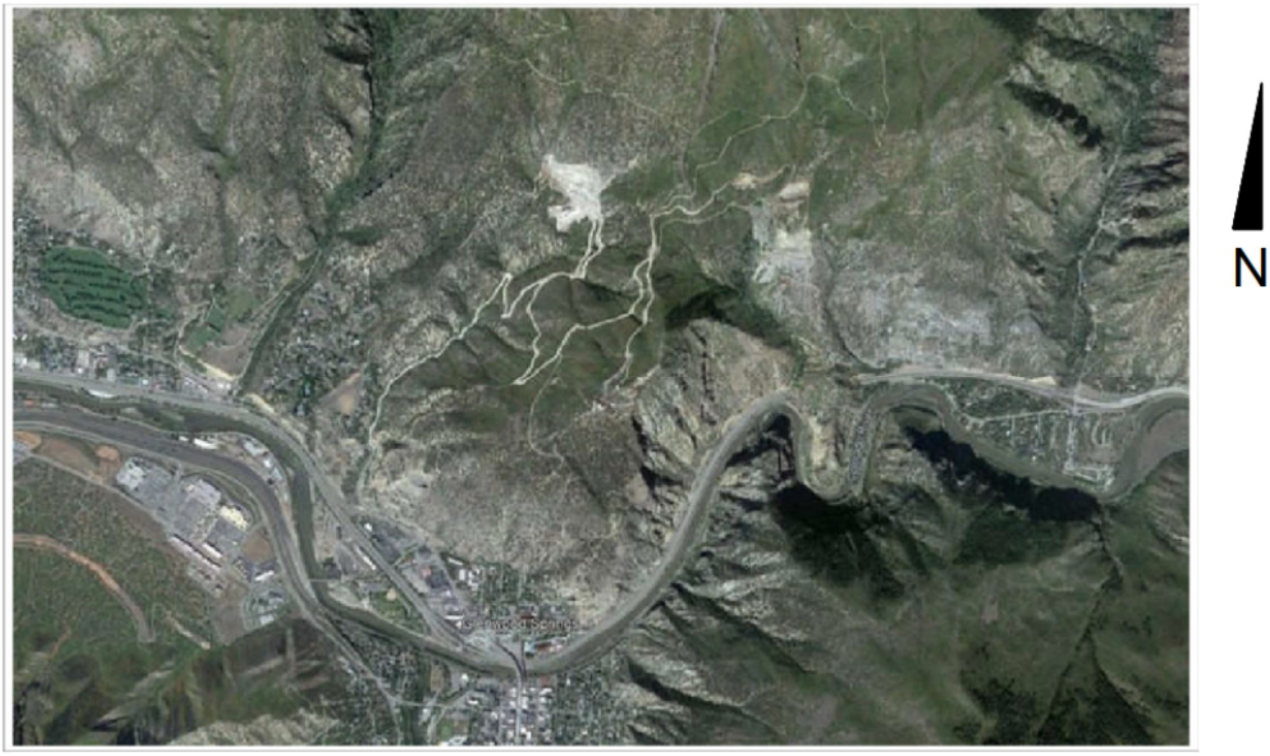
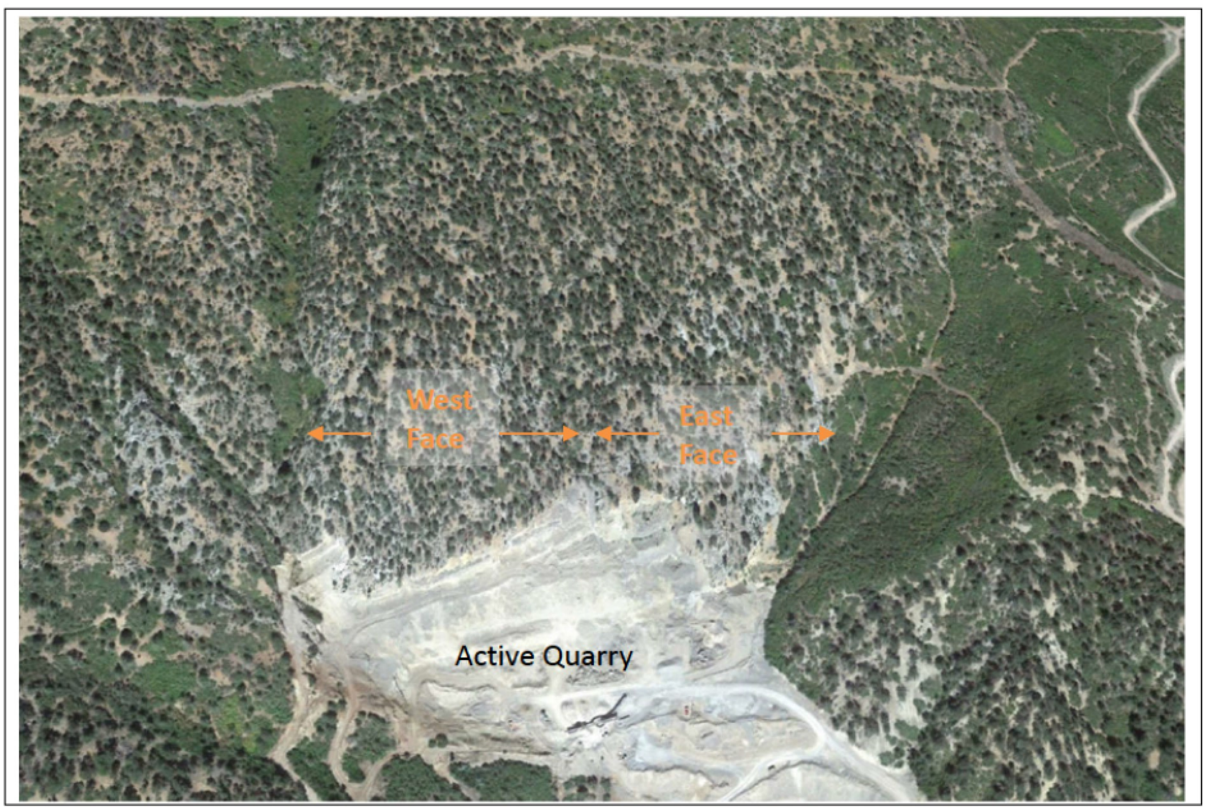
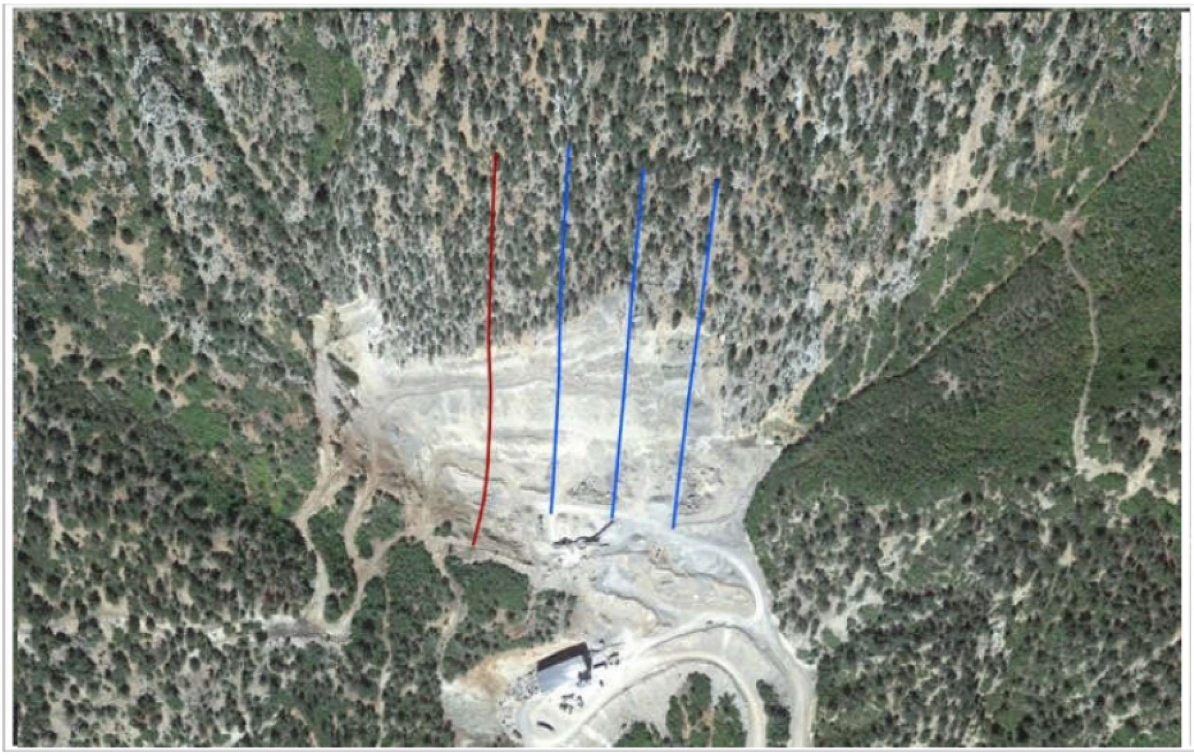
# FIGURES

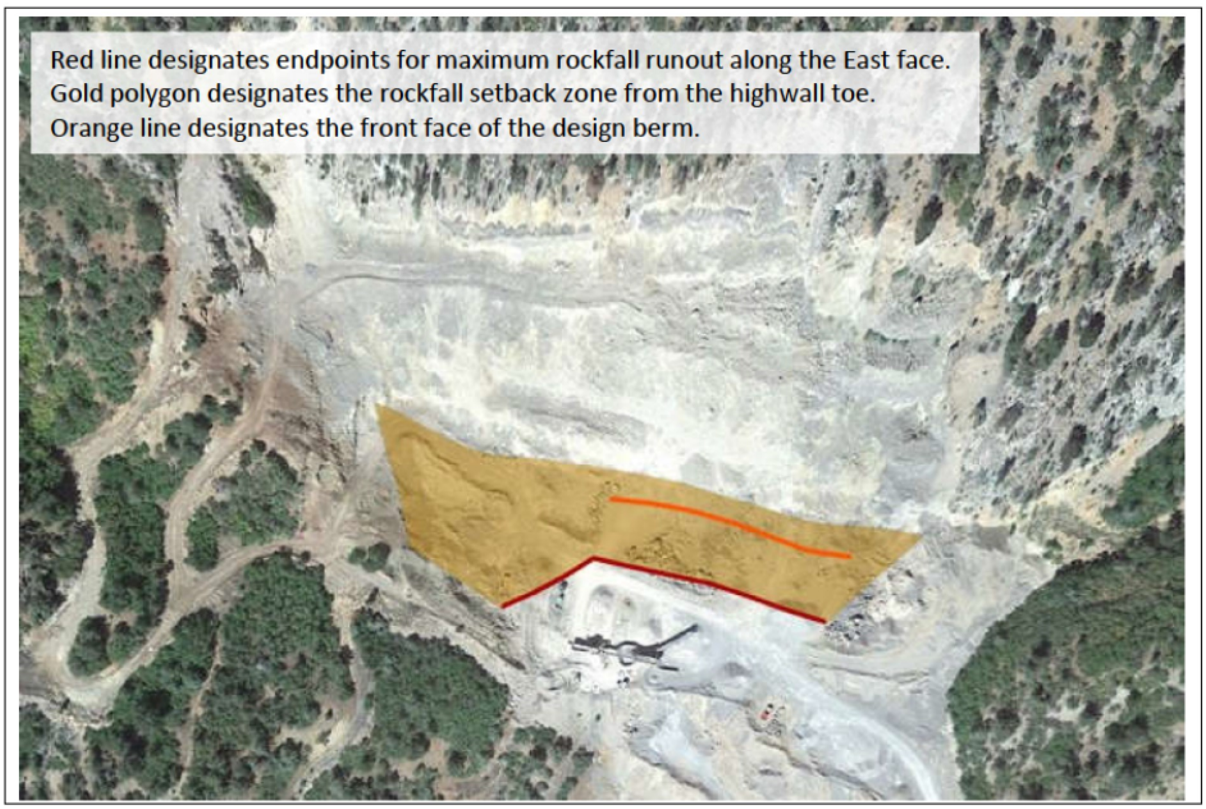


N




| REV 0 | SCALE: AS SHOWN | KILDUFF UNDERGROUND ENGINEERING, INC. 535 16TH STREET, SUITE 620 DENVER, CO 80202 (303)-732-3692 | MID CONTINENT LIMESTONE QUARRY FAILURE ANALYSES AND STABILIZATION GLENWOOD SPRINGS, CO | SITE LOCATION | DATE 08/10/2023 |
|---|---|---|---|---|---|
| DRAWN BY: IF | | | | | FIGURE 1 |
| DESIGNED BY: SS | | | | | |
| CHECKED BY: SS | | | | | |






N

| | | | | | |
|---|---|---|---|---|---|
| REV 0 | SCALE: AS SHOWN | KILDUFF UNDERGROUND ENGINEERING, INC. 535 16TH STREET, SUITE 620 DENVER, CO 80202 (303)-732-3692 | MID CONTINENT LIMESTONE QUARRY FAILURE ANALYSES AND STABILIZATION GLENWOOD SPRINGS, CO | ROCKFALL | DATE 08/10/2023 |
| DRAWN BY: IF | | | | | FIGURE 2 |
| DESIGNED BY: SS | | | | | |
| CHECKED BY: SS | | | | | |

# Appendix A

# FIELD MAPPING PHOTOGRAPHS


Photo 1: View of the Mid Continent Mine, west face on the left and East Face on the right. The January 2023 headwall ground event can be seen on the left, releasing on a consistent, NE-dipping joint plane. (1/26/23 Photo# 0613)

[redacted]

KILDUFF UNDERGROUND ENGINEERING, INC.

**Site Photographs**

Mid Continent Mine

Glenwood Springs, CO

January and April, 2023

Photo 3: Side view, looking east, of the two upper units of the limestone with bedding acting as the slide plane. (1/26/23 Photo# 0598)

Photo 4: Icicles were formed particularly along the basal contact of the upper limestone bed. (1/26/23 Photo# 0584)

Photo 5: Side view, looking west, of the two upper units of the limestone of the East Face. The West Face ground event can be seen in the background along strike. (4/14/23 Photo# 2014)

Photo 6: Bedding plane of upper limestone unit exposed within the East drainage. Plane has very high persistence, planar, moderately rough, JRC 10-12. (4/14/23 Photo# 2016)

Photo 7: Bedding plane of upper limestone unit on the East face with the secondary joint release plane defining the structure of the outcrop. (4/14/23 Photo# 2023)

Photo 8: Open aperture of the upper and lower limestone bed where the interbed has been eroded back 3 – 5 feet frm the outcrop face. Asperities and direct connections between the two limestone beds creates a rough to very rough surface. (4/14/23 Photo# 2023)

Photo 9: Stalactites formed from $CaCO_3$ water leeching down the face of the limestone and along the basal contact adhering the two beds together. Other young stalactites can be seen. (4/14/23 Photo# 2023)

Photo 10: Location of exposed interbed of Photos 11 and 12 eroded back from outcrop face approximately 3 ft (4/14/23 Photo# 2024)

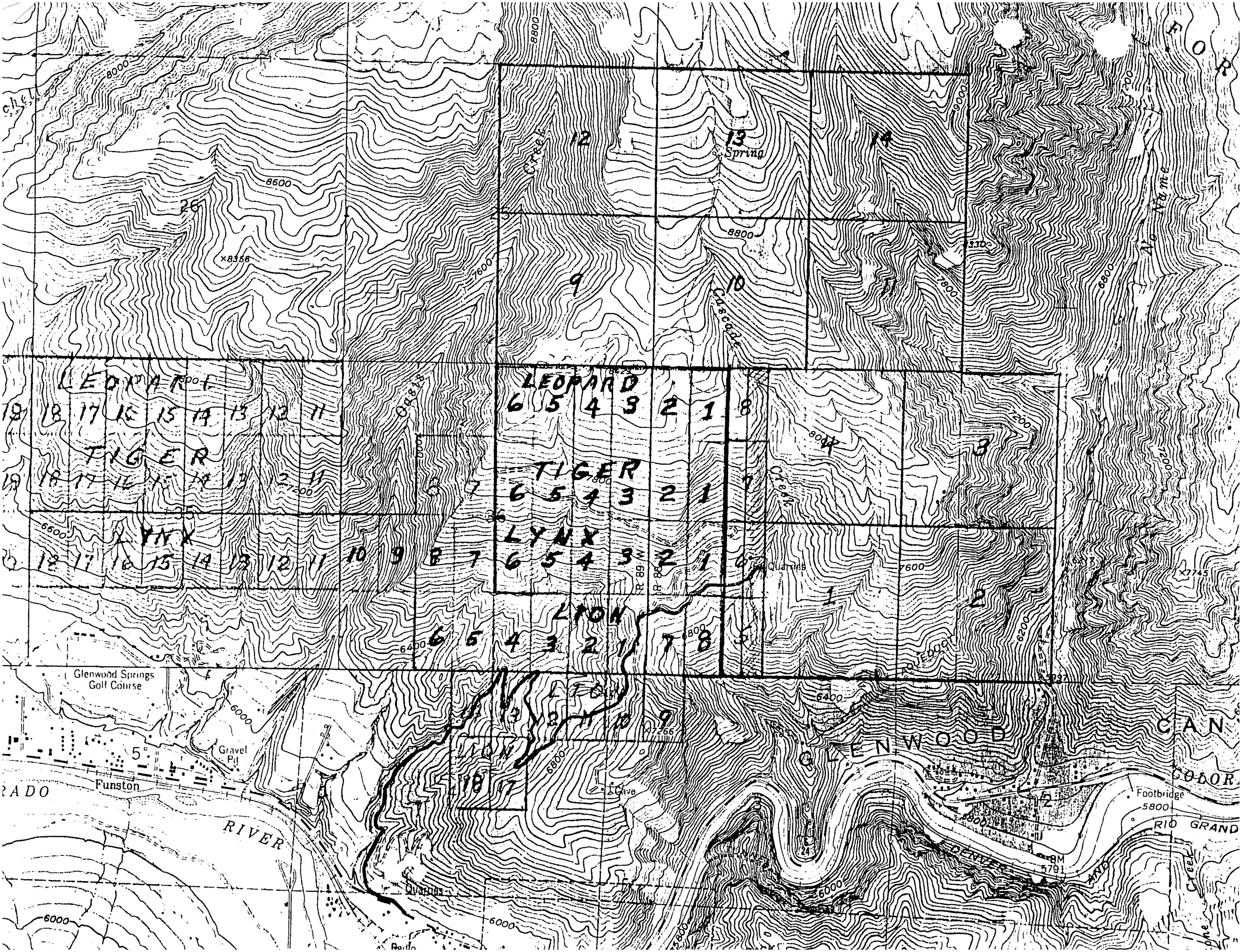
Photo 11 and 12: Interbed material exposed at the East Face is a weak, cemented mudstone with clasts of limestone.
(4/14/23 Photos# 2028 and 2025)

Photo 13: Bedding plane and limestone outcrop on the western extent of the East Face with the West face ground event visible in background along strike. The Bedding plane is undulating and rough with $CaCO_3$ stalactites and asperities of hard crystals. (4/14/23 Photo# 2032)

Photo 14: Looking up and north at the East Face. The bedding breaks defining the upper limestone beds are apparent. The East drainage on the right defines the eastern limit of operations. (4/14/23 Photo# 2002)

# Appendix B

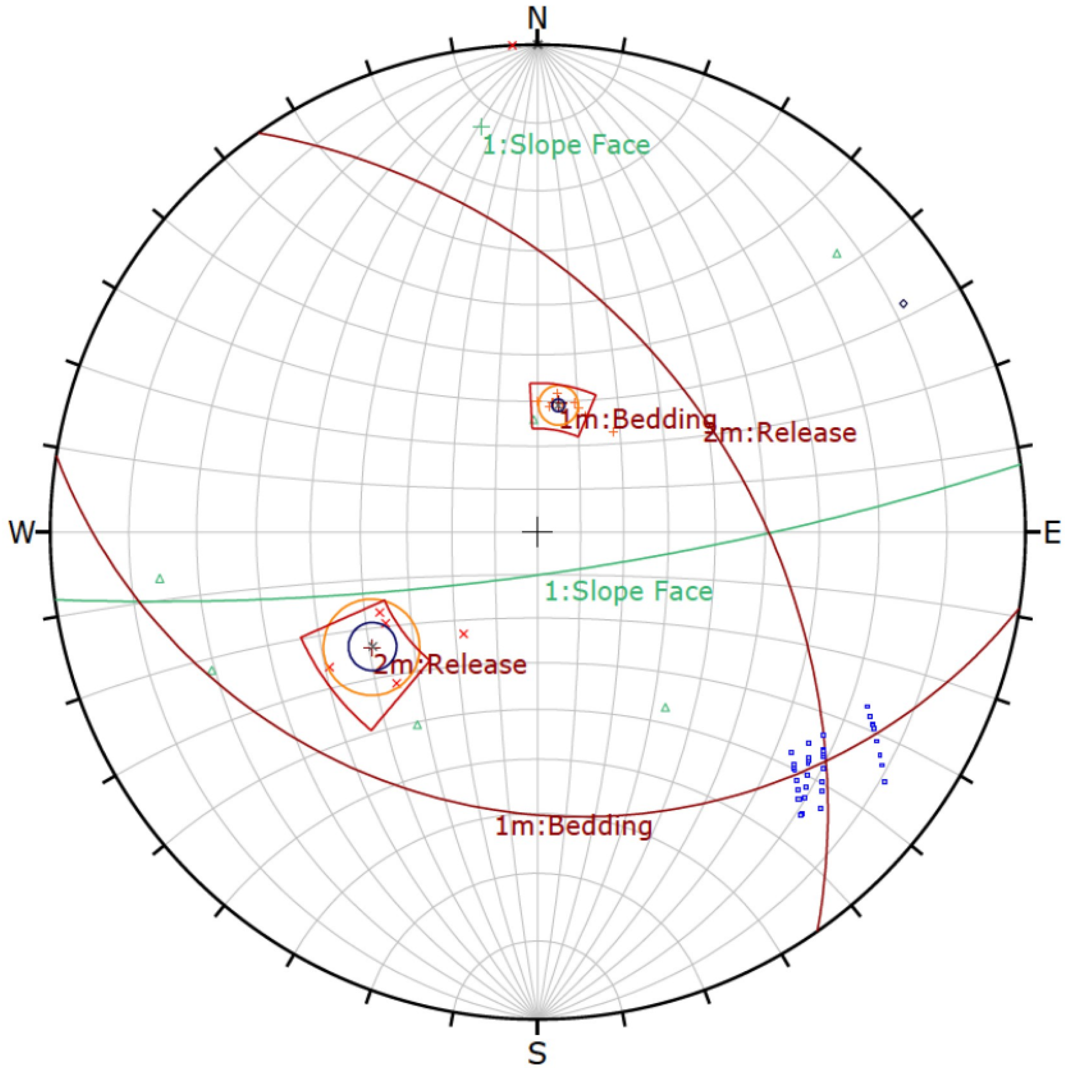
# EAST FACE DISCONTINUITY MAPPING and HISTORICAL BOREHOLES


LEOPARD
TIGER
LYNX
LION
Spring
Creek
Cascade
No Name
FOR
Glenwood Springs Golf Course
Gravel Pit
Funston
RIVER
GLENWOOD
CAN
Cave
Quarries
Footbridge
RIO GRANDE

[redacted]

# Appendix C

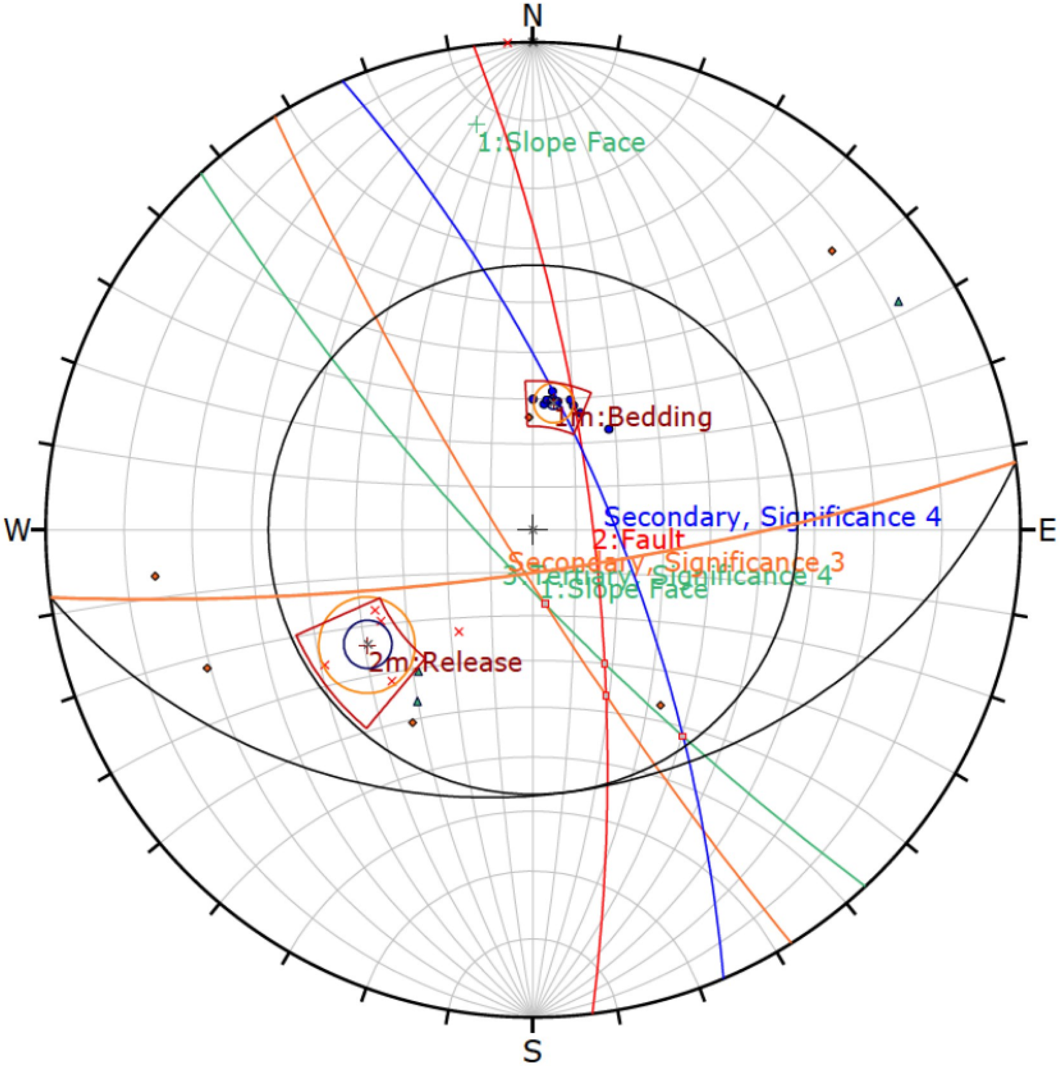
# KINEMATIC RESULTS




| Symbol | PERSISTENCE | Quantity |
|---|---|---|
| ◇ | High | 1 |
| × | Low | 6 |
| △ | Medium | 6 |
| + | Very High | 10 |
| **Symbol** | **Feature** | |
| ▫ | Intersection | |

| | |
|---|---|
| **Plot Mode** | Pole Vectors |
| **Vector Count** | 23 (23 Entries) |
| **Intersection Mode** | All Set Planes |
| **Intersections Count** | 40 |
| **Hemisphere** | Lower |
| **Projection** | Equal Angle |

| | | | |
|---|---|---|---|
| [redacted] | *Project* RMI Mid Continent Mine | | |
| | *Analysis Description* East Face Pole Plot | | |
| | *Drawn By* Sundermann | *Company* Kilduff Underground | |
| DIPS 8.021 | *Date* 4/27/2023, 2:35:05 PM | *File Name* EastFace.dips8 | |



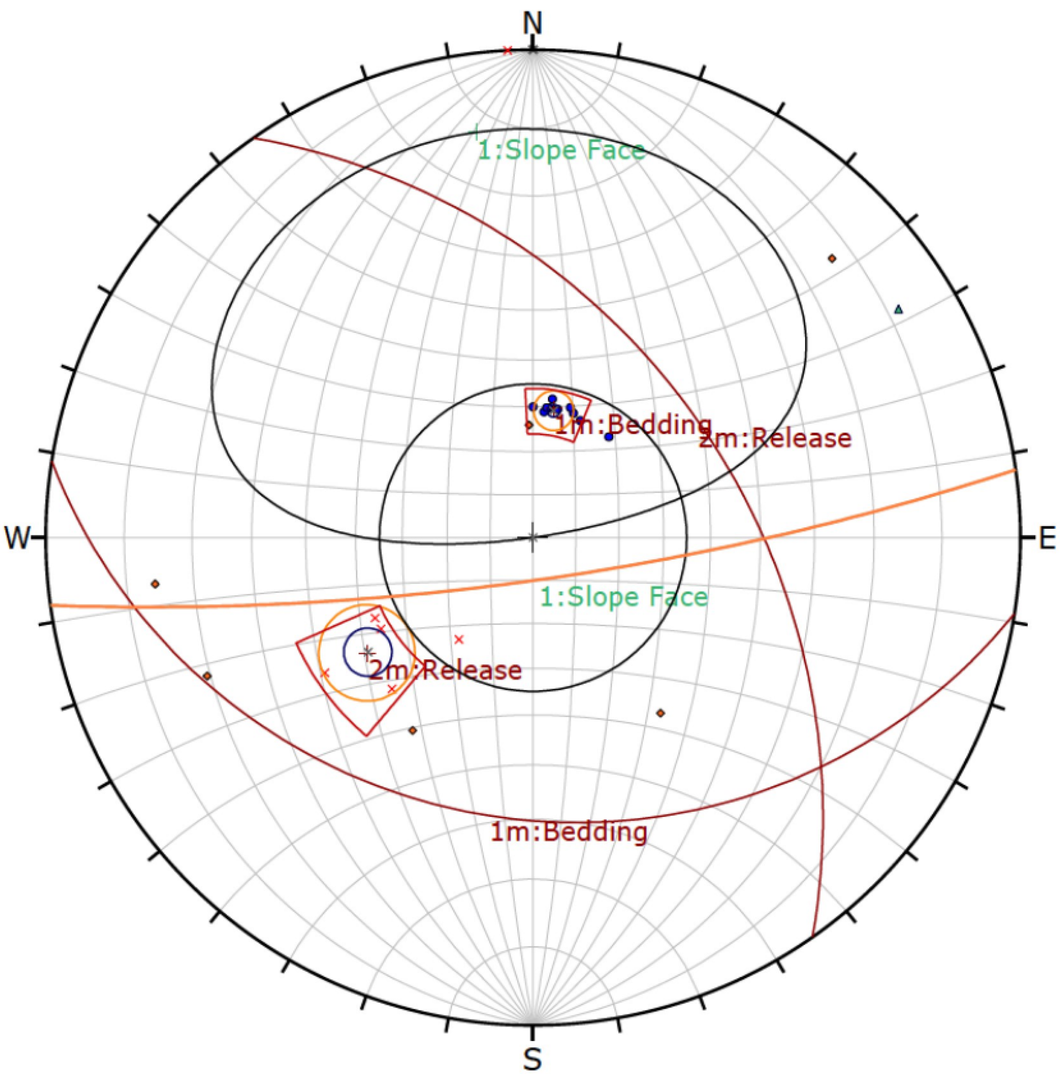

| Symbol | PERSISTENCE | Quantity |
|---|---|---|
| ▲ | High | 3 |
| × | Low | 6 |
| ◆ | Medium | 6 |
| ● | Very High | 10 |
| **Symbol** | **Feature** | |
| □ | Critical Intersection | |

| | | | |
|---|---|---|---|
| **Kinematic Analysis** | Wedge Sliding | | |
| **Slope Dip** | 80 | | |
| **Slope Dip Direction** | 172 | | |
| **Friction Angle** | 33° | | |
| | **Critical** | **Total** | **%** |
| Wedge Sliding | 4 | 300 | 1.33% |

| | Color | Dip | Dip Direction | Label |
|---|---|---|---|---|
| **User Planes** | | | | |
| 1 | | 80 | 172 | Slope Face |
| 2 | | 76 | 83 | Fault |
| 3 | | 80 | 227 | Tertiary, Signific |
| 4 | | 83 | 238 | Secondary, Sigr |
| 5 | | 72 | 67 | Secondary, Sigr |
| **Mean Set Planes** | | | | |
| 1m | | 30 | 189 | Bedding |
| 2m | | 45 | 55 | Release |

| | |
|---|---|
| **Plot Mode** | Pole Vectors |
| **Vector Count** | 25 (25 Entries) |
| **Intersection Mode** | Grid Data Planes |
| **Intersections Count** | 300 |
| **Hemisphere** | Lower |
| **Projection** | Equal Angle |

| | | | |
|---|---|---|---|
| [redacted] | *Project* RMI Mid Continent Mine | | |
| | *Analysis Description* East Face - Wedge Interpreted | | |
| | *Drawn By* Sundermann | *Company* Kilduff Underground | |
| DIPS 8.021 | *Date* 4/27/2023, 2:35:05 PM | *File Name* EastFace_Wedge.dips8 | |




| Symbol | PERSISTENCE | Quantity |
|---|---|---|
| ▲ | High | 1 |
| × | Low | 6 |
| ◆ | Medium | 6 |
| ● | Very High | 10 |

| Kinematic Analysis | Planar Sliding | | |
|---|---|---|---|
| Slope Dip | 80 | | |
| Slope Dip Direction | 172 | | |
| Friction Angle | 35° | | |
| | Critical | Total | % |
| Planar Sliding (All) | 0 | 23 | 0.00% |

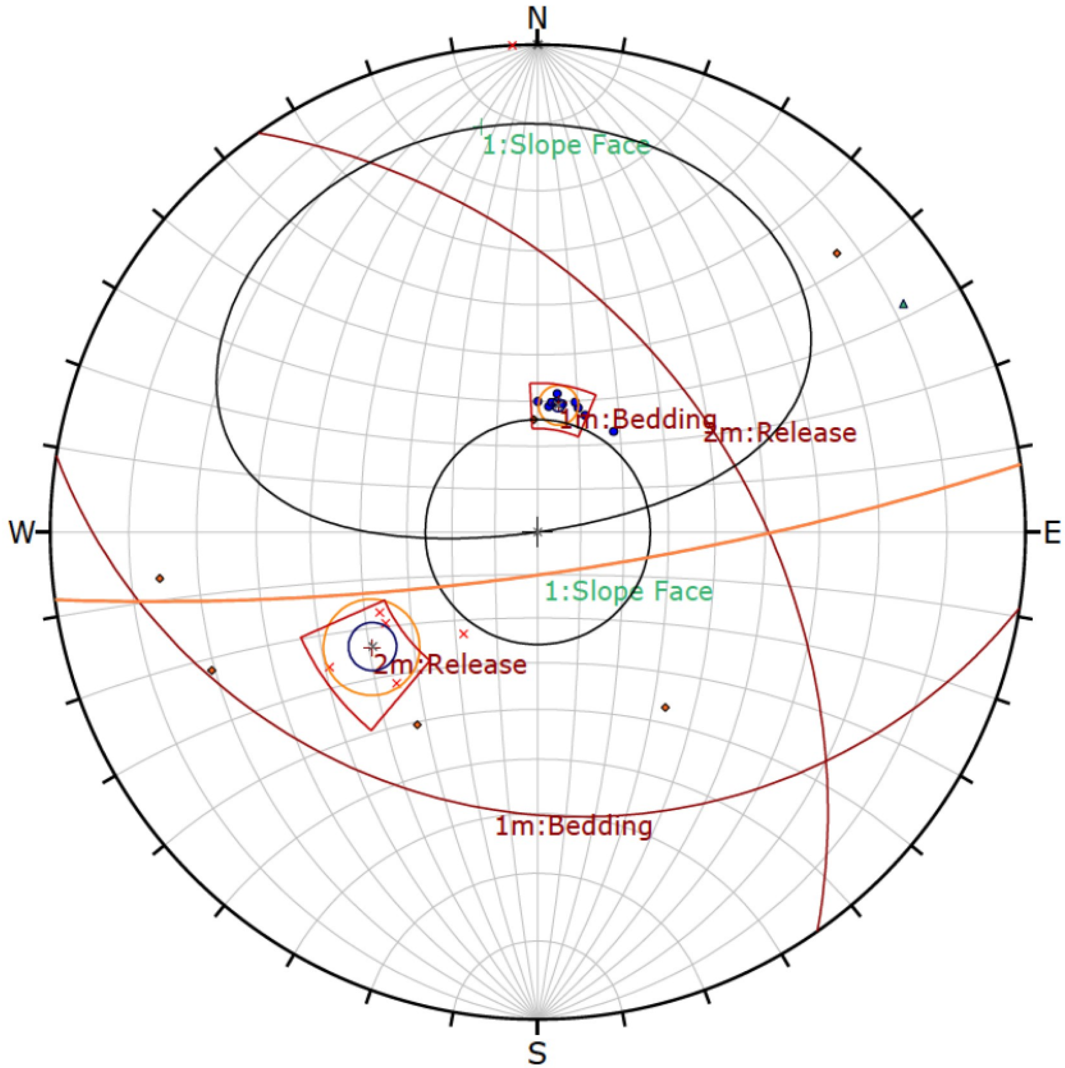
| | Color | Dip | Dip Direction | Label |
|---|---|---|---|---|
| User Planes | | | | |
| 1 | | 80 | 172 | Slope Face |
| Mean Set Planes | | | | |
| 1m | | 30 | 189 | Bedding |
| 2m | | 45 | 55 | Release |

| | |
|---|---|
| Plot Mode | Pole Vectors |
| Vector Count | 23 (23 Entries) |
| Hemisphere | Lower |
| Projection | Equal Angle |

[redacted]

| | | | |
|---|---|---|---|
| *Project* | RMI Mid Continent Mine | | |
| *Analysis Description* | East Face Planar Slide - Limestone | | |
| *Drawn By* | Sundermann | *Company* | Kilduff Underground |
| *Date* | 4/27/2023, 2:35:05 PM | *File Name* | EastFace_Planar NoLimits.dips8 |

DIPS 8.021




| Symbol | PERSISTENCE | Quantity |
|---|---|---|
| ▲ | High | 1 |
| × | Low | 6 |
| ◆ | Medium | 6 |
| ● | Very High | 10 |

| | | | |
|---|---|---|---|
| Kinematic Analysis | Planar Sliding | | |
| Slope Dip | 80 | | |
| Slope Dip Direction | 172 | | |
| Friction Angle | 26° | | |
| | Critical | Total | % |
| Planar Sliding (All) | 11 | 23 | 47.83% |
| Planar Sliding (Set 1: Bedding) | 10 | 10 | 100.00% |

| | Color | Dip | Dip Direction | Label |
|---|---|---|---|---|
| User Planes | | | | |
| 1 | green | 80 | 172 | Slope Face |
| Mean Set Planes | | | | |
| 1m | dark red | 30 | 189 | Bedding |
| 2m | dark red | 45 | 55 | Release |

| | |
|---|---|
| Plot Mode | Pole Vectors |
| Vector Count | 23 (23 Entries) |
| Hemisphere | Lower |
| Projection | Equal Angle |

[redacted]

| | | | |
|---|---|---|---|
| *Project* | RMI Mid Continent Mine | | |
| *Analysis Description* | East Face Planar Slide - Mudstone Interbed (26 phi) | | |
| *Drawn By* | Sundermann | *Company* | Kilduff Underground |
| *Date* | 4/27/2023, 2:35:05 PM | *File Name* | EastFace_Planar NoLimits.dips8 |

DIPS 8.021

# Appendix D

# PLANAR FAILURE RESULTS

[redacted]

[redacted]

# Appendix E

# ROCKFALL MODELING RESULTS

Eas  Face_Berm3000
Mi  Continen  Mine
Kilduf  Undergroun  Engineering
Date Created: 5/26/2023, 12:24:29 PM
Software Version: 8.022

# East Face_Berm3000

# Mid Continent Mine

## Project Summary

| | |
|---|---|
| File Name | East Face_Berm3000.fal8 |
| File Version | 8.022 |
| Project Title | Mid Continent Mine |
| Analysis | East Face - 15ft Berm |
| Author | Sundermann |
| Company | Kilduff Underground Engineering |
| Date Created | 5/26/2023, 12:24:29 PM |

# Project Settings

## General Settings

| | |
|---|---|
| Engine | Rigid Body |
| Units | Imperial Foot-Pounds (ft, lbm, ft-lbf) |
| Rock throw mode | Number of rocks controlled by seeder |
| Use tangential CRSP damping | Yes |

## Engine Conditions

| | |
|---|---|
| Maximum steps per rock | 40000 |
| Normal velocity cutoff (ft/s) | 0.33 |
| Stopped velocity cutoff (ft/s) | 0.33 |
| Maximum timestep (s) | 0.01 |
| Switch velocity (ft/s) | -3.3e-09 |

## Random Number Generation

| | |
|---|---|
| Sampling method | Latin-Hypercube |
| Material Properties Sampling | Per simulation |
| Random seed | Pseudo-random seed: 12345234 |

# Crest Loss

| Vertex | Mean | Distribution | Std.Dev. | Rel. Min | Rel. Max | Mean | Distribution | Std.Dev. | Rel. Min | Rel. Max |
|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 20 | None | | | | 20 | None | | | |
| 13 | 30 | None | | | | 30 | None | | | |
| 16 | 30 | None | | | | 20 | None | | | |

# Material Properties

## Limestone Headwall

| "Limestone Headwall" Properties | | | | | |
|---|---|---|---|---|---|
| Color | | | | | |
| | Mean | Distribution | Std.Dev. | Rel. Min | Rel. Max |
| Normal Restitution | 0.32 | Normal | 0.04 | 0.12 | 0.12 |
| Tangential Restitution | 0.71 | Normal | 0.04 | 0.12 | 0.12 |
| Dynamic Friction | 0.55 | Normal | 0.04 | 0.12 | 0.12 |
| Rolling Friction | 0.15 | Normal | 0.02 | 0.06 | 0.06 |
| **"Limestone Headwall" Advanced Properties** | | | | | |
| Forest and Vegetation Damping | | Disabled | | | |
| Scarring | | Disabled | | | |
| Viscoplastic Damping | | Disabled | | | |

## Limestone Scree / Blast Pile

| "Limestone Scree / Blast Pile" Properties | | | | | |
|---|---|---|---|---|---|
| Color | | | | | |
| | Mean | Distribution | Std.Dev. | Rel. Min | Rel. Max |
| Normal Restitution | 0.32 | Normal | 0.04 | 0.12 | 0.12 |
| Tangential Restitution | 0.71 | Normal | 0.04 | 0.12 | 0.12 |
| Dynamic Friction | 0.55 | Normal | 0.04 | 0.12 | 0.12 |
| Rolling Friction | 0.3 | Normal | 0.04 | 0.12 | 0.12 |
| **"Limestone Scree / Blast Pile" Advanced Properties** | | | | | |
| Forest and Vegetation Damping | | Disabled | | | |
| Scarring | | Disabled | | | |
| Viscoplastic Damping | | Disabled | | | |

# Berm Properties

## Berm

| "Berm" Properties | | | | | |
|---|---|---|---|---|---|
| Berm Property | | | Calculate Impact | | |
| | Mean | Distribution | Std.Dev. | Rel. Min | Rel. Max |
| Normal Restitution | 0.31 | Normal | 0.04 | 0.12 | 0.12 |
| Tangential Restitution | 0.82 | Normal | 0.04 | 0.12 | 0.12 |
| Dynamic Friction | 0.55 | Normal | 0.04 | 0.12 | 0.12 |
| Rolling Friction | 0.6 | Normal | 0.01 | 0.03 | 0.03 |

# Seeders

## Seeder 1

| Seeder Properties | | | | | |
|---|---|---|---|---|---|
| Name | Seeder 1 | | | | |
| Location | (366.167, 6931.79), (392.116, 6948.01) | | | | |
| **Rocks to Throw** | | | | | |
| Number of Rocks | 3000 Overall | | | | |
| Rock Types | Small Blocks, | Medium Blocks, | Large Blocks | | |
| **Initial Conditions** | | | | | |
| | Mean | Distribution | Std.Dev. | Rel. Min | Rel. Max |
| Horizontal Velocity (ft/s) | 6 | Normal | 2 | 6 | 6 |
| Vertical Velocity (ft/s) | 0 | None | | | |
| Rotational Velocity (deg/s) | 0 | None | | | |
| Initial Rotation (deg/s) | 0 | Uniform | | 0 | 360 |

# Rock Types

## Small Blocks

| Properties | | | | | |
|---|---|---|---|---|---|
| Name | Small Blocks | | | | |
| Color | | | | | |
| Smooth Shapes | Square, | Pentagon, | Rhombus | | |
| Polygons | None | | | | |
| | Mean | Distribution | Std.Dev. | Rel. Min | Rel. Max |
| Mass (lbm) | 2022.2 | Normal | 2 | 6 | 6 |
| Density (lbm/ft3) | 150 | Normal | 3 | 9 | 9 |

## Medium Blocks

| Properties | | | | | |
|---|---|---|---|---|---|
| Name | Medium Blocks | | | | |
| Color | | | | | |
| Smooth Shapes | Square, | Pentagon, | Rhombus | | |
| Polygons | None | | | | |
| | Mean | Distribution | Std.Dev. | Rel. Min | Rel. Max |
| Mass (lbm) | 20227.2 | Normal | 2 | 6 | 6 |
| Density (lbm/ft3) | 150 | Normal | 3 | 9 | 9 |

## Large Blocks

| Properties | | | | | |
|---|---|---|---|---|---|
| Name | Large Blocks | | | | |
| Color | | | | | |
| Smooth Shapes | Square, | Pentagon, | Rhombus | | |
| Polygons | None | | | | |
| | Mean | Distribution | Std.Dev. | Rel. Min | Rel. Max |
| Mass (lbm) | 93642 | Normal | 2 | 6 | 6 |
| Density (lbm/ft3) | 156.07 | None | | | |

# Collectors

| | |
|---|---|
| Record paths' first impacts only? | No |
| **Collector 1** | |
| Name | Collector 1 |
| Location | (111.848, 6685.46) to (112.031, 6718.94) |
| **Collector 2** | |
| Name | Collector 2 |
| Location | (150.83, 6689.04) to (150.86, 6766.9) |
| **Collector 3** | |
| Name | Collector 3 |
| Location | (126.142, 6684.2) to (126.306, 6718.94) |

# Appendix F

# JULY 2023 WEST FACE FIELD PHOTOGRAPHS

Photo 1: View of the Mid Continent Mine, west face on the left. The January 2023 headwall ground event (extent indicated by white arrows) released on a consistent, NE-dipping joint plane. (1/26/23 Photo# 0613)

[redacted]

Photo 3: Tape measured 15 ft of upper beds sitting on laterally continuous bed surface, dipping 34°;185. No significant aperture or interbed between the upper and lower limestone. Location on Figure 2. (7/6/23 Photo# 2209)

Photo 4: Looking west across drainage, commensurate laterally continuous bed surface exposed. Loss of upper beds at the drainage confluence ridgeline in foreground. (7/6/23 Photo# 2210)

[redacted]

KILDUFF UNDERGROUND ENGINEERING, INC.

**Site Photographs**

Mid Continent Mine

Glenwood Springs, CO

July, 2023

[redacted] [redacted]

[redacted] [redacted]

# Appendix G

# ACTIVE STABILIZATION DESIGN

# Technical Summary

## *Scope*

Preliminary design of active stabilization of the Mid Continent Mine utilizing tensioned tiebacks. Anchored slope design was performed for upper limestone thicknesses of 5 feet for static and seismic conditions.

## *Design References*

- Rock Slope Engineering 4th edition, Wyllie and Mah, 2005
- PTI DC35.1-14, Recommendations for prestressed rock and soil anchors, 2014.
- Soil Nails Reference Manual, FHWA GEC 007, Federal Highway Publication No. FHWA-NHI-14-007.
- Structure Repsonse and Damage Produced by Ground Vibration from Surface Mine Blasting, US Department of Interior.

## *Design Assumptions*

1. Rock parameters were assumed from a back analysis of the west wall ground disturbance performed in RocPlane.
2. Existing west face slope angles were determined from a slope angle heat map from onXmaps.
3. Empricial strength values used due to decrease in cohesion during possible sliding (conservative)

tension crack length, RocPlane: $t_{cr} := 2.22 \cdot ft$

Joint cohesion, KUE: $c := 40 \cdot psf$

Joint friction angle, KUE: $\phi_{jt} := 25 \cdot deg$

Anchor inclination: $\phi_{st} := 45 \cdot deg$

Upper face length: $L_{up} := \dfrac{w_{up}}{\cos(\sigma_{up})} = 24.42\ ft$

Required tieback load: $T_{max} := 4.5 \cdot klf$ Iterative to achieve FS

per slope length

Area of sliding plane per linear foot: $A := \dfrac{(H - t_{cr})}{\sin(\sigma_{fp})} = 28.49\ ft$

Total resisting force, Wylie & Mah:

$$F_{res} := c \cdot A + \left[T_{max} \cdot \sin((\sigma_{fp} + \phi_{st})) + F_{norm.exis} - F_{water}\right] \cdot \tan(\phi_{jt}) = 8.57 \cdot klf$$

Total driving force, Wylie & Mah: $F_{driving} := F_{dr.exis} - T_{max} \cdot \cos(\sigma_{fp} + \phi_{st}) = 5.74 \cdot klf$

Factor of safety: $FS := \dfrac{F_{res}}{F_{driving}} = 1.5$

Pattern vertical spacing: $V_{sp} := 5 \cdot ft$

Pattern Horizontal spacing: $H_{sp} := 30 \cdot ft$

Required resisting force per anchor column: $T_{req} := T_{max} \cdot H_{sp} = 135 \cdot kip$

Number of anchors in column: $n := 1$

Required resisting force per anchor $T_{req\_an} := \frac{T_{req}}{n} = 135 \cdot kip$

**Tieback Anchor**

Multi strand anchors, class 1

Bond strength in lower Limestone layer: $BS := 150 \cdot psi$

Factor of safety - pullout: $FS_{po} := 2$

Anchor inclination from perpendicular to slope: $\phi_{st} = 45 \cdot deg$

Strand ultimate strength: $T_{t\_s} := 234 \cdot kip$ 4 strand

**Strand Anchor System** ASTM A416

| Number of Strands | Cross-Sectional Area (Aps) | Ultimate Load (fpu*Aps) | Maximum Jacking Load (0.8*fpu*Aps) | Maximum Design Load (0.6*fpu*Aps) | HDPE Tubing | Anchor Heads | Weight per Foot |
|---|---|---|---|---|---|---|---|
| 1 | 0.217 in² (140 mm²) | 58.6 kips (261 kN) | 46.9 kips (209 kN) | 35.2 kips (157 kN) | 3" nom. (3.5" OD) | C4.6 | 0.74 lbs (0.34 kg) |
| 2 | 0.434 in² (280 mm²) | 117 kips (522 kN) | 93.8 kips (418 kN) | 70.4 kips (314 kN) | 3" nom. (3.5" OD) | C4.6 | 1.48 lbs (0.67 kg) |
| 3 | 0.651 in² (420 mm²) | 176 kips (783 kN) | 141 kips (627 kN) | 106 kips (471 kN) | 3" nom. (3.5" OD) | C4.6 | 2.22 lbs (1.01 kg) |
| 4 | 0.868 in² (560 mm²) | 234 kips (1044 kN) | 188 kips (836 kN) | 141 kips (628 kN) | 3" nom. (3.5" OD) | C7.6 - Class 1 C4.6 - Class 2 | 2.96 lbs (1.34 kg) |
| 5 | 1.09 in² (700 mm²) | 293 kips (1305 kN) | 235 kips (1045 kN) | 176 kips (785 kN) | 3" nom. (3.5" OD) | C7.6 | 3.70 lbs (1.68 kg) |
| 6 | 1.30 in² (840 mm²) | 352 kips (1566 kN) | 281 kips (1254 kN) | 211 kips (942 kN) | 3" nom. (3.5" OD) | C7.6 | 4.44 lbs (2.01 kg) |
| 7 | 1.52 in² (980 mm²) | 410 kips (1827 kN) | 328 kips (1463 kN) | 246 kips (1099 kN) | 3" nom. (3.5" OD) | C7.6 | 5.18 lbs (2.35 kg) |
| 8 | 1.74 in² (1120 mm²) | 469 kips (2088 kN) | 375 kips (1672 kN) | 282 kips (1256 kN) | 3" nom. (3.5" OD) | C9.6 | 5.92 lbs (2.69 kg) |
| 9 | 1.95 in² (1260 mm²) | 527 kips (2349 kN) | 422 kips (1881 kN) | 317 kips (1413 kN) | 4" nom. (4.6" OD) | C9.6 | 6.66 lbs (3.02 kg) |
| 10 | 2.17 in² (1400 mm²) | 586 kips (2610 kN) | 469 kips (2090 kN) | 352 kips (1570 kN) | 4" nom. (4.6" OD) | C12.6 | 7.40 lbs (3.36 kg) |

Free length, PTI: $T_{fl} := 15 \cdot ft$ through upper limestone

Required tail length: $T_t := 2 \cdot ft$

Hole diameter: $d_t := 6 \cdot in$

Required bond length, PTI:

$$T_{bl} := \frac{T_{req\_an} \cdot FS_{po}}{3.14 \cdot BS \cdot d_t} = 7.96\ ft$$

Check strand tensile capacity (ASD):

$$Ckeck := \begin{cases} \text{"OK"} & \text{if } .6 \cdot T_{t\_s} \geq T_{req\_an} \\ \text{"WARNING"} & \text{otherwise} \end{cases} = \text{"OK"}$$

Anchor total length:

$$L_{total} := T_{fl} + T_{bl} + T_t = 24.96\ ft$$

$$L_{total} = 25\ ft$$

## *Slope Stability support - Seismic*

Max highwall height - $H := 25 \cdot ft$

Peak ground acceleration coefficient (1000-yr return) - $PGA := 0.196$ AASHTO Fig. 3.10.2.1-1

Horizontal Response Spectral Acceleration coefficient - $S_1 := 0.082$ AASHTO Fig. 3.10.2.1-3

Thickness of limestone layer - $d_1 := 90 \cdot ft$

Thickness of shale layer - $d_2 := 0.5 \cdot ft$

Thickness of dolomite layer - $d_3 := 100 \cdot ft - d_1 - d_2 = 9.5\,ft$

Average blow counts in ground layer one - $N_1 := 100$

Average blow counts in ground layer two - $N_2 := 50$

Average blow counts in ground layer three - $N_3 := 100$

Average SPT over top 100 ft - $N_{bar} := \dfrac{d_1 + d_2 + d_3}{\dfrac{d_1}{N_1} + \dfrac{d_2}{N_2} + \dfrac{d_3}{N_3}} = 100$ Eq. 4.2

Site Class = A, Hard rock Table 4.8

Site adjustment factors - $F_{pga} := 0.8$ Table 4.9

$F_v := 0.8$ Table 4.10

Design peak ground accleration - $PGA_D := F_{pga} \cdot PGA = 0.16$ Eq. 4.3

Design site-corrected response acceleration - $S_{1D} := F_v \cdot S_1 = 0.07$ Eq. 4.4

Seismic Zone -

$$SZ := \begin{cases} \text{"Seismic Zone 1"} & \text{if } S_{1D} \le 0.15 \\ \text{"Seismic Zone 2"} & \text{if } S_{1D} > 0.15 \wedge S_{1D} \le 0.30 \\ \text{"Seismic Zone 3"} & \text{if } S_{1D} > 0.30 \wedge S_{1D} \le 0.50 \\ \text{"Seismic Zone 4+"} & \text{otherwise} \end{cases} = \text{"Seismic Zone 1"}$$

6.8.1

[redacted]

Calculated driving force, RocPlane: $F_{dr.exis} := 8414.41 \cdot plf$

Calculated existing normal force, RocPlane: $F_{norm.exis} := 10902.77 \cdot plf$

Calculated existing water force, RocPlane: $F_{water} := 190.27 \cdot plf$

Upper face angle, KUE: $\sigma_{up} := 28 \cdot deg$

Failure plane angle, KUE: $\sigma_{fp} := 30 \cdot deg$

Total height, RocPlane: $H := 16.463 \cdot ft$

Upper face width, RocPlane: $w_{up} := 21.559 \cdot ft$

tension crack length, RocPlane: $t_{cr} := 2.22 \cdot ft$

Joint cohesion, KUE: $c := 40 \cdot psf$

Joint friction angle, KUE: $\phi_{jt} := 25 \cdot deg$

Anchor inclination: $\phi_{st} := 45 \cdot deg$

Upper face length: $L_{up} := \dfrac{w_{up}}{\cos(\sigma_{up})} = 24.42\ ft$

Required tieback load: $T_{max} := 6.1 \cdot klf$ Iterative to achieve FS

per slope length

Area of sliding plane per linear foot: $A := \dfrac{(H - t_{cr})}{\sin(\sigma_{fp})} = 28.49\ ft$

Total resisting force, Wyllie & Mah:

$$F_{res} := c \cdot A + \left[T_{max} \cdot \sin\left(\left(\sigma_{fp} + \phi_{st}\right)\right) + F_{norm.exis} - F_{water}\right] \cdot \tan\left(\phi_{jt}\right) = 8.88 \cdot klf$$

Total driving force, Wyllie & Mah: $F_{driving} := F_{dr.exis} - T_{max} \cdot \cos\left(\sigma_{fp} + \phi_{st}\right) = 6.84 \cdot klf$

Factor of safety: $FS := \frac{F_{res}}{F_{driving}} = 1.3$

Pattern vertical spacing: $V_{sp} := 5 \cdot ft$

Pattern Horizontal spacing: $H_{sp} := 30 \cdot ft$

Required resisting force per anchor column: $T_{req} := T_{max} \cdot H_{sp} = 183 \cdot kip$

Number of anchors in column: $n := 1$

Required resisting force per anchor $T_{req\_an\_seis} := \frac{T_{req}}{n} = 183 \cdot kip$

**Tieback Anchor**

Multi strand anchors, class 1

Bond strength in lower Limestone layer: $BS := 150 \cdot psi$

Factor of safety - pullout: $FS_{po} := 1.5$ Seismic

Anchor inclination from perpendicular to slope: $\phi_{st} = 45 \cdot deg$

Strand ultimate strength: $T_{us} := 234 \cdot kip$ 4 strand

**Strand Anchor System** — ASTM A416

| Number of Strands | Cross-Sectional Area (Aps) | Ultimate Load (fpu*Aps) | Maximum Jacking Load (0.8*fpu*Aps) | Maximum Design Load (0.6*fpu*Aps) | HDPE Tubing | Anchor Heads | Weight per Foot |
|---|---|---|---|---|---|---|---|
| 1 | 0.217 in² (140 mm²) | 58.6 kips (261 kN) | 46.9 kips (209 kN) | 35.2 kips (157 kN) | 3" nom. (3.5" OD) | C4.6 | 0.74 lbs (0.34 kg) |
| 2 | 0.434 in² (280 mm²) | 117 kips (522 kN) | 93.8 kips (418 kN) | 70.4 kips (314 kN) | 3" nom. (3.5" OD) | C4.6 | 1.48 lbs (0.67 kg) |
| 3 | 0.651 in² (420 mm²) | 176 kips (783 kN) | 141 kips (627 kN) | 106 kips (471 kN) | 3" nom. (3.5" OD) | C4.6 | 2.22 lbs (1.01 kg) |
| 4 | 0.868 in² (560 mm²) | 234 kips (1044 kN) | 188 kips (836 kN) | 141 kips (628 kN) | 3" nom. (3.5" OD) | C7.6 - Class 1 C4.6 - Class 2 | 2.96 lbs (1.34 kg) |
| 5 | 1.09 in² (700 mm²) | 293 kips (1305 kN) | 235 kips (1045 kN) | 176 kips (785 kN) | 3" nom. (3.5" OD) | C7.6 | 3.70 lbs (1.68 kg) |
| 6 | 1.30 in² (840 mm²) | 352 kips (1566 kN) | 281 kips (1254 kN) | 211 kips (942 kN) | 3" nom. (3.5" OD) | C7.6 | 4.44 lbs (2.01 kg) |
| 7 | 1.52 in² (980 mm²) | 410 kips (1827 kN) | 328 kips (1463 kN) | 246 kips (1099 kN) | 3" nom. (3.5" OD) | C7.6 | 5.18 lbs (2.35 kg) |
| 8 | 1.74 in² (1120 mm²) | 469 kips (2088 kN) | 375 kips (1672 kN) | 282 kips (1256 kN) | 3" nom. (3.5" OD) | C9.6 | 5.92 lbs (2.69 kg) |
| 9 | 1.95 in² (1260 mm²) | 527 kips (2349 kN) | 422 kips (1881 kN) | 317 kips (1413 kN) | 4" nom. (4.6" OD) | C9.6 | 6.66 lbs (3.02 kg) |
| 10 | 2.17 in² (1400 mm²) | 586 kips (2610 kN) | 469 kips (2090 kN) | 352 kips (1570 kN) | 4" nom. (4.6" OD) | C12.6 | 7.40 lbs (3.36 kg) |

Free length, PTI: $T_{fl\_seis} := 15 \cdot ft$ through upper limestone

Required tail length: $T_{t\_seis} := 2 \cdot ft$

Hole diameter: $d_t := 6 \cdot in$

Required bond length, PTI: $T_{bl\_seis} := \frac{T_{req\_an} \cdot FS_{po}}{3.14 \cdot BS \cdot d_t} = 5.97\ ft$

Check strand tensile capacity (ASD): $Ckeck := \begin{cases} \text{"OK"} & \text{if } 0.75 \cdot T_{t\_s} \geq T_{req\_an} \\ \text{"WARNING"} & \text{otherwise} \end{cases} = \text{"OK"}$

Anchor total length: $L_{total\_seis} := T_{fl\_seis} + T_{bl\_seis} + T_{t\_seis} = 22.97\ ft$

$L_{total\_seis} = 23\ ft$

## *Blasting Impacts*

Peak particle velocity: $ppv := 0.3 \cdot \frac{in}{sec}$

Frequency: $f := 25 \cdot Hz$

Gravity: $g := 32.2 \cdot \frac{ft}{sec^2}$

Peak ground acceleration: $\alpha := \frac{2 \cdot \pi \cdot f \cdot ppv}{g} = 0.12$

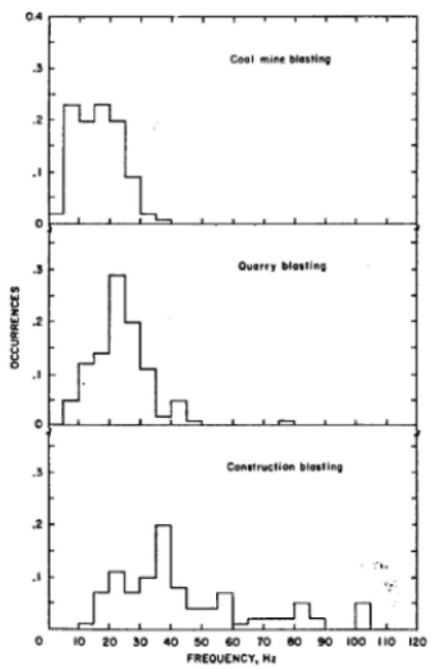



**Figure 2.—Predominant frequencies of vibrations from coal mine, quarry, and construction blasting.**

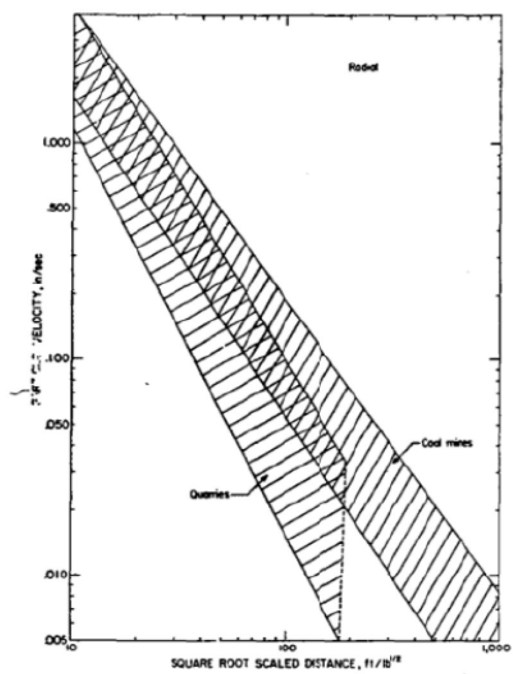



**Figure 11.—Zones of mean propagation regressions for two major types of blasting.**

$Ckeck := \begin{cases} \text{"Blasting Controls"} & \text{if } \alpha \geq k_h \\ \text{"Seismic Controls"} & \text{otherwise} \end{cases} = \text{"Seismic Controls"}$

## *Active Support Summary*

$Ckeck := \begin{cases} \text{"Static Controls"} & \text{if } T_{req\_an} \geq T_{req\_an\_seis} \\ \text{"Seismic Controls"} & \text{otherwise} \end{cases} = \text{"Seismic Controls"}$

# Technical Summary

## *Scope*

Preliminary design of active stabilization of the Mid Continent Mine utilizing tensioned tiebacks.
Anchored slope design was performed for upper limestone thicknesses of 10 feet for static and seismic conditions.

## *Design References*

- Rock Slope Engineering 4th edition, Wyllie and Mah, 2005
- PTI DC35.1-14, Recommendations for prestressed rock and soil anchors, 2014.
- Soil Nails Reference Manual, FHWA GEC 007, Federal Highway Publication No. FHWA-NHI-14-007.
- Structure Repsonse and Damage Produced by Ground Vibration from Surface Mine Blasting, US Department of Interior.

## *Design Assumptions*

1. Rock parameters were assumed from a back analysis of the west wall ground disturbance performed in RocPlane.
2. Existing west face slope angles were determined from a slope angle heat map from onXmaps.
3. Empricial strength values used due to decrease in cohesion during possible sliding (conservative)

tension crack length, RocPlane: $t_{cr} := 4.57 \cdot ft$

Joint cohesion, KUE: $c := 40 \cdot psf$

Joint friction angle, KUE: $\phi_{jt} := 25 \cdot deg$

Anchor inclination: $\phi_{st} := 45 \cdot deg$

Upper face length: $L_{up} := \frac{w_{up}}{\cos(\sigma_{up})} = 44.02\ ft$

Required tieback load: $T_{max} := 20 \cdot klf$ Iterative to achieve FS

per slope length

Area of sliding plane per linear foot: $A := \frac{(H - t_{cr})}{\sin(\sigma_{fp})} = 52.19\ ft$

Total resisting force, Wyllie & Mah:

$$F_{res} := c \cdot A + \left[T_{max} \cdot \sin((\sigma_{fp} + \phi_{st})) + F_{norm.exis} - F_{water}\right] \cdot \tan(\phi_{jt}) = 31.02 \cdot klf$$

Total driving force, Wyllie & Mah: $F_{driving} := F_{dr.exis} - T_{max} \cdot \cos(\sigma_{fp} + \phi_{st}) = 20.25 \cdot klf$

Factor of safety: $FS := \frac{F_{res}}{F_{driving}} = 1.5$

Pattern vertical spacing: $V_{sp} := 10 \cdot ft$

Pattern Horizontal spacing: $H_{sp} := 10 \cdot ft$

Required resisting force per anchor column: $T_{req} := T_{max} \cdot H_{sp} = 200 \cdot kip$

Number of anchors in column: $n := 1$

Required resisting force per anchor $T_{req\_an} := \frac{T_{req}}{n} = 200 \cdot kip$

**Tieback Anchor**

Multi strand anchors, class 1

Bond strength in lower Limestone layer: $BS := 150 \cdot psi$

Factor of safety - pullout: $FS_{po} := 2$

Anchor inclination from perpendicular to slope: $\phi_{st} = 45 \cdot deg$

Strand ultimate strength: $T_{t\_s} := 352 \cdot kip$ 6 strand

**Strand Anchor System** ASTM A416

| Number of Strands | Cross-Sectional Area (Aps) | Ultimate Load (fpu*Aps) | Maximum Jacking Load (0.8*fpu*Aps) | Maximum Design Load (0.6*fpu*Aps) | HDPE Tubing | Anchor Heads | Weight per Foot |
|---|---|---|---|---|---|---|---|
| 1 | 0.217 in² (140 mm²) | 58.6 kips (261 kN) | 46.9 kips (209 kN) | 35.2 kips (157 kN) | 3" nom. (3.5" OD) | C4.6 | 0.74 lbs (0.34 kg) |
| 2 | 0.434 in² (280 mm²) | 117 kips (522 kN) | 93.8 kips (418 kN) | 70.4 kips (314 kN) | 3" nom. (3.5" OD) | C4.6 | 1.48 lbs (0.67 kg) |
| 3 | 0.651 in² (420 mm²) | 176 kips (783 kN) | 141 kips (627 kN) | 106 kips (471 kN) | 3" nom. (3.5" OD) | C4.6 | 2.22 lbs (1.01 kg) |
| 4 | 0.868 in² (560 mm²) | 234 kips (1044 kN) | 188 kips (836 kN) | 141 kips (628 kN) | 3" nom. (3.5" OD) | C7.6 - Class 1 C4.6 - Class 2 | 2.96 lbs (1.34 kg) |
| 5 | 1.09 in² (700 mm²) | 293 kips (1305 kN) | 235 kips (1045 kN) | 176 kips (785 kN) | 3" nom. (3.5" OD) | C7.6 | 3.70 lbs (1.68 kg) |
| 6 | 1.30 in² (840 mm²) | 352 kips (1566 kN) | 281 kips (1254 kN) | 211 kips (942 kN) | 3" nom. (3.5" OD) | C7.6 | 4.44 lbs (2.01 kg) |
| 7 | 1.52 in² (980 mm²) | 410 kips (1827 kN) | 328 kips (1463 kN) | 246 kips (1099 kN) | 3" nom. (3.5" OD) | C7.6 | 5.18 lbs (2.35 kg) |
| 8 | 1.74 in² (1120 mm²) | 469 kips (2088 kN) | 375 kips (1672 kN) | 282 kips (1256 kN) | 3" nom. (3.5" OD) | C9.6 | 5.92 lbs (2.69 kg) |
| 9 | 1.95 in² (1260 mm²) | 527 kips (2349 kN) | 422 kips (1881 kN) | 317 kips (1413 kN) | 4" nom. (4.6" OD) | C9.6 | 6.66 lbs (3.02 kg) |
| 10 | 2.17 in² (1400 mm²) | 586 kips (2610 kN) | 469 kips (2090 kN) | 352 kips (1570 kN) | 4" nom. (4.6" OD) | C12.6 | 7.40 lbs (3.36 kg) |

Free length, PTI: $T_{fl} := 15 \cdot ft$ through upper limestone

Required tail length: $T_t := 2 \cdot ft$

Hole diameter: $d_t := 6 \cdot in$

Required bond length, PTI:

$$T_{bl} := \frac{T_{req\_an} \cdot FS_{po}}{3.14 \cdot BS \cdot d_t} = 11.8\ ft$$

Check strand tensile capacity (ASD):

$$Ckeck := \begin{cases} \text{"OK"} & \text{if } .6 \cdot T_{t\_s} \geq T_{req\_an} \\ \text{"WARNING"} & \text{otherwise} \end{cases} = \text{"OK"}$$

Anchor total length:

$$L_{total} := T_{fl} + T_{bl} + T_t = 28.8\ ft$$

$$L_{total} = 29\ ft$$

## ***Slope Stability support - Seismic***

Max highwall height - $H := 25 \cdot ft$

Peak ground acceleration coefficient (1000-yr return) - $PGA := 0.196$ AASHTO Fig. 3.10.2.1-1

Horizontal Response Spectral Acceleration coefficient - $S_1 := 0.082$ AASHTO Fig. 3.10.2.1-3

Thickness of limestone layer - $d_1 := 90 \cdot ft$

Thickness of shale layer - $d_2 := 0.5 \cdot ft$

Thickness of dolomite layer - $d_3 := 100 \cdot ft - d_1 - d_2 = 9.5\,ft$

Average blow counts in ground layer one - $N_1 := 100$

Average blow counts in ground layer two - $N_2 := 50$

Average blow counts in ground layer three - $N_3 := 100$

Average SPT over top 100 ft - $N_{bar} := \dfrac{d_1 + d_2 + d_3}{\dfrac{d_1}{N_1} + \dfrac{d_2}{N_2} + \dfrac{d_3}{N_3}} = 100$ Eq. 4.2

Site Class = A, Hard rock Table 4.8

Site adjustment factors - $F_{pga} := 0.8$ Table 4.9

$F_v := 0.8$ Table 4.10

Design peak ground accleration - $PGA_D := F_{pga} \cdot PGA = 0.16$ Eq. 4.3

Design site-corrected response acceleration - $S_{1D} := F_v \cdot S_1 = 0.07$ Eq. 4.4

Seismic Zone -

$$SZ := \begin{cases} \text{"Seismic Zone 1"} & \text{if } S_{1D} \le 0.15 \\ \text{"Seismic Zone 2"} & \text{if } S_{1D} > 0.15 \land S_{1D} \le 0.30 \\ \text{"Seismic Zone 3"} & \text{if } S_{1D} > 0.30 \land S_{1D} \le 0.50 \\ \text{"Seismic Zone 4+"} & \text{otherwise} \end{cases} = \text{"Seismic Zone 1"}$$

6.8.1

Calculated driving force, RocPlane: $F_{dr.exis} := 30975.47 \cdot plf$

Calculated existing normal force, RocPlane: $F_{norm.exis} := 40175.99 \cdot plf$

Calculated existing water force, RocPlane: $F_{water} := 660.17 \cdot plf$

Upper face angle, KUE: $\sigma_{up} := 28 \cdot deg$

Failure plane angle, KUE: $\sigma_{fp} := 30 \cdot deg$

Total height, RocPlane: $H := 30.666 \cdot ft$

Upper face width, RocPlane: $w_{up} := 38.867 \cdot ft$

tension crack length, RocPlane: $t_{cr} := 4.57 \cdot ft$

Joint cohesion, KUE: $c := 40 \cdot psf$

Joint friction angle, KUE: $\phi_{jt} := 25 \cdot deg$

Anchor inclination: $\phi_{st} := 45 \cdot deg$

Upper face length: $L_{up} := \dfrac{w_{up}}{\cos(\sigma_{up})} = 44.02\,ft$

Required tieback load: $T_{max} := 25 \cdot klf$ Iterative to achieve FS

per slope length

Area of sliding plane per linear foot: $A := \dfrac{(H - t_{cr})}{\sin(\sigma_{fp})} = 52.19\,ft$

Total resisting force, Wyllie & Mah:

$$F_{res} := c \cdot A + \left[T_{max} \cdot \sin\left(\left(\sigma_{fp} + \phi_{st}\right)\right) + F_{norm.exis} - F_{water}\right] \cdot \tan\left(\phi_{jt}\right) = 31.77 \cdot klf$$

Total driving force, Wyllie & Mah: $F_{driving} := F_{dr.exis} - T_{max} \cdot \cos\left(\sigma_{fp} + \phi_{st}\right) = 24.5 \cdot klf$

Factor of safety: $FS := \dfrac{F_{res}}{F_{driving}} = 1.3$

Pattern vertical spacing: $V_{sp} := 10 \cdot ft$

Pattern Horizontal spacing: $H_{sp} := 10 \cdot ft$

Required resisting force per anchor column: $T_{req} := T_{max} \cdot H_{sp} = 250 \cdot kip$

Number of anchors in column: $n := 1$

Required resisting force per anchor $T_{req\_an\_seis} := \dfrac{T_{req}}{n} = 250 \cdot kip$

**Tieback Anchor**

Multi strand anchors, class 1

Bond strength in lower Limestone layer: $BS := 150 \cdot psi$

Factor of safety - pullout: $FS_{po} := 1.5$ Seismic

Anchor inclination from perpendicular to slope: $\phi_{st} = 45 \cdot deg$

Strand ultimate strength: $T_{t\_s} := 352 \cdot kip$ 6 strand

**Strand Anchor System** ASTM A416

| Number of Strands | Cross-Sectional Area (Aps) | Ultimate Load (fpu*Aps) | Maximum Jacking Load (0.8*fpu*Aps) | Maximum Design Load (0.6*fpu*Aps) | HDPE Tubing | Anchor Heads | Weight per Foot |
|---|---|---|---|---|---|---|---|
| 1 | 0.217 in² (140 mm²) | 58.6 kips (261 kN) | 46.9 kips (209 kN) | 35.2 kips (157 kN) | 3" nom. (3.5" OD) | C4.6 | 0.74 lbs (0.34 kg) |
| 2 | 0.434 in² (280 mm²) | 117 kips (522 kN) | 93.8 kips (418 kN) | 70.4 kips (314 kN) | 3" nom. (3.5" OD) | C4.6 | 1.48 lbs (0.67 kg) |
| 3 | 0.651 in² (420 mm²) | 176 kips (783 kN) | 141 kips (627 kN) | 106 kips (471 kN) | 3" nom. (3.5" OD) | C4.6 | 2.22 lbs (1.01 kg) |
| 4 | 0.868 in² (560 mm²) | 234 kips (1044 kN) | 188 kips (836 kN) | 141 kips (628 kN) | 3" nom. (3.5" OD) | C7.6 - Class 1 C4.6 - Class 2 | 2.96 lbs (1.34 kg) |
| 5 | 1.09 in² (700 mm²) | 293 kips (1305 kN) | 235 kips (1045 kN) | 176 kips (785 kN) | 3" nom. (3.5" OD) | C7.6 | 3.70 lbs (1.68 kg) |
| 6 | 1.30 in² (840 mm²) | 352 kips (1566 kN) | 281 kips (1254 kN) | 211 kips (942 kN) | 3" nom. (3.5" OD) | C7.6 | 4.44 lbs (2.01 kg) |
| 7 | 1.52 in² (980 mm²) | 410 kips (1827 kN) | 328 kips (1463 kN) | 246 kips (1099 kN) | 3" nom. (3.5" OD) | C7.6 | 5.18 lbs (2.35 kg) |
| 8 | 1.74 in² (1120 mm²) | 469 kips (2088 kN) | 375 kips (1672 kN) | 282 kips (1256 kN) | 3" nom. (3.5" OD) | C9.6 | 5.92 lbs (2.69 kg) |
| 9 | 1.95 in² (1260 mm²) | 527 kips (2349 kN) | 422 kips (1881 kN) | 317 kips (1413 kN) | 4" nom. (4.6" OD) | C9.6 | 6.66 lbs (3.02 kg) |
| 10 | 2.17 in² (1400 mm²) | 586 kips (2610 kN) | 469 kips (2090 kN) | 352 kips (1570 kN) | 4" nom. (4.6" OD) | C12.6 | 7.40 lbs (3.36 kg) |

Free length, PTI: $T_{fl\_seis} := 15 \cdot ft$ through upper limestone

Required tail length: $T_{t\_seis} := 2 \cdot ft$

Hole diameter: $d_t := 4 \cdot in$

Required bond length, PTI: $T_{bl\_seis} := \frac{T_{req\_an} \cdot FS_{po}}{3.14 \cdot BS \cdot d_t} = 13.27\,ft$

Check strand tensile capacity (ASD): $Ckeck := \begin{cases} \text{"OK"} & \text{if } 0.75 \cdot T_{t\_s} \geq T_{req\_an} \\ \text{"WARNING"} & \text{otherwise} \end{cases} = \text{"OK"}$

Anchor total length: $L_{total\_seis} := T_{fl\_seis} + T_{bl\_seis} + T_{t\_seis} = 30.27\,ft$

$L_{total\_seis} = 30\,ft$

## *Blasting Impacts*

Peak particle velocity: $ppv := 0.3 \cdot \frac{in}{sec}$

Frequency: $f := 25 \cdot Hz$

Gravity: $g := 32.2 \cdot \frac{ft}{sec^2}$

Peak ground acceleration: $\alpha := \frac{2 \cdot \pi \cdot f \cdot ppv}{g} = 0.12$

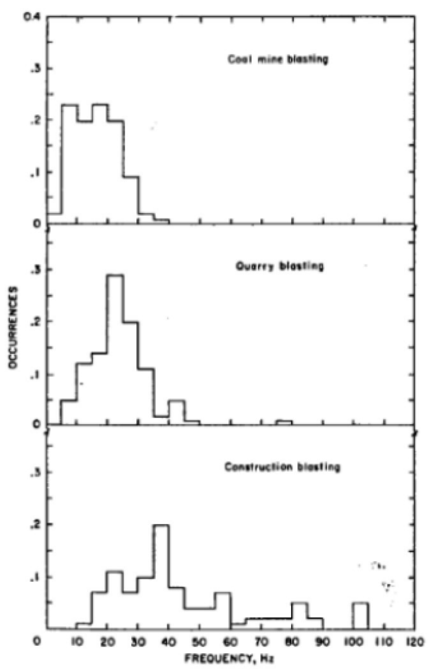



**Figure 2.—Predominant frequencies of vibrations from coal mine, quarry, and construction blasting.**

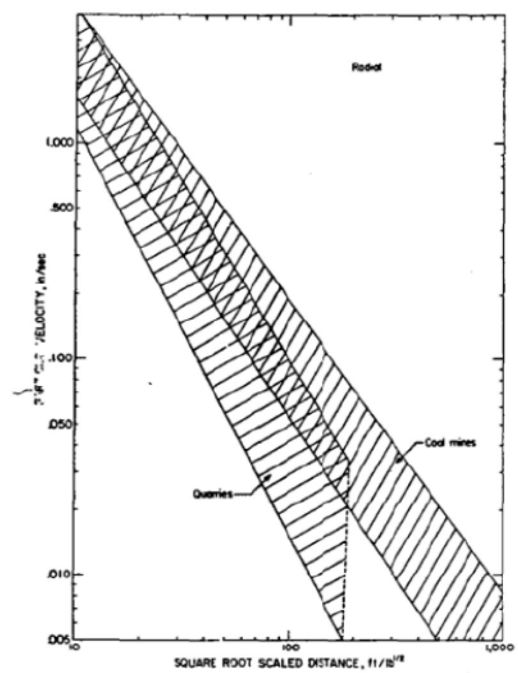



**Figure 11.—Zones of mean propagation regressions for two major types of blasting.**

$Ckeck := \begin{cases} \text{"Blasting Controls"} & \text{if } \alpha \ge k_h \\ \text{"Seismic Controls"} & \text{otherwise} \end{cases} = \text{"Seismic Controls"}$

## *Active Support Summary*

$Ckeck := \begin{cases} \text{"Static Controls"} & \text{if } T_{req\_an} \ge T_{req\_an\_seis} \\ \text{"Seismic Controls"} & \text{otherwise} \end{cases} = \text{"Seismic Controls"}$

# Technical Summary

## *Scope*

Preliminary design of active stabilization of the Mid Continent Mine utilizing tensioned tiebacks. Anchored slope design was performed for upper limestone thicknesses of 15 feet for static and seismic conditions.

## *Design References*

- Rock Slope Engineering 4th edition, Wyllie and Mah, 2005
- PTI DC35.1-14, Recommendations for prestressed rock and soil anchors, 2014.
- Soil Nails Reference Manual, FHWA GEC 007, Federal Highway Publication No. FHWA-NHI-14-007.
- Structure Repsonse and Damage Produced by Ground Vibration from Surface Mine Blasting, US Department of Interior.

## *Design Assumptions*

1. Rock parameters were assumed from a back analysis of the west wall ground disturbance performed in RocPlane.
2. Existing west face slope angles were determined from a slope angle heat map from onXmaps.
3. Empricial strength values used due to decrease in cohesion during possible sliding (conservative)

tension crack length, RocPlane: $t_{cr} := 6.479 \cdot ft$

Joint cohesion, KUE: $c := 40 \cdot psf$

Joint friction angle, KUE: $\phi_{jt} := 25 \cdot deg$

Anchor inclination: $\phi_{st} := 45 \cdot deg$

Upper face length: $L_{up} := \dfrac{w_{up}}{\cos(\sigma_{up})} = 80.72\ ft$

Required tieback load: $T_{max} := 55 \cdot klf$ Iterative to achieve FS

per slope length

Area of sliding plane per linear foot: $A := \dfrac{(H - t_{cr})}{\sin(\sigma_{fp})} = 92.83\ ft$

Total resisting force, Wylie & Mah:

$$F_{res} := c \cdot A + \left[T_{max} \cdot \sin((\sigma_{fp} + \phi_{st})) + F_{norm.exis} - F_{water}\right] \cdot \tan(\phi_{jt}) = 80.88 \cdot klf$$

Total driving force, Wyllie & Mah: $F_{driving} := F_{dr.exis} - T_{max} \cdot \cos(\sigma_{fp} + \phi_{st}) = 52.91 \cdot klf$

Factor of safety: $FS := \dfrac{F_{res}}{F_{driving}} = 1.5$

Pattern vertical spacing: $V_{sp} := 10 \cdot ft$

Pattern Horizontal spacing: $H_{sp} := 10 \cdot ft$

Required resisting force per anchor column: $T_{req} := T_{max} \cdot H_{sp} = 550 \cdot kip$

Number of anchors in column: $n := 2$

Required resisting force per anchor $T_{req\_an} := \frac{T_{req}}{n} = 275 \cdot kip$

**Tieback Anchor**

Multi strand anchors, class 1

Bond strength in lower Limestone layer: $BS := 150 \cdot psi$

Factor of safety - pullout: $FS_{po} := 2$

Anchor inclination from perpendicular to slope: $\phi_{st} = 45 \cdot deg$

Strand ultimate strength: $T_{t\_s} := 469 \cdot kip$ 8 strand

**Strand Anchor System** ASTM A416

| Number of Strands | Cross-Sectional Area (Aps) | Ultimate Load (fpu*Aps) | Maximum Jacking Load (0.8*fpu*Aps) | Maximum Design Load (0.6*fpu*Aps) | HDPE Tubing | Anchor Heads | Weight per Foot |
|---|---|---|---|---|---|---|---|
| 1 | 0.217 in² (140 mm²) | 58.6 kips (261 kN) | 46.9 kips (209 kN) | 35.2 kips (157 kN) | 3" nom. (3.5" OD) | C4.6 | 0.74 lbs (0.34 kg) |
| 2 | 0.434 in² (280 mm²) | 117 kips (522 kN) | 93.8 kips (418 kN) | 70.4 kips (314 kN) | 3" nom. (3.5" OD) | C4.6 | 1.48 lbs (0.67 kg) |
| 3 | 0.651 in² (420 mm²) | 176 kips (783 kN) | 141 kips (627 kN) | 106 kips (471 kN) | 3" nom. (3.5" OD) | C4.6 | 2.22 lbs (1.01 kg) |
| 4 | 0.868 in² (560 mm²) | 234 kips (1044 kN) | 188 kips (836 kN) | 141 kips (628 kN) | 3" nom. (3.5" OD) | C7.6 - Class 1 C4.6 - Class 2 | 2.96 lbs (1.34 kg) |
| 5 | 1.09 in² (700 mm²) | 293 kips (1305 kN) | 235 kips (1045 kN) | 176 kips (785 kN) | 3" nom. (3.5" OD) | C7.6 | 3.70 lbs (1.68 kg) |
| 6 | 1.30 in² (840 mm²) | 352 kips (1566 kN) | 281 kips (1254 kN) | 211 kips (942 kN) | 3" nom. (3.5" OD) | C7.6 | 4.44 lbs (2.01 kg) |
| 7 | 1.52 in² (980 mm²) | 410 kips (1827 kN) | 328 kips (1463 kN) | 246 kips (1099 kN) | 3" nom. (3.5" OD) | C7.6 | 5.18 lbs (2.35 kg) |
| 8 | 1.74 in² (1120 mm²) | 469 kips (2088 kN) | 375 kips (1672 kN) | 282 kips (1256 kN) | 3" nom. (3.5" OD) | C9.6 | 5.92 lbs (2.69 kg) |
| 9 | 1.95 in² (1260 mm²) | 527 kips (2349 kN) | 422 kips (1881 kN) | 317 kips (1413 kN) | 4" nom. (4.6" OD) | C9.6 | 6.66 lbs (3.02 kg) |
| 10 | 2.17 in² (1400 mm²) | 586 kips (2610 kN) | 469 kips (2090 kN) | 352 kips (1570 kN) | 4" nom. (4.6" OD) | C12.6 | 7.40 lbs (3.36 kg) |

Free length, PTI: $T_{fl} := 15 \cdot ft$ through upper limestone

Required tail length: $T_t := 2 \cdot ft$

Hole diameter: $d_t := 6 \cdot in$

Required bond length, PTI:

$$T_{bl} := \frac{T_{req\_an} \cdot FS_{po}}{3.14 \cdot BS \cdot d_t} = 16.22\ ft$$

Check strand tensile capacity (ASD):

$$Ckeck := \begin{cases} \text{"OK"} & \text{if } .6 \cdot T_{t\_s} \geq T_{req\_an} \\ \text{"WARNING"} & \text{otherwise} \end{cases} = \text{"OK"}$$

Anchor total length:

$$L_{total} := T_{fl} + T_{bl} + T_t = 33.22\ ft$$

$$L_{total} = 33\ ft$$

## *Slope Stability support - Seismic*

Max highwall height - $H := 25 \cdot ft$

Peak ground acceleration coefficient (1000-yr return) - $PGA := 0.196$ AASHTO Fig. 3.10.2.1-1

Horizontal Response Spectral Acceleration coefficient - $S_1 := 0.082$ AASHTO Fig. 3.10.2.1-3

Thickness of limestone layer - $d_1 := 90 \cdot ft$

Thickness of shale layer - $d_2 := 0.5 \cdot ft$

Thickness of dolomite layer - $d_3 := 100 \cdot ft - d_1 - d_2 = 9.5\,ft$

Average blow counts in ground layer one - $N_1 := 100$

Average blow counts in ground layer two - $N_2 := 50$

Average blow counts in ground layer three - $N_3 := 100$

Average SPT over top 100 ft - $$N_{bar} := \frac{d_1 + d_2 + d_3}{\frac{d_1}{N_1} + \frac{d_2}{N_2} + \frac{d_3}{N_3}} = 100$$ Eq. 4.2

Site Class = A, Hard rock Table 4.8

Site adjustment factors - $F_{pga} := 0.8$ Table 4.9

$F_v := 0.8$ Table 4.10

Design peak ground accleration - $PGA_D := F_{pga} \cdot PGA = 0.16$ Eq. 4.3

Design site-corrected response acceleration - $S_{1D} := F_v \cdot S_1 = 0.07$ Eq. 4.4

Seismic Zone -

$$SZ := \begin{cases} \text{"Seismic Zone 1"} & \text{if } S_{1D} \le 0.15 \\ \text{"Seismic Zone 2"} & \text{if } S_{1D} > 0.15 \wedge S_{1D} \le 0.30 \\ \text{"Seismic Zone 3"} & \text{if } S_{1D} > 0.30 \wedge S_{1D} \le 0.50 \\ \text{"Seismic Zone 4+"} & \text{otherwise} \end{cases} = \text{"Seismic Zone 1"}$$ 6.8.1

Calculated driving force, RocPlane: $F_{dr.exis} := 81796.53 \cdot plf$

Calculated existing normal force, RocPlane: $F_{norm.exis} := 105871.37 \cdot plf$

Calculated existing water force, RocPlane: $F_{water} := 1964.16 \cdot plf$

Upper face angle, KUE: $\sigma_{up} := 28 \cdot deg$

Failure plane angle, KUE: $\sigma_{fp} := 30 \cdot deg$

Total height, RocPlane: $H := 52.896 \cdot ft$

Upper face width, RocPlane: $w_{up} := 71.271 \cdot ft$

tension crack length, RocPlane: $t_{cr} := 6.479 \cdot ft$

Joint cohesion, KUE: $c := 40 \cdot psf$

Joint friction angle, KUE: $\phi_{jt} := 25 \cdot deg$

Anchor inclination: $\phi_{st} := 45 \cdot deg$

Upper face length: $$L_{up} := \frac{w_{up}}{\cos(\sigma_{up})} = 80.72\ ft$$

Required tieback load: $T_{max} := 69 \cdot klf$ Iterative to achieve FS

per slope length

Area of sliding plane per linear foot: $$A := \frac{(H - t_{cr})}{\sin(\sigma_{fp})} = 92.83\ ft$$

Total resisting force, Wyllie & Mah:

$$F_{res} := c \cdot A + \left[T_{max} \cdot \sin\left(\left(\sigma_{fp} + \phi_{st}\right)\right) + F_{norm.exis} - F_{water}\right] \cdot \tan\left(\phi_{jt}\right) = 83.24 \cdot klf$$

Total driving force, Wyllie & Mah: $F_{driving} := F_{dr.exis} - T_{max} \cdot \cos\left(\sigma_{fp} + \phi_{st}\right) = 63.94 \cdot klf$

Factor of safety: $FS := \frac{F_{res}}{F_{driving}} = 1.3$

Pattern vertical spacing: $V_{sp} := 10 \cdot ft$

Pattern Horizontal spacing: $H_{sp} := 10 \cdot ft$

Required resisting force per anchor column: $T_{req} := T_{max} \cdot H_{sp} = 690 \cdot kip$

Number of anchors in column: $n := 2$

Required resisting force per anchor $T_{req\_an\_seis} := \frac{T_{req}}{n} = 345 \cdot kip$

**Tieback Anchor**

Multi strand anchors, class 1

Bond strength in lower Limestone layer: $BS := 150 \cdot psi$

Factor of safety - pullout: $FS_{po} := 1.5$ Seismic

Anchor inclination from perpendicular to slope: $\phi_{st} = 45 \cdot deg$

Strand ultimate strength: $T_{us} := 469 \cdot kip$ 8 strand

## Strand Anchor System

ASTM A416

| Number of Strands | Cross-Sectional Area (Aps) | Ultimate Load (fpu*Aps) | Maximum Jacking Load (0.8*fpu*Aps) | Maximum Design Load (0.6*fpu*Aps) | HDPE Tubing | Anchor Heads | Weight per Foot |
|---|---|---|---|---|---|---|---|
| 1 | 0.217 in² (140 mm²) | 58.6 kips (261 kN) | 46.9 kips (209 kN) | 35.2 kips (157 kN) | 3" nom. (3.5" OD) | C4.6 | 0.74 lbs (0.34 kg) |
| 2 | 0.434 in² (280 mm²) | 117 kips (522 kN) | 93.8 kips (418 kN) | 70.4 kips (314 kN) | 3" nom. (3.5" OD) | C4.6 | 1.48 lbs (0.67 kg) |
| 3 | 0.651 in² (420 mm²) | 176 kips (783 kN) | 141 kips (627 kN) | 106 kips (471 kN) | 3" nom. (3.5" OD) | C4.6 | 2.22 lbs (1.01 kg) |
| 4 | 0.868 in² (560 mm²) | 234 kips (1044 kN) | 188 kips (836 kN) | 141 kips (628 kN) | 3" nom. (3.5" OD) | C7.6 - Class 1 C4.6 - Class 2 | 2.96 lbs (1.34 kg) |
| 5 | 1.09 in² (700 mm²) | 293 kips (1305 kN) | 235 kips (1045 kN) | 176 kips (785 kN) | 3" nom. (3.5" OD) | C7.6 | 3.70 lbs (1.68 kg) |
| 6 | 1.30 in² (840 mm²) | 352 kips (1566 kN) | 281 kips (1254 kN) | 211 kips (942 kN) | 3" nom. (3.5" OD) | C7.6 | 4.44 lbs (2.01 kg) |
| 7 | 1.52 in² (980 mm²) | 410 kips (1827 kN) | 328 kips (1463 kN) | 246 kips (1099 kN) | 3" nom. (3.5" OD) | C7.6 | 5.18 lbs (2.35 kg) |
| 8 | 1.74 in² (1120 mm²) | 469 kips (2088 kN) | 375 kips (1672 kN) | 282 kips (1256 kN) | 3" nom. (3.5" OD) | C9.6 | 5.92 lbs (2.69 kg) |
| 9 | 1.95 in² (1260 mm²) | 527 kips (2349 kN) | 422 kips (1881 kN) | 317 kips (1413 kN) | 4" nom. (4.6" OD) | C9.6 | 6.66 lbs (3.02 kg) |
| 10 | 2.17 in² (1400 mm²) | 586 kips (2610 kN) | 469 kips (2090 kN) | 352 kips (1570 kN) | 4" nom. (4.6" OD) | C12.6 | 7.40 lbs (3.36 kg) |

Free length, PTI: $T_{fl\_seis} := 15 \cdot ft$ through upper limestone

Required tail length: $T_{t\_seis} := 2 \cdot ft$

Hole diameter: $d_t := 4 \cdot in$

Required bond length, PTI: $T_{bl\_seis} := \frac{T_{req\_an} \cdot FS_{po}}{3.14 \cdot BS \cdot d_t} = 18.25\, ft$

Check strand tensile capacity (ASD): $Ckeck := \begin{cases} \text{"OK"} & \text{if } 0.75 \cdot T_{t\_s} \geq T_{req\_an} \\ \text{"WARNING"} & \text{otherwise} \end{cases} = \text{"OK"}$

Anchor total length: $L_{total\_seis} := T_{fl\_seis} + T_{bl\_seis} + T_{t\_seis} = 35.25\, ft$

$L_{total\_seis} = 35\, ft$

## *Blasting Impacts*

Peak particle velocity: $ppv := 0.3 \cdot \frac{in}{sec}$

Frequency: $f := 25 \cdot Hz$

Gravity: $g := 32.2 \cdot \frac{ft}{sec^2}$

Peak ground acceleration: $\alpha := \frac{2 \cdot \pi \cdot f \cdot ppv}{g} = 0.12$ percent

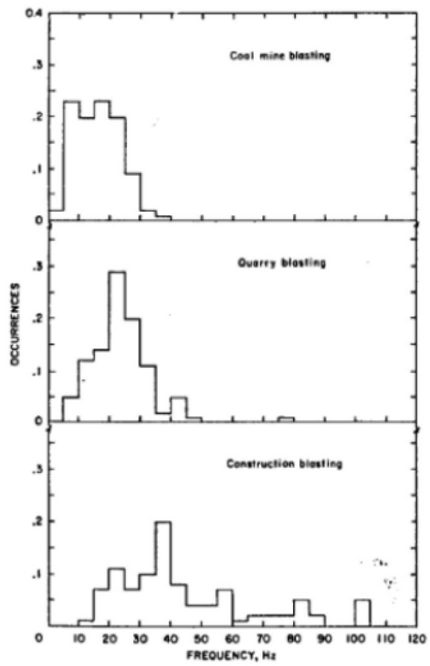



**Figure 2.—Predominant frequencies of vibrations from coal mine, quarry, and construction blasting.**

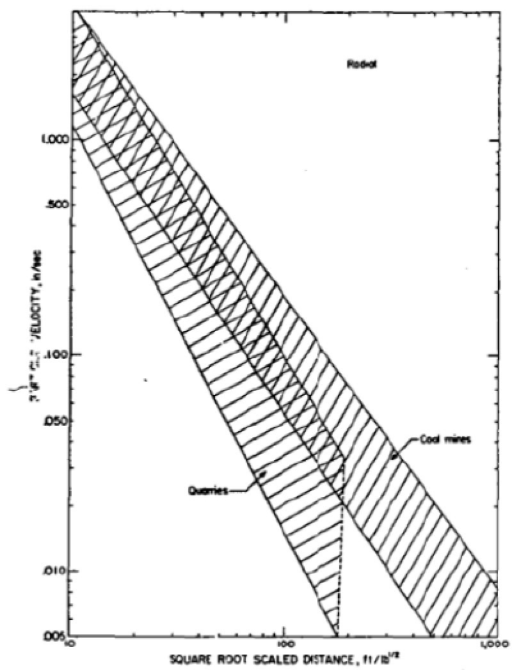



**Figure 11.—Zones of mean propagation regressions for two major types of blasting.**

Ckeck := | "Blasting Controls" if $\alpha \geq k_h$ = "Seismic Controls"
| "Seismic Controls" otherwise

## *Active Support Summary*

Ckeck := | "Static Controls" if $T_{req\_an} \geq T_{req\_an\_seis}$ = "Seismic Controls"
| "Seismic Controls" otherwise