HAZARDOUS HIGHWALLS – GROUND CONTROL FOR SURFACE MINES

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Fatalities #5 & #6 - April 17, 2007
Fall of Highwall - Surface - Maryland
Tri-Star Mining Inc - Job #3

COAL MINE FATALITY - On Tuesday, April 17, 2007, a 51-year old excavator operator and a 38-year old bulldozer operator, with 15 years and 2 years of mining experience respectively, were fatally injured when a highwall failed. Both miners were operating equipment beneath the highwall measuring approximately 275 feet high, 240 feet wide, and 90 feet deep. The work was being performed near old underground mine works.
Coal Mine Fatal Accident 2007-05 & 06

Operator: Tri-Star Mining, Inc.
Mine: Job #3
Accident Date: April 17, 2007
Classification: Fall of Highwall
Location: Dist. 3, Allegany County, Maryland
Mine Type: Surface Coal Mine
Employment: 71
Production: 2,100 Tons/Day
MINING SAFETY IS NOT JUST FOR UNDERGROUND MINES!!

- GROUND CONTROL IS VERY IMPORTANT TO SURFACE MINES

- HIGHWALL FAILURES CAN BE DEADLY

- UNDERSTANDING THE ROCK MECHANIC PROPERTIES IS CRUCIAL
Highwall hazards are created when workers are exposed to highwalls with the potential for failure.

It is critical that all impacts to a given highwall are identified, analyzed, and provisions incorporated into the highwall design to account for all potential hazards.
MINIMUM ROCK MECHANIC AND PHYSICAL FEATURES THAT MUST BE CONSIDERED FOR HIGHWALL SAFETY:

HIGHWALL DESIGN GEOMETRY

GEOLOGIC STRUCTURE

ROCK FRACTURING PATTERNS

HYDROGEOLOGIC CONDITIONS
HIGHWALL DESIGN GEOMETRY
Typical Highwall
GEOLOGIC STRUCTURE
A little geometry: A plane can be defined by two lines
For geology, we use either
-Strike and Dip
or
-Dip and Dip direction
Strike - Direction of horizontal line in a dipping plane

Dip - The true maximum slope of a bed measured from horizontal

Dip Direction - Direction of the maximum dip; also 90° from strike
ROCK MECHANICS DISCONTINUITIES:

BEDDING
JOINTS
FRACTURES
GENERALLY THE HIGHWALL ROCK MASS PROPERTIES CAN DIFFER GREATLY FROM THE INTACT INDIVIDUAL ROCK BLOCKS
A discontinuity is defined as a disconnect in the continuity of rock material. It creates a weak structural plane where movement and failure can occur.
Effect of Discontinuities on Intact Rock
Properties of Discontinuities

- Orientation
- Spacing
- Persistence
- Roughness
- Aperture
- Infilling
- Seepage
- Number of Sets
- Block Size

(USDOT 1998)
Obtaining Data on Discontinuities

- Field mapping
- Core drilling
Bedding
Bedding
Moderately Dipping Bedding
Favorable Orientation
Beds Dipping Into Highwall

Top

Bench
Unfavorable Orientation
Beds Dipping Out of Highwall
Joints
Two Sets of Vertical Joints (3-D)
2 joint sets
45° to face
Widely Spaced
2 joint sets.
Sub-parallel and perpendicular to face.
Closely Spaced
Non-Perpendicular Joint Intersection Near Face
HYDROGEOLOGIC CONDITIONS
Water is often a contributing factor to highwall failures.

Effects of water:
- adds weight to the potential sliding mass
- reduces strength of soil/rock
- erodes supporting material
- provides driving force in joints
Dry Highwall FS=1.3

F.S. = 1.3
C = 1000 psf
\( \phi = 36^\circ \)
D = 160 pcf

Joint
Saturated Highwall FS = 1.1

F.S. = 1.1
C = 1000 psf
$\phi = 36^\circ$
D = 160 pcf
**Water Pressure in Joints**

\[ P_{\text{max}} = 62.4 \times \text{depth} \]

\[ F = 0.5(P_{\text{max}} \times \text{depth}) / 2000 \]

<table>
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<th>DEPTH, D, FEET</th>
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<td>FORCE, TONS</td>
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Saturated Highwall with Water Column FS < 1.0

F.S. <1.0
C = 1000 psf
Ø = 36°
D = 160 pcf
Ice is a Common Sight on Highwalls

- It identifies seepage locations.
• The ice acts as a dam on the face of the highwall which raises the internal water elevation.
• The ice also adds weight to the wall.
HIGHWALL FAILURE MODES
Rock Mass Failure Modes

- Planar
- Wedge
- Toppling
- Circular
Rock Mass Failure
Planar Failure
Planar failures involve sliding movement along a single discontinuity surface; however, additional discontinuities typically define the lateral extent of the failures.
Planar Failure
Wedge Failure
Wedge Failure
Wedge failures involve sliding movement along two discontinuity surfaces that intersect at an angle forming a wedge shaped block in the highwall face.
Wedge Failure
Toppling Failure
Toppling failures involve rotational movement around the base of a slab or column formed by steeply dipping discontinuities oriented parallel or sub-parallel to the highwall face.
Non-Fatal Toppling Failure Accident
Non-Fatal Toppling Failure Accident
Circular Failure
Circular failures involve rotational and sliding movement along a failure surface. Circular failures are not common in small highwall situations < 100’. However, circular failures can and have occurred when highwalls are oriented near or parallel to fractures.
Circular Failure – Before
Rock Falls

04/22/2003
Coal Mine Fatal Accident 2006-35

Operator: Hendrickson Equipment, Inc.
Mine: Smith Branch No. 1
Accident Date: July 18, 2006
Classification: Fall of Highwall
Location: Dist. 6, Knott County, Kentucky
Mine Type: Surface Coal Mine
Employment: 7
Production: 150 Tons/Day
# Rock Fall Energy

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<td>69</td>
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<tr>
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<td>6</td>
<td>69</td>
<td>3200</td>
<td>12,800</td>
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[1] Assuming that the ground surface is soft enough that the rock penetrates the ground surface 3-inches upon impact. A smaller penetration results in a larger force of impact.
Effects of Highwall Geometry on Rock Fall

(Ritchie 1963)
Rock rolling down face will not fall to toe.

Ledge could cause rock to project further out.
Launch Feature
REMEDIATING THE HAZARD
Rock reinforcement methods for highwall stabilization.

1. Reinforced concrete dowel to prevent loosening of slab at crest
2. Tensioned rock anchors to secure sliding failure along crest
3. Tieback wall to prevent sliding failure on fault zone
4. Shotcrete to prevent raveling of zone of fractured rock
5. Drain hole to reduce water pressure within slope
6. Concrete buttress to support rock above cavity

(TRB 1996)
Rock Anchors
If a water problem is expected, defensive measures can be taken:

- Grouting to prevent infiltration,
- Diversion ditches above the highwall to prevent surface runoff,
- Vertical wells behind the highwall crest, and
- Horizontal drains in the highwall face.
The goal of rock removal is to remove potentially loose rock from the face of the highwall.

Rock removal is preferred over rock reinforcement when a stable face can be achieved.

Pre-splitting during blasting helps reduce broken rock in highwall face.
Rock removal methods for highwall stabilization.

1. Resloping of unstable weathered material in upper part of slope
2. Removal of rock overhang by trim blasting
3. Removal of trees with roots growing in cracks
4. Hand scaling of loose blocks in shattered rock
5. Clean ditch

(TRB 1996)
Scalers Supported by Ropes
Pre-Splitting Highwall
Mechanical Scaling

- Mechanical scaling is generally considered to be scaling by heavy equipment.
- It is not very selective and will generally only remove excessively loose material.
- It may also cause damage to the highwall, creating more loose material in the process.
- Dragging the face of the highwall with a chain or similar object is marginally effective at best.
Dragging the Face
Scaling with Crane
Scaling with Excavator
Catch Fence
Protection Measures More Commonly Used in Mining

- Examination
- Restrict Access
- Equipment Position
- Benches
- Berms
- Computer Modeling
- Monitoring
Methodology can also be used to design berms.
Equipment Position Relative to the Highwall Face
Benches reduce the distance a rock can fall
Full Benches
Berm Containing Material
Is Berm Properly Sized and Located?
Computer models such as the Colorado Rockfall Simulation Program (CRSP) can be used to design rockfall protection measures.

Computer programs:
- model field conditions,
- apply random affects,
- run many simulations, and
- analyze patterns.
70-degree vs. 80-degree slope angles

60 feet

25 feet
Highwalls with a Ledge

120+ feet

120 feet
MSHA IS NOW REQUIRING THAT ALL SURFACE MINES SUBMIT A GROUND CONTROL PLAN TO ENSURE HIGHWALL STABILITY EXCEEDS A STATIC FACTOR OF SAFETY OF 1.3. AFTER MUCH RESEARCH AND ANALYSIS, WE HAVE DEVELOPED A STABILITY MODEL WHEREBY WE CAN ANALYZE THE OVERALL FACTOR OF SAFETY FOR ALL HIGHWALLS.
Engineering Geology Design Challenges at the Soo Lock Replacement Project

Infrastructure Systems Conference
25-29 July, 2007
Bedrock strength parameters were established in accordance with EM 1110-1-2908 “Rock Foundations,” dated 30 Nov 1997 while utilizing:

- Rock mechanics testing data
  - Unconfined Compressive (elastic modulus & Poisson’s Ratio)
  - Anchor Bond Pull-out
  - Direct Shear Tests (intact, natural fracture, grout-on-rock)
  - Direct Tensile
  - Unit Weight

- Rock mass characteristics

- Data from current and past exploration

- Foundation reports of the construction of the Poe Lock
## Geologic Site Characterization – Bedrock Parameters

**US Army Corps of Engineers**
Huntington & Detroit Districts

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<tr>
<th>Rock Unit</th>
<th>Sliding Friction</th>
<th>Cross Bed Shear</th>
<th>Allowable Bearing Capacity</th>
<th>Working Bond Strength</th>
<th>Modulus of Deformation</th>
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<tr>
<td></td>
<td>φ</td>
<td>c</td>
<td>φ</td>
<td>c</td>
<td>psi</td>
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<td>32</td>
<td>25</td>
<td>62**</td>
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*Note 1: 187 psi if Shaly and weathered Sandstone Members are confined and unexposed*

**Bedrock Strength Parameter Values**
References

- Miscellaneous POWERPOINT INFORMATION from Stan Michalek, P.E.
CTL Engineering of WV, Inc.  
733 Fairmont Road  
Morgantown, WV 26501  
304-292-1135  

510 C St.  
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Mining Engineering & Investigations  
Soils, Rock, Concrete, Asphalt Testing  
Materials Testing Laboratory  
Soil & Rock Drilling, Sampling  
Environmental Site Assessments & Remediation  
Permit Preparation, Impoundment Design  
Surface & Groundwater Hydrology