undrained (CU), and consolidated-drained (CD). The consolidation term refers to the preparation of the sample prior to testing, and the drainage term refers to conditions during testing. When a CU triaxial test is performed, measurement of the porewater pressure permits the data to be reduced to the pressure that is borne only by the soil particles. This produces what is referred to as the effective shear strength parameters: ϕ' and C'. In general, the effective shear strength parameters best mirror long-term conditions and are the most beneficial in analyzing landslides.

All of the laboratory tests were performed on selected fine- and coarse-grained soils. Material of coarse gravel size (19 mm and greater) and above was removed prior to laboratory runs owing to the constraints imposed when testing material in direct shear boxes or triaxial chambers. Generally, a standard 71-mm-diameter triaxial specimen can have particles no larger than one-sixth its diameter, or approximately 12 mm.

Soil, from which testing was accomplished, was collected from exploratory drill holes. Eleven of the 38 tests were performed on undisturbed soil recovered primarily from Shelby tubes. Twenty-three of the tests were performed on remolded soil. Remolding is the process of kneading or working a soil to produce higher densities. These samples were remolded from 85% to 95% of their maximum dry unit weight.

Data compiled from all the triaxial CU tests give average shear strength parameters of $\phi' = 29.7$ and $C' = 4.9$ kPa. Some variations exist among different soil types as shown from the average values listed below:

colluvium, $\phi' = 30.6$ and $C' = 3.1$ kPa

spoil, $\phi' = 27.8$ and $C' = 9.7$ kPa

residual, $\phi' = 28.6$ and $C' = 1.1$ kPa

fill, $\phi' = 27.9$ and $C' = 6.2$ kPa

The above parameters represent peak strength condition. Swanson et al. (1983) noted similar values for spoil ϕ' with an average of 29°. Residual strength values for the spoil are less, averaging approximately 20°. Residual values are more representative of a failed material's strength characteristics. The friction angle for the residual state in clays is generally much lower than the peak strength values. Unfortunately, residual strength data were not determined for this data set. Consideration should be given to utilizing residual data when stabilizing failed landslides comprised largely of clays.

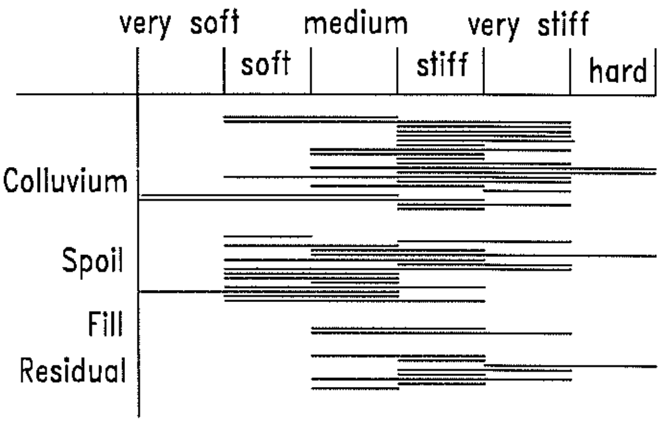

Figure 5. Ranges of clay consistency encountered in eastern Kentucky's AML landslides.

Table 3. Laboratory determined shear strengths.

Landslide name/soil layer	Effective friction angle (ϕ')	Effective cohesion, (C', kPa)	Test	Sample type	Percent remolded	Maximum dry unit weight, kg/m^3	Optimum moisture, %
Allen-Banner/1	27	2.4	CU	Remolded	90	1,897	13.3
Bear Branch/3	29.9	0	CU	Undisturbed	–	1,845	14.3
Bentley/1	39	0	CU	Undisturbed	–	1,796	11.1
Birchfield/1	30.1	1.0	CU	Remolded	91	1,839	14.1
Birchfield/2	30.6	1.0	CU	Remolded	91	1,954	11.6
Bonnyman II/1	24.2	29.7	DS	–	–	–	–
Bryant/1	30.7	3.4	CU	Undisturbed	–	1,826	15.3
Bryant/2	25.5	2.4	CU	Remolded	90	1,892	14.5
Carol Begley/1	28.7	2.4	CU	Remolded	92	1,808	13.9
Carol Begley/2	28.7	2.4	CU	Remolded	92	1,877	13.9
Clear Creek/1	27.3	3.8	CU	Remolded	92	1,800	12.7
Clear Creek/2	26.7	5.3	CU	Remolded	92	2,111	11.8
Clear Creek/3	32	0	CU	Remolded	92	1,938	11.1
Cubert Spence/2	27.8	1.0	CU	Remolded	–	1,720	17.3
Denver Newsome/1	23	71.9	CU	Undisturbed	–	–	–
Eva Hamilton/1	29.9	2.4	CU	Undisturbed	–	1,849	13.9
Eva Hamilton/2	28.6	0	CU	Undisturbed	–	1,784	14.4
Everage/1	34.5	10.1	CU	Undisturbed	–	1,778	17.5
Frazier/1	32.3	7.2	CU	Undisturbed	–	1,866	13.7
French III/1	28.7	0	CU	Remolded	90	1,865	16.3
Grose/1	35.3	2.4	CU	Undisturbed	–	1,776	16.5
John Kennedy/1	27.4	10.1	CU	–	–	1,732	18.1
John Kennedy/2	28.7	9.6	CU	–	–	1,688	17.4
Loftis/1	28.4	2.4	CU	Remolded	95	1,967	12.1
Maynard/2	5.2	10.4	UU	–	–	–	–
Moore II/2	27.4	2.9	CU	Remolded	90	1,834	14.4
Pinky Lee/1	27.5	1.0	CU	Remolded	92	1,776	16.6
Ray/1	30/36	1.9	DS	Remolded	–	–	–
Ritchie/2	32.6	0	CU	Remolded	92	1,975	11.2
Ritchie/3	32.5	10.5	CU	Undisturbed	–	1,861	14.2
Ronnie Anderson/4	27.5	2.9	CU	Remolded	91	1,901	12.7
Sanders/1	26.5	3.8	CU	Remolded	85	1,901	13.3
Spradlin Branch II/3	32	0	CU	Remolded	88	1,964	11.4
Stone/1	29.7	1.0	CU	Remolded	92	1,903	12.7

Landslide name/soil layer	Effective friction angle (ϕ')	Effective cohesion, (C', kPa)	Test	Sample type	Percent remolded	Maximum dry unit weight, kg/m^3	Optimum moisture, %
Stone/2	27.9	3.8	CU	Remolded	92	1,815	15.2
Wells-Pennington/1	28.4	3.4	CU	Remolded	95	1,780	17.6
Wells-Pennington/2	28.9	1.4	CU	Remolded	95	1,807	15.9
Winfield-Weaver/1	33.7	0	CU	Undisturbed ...	–	–	–

CU Consolidated undrained triaxial with pore pressure measurements.
DS Direct shear.
UU Unconsolidated undrained triaxial.
NOTE.–Dash indicates not determined.

It has become general practice to assume C′ equals zero for eastern Kentucky AML landslides. Analysis of laboratory data suggests this may not be prudent. An average of 4.9 kPa was obtained from all tests. This value seems reasonable since near surface soils are subjected to considerable wetting and drying which can cause overconsolidation ($C' > 0$). Sensitivity studies, using analytical slope stability procedures, indicate that a 5-kPa cohesion value could produce consequential increases in the slope's safety factor.

Stability Analysis

When a landslide occurs, the shear strength of the soil is mobilized along the full length of the failure surface. An estimate of the safety factor at this state can be made by performing a technique known as *stability analysis*. If the geometry of soil layers and the position of the phreatic and failure surfaces are known, the uniquely determined laboratory values of ϕ' and C′ can be evaluated. Safety factors greater than 1 would indicate the laboratory values of ϕ' and C′ are overestimating in situ soil strength. Safety factors below 1 would indicate the opposite.

In theory, the effective shear strength parameters could be determined by utilizing the back analysis technique. This technique assumes the safety factor of the failed slope is equal to 1. Strength values for the entire soil mass are evaluated by altering ϕ' and C′ until the safety factor equals 1. Unfortunately, these material properties cannot be uniquely defined since there are two effective shear strength parameters for each layer and several layers often exist for each landslide.

Sufficient data does exist to perform stability analysis on four landslides: Bryant (fig. 2), Eva Hamilton (fig. 3), Wells-Pennington (fig. 6), and Clear Creek (fig. 7). Each of these sites had suitable geotechnical data for determining the precise safety factors along observed failure surfaces. When uniquely determined laboratory values for ϕ' and C′ were input into stability analysis, safety factors between 1.3 and 2.3 were calculated (table 4). The stability technique used was the Spencer Method contained within the SB-SLOPE program.

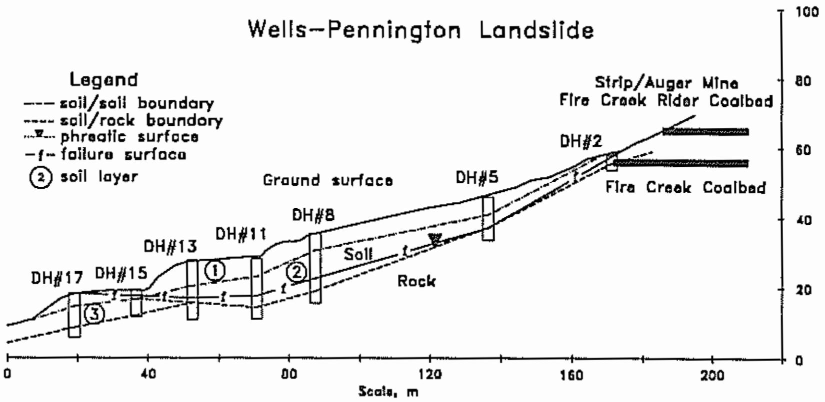

Figure 6. Cross-sectional view of the Wells-Pennington landslide.

Two solutions seem plausible to explain this discrepancy. The first would be that the field-determined locations of the phreatic surfaces are incorrect. Problems with evaluating phreatic surfaces after landslide initiation have already been discussed. The second is that laboratory-determined strength values of colluvium/spoil material are unreliable. One possible explanation for this is that laboratory testing does not consider the influence of particles greater than approximately 12 mm in dimension. Considerable mention has been made of the rock fragments occurring within both the colluvium and spoil layers (fig. 8). These large particles may influence the performance of the soil mass to a greater extent than had been previously believed. This could diminish the importance of testing soil void of rock fragments.

Summary and Conclusions

Using data gathered from drilling, observational, and laboratory techniques, the following important factors that affect AML landslides in eastern Kentucky were determined:

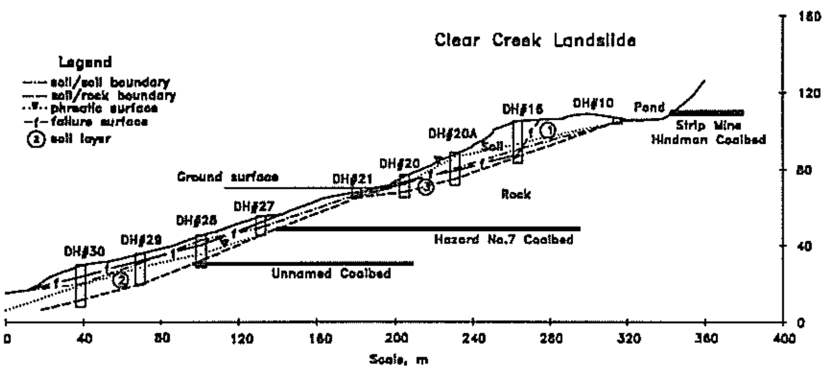

Figure 7. Cross-sectional view of the Clear Creek landslide.

1. A lack of reclamation has allowed rainfall and/or mine water to drain directly into the AML slopes, increasing the porewater pressure and lowering the shearing resistance of the soil.
2. Sixty-six percent of the landslide layers were classified as fine-grained soils (clays or silts). All of the coarse-grained soils were classified as dirty (clayey or silty) sands.
3. A significant portion of the colluvium and spoil contains large particles ranging from gravel to boulders in size and floating in a matrix of clay and sand mixtures.

Table 4. Safety factors of landslides using laboratory test data.

Landslide Name/soil layer	Laboratory Test			Stability Analysis			Safety Factor
	ϕ'	C'	Unit Weight, kg/m^3	ϕ'	C'	Unit Weight, kg/m^3	
Bryant/1	30.7	3.4	1922	31	3.4	1922	1.9
Clear Creek/1	27.3	3.8	2082	27	3.8	2082	1.3
Clear Creek/2	26.7	5.3	1999	27	5.3	1999	
Clear Creek/3	32	0	1986	32	0	1986	
Eva Hamilton/1	29.9	2.4		30	2.4	2002	2.1
Eva Hamilton/2	28.6	0		29	0	2002	
Eva Hamilton/3				29	0	2002	
Wells-Pennington/1	28.4	3.4	1991	28	3.4	1986	2.3
Wells-Pennington/2	28.9	1.4	1994	29	1.4	1986	
Wells-Pennington/3				29	1.4	1986	

4. Eastern Kentucky's AML slopes have a widespread of phreatic surface conditions ranging from below the rock line to close to the ground surface. Phreatic levels and/or drainage from abandoned mines are generally controlled by seasonal changes in rainfall.
5. Soils above the phreatic surface were found to have a wide range in saturation.
6. Wide variations were encountered in clay consistency. Spoil layers are less stiff than the colluvium, residual, and fill layers.
7. Colluvium and spoil are nonuniformly consolidated. Colluvium had compacted an average of 92% of its optimum value and the aging spoil an average of 94%.
8. Thirty-eight shear strength tests were analyzed from 28 different AML landslides. Particles greater than 12 mm were removed prior to laboratory runs. Data compiled from all the triaxial CU tests give average shear strength parameters of $\phi' = 29.7$ and $C' = 4.9$ kPa.
9. Stability analysis performed on four landslides using laboratory-determined ϕ' and C' produced safety factors between 1.3 and 2.3.

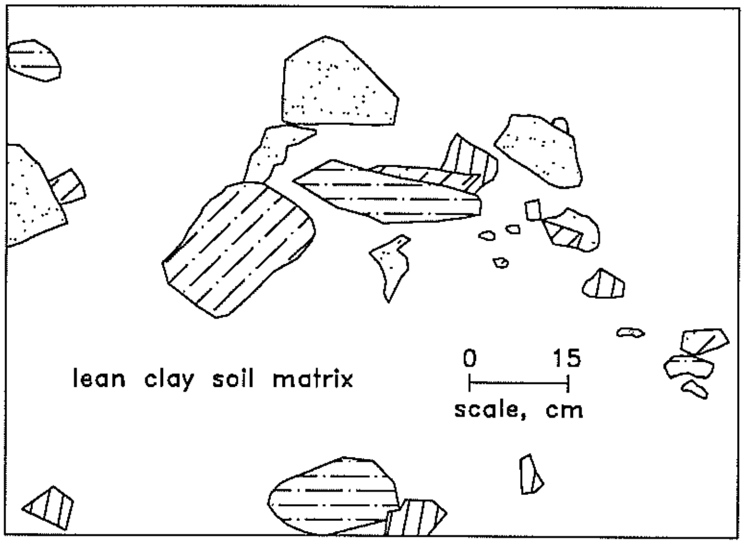

Figure 8. Image of a photograph showing the concentration of rock fragments within the colluvium of an AML landslide, near Hazard, KY.

Conclusions drawn from this investigation are:

Most of the AML landslides occurred either in the outcasted spoil material or within the saturated natural soil slopes. These slopes contain high concentrations of shale, siltstone, and sandstone rock debris. The shales and siltstones weather rapidly, producing well-graded colluvium and spoil with poor permeability. Because the spoil (and to a lesser degree the colluvium) is relatively young geologically, much of this material is still disintegrating with time, producing higher concentrations of fines. This implies that AML landslides will continue to occur in eastern Kentucky as strength conditions adjust to changing soil compositions.

Soil strength conditions were examined using laboratory and stability analysis techniques. The lack of agreement between these techniques presents difficulties. More attention needs to be focused on the most probable location of the phreatic surface during slope failure. The research community must also better establish the role of rock debris in slope strength.

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