SETTLEMENT EVALUATION OF END DUMPED COAL MINE SPOIL FILL[1]

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Abstract. Strip mining for coal reserves has been and will continue to be a cost effective means of obtaining energy sources for the needs of the United States. A byproduct of strip mining is thousands of acres of relatively flat land created by placing the spoil material in valleys and over previously mined benches. These mine spoil fills offer an opportunity to build large developments and industrial facilities. However, due to the many unknowns associated with the performance of mine spoil fills there is reluctance to invest large sums of money into a mine spoil fill site due to the risk of detrimental settlement. This paper discusses research conducted on two previously mined sites that are currently being developed into industrial parks. The sites were strip mined using mountain top removal and contour mining methods. The mine spoil was placed using end dumping methods. End dumping consists of using dump trucks and scrapers to remove the spoil from the mining area and hauling it to the disposal areas.

The purpose of the research on the two sites was to develop a reasonable predictive model to evaluate the future settlement of the mine spoil fill. Settlements were monitored using surface monuments and extensometers located throughout the site. The extensometers were monitored for five years. The results of the settlement monitoring indicated that on end dumped mine spoil fill sites which are less than 100 feet (30m) thick and over 10 years old, large settlements associated primary compression of the fills have stopped and the fill is in a secondary compression phase. Future additional settlements due to secondary compression were found to be less than 1 inch (2.5 cm) over the five year monitoring period.

This research resulted in developing a predictive settlement model that will assist in understanding the settlement characteristics of similar mine spoil fill sites. This model will result in less conservative site development options, providing cost savings without increasing the risk of detrimental settlements when building on end dumped mine spoil fill sites.

Additional Key Words: Valley fills, Borehole Extensometers,

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Introduction

Mountaintop removal and contour mining have been common methods of surface mining for many years. During mountaintop removal of coal, huge quantities of spoil material (soil and rock) are dumped into adjacent valleys and back stacked on rock benches creating acres of relatively flat land. There are two types of valley fills: overburden or mine spoil taken off the mountains and dumped into the valley, and coal processing waste or coal refuse (tailings). The focus of this paper is on the mine spoil fills.

The mine spoil fills are generally constructed using either draglines sitting on a bench and casting the spoil material in windrows or using dump trucks and scrapers building a fill from the top down by end dumping. This paper discusses end dumped mine spoil fills. The thickness of the end dumped mine spoil can vary from a few feet to over a hundred feet deep. End dumping of the spoil creates a fairly loose structure that has a tendency to settle thereby reducing the void space between particles over long periods of time. This reduction in void space causes the spoil to settle.

End dumped mine spoil fills have the potential to settle significantly under their own weight, with settlement continuing for long periods after placement. Factors affecting the magnitude and duration of total and differential settlements include: placement procedures, material composition, depth of fill, age of fill, groundwater levels, rate of surface water infiltration and loading conditions. Some of the factors are more difficult to quantify than others.

Mine spoil fills create level land above Appalachian flood plains. These areas have been used for construction of schools, housing and light commercial developments. In recent years the economic development community has considered these sites for large industrial parks. Presently development in these parks consists of only a few large, generally lightly loaded buildings; column loads of less than 100 kips (44.4 kN). These old mine spoil fill sites are being offered to industrial developers to locate their facilities in the region.

There have been several high profile failures of buildings constructed on mine spoil fill which resulted in a lack of confidence that the old mine spoil sites can be developed successfully. Research previously conducted in Canada (Hankins, 1984) and in England (Charles, et al, 1978) was successful in predicting settlement for roadways and residential construction. However, there was limited information within for the coal fields region in the southeastern United States. The lack of a predictive model of Eastern Kentucky mine spoil increases the risks associated with development on the sites. The results of the research presented in this paper will provide a higher level of confidence that the risks associated with these old mine spoil sites can be quantified.

Previous Failures

A motel was built on a mine spoil site near Hazard, Kentucky in the early 1990's. The motel was constructed on a relatively level tract of ground created by the filling of an old strip mine. The age of the mine spoil fill at the time of construction was about 8 years old. The original geotechnical engineer drilled numerous borings to depths typically considered adequate on similar projects. The material was found to be stiff to very stiff in consistency and was judged acceptable to support the proposed two-story motel on spread footing foundations.

During construction, the contractor noticed that one of the wings of the motel was settling at a much higher rate than was anticipated. The settlement was near 3 feet (0.9 m) within 12 months after construction had started. The portion of the development in the area of the most severe settlement was never used.

A detailed subsurface analyses was conducted and found that the building site was partially situated over an old mine bench. A portion of the building was founded on about 15 feet (4.6 m) of mine spoil fill and the portion that experienced the severe settlement was founded on about 75 feet (23 m) of mine spoil fill. Eventually, the entire motel development was razed due to the excessive settlement.

A second failure occurred on a small fast food restaurant constructed over previously placed mine spoil fill in the mid 1990's. The restaurant site's subsurface conditions were explored using shallow borings since the small restaurant building was very lightly loaded. The borings encountered stiff rock/soil extending throughout the 15 feet (4.6 m) depth of the borings. The building was founded on stiff material using conventional spread footing foundations. After a few months of operations, the owner noticed settlement cracks in the walls. A subsequent investigation revealed that the building was situated on a site with over 100 feet (30 m) of mine spoil fill. Although the material was fairly consistent in depth, the magnitudes of settlement were beyond the tolerance of the conventional foundation system. Over time the consolidation of the fill slowed allowing the building to be repaired.

A hospital built on a mine spoil fill site near Hazard, Kentucky experienced excessive settlement that required remediation. The hospital was constructed in several phases beginning in the early 1980's. The construction consisted of a 4 or 5 story central building with a single story portion surrounding the central multi story section. The building was situated over an old mine bench such that the majority of the building had bedrock about 35 to 50 feet (4 to 15 m) below ground. A small portion of the single story building extended over a buried side hollow and was situated over about 80 feet (24 m) of fill. The original topography consisted of the top of a hill with a head of a valley starting where the deeper fill was located under the building. The fill was placed by end dumping down a long slope. No compactive effort was applied during placement. The original geotechnical engineer did not discover the old valley with the boreholes.

Due to the loading conditions of the interior 4 or 5 story portion of the building, it was supported on drilled shafts founded on bedrock. However, the single story section was supported on conventional spread footing foundations. Within 3 months of completion, the single story portion of the building where the deeper fill was located showed signs of settlement. To correct the problem, a series of drilled shafts were installed around the corner to support the portion of the building that showed the most settlement. The solution was unsuccessful. The interior spread footings continued to settle along with the concrete floor slab. The interior footings and floor slab settled several inches causing the exterior wall to lean in toward the building.

All three of the projects discussed went through litigation. The settlement amount for the motel and the hospital are not known by the authors. However, the restaurant litigation was settled out of court for over $450,000 in 1994 not including lawyer fees and the forensic work conducted by the expert witness.

Site Descriptions

Two sites were selected for evaluation of end-dumped mine spoil fills. Both sites were located in southeastern Kentucky. The Coalfields Industrial Park is located about 10.7 miles (17.2 km) northwest of Hazard, Kentucky (Fig. 1). The Gateway Business Park site is located about one mile (1.6 km) southwest of downtown Jenkins, Kentucky (Fig. 2). The two sites were evaluated by conducting a detailed document review to develop an understanding of the mining history of the sites, drilling confirmatory exploratory borings and utilizing localized geophysical testing.

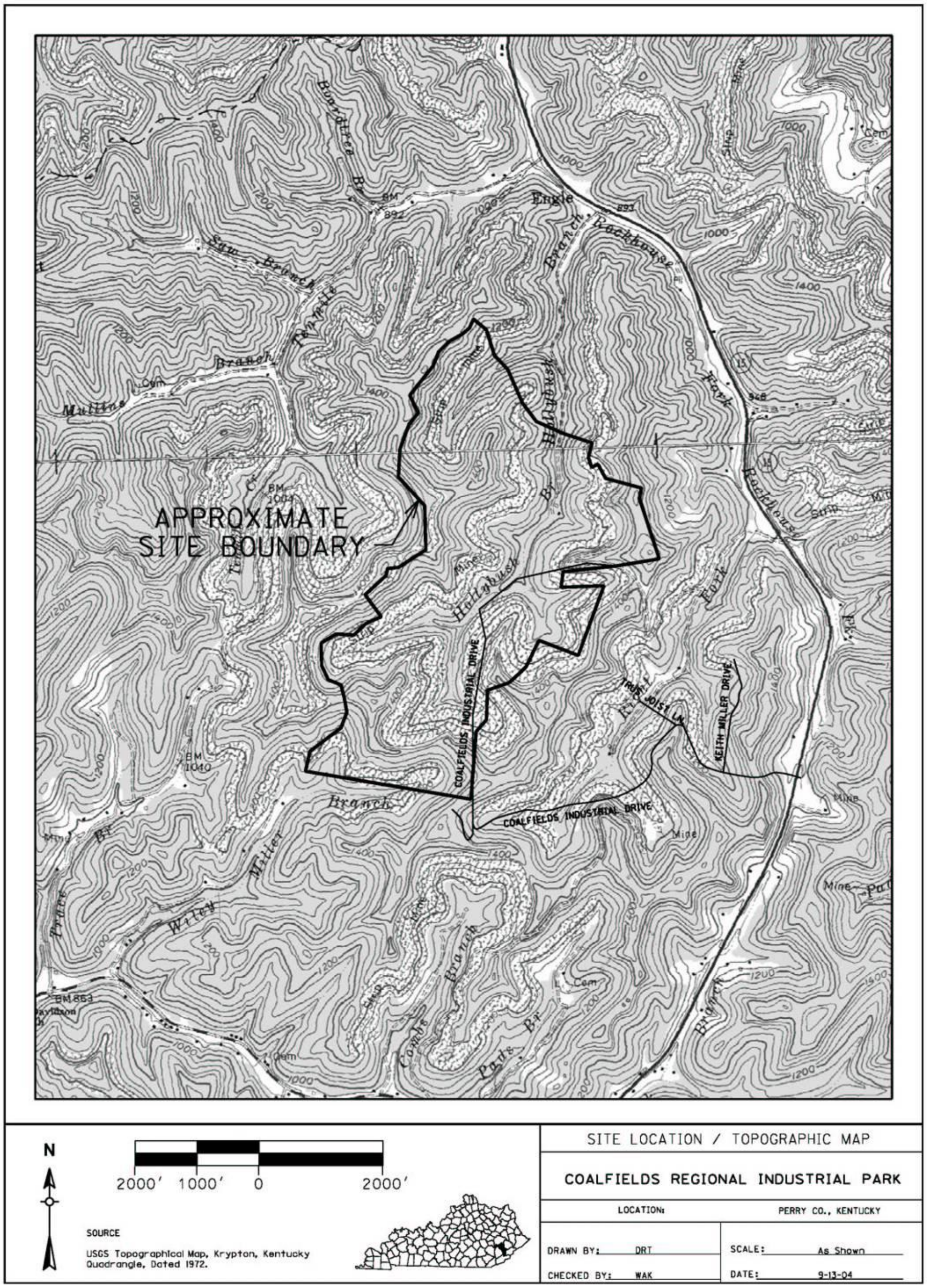

Figure 1: Topographic Map of Coalfields Industrial Park (USGS, Krypton Quadrangle, 1972). Dark Line Represents the Park Boundary. Contour Interval = 40 feet.

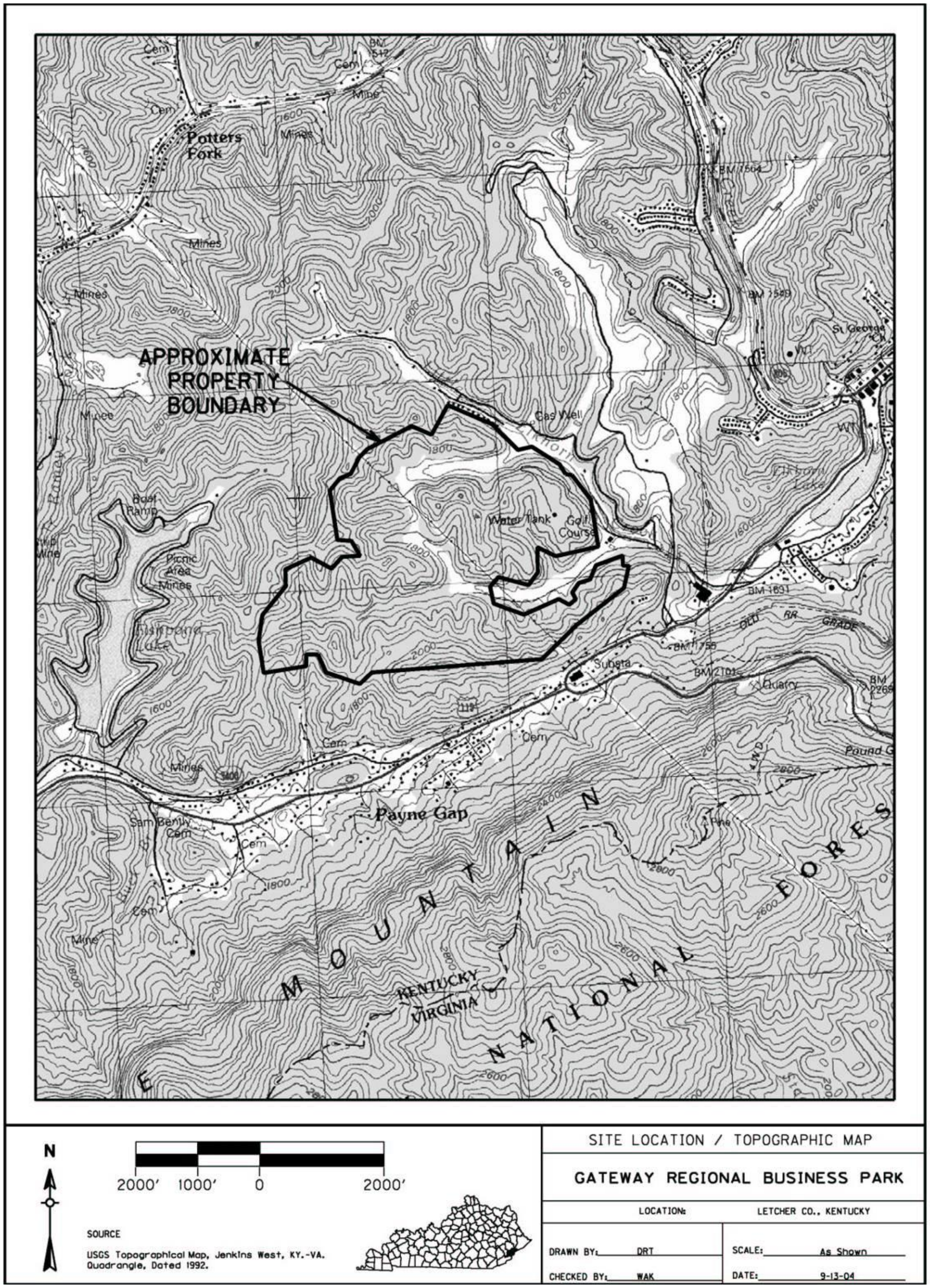

Figure 2: Topographic Map of Gateway Business Park (USGS, Jenkins West KY-VA Quadrangle, 1992). Dark Line Represents Park Boundary. Contour Interval = 40 feet.

To evaluate the settlement of the mine spoil fills, a series of borehole extensometers were installed at various locations on the sites. In addition to the extensometers, surface settlement monuments were also installed. At the Coalfields Industrial Park site, an area of the mine spoil was also subjected to a surcharge load and monitored using settlement platforms.

Coalfields Industrial Park:

The Coalfields Industrial Park encompasses about 386 acres (156 hectares). The original site topography consisted of the north-south trending narrow Hollybush valley surrounded by steeply sloping hillsides that climb to narrow, winding ridgelines. The top of the original ridges varied in elevation from about 1420 to 1460 ft (433 to 445 m) mean sea level (msl). The valley floor elevations varied from about 1140 ft (348 m) msl at the head of the hollow to about 1080 ft (329 m) msl at the north end of the valley. The mining activity occurring from the mid 1980's through early the early 1990's resulted in the excavation of the ridges to about elevation 1170 to 1210 ft (357m to 369m) and the filling of the hollows with mine spoil. The subsequent reclamation returned the site to its present surface elevation of 1260 to 1280 ft (384 to 390 m) msl. The current site topography is characterized as a gently rolling plateau. The majority of the site is grass covered with a few small trees. For the most part the site appears well drained. Surface water is dissipated chiefly by runoff and infiltration into the fill. There were several small ponds on the site.

The geology at the Coalfields site consists of the lower and middle Pennsylvanian aged siltstone, sandstone, shale, underclay and coal locally referred to as the Breathitt formation. In the site vicinity, the overburden consists of sandstones, shales and siltstones. Underclay also occurs as a minor unit. The shales are typically non durable and weather into a soil-like consistency.

Gateway Business Park

The Gateway Business Park encompasses about 348 acres (141 hectares). The original topography consisted of a mountaintop with adjacent deep valleys. The current topography of the developable area of the park range in elevations from about 1800 ft (549 m) msl to about 1890 ft. (576 m) msl. The surface is generally covered with high weeds and occasional large sandstone rock fragments. The property is generally surrounded by steep wooded slopes. The slopes on the southern and western boundary range from about 1850 ft. (564 m) msl to in excess of 2050 ft (625 m) msl.

The site geology is similar to the Coalfields site; it consists of the lower and middle Pennsylvanian aged siltstone, sandstone, shale, limestone and coal locally referred to as the Breathitt Formation.

Mining Activity

Mountaintop or Ridge top removal mining removes the entire top of a mountain ridge creating a level surface at the coal seam. The same type of equipment used for contour mining is used in mountaintop removal. Mountaintop mining does affect much larger areas of land versus the relatively thin bands characteristic of contour mining.

The excavation begins along the deepest economically removable coal seam outcrop parallel to the ridgeline. To start the operation, the first cut is transferred by rock trucks to the hollow fill. After overburden drilling and blasting, front end loaders and rock trucks work progressively toward the center of the mountain. Concentrically circling the mountain, the lower benches advance ahead of the upper excavations. The excavation continues with rock trucks hauling material to the mine spoil storage area using ramps connecting the series of benches until a level surface remains.

The spoil material is placed in the hollow fill by end dumping. End dumping of the spoil creates a fairly loose structure that has a tendency to settle thereby reducing the void space between particles over long periods of time. This differential reduction in void space causes the spoil to settle differentially. Figure 3 illustrates typical end-dumping placement methods.

The Coalfields Industrial Park site was surface mined in the late 1980's to 1993 using contour mining and mountain top removal mining methods. The Gateway Business Park was surface mined from the early 1990's ending in 1996. The mine spoil fill at both sites was placed using dump trucks and dozers. The bulldozers were Caterpillar model D9N's and D10N's and the dump trucks were Caterpillar model 777B (triple 7's).

Figure 3: Typical End-Dumping Placement Methods

Subsurface Conditions after Reclamation

Coalfields Industrial Park

The subsurface conditions at the Coalfields site resulted from the previous mining and reclamation activities. The most prominent features are a buried drainage valley which dissects the northern and central portion of the site and the buried plateaus from the ridge-top removal.

The plateau and valley floor are separated by remnants of the original steeply sloping hillside. All are now buried beneath mine spoil fill. The fill depth ranges from about 40 to 60 ft (12.2 to 18.3 m) in the south to over 250 ft (76.3 m) over the buried valley. The northern portion of the site contains an approximately 75 acre (33.6 hectares) area that is underlain by a fairly uniform depth of fill of 100 to 115 ft (30.5 to 35.1 m). The southern portion of the site includes an approximately 110 acre area (33.6 hectares) with a consistent overburden depth of 40 to 60 ft (12.2 to 18.3 m).

The mine spoil material is a mixture of shale, siltstone and sandstone. Particle size ranged from fine sand to boulders. The shale ranged from durable to clayey shale. Standard penetration tests performed in the mine spoil fill throughout the depth of the soil provided a measure of relative consistency between samples in the fill. The standard penetration resistance N-values indicates that the fill contains zones of soil-like material (N-values less than 50 blows per foot) and zones of boulders or dense rock (N-values greater than 50 blows per foot). The N-values confirm a zonal deposition of the spoil as it was end dumped from the haul trucks. Large particles and finer particles occur together and in a somewhat alternating pattern. Zones of sandstone boulders were encountered throughout the fill. The standard penetration tests did not indicate large voids.

Groundwater was typically encountered within 10 ft (3 m) of the bedrock surface. When constructing mine spoil fills, the base of the fill generally consists of large durable boulders used as a “blanket” drain. The borings confirmed that a blanket drain exists at the Coalfields site.

The entire overburden/mine spoil placement operation was conducted using bulldozers and dump trucks. Caterpillar model D10N dozers and Caterpillar model 777B (triple 7’s) off road dump trucks were used to place the mine spoil. The mine spoil was loaded into the triple 7’s using rubber tired loaders. The mine spoil was end dumped into the valley fill or on the benches. The D10 dozers were used to spread the material on top of the fill. Other than trucks traversing the fill, no compaction was conducted in the valley fill.

Gateway Business Park

The subsurface conditions at the Gateway site consisted of two hollow fills. Both valleys run east-west with one located on the north end of the site and the other on the south end of the site. A buried plateau from the contour and ridge top removal is located between the two valleys. The depth of the mine spoil fill varied greatly depending upon the location within the business park. The north central portion of the site is located over a buried plateau created from mountaintop removal. The mine spoil fill depths were generally less than 30 ft (9.2 m). Along the area of contour mining, the mine spoil fill depths range from 30 ft to in excess of 60 ft (9.2 to 18.4 m). The mine spoil fill placed in valleys at the north end of the site were typically 60 ft to 100 ft thick (18.4 to 30.4 m). Fills in the southern valley were in excess of 100 ft thick (30.4 m). The composition of the mine spoil ranged from large sandstone and shale boulders to clay sized particles.

Groundwater was generally not encountered in the test borings, however, water is typically found at the bedrock surface. By comparing the standard penetration test N-values between the Coalfields and Gateway sites, it was observed that both sites were statistically similar. Table 1 presents the N-values for the sites.

Table 1. Comparison of Standard Penetration Resistances at Coalfields and Gateway

	Gateway	Coalfields
Mean N-value	26.8	27.5
Median N-value	21	22
Standard Deviation	16.3	18
Minimum N-value	3	3
Maximum N-value	87	70
Number of samples	127	237

The field instrumentation used at the Gateway Business Park and the Coalfields Industrial Park consisted of multipoint borehole extensometers and surface settlement points. Additionally, an area surcharged within the Coalfields Industrial Park was monitored using two settlement points. The extensometers were used to evaluate variations in settlement of the mine spoil with depth. The surface settlement points were used to measure settlement at the top of the ground surface. In addition to the multipoint extensometers, the borehole which housed the extensometers was used to obtain approximate groundwater levels.

The model 1900 magnetic extensometers manufactured by Geokon, Inc. was used. The model 1900 is designed to measure movement between magnetic targets anchored at various depths in the ground. The extensometers were extended to bedrock. The extensometer consists of a 1 inch (2.54 cm) diameter rigid pipe that is lowered into the open borehole. Magnetic anchors are placed over the pipe and slid into place at specified intervals. The anchors attached themselves to the surrounding fill using spring loaded arms that are released from the surface using a tether. The borehole and anchors are grouted using a weak grout. A probe is inserted into the pipe and lowered to the bottom. The probe reads the thin magnetic field produced by the anchor. A calibrated tape reads the distance between anchors determining the movement between intervals.

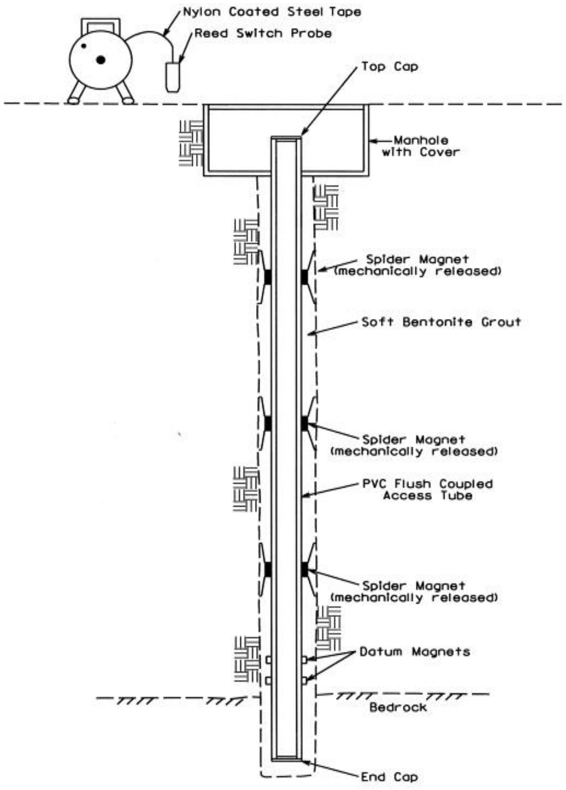

Figure 4: Typical Borehole Extensometer Installation

The extensometers were installed in a 4 inch (10 cm) diameter borehole drilled with a Mobile B-80 Drill Rig using solid flight augers or using a casing advancer. The extensometers located in deeper mine spoil fills (> 100 ft) were installed in boreholes drilled using a CME 750 all terrain vehicle drill using an HQ casing advancer with the drilling tools. The casing advancer allows for greater control of the borehole diameter by cutting through larger rocks within the fill. The borehole was logged to evaluate the subsurface conditions and standard penetration testing was conducted at various intervals. Once the extensometers were installed bentonite grout was used as backfill.

The extensometers were measured about every 6 months. Differences between the initial reading and each subsequent reading were plotted. In addition surface measurements were made on the extensometer cover pad. Typical graphical representations of the extensometer and the surface monument data are shown in Fig. 5.

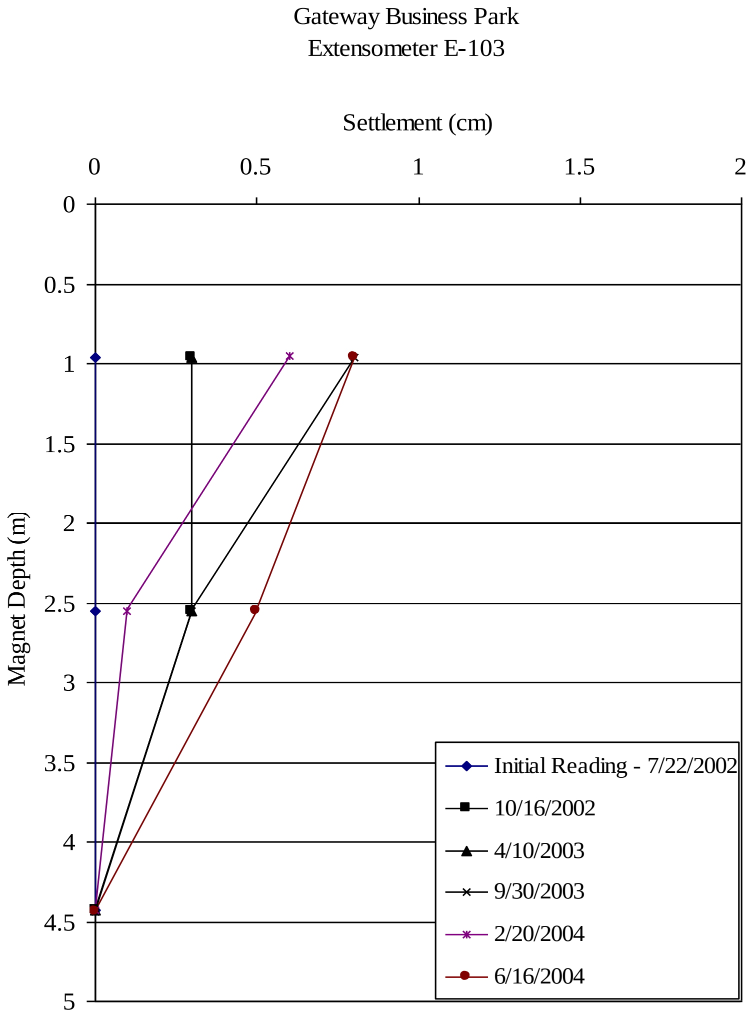

Figure 5: Typical Representation of Extensometer Readings

The instrumentation installed at each of the sites was located in areas to evaluate settlement in fills of varying thicknesses. Several variables affect the potential settlement of mine spoil fills of which the fills age and depth are two of the most easily evaluated. The placement method has also been found by other researchers to affect the settlement characteristics of mine spoil fill. The mine spoil fill depths that were monitored ranged from 55 ft (17 m) to 97 ft (30 m) at the Coalfields site and 15 ft (5 m) to 110 ft (34 m) at the Gateway site. The intent of the extensometer installation was to evaluate the settlement of the mine spoil as a function of time, method of fill placement and depth of fill. The information obtained during the monitoring period was used to develop a reasonable predictive model of the mine spoil fill to determine magnitudes of settlement.

The normal unsaturated compression of mine spoil fills appears to occur in a similar manner to the consolidation process of clays. The initial short term consolidation period of large settlements is followed by a period of secondary compression in which small settlements which decrease slowly with time, continue for years. Studies on rock fill dams by Sowers (1965) indicated that in rock fills, the rate of continuing settlement is similar to the secondary compression in clays. However, the secondary compression in clays is associated with the clay minerals and their absorbed water. In the case of rock fills, continuing settlement of the rock involves compression or crushing of the rock point contacts.

The mine spoils in Eastern Kentucky primarily consist of a mixture of shale, siltstone and sandstone. The shale and some of the sandstone are considered non-durable and break down easily when subjected to moisture content changes and induced stress. The amount of large rock boulders with respect to the fine grained material varies significantly from site to site depending upon the local geology. The material is generally placed in a loose condition. No compactive effort is conducted other than dump trucks and bulldozers traversing the site. Previous research indicated that dry unit weights ranging from about 80 pounds per cubic foot (12.5 kN/m^3) to 105 pounds per cubic foot (16.5 kN/m^3) were measured in fills end dumped using dump trucks and dry unit weights from 65 pounds per cubic foot (10.2 kN/m^3) to 130 pounds per cubic foot (20.4 kN/m^3) in mine spoil fills placed using draglines. The maximum dry unit weights of Eastern Kentucky mine spoil specimens tested by Drnevich (1975) ranged from about 122 pounds per cubic foot (19.1 kN/m^3) to 125 pounds per cubic foot (19.6 kN/m^3).

The initial settlement of mine spoil fills is primarily due to a reduction in void space within the material associated with the self weight of the overlying fill itself. The amount of time for this primary initial settlement to occur will vary based on the individual site conditions. However, prior research on mine spoil sites in England (Kilwinny, 1968) suggests that the majority of the settlement occurs within the first 8 to 10 years after the mine spoil was placed. Once the void space reduction occurs, additional initial settlement results for short term compression as the fine grained material is loaded. Short term compression will continue until the stresses are distributed uniformly throughout the fill at which time long term or secondary settlement begins.

There are many factors that affect the magnitude of settlement in mine spoil fill. The primary factors are placement methods, age of the fill, composition, thickness and water infiltration/ hydroconsolidation. The type of equipment used to place the mine spoil and the method of placement greatly affect the amount of settlement that can occur. Ideally during placement of the mine spoil, the fill should be placed in lifts of uniform thickness and compacted with suitable compaction equipment. However, the cost associated with compacting such large fills prohibits this type of placement.

The age of the mine spoil fill will affect the settlement amounts. As previously mentioned after placement an initial settlement phase has been observed to occur within 8 to 10 years of the mine spoil fill placement for fills generally less than about 100 ft (30 m) thick. However, secondary settlement can continue for years and may be substantial depending upon the composition and matrix of the fill.

The composition of the mine spoil fill can affect the settlement magnitudes and the time durations. Fine grained material within the fill tends to have a longer initial settlement period. Larger rock fills will complete its initial settlement period and develop a point to point contact thereby initiating its secondary settlement stage. Mine spoil can contain zones of loose heterogeneous material, homogenous densely packed material and zones of hard large diameter rock pieces interacting as blocks with large voids between those blocks. If the large diameter pieces are "floating" in a matrix of fine grained material, the fine material will govern the settlement characteristics of the mine spoil.

The fill thickness will affect the settlement magnitudes of mine spoil fills. In deeper fills, the overburden pressure will increase the rate of void reduction and increase the amount of point to point degradation of the larger rock particles within the fill. In shallower fills (< 100 ft); the fills will stabilize much faster than deeper fills. As evidenced by the extensometer data, the Coalfields and Gateway settlement readings were generally less than about 1 inch (3 cm). The Gateway and Coalfields fills were about 10 years old and generally < 100 ft (33 m) thick.

Evaluation of the Settlement Data at the Eastern Kentucky Sites

The extensometers installed at the sites used for this research were installed 7 to 10 years after completion of the mine spoil placement. Therefore the data obtained in this research can be used to confirm and predict long term or secondary settlement on the mine spoil sites. The extensometers for Coalfields and Gateway were installed in mid 2002. Once the installation was completed, an initial reading was obtained. Subsequent readings were made on about 6 month intervals. To calculate the settlement the data was referenced from a datum magnet located at the base of the extensometer pipe. The datum is assumed to be stable while the top of the pipe is assumed to be settling.

Analyses of the extensometer settlement data at both sites indicate a small gradual settlement of less than 1 inch (3 cm) over the monitoring period. In addition to the extensometer readings surface elevations were obtained at each of the extensometer cap locations. The surface elevations indicated very small surface settlements of about 1 cm at each extensometer location.

To observe the settlement of the surface of the mine spoil under a surface load, a 15 ft tall surcharge fill was placed over a section of mine spoil with a depth of 250 ft (76 m) at the Coalfields site. The footprint of the surcharge fill measured approximately 300 ft by 300 ft. Two settlement points located about 200 ft (60 m) apart recorded similar settlement under the mass of the surcharge. The settlement points were located at the interface between the ground surface and the surcharge fill. A total of approximately 2 ½ inches (6.4 cm) occurred over the monitoring period with about 90 percent occurring within 100 days after completion of the surcharge placement. After 100 days, the settlement continued at a much slower rate.

To evaluate the settlement measured for the extensometers, the maximum settlement at each extensometer location was evaluated based on the depth of the fill. Figure 6, illustrates the comparison.

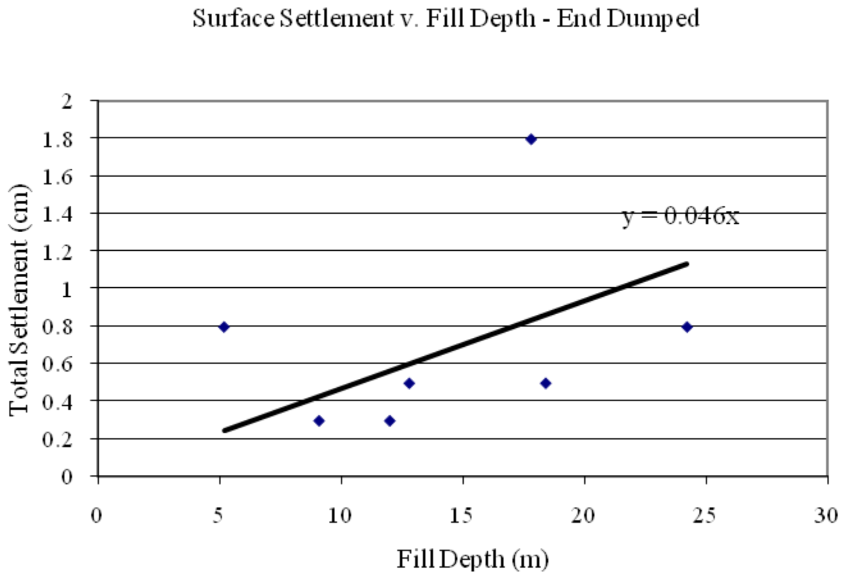

Figure 6: Total Settlement versus Mine Spoil Fill Depths

The settlement plotted in Fig. 9 is not time dependent. The settlement is based on the depth of the mine spoil fill at the location of the extensometers. Observations of the surface settlements surveyed at the cap of each extensometer were all less than 1 cm and did not indicate an obvious trend. The small magnitudes of the settlement make a correlation to fill depths not practical. Therefore, no graphical presentation to analyze the surface settlement from the survey points at the surface is presented.

To observe possible trends in the end dumped mine spoil, the extensometer data from the Coalfields and Gateway sites have been combined. Figure 7 illustrates the combined end-dumped extensometer data. The purpose of this comparison was to evaluate the potential additional settlement over time after placement of the mine spoil fill. There was no definitive trend in the data therefore, no linear interpretation was developed. However, the data shows that the majority of the settlement falls below approximately 0.05 percent of the fill height. This corresponds well to the correlation between total settlement and fill height as presented in Fig. 6.

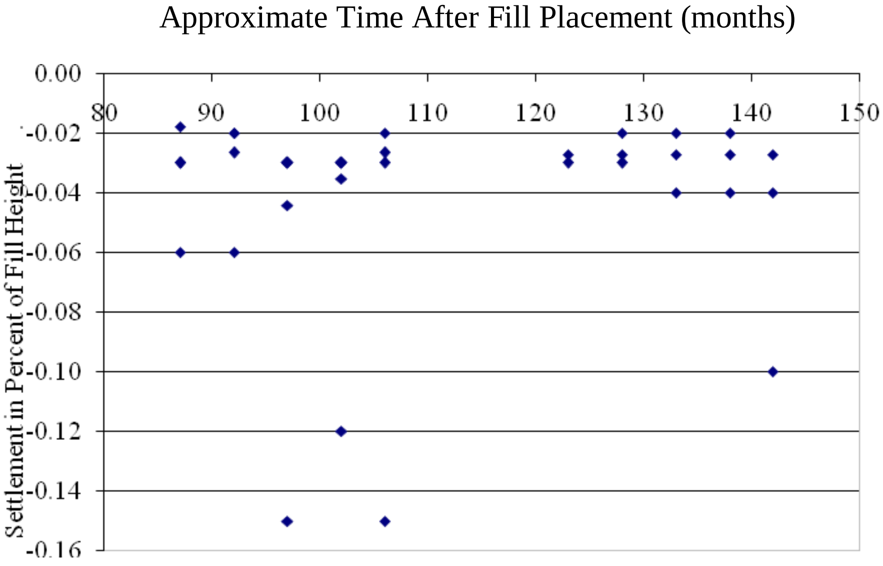

Figure 7: Combined Normalized Settlement

Model to Predict Settlement of Mine Spoil Fill

As indicated on Fig. 7, no settlement trends based on time have occurred with the combined data from the sites where end dumping of the mine spoil occurred. The data indicate that after the initial settlement period on fills of less than about 100 ft (30 m), trends to estimate secondary settlement versus time after placement could not be established. However, when the raw settlement data was compared to the fill depth, some trends were observed. For end dumped fill with depths of less than 100 ft (30 m) that have been in place for over 10 years, the following relationship was observed.

$$S = 0.05\,H \qquad (1)$$

Where S = Secondary Settlement, cm

H = Fill height, m

This relationship is based on a very small sampling; therefore the values obtained from this relationship should be considered as an order of magnitude and not exact. After the initial settlement has occurred, the largest cause of settlement in mine spoil fill is hydroconsolidation. The magnitude of settlement from hydroconsolidation is difficult to predict but can be substantial.

Comparison to Other Settlement Models

Research on rock fills for dams has yielded various equations for predicting the amount of settlement. Sowers (1965) observed that in the United States, rock fill dams yielded settlements of ½ to 2 percent of the fill height after 5 years with decreasing rates of settlement occurring beyond 10 years. Sowers found that when plotting the logarithm of time after placement to the settlement as a percentage of the fill height the following equation could be used to predict secondary or long term settlement.

$$S = \frac{\alpha H}{100}(\log t_2 - \log t_1) \qquad (2)$$

Where: S = Settlement

H = height of fill

α = the slope of the settlement-log time curve

t_1 = beginning of the period of interest

t_2 = end of the period of interest

The value of α was found to generally range from 0.2 to 0.7 for all but one dam. Kilkenny (1968) found α to be 0.74 for mine spoil fills consisting of shale, mudstone and some sandstone in England.

Soydemir and Kjaerisli (1979) analyzed crest settlement and fill height on 14 uncompacted rockfill dams worldwide with various geologic conditions. Based on plots of settlement versus fill height, an empirical correlation for long term settlement which was defined as 10 years after construction was developed.

$$S = aH^{2/3} \text{ for uncompacted rockfill dams} \qquad (3)$$

Where: S = crest settlement

H = height of dam

a = 0.001 for settlement and height in meters

$a = 5.52 \times 10^{-4}$ for settlement and height in feet

In a study of deep rock fills consisting of sandstone and marlstone in Colorado, Clift (1994) found that in a relationship between settlement versus fill height for uncompacted rock fills, the total settlement can be estimated as;

$$S = (2 \times 10^{-6})\, H^{2.5243} \qquad (4)$$

Where: S = Settlement in feet

H = Fill height in feet

To compare the various settlement models, a fictitious site with a mine spoil fill depth of 70 ft (21 m) will be evaluated. The mine spoil is over 10 years old placed using end dumping methods. Based on equation 2, the anticipated additional settlement should be on the order of less than ½ inch (1 cm). This calculated settlement compares fairly well to the results obtained from using other researchers' correlations to determine settlement in rock filled dams. When using Sowers' (1965) correlations, Equation 2, based on a 20-year evaluation period, settlements of 1.8 inches (4.5 cm) were calculated. Soydemir and Kjaerisli (1979), Equation 3, a settlement of 0.1 inches (.28 cm) was calculated and Cliff (1994), Equation 4, determined a settlement of 1 inch (2.5 cm). The results are summarized in Table 2.

As shown in Table 2, the calculated settlements of the four researchers are within a reasonable order of magnitude.

Table 2. Summary of Calculated Settlements

Researcher	Settlement, inches (cm)
Sowers	1.8 (4.5)
Soydemir and Kjaerisli	0.1 (.25)
Cliff	1.0 (2.5)
Karem	0.5 (1.2)

Summary

There are many uncertainties when building on mine spoil-fill sites. These uncertainties result in significant and often excessive costs associated with site development. A few high profile failures in combination with inadequate knowledge of the performance of mine spoil fills have resulted in a high degree of conservatism in site development methods. With some knowledge of the long term performance of mine spoil fills and an understanding of the site subsurface conditions, reasonable site preparation options can be developed that will allow an evaluation of the level of risk associated with a specific site with respect to its intended use.

The results obtained from this research provide a basis for developing a reasonable site development option on the two sites that were monitored. If a site is of sufficient age and depth to determine that the initial settlement phase has occurred, the secondary settlement can be reasonably quantified using the methods discussed in this paper. The secondary settlements evaluated in this paper on the sites studied were found to be within a similar order of magnitude. Therefore, additional settlement due to self weight of the mine spoil fill was considered within tolerable ranges.

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Literature Cited

Charles, J. A., W. A. Naismith and D. Burford, "Settlement of Backfill at Horsley Restored Open Cast Coal Mining Site", Foundations and Soil Technology: Practical Studies from the Building Research Establishment, Lancaster England, 1978.

Clift, Anne E., 1994, "In Situ Properties of Settlement Characteristics of Rock Fill", PhD Dissertation, T 4375, Colorado School of Mines, Golden, Colorado

Drnevich, Vincent P., Ronald J. Ebelhar, and G. Perry Williams, "Geotechnical Properties of Some Eastern Kentucky Surface Mine Spoils," Ohio River Valley Soil Seminar, 1973, pp. 1-1 to 1-13.

Drnevich, Vincent P., G. Perry Williams and Ronald J. Eberhar, " Soil Mechanics Tests for Coal Mine Spoils," Second Kentucky Coal Refuse Disposal and Utilization Seminar, Institute for Mining and Minerals Research, University of Kentucky, Lexington, Kentucky, May 1976, pp. 47-59.

Dusseault, M.B., J. D. Scott, G. Zinter and S. Moran, "Simulation of Spoil Pile Subsidence", Fourth Australia-New Zealand Conference on Geomechanics, Perth, Western Australia, 1984

Hankins, P. G., "Predictive Settlement Analysis of Mine Spoil at an Alberta Open Pit Coal Mine", Masters Thesis, University of Alberta, Department of Civil Engineering, 1984.

Karem, Wayne A., 2005 "Development of a Predictive Model to Evaluate Mine Spoil Fills for Industrial Development", PhD Dissertation, University of Kentucky, Lexington, Kentucky

Karem, Wayne A., Kalinski, M. E. and Hancher, D.E., "Settlement of Mine Spoil Fill from Water Infiltration: Case Study in Eastern Kentucky," Journal of Performance of Constructed Facilities, American Society of Civil Engineers, September/October 2007. http://dx.doi.org/10.1061/(ASCE)0887-3828(2007)21:5(345).

Kilkenny, W. M. "A Study of the Settlement of Restored Opencast Coal Sites and Their Suitability for Building Development", University of New Castle upon Tyne, Department of Civil Engineering, May 1968.

Krebs, Robert D., and Carl E. Zipper, "Foundation for Housing on Reclaimed Land Mined Lands", Virginia Cooperative Extension, Publication Number 460-115, January 1997.

Penman A. D. M, and E. W. Godwin, “Settlement of Experimental Houses on Land Left by Open Cast Mining at Colby”, Settlement of Structures: Conference organized by the British Geotechnical Society at the Lady Mitchell Hall, Cambridge, April 1974.

Sowers, G. F., Williams, R.C. and Wallace, T.S. 1965, “Compressibility of Broken Rock and the Settlement of Rockfills”, Proceedings of the Sixth International Conference of Soil Mechanics.

Soydemir, C. and Kjaernsli, 1979, “Deformations of Membrane-Faced Rockfill Dams”, Proceedings of the British Geotechnical Society, Design Parameters in Geotechnical Engineering, London England.

Thomson, S., and T. M. Schulz, “Settlement Studies of and Open Pit Mine Backfill in Western Canada”. Proceedings of the 3rd International Conference: Ground Movements and Structures, University of Wales, Institute of Science and Technology, Cardiff, England, July, 1984.

Thomson, S., J. D. Scott, D. C. Sego, and T. M. Schulz, "Testing of Model Footings on Reclaimed Land, Wabamun, Alberta," Canadian Geotechnical Journal, Volume 23, November 1986, pp. 541-547 http://dx.doi.org/10.1139/t86-083

Thomson, S., R. Sonnenberg, "Settlement instrumentation to Observe Open Pit Backfill and a Prototype Foundation in Western Canada," Canadian Geotechnical Journal, Volume 24, November 1987, pp. 663-669. http://dx.doi.org/10.1139/t87-081.

Zipper, Carl E. and Steven Winter, “Stabilizing Reclaimed Mines to Support Buildings and Development,” Reclamation Guidelines for Mined Land in Southwest Virginia: Powell River Project, Virginia Cooperative Extension, Publication 460-130, 1997.