ASSURING STABILITY OF MINIMIZED VALLEY FILLS: A REVIEW OF POTENTIAL CAUSES OF INSTABILITY AND AVAILABLE COUNTERMEASURES[1]

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Abstract. A particular geotechnical design and construction challenge faces the coal industry. It is shared by state and federal regulatory personnel responsible for approval of excess spoil or valley fills in steep-sloped Appalachia. Competing regulatory requirements under the Clean Water Act (CWA) and Surface Mining Control and Reclamation Act (SMCRA) encourage the construction of smaller valley fills (so that stream impacts are minimized), while also assuring long-term stability. To satisfy both CWA and SMCRA requirements, mining companies may opt to site valley fills further upstream on steeper foundation slopes. Three recent investigations documented the potentially destabilizing effect of steeper foundations on mass stability: A 2002 study by the U.S. Office of Surface Mining Reclamation and Enforcement (OSM) found that, among the relatively small number of fill failures in a 23 year period, a disproportionate number had foundations in excess of 20 percent slope. The results of a more recent OSM investigation of a 2004 fill failure in Kentucky seemed to confirm the negative effect of a steep foundation. Finally, a 2006 joint study between the Kentucky Department of Natural Resources and OSM emphasized the influence of weak, soil-like materials on fills placed on steep natural slopes. This paper reviews long-standing issues pertaining to proper design and construction measures with respect to valley fills, especially "durable rock" fills, and discusses how they will become more critical as spoil minimization is practiced. Stabilizing countermeasures available within the existing State and Federal regulatory framework are also discussed.

Introduction

The U.S. Office of Surface Mining Reclamation and Enforcement (OSM) is proposing changes to the Code of Federal Regulations in the interest of minimizing the adverse effects of excess-spoil-fill construction on the "prevailing hydrologic balance, fish, wildlife and other environmental values" (70 *FR* 35112). The proposed changes will require: (1) minimization the amount of excess spoil generated at a mine site; (2) minimization of the size of the fills constructed; (3) consideration of alternative configurations for disposal; and (4) development of a disposal plan that would minimize adverse impacts to the environment.[3] To achieve those objectives, mining companies operating in steep-sloped Appalachia will likely build excess spoil fills that toe out at higher elevations in the hollows (i.e. to prevent or limit burial of streams). Consequently, the slopes of fill foundations will generally be steeper.

Whereas the authors of this paper support these measures to protect the hydrologic balance and general environment, we wish to point out that placement of fills on steeper foundations can negatively impact the stability of the fills if proper care is not taken during their construction. It is important to note that in addition to impairing human safety, valley fill instability can negatively impact streams, the riparian habitat etc., and thus defeat the very purpose of the spoil minimization measures proposed. We do not, however, propose additional regulatory requirements pertaining to valley fill stability. Rather, we intend to emphasize the importance of engineering requirements already on the books, especially as they apply to the predominant type of valley fill constructed: the durable rock fill. We believe that the practice of restricting valley fills to higher elevations in the watershed leaves less room for error in the design and construction of stable structures.

This paper gives a quick review of the nature of excess spoil generation, methods and requirements of excess spoil fill construction, and the to-date stability record of the fills. The interest in excess spoil minimization and how it affects valley fill construction is also discussed. Most importantly, we will review long-standing issues pertaining to proper design and construction measures with respect to durable rock fills and discuss how they will become more critical as excess spoil minimization is practiced. The information presented herein results from several past investigations. Cited references that directly address the influence of steep foundations on fill stability are identified as follows[4]:

- "Long-Term Stability of Valley Fills" (OSM, 2002), hereafter referred to as the EIS stability study: The document describes an investigation in support of the Mountaintop Mining/Valley Fill Environmental Impact Statement (USEPA, 2003). Among other tasks, the three-year study included the collection and analysis of permit and field data for 128 valley fills in eastern Kentucky, southern

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[3]The proposed rule changes also include a revision to the "stream buffer zone" regulation to clarify the kinds of coal mining activities that are subject to the rule. For a summary of the regulation and the proposed revision, the reader is referred to the proposed rule in the Federal Register Notice, 69 *FR* 1036.

[4] These references are available at the OSM Appalachian Regional Office in Pittsburgh, PA.

West Virginia, southwestern Virginia, and east-central Tennessee. The data set included all 20 failed valley fills known at the time.

- "Field Report: HNR Valley Fill Failure" (Michael, 2005): The report analyses a valley fill failure that occurred in Kentucky in December 2004. This is the only known valley fill failure since completion of the EIS stability study. The event is presented as a case study in the latter part of this paper.

- "Evaluation Year 2006, Excess Spoil Fill Stability" (KYDNR et al., 2006), hereafter referred to as the KY stability evaluation: The document presents the findings and recommendations of a two-year joint study by the Kentucky Department of Natural Resources (KYDNR) and OSM of the permit application review, construction, and inspection of valley fills in Kentucky. Data pertaining to 59 fills were gathered and analyzed. The report also includes a series of slope stability analyses to model the effects soil-like foundation materials on valley fills placed on steep natural slopes.

Excess Spoil Fills

When coal is mined by surface mining methods, rock and soil that overlie the coal must be first temporarily removed and stored outside of the immediate mining area. The rock is blasted as it is removed. The angular blast rock, or "spoil," incorporates voids and therefore is less dense than undisturbed rock. Therefore, the volume of spoil removed during mining increases or "bulks" relative to the volume of rock that was in place prior to mining. After coal removal, the mine operator returns most of the spoil to the mined-out area for reclamation.

The operator grades the spoil so that it closely resembles the pre-mining topography or the "approximate original contour" (AOC). There are situations, particularly in steep terrain, where the volume of spoil is more than sufficient and technically feasible to return to the mined-out area when reclaiming the site. The "excess spoil" is disposed of in locations other than the mined-out area, except for material used to blend spoil with surrounding terrain in achieving AOC in non-steep-slope areas. Relatively large volumes of excess spoil may be generated in steep-slope terrain when the operator proposes to reclaim the mining area to a flatter or more gently rolling topography in lieu of AOC so that a more economical viable land use may result. In these situations, the regulatory authority must approve the mountaintop removal AOC variance.

Most excess spoil produced in steep terrain is placed either in adjacent valleys or on previously mined sites. Excess spoil fills placed in valleys with maximum side slopes greater than 20 degrees (36 percent) and average profile slopes greater than 10 degrees (18 percent) are called "valley fills" in the Federal regulations. Figure 1 shows an example of a valley fill. In areas where precipitation is ample, even small drainage areas harbor small streams; so, many of these valley fills are constructed over small headwater streams.
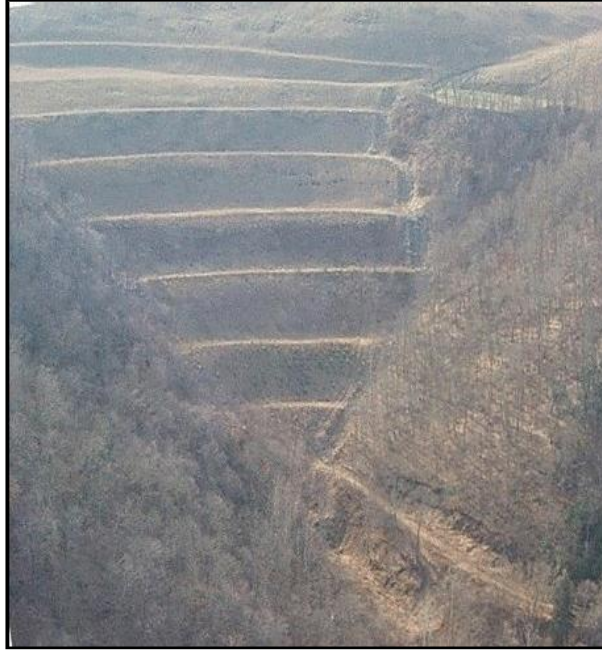
Figure 1: Valley Fill. Note terraces and side drains constructed on the outslope to control surface runoff and erosion. (Aerial photo taken in December 1999 during the EIS stability study).

Excess spoil generation and fill construction are almost exclusively limited to states in the central Appalachian coal fields. During the period October 1, 2001 to June 30, 2005, 1589 of the 1612 fills (98.6 %) approved to be constructed nationwide were located in Kentucky (1079), Tennessee (13), Virginia (125), and West Virginia (372), and only 23 fills outside of central Appalachia. Coal mining permits issued between October 1, 2001 and June 30, 2005 anticipate that approximately 861 kilometers (535 miles) of streams will be temporarily or permanently relocated or buried. Of this length, about 591 kilometers (km) (367 miles) are located in the Appalachia coal fields, particularly Kentucky (~233 km or 145 miles), Ohio (~69 km or 43 miles), Virginia (~87 km or 54 miles), and West Virginia (~201 km or 125 miles).

Valley fills in steep-slope Appalachia vary greatly in size. For example, the 128 sampled fills analyzed in the EIS stability study ranged in volume from 0.15 to more than 152 million cubic meters (0.2 to more than 200 million cubic yards); and they varied in length from 90 to nearly 3000 meters (300 to nearly 10,000 feet) (OSM, 2002).

Durable Rock Fills

Excess spoil fill construction methods that are recognized by the Federal regulations include: (a) the 'conventional' lift-type construction method; (b) the head-of-hollow fill method; (c) disposal on preexisting mine benches; and, (d) the durable rock (gravity segregated) fill method. There are other fill types that are not specifically listed in the Federal regulations, but are recognized in the regulations of several States and approved by OSM. They include: (e) the "side hill fill" in West Virginia; and (f) the "zoned concept" in Virginia. In most of these construction methods, excess spoil is deposited in uniform and compacted horizontal lifts or layers (four feet or less in thickness). Prior to

placement of the spoil, the foundation (i.e. valley floor and sides where the spoil will be placed) must be prepared and rock underdrains installed to accommodate groundwater seepage and surface-water infiltration. The Federal regulations require that the rock underdrain be durable (rock that will not slake in water nor degrade to soil material); non-acid or toxic forming; and free of coal, clay or other non-durable material [30 CFR §816/817.71(f)(3)].

The predominant valley fill construction technique in steep-sloped Appalachia is the *durable rock fill* method (Fig. 2). Unlike other fill construction techniques this method does not require underdrain construction prior to spoil placement or spoil placement in thin lifts. Instead spoil is end-dumped into valleys in a single lift or multiple lifts (30 CFR §816/817.73). The fill construction begins at an elevation between the lowest coal seam mined and where the crown or top of the completed fill will occur. Dump trucks haul spoil to the center of the hollow and dump the material down slope. This continues to take place, allowing a platform of spoil to lengthen down the hollow, and ends when the toe or bottom of the fill approaches its as-designed final location. Lifts of existing fills are known to range between 9 to over 120 meters (30 to over 400 feet) in thickness. At the completion of spoil placement, the face of the fill is graded from its dumped angle of repose (the natural slope of spoil material under its own weight) into a less steep, terraced configuration. The durable rock fill method can only be used if durable rock overburden is present and will comprise at least 80 percent (by volume) of the fill. The installation of a designed rock drain prior to spoil placement is not required for this type of fill, since the gravity segregation during dumping forms a highly permeable, or free-draining, zone of large-sized durable rock in the lower one-third of the fill.
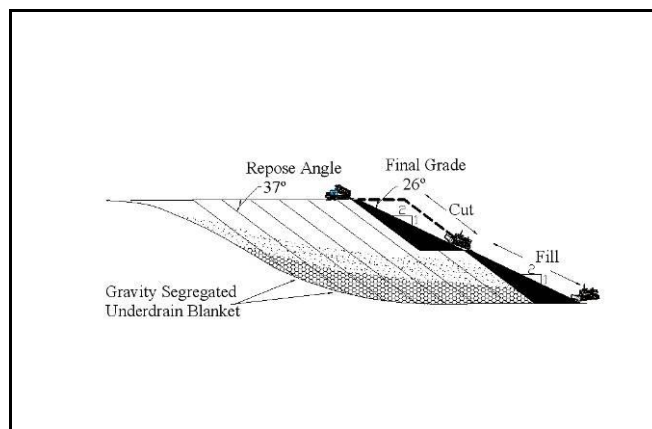

Figure 2: Schematic of a Durable Rock Fill.

Among these different methods of valley-fill construction, end-dumping to build a durable rock fill has been, by far, the most commonly applied since 1980. It is less expensive than lift construction; and, with the sampling and testing practices commonly in use, most permits demonstrate excess spoil volumes of at least 80 percent durable rock.

<u>Concept of Durable Rock</u>

Durable rock is defined in Federal regulations at 30 CFR §816/817.73(b) as rock which is non-toxic and does not slake in water and will not degrade to soil material. The regulatory intent is to selectively obtain rock that can withstand surface mining conditions, and natural forces affecting the fill mass after final placement, without significant degradation. The intent is that, over the long term, the durable rock fill behaves as a mass of broken, free-draining rock and not as soil. A rock mass is inherently more stable than soil with similar volume, geometry, and foundation conditions because it has greater shear strength and is more permeable. Weak, nondurable rock will degrade into finer soil-like particles. In a fill comprised of too much non-durable rock, the drainage system provided by the void space between the rocks may become clogged. The clogging will reduce the underdrain permeability and introduce a phreatic surface to the fill mass. Excess pore water pressures may develop and decrease the shear resistance or shear strength of the fill material. Therefore, the correct assessment of the strength and durability of the rock is a critical design factor. It is also a critical construction factor; the fill construction method may need to be modified if the spoil engineering properties are observed to be different in the field than what were documented in the permit.

Some OSM-approved design and construction requirements for durable rock fills are unique to State programs. For example, the Kentucky and West Virginia definitions of durable rock are more specific than the Federal definition. The Kentucky regulations require a Slake Durability Index (SDI) [ASTM D-4644 (ASTM, 2006)] of at least 90%, or similar result using another test that's equivalent to the SDI to the State's satisfaction [405 KAR 16:130 § 4 (1)(a)2]. The West Virginia regulations reject soil-like material in the durable rock definition: rock capable of degrading to a material, of which at least 50% is finer than 0.074 millimeter (0.003 inch), has plasticity, and is classified as ML, CL, OL, MH, CH, or OH [under ASTM D-2487 (ASTM, 2006)], is considered to be soil (38 CSR 2-14.14.g.1.B). The West Virginia rules also have a construction limitation: the final toe of the durable rock fill is not allowed to rest on a natural slope greater than 20 percent.

Unfortunately, there is no consensus among geotechnical experts working for the industry, environmental groups, and government as to what constitutes a rock durability testing protocol (i.e. to determine whether or not a material is durable enough to be used in an underdrain, chimney drain, or durable rock fill) that represents the conditions rocks are subject to by excavation and placement during mining, and as long-term residence within a fill. The rigor of various testing techniques proposed varies widely.

In all states, the industry and state agencies have relied upon the SDI as the primary method to evaluate rock durability. However, early OSM special studies and inspection reports indicated that weak, non-durable rock was being used in durable rock applications. Consequently, the agency undertook a major study that developed an alternative testing protocol and classification system (called the "strength-durability classification") and examined the results of applying it and the SDI test to116 overburden samples collected from 61 mine sites in the same four states covered by the EIS stability study (Welsh et. al., 1991). The researchers concluded that the strength-durability classification was more effective than the SDI in discriminating weak, non-durable rock.

OSM emphasized that the recommended protocol was not only effective, but also simple and inexpensive.

The proposed strength-durability classification utilizes a phased approach (Fig. 3). The initial phase consists of soaking rock samples in water for 24 hours to identify very low-durability rock by its short-term slaking behavior. Samples passing this phase are then subjected to a second phase of free-swell and point-load tests. The point-load strength and swell-test data are plotted on a graph, and the points are compared to "zones" on the same graph representing the acceptable value ranges for durable rock classification.
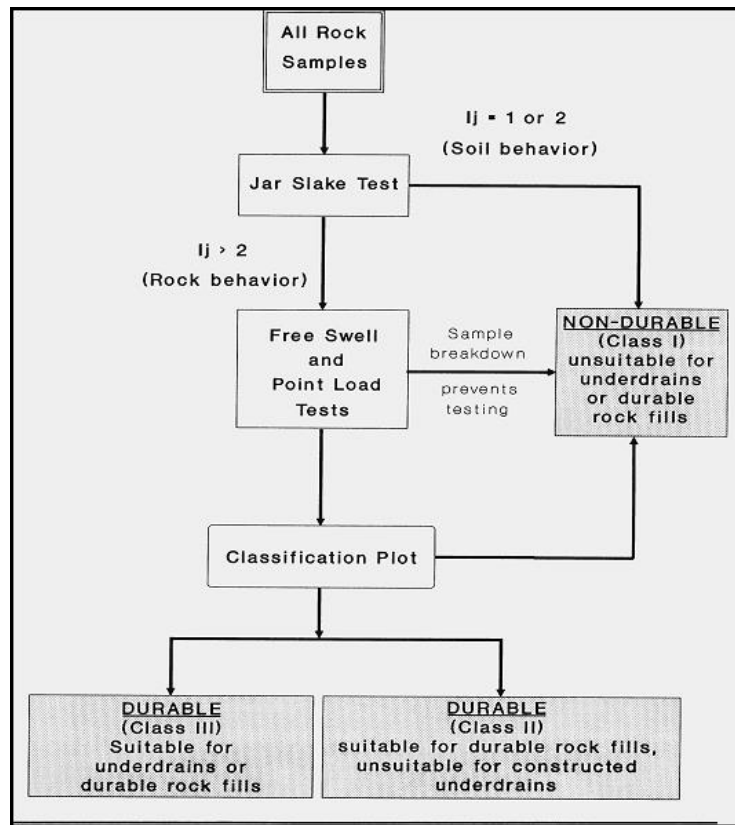

Figure 3: Proposed OSM Strength-Durability Classification System (Welsh et al., 1991).

Since this OSM study was published, the strength-durability system has received both support and criticism. There has been broad consensus among the state and Federal regulatory agencies that the SDI does not adequately discriminate non-durable rock for surface coal mining and excess spoil fill construction. Comments against the strength-durability classification protocol have asserted that its requirements for durability are unrealistically stringent (Casagrande, 1991). There are other classification systems in the literature that relate to rocks unlike those encountered in coal mining, e.g. rocks of the igneous and metamorphic variety which are heavily influenced by chemical weathering of constituent minerals. Hudec (1997) points out that shale has the most rapid weathering rates of all rock types, but also that its weathering is almost entirely physical in nature.

Other protocols incorporate SDI or are applicable only to shale. A system proposed by Palicki in (1997) is applicable to a variety of rock types. The protocol starts with a "rate of strength change" rating based on how much a specimen slakes in water after 30 minutes. Once given one of four ratings or "R-values", the sample is further classified according to unconfined compressive strength and "discontinuity significance." Like the strength-durability protocol above, this system does not depend on sophisticated testing equipment.

We and others in OSM do not anticipate that a widely-accepted resolution on the issue of realistic rock-durability testing will be reached in the near future. Partly for this reason, the OSM inspection and enforcement program is now emphasizing the "bottom line," i.e. on-site, visual evidence for the formation of an durable rock fill underdrain during the end dumping process. The agency is also stipulating the prevention of uncontrolled drainage over the fill outslope during, as well as after, construction. Among other purposes this requirement protects the underdrain from being clogged by eroded fine sediment, or "outwash."

Excess Spoil Fill Stability

The objective of most of the Federal regulatory requirements pertaining to excess spoil fills is to ensure long-term stability. The long-term stability of the fills is of great importance because the structures are not monitored or maintained by the mining industry or government following final bond release of a mining permit. Required steps to achieve stability include:

- A site investigation for each proposed excess spoil fill, specifically an investigation of the terrain and materials that will form the foundation of the fill. Important concerns include soil depth, the engineering strength of the soil or rock foundation materials, and the occurrence of seeps or springs.

- A stability analysis of the designed fill based on (1) accurate values representing the engineering strengths (i.e. internal friction angle and cohesion) of the placed spoil and foundation material and (2) anticipated pore-water pressures in the fill mass. The analysis must demonstrate a static safety factor (SF) of 1.5 and dynamic SF of 1.1.

- Professional engineer's certifications during the construction of the fills, quarterly and during critical phases of construction, to document that the fill is being constructed according to the permit plan. Critical construction phases include: foundation preparation; underdrain construction; surface drain construction; grading; and revegetation.

In the case of durable rock fills, additional information is required in the design phase to demonstrate in the permit that the structures will comprise 80 percent durable rock by volume.

To-date the record of excess spoil fill stability in steep-slope Appalachia generally has been good. The EIS stability study documented that major instabilities[5] on valley fills were neither commonplace nor widespread. Only 20 occurrences of major valley fill instability were recorded out of more than 4,000 fills constructed over a 23-year period.[6] None of occurrences resulted in the loss of life or significant property damage. All occurrences took place on active permits and all but one were repaired prior to bond release. One instability remained unreclaimed following bond forfeiture.

Keeping in mind the need for <u>long-term</u> (i.e. post-bond-release) stability the study did identify areas of potential improvement in the design, construction, and regulatory enforcement of valley fills.   The recommendations included the following: (1) more discriminating methods for determining rock durability; (2) consideration of alternative fill construction techniques to assure optimal foundation and drainage control; (3) better guidance on requirements for foundation investigations and stability analyses; (4) better documentation and record keeping for critical construction phase certifications; (5) prohibition of "wing dumping" excessive distances beyond the fill face; (6) additional assurances for fill foundations on steep slopes; (7) consideration of limits on fill-construction temporary cessation periods before requiring face completion; (8) additional studies of completed fills; and, (9) diligence in assuring a prohibition of impoundment construction on fills.

Some of the above recommendations had already been implemented by State regulatory authorities.   Recent developments in Kentucky and West Virginia are particularly noteworthy. Kentucky, through the 2002 promulgation of RAM No. 135 and Procedure No. 36, require designated zones near the toe and near the top of the fill where underdrains will be constructed instead of dumped. This to ensure: (1) the placement of adequate underdrains at the top of the fill footprint where the slope of the developing fill face is too short for effective gravity segregation; and (2) prevention of underdrain plugging near the bottom of the structure during fill-face regrading   They further require the mine operator to identify (in the field by flagging) a "stability point" upslope of designed toe location, above which a static safety factor of at least 1.5 cannot be demonstrated. Should the completed fill be smaller than initially designed, its toe must

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[5] For the purposes of the study, fill instability was defined as evidence that (1) part of the fill's mass had separated from the rest of the fill; (2) the separation occurred along a continuous slip surface, or continuous sequence of slip surfaces, intersecting the fill's surface; and (3) some vertical displacement took place. "Major" instabilities were those judged to have occurred over a large fraction of the fill face (e.g. over at least a few outslope benches) and/or required a major remediation effort (redistribution of the spoil form one part of the fill to another, construction of rock-toe buttresses, extensive reworking or augmenting of the drainage systems etc.).

[6] This number does not include several cases of catastrophic washouts and flooding from unfinished fills (either temporarily inactive or in the process of final regrading) in West Virginia. However, those instances did not involve major mass instability.

still at least reach the stability point. Finally, wing dumping[7] is controlled by requiring the operator to flag the design "crest limit" of the structure (defined by the length of the fill's top bench). The operator is not allowed to end dump material anywhere down valley of the crest limit.

While the changes in Kentucky have been made for the primary purpose of ensuring fill stability, changes in the West Virginia regulations respond to erosion and flooding problems below unfinished durable rock fills. The current regulations stipulate, among other requirements, that the fills be constructed in one of two ways: (1) by establishment (prior to end-dumping) of an "erosion protection zone" of mechanically placed and graded durable rock reaching a specified distance downslope of the final toe of the designed fill (Fig. 4); or (2) construction of the fill from the toe upwards with dumping increments not exceeding 100 feet (see 38 CSR 2 14.14.g.2 and g.3.). The erosion protection zone is intended to reduce siltation down gradient of the toe of the fill by dissipating runoff energy, but the erosion protection zone will likely enhance stability as well. The toe-upward construction may allay the risk of severe flooding and siltation downstream, but it is uncertain as to whether the method will have a positive influence on long-term stability. Regrading the fill face to a 50 percent slope contemporaneously with the lift placement should ensure stability during the construction process. These changes apply only to fill designs approved after the promulgation of the current regulations governing excess spoil fills. The approved plans for a large number of fills still under construction predate these regulations.
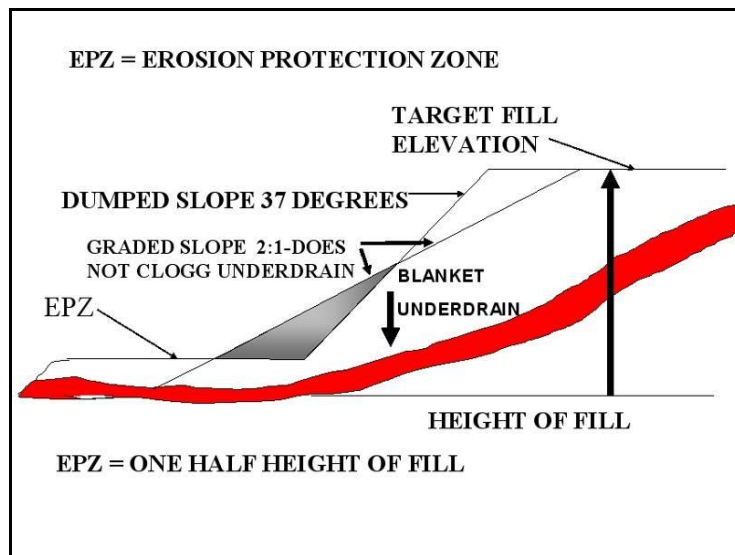

Figure 4: Erosion Protection Zone used in West Virginia.

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[7] A common problem in mountaintop mining has concerned the dumping (or "wing dumping") of spoil across the valley from the mining bench at points down-valley of the toe of a developing fill. Ideally, all spoil is first transported up the valley and then dumped from the top of the fill in the down-valley direction. In this way, the end-dumped face of an advancing fill progresses uniformly down the valley and parallel to the fill face. This preferred procedure maximizes gravity segregation of competent (unweathered) rock for underdrain development; and minimizes spoil exposure, and consequent breakdown and stream sedimentation.

Excess Spoil Minimization

As the population and the cumulative extent of surface mines and excess spoil fills increased especially in the Appalachian coalfields due to market forces and larger and more efficient earth-moving equipment, so have the concerns regarding the adverse environmental effects. In 1997, OSM, the U.S. Environmental Protection Agency (EPA), the U.S. Army – Corps of Engineers (USACE), and the U.S. Fish and Wildlife Service began discussing issues related to excess spoil fills and began a series of studies to examine excess spoil fills in the Appalachian coal fields.

As part of routine oversight activities, OSM conducted studies in Kentucky (OSM, 2000), Virginia (OSM, 1999a), and West Virginia (OSM, 1999b) to determine how the regulatory authorities were administering the SMCRA programs regarding AOC and post mining land use requirements. When permit files and reclaimed mines were examined, OSM found it difficult to distinguish between the reclamation configuration of mines that were not to be reclaimed to AOC and the reclamation configuration of mines that were to be reclaimed to AOC. There were no clear differences in the number and size of the excess spoil fills, and non-AOC mines should generally have larger or more numerous fills. OSM determined that, typically, coal mine operators could have retained more spoil on mined out areas under applicable AOC requirements than they were actually retaining. OSM also found that in many instances coal mine operators were overestimating the anticipated volume of excess spoil. As a result, OSM concluded that coal companies were designing fills larger than necessary to accommodate the anticipated excess spoil. Where fills are larger than needed, more land outside the coal extraction area is disturbed. OSM attributed these problems, in part, to lack of or inadequate regulatory guidance.

Following the oversight review, Kentucky, Virginia, and West Virginia developed new guidance to address AOC and to address issues regarding excess spoil. Notwithstanding, OSM concluded that the current SMCRA regulations concerning excess spoil placement are primarily focused on ensuring that fills are safe and stable but do not explicitly evoke consideration and minimization of the environmental effects of fill construction.[8] OSM published proposed "excess spoil / stream buffer zone" rules in the Federal Register on January 7, 2004 [69 *FR* 1036]. OSM is currently engaged in preparing a draft environmental impact statement in support of the proposed rules.

It is important to note that efforts to minimize excess spoil fill impacts on streams and the general environment are already ongoing at the federal and state level. For instance, OSM issued a post-mining land use policy in June 2000 clarifying the criteria for mine sites to qualify for non AOC reclamation. This emphasis on AOC requirements leads permit applicants to avoid stream impacts and seek upland locations for spoil placement. Also, a variety of Clean Water Act (CWA) programs apply to the impact of valley fills on the chemical, physical, and biological integrity of the nation's waters. Section 404 of the

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[8] There were several other events leading up to OSM's proposed rule changes, which included litigation, starting in 1998, by environmental groups and other concerned citizens against several government agencies concerning, among other issues, the damaging effects of excess spoil fills on streams. For a summary of suits filed and related court decisions, the reader is referred to 69 *FR* 1036.

CWA regulates the discharge of dredged or fill material into waters of the U.S. Section 402 regulates all other point source discharges of pollutants into the U.S. waters under the National Pollutant Discharge Elimination System (NPDES) program. Permits for the discharge of pollutants under the NPDES are based on applicable technology-based standards of pollutants associated with a particular industry and water quality standards. Section 401 provides states with the authority to review and either deny or grant certification for any activities requiring a federal permit or license, to ensure that they will not violate applicable state water quality standards.

Under the authority of Section 404, the USACE Louisville, KY District collaborated with EPA and the Kentucky state water quality agency to assemble procedures for data collection and analysis to evaluate activities filling waters in the U.S. Use of the Louisville District Stream Assessment Protocol (2000) provides a numerical "score" for stream segments based on physical, chemical, and macro-invertebrate data collection. The stream score helps to determine the size, number and location of valley fills that are least damaging to the local watershed. The score is also used to evaluate whether mitigation projects can offset unavoidable impacts by recreating stream functions on site or improving functions off-site within the same watershed. The protocol is currently used by the Louisville, Nashville, Huntington districts in Kentucky and Tennessee. The Huntington and Norfolk districts are presently calibrating the protocol for West Virginia and Virginia. The ability to comply with CWA Section 404 and avoid costly watershed mitigation projects are significant motivations for mining companies to limit the downstream reach (and thus the size) of valley fills.

The West Virginia Department of Environmental Protection's (WVDEP) "Final AOC Guidance Document Policy" (commonly referred to as AOC-Plus), the "AOC/Excess Spoil Guidelines," and the "Durable Rock Fills" policies found at Section 29 of the State's Permit Handbook all serve to reduce fill impacts. Adherence to these policies serves to maximize back stacking of spoil onto the mine bench and/or to otherwise limit excess spoil placement. The application and implementation of the above AOC policies is commonly referred to as "spoil optimization" (Fig. 5). In addition, WVDEP integrated programs require concurrent submittal of applications to the USACE for Individual 401 Certification relating to proposed intermittent or perennial (in-stream) or wetland impacts. Part III of the Individual 401 Certification Application provides for a detailed analysis of No Practical Alternatives Analyses (NPA). The required utilization of all available upland practical alternatives serves to minimize the footprints of valley fills. The general thrust to minimize fills is also taking place in Virginia and Tennessee.
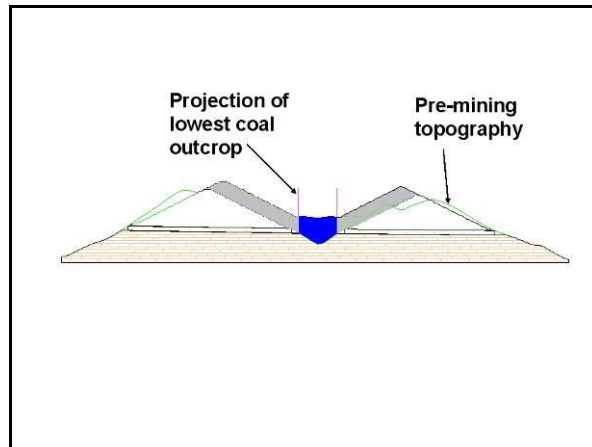
Figure 5: Schematic of Spoil Optimization. Original backfill above the mine pavement is shown in white; additional backfill in gray; and excess spoil in blue.

Trends in Excess Spoil Generation and Fill Size

Trends in the amount of excess spoil generated and sizes of excess spoil fills constructed were previously analyzed in the Mountaintop Mining/Valley Fill Environmental Impact Statement (USEPA, 2003). The analysis covered the years from 1985 to 2001. Based on data acquired from permit applications, the number of valley fills constructed or proposed to be constructed generally decreased. Trends in valley fill acreage and affected watershed acreage (both total and average) were erratic for most states. Total valley fill and watershed areas in Kentucky generally decreased, especially beginning in 1992 [from about 2,000 to 520 hectares (5,000 to 1,300 acres) and 8,000 to 3,000 hectares (20,000 to 7,500 acres) respectively]. Average valley fill and watershed acreages for the state generally increased from 1985, but steadily declined starting in 1998 [from approximately 7.2 to 4.4 hectares (18 to 11 acres) and 30 to 20 hectares (74 to 50 acres), respectively].

Available data for 2002 to 2005 show similar trends. For instance, the number of fills permitted in Kentucky and West Virginia declined (from 262 to 92 and 86 to 56 fills, respectively) (Fig. 6). The average footprint acreage of proposed excess spoil fills in West Virginia shows an erratic trend over these years. However, the average size of the Kentucky fills continues to show a general decline [from 7.7 to 2.9 hectares (19 to 7 acres)] (Fig. 7).
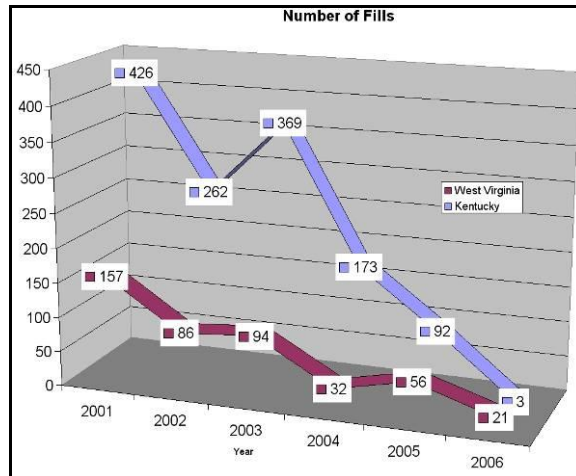
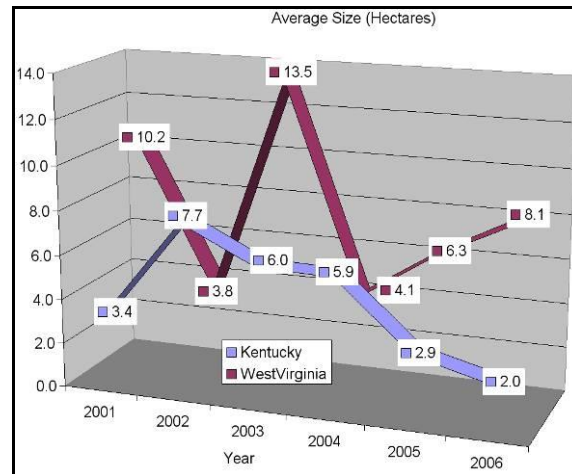Figure 6: Annual Trends in Number of Excess Spoil Fills Permitted.[9]

Figure 7: Annual Trends in Average Excess Spoil Fill Acreage.

The value of the analysis above is limited by the fact that the data is derived from permit applications and not directly from constructed excess spoil fills in the field. It is common knowledge among regulatory personnel working with valley fills that not all proposed fills are actually constructed.[10] The sizes of individual fills that have been built also frequently change (from as-designed to as-built) (Fig. 8), although it is much less clear whether and how much they increase or decrease. For example, the EIS valley fill

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[9] The data for Figures 6 and 7 were obtained from GIS layers available at http://gis.wvdep.org./data/omr.html (for West Virginia) and by digitizing imagery available at ftp://ftp.ky.gov/fsa (for Kentucky). Data for 2006 is current through August.

[10] For instance, according to the MTM/VF EIS, the inventory of planned fills in Kentucky exceeded 4,000; however, the as-built data showed less than 2,000 on-the-ground fills.

stability study identified a little less than half of the 129 fill samples in the study database as having at least one revision changing fill size in the permit files. In terms of volume or length, the permit modifications were close to evenly split between proposed enlargements and proposed size reductions. Too make matters even more complicated, there appears to be a significant number of constructed fills that are undocumented. The WVDEP, for instance, developed an inventory of "mining fills" based on a difference between elevation grids representing two distinct time periods (Shank, 2004). Preliminary results indicated the presence of over 500 fills in approximately 9 counties that were not represented in an existing fill inventory digitized from permit maps. The previously unmapped fills covered a total of approximately 3,880 hectares (9,700 acres) and over 138 stream channels.
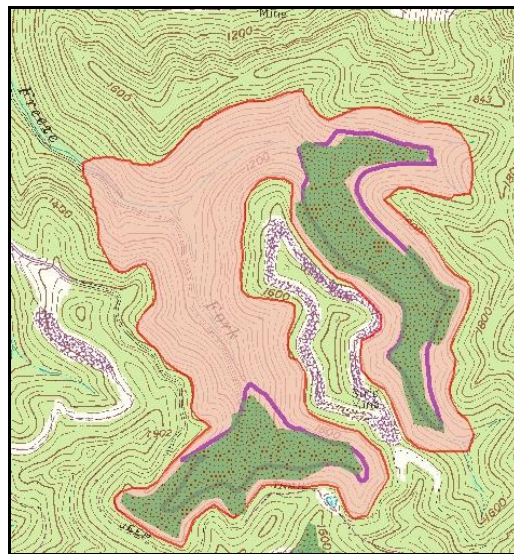

Figure 8: Valley Fill Size Reduction from Initial Permit Design (orange) to As Built (green with red dots).

It is worth keeping in mind that even if we had complete and reliable numerical data on actual fill construction, we would yet need more information to determine just how much minimization regulations, policies, or guidelines affect fill size. The EIS stability study attempted to develop a database to evaluate why permitted size reductions occurred. Seven explanatory categories were identified: (1) change in market conditions during the mining operation; (2) change in coal quality during mining; (3) pinch out of a coal seam; (4) interception with abandoned underground or auger mines; (5) inaccurate spoil volume calculations in the permit; (6) permit revocation; and (7) reason unknown. There was insufficient data to identify prevailing factors on the size reductions.

In addition to minimization and the size-reduction factors listed above, the construction of small fills on steep natural slopes can result from the convenience of short haulage distances. The hollows occupied by these thin "sliver fills" are often inefficient storage areas. Whereas the fills may not significantly impact waters and riparian zones in

the hollows they occupy (that is, *if they are stable*), they do not contribute to spoil optimization and the protection of watersheds over the entire permit area.

Excess Spoil Minimization and Fill Stability

Long-standing valley fill stability issues that we believe will increase in significance with minimization include foundation slope, foundation shear strength, subsurface drainage control, surface drainage control, contemporaneous reclamation, and quality control. These are discussed as follows:

Foundation Slope
To date, we do not have strong empirical evidence that excess spoil minimization will result in less stable excess spoil fills or backfill. Yet, the steepness of a valley fill's foundation slope is one of several important factors potentially affecting long-term stability. Fill minimization in the interest of reducing environmental impacts such as stream loss can result in smaller fills placed in higher elevations where the slope of the valley bottom is steep. Absent the influence of other mitigating factors an increase in foundation slope can reduce fill stability. Whether the consequential failure of a greater proportion of newly constructed fills will be avoided in the future will depend on how carefully excess spoil sites are selected and investigated, and on how carefully the fills will be designed and constructed. The effect of steep foundation slopes must be off-set by proper foundation preparation and placement of underdrains that efficiently convey seepage out of the valley fill.

What data we have on the effect of steep foundations is largely limited to the EIS long-term stability study. Among other related tasks, the investigation performed a simple experiment to quantitatively assess the significance of steeper foundation slopes. The team conducting the study selected a West Virginia valley fill and determined the maximum foundation slope at which a stability analysis resulted in a SF less than 1.5. Using the Simplified Bishop Circle method of analysis (1955) and the SB-Slope computer program[11], the slope was gradually increased by moving the fill toe to various elevations up-valley from its original location (where the slope was 7 percent). At each elevation, the profile of the fill face was adjusted to maintain 15-meter (50-foot) vertical distances and 2:1 slopes between terraces. Fill volume decreased each time the toe moved up the valley slope; i.e. spoil material was never added to the top of the top of the fill to maintain the original volume. The material input parameters of the stability analysis in the permit application were held constant (Table 1).

The toe-foundation slope at which the SF dipped below 1.5 occurred between 25 and 27 percent (14 and 15 degrees). This result corroborated with observations made from the general sample of 128 valley fills evaluated in the study. Although the average toe foundation slope among the samples was 10 percent, 5 of them have foundation slopes at the toe of the fill that were greater than 25 percent. Four of these have experienced major instability. It is important to note that the analysis have may have resulted in an SF

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[11] The publisher and supplier of SB Slope is Von Gunten Engineering Software Inc., Fort Collins, CO. Reference to this software is not intended to be an endorsement of the product.

below 1.5 sooner (starting with a foundation slope less than 25 percent) if the spoil volume in the fill remained constant as the toe was moved upslope. A constant volume would have forced the placement of more spoil in the uppermost parts of the existing fills (similar to backstacking in the interest of excess spoil minimization), i.e. those parts where the driving forces of instability are strongest and the resisting forces are weakest. Also, the pore water pressure ratio assumed for the spoil was zero. This may have been reasonable for the specific fill analyzed. Most stability analyses in permit applications for excess spoil fills more conservatively apply an in-spoil pressure of 0.05.

Table 1. Spoil and Foundation Engineering Parameters.

Property	Spoil	Foundation
Unit weight, kg/m^3 (pcf)	2,070 (129)	2,000 (125)
Cohesion, kg/m^2 (psf)	190 (40)	760 (200)
Friction angle (°)	38	30
Pore pressure ratio	0	0.05

Other observations from empirical data collected from mining permits seemed to support the significance of foundation slope as a factor in fill stability: Whereas the average foundation slope at the toe among all the fills in database was about 10 percent, the average of the 20 failed fills was approximately 16 percent. Twelve of the 20 failed fills had toe slopes above the database average. Six had slopes greater than 20 percent, a number which is disproportionate relative to the distribution of foundation slope in the general database[12] (Fig. 9).

For a fill with a steep foundation slope, engineering practices that may have been considered sound under past circumstances may not suffice at certain sites. A stability analysis depends on assumed parametric values for the engineering strength of materials and pore-water pressures in the fill mass. It is conceivable that values selected as "appropriately conservative" may turn out to be not conservative enough. In the case of durable rock fills, this is especially true for estimations of pore-water pressure at a location where the hollow is characterized with high-discharge seepage and the availability of durable rock (to form an underdrain during end dumping) is questionable. In these circumstances, a demonstration of a 1.5+ safety factor may not be sufficient ground for approving a valley fill design. A general policy limiting the allowable inclination of the toe foundation slope (in lieu of regulatory authority's site-specific approval) during the development of excess spoil fill placement alternatives may be

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[12] This assumes that the distribution of toe foundation slope in the sample set approximates that of the entire population of fills.

appropriate. Our very limited data suggests that West Virginia's foundation slope limitation of 20 percent might work but this may need to be empirically verified or adjusted as minimized fills are constructed in the future.
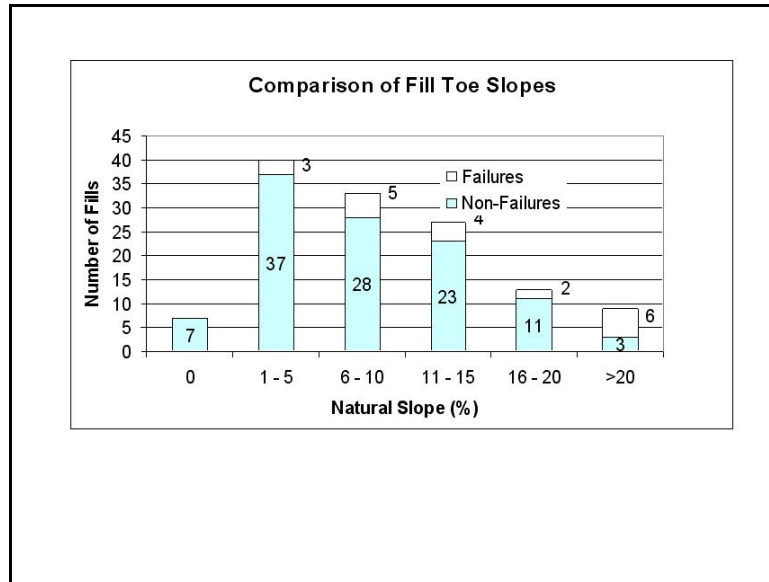

Figure 9: Frequency Distribution of Toe Foundation Slope.

Foundation Shear Strength

A potential benefit of excess spoil minimization concerning valley fill stability relates to the decrease in soil depth that typically occurs when one traverses from lower to higher elevations up a hollow in steep sloped Appalachia. As a rule we should expect minimized excess spoil fills to be founded on soils that are shallower than those underlying un-minimized fills. All else being equal, this should add stability to the former fill type. However, the limited amount of data we have on valley fill stability indicates that generally thinner soil layers beneath minimized fills does not completely compensate for the effect of steeper foundation slopes. Most natural soils at valley fill sites are composed of colluvium above weathered rock and they tend to thicken downslope towards base level. However, deep soils can occur locally in higher elevations where weak rock types (e.g. mud rocks like shale and claystone) are exposed. Also, in many past and future cases of major fill instability resulting from weak foundations, the thickness of the soil may not be an important factor. Natural landslides in steep-sloped Appalachia are commonly translational as opposed to rotational in nature and this seems also to be true of at least some of the slope movements on valley fills. Translational mass movements of almost entire fill structures can occur above a continuous veneer of relatively thin soil-like foundation material. Figure 10 is an example of translational movements on an excess spoil fill. A separate land slip occurred on each side of the center drain. The one to the reader's left has a well developed scarp near the crest of the fill outslope and the bottom of the slip is located at the fill toe.

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Figure 10: Translational Land Slips on a Durable Rock Fill.
(Aerial photo taken in December 1999 during
the EIS fill stability study).

The KY stability evaluation confirmed the significance of foundation materials beneath a fill (KYDNR et al., 2006). The study included the application of a series of stability analyses to a model fill on a steep slope [foundation with a 10 percent slope for the first 91 meters (300 feet) upslope of the toe, then steeper grade for an additional 76 meters (250 feet) to the fill crest]. The model was manipulated by applying different configurations of colluvium in the foundation: i.e. uniform thicknesses of 0, 0.6, 1.5, and 3.0 meters (0, 2, 5, and 10 feet); and other scenarios such as the presence of a rock outcrop in the foundation, and thicker colluvium nearer the toe of the fill. Both non-circular and circular analyses were used. The analyses tested two sets of engineering properties for the colluvium: (1) 24 degrees and 780 kg/m^2 (160 psf)[13] and (2) 30 degrees and 488 kg/m^2 (100 psf) for internal friction angle and cohesion, respectively. Unit weight was held to 2,000 kg/m^3 (125 pcf), and pore water pressure ratio to 0.05. The findings of the exercise were as follows:

- For fills resting on steeper foundation slopes, the most critical failure surface was non-circular and was located at shallow depth in the colluvium parallel to the spoil-colluvium interface;

- The presence of a weak layer underlying the structure had a significant impact on the stability safety factor, causing a decrease from 1.81 (for rock-like foundation material) to 1.14 (for colluvium with a 24-degree friction angle); and

- For both non-circular and circular failure surfaces, the depth of colluvium below the fill (starting at two feet) did not affect the stability safety factor.

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[13] These values are adopted by the KY stability evaluation as typical for colluvium in eastern Kentucky.

In conclusion, the study emphasized that the identification of soil-like material in the foundation of a proposed excess spoil fill—and the use of accurate foundation shear strength properties—is essential for a realistic valley fill stability analysis. Absence of soil-like properties in the analysis should only coincide with the permit applicant's documented intent to remove the soil from the fill footprint prior to excess spoil placement.

Both the Kentucky stability evaluation and the earlier EIS stability study recommended needed improvements to foundation investigations in support of the permit application process.

Subsurface Drainage Control

The effectiveness of gravity-segregated underdrain depends on whether the end-dumped material is sufficiently permeable to convey subsurface water out from the durable rock fill. An inadequate underdrain results in pore-water pressure build-up in the spoil, which diminishes the stabilizing effects of internal friction and cohesion. In the case of non-durable rock fills, underdrains can easily be designed and constructed to meet site-specific subsurface drainage conditions. In durable rock fills, however, the quality of the end-dumped underdrain depends on: the supply of durable rock; the selective use of durable rock during end-dumping (if necessary); and the effectiveness of the gravity segregation process. In most cases, as long as a permit application successfully demonstrates the on-site availability of 80 percent durable material in the coal overburden and interburden (through the use of SDI or some other accepted lab testing protocol), construction of a durable rock fill is permitted. However, our experience over the years has indicated that the correlation between lab-tested rock durability and the formation of an effective underdrain is not strong (Welsh et al., 1991, OSM, 2002). The regulations do require a durable rock fill underdrain to be "…capable of carrying anticipated seepage of water due to rainfall away from the excess spoil fill and from seeps and springs in the foundation of the disposal area…." However, the technology does not exist (to our knowledge) to quantitatively measure the permeability of an underdrain being formed during end dumping or measure whether it is pervious enough to effectively transmit ground water out of the fill.

Currently OSM, though its valley fill inspection consistency initiative, is emphasizing the importance of visible evidence of durable rock fill underdrain formation, i.e. that gravity segregation during end dumping is visibly resulting in a graded fill face, with the largest particle size at the bottom and gradually decreasing particle sizes up the fill outslope. The absence of a visible segregation may result from an insufficient volume of durable rock in the spoil. It may also result from improper construction practices. For instance, part of the underdrain area may be filled with weak material derived from "pre-stripping" of weathered rock during the early stages of the mining operation.

One of the tasks of the EIS stability study was for the team members to visibly estimate percent durable rock for 44 durable rock fills under construction and judge whether a discernable gravity-fed underdrain was forming. Of 44 fills under construction, 28 appeared to have less than 80 percent durable rock[14] and 5 were

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[14] The percent durable rock estimates for those under 80 percent ranged from 20 to 70 percent.

considered to lack underdrains. A similar exercise was performed by KYDMRE and OSM personnel during the Kentucky stability evaluation. Four of 29 durable rock fills visited had "questionable" underdrains. A contrast between effective and ineffective gravity segregation is illustrated in Fig. 11. The photograph shows a unique toe area of a durable rock fill under construction in which two distinct rock lithologies (brown sandstone and black shale) are end dumped from different positions at the crest of the fill outslope. Gravity segregation of coarse sandstone particles at the fill toe is evident. This is not the case with respect to the shale particles.

Visible evidence that the underdrains were properly functioning was also emphasized in both investigations. Seeps or springs were identified on the fill outslope above the toe on a number of reclaimed durable rock fills during the EIS stability study.

Figure 11: Comparative Effectiveness of Gravity Segregation between Sandstone and Shale Particles at Toe of Durable Rock Fill Under Construction. (Photo taken in spring 2000 during the EIS stability study).

Other issues pertaining effective underdrain formation include: (1) the placement of weathered material at the base of a durable rock fill (where the underdrain is supposed to be) due to the practice of "wing dumping;" (2) inadequate gravity segregation due to slopes (over which end dumping is taking place) that are either too short or (where the amount of durable rock is small) too long; and (3) plugging of underdrains during regrading of the fill outslope. All of these concerns have been discussed in the EIS stability study and KY stability evaluation. They also have been addressed by recent changes in state regulations and policies.

The question as to how the practice of excess spoil minimization will generally affect seepage rates in valley fills has two aspects. The first of these is a potentially positive aspect in the sense that minimized fills constructed in higher elevations will be influenced by smaller drainage areas and, consequently, generally lower amounts of seepage and runoff. Thus pore-water discharge through the fill mass should be relatively less than through un-minimized fills. However, we do not have the field data necessary to predict

how much of a discharge difference this would make. Based on the small amount of data obtained in the OSM stability study, it appears that less drainage in minimized valley fills does not completely compensate for relatively steep foundation slopes. Potential instability in minimized fills built on steep foundation slopes should still be a concern. One way in which reduction of seepage through a minimized fill can turn into a clear advantage is to have in place a regulatory policy and practice that consistently ensures the placement of effective underdrains.

The second consideration pertaining to pore-water drainage relates to cases where excess spoil minimization results in contiguity between valley fills and backfills. Typically, an un-minimized valley fill is located far enough downslope from the mined bench or mountaintop pavement to where the crown of the fill is not in contact with backfill. Drainage originating upslope of the valley fill can be intercepted, directed into constructed channels, and kept from entering the fill mass. This is not necessarily the case where excess spoil minimization is applied. Subsurface flows in backfills that enter valley fills cannot be readily observed during the mining and reclamation process. Generally, the Federal and state regulations do not require construction of drainage structures on mine benches and mountaintop pavements. Without effective subsurface conveyance systems that are continuous with valley fill underdrains, unchecked drainage can elevate pore pressures in excess spoil fills and risk instability.

Surface Drainage Control

The practice of excess spoil minimization will also increase the importance of surface drainage control over and around durable rock fills. 30 CFR §816.71(f)(1) and (2) and 816.73(f) require control of surface drainage through the use of diversion channels (meeting the requirements of § 816.43) for excess spoil fills in general and durable rock fills, respectively. 30 CFR 816.73(f) stipulates that: "Surface water runoff from areas adjacent to and above the fill is not allowed to flow onto the fill and is diverted into stabilized diversion channels designed to meet the requirements of § 816.43 and to safely pass the runoff from a 100-year, 6-hour precipitation event."

Excess spoil fills other than durable rock fills are constructed from the bottom of the fill, or toe, upwards. As such, the final surface drains are installed with each lift during fill construction. For durable rock fills constructed via end dumping of the excess spoil, final surface drains are not installed until the fill placement is complete and ready for final regrading. However, the mine operator, certifying engineer, and regulatory inspector are still charged with ensuring effective drainage control *throughout the construction of the fill*. There should never be any uncontrolled drainage over the face of the fill. The crest of the fill should be sloped to direct surface water from above the fill outslope into temporary side drains or into temporary, stabilized diversion ditches on the fill. Uncontrolled surface drainage over a barren outslope results in severe erosion and transport of fines towards the fill toe. Clogging or burying of the underdrain can result. Further, sedimentation beyond the advancing toe can become weak foundation materials below the finished fill if not removed.

Some of the most dramatic cases of fill-associated erosion, wash-out sedimentation, and localized flooding took place during the last five years in West Virginia (Fig. 12 and 13). These events followed high-intensity rainfall and occurred in small watersheds containing unreclaimed or partly unreclaimed valley fills. Temporary surface drainage

structures were not in place or adequate to handle the high discharge flow. Consequently large volumes of water cascaded over the fill outslopes; causing sloughing and erosion of un-compacted spoil, breaching of sediment ponds, and downstream flooding. The most severe instance occurred in Lyburn, Logan County WV on July 18, 2002 when heavy rains occurred while the face of the fill was being regraded to final configuration.

Figure 12: Erosion and Sloughing on Fill Face from Uncontrolled Storm Runoff.

Figure 13: Post-Storm Mudflow and Outwash from Unreclaimed Durable Rock Fill with Inadequate Surface Drainage Control.

OSM investigations of these major washout events indicated that future impacts from heavy precipitation can be minimized by: (1) timely and phased reclamation; (2) proper installation and maintenance of surface drainage; (3) proper location of the fills; (4) minimization of additional disturbance of the surrounding area; (5) building in extra sediment and flood storage facilities; and (6) following proper fill certification procedures. However, it is important to note that at least most of these measures should also be used to minimize more gradual erosion over a fill face over an extended time

period. Ironically, those less severe cases may be more damaging to the long-term mass stability of a fill, since they receive less public attention and consequently may benefit less from remediation.

Contemporaneous Reclamation

Timely reclamation of durable rock fills will also become more critical as the size of the fills is minimized. 30 CFR 816.71 requires that "…slope protection be provided to minimize surface erosion at the site." Further, § 816.100 states that reclamation efforts, "including but not limited to backfilling, grading, topsoil replacement, and revegetation, on all land that is disturbed by surface mining activities shall occur as contemporaneously as practicable with mining operations…." The purpose of these provisions is to avoid erosion, sedimentation, flooding, and (in the case of durable rock fills) accelerated slaking of excess spoil resulting from a temporarily abandoned, unreclaimed fill. The problems associated with uncontrolled drainage discussed above are accentuated as a result of the longer time periods over which the spoil is exposed. Weathering of "durable" spoil, including underdrain material, is also accentuated due to prolonged surface exposure. Once buried by additional end-dumped spoil, these materials may constitute zones of structural weakness in the fill.

The EIS stability study noted that some durable rock fills were abandoned for long periods of time following partial construction. It found eight cases of unreclaimed durable rock fills where end-dumping or regrading-and-seeding work had not occurred for a year or more (Fig. 14).

Figure 14: Durable Rock Fill Lacking Contemporaneous
Reclamation.

Quality Control

As stipulated above, proper foundation preparation, underdrain construction, surface drainage control, and timely completion of a fill will be increasingly essential with spoil and valley fill minimization. Assurance that these measures are adequately carried out necessitates effective quality control on the part of a registered professional engineer (designated by the mining company) as well as the regulatory authority. Requirements for a registered professional engineer's inspections and certifications of the fill construction process are delineated in 30 CFR 816.71 (h). The section states that a certified professional engineer must inspect the fill "…at least quarterly throughout

construction and during critical construction periods." The critical construction periods include at a minimum: foundation preparation; placement of underdrains and protective filter systems; installation of final surface drainage systems; and the final graded and revegetated fill.

Section 816.71 (h) (2) requires the engineer to provide a certified report that "…the fill has been constructed and maintained as designed and in accordance with the approved plan…." The report "…shall include appearances of instability, structural weakness, and other hazardous conditions." Section 816.71 (h) (3) provides that color photographs be taken during and after construction of the excess spoil fill. For excess spoil fills that are not durable rock fills, color photographs must be taken of the underdrain system and protective filters before they are covered with excess spoil. For durable rock fills, color photographs "…shall be taken of the underdrain as the underdrain system is being formed." For all excess spoil fills, the photographs "…accompanying the certified report shall be taken in adequate size and number with enough terrain or other physical features of the site shown to provide a relative scale to the photographs and to specifically and clearly identify the site."

Historically, the record of certification completeness for permitted excess spoil fills has not been good. This was apparent during the EIS stability study. Out of 128 permitted valley fills only eighteen fills had certifications that covered all critical phases. Incomplete sets of certifications were found in the permits of 113 fill samples. A similar pattern was found with respect to photographs. No fills had a set of original color prints or copies of photographs that cover all critical construction phases. Original prints and copies of photographs for some, but not all, of the critical phases were found in the permits of 42 and 35 fill samples, respectively. The Kentucky stability evaluation noted a general absence of full certification for durable rock fill underdrains. The report stipulated that excess spoil fills designed using RAM #135 criteria should have, at a minimum, certification for each of three stages of the drain construction: (1) the placed underdrain at the head of the fill; (2) the gravity-segregated underdrain at the fill midsection; and (3) the placed underdrain at the toe section.

It's important to point out that certifications and accompanying photographs should not be vague but should clearly address specific fill construction issues for which the professional engineer and coal company are responsible. For instance, color photographs of a durable rock fill underdrain should be clearly labeled as to which fill and what part of the fill is being depicted. They should clearly show whether effective gravity segregation is occurring and if the spoil material at the base of the fill is truly durable. Ideally, the photographs should be taken from various distances, including: (1) a broad perspective of the entire fill face that demonstrates particle gradation from gravity segregation; and (2) a close-up perspective to show the quality of rock forming the underdrain. During end-dumping, photographs should also clearly demonstrate proper routing of surface drainage.

2004 Valley Fill Failure in Kentucky

Fortunately, since the completion of the EIS stability study, we know of only one more mass failure in a valley fill (Figure 15). However, the case is emblematic of future instabilities that could occur on improperly constructed fills resting on steeply inclined natural slopes. It is the second time a major failure has occurred on a bond-forfeiture mine site. At the time this paper was written, work was underway to remediate the fill (henceforth called Fill 1). OSM investigated the fill failure in 2005.

Figure 15: General View of Landslide on Durable Rock Fill, Looking Upslope from Toe. (Photograph taken in April 2005).

Fill 1 was designed and constructed as a durable rock, excess spoil fill from August 1997 to December 1998. The as-built structure was small, approximately 505,000 cubic meters (661,000 cubic yards) in volume and 274 meters (900 feet) in length (Fig. 16). It vertically extended 122 meters (400 feet) from 290 to 412 meters (950 to 1350 feet) above mean sea level. The top of the fill rested on top of a surface mine bench. The grade of outslope was designed to be 2:1 or 50 percent. The average foundation slope, or natural slope in the footprint of the fill was 40 percent. Maximum thickness of the structure was only 27 meters (90 feet). The footprint of the structure is intersected by four mapped coal seams. Limited data from the survey of local mine benches suggest that the local dip of the coal strata is one percent into the northwest-facing footprint of the fill.

Not counting tension cracks in otherwise intact portions of the fill face, the landslide affected approximately 90 to 95 percent of the structure. The crown-to-toe length was approximately 354 meters (1,160 feet); the maximum width between side scarps, about 183 meters (600 feet); and the vertical drop and lateral transport distances were approximately 61 and 79 meters (200 and 260 feet), respectively. In addition to the 61-

meter (200-feet) deep head scarp, the slide morphology also included a smaller scarp close to the landslide toe.
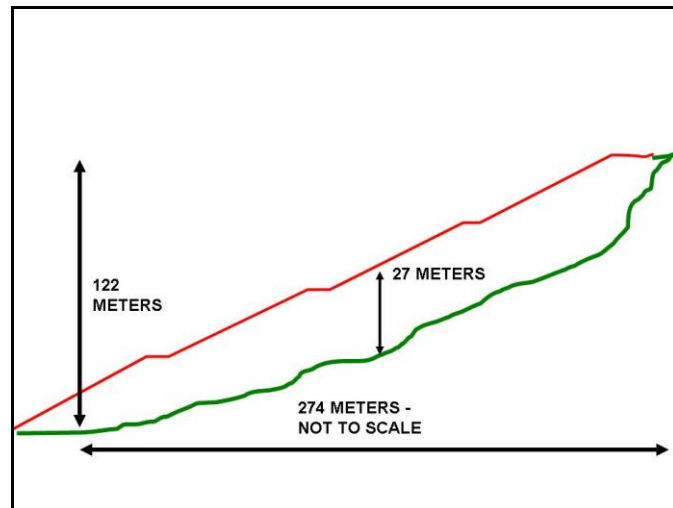

Figure 16: Schematic Cross Section of Fill 1 Prior to Failure. The steep foundation of the fill results from its construction from the crest of the natural slope and its minimized length.

The spoil materials exposed in the landslide scarps were poorly sorted, exhibiting a roughly even volumetric distribution of clay-to-gravel grain sizes. Assuming that the relative amount of gravels and boulders in the observable spoil was roughly indicative of the amount of durable rock present, an OSM investigator estimated to percent durable rock by volume to be somewhere between 30 and 40 percent. There was no evidence of gravity segregation of particle size in the exposures of the spoil. The low percentage of durable rock and absence of gravity segregation were apparent during a site visit in April 2005. As Fig. 17 illustrates, those observations were confirmed at depth after the toe region of the fill was excavated for underdrain installation.

Evidence of another potential factor behind the failure was found just beyond the toe of the slide: a thick sequence of colluvium and deeply weathered bedrock, exposed by the construction of a new settlement pond and haulage road, may be indicative of weak foundation conditions beneath the fill (Fig. 18 and 19).

Figure 17: Particle Size Distribution at the Toe of Fill 1. The photograph was taken by KYDEP during new underdrain installation in October 2006.

Figure 18: View of Toe and Settlement Pond from the Outslope of Fill 1. Exposure of thick colluvium and weathered bedrock occurs to the right of the pond. (Photo taken in April 2005).

Figure 19: Close-up of Colluvium and Weathered Bedrock Near Toe of Fill 1. (Photo taken in April 2005).

<u>Documentation</u>

The first indication of ground instability at the fill site is found in the inspection report, dated July 14, 1998. The report states, "Ground surface between pond #1 and hollowfill #1 has become unstable. This area is on permit but needs to be stabilized before pond #1 is affected." The instability did not occur in spoil but in natural soil. A slump had occurred on one of the natural side slopes adjacent to the fill toe and pond.

Subsequent inspection reports include four other separate instances of instability in adjacent natural ground or in the spoil fill itself (identified by reports dated March 17, 1999, April 4, 2001, May 5, 2002, and February 5, 2003). Each event was followed by attempted remediation by regrading. The 1999 and 2002 reports state that tension cracks had formed on the fill face. The 2001 inspection report said that "…a slide has broken and moved into the pool area of pond #1." This slide occurred on a natural side slope opposite to the one reported as unstable in 1998. The 2003 report identified the slide in Fill 1: "…a bulge at the lower terrace and slumping along the upper terrace." These symptoms occurred close to two years before a citizen's complaint of heavy stream sedimentation lead to the discovery of the fill landslide.

The engineer's construction certifications, extending from September 29, 1997 to January 8, 1999, indicate that end-dumping was completed by December 31, 1997. Final certification, post terracing, diversion-ditch construction, and revegetation, was first submitted by the mining company on December 4, 1998. The KYDNR returned the certification "…due to deviations from the proposed design" (January 1, 1999 mine inspection report). The "deviations" involved about a 46-meter (150-foot) sideways shift in fill location, from as-designed to as-built, within the hollow (Fig. 20). The final certification, with new stability analyses for the as-built fill, was resubmitted on January 8, 1999.
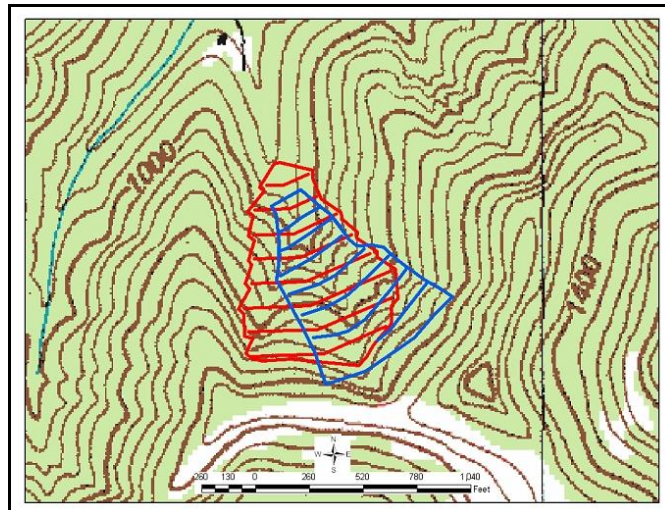

Figure 20: Shift in Fill 1 Location from As-Designed (Red)
to As-Built (Blue).

The July 1, 1997 certification of design identified seven out of seventeen rock units in the overburden suitable for constructing an excess spoil fill with 80 percent "durable

sandstone" and 20 percent "non-durable sandy shale[15]." Proper construction of the durable rock fill required selective placement of the spoil derived from that rock strata. All of the engineer's certifications of construction reported that the fill was being built according to plan and appeared to be functioning properly. However, only the September 29, 1997 certification included color photographs. The photographs indicated poorly sorted end-dumped spoil similar to what was observed in the field. Neither gravity segregation nor selective spoil placement was evident.

The file included three analyses dated July 22, 1997, January 8 1999, and August 13, 2003. The 1997 analysis was performed for the as-designed fill, i.e. prior to construction. The second was applied to the as-built fill and corresponds to the mining company's second submittal of the final certification. The 2003 analysis was applied to the same profile as in 1999, but after several cycles of fill failure and attempted remediation. Each analysis used two different methods to calculate the SF. All employed the REAME circular failure method. The 1997 and subsequent analyses also used the SWASE sliding wedge method and REAME non-circular or planar method, respectively.[16] The engineering parameters employed are shown in the Table 2.

Table 2. Engineering Parameters Applied to Fill 1 Stability Analysis.

Date of Analyses	7/1/97	1/8/99	8/13/03
Unit Weight, kg/m^3 (pcf)	2036 (127.1)	2036 (127.1)	2002 (125)
Internal Friction Angle (°)	30	36	34
Cohesion, kg/m^2 (psf)	976 (200)	195 (40)	488 (100)
Pore-Water Pressure Ratio	0.1	0.05	0.05

The 1999 analysis justified values assigned to unit weight, internal friction angle, and cohesion based on weighted averages of the source rock of the spoil. All analyses except one resulted in a calculated static SF above the minimum of 1.5 required in the State and Federal regulations. The 1997 sliding wedge analysis resulted in an SF of 1.45 (rounded to 1.5). All analyses had dynamic SF's above the acceptable minimum of 1.1. However,

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[15] Rock durability was determined based on the Slake Durability Index (SDI).

[16] The publisher and supplier of REAME and SWASE is the Civil Engineering Software Center of the University of Kentucky, Lexington, KY. Reference to these software is not intended to be an endorsement of the products.

none of them employed separate values for materials comprising the foundation of the fill.

The draft remediation plan includes a stability analysis for the proposed fill design. The analysis employs the Simplified Bishop Circle (1955) and Janbu Block (1954) analysis methods and PCSTABL6[17] computer program. The engineering parameters are shown in Table 3.

Table 3. Spoil and Foundation Engineering Parameters
Used in Remediation Stability Analysis.

Material Description	Spoil (Non-Durable Rock)	Foundation Material
Unit Weight, kg/m^3 (pcf)	2,002 (125)	2,002 (125)
Internal Friction Angle (°)	30	24
Cohesion, kg/m^2 (psf)	976 (200)	780 (160)

Based on the fill profile coordinates, the analysis appears to assume a foundation-soil thickness of between three and four feet.

OSM Stability Analysis

Using the software, Galena[18], OSM performed its own stability analysis, using both circular and non-circular modes of failure, on the as-built fill profile. The analysis initially tested all the parameter values described above. Then the more conservative 1997 values were adopted and adjusted in order to replicate conditions that may have led to the failure of the fill. In general, the analyses confirmed that the inaccurate safety-factor calculations of the 1997-2003 analyses had resulted from the selection of unrealistic shear-strength and pore-water pressure ratio values, and the decision not to include parametric values for the foundation. Specific findings are as follows:

1. The application of the 1997, 1999, and 2003 strength and pore-water pressure values all resulted in a stable as-built fill. However, the SF from the 1997 values was 1.43, slightly below the required minimum of 1.5.

2. A soil-like foundation equal in strength and thickness to the one in the remediation plan was added to the as-built fill and the 1997 parameters were

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[17] The publisher and supplier of PCSTABL6 is Purdue University, West Lafayette, IN. Reference to this software is not intended to be an endorsement of the product.

[18] The publisher of Galena is BHP Engineering Pty Ltd, Australia. The supplier is Rockware Inc., Golden, CO. Reference to this software is not intended to be an endorsement of the product.

applied to the spoil. The fill still ended up stable, but with an SF of about 1.2, i.e. significantly below the required minimum of 1.5.

3. OSM repeated step 2 above, but also increased the pore-water pressure ratio to the point of fill failure (SF $\leq$ 1.0). The fill became unstable when the pressure reached approximately 0.4, i.e. four times the value used in 1997 stability analysis and eight times the value used in the 1999 and 2003 analyses.

4. OSM again repeated step 2, but this time decreased the internal friction angle of the foundation from 24 degrees to the point of fill failure (maintaining the pore-water pressure at 0.1). The fill lost stability when the friction angle reached between 15 and 18 degrees.[19]

Discussion

Based on current information, there were three potential factors that significantly influenced the instability of Fill 1:

1. **Foundation slope:** The fill's foundation was steep, averaging 40 percent in slope. According to data in the 1999 and 2003 stability analyses, the foundation slope at the as-built fill toe was 12.3 percent. Ironically, the foundation slope of the 1997 as-designed toe, which is located 46 meters (150 feet) downslope of the as-built toe, was steeper: 24.7 percent. The slope of the remaining profile segments in the as-designed foundation are 22 percent or greater. It is possible that a natural bench near the toe of the as-built fill explains the 12.3 percent toe slope in the profile. Nevertheless, the fill is short in length and its crown is located at the top of the ridge. The steepness of at least most of the foundation slope was an important factor behind the instability.

2. **Seeps and deep soils in the foundation:** The foundation also appears to be affected by relatively heavy drainage and deep soils. As stated previously, thick soils were observed on a side slope near the toe of the landslide. The instabilities in natural soil reported in the 1998 and 2001 inspection reports seem to support the presence of deep soils in at least part of the hollow. Also, corrugating contours on the topographic map indicate gully erosion of colluvium on northwestern facing slopes in the area, including within the footprint of the as-built Fill 1 (Figure 20). This contour pattern is one of several symptoms of "landslide topography," depicting a combination of significant drainage and relatively thick soils of low engineering strength.

    The corrugating pattern is not precisely replicated in a larger-scale (1 inch to 122 meters or 400 feet) permit map. Instead, the map shows a confluence of two drain ways, one occupied by intermittent stream in the footprint approximately 15 vertical meters (50 vertical feet) up the natural slope from the toe of the as-built fill. Whether or not the stream was active during construction, its source was

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[19] It is noted that the 24-degree friction angle approximates typical values for soils dominated by mixtures of silt to fine-sand and clay; and friction angles of 15 degrees are considered typical of soils that are predominantly clay.

probably a seep in the foundation. The stream may correspond to one of several seeps observed near the top of the fill during the OSM inspection in 2005.

3. **Underdrain construction:** Attempting to reconstruct the influence over time of pore-water pressure on the instability of Fill 1 would require measuring the seasonal variations in seepage discharge and testing a representative number of spoil samples for permeability. According to the State inspector, water did at times flow from the toe of the fill (prior to the failure), so it seems the underdrain system was functioning to some degree. The year of 2004 experienced above average rainfall, especially in May and June. It seems likely that at some point in time subsurface water discharge exceeded the carrying capacity of the underdrain, and that a buildup of hydrostatic head in the fill played an important role in the failure. Observations of spoil placement from the aerial video and of the scarp-exposed spoil on site indicate that an "underdrain" is composed of poorly sorted, non-porous, and hence low-permeability material.

Conclusion

The authors support measures of several government agencies, including OSM, to minimize adverse impacts to streams and riparian zones from the construction of excess spoil fills in the hollows of steep-slope Appalachia. Minimization of excess spoil generation, and the size and downstream reach of excess spoil fills, are the most effective ways to control impacts. However, effective protection of the aqueous environment also necessitates that smaller fills that result from the minimization process are structurally stable.

Valley fills that are placed at higher elevations in steep topography generally are founded on steeper foundation slopes. All else being equal, fills founded on steeper natural slopes can have lower stability safety factors. The influence of foundation slope on fill stability appears to have been confirmed by the limited amount of empirical data currently available. With less room for error, valley fills may need to be designed and constructed with greater care in order to prevent increased occurrences of massive instability. There are a number of counterbalancing measures that can be exercised within the existing Federal and state regulatory framework. These include: (1) thorough foundation investigation during fill design and careful foundation preparation during construction; (2) the application of durable rock fill construction methods that result in observable gravity segregation of end dumped spoil; (3) realistic assessment during fill design and construction whether the underdrain is capable of conveying site-specific spring and seepage discharges out of the fill; (4) establishment of an effective surface drainage system that will prevent uncontrolled drainage over the face of the fill; (5) contemporaneous reclamation; and (6) effective quality control on the part of the certifying professional engineers, and State and Federal inspectors.

Acknowledgements

Literature Cited

American Society for Testing and Materials (ASTM), 2006. Book of Standards, vol. 4.08. ASTM International, West Conshohocken, PA.

Bishop, A.W., 1955. The Use of the Slip Circle in the Stability Analysis of Slopes. p. 7-17. In: Geotechnique, vol. 5, no. 1. http://dx.doi.org/10.1680/geot.1955.5.1.7.

Casagrande, D.R., 1991. Letter to Ratcliff, J.E. of Hobet Mining Inc. re: Surface Mining Regulations for Durable Rock Fills. 11 pp. Casagrande Consultants, Arlington, MA.

Hudec, P.P., 1997. Changes in Engineering Properties of Weak and Weathered Rock with Time. p. 53-71. *In*: Characterization of Weak and Weathered Rock Masses (P.M. Santi and A. Shakoor, eds.), Association of Engineering Geologists Special Publication #9.

Janbu, N., 1954. Application of Composite Slip Surfaces for Stability Analysis. p. 43-49. *In*: proceedings, European Conference on Stability of Earth Slopes, Stockholm.

Kentucky Department of Natural Resources and U.S. Office of Surface Mining, 2006. Excess Spoil Fill Stability. 28 pp. plus appendices. Evaluation Year 2006 Special Study, OSM open file report, Lexington, KY.

Michael, P.R., 2005. Field Report: HNR Valley Fill Failure. 15 pp. plus appendices. Technical Assistance to the OSM Lexington, Kentucky Field Office, OSM open file report, Pittsburgh, PA.

Pallicki, K.S., 1997. A Graphical Method for the Classification of Rock and Weak Rock Masses Based on Field Observations. p. 7-12. *In*: Engineering and Environmental Geoscience, vol. 3, no. 1.

Shank, Michael, 2004. Development of a Mining Fill Inventory from Multi-Date Elevation Data. 9 pp. *In:* the OSM Technical Information Processing System conference on Advanced Integration of Geospatial Technologies in Mining Reclamation, December 7-9, 2004, in Atlanta Georgia, OSM, Denver, CO.

U.S. Army Corps of Engineers (USACE), 2002. Eastern Kentucky Stream Assessment Protocol. USACE Louisville District, Louisville, KY.

Available at: www.lrl.usace.army.mil/orf/default.asp. Accessed March 15, 2007.

U.S. Environmental Protection Agency, 2003. Draft Programmatic Environmental Impact Statement—Mountaintop Mining/Valley Fills in Appalachia, EPA 9-03-R-00013, EPA Region 3, Philadelphia, PA.

Available at: http://www.epa.gov/region3/mtntop/eis.htm.

U.S. Office of Surface Mining Reclamation and Enforcement (OSM), 1999a. An Evaluation of Approximate Original Contour Variances and Postmining Land Uses in Virginia. 4 pp. plus appendices. OSM open file report, Big Stone Gap, VA.

Available at: http://www.OSM.gov/mtvafinalrep.htm. Accessed March 16, 2007.

U.S. Office of Surface Mining Reclamation and Enforcement (OSM), 1999b. Final Report: An Evaluation of Approximate Original Contour and Postmining Land Use in West Virginia. 152 pp. plus appendices. OSM open file report, Charleston, WV.

Available at: http://www.OSM.gov/mtreport.htm. Accessed March 16, 2007.

U.S. Office of Surface Mining Reclamation and Enforcement (OSM), 2000. An Evaluation of Approximate Original Contour and Post-Mining Landuse in Kentucky. 7 pp. plus appendices. OSM open file report, Lexington, KY.

Available at: http://www.OSM.gov/pdf/mtkentucky051000.pdf. Accessed March 16, 2007.

U.S. Office of Surface Mining Reclamation and Enforcement, 2002. Long-Term Stability of Valley Fills. 49 pp. plus appendices. *In*: Appendices A-C to U.S. Environmental Protection Agency, 2003, Draft Programmatic Environmental Impact Statement— Mountaintop Mining/Valley Fills in Appalachia, EPA 9-03-R-00013, EPA Region 3, Philadelphia, PA.

Available at: http://www.epa.gov/region3/mtntop/appendix.htm.

Welsh, R.A., Jr., Vallejo, L.E., Lovell, L.W., and Robinson, M.K., 1991. The U.S. Office of Surface Mining (OSM) Proposed Strength-Durability Classification System. p. 19-24. *In*: proceedings of Symposium on Detection of and Construction at the Soil/Rock Interface (W.F. Kane and B. Amadei, eds.), ASCE Geotechnical Special Publication No. 28, American Society of Civil Engineers, New York, NY.