GUIDANCE TO PLAN, DESIGN, EVALUATE AND INSPECT ABOVE- DRAINGAGE COALMINES OUTCROP BARRIERS TO PREVENT BLOWOUTS

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ABSTRACT

Outcrop barrier pillars serve to keep mine personnel and the public safe from sudden uncontrolled flows of water accumulated in active and abandoned underground mine workings. When an outcrop barrier fails, the result is an outbreak of water to the surface and is termed as blowout. Mine blowouts are associated with above-drainage mines and can occur through the coal outcrop and sealed portals. A blowout is often catastrophic, a threat to the people on the surface living or working in the path of a potentially large flood. In addition, blowouts can destroy homes, cause landslides and severe erosion and release pollution and acid mine drainage. This paper provides guidance on the planning, design, evaluation and inspection of barriers to address the problem of mine blowouts associated with above-drainage coal mines.

INTRODUCTION

In 1995, pressure from a water-filled abandoned underground coalmine in Virginia caused the sudden release of mine pool water through a "blowout" in the hillside above the mine. The blowout resulted in the fatality of a person living in a house down-slope of the blowout. A subsequent survey to evaluate the scope of the blowout problem was led by Office of Surface Mining (OSM) (Office of Surface Mining, 1996). It included representatives from several Federal and State agencies, the mining industry, mining consultants, and universities. This survey found that there were several other, non-fatal, blowouts in the past. As a result of this review of the available information on blowouts, the survey team recommended that a guidance manual[1] be developed on planning, designing, evaluating, and inspecting outcrop barriers for above drainage coal mines applicable to both active coalmines which will be abandoned in the future and existing abandoned mines. This paper summarizes the major features of the manual which provides technical and engineering details on how to plan, design, evaluate, and inspect outcrop barriers to prevent blowouts in the future at above-drainage coalmines.

BACKGROUND

Prior to the passage of the Surface Mining Control and Reclamation Act of 1977 (SMCRA), above-drainage underground coalmining in the Appalachian Coalfields was done "up-dip" where feasible, to allow water entering the mine to flow out by gravity to save pumping costs (Figure 1).

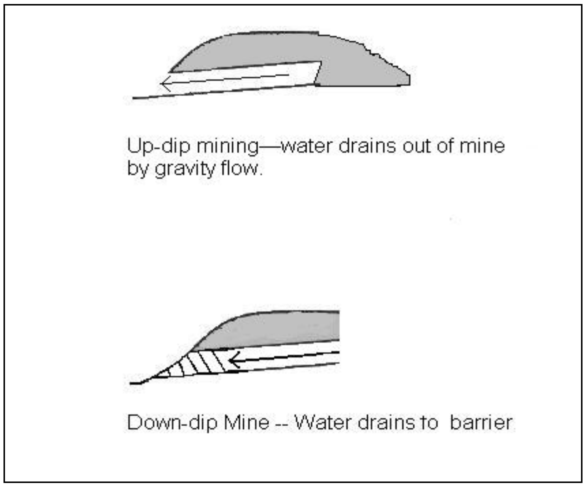

Figure 1. Up-Dip Mining and Down-Dip Mining

However, after the implementation of SMCRA, this practice decreased due to environmental considerations and the number of down-dip mines increased. Several up-dip mines still do exist. After a down-dip mine closes and the dewatering activity ceases, the mine workings and the overburden become flooded. At several locations, such water filled abandoned mines are used as reservoirs for municipal water supplies (Lessing and Hobba, 1981; Mull et al., 1981). However, these flooded mines also become a source of potential blowouts. Without adequate coal barriers, seepage from the water-filled mines may result in landslides and in several cases catastrophic failure in the form of blowouts at the outcrop barrier or mine seal.

In order to understand what causes blowouts, the failure mechanisms needs to be understood. The review of historical blowouts indicates that most failures occur in

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[1] The manual will be released January 2007.

the immediate overburden of the flooded area. Therefore, the overlying strata along with the coal barrier must be evaluated for potential failure.

FACTORS AFFECTING BARRIER BLOWOUTS

The following geologic, hydrologic, and mining factors can potentially contribute to blowout failure:

- Overburden Thickness: The thickness as well as the condition of the overburden plays an important role in the design of an outcrop barrier. After mine closure and inundation, the overburden may be uplifted by hydraulic forces. If the overburden is shallow, there is a possibility of seepage over the top of the coal, with water draining through the overburden. This may eventually cause failure of the overburden if the buoyancy forces are greater than the resisting forces.
- Physical Properties of Overburden (Strength, Permeability): The two most important properties of the overburden that are directly related to blowout potential are strength and permeability. The permeability of the overburden strata usually increases after mining due to opening of joints and fractures. The increase in permeability weakens the overburden strength, which can cause potential failure.
- Surface Slope and Soil Condition: Under steep slopes, poor soils are prone to landslides when saturated. A landslide may trigger a blowout. Conversely, shallow slopes, which are common in side valleys, may result in thin overburden conditions which can promote leakage if the barrier design does not consider slope.
- Hydrostatic head: The maximum potential head behind an outcrop barrier is estimated by finding the difference in elevation between the outcrop barrier and the highest point of elevation of surface water (see Figure 2)

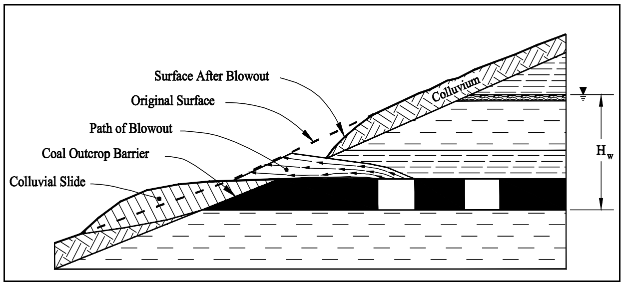


Figure 2. Example of Blowout Potential Caused by Hydrostatic Head. (Adapted from Bukovansky et al., 1983)

  In some cases, where the strata are porous or where secondary mining has taken place, increased water flow combined with high pore pressure within the strata may increase the hydrostatic head. The outcrop barrier can fail if it is not designed to sustain the estimated head taking all these factors into consideration. That increase in head, while temporary, could initiate failure in a coal outcrop barrier. As a result, it is necessary that mine planning include all reasonable provisions for known geologic and hydrogeologic factors and include some safety factor for unanticipated changes in mine conditions.
- Coal Characteristics: Weak spots in the outcrop barrier due to fractures or weathering may fail and expand into direct openings as the hydrostatic pressure increases. Blasting near the outcrop barrier can also weaken the barrier.
- Proximity of Active and Abandoned Flooded Mines: Hydrogeologic conditions can affect the hydrostatic head of a mine pool. Although the difference in elevation between the highest and lowest elevations in the mine workings will generally define the head potential (hydrostatic head) for a given mine, the total head achieved within a mine may be significantly greater than that estimated by simply calculating the elevation differential. An under estimation of the head potential can result from unknown or unforeseen factors, such as hydraulic connection to flooded mine working above, or surface water entering the mine through natural fractures or fractures caused by mine subsidence. Also, any catastrophic massive roof failure can instantaneously increase static head (i.e., short term surge) in a flooded mine.
- Roof falls: can create rock debris in the mine, drainage pipes in wet seals can become blocked, resulting in mine flooding. All mines intersect fractures or weathered bedrock as the mine workings approach the outcrop, which enhances recharge from water stored in the overburden aquifer. Almost all of the rock and coal within approximately 100 feet of

the ground surface is weathered and fractured, which can drastically reduce material strength and integrity. Roof fall in the entries near the outcrop barrier can also create openings to the surface and/or fracture the overburden thereby releasing the impounded water, causing a blowout.

- Multiple seam mining: can create conditions for potential blowouts in the lower seam if the upper seam is flooded, because of higher hydrostatic head.
- Partial mining: near the barrier can weaken pillars, which can fail and cause the overburden to collapse, resulting in a blowout.

The investigative report by OSM (Office of Surface Mining, 1996) revealed that failure mechanisms associated with outcrop barrier blowouts usually develop when one or more of the influencing factors described above combine. The most probable factors are illustrated in Figure 3 which shows the relationship of several but not all the factors that can affect mine blowouts in the underground mines.

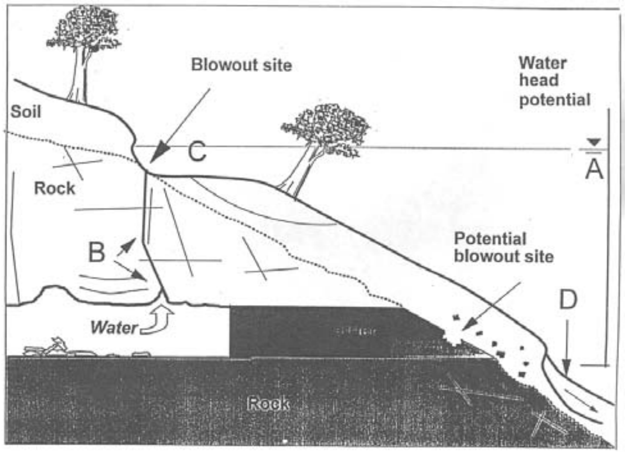


Figure 3. Factors that Can Cause Blowouts.

The reader should note that there are other scenarios leading to mine blowout situations that are not represented in this example. The hydrostatic head potential (A) represent the level to which water could rise in the mine. If water was allowed to rise to the maximum head potential shown, it would fill the void space in the mine, and would also have enough head to exit the mine along highly-conductive pathways in the overburden along the hill slope. If near-surface fractures are sufficiently interconnected (B), a pathway may result that will allow water to discharge from the mine. A seep or spring may develop, leading to slope saturation, and eventually slumps or landslides. In the more severe case shown here, a blowout occurs when the water pressure exceeds the lithic support of the coal roof (C). Springs or seeps can also form along the outcrop of rider seams a short distance above the elevation of the main seam being mined. At the coal barrier, water under pressure can move through highly-conducive cleats or joints in coal. If steady and substantial leakage occurs, earth movement such as landslides and slumps can result (D). In extreme cases where the coal barrier width is inadequate, water may move through the cleats or fracture with sufficient velocity to cause erosion of the barrier (Piping), resulting in an outcrop barrier blowout. The blowout may also occur along the contact of the roof or floor rock and the coal seam if the surrounding rock is incompetent. The thickness of the soil along the hill slopes can be quite variable, and cannot always be accurately estimated without performing site-specific tests, such as soil borings. Estimating soil cover by examining the surface topography or slope angles from maps is not recommended. Thin or non-cohesive soils are poor barriers to water movement, especially when saturated, and may contribute to blowout situations. Therefore, the soil cover should not be considered an adequate hydraulic barrier.

FAILURE MECHANISMS

Some examples of possible failure mechanisms include:

- Overburden blowout/hydrostatic lift: The material above the outcrop barrier may be lifted up due to buoyancy caused by hydrostatic pressure. As a result the effective overburden weight which is resisting this upward lift decreases and causes the blowout (see Figure 2).
- Overtopping blowout: A sudden roof fall in an entry near the outcrop in shallow overburden could cause an opening or cracks to the surface. The impounded water will suddenly gush out causing blowout (see Figure 4).

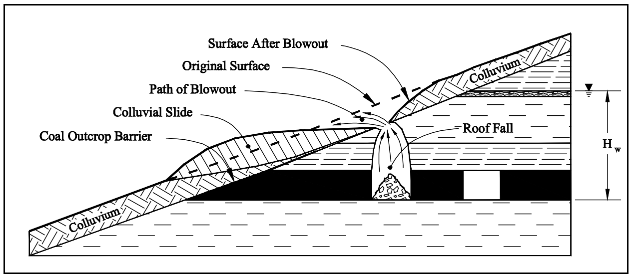


Figure 4. Blowout Caused by Roof Fall.

- Piping: The presence of geologic discontinuities in the overburden (such as fractures) near the surface can provide pathways for water flow (piping) that can gradually compromise outcrop barrier stability. Mine water will seek the path of least resistance to the surface if the hydrostatic head is higher than the surface elevation of the edge of the barrier pillar. Possible pathways to the surface can include any normal planes of weakness such as intraformational joints, stress-relief joints, and bedding interfaces. Movement of water (piping) through these interfaces will gradually increase the opening and cause a blowout (see Figure 5).

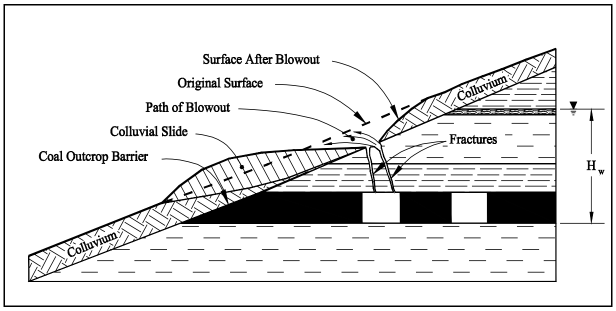


Figure 5. Blowout Caused by Piping.

- Slide: A surface slide associated with slope failure is another cause of outcrop barrier instability. Mining near an outcrop, and the creation of an outcrop barrier, influences the stress distribution in the adjacent slope. Steep slopes may be marginally stable under natural conditions, and any changes in the stress distribution can add to slope instability, leading to large landslide failure. Any geologic condition which supports the flow of water from behind an outcrop barrier to the surface will cause water saturation. This saturation and freeze- thaw cycles can further weaken the slopes. These slides do not affect the bedrock, and therefore the outcrop barrier, directly, but they do remove overlying mass and can increase the risk of overburden blowouts.
- Sliding wedge failure: When the sliding forces against the wedge caused by the hydrostatic head are greater than the resisting forces from the weight of overburden material over the barrier, the barrier pillars near the outcrop can slide and cause blowout. (see Figure 6)

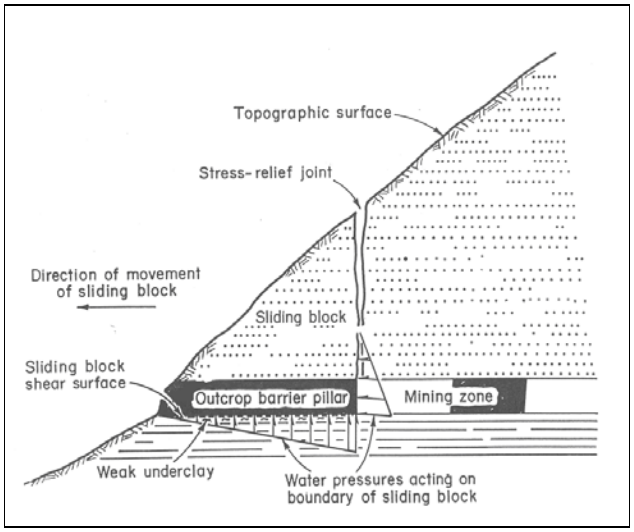


Figure 6. Blowout Caused by Sliding Wedge Failure. (Adapted from Bukovansky et al., 1983.)

Post –blowout studies (OSM et al., 1996, Geological Services, Inc., 1988 and Pearson et al., 1981) coupled with statements from witnesses; reveal that the primary cause of blowouts is overburden failure caused by hydrostatic lift. It is characterized by the forcible ejection of mine water through a weak joint system originating within the mine void and traversing immediately atop of the coal barrier. Analysis of this phenomena (uplift) indicates that the zone of weakness lies in the near vertically inclined fracture and joint system. Therefore, planning for long term containment must be made in order to maintain coal barrier's safety and integrity. The technical guidance manual prepared by OSM covers specific engineering practices and suggestions to assist in the design and evaluation of outcrop barriers.

REGULATORY GUIDELINES FOR COALMINE OUTCROP BARRIERS

Federal regulations do not provide any guidelines to plan, design, and evaluate the outcrop barriers. However, several state regulatory agencies in the Appalachian Coalfield, which are having barrier blowout problems, have recognized the need for such guidelines and have incorporated them in their regulations. Some of these guidelines are summarized below:

- All states require that weathered and fractured rocks and the outcrop coal should not be included when sizing the barrier width.

- The State of Virginia (Virginia Department of Mines, Mineral and energy, 1995) has outlined three acceptable or adequate methods for assessing the potential blowouts:

1. Installation of down-dip dewatering devices to prevent water accumulation in the low lying mined-out areas where blowout potential could develop.
2. A minimum barrier of 100 feet of vertical overburden (see Figure 7) or a horizontal barrier equal to 50 feet plus the anticipated head at the point of the barrier (the barrier of greatest width would be required when considering both the horizontal and vertical components).
3. If an onsite investigation is made, a barrier width smaller than the rule of thumb can be used.

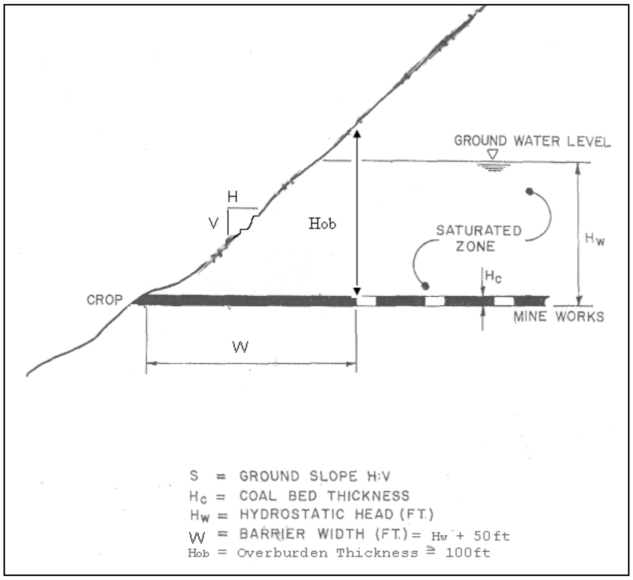


Figure 7. Illustration of Empirical Formula.

DESIGN OF OUTCROP BARRIERS

Empirical Guidelines:

1. Mine Inspector's or Ashley's Formula:

Ashley's Formula (Ashley, 1930) was developed in Pennsylvania to design the size of outcrop coal barriers to impound water and protect active workings from inundation in the Anthracite mines. The minimum barrier width is expressed as:

$$\mathbf{W = 20 + 4T + 0.1D} \qquad \textbf{Equation 1}$$

Where

W = barrier width, feet
T = mining height, feet
D = maximum water head possible, feet

This formula has been used to design the size of outcrop coal barriers in Pennsylvania; however, it does not take into account many factors which influence the stability of the outcrop barrier. Therefore, its acceptance today is questionable.

2. Rule of Thumb Formula:

This formula is mostly used to compute the width of coal barrier width in the coalfields (see Figure 7).

$$\mathbf{W = 50 + H} \qquad \textbf{Equation 2}$$

Where

W = barrier width, feet
H = the maximum water head, feet

Geologic features, such as faults, slope failures, stress relief along joints, weathering, etc., can facilitate leakage across the barriers. Therefore, wherever such features exist, they should not be included as part of the barrier width. Second mining (retreat mining/pillaring) near the outcrop barrier must not be done and the supporting pillars near the outcrop must be designed for long term stability.

3. Site Specific Design for Outcrop Barriers:

A site specific design incorporates a comprehensive assessment of the various influencing factors, such as the geology and structure of the site, weathering, erosion, faulting, mine and slope stability, hydrogeologic factors, and other relevant considerations.

The 1981 report, Outcrop Barrier Design Guidelines for Appalachian Coal Mines, prepared by Dames and Moore under contract to the US Bureau of Mines (Pearson et al., 1981) is considered the most comprehensive compilation on outcrop barriers. The report describes and analyzes two major causes of blowouts:

1. Vertical displacement: When the force exerted by the hydrostatic head uplifts weak, fractured overburden strata. (see Figure 2). Blowouts of this type are common based on recent investigation reports, and

2. Wedge type failure: When the force exerted by the hydrostatic head on the overburden strata above the barrier causes the barrier to slide and blowout. (see Figure 6). Blowouts of this type are not common based on the recent investigation reports.

In addition, the report recognizes a third cause:

3. Surface Landslides: Surface landslides may result from surface slope failures. Slope failures that result in landslides can cause a barrier blowout either acting alone or in combination with the other two failure modes discussed above. Landslides near the outcrop barrier can be related to saturated conditions caused by seepage of impounded water. These slides do not affect bedrock, and therefore the outcrop barrier, directly, but they do remove overlying mass and can increase the risk of overburden or overtopping blowout. Therefore, it is important to recognize that since these conditions can only be discovered by on-site analysis, the results of field and laboratory investigation should be incorporated into blowout analysis.

The following discussion (with examples) of site-specific methods of analysis of barrier design demonstrates that different design methods can yield varying results. However, due to potential danger to the public, the method that uses site specific influencing factors and results in a stable condition should be used. It is important to note that the following examples, calculations and references are only intended to serve as an aid to the user.

ANALYSIS OF OUTCROP BARRIER FAILURE BY HYDROSTATIC LIFT OF OVERBURDEN

Post-blowout studies reveal that when an overburden blowout occurs, generally, the forceful release of water is in a vertical direction instead of horizontally (see Figure 2), (Geological Consulting Services Inc., 1988 and Pearson et al., 1981). The reports indicate that the zone of weakness lies in the near vertically inclined fracture and joint system.

The purpose of performing an analysis of an overburden blowout by hydrostatic lift is to determine the point beyond which the upward buoyant forces of the impounded water exceed the effective weight of the overlying weathered and fractured overburden.

The following examples were taken from a report of an actual investigation performed by Geological Consulting Services Inc. (GCSI) in 1988. The results obtained from GCSI report was compared to the results obtained using the Dames and Moore (Pearson et al., 1981) and the rule of thumb (empirical) formulas.

The analysis essentially calls for the determination of the overburden and coal thickness necessary to offset the anticipated buoyant forces and hydrostatic head of the water impounded behind the barrier. This is assumed to exist at the mining side (see Figure 8) of the coal barrier, where most of the observed failures appear to have been initiated. The combined thickness of the overburden and the coal, together with a surface slope factor, determine the outcrop barrier width.

In this analysis the controlling factors are the unit weights of the water and overburden material, the hydrostatic head, and the surface slope. Also, the cohesion and friction factors, although always present, are not considered. Because of these assumptions, the results are deemed to be conservative.

The following formula developed by GCSI is used to determine the outcrop barrier width required to protect against a blowout caused by overburden failure by hydrostatic lift (see Figure 8).

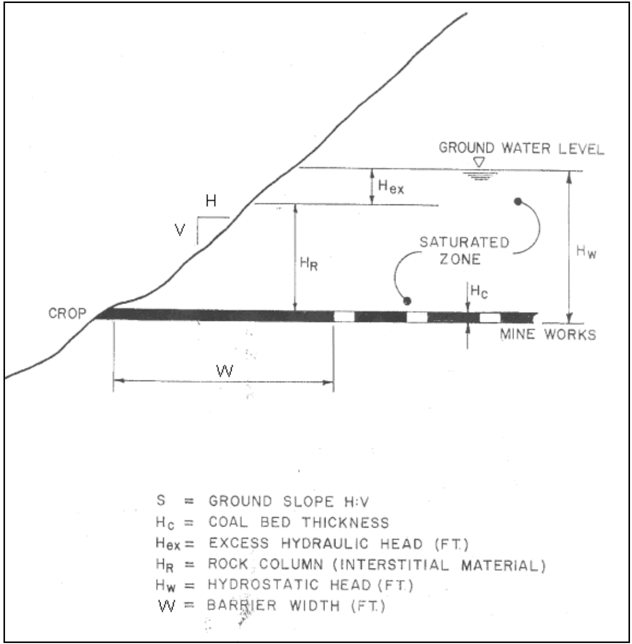


Figure 8. Barrier Design Using GCSI Formula.

$$W = S\,(0.385H_c + 0.48H_w) \qquad \textbf{Equation 3}$$

Where:

W = Barrier Width, ft
S = Slope (H:V)
H_c = Coal Thickness, ft
H_w = Total Hydrostatic Head, ft

Solving for W (barrier width) determines the equilibrium state of the buoyant forces against the thickness of coal and the overburden. A factor for safety of at least 1.5 is recommended.

Example 1:

Assume that in designing an outcrop barrier, W, the following values are given:

Coal thickness = 7 feet
Hydrostatic head = 31 feet
Surface Slope H:V = 2.24:1

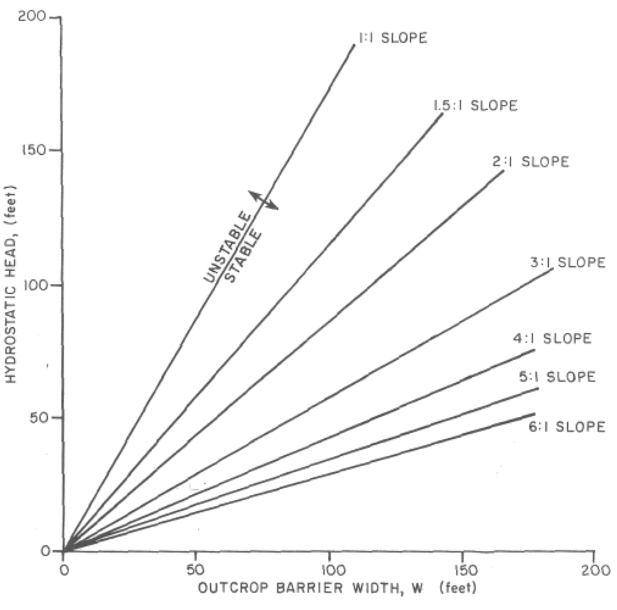
Using the Equation 3, the calculated outcrop barrier width will be

W = 2.24 x (0.385 x 7 + 0.48 x 31)
= 2.24 x 17.575 = 39.36 or 39 feet

This represents the barrier width at the point of equilibrium. Next we multiply this result by1.5 to add a safety factor, to obtain the final barrier width.

W = 39 x 1.5 = 58.5 or 59 ft.

The results obtained using the same data and different formulas are compared below; the 1.5 safety factor is also included in the Dames and Moore (Pearson et al., 1981) Graph (see Figure 9), and the Rule of Thumb result incorporates its own safety factor:



NOTE:
FOR EACH OVERBURDEN SLOPE, THE UNSTABLE BARRIER WIDTH IS ABOVE THE LINE AND THE STABLE BARRIER WIDTH IS BELOW THE LINE.

Figure 9. Barrier Design Using Dames and Moore Formula. (Adapted from Pearson et al., 1981).

- GCSI Equation (Equation 3, see Figure 8) barrier width = **59 feet**
- Dames and Moore (Pearson et al., 1981) Graph (see Figure 9) barrier width = **65 feet**
- Rule of Thumb Equation (Equation 2, see Figure 7) barrier width = **81 feet**

As discussed earlier, the Rule of Thumb equation was derived empirically. Because of this, one would expect a more conservative value than for site-specific design methods, such as those used by GSCI or Dames and Moore. It is important to note that the empirical method does not consider actual field conditions; therefore, its use can mislead the designer. The following example provides evidence of the shortfall of relying on the rule of thumb method.

Example 2:

With the same assumption as above for coal thickness and hydrostatic head, i.e. 7 feet and 31 feet respectively, but with a more gentle slope (H:V) ratio of 5:1, which is 20% slope, the values for W are as follows:

Using GCSI Equation
W = 5 x (0.385 x 7 + 0.48 x 31) = 87.8 or 88 feet
Providing for a 1.5 safety factor,
W = 88 x 1.5 = 132 feet

Comparing this result to those obtained from the graph (see Figure 9) developed by Dames and Moore, and the rule of Thumb Formula (with included safety factors) are given below:

- barrier width using GCSI formula = **132 feet**
- barrier width using Dames and Moore (Pearson et al., 1981) graph = **150 feet**
- barrier width using Rule of Thumb formula = **81 feet**

The Rule of Thumb barrier width is significantly smaller than the site design barrier widths using other two approaches, these results indicate the potential hazards of omitting a site investigation and relying solely on the rule of thumb approach.

ANALYSIS OF OUTCROP BARRIER FAILURE BY SLIDING WEDGE STABILITY

A Wedge Stability analysis (see Figure 6) is used here:

The assumptions for this analysis are as follows:

- The study zone is saturated vertically to the point of hydrostatic head (this is a conservative assumption),

- Joint patterns and stress relief fractures lie vertically,
- Bedding planes are approximately horizontal,
- There is no friction within the vertically inclined joints or fractures,
- The sliding surface will be the one demonstrating the lowest angle of internal friction,
- The angle of internal friction for the bedrock is assumed to be 50 degrees,
- The angle of internal friction for the coal is assumed to be 35 degrees,
- The angle of internal friction for the coal/underclay contact plane to be 29 degrees

The following equation developed by GCSI using the above assumption is used to determine the outcrop barrier width:

$$31.2H_w^2 = [51.3(W^2/S)+(17.6H_cW)+ 8.8(Hc^2S)]\mathrm{Tan}\Phi \qquad \textbf{Equation 4}$$

Where:

H_w = Hydrostatic Head in feet
W = Barrier Width in feet
S = Surface Slope H:V
H_c = Coal Seam Thickness in feet
Φ = Internal Angle of Friction (29 degrees)

Example 3:

The following example demonstrates the application of this formula. The parameters used in this example are the same as used in Example 1, plus angle of internal friction of 29^o is added to equation 4.

$$31.2 \times 31^2 = [\ 51.3\ (\ W^2/2.24) + (17.6x7)W + (8.8 \times 7^2 \times 2.24)]\ \mathrm{Tan}\ 29^o$$

W (barrier width) can be determined by solving the quadratic equation or by a trial and error method.
W (barrier width) represents the equilibrium state when the hydrostatic forces acting on the outcrop barrier are equal to resisting sliding forces. The barrier width thus obtained is multiplied by a safety factor of 1.5.

Solving for W using the trial and error method, results in a barrier width, W, of approximately 46 feet. When a 1.5 safety factor is added W becomes 69 feet
This result is compared with those obtained from Dames and Moore (Pearson et al., 1981) graph (see Figure 8), and the Rule of thumb formula:

- barrier width using GSCI formula = **69 feet**
- barrier width using Dames and Moore (Person et al., 1981) graph = **65 feet**
- barrier width using Rule of thumb formula = **81 feet**

EVALUATION OF EXISTING OUTCROP BARRIERS

Several factors must be considered when evaluating existing outcrop barriers. One must consider geology, hydrologic systems, development of hydrostatic forces, effects of mining from both underground and surface methods, and dynamic forces occurring as a result of a combination of all these factors. Therefore, anyone evaluating, designing, or developing outcrop barriers must develop a working knowledge of these forces and evaluate their effect on the outcrop barriers.

Traditionally, outcrop coal barriers were designed to provide a sufficient thickness of overburden for mine entry stability. Barriers designed for this purpose perform well during active mining. But after mines are closed, water may accumulate behind these barriers and create a potential hazard. This potential is compounded when dewatering ceases as a result of mine abandonment and a hydrostatic head develops. Several factors must be considered when evaluating outcrop barriers; they are discussed below:

Barrier thickness:

- Determine barrier thickness as accurately as possible considering the various failure modes.
- Exclude any thickness of weathered coal near the outcrop.
- Show the barrier on mine maps as accurately as possible considering coal elevations, the outcrop contour lines, and barrier design.
- Adjust the width of the barrier for surface slope to ensure adequate barrier width.
  Because the thickness of the overburden at the inner edge of the barrier for gentle surface slope may be the controlling factor to determine the width of the barrier.

Overburden depth:

- Determine the overburden depth above the inside edge of the outcrop barrier.
- Determine the maximum amount of competent rock in the overburden.
- Locate the outcrop contour lines as accurately as possible using surveys and exploration information in order to evaluate head potential.
- Determine the maximum water head likely to build up behind the barrier,
- Determine if there are any flooded abandoned flooded mine workings above the mine barrier.
- Determine if there are any springs or aquifers above the barrier.

Physical and Geological Properties of the Overburden Strata:

Determine the physical and geological properties of the following:

- Overburden strata above the barrier and above the mine workings closest to the barrier,
- Floor strata in the entries near the barrier. Also determine the impact of floor strata on pillars after flooding. This is crucial if fireclay is present in the floor.
- Any weathered and fractured rock, or unconsolidated soil in the overburden strata above the barrier and above the mine workings closest to the barrier,
- Any fault or geological anomalies in the overburden above the barrier and above the mine workings closest to the barrier,
- Any badly weathered or deteriorated roof rock and roof falls in the entries near the barrier, as these conditions cause the pillars to be unstable. Usually, the roof in the entries within 100 feet of the outcrop is in a deteriorated condition and thus weaker than further away from the outcrop.

Mine Maps:

- Verify that all mine maps:
  - are certified by a Registered Professional Engineer,
  - show the date of abandonment and last survey,
  - show coal seam contours,
  - show the elevation of the lowest point in the mine.

- As mining progresses, analyze head potential to validate the head used in the design.

Method of Mining:

- Assess subsidence potential and its impacts adjacent to the barrier,
- Determine type of mining done near the outcrop barrier, room and pillar (1st mining, 2nd mining) or partial mining,
- Assess roof fall potential and its impacts adjacent to the barrier,
- Determine if there are any active or abandoned mines above, below, or adjoining, and whether they are dry or flooded,
- Determine if there are any auger holes, punch mines and adits near the barrier,
- Determine if any blasting has been done within 100 feet of the barrier pillars (blasting weakens the barrier pillars)

Field Investigation:

The field inspection verifies the information obtained by reviewing mine plans, mine history, and mine maps. It alerts the evaluator to deviations from the information shown on the maps.

The field investigation should include the followings:

- Determine the minimum overburden thickness above the mine workings closest to the barrier (see Figure 7)
- Inspect the surface area close the proposed barrier for natural benches and other surface features (e.g. road cuts) that could reduce the overburden thickness and jeopardize the barrier stability.
- Verify the correct location of the outcrop on the mine maps. Usually, the outcrop is plotted from topographic maps,
- Determine if there is any water seepage, its quantity and location,
- Identify any other unusual features which may impact the integrity of the barrier,
- Determine the presence of subsidence or sinkhole cracks, as these zones of weakness and can contribute to potential blowout. impact the integrity of the barrier,
- Determine the presence of subsidence or sinkhole cracks, as these are zones of weakness and can contribute to potential blowout.

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