SITING OF A FEDERAL PRISON FACILITY ON A RECLAIMED STRIP MINE IN EASTERN KENTUCKY - A CASE STUDY[1]

by

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Abstract. The U.S. Department of Justice, Federal Bureau of Prisons (FBOP) assessed the feasibility of developing a United States Penitentiary (USP) over a narrow reclaimed ridge-top coal strip mine in Martin County Kentucky. The assessment addressed the potential for ground subsidence, thickness and character of fill placed over the former strip mine and within adjacent valleys, development of alternatives for placement of the USP, and an assessment of fill compaction techniques.

Drilling and trenching programs determined the thickness of reclamation fill over the mine bench varied from 4.57 meters (m) (15 ft) to 17.4 m (57 ft) and consisted of cobbles with large boulders in an uncompacted, soft silty to clayey SAND matrix. Fill of similar composition exists on side-slopes and in adjacent valleys (hollows) to a depth of 1.5 m (5 ft) to 54.8 m (180 ft). Voids of varying size, including subsidence features were observed within the fill.

It was determined that ground subsidence could occur in two manners: (1) settlement of reclamation fill, and (2) failure of deep mining structures. While ground subsidence resulting from the failure of deep mine structures was determined not to be a critical issue on the site, extensive improvement to the existing fill would be required to provide an adequate foundation for the proposed structures. Where appropriate a combination of in-place densification and/or reconstruction of the fill material would be the most advantageous solution to address fill stability.

Insufficient acreage was found for a standard maximum security compound footprint over the former strip mine. However, useable acreage existed in the adjacent valley, provided a tremendous amount of earthwork is performed to extend the mine bench margin into the adjacent valley. To create sufficient level acreage to construct the facility, an earthworks quantity volume estimate of approximately 10,700,000 cubic meters (14,000,000 cubic yards) to 19,100,000 cubic meters (25,000,000 cubic yards) was established using a best-fit layout scheme.

Introduction

The Federal Bureau of Prisons (FBOP) proposes to construct and operate a United States Penitentiary (USP), at a site located in Martin County, Kentucky. The Honey Branch Site is located in eastern Kentucky, along the Martin-Johnson County border, south of Kentucky State Route 3 (Figure 1). The area of interest on the Honey Branch site consists of about 1.21 kilometers^2 (300 acres) extending along a ridge top between Honey Branch Creek and a tributary to the Little Beech Fork. The estimated area required for the main compound facility is about 0.16 (40 acres) to 0.24 kilometers^2 (60 acres), preferably in a square or rectangular shape. The proposed USP will consist of one and two story buildings in addition to four-story housing units. Structures generally will be constructed of pre-cast masonry or cast-in-place concrete.

The site has been mined for coal both by stripping and underground methods. Strip-mined areas were primarily along the ridge top. Underground mining occurred in two coal seams about 61 m (200 ft) and 88.4 m (290 ft) below the present surface. The mining operations ended about 1990.

The objective of the multiple-phase feasibility study was to assess key FBOP siting and development criteria. The siting and development criteria contained both engineering and economic elements, which are the subject of this paper. These criteria include:

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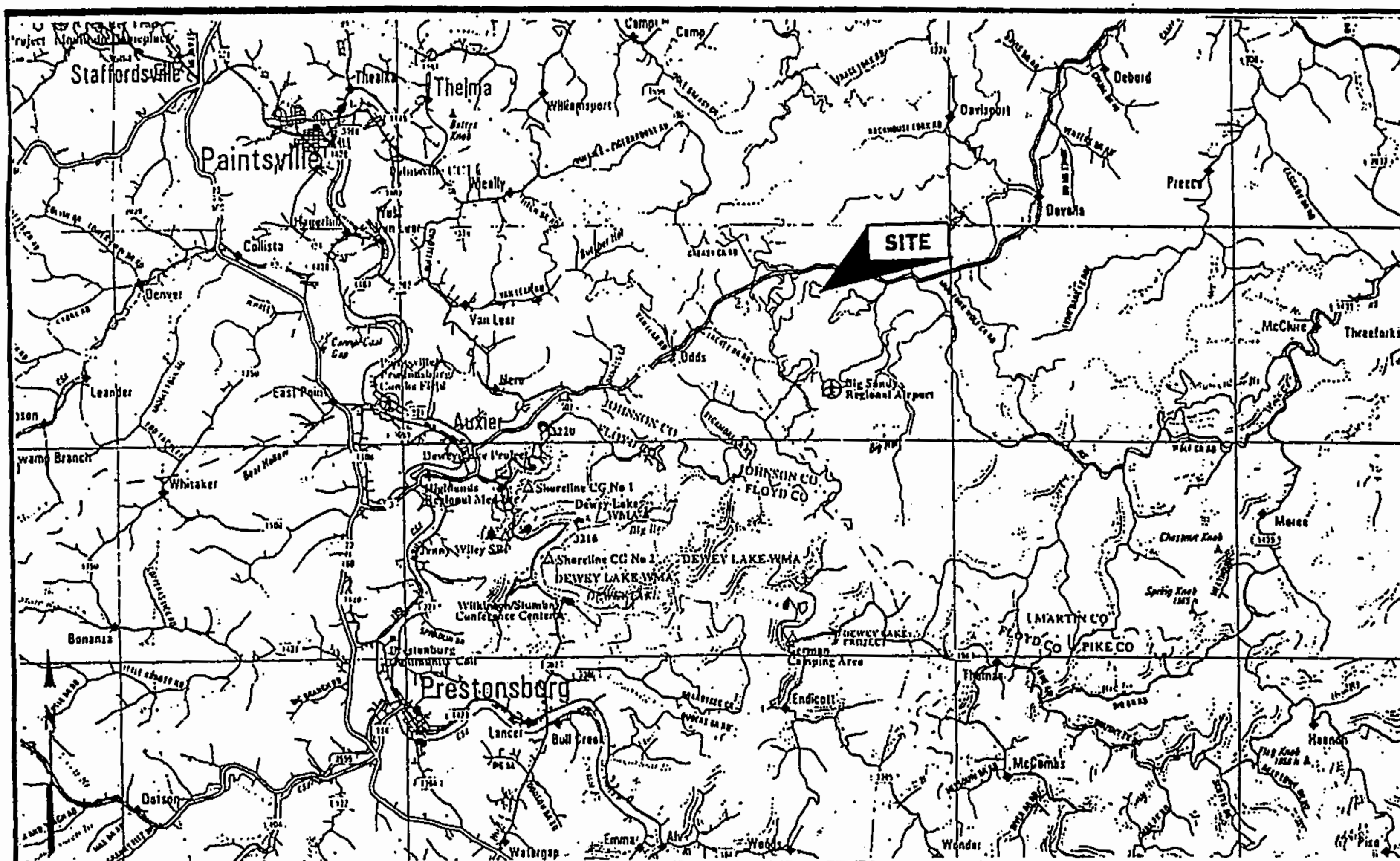

FIGURE 1

Site Location Map

Proposed United States Penitentiary Site
Martin County, Kentucky

1. Site Mining History
2. Geotechnical Assessment
3. Subsidence Analysis
4. Preliminary Facility Layout
5. Fill Improvement Requirements

Regional and Site Geology

The site is located in the Appalachian Plateau province of Kentucky, which is mostly a highland region underlain by generally flat lying clastic rocks. A deeply dissected landscape of steep slopes and narrow, sinuous ridges and valleys has been created by erosion through the flat lying rocks. Bedrock units vary in lithology and thickness through the region, and topography varies directly with the stratigraphy.

Martin County is dominated by rocks of the Lower and Middle Pennsylvanian age Breathitt Formation. The Breathitt Formation is a westward-thinning wedge of sandstone, siltstone, shale, and coal. There are three main mapped coal seams that have been mined at the Martin County site. The uppermost seam at the site is locally called the Clarion seam. It corresponds to the Richardson coal bed in the geologic literature. It is about 3.6 m (12 ft) thick and its bottom is at about elevation 359.7 m (1180 ft) mean sea level (msl). The next lower seam is locally called the Stockton. It corresponds to the Lower Broas coal bed in literature and is at an elevation of about 304.8 m (1000 ft) msl. The lowest seam mined is the Coalburg seam. This seam corresponds to the Upper Peach Orchard coal bed in literature and it is at about elevation 274.3 m (900 ft) msl.

Site Mining History

Mining has removed most of the Clarion seam by stripping. Stripping removed up to 38.7 m (127 ft) of overburden and resulted in a relatively level surface at about elevation 359.7 m (1180 ft) msl. Reclamation of stripped land occurred using the removed overburden (mine spoil) to approximate the former ground contour along the mountaintop, to flatten previous hillsides (sidehill or outslope fill), and to raise the valley floor grade (hollow fill).

The deeper Stockton and Coalburg coal seams have been worked extensively at the site, mainly by underground methods. The Stockton workings at about elevation 304.8 m (1000 ft) mea sea level (msl) are about 60.1 m (200 ft) to 64 m (210 ft) below current grade, while the Coalburg workings at about elevation 274.3 m (900 ft) msl are about 91.4 m (300 ft) to 94.5 m (310 ft) below current grade.

The bulk of the mining in the Stockton and Coalburg seams at the site was by the room and pillar extraction method. Based on mine records coal recovery from the Stockton seam appears to have been 50 to 75 percent. Coal recovery from the underlying Coalburg seam is estimated at about 50 percent.

Geotechnical Findings

Exploration programs consisted of soil test borings, deep rock coring, geologic map and literature reviews, and laboratory testing. Drilling was conducted both on and off the mine bench, and in the adjacent hollow to address specific geotechnical issues. The term "mine bench" in this paper refers to the ground surface exposed following strip mining of the ridge top, which is often significantly higher in elevation, then the surrounding valley (hollow) in this region.

Surface Reclamation Fill

The mine bench top in the development area was explored with shallow test pits and 39 borings through the existing reclamation fill into the underlying bedrock using air rotary drilling. Thickness of fill over rock ranged from 4.6 m (15 ft) to 17.4 m (57 ft) and generally consisted of cobbles with large boulders in an uncompacted, loose silty to slightly clayey SAND matrix. Voids of varying size within the fill were encountered while drilling and also observed within the test pits. Soil classifications performed on the matrix materials indicated a non-plastic soil with about 20 percent fines classifying as clayey SAND, silty SAND with gravel (SM) in accordance with the USCS classification system. In most cases, water levels, where present within the fill, were less than 3 m (10 ft) above the mine bench, representing perched conditions.

Side Slope and Hollow Fill

Side slope and hollow fills were explored with 21 borings using sonic drilling. Fill thickness ranged from as little as 1.5 m (5 ft) to 54.9 m (180 ft). The fill materials encountered were similar to those reported as bench top fill. Loose, uncompacted, silty SAND containing significant amounts of sandstone fragments, and clayey SAND containing significant amounts of shale fragments were interbedded within cobble and boulder zones. Subsidence features and sloughing of the fill were observed along side slopes of the mine bench. Four borings encountered soft organic horizons (e.g., trees) within discrete zones near the bottom of the fill.

Bedrock

Six deep core borings extended from the top of the mine bench to the underlying Stockton seam. Over 365.7 m (1,200 ft) of core was collected and examined, with cored intervals ranging from 32 m (105 ft) to 54.3 m (178 ft). The underlying bedrock encountered was typically interbedded shale, siltstone and massive sandstone. Overall core recovery was greater than 85% and Rock Quality Designation (RQD) typically ranged from 75% to 100%. Unconfined compressive strength of cores ranged from 173.6 (2470 psi) to 355 kilograms/cm^2 (5050 psi), which is in the low to moderate strength range for sandstone and shale. The examined core appeared to represent massive, competent roof material overlying the Stockton seam. Several feet of coal was cored at the elevation of the Stockton seam in two borings, suggesting in-place pillars. Void space encountered at the elevation of the Stockton seam in other core runs suggests that some mine rooms remain open. Rubble zones, suggestive of roof collapse over the mined horizon, were not apparent in the examined core.

Subsidence Analysis

The potential for ground subsidence was a critical element in this siting assessment. A significant potential for ground subsidence would lessen the consideration of the site for development. It was determined that ground subsidence could occur on the site via two mechanisms; (1) subsidence/settlement of reclamation fill, and/or (2) failure of deep mining structures.

Potential for Fill Volume Change

In order for the reclamation fill to provide an adequate foundation for the proposed structures it must remain stable against significant volume change. The reclamation fill is poorly compacted due to the coarse size of the rock debris and the resulting thick lift heights which must have been employed when filling the site.

The following conditions could induce volume change:

- Change in effective stress, due to changing groundwater level or foundation loading,
- Change in moisture content, due to infiltration or fluctuation of groundwater level,
- Decomposition of organic matter, such as buried trees and shrubs, and
- Chemical reactions, such as expansion of pyritic shale.

The existing reclamation fill is likely to be susceptible to significant volume change from all the above factors. Experience with similar materials suggests that changes of moisture content and groundwater rise could generate collapse settlements of typically 3% to 5% of the fill thickness equating to settlements of up to 0.6 m (2 ft) on this site. Decomposition of organic material could result in additional settlement of a similar magnitude with substantial variations across the site. Significant differential settlements would be anticipated in conjunction with the large potential total settlements. In addition, the swelling of pyritic shale could damage foundations if the swelling occurs immediately beneath prison structures.

Potential Subsidence from Historic Deep Mining

Subsidence generated by long term effects may occur above deep coal workings due to two mechanisms: pillar failure and roof failure.

Pillar Failure. It is difficult to predict the likelihood of pillar failure due to long term degradation of pillars. Pillar failure results in a redistribution of stress from the collapsed pillar to adjacent pillars causing a rapid increase in stress, sometimes resulting in complementary failure. This effect can propagate laterally causing settlement over a significant area. The Stockton and Coalburg seams are prone to this type of failure as pillars have been pulled during mining, inducing residual over stressing in adjacent pillars.

If pillar failure does occur in either seam, the maximum settlement of the bedrock/fill interface is likely to be small and gradual due to the seam thickness which would tend to form beams, spreading the settlement effect. Based on current conditions, a number of pillars would have to fail completely for significant settlement to occur at the surface. Maximum surface settlement could occur if the width of failure were of the order of 41.1 m (135 ft) and 56.4 m (185 ft) for both the Stockton and Coalburg seams, respectively.

Roof Failure. The Stockton seam is overlain by 57.8 m (190 ft) of sandstone while the roof of the Coalburg seam comprises 27.4 m (90 ft) of sandstone. Typical mine excavation widths are in the order of 6.1 m (20 ft). Such spans would suggest good roof conditions. The amount of settlement exhibited at the bedrock/backfill interface and the time scale over which such settlement occurs can only be estimated using fairly broad assumptions. Based on a strength of cored sandstone of 20 MPa and the average

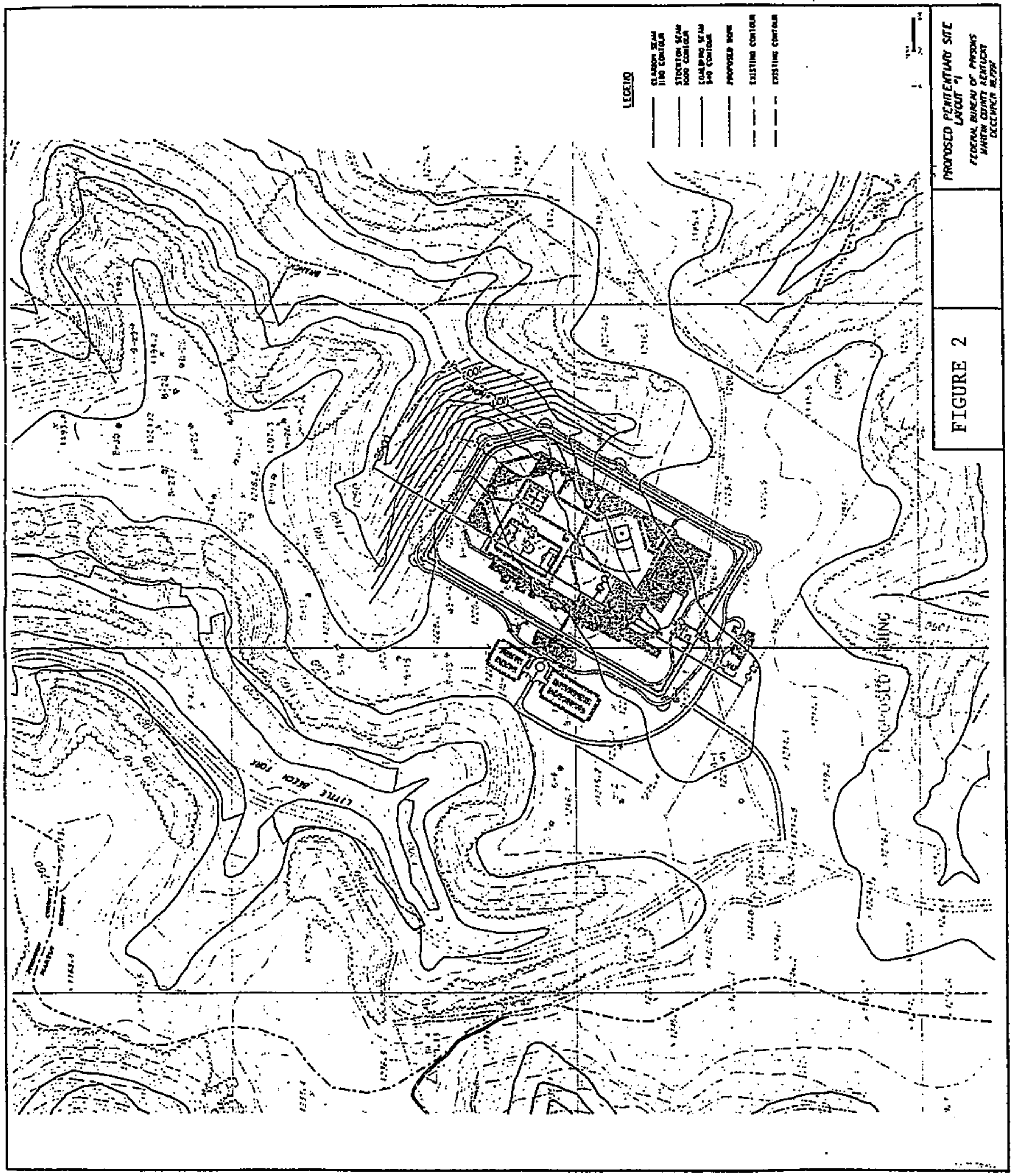
PROPOSED PENITENTIARY SITE
LAYOUT #1
FEDERAL BUREAU OF PRISONS
MARTIN COUNTY KENTUCKY
LEGEND
EXISTING CONTOUR
LITTLE BEECH FORK

FIGURE 2

RQD of ~90%, the roof conditions for the Stockton seam are likely to be favourable as they appear to be massive in nature.

If roof failure occurred, void propagation would take place vertically. Estimated void propagation is unlikely to be more than 24.2 m (80 ft). Such failure would not likely reach the bedrock/fill interface from the Stockton seam.

If this type of failure occurred in the Coalburg seam it may induce pillar failure in the overlying Stockton seam by reducing the bearing capacity of the ground underlying pillars. This is likely to be a localised effect, but it could propagate pillar failure. The strength of the roof sandstone overlying the Stockton seam indicates such failure is unlikely.

Siting Analysis

The methodology used to develop preliminary layouts of the USP over the property considered the requirement that a relatively flat site measuring about 518.2 m (1,700 ft) by 731.5 m (2,400 ft) would be required. Insufficient acreage was found to exist for a standard maximum security compound over the former strip mine bench early in the siting process. However, useable acreage existed in an adjacent valley, provided a tremendous amount of earthwork is performed. In order to accommodate the footprint, the ridge margins would have to be extended into the adjacent hollow, with engineered fill. The goal of developing alternative site layouts was to position the facility such that it would minimize the amount of site work, considering the following constraints:

- Base grade for the facilities located over a mine bench top were 359.7 m (1180 ft). This elevation was also maintained because lowering the elevation would require blasting over existing deep mines which is considered undesirable.
- An attempt was made to use as much bench (ridge) top area as possible to minimize fill requirements within the hollow.
- The facility had to be sited over the head of a drainage feature to avoid an unacceptable damming effect as the required fill footprint encroached over the invert of the hollow.

Development Alternatives

The study provided an analysis of six development alternatives and their associated earthwork estimates and site preparation costs as part of the initial siting assessment program. Earthwork volumes and construction practicability were key site selection criteria.

It was recommended to the FBOP that the optimal location for the facility straddles the Honey Branch Hollow located between two ridge tops within the southwestern margin of the site. The prison layout straddles the head of the Honey Branch Hollow and is positioned such that the longitudinal axis of the facility is parallel with the hollow. This layout was positioned in an effort to maximize mine bench top coverage (minimizing earthwork costs); however, the layout still overhangs the Honey Branch Hollow and a portion of a previously unfilled hollow to the west. The recommended layout is illustrated in Figure 2.

Using a preliminary fill cost estimate of $2 to $3 per 0.8 cubic meter (1 cubic yard), site development costs could approach approximately $50,000,000. The calculated earthwork volumes estimated for the recommended layout are listed in Table 1.

Fill Improvement

The potential total and differential settlements of the existing reclamation fill are substantial and indicate that conventional strip or pad foundations will not be suitable. The following options could produce satisfactory foundations:

- Piled rafts and piled services within existing reclamation fill,
- Excavate, select/treat and recompact reclamation fill as an engineered fill. Conventional strip or raft foundations can then be employed.

Piled Raft. Piled raft foundations can be employed to support the proposed structures with piles being taken through the reclamation fill and into the underlying rock. Piles would need to be designed for full downdrag in the fill. The nature of the reclamation fill indicates that driven piles would not be satisfactory. Bored piles would require casing through the fill. Support of structures on piled rafts would maintain their structural integrity. The substantial potential movements of the ground beneath and adjacent to the structures would cause severe damage to utility services unless these were also piled.

Excavate and Recompact. An alternative to piled support of the structures and services is the improvement of the performance of the reclamation fill, including mine bench and hollow fill. This can be achieved by excavation of the existing fill, screening out of unsuitable material and recompaction (conventional and/or dynamic compaction methods). Unsuitable material would include all organic

Table 1. Estimated Earthwork Calculations for Recommended Facility Layout

Position	Cut Volume, M^3	Fill Volume, M^3	Existing Fill Volume, M^3	Total Estimated Earthwork Vol. M^3
Layout #1	2,697,273 (3,527,900 CY)	7,580,053 (9,914,335 CY)	5,593,155 (7,315,570 CY)	18,766,360 (24,545,475 CY)

matter and rock materials in excess of a maximum size of approximately 15.2 cm (6 inches). It may be feasible to break down larger boulders to a suitable size. Recompaction using conventional means would typically be in 30.5 cm (12-inch) layers to achieve a dry density greater than 95% of the Proctor maximum dry density (ASTM D-698). Within the upper 1.8 m (6 ft) of the fill below the level of proposed foundations expansive material such as pyritic shale would be excluded. Collapse settlements of fills compacted to these requirements should not exceed 0.5% of the total fill thickness, equating to settlements of 5.1 cm (2 inches) to 25.4 cm (10 inches) on this site, depending on the location of the fill (mine bench or hollow fill). Shallow (structural) raft foundations and reinforced strip foundations can be used to support the structures on the engineered fill.

Dynamic compaction also is an acceptable method and there have been many successful projects in the region where dynamic compaction techniques have been used to densify in place mine spoils. Although improvement to depths as great as 30.5 m (100 ft) to 38.1 m (125 ft) are reported, typical depths of effective compaction are generally 12.2 m (40 ft) to 18.3 m (60 ft). Dynamic compaction consists of dropping a heavy weight from a large crane several times to create an impact force in the underlying soil mass and force the densification of the mass.

Several building failures have been cited in Eastern Kentucky where mine spoils have not been improved prior to construction. Recent engineered construction on improved mine spoils has performed favorably, however (*personal communication*).

Conclusions

This feasibility assessment addressed FBOP siting criteria and concluded the following:

1. The site is considered suitable for the construction of the USP facility, within FBOP siting criteria.
2. Any amount of settlement induced at the bedrock/fill interface by deep mine roof or pillar failure is likely to be small.
3. Insufficient acreage was found to exist for a standard maximum security compound over the former strip mine bench. However, useable acreage existed in an adjacent valley, provided a tremendous amount of earthwork is performed.
4. The reclamation fill is likely to be poorly compacted due to the coarse size of the rock debris and the resulting thick lift heights which must have been employed when filling the site.
5. In order for the reclamation fill to provide an adequate foundation for the proposed structures it must remain stable against significant volume change to minimize differential settlement.
6. An alternative to piled support of the structures and services is the improvement of the performance of the reclamation fill within the development area. This can be achieved by excavation of the existing fill, screening out of unsuitable material and recompaction using conventional and/or dynamic compaction methods.
7. Consideration should be given to locate the main prison compound on the southwestern portion of the site. This part of the site has the largest area over the former strip mine bench and thus would require the least earthwork and fill reconstruction.

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