STABILITY MONITORING OF A COAL MINING EXCESS SPOIL FILL[1]

X. Zeng, R.A. Rohlf, B. Hippley, and J.D. Reynolds[2]

Abstract. The disposal of excess spoil created by coal mining operations in the Appalachian Coal Field is usually accomplished by placing this material in valley fills. As a result, hundreds of excess spoil fills have been built in Kentucky, Tennessee, West Virginia, and Virginia. The stability of these structures is regulated by the Federal Office of Surface Mining and state regulatory authorities.

A joint Office of Surface Mining and Kentucky Department for Surface Mining fill team inspected an excess spoil fill located just outside Prestonsburg, KY. The fill was finished in 1998. In the design of the fill, the phreatic surface was assumed to be very low, resulting in a factor of safety of 1.5 for slope stability. The factor of safety (FS) for a slope is defined as the ratio of the moment resisting sliding over the moment causing sliding. However, during the field inspection water was observed exiting the structure at about 1/3 the height of the fill, resulting in a factor of safety near 1.27. There is concern that during the late winter and spring wet season, the phreatic surface could increase further. Failure of the fill could result in blockage of a headwater stream with potential increased sediment loads to the nearby Corps of Engineers Dewey Lake, contaminating water in the reservoir, and effect a proposed industrial, residential, and recreational development project nearby.

This paper reports the results of a study that installed a comprehensive deformation monitoring system on the fill, investigated water movement, and tested soil samples obtained at the site. The deformation of the fill at a number of surface points has been surveyed over three years. The moisture content changes at selected locations on the surface of the fill were monitored as well. Soil properties for slope stability analysis have been determined in the laboratory. This study is supported by grants from the National Science Foundation and Office of Surface Mining.

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Introduction

The disposal of spoil generated by coal mining operations in eastern Kentucky is routinely accomplished by placing this material in excess spoil fills. Regulations governing the construction of excess spoil fills contain special provisions for "durable rock fills" which allow fills to be constructed by end dumping in a single lift if the material passes a durability test (405 KAR 16:130 Section 4). These fills are dependent on gravity segregation of the material to form an underdrain as the fill is constructed. Over the last several years, concern has increased over the amount of fine material occurring in some excess spoil fills (Robinson and Ventura, 1983; Office of Surface Mining, 1992). Fine material decreases the overall permeability of the fill and can block or hinder the development of an adequate underdrain.

End-dumped fills are graded down to achieve a final outslope of 2:1 or less as required by regulation (405 KAR 16:130 Section 1(4)(c)2). Grading down excess spoil fills can move fine material from near the top of the fill to the toe of the fill, thus creating a zone of fine material at the toe, which can restrict drainage. End-dumped fills that contain excess fine material are initially loose, unsaturated, and are subject to unsaturated soil collapse as a result of wetting from rainfall infiltration and groundwater seepage. The amount and timing of collapse may be important in determining the stability of these fills. On the one hand, the reduction in volume that occurs during collapse may induce strain hardening and thus improve overall stability. In addition, if a fill is near saturation a rapid reduction in volume could produce positive pore pressure and lead to mud slides and failure. Such effect was studied by Rohlf et al. (2000).

In the late 1990's, concern over the ecological effects of large valley fills primarily generated by mountaintop removal mining operations resulted in the formation of a multi-Federal agency task force including the Office of Surface Mining, Corps of Engineers, Environmental Protection Agency, and National Fish and Wildlife Service to investigate both the environmental and stability aspects of excess spoil fills. This task force is considering fill design requirements that would minimize stream loss and the fill "footprint".

These requirements would result in the disposal of more spoil in the mine backfill and create higher fills placed on steeper slopes thus increasing the risk of stability problems. In addition to the Federal investigation, OSM and the Kentucky Department for Surface Mining Reclamation and Enforcement (DSMRE) conducted a joint investigation into the stability of excess spoil fills.

Fieldwork for this investigation was completed in 1999 and a report documenting findings and recommendations of the study group was issued.

The joint DSMRE-OSM investigation inspected a durable rock fill associated with a multiple seam contour and mountaintop removal mining operation located near Prestonsburg, KY in February 1999. The lower portion of this fill was placed on natural ground and the upper portion was placed over a multi-seam contour operation. The completed fill is approximately 1200' long, 500' wide, and 100' deep at the valley centerline.

At the time of the inspection, groundwater was discharging from near the toe and a couple of points located at approximately one-third of the fill height up from the toe (bench 9). A possible source of groundwater is a coal seam located at about the mid-point of the fill. A limit equilibrium stability analysis using average soil strength parameters developed by Huang (1996) and an estimated phreatic surface based on the upper seepage points gave a factor of safety of 1.12 using the simplified Bishop method. Therefore, there is the possibility of failure of this fill, which prompted the study reported here.

Monitoring Program

Currently, the monitoring of fills is carried out by visual observation of a field inspector in a qualitative way. It depends critically on the experience of the inspector and it cannot detect pre-failure indications. Therefore, an advanced monitoring system depending on quantitative measurement is necessary. In the spring of 1999, a one-year investigation was initiated with a grant from the National Science Foundation (Grant Number: CMS 9977869, PIs: X. Zeng and R.A. Rohlf, grant period 06/15/99 to 11/30/2000). Forty permanent survey monuments were installed along benches on the fill. Two survey stations were established on rock outcrops across the valley, and three surveys were conducted on March 24, April 28, and June 26 of 2000. In March 2001, a second grant was provided by the Office of Surface Mining to continue the monitoring. Three more surveys were conducted during the spring (April 5), summer (August 14), and fall of 2001 (November 16). The view of the fill and the location of one survey station are shown in Figure 1. Soil samples were taken at the top and toe of the fill and laboratory tests (soil classification, strength, and consolidation tests) were conducted to determine soil properties.

During one field trip, a hand-operated auger was used to take soil samples up to 4 feet deep at two sites on the fill.

Figure 1. An excess spoil fill in Prestonsburg Kentucky and one of the survey stations.

The layout of the survey monuments is shown in Figure 2. Most of the benches had three survey monuments while at the four benches in the middle that are most likely to have large deformation, four monuments were installed on each bench. The monuments were made of aluminum with a typical length of 30 inches with a flared end, and were manufactured by Berntsen International, Inc. of Madison Wisconsin. For the installation of a monument, a hole was dug in the soil up to 27 inches deep. The monument was placed in the hole and the surrounding void was refilled with local soil and compacted. The first survey was conducted one month later to allow the monuments to settle. A typical monument in place is shown in Figure 3.

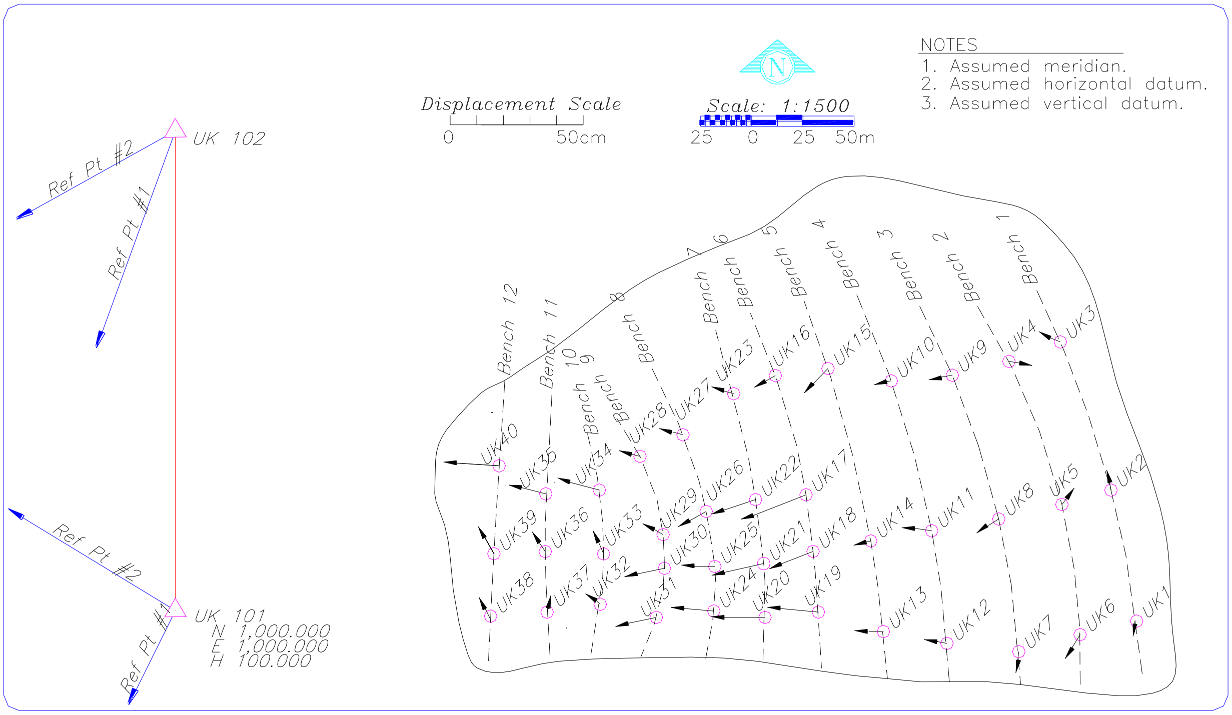

Figure 2. The plan layout of the survey monuments, stations, and recorded displacement during a period of 20 months. (The arrows show the vector of displacement with the scale at the top of the figure)

Figure 3. A survey monument buried in soil.

During the survey period, there was no relative displacement between the two survey stations, indicating that the positions of the stations remained stable. Since we are only interested in the deformation of the survey monuments relative to the survey stations, the meridian, horizontal datum, and vertical datum were assumed for one of the station, which was used as the reference point. The results of the surveys show that there was significant vertical deformation (settlement) and down slope movement within two zones, as shown in Figure 2. The first zone located at the northern end of the 1st, 2nd, and 3rd benches, where the maximum settlement was more than 30 cm and the maximum lateral displacement 20 cm. In fact, surface cracks developed in that zone with one small area of local failure observed. This was near one of the spots where surface water exit was observed during the survey. The second zone located at the southern end of the middle benches (benches 6, 7, 8, and 9) where groundwater seepage was observed throughout the survey period. The maximum settlement was close to 50 cm and lateral movement close to 30 cm. Again, signs of cracks and local failure were observed in this area. The close link between the groundwater table and slope displacement is obvious. In comparison, most other places recorded settlement or displacement of a few centimeters.

Results of Soil Testing

In order to analyze the stability of the fill more accurately, soil samples at the top, middle, and bottom of the fill were taken back to the laboratory for testing. In addition, soil samples at up to 4 feet depth were also taken using a hand-operated auger. Basic soil tests such as Atterberg limit test, specific gravity test, particle size distribution test, and triaxial test were conducted. The tests show that little variation in soil characteristics exists at the selected sampling locations. The liquid limit of the soil is about 30% and the plastic limit is about 21%. Hence, the plasticity index of the soil is about 9%. The specific gravity of the soil is 2.65. Sieve and hydrometer tests were conducted to determine the particle size distribution of the soil and a typical test result is shown in Figure 4.

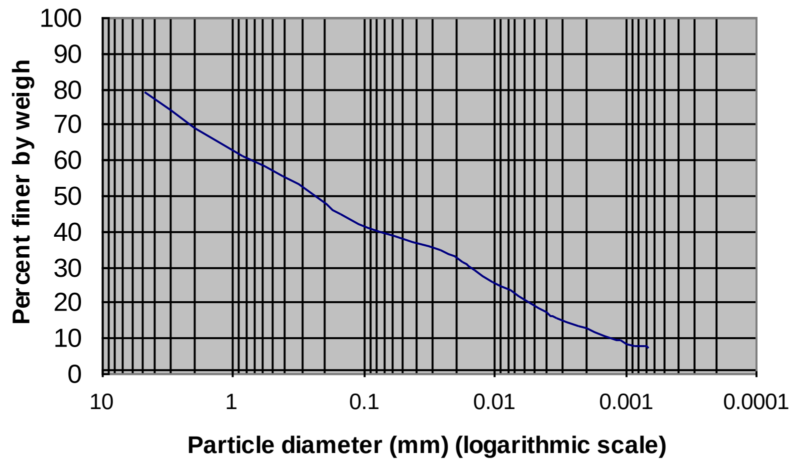

Figure 4. Particle size distribution curve of soil from the 2nd bench.

Based on the results of laboratory tests, the soil is classified as poorly graded clayey sand with gravel and boulders using the Unified Soil Classification System.

The strength of the soil was measured by triaxial tests. A typical test result is shown in Figure 5.

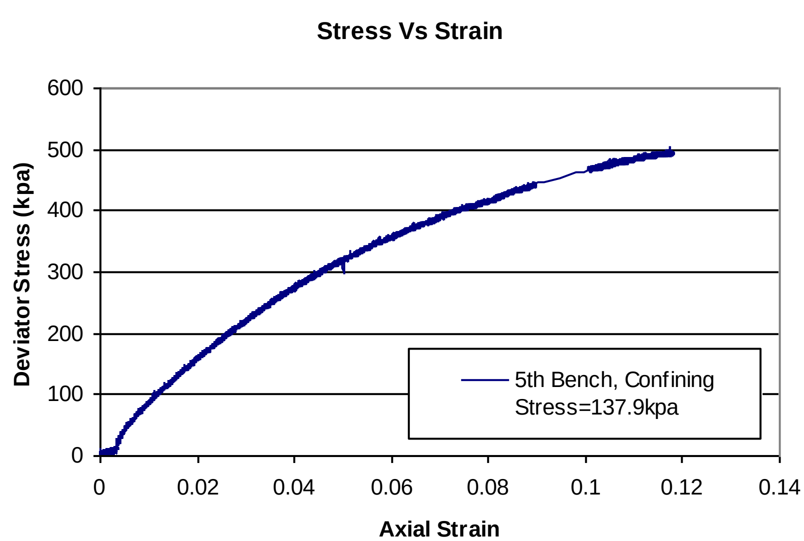

Figure 5. Result of triaxial test on soil from the 5th bench.

The strength of the soil is quite high with a friction angle ranging from 35 to 38 degrees. Moisture samples at the surface, 1 ft., and 2 ft. depth were taken near the top, middle, and bottom of the fill during each survey. Despite average and above average precipitation, soil moisture decreased within the upper 2 ft. during the survey period. The decrease in surface soil moisture can be attributed to evapotranspiration from the soil surface and reduced infiltration caused by low hydraulic conductivity exhibited by partially saturated soil. Groundwater continued to discharge from seepage points during the survey period.

Stability Analysis

A two-dimensional limit equilibrium stability analysis using soil strength parameters determined from soil sampling (c = 0, φ = 35°, γ = 125 pcf) and a phreatic surface based on the upper seepage points gave a factor of safety of 1.27 for the simplified Bishop method. The fill profile, phreatic surface, and failure surface are presented in Figure 6. Infiltration and continued discharge from coal seams could increase the phreatic surface above the elevation of the current seepage points. A second stability analysis using a phreatic surface closer to the lowest coal seam produced a factor of safety of 0.94 for a moderately deep circle and 1.12 for a deep circle (Figure 7).

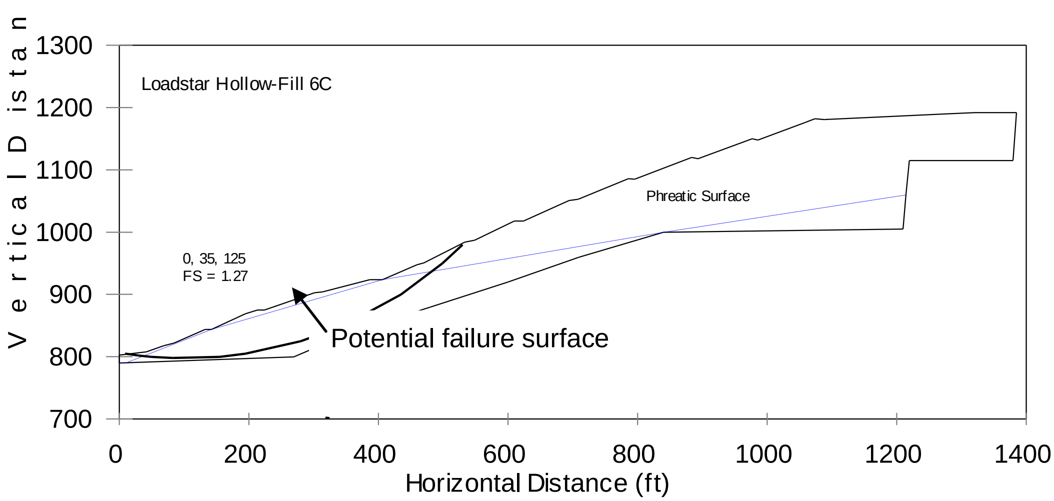

Figure 6. Stability analysis at current estimated phreatic surface.

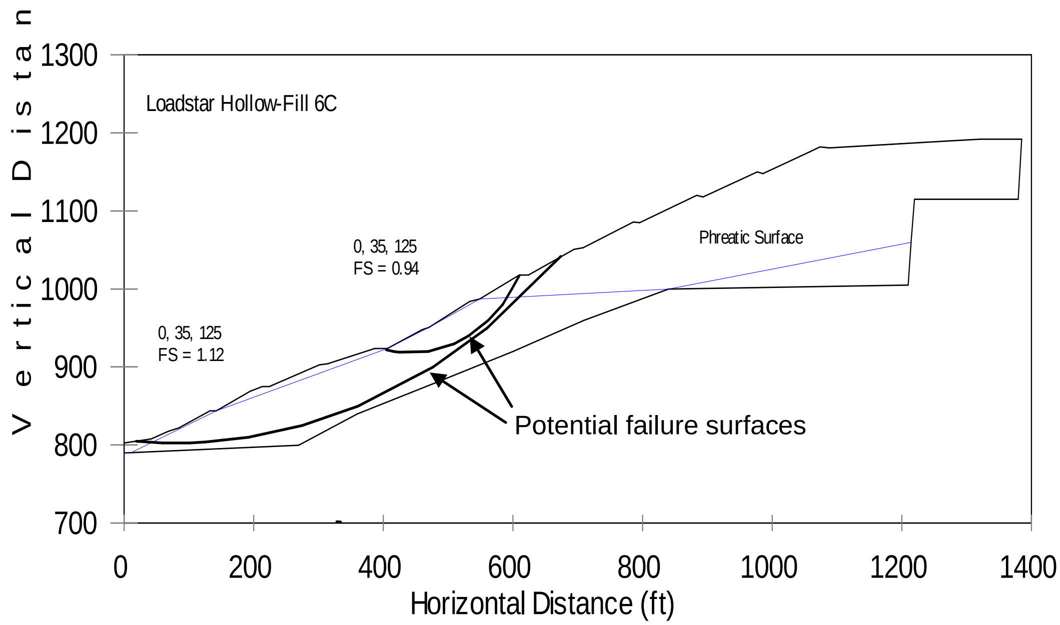

Figure 7. Stability analysis at a higher phreatic surface.

As shown above, a stability analysis using soil strength parameters determined from on-site sampling and a current estimated phreatic surface indicates a factor of safety of 1.27 which is well below the 1.5 factor of safety required by regulation (405 KAR 16:130 Section 1(2)(b)). In addition, the second stability analysis assuming a plausible higher phreatic surface gave a factor of safety of 0.94. Consequently, the long-term stability of this fill is questionable. Stability of this fill is crucial to the Prestonsburg economic development project and downstream Corps of Engineers Dewey Lake. Therefore, continued monitoring of the stability of the fill is very important. With the installment of the survey markers, a continued monitoring is possible. Local failures and crucial zones can be detected early and procedures can be adopted to prevent overall failure.

Conclusions

This study is the first time that the stability of a fill has been monitored in detail for a long period of time in conjunction with traditional slope stability analysis. The following conclusions can be drawn based on the results of this project thus far:

1. A monitoring system has been successfully used to monitor the stability of a fill. The localization of deformation has been clearly identified based on the results of surveys. The location of large deformation is closely associated with the level of ground water table.
2. The soil at the site had little variation from place to place. The strength of the mixture of clay, sand, gravel, and boulder was quite high.
3. Conventional slope stability analysis generated reasonable results about the stability of the fill. The crucial factor affecting the factor of safety is the ground water table. Therefore, the effectiveness of the drainage system is very important.

Depending on the availability of funding, the monitoring system can be utilized in the future to ensure that the slope remains stable. If the localized deformation continues to increase, remedial procedures will be recommended to make sure that the fill has long-term stability. Therefore, this system can help us avoid catastrophic failure of a fill. In addition, with the availability of commercial GPS system that can generate the kind of accuracy needed, cost for future survey can be significantly reduced.

Acknowledgment

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