ENVIRONMENTAL RISKS ASSOCIATED WITH COAL REFUSE IMPOUNDMENT RECLAMATION

An assessment of the possibility of an underground mine breakthrough occurring as a result of the impoundment reclamation process.

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Purpose and Scope of Investigation

The original focus of this study concerned whether the weight of soil distributed over the top of an impoundment during its reclamation would increase the likelihood of a flowable fine refuse breakthrough into an adjacent or subjacent underground mine. After several preliminary telephone interviews and literature reviews, the authors chose to expand the question to include the potential effects of the "abandonment"[1] process, which includes the construction of a cap composed of coarse coal refuse or strip material[2] over the impoundment prior to soil placement and vegetation. The thickness of the soil typically ranges from 1 to 5 feet, but that of the cap material ranges from 2 to 30 feet (Figure 1). The authors decided that the inclusion of the entire cap material in the analysis was an appropriately conservative approach to assess the breakthrough potential.

[1] Abandonment is a term used by the Mine Safety and Health Administration (MSHA) to describe the entire process of permanently eliminating the impounding capacity of a coal waste impoundment; including dewatering, capping the fine refuse material, and verifying slope and embankment stability. Since the word, "abandonment," normally has a negative connotation in the jargon of this agency (the U.S. Office of Surface Mining) the term is not used hereafter. The terms reclamation and capping will be used instead. Reclamation, like abandonment, describes the full process of dewatering, capping, top soiling, and revegetating the coal waste impoundment, while capping describes the specific step in the reclamation process where the fine waste material is covered with coarse refuse or strip material and compacted soil.

[2] Herein the authors define strip material as material obtained from any earth moving activities (including but not limited to surface mining) where coarse material is abundant.

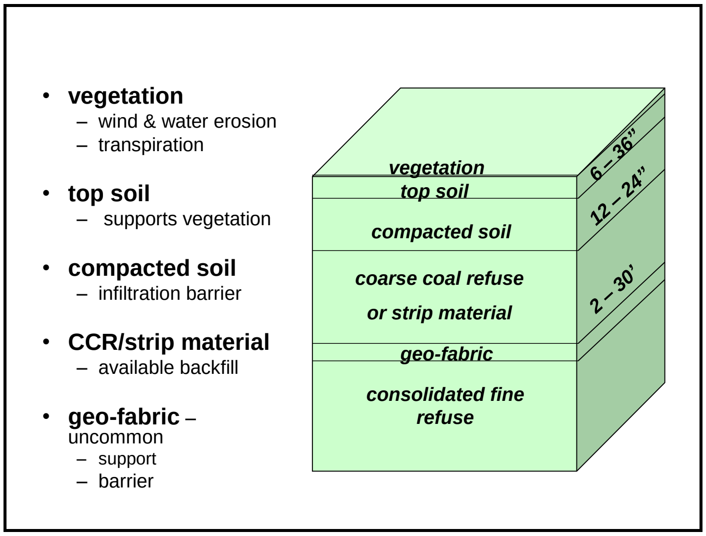

Figure 1: Sequence and thickness of materials used to cap and reclaim fine coal refuse impoundments (modified from Shinavski, 2006).

Sources of information in this investigation include: (a) interviews with members of the OSM impoundment oversight team; (b) interviews with engineers and impoundment inspectors of the U.S. Department of Labor, Mine Safety and Health Administration (MSHA); (c) interviews with state regulatory managers, engineers, and mine inspectors; (d) geotechnical engineering papers and government documents on impoundment capping and reclamation obtained through literature searches provided by Nerac, Inc.[3]; (e) various web sites on the internet; and (f) documents on impoundment design, construction, maintenance, and reclamation obtained by other means.

It is noteworthy that published information on impoundment capping is largely limited to a description of the process. The authors found very little documented data or narratives pertaining to the risks to impoundment integrity, particularly with respect to the underground mine barriers, during reclamation. Almost all information on the subject was obtained from the interviews.

Summary of the Impoundment Reclamation Process

The purpose of impoundment reclamation is to eliminate the impounding capability of the structure, prevent overland runoff from entering the impoundment, and reduce water infiltration into the fine coal refuse. Dangers associated with inactive impoundments that remain unreclaimed or otherwise unmanaged include: seepage of polluted water from the impounded area into the local groundwater; overtopping or failure of the coarse coal

[3] Nerac, Inc. provides customized information services for clients across all industrial sectors. The company combines a powerful internet search engine with a computing environment staffed with technical information specialists who use a wide variety of databases and professional contacts to provide information on request. Nerac services are delivered to OSM under contract and are managed by the WRCC Librarian.

refuse embankment and consequent flooding and pollution of streams and rivers; and underground mine breakthroughs.

The reclamation process includes the following steps:

1. Dewatering the impoundment, including eliminating the layer of clear water above the settled fine coal refuse (Figure 2) and reducing the moisture content of the fines as much as possible. The dewatering is achieved by: (a) pumping out water through existing decant pipes, slurry lines, and return water lines; (b) construction of dewatering trenches within the fine refuse (Figure 3); and (c) application of special sprinklers which spray impounded water into the air and speed evaporation. Dewatering continues during subsequent stages in the reclamation procedure via evaporation and drainage from the bottom of the impoundment or through wick drains. It is important to note, however, that the lower layers in the fine refuse may still remain saturated during the reclamation procedure.

Figure 2: Pool of clear water above settled fine refuse prior to dewatering (left) and dewatered fine refuse (right) (modified from Shinavski, 2006).

Figure 3: Dewatering ditch (modified from Shinavski, 2006).

2. Constructing drainage diversion ditches around the perimeter of the impoundment to intercept surface runoff. MSHA regulations require that these diversion ditches have an appropriate configuration and elevation around the reclaimed impoundment, determined on a case-by-case basis. New diversion ditches must be constructed if the existing ditches created at the time of impoundment construction do not meet the reclamation requirements. The regulations also dictate that the channels have a flow capacity for a 100-year, 24-hour storm and have long-term protection against erosion and deterioration. The latter stipulation is very important because neither MSHA nor OSM have jurisdiction over the structures past final bond release.

3. Capping the impoundment with coarse coal refuse or strip material. Steps in the capping process include: (a) pushing out coarse-refuse embankment material into the reservoir; (b) establishing a stable working base over the fines to support mine workers and the operation of earthmoving equipment; and (c) covering the remainder of the impoundment (Figure 4). An example design profile section of a capped upstream fine coal refuse impoundment is shown in Figure 5. It is important to note that the overall design of the impoundment cap should allow for continuing differential settlement of the fine coal refuse material. The final cap grade should not allow any ponding to occur over the reclaimed impoundment.

Figure 4: Impoundment cap construction with coarse coal refuse (left) and strip material (right) (modified from Shinavski, 2006).

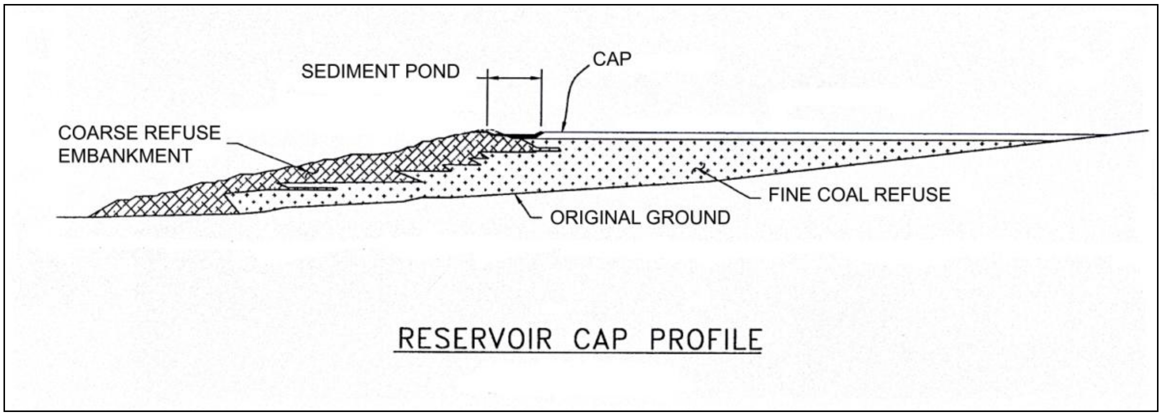

Figure 5: Example profile of a capped upstream fine coal refuse impoundment (modified from CBC Engineering and Associates, Ltd., 1998).

4. Breaching the remaining coarse-refuse embankment.

5. Finishing and grading of the impoundment cap. The backfill cap should be graded to convey runoff into the perimeter ditches and minimize infiltration into the fine refuse.

6. Sealing the decant pipe.

7. Placing top soil over the cap and vegetating the cap surface (Figure 6).

Figure 6: Aerial (left) and ground level (right) views of fully reclaimed impoundments (modified from Shinavski, 2006).

Assessment of Mine Breakthrough Potential

From information garnered from the interviews and document reviews, the authors have concluded that the occurrence of an underground-mine breakthrough during the impoundment reclamation process is theoretically possible but also preventable. Further, if a breakthrough should occur, the velocity and extent of the flow of the fine coal refuse would be markedly less than that from a breakthrough below a water-laden, active or unreclaimed inactive impoundment. This conclusion stems from a number of observations and considerations, as described below:

1. **To-date there have not been any underground mine breakthroughs resulting from or occurring during the capping of a fine coal refuse impoundment. However, relative to the total population of impoundments, very few have been reclaimed.** Impoundment status may be defined as active (i.e. still receiving coal refuse slurry from an active coal-cleaning operation), inactive, or reclaimed. Those structures that are inactive may be under a current permit, or “orphaned”. Orphan impoundments are those for which there is no responsible mine operator accountable for the structure and where the impoundment has not been properly reclaimed under MSHA standards. Generally, impoundments constructed prior to the passage of the Surface Mining Control and Reclamation Act are not reclaimed unless they are re-permitted under the permanent program or they present an apparent safety hazard to the public or imminent harm to the environment. Impoundments on bond-forfeiture sites may not be reclaimed if there is insufficient bond or insurance money to cover the cost of the work. Most impoundments that are reclaimed are capped and vegetated. Some are converted into ponds or lakes for recreational use under the experimental practice[4] program. Other impoundments are remined.

   The authors are unaware of any national or regional data bases that have complete and up-to-date information on the status or condition of all existing fine coal refuse impoundments. The MSHA National Impoundment and Refuse Pile Inventory includes a total of 632 structures that meet the size criteria for MSHA jurisdiction. However, information on the status of these impoundments is not yet complete. Wheeling Jesuit University maintains the website, http://www.coalimpoundment.com (the Coal Impoundment Location and Information System), as part of the university’s coal impoundment project. The project relies on information from state regulatory officials to build and maintain a database on impoundment locations in 6 states, PA, WV, KY, VA, TN, and OH. The focus of this project is citizen awareness and emergency responder preparedness, so impoundment status is not tracked or mentioned.

[4] An experimental practice is defined as a variance from the environmental protection performance standards of SMCRA in which an alternative post mining land use is undertaken for experimental or research purposes, if approved by the regulatory authority and the OSM Director. An experimental practice is potentially more, or at least as, environmental protective during and after mining than the standards set forth in SMCRA. The details of experimental practice applications are found under 30 CFR 785.13.

The authors have obtained the following information directly from three Appalachian state regulatory authorities: out of a total of 113 fine coal refuse impoundments in Kentucky, 6 have been reclaimed; only a "handful" from a total of 110 West Virginia impoundments has been capped; and there are 17 active fine coal refuse impoundments, 1 pre-law inactive impoundment, and zero reclaimed impoundments in Virginia. Cited reasons for the infrequency of fine coal refuse impoundment reclamation include weak regulatory controls over the reclamation process, particularly with respect to the timing of the process, and the high cost of reclamation. One interviewee expressed the opinion that some inactive impoundments that have been constructed in large watersheds are not reclaimable. Surface and subsurface drains cannot be constructed to adequately pass high discharge runoff and keep the impoundment area properly dewatered.

The absence of breakthroughs resulting from fine coal refuse impoundment reclamation to-date should not be regarded as strong evidence that such breakthroughs will not occur in the future. This is especially true, since it is not known how many reclaimed impoundments border underground mine workings.

2. **The additional vertical load exerted on a mine barrier from weight of cap material theoretically could cause an underground mine breakthrough.** Cap material is commonly comprised (from top to bottom) of 6-36 inches of top soil, 12-24 inches of compacted soil, and 2-30 feet of coarse coal refuse and/or mine spoil (Shinavski, 2006). Average densities of these materials are 95, 125, and 115 pounds per cubic foot[5] (pcf) respectively. Therefore, pressures exerted from the cap material alone could range from approximately 432 to 4032 pounds per square foot.

   The average density of fine refuse is 78 pcf. The maximum depths of fine coal refuse impoundments commonly are several hundred feet deep. However, underground-mined coal seams commonly crop out into impoundments at much shallower depths. For instance, at the Big Branch Slurry Impoundment, site of the October 11, 2000 breakthrough into the mined Coalburg Coalbed, the failed coal barrier was only about 30 feet below the water/slurry level. Considering a hypothetical impoundment where a barrier at similar depth has not yet failed, a 30-foot column of static fine refuse should exert approximately 2300 psf on the top of a barrier. In that case, a 2-30 foot cap would increase the load on the barrier between just less than 20 to almost 200 percent. If a barrier was weak enough to vertically fail under a compressive force between 2300 and 4032 psf, then the weight of the cap would be a significant factor behind the failure.

   It is important to note that the removal of the clear water layer of the impoundment and the drying of fine refuse would reduce the weight exerted on the impoundment basin. For instance, 10 feet of clear water in an impoundment

[5] 115 pcf is a rounded average between typical densities of 108 and 125 pcf for dry coarse refuse and mine spoil respectively.

would apply a pressure of 624 psf that will be removed when the reclamation process begins. It is further noteworthy that all of the above reasoning only applies in situations where overburden weight is the only factor affecting barrier stability. If the mechanisms of breakthrough include piping or gradual weakening of the barrier through weathering, then the added vertical load of a cap on the structure should not increase the likelihood of a breakthrough. Finally, the analysis only considers the effect of cap-material load under static conditions. The combined effects of cap material and dynamic loading from an earthquake may be significant if the lower layers of fine refuse remain saturated and structurally weak.

3. **A temporary increase or surge in pore-water pressure in the fines during the fine coal refuse impoundment capping process could contribute an underground mine breakthrough.** Although the authors believe this concern is worthy of consideration, the only literature found that supports it pertains to the construction of the fine coal refuse impoundments, not to their reclamation. Also, the literature focuses on the structural stability of the impoundment and worker safety and not on the potential of an underground mine breakthrough. Still, the authors feel that the mechanisms that can affect structural stability and worker safety might also catalyze a mine breakthrough.

   Huang et al. (1987) and Zeng et al. (1998) studied the combined effects of the slurry impoundment construction process and dynamic loading. They recommended a slow and carefully monitored upstream impoundment construction procedure. They claimed that this approach was necessary to provide adequate time for the development of enough consolidated strength in the fine refuse to resist pore-pressure increases during earthquakes and ensure dynamic stability of the structure. In the interest of worker safety, Thacker (2008) emphasized the need to at times redirect impoundment construction away from the top of the coarse-refuse embankment to allow dissipation of excess pore-water pressure in the fine refuse. If the construction proceeds too rapidly, the dumping of coarse refuse can increase pore pressures, and consequently mobilize the wet fine refuse and destabilize the embankment. The consequence of excessively rapid slurry impoundment construction is exemplified by three embankment failures at the Robena Slurry Impoundment in Masontown, PA in February 1997, March 2000, and September 2000 (Figure 7). All three were diagnosed as having resulted from excessive rates of coarse-refuse "push-out" up over the fines and consequent pore-water-pressure mobilization (Ibrahim, 1997, and 2000a and 2000b). An additional factor in the 1997 incident was the thickness of the push-out, which was over 20 feet in some places, and the inability of the fine refuse to support it.

Figure 7: 1997 tension cracks (left) and 2000 slope failure in coarse refuse embankment of the Robena Slurry Impoundment in Masontown, PA (Smith et al., 2002).

These challenges are analogous to problems that can occur during one of the phases of impoundment reclamation, i.e. placement or “pushing out” of cap material over the fine refuse. The placement procedure begins with the push-out of coarse-refuse embankment material into the reservoir and establishment of a working base over the fines. The remainder of the impoundment is then covered. Several interviews with MSHA inspectors have highlighted excessive pore-water pressure build-up and consequent dangerous instabilities that may occur when the placement process takes place too rapidly or prior to adequate dewatering and settlement of the fines. Pore-pressure increases that result from impoundment capping tend to be relieved upward by the upwelling or bulging up of the fine refuse in front of the work pad. However, where there is a structurally weak underground mine barrier or plugged mine portal at depth, it is conceivable that a pore-pressure increase in the fines from premature or rapid placement of cap material can also be relieved downward via a breakthrough.

4. **If a breakthrough into an underground mine did occur, the fine coal refuse would experience viscous flow and the rate and distance of travel would be limited.** In 2005, OSM conducted a study into the flowability of impounded coal refuse (Michael et al.). The purpose of the study was to review current knowledge applicable to the potential flow characteristics of impounded coal refuse. The review explored two interrelated issues: (a) given the occurrence of a breakthrough event that would result in a potential flow conduit between an underground mine and an impoundment, should we expect coal refuse to flow into the mine? And (b) if the refuse would flow, what would be the nature (e.g. velocity and extent) of that flow?

   Following the interviews and literature review, the investigators could not make assurances that fine refuse in all (or even the majority of) existing refuse impoundments would not flow through breakthroughs into an underground mine. One basis for their concern was the slow rate of consolidated strength development that takes place in the fine refuse. They were also concerned about the influence of pore water pressure in the fine refuse and potentiality of static liquefaction; and the sense that at least some impoundments are not constructed to adequately allow drainage of excess water from the fines. However, the study did not find any empirical data on the potential flow characteristics of coal-refuse. It became apparent that the flow behavior, or rheology, of viscous fluids is influenced by a complex interrelationship among a number of factors. There was some indication that one particular flow model, called "Bingham Plastic," may be applicable to coal-refuse flow. But the investigators emphasized that a model is only a relationship among constants and variables, and cannot tell us how refuse in a specific, existing impoundment might respond to an opening to an underground mine.

It is important to note that the focus of the 2005 investigation was not on fine coal refuse impoundments being or having been reclaimed. A vital step in the capping procedure is the dewatering of the reservoir. This requires removing the clear water layer above the fine refuse. It also necessitates reducing the moisture content of the fine refuse for the material to have sufficient shear strength to support a working base for the capping activity. Even if the lower layers remain saturated during reclamation, less fine refuse will flow into the mine post breakthrough and the fine refuse that will enter the mine will flow less extensively. Environmentally catastrophic events, on the order of the 2000 Big Branch Slurry Impoundment breakthrough in Martin County, KY, are much more likely to recur on sites occupied by unreclaimed fine coal refuse impoundments.[6]

5. **Catastrophic breakthroughs of impounded fine coal refuse into underground mines are preventable.** Means of avoiding breakthroughs during the reclamation process can be applied at any point during the life of the impoundment. Nearby active and abandoned underground mine works can be identified and their boundaries located relative to the shape of the reservoir. In the case of impoundments not yet constructed, open entries that intersect the structure can be plugged and mine barriers enhanced to meet imposed loads throughout the life of the structure. For existing, inactive impoundments where open entries and mine barriers cannot be enhanced it is prudent to assume that all minable coal seams have been mined unless proven otherwise.

   Prior to reclamation, additional loads imposed from the proposed cap and the competence of plugged entries and mine barriers can be estimated and compared. There are tools available or under development that can help identify and demarcate the boundaries of underground mine works in cases where mine maps

[6] Fortunately regulatory authorities have taken steps to prevent future breakthroughs in active and proposed impoundments. In July 2001 the OSM Lexington Field Office, in cooperation with the OSM Appalachian Region, regional MSHA authorities, and the state regulatory authorities of Kentucky, Virginia, and West Virginia, authored "Criteria for Evaluating the Potential for Impoundment Leaks into Underground Mines (Existing and Proposed Impoundments)" (OSM et al., 2001). This guidance document provides detailed information on evaluating breakthrough potential for state and federal regulatory officials. Impoundment reclamation is not discussed in the document.

are inaccurate or unavailable. The MSHA has recently published the results of the "Mine Void Detection Demonstration Projects." The project was funded in response to near fatalities of several miners trapped in the Que Creek works by flood water entering from an inaccurately mapped adjacent mine. Fifteen geophysical mine-void-detection techniques were tested with various degrees of success. The more promising methodologies that are also most applicable to abandoned mine detection near impoundments include surface high-resolution seismic reflection and reverse vertical seismic profiling. Most reliable were two additional (non-geophysical) technologies tested in conjunction with several geophysical applications: Downhole laser and sonar imaging for air-filled and water-filled mines respectively. After a mine void has been located and accessed through a borehole, these imaging techniques can determine the dimensions, orientation, and interior condition of the mine up to several hundred feet.

Application of the technologies discussed above may not ensure that all underground mines proximate to the fine refuse impoundment are accounted for. However, there remain several measures that can be taken during reclamation that can further minimize breakthrough potential: these include dewatering the fine refuse slurry reservoir and monitoring pore-water pressures in the fines. Dewatering the reservoir is the one activity in the reclamation process that reduces the potential for: (1) failure or breaching of the coarse refuse embankment; (2) failure of the cap working base; and (3) breakthroughs into underground mine voids. Impoundments most likely to experience hazardous and environmentally damaging breakthroughs are those which are older and cannot be safely reclaimed in the first place. That is because the saturated fines cannot be adequately dewatered prior to safe and effective capping. This condition would apply to some structures that are impounding discharged ground water. Where reclamation is feasible, dewatering the fine refuse should be maximized in order to limit or eliminate the volume of saturated fines in the lower levels of the reservoir.

It is noteworthy that several interviewees expressed concern that the fine refuse of reclaimed and bond-released impoundments may become re-saturated from seepage through the cap material, following (1) differential settlement and ponding on the cap or (2) failure of the drainage diversion system. Re-saturation could change the equilibrium or loading on an underground mine barrier. It would also increase the volume of flowable fine coal refuse. In the absence of data or applicable case histories, the authors cannot determine the validity of the latter concern. Slurry dewatering is part of a consolidation process that also involves compaction and void-space reduction. Logically, the low permeability of the dewatered refuse should to some degree inhibit a re-introduction of moisture into the reservoir. Any consolidation of the fine refuse that has occurred should also reduce the risk of re-saturation. In either case, minimization of re-saturation potential is achieved by monitoring and carefully assessing the stability of the multi-layer, infiltration-reducing cap and the functionality of the drainage structures prior to final bond release.

Finally, the potential build-up of pore-water pressure can be monitored during the capping process. For instance, piezometers were installed at the Robena impoundment after the several embankment failures. A particularly notable example is the employment of piezometers during the construction of an excess spoil fill on top of a capped impoundment in Raleigh County, West Virginia (Figure 8). Their purpose is to monitor pore pressures in the fine refuse as the toe of the valley fill approaches the impoundment embankment. The construction plan includes a provision that fill placement will be adjusted (i.e. delayed or redirected) to allow time for pore-pressure dissipation or the construction of horizontal or vertical drains if and when piezometer recordings above a warning level occur. Although the focus of concern is the structural integrity of the embankment and fine refuse, it is noteworthy that the reservoir is in contact with underground mine portals that were blocked and grouted. To-date pore pressures in the fine refuse have not risen to the warning levels; and failures in the cap, embankment, or a mine portal have not occurred.[7]

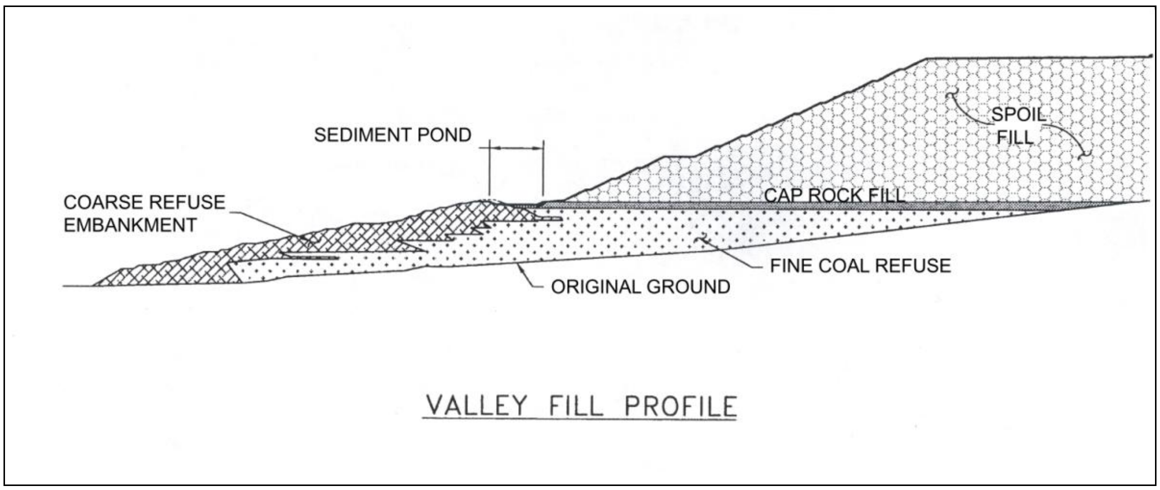

Figure 8: Design profile of excess spoil fill positioned above a capped upstream coal refuse slurry impoundment (modified from CBC Engineers and Associates, Ltd., 1998).

Conclusions

The authors have concluded that an underground mine breakthrough during impoundment reclamation is a theoretical but remote possibility based on the following considerations: (a) there is insufficient empirical evidence to the contrary from the performance of existing reclaimed impoundments; (b) cap material may add extra weight to the burden above a plugged underground mine portal or barrier; (c) saturated, liquefiable slurry may exist in the lower levels of the impoundment reservoir during and

[7] The authors use this example to encourage close monitoring of pore pressures during the capping process, not to endorse the practice of constructing excess spoil fills on top of reclaimed coal refuse slurry impoundments.

after reclamation; and (d) it is possible that the capping process could result in a temporary surge in pore pressure in the fine refuse slurry that, by supplementing an existing static load, is significant enough to punch through a weak barrier or sealed portal.

The authors do not possess enough information to estimate the probability of a "reclamation breakthrough" taking place in the future. However, it is felt that a catastrophic breakthrough on the order of the 2000 Big Branch Slurry Impoundment event is very unlikely. The dewatering process necessary for impoundment capping should significantly decrease the rate and extent of slurry flow. Finally, the authors believe a breakthrough of any magnitude is preventable, primarily through effective dewatering of the impoundment reservoir and careful monitoring of pore pressures during the capping process.

It is the authors strong opinion that reclaiming (in comparison to not reclaiming) a fine coal refuse impoundment decreases the risk of breakthrough. The process dewaters the fine refuse and decreases infiltration into the reservoir, thereby reducing hydrostatic pressure and providing a more stable environment generally. Leaving a site unreclaimed has its own inherent risks. Failure of drainage diversion ditches around an inactive, unreclaimed impoundment can lead to increased flow into the reservoir and aggravate hydrostatic loading on the coarse-refuse embankment as well as a mine barrier. Under these conditions, the impoundment's stability is greatly jeopardized during large precipitation events or the occurrence of other external forces (earthquakes, rodents tunneling into the coarse refuse, etc.).

Further research would be necessary to fully access long term stability of slurry impoundments. Future study should be directed at all phases of impoundment construction, including reclamation, but should also include analysis of both inactive and reclaimed structures.

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