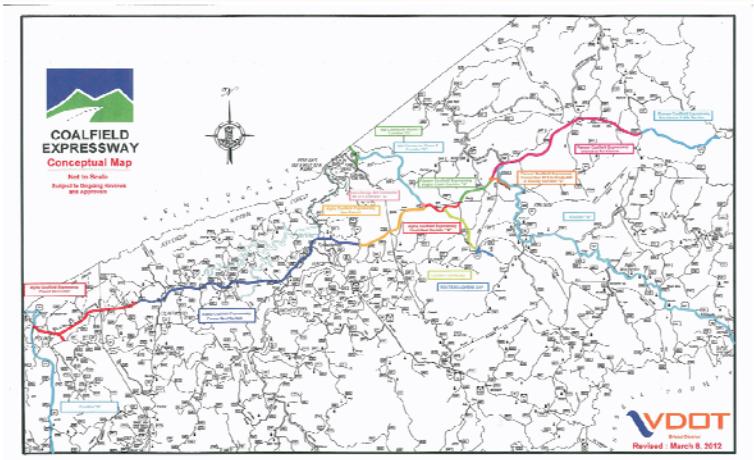
S&ME

"Geotechnical Design Challenges for Corridor Q US460 Connector in SW Virginia"

Joe Young, P.E.

S&ME

COALFIELDS EXPRESSWAY



S&ME

US 460, BRIDGE ON SECTION I

S&ME

Project Scope

- 6.2 miles of new four-lane divided highway
- Only one intersection (Route 609)
- 25 cut areas up to 215 feet deep
- 25 fill areas up to 187 feet high.

Exploration

- Exploration occurred August 4, 2013 and November 3, 2013 and April 4, 2014 and April 7, 2014
- 88 borings for the roadway alignment
- 3 borings for the State Route 609 interchange
- 3 borings for potential borrow sources
- 68 highwall test pits
- 17 toe-of-fill test pits
- 5 test pits in severely weathered, soil-like sandstone

LABORATORY TESTING

Test Description	ASTM Designation	Number of Tests Performed
Unconfined Compressive Strength Test – Rock Core	D 7012, Method C	104
Slake Durability Index Test	D 4644, 5-Cycle Modification	274
Atterberg Limits	D 4318	17
Particle Size Analyses	D 422	17
Standard Proctor Test	D 698, Method A	2
Flexible Wall Permeability Test	D 5084	4
Consolidation Test	D 2435	2
Consolidated Undrained (CU) Triaxial Test	D 4767	4

S&ME

METHODOLOGY

- Global stability analyses were performed using Slide (Version 6.0) developed by Rocscience, Inc.
- Global slope stability analyses were performed on the embankment slopes Spencer's method (Spencer, 1967)
  - Deterministic approach
  - 3-foot thick layer of durable sandstone fill at base (drainage layer)
  - Circular failure mode
- Reinforced soil slopes were analyzed using ReSSA (Version 3.0) developed by Adama Engineering Inc.
  - 2-D limit equilibrium slope stability (internal and global)
  - translational
  - three-part wedge failure analyses
- Reliability analyses were performed for each embankment slope analyzed
  - J. Michael Duncan's *Factors of Safety and Reliability in Geotechnical Engineering* article (dated April 2000).
  - Probability of success equal to or greater than 99 percent required
  - Estimated standard deviation using the three-sigma-rule (3σ)
  - Lowest conceivable values (LCV) and highest conceivable values (HCV)

S&ME

VDOT ROCK CUT SLOPE DESIGN CRITERIA

Bedrock Category	SRQD (%)	UCS (psi)	Slop Ratio (H:V)[1,4]	Max. Height Between Benches[3] (ft)
		> 5,000	½H:1V[2]	
A	>70	3,000-5,000	½H:1V	40
		<3,000	IH:IV	
		>5,000	½H:1V	
B	51-70	3,000-5,000	½H:1V	40
		<3,000	IH:IV	
		>5,000	½H:1V	
C	20-50	3,000-5,000	IH:IV	40
		<3,000	IH:IV	
D	<20%	NA	1.5H:1V	NA

S&ME

PARAMETERS USED FOR GLOBAL STABILITY ANALYSES – CUT SLOPES

Geologic Unit/Material	UCS (psf)	m_i	GSI	D	Φ (degrees) (6)	c (ksf) (7)
Overburden Soil	N/A	N/A	N/A	N/A	27	N/A
Weathered Sandstone	631,400	13	30	0.7	33.1	3.3
Weathered Shale	442,200	5	25	0.7	20.0	1.7
Campbell Creek Sandstone	1,965,700	19	70	0.8	58.8	26.5
Betsie Shale	2,193,300	6	40	0.8	37.2	6.4
Clintwood Sandstone	1,750,100	19	70	0.8	58.1	24.4
Lyons Shale	427,400	6	25	0.8	18.6	1.6
Dorchester Sandstone	826,600	18	65	0.8	51.5	11.7
Dorchester Shale	978,600	6	25	0.8	23.5	2.3
Gladeville Sandstone	1,933,500	18	65	0.8	56.7	19.9
Norton Shale	1,489,400	6	35	0.8	32.1	4.2
Norton Sandstone	1,365,000	17	60	0.8	52.5	12.5
Lower Norton Sandstone	1,983,400	19	70	0.8	58.6	26.9
Eagle Shales	1,085,300	6	35	0.8	31.5	3.2
Hagy Sandstone	2,323,800	19	70	0.8	59.4	30.4
Upper Hagy Shales	1,329,700	6	40	0.8	34.0	4.9
Lower Hagy Shales			(2)			
Lower Hagy Sandstone			(3)			
Upper Splashdam Shales	1,038,600	6	35	0.8	29.5	3.6
Splashdam Shales			(4)			
Lower Splashdam Shale			(5)			
Overburden Soil	N/A	N/A	N/A	N/A	27	N/A
Lower Splashdam Sandstone (1)	1,398,000	17	60	0.8	52.8	12.6
Upper Banner Sandstone (1)	2,191,100	19	70	0.8	59.1	29.1
Banner Shale	2,048,100	6	40	0.8	36.8	6.2
Coal	100,000	4	20	0.8	10.4	0.4

S&ME

Parameters Used For Global Stability Analyses – Cut Slopes Notes

(1) Phase I Parameters

(2) Combined test results with Upper Hagy Shale test results.

(3) Combined test results with Hagy Sandstone test results.

(4) Combined test results with Upper Splashdam Shale test results.

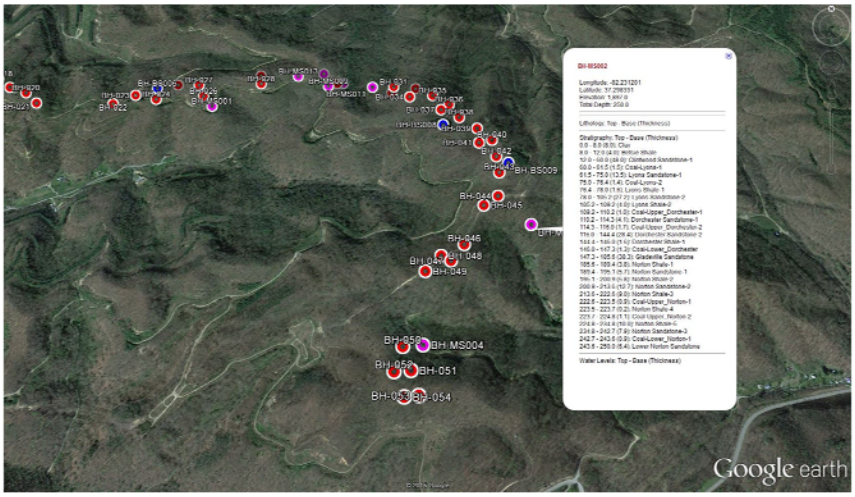
(5) Lower Splashdam Shale was weathered where encountered. Used Weathered Shale parameters in the analyses.

(6) Effective friction angles calculated with Hoek-Brown Criterion for bedrock material.

(7) Effective cohesion values calculated with Hoek-Brown Criterion for bedrock material.

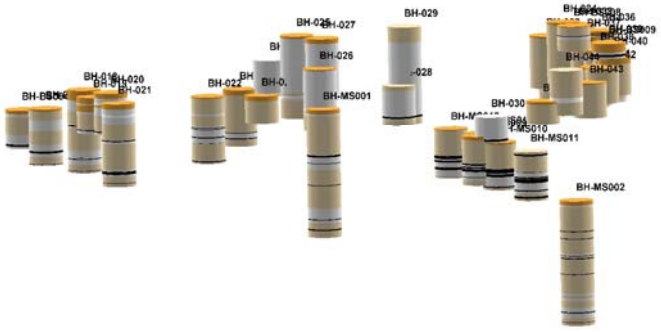
S&ME

EXAMPLE BOREHOLE LOCATIONS

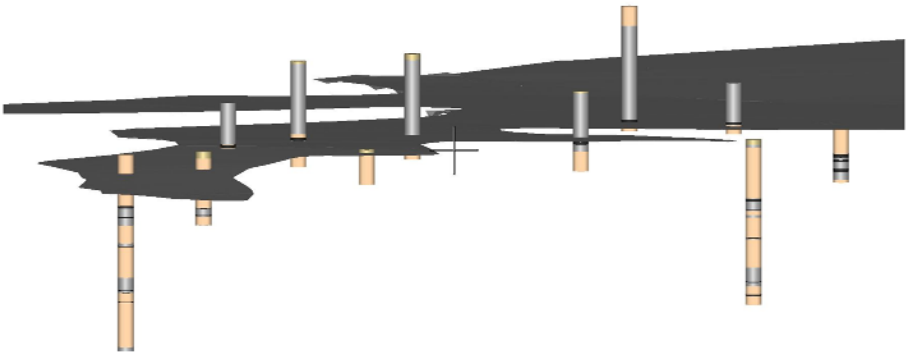


S&ME

3D BOREHOLE STRATA EXAMPLE



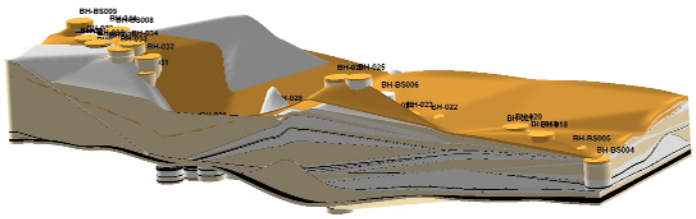
GINT LOGS WITH COAL SEAMS



Used Rockworks to create the InRoads DTM of the Coal Seam.

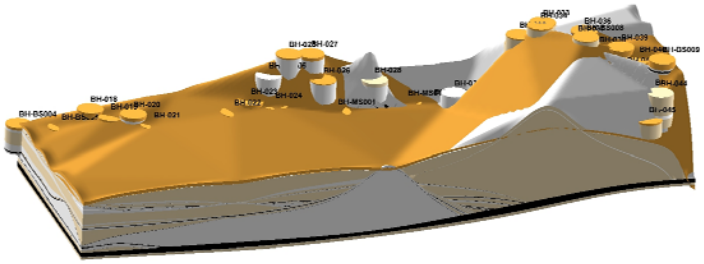
The main benefit of Rockworks, that all of the borings were along the proposed alignment.

3D BOREHOLE STRATA EXAMPLE



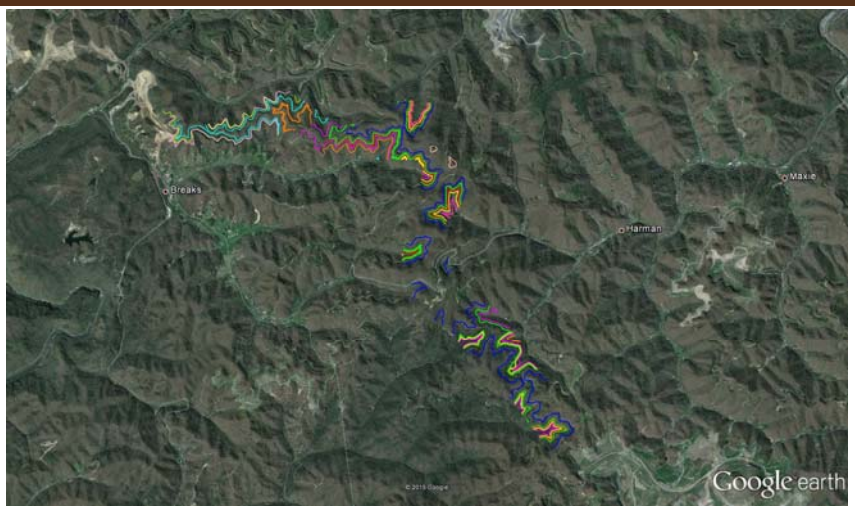
S&ME

3D BOREHOLE STRATA EXAMPLE



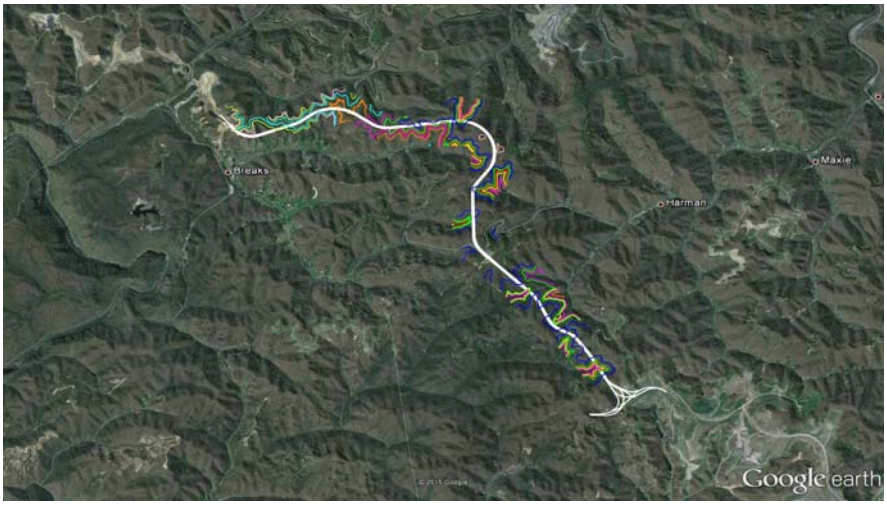
S&ME

COAL SEAM OUTCROPS



S&ME

COAL SEAM OUTCROPS W/CL



S&ME

ZOOMED COAL OUTCROPS & CL

FIELD DATA COLLECTION

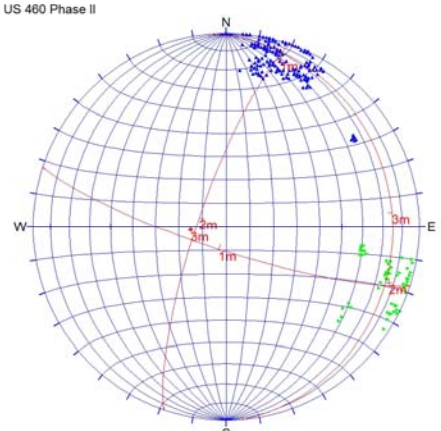
Portion of cut at the end of Phase I/beginning of Phase II

Portion of cut at Bull Gap

- DOCUMENTED ROCK AND COAL OUTCROPS
- MEASURED STRIKE AND DIP
- DOCUMENTED BEDDING THICKNESS
- MEASURED JOINT ANGLES AND ORIENTATION

STEREONET

US 460 Phase II



BEDDING/JOINT

- Bedding [1]
- Primary Joint [182]
- Secondary Joint [64]

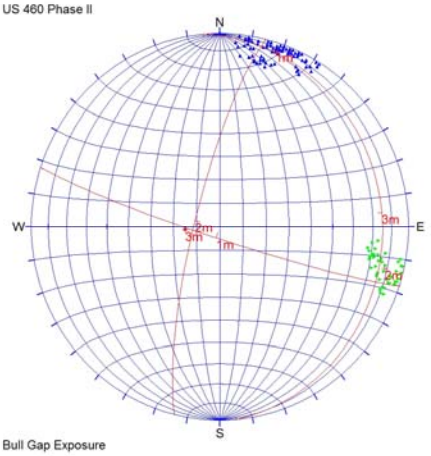
Equal Area
Lower Hemisphere
247 Poles
247 Entries

End of Phase I/Beginning of Phase II Cut Area

S&ME

STEREONET

US 460 Phase II



BEDDING/JOINT

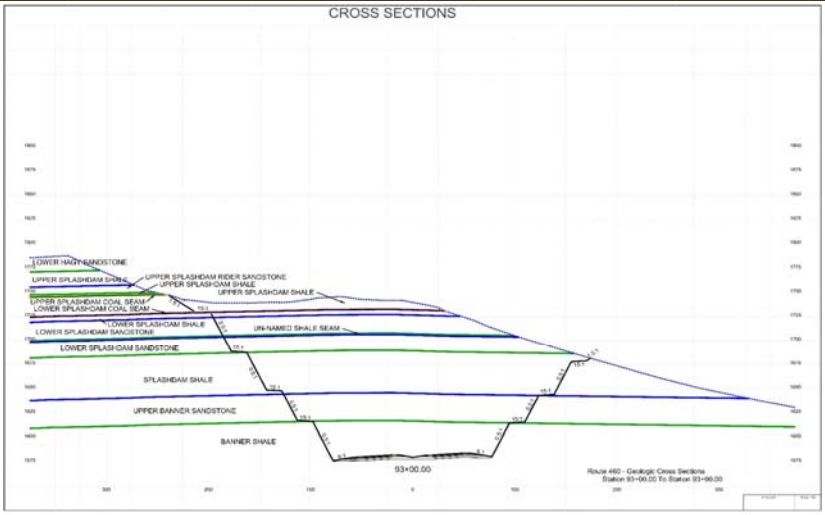
- Bedding [1]
- Primary Joint [98]
- Secondary Joint [45]

Equal Area
Lower Hemisphere
144 Poles
144 Entries

Bull Gap Exposure

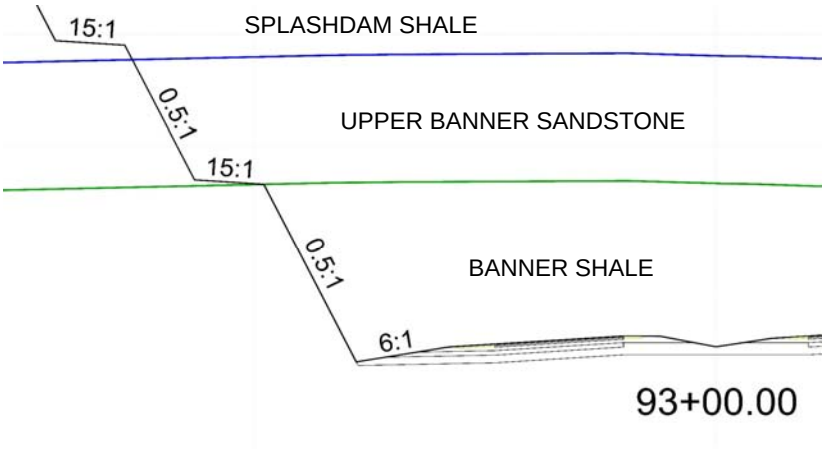
S&ME

CATCHMENT DESIGN TYPICAL



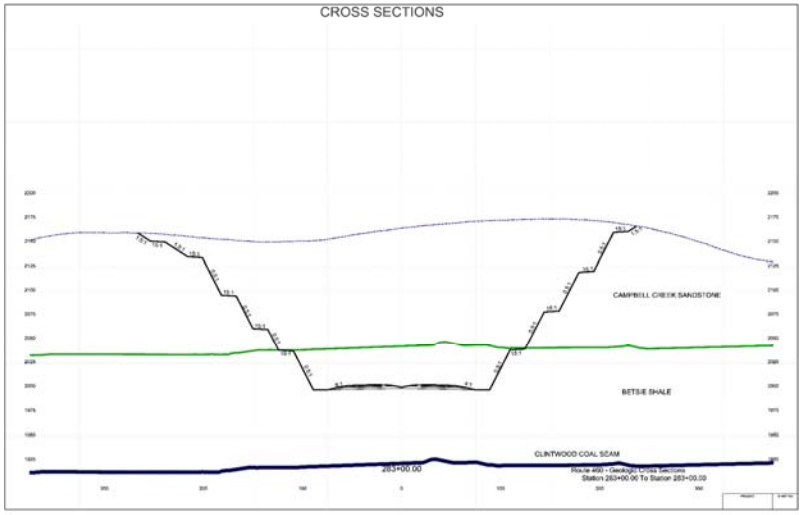
S&ME

CATCHMENT DESIGN DETAIL



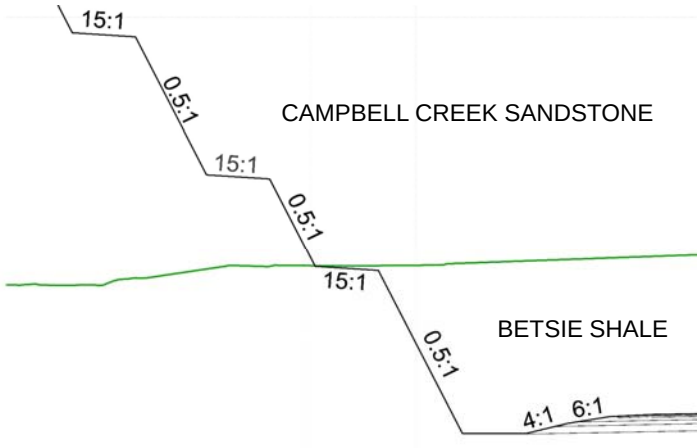
S&ME

CATCHMENT DESIGN COMPOSITE



S&ME

CATCHMENT DESIGN COMPOSITE DETAIL



S&ME

STA. 364+50 CUT SLOPE GEOMETRY

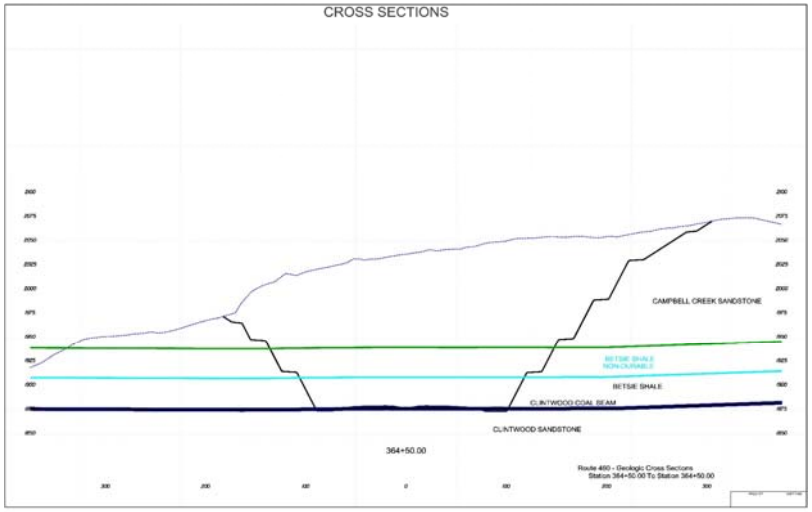
Summary of Cut Slope Geometry
Cut 19 Stations 359+50 to 366+00
US 460 Connector - Phase II
Buchanan County, Virginia

Geologic Unit	Slake Durability Index, 5-Cycle	SRQD	UCS (psi)	Bedrock Category	Max. Slope Configuration (H:V)
Completely Weathered Sandstone (Soil)	N/A	N/A	N/A	N/A	2:1
Weathered Sandstone [1]	16.3 - 86.9	32 - 72	1,128 - 4,777	C - D	1.5:1
Campbell Creek Sandstone	89.1 - 95.6	41 - 46	4,415 - 14,122	C	0.5:1
Betsie Shale	85.7 - 95.0	68 - 80	5,661 - 10,171	A-B	0.5:1

(1) Range of Weathered Sandstone (Campbell Creek) test results from Borings BH-046, BH-049, BH-079, BH-081, and BH-609-01

Borings: 13BH-072
13BH-073
13BH-074

STA. 364+50 CRSP



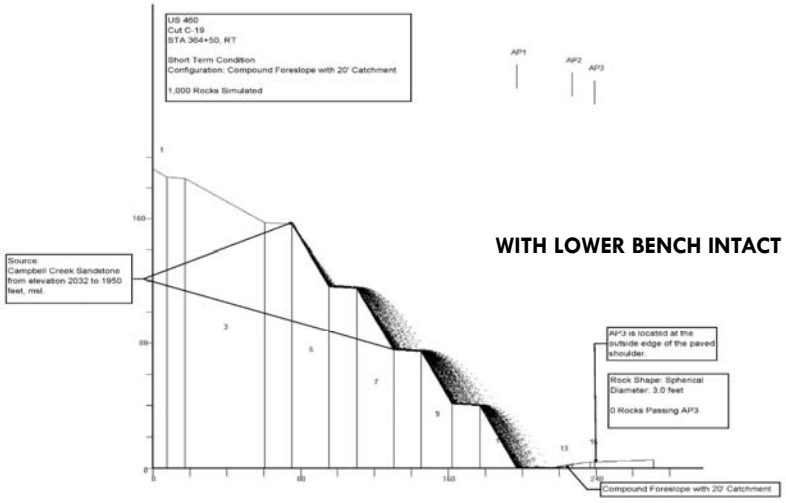
STA. 364+50 CRSP PARAMETERS

Parameters used for Rockfall (CRSP) Analyses

Geologic Unit/Material	Surface Roughness	Tangential Coefficient	Normal Coefficient	Unit Wt. (pcf)
Overburden Soil	0.5	0.65	0.2	125.0
Weathered Sandstone	0.5	0.8	0.2	141.8
Weathered Shale	0.5	0.8	0.2	149.6
Betsie Shale	0.5	0.8	0.2	165.7
Clintwood Sandstone	0.5	0.9	0.25	159.7
Gladeville Sandstone	0.5	0.8	0.2	161.3
Norton Shale	0.5	0.8	0.2	160.2
Norton Sandstone	0.5	0.85	0.25	156.9
Hagy Sandstone	0.5	0.9	0.25	161.0
Coal	N/A	N/A	N/A	80.0
Rockfall Containment Ditch	0.5	0.65	0.2	
Talus Buildup on Benches below Shale Units	0.5	0.7	0.2	N/A
Roadway	0.25	0.25	1	N/A

S&ME

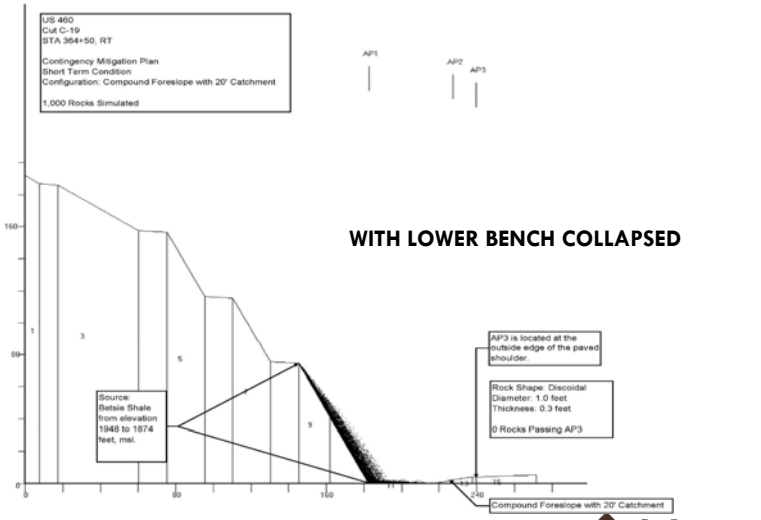
STA. 364+50 CRSP AND SLIDE ANALYSES



WITH LOWER BENCH INTACT

S&ME

STA. 364+50 CRSP



COAL SEAM MITIGATION

TABLE 22 – Anticipated Mitigation Measures

Note	Station		Offset	Feature	Seam	Action Required
	Begin	End				
1	115+00	117+00	L-CL-R	Coal within close proximity of rough grade	Lower Splashdam	Undercut coal per Table 20 of Geotechnical Report
2	115+00	117+50	Left	Auger / Highwall Miner holes	Upper Splashdam	Backstow openings in slope
3	117+50	118+50	L-CL-R	Coal within close proximity of rough grade	Upper Splashdam	Undercut coal per Table 20 of Geotechnical Report
4	121+25	128+50	Left	Deep mine openings, Auger / Highwall Miner holes	Hagy	Backstow openings in slope
5	125+00	128+50	Right	Deep mine openings, Auger / Highwall Miner holes	Hagy	Backstow openings in slope
6	128+00	130+50	L-CL-R	Deep mine mitigation, coal within close proximity of rough grade	Hagy	Undercut coal per Table 20 of Geotechnical Report
7	156+00	157+00	L-CL-R	Coal within close proximity of rough grade	Lower Norton	Undercut coal per Table 20 of Geotechnical Report
8	168+00	171+00	L-CL-R	Coal within close proximity of rough grade	Upper Norton	Undercut coal per Table 20 of Geotechnical Report
9	180+00	183+00	L-CL-R	Coal within close proximity of rough grade	Lyons	Undercut coal per Table 20 of Geotechnical Report
10	190+00	199+00	Left	Auger / Highwall Miner holes	Clintwood	Backstow openings in slope

AUGER MINING

UNDERGROUND MINING

THIN SEAM MINING

S&ME

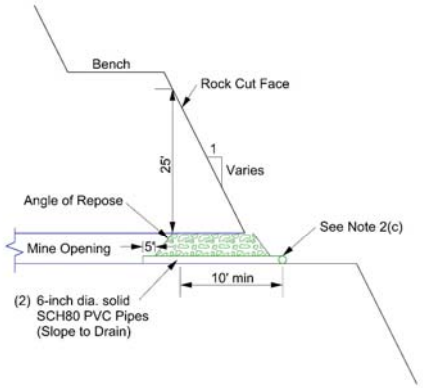
INTACT COAL SEAMS

S&ME

COAL SEAM MITIGATION

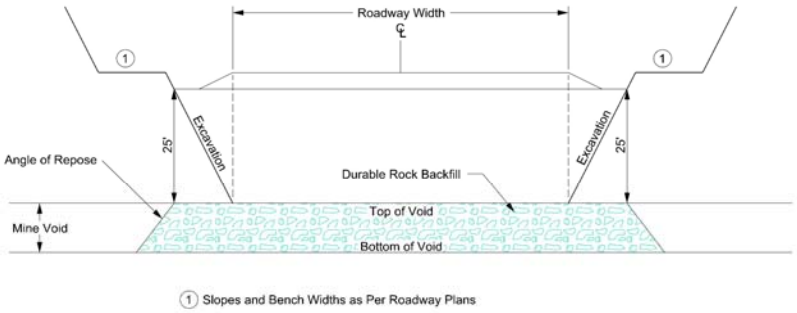
- **MINE VOID EXPOSED IN CUT SLOPE OR AT-GRADE MINE OPENINGS**
- **UNDERGROUND MINING BENEATH PLANNED ROADWAY**
- **MINE VOIDS COVERED BY EMBANKMENT**
- **MITIGATION OF EXISTING HIGHWALLS**

MINE VOID EXPOSED IN CUT SLOPE



TYPICAL TREATMENT OF MINE VOIDS
CUT SLOPE

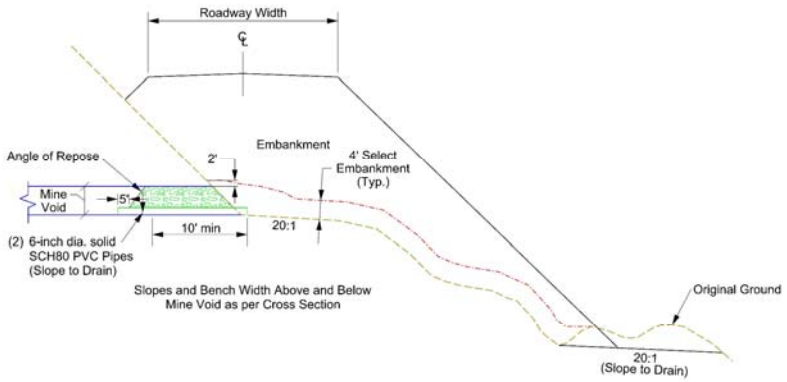
TYPICAL TREATMENT OF MINE VOIDS BELOW GRADE DETAIL



TYPICAL TREATMENT OF MINE VOIDS
BELOW GRADE

S&ME

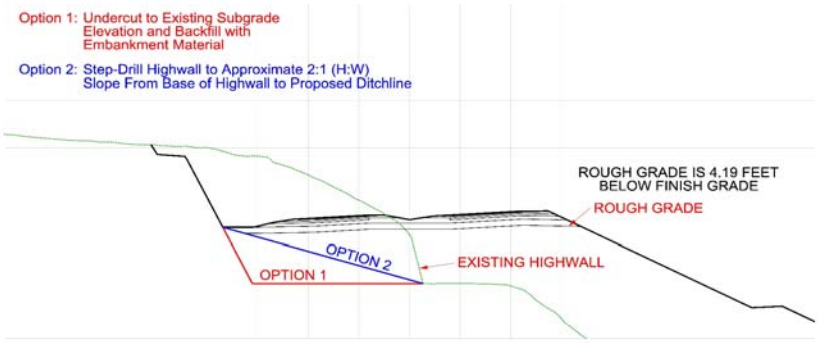
TYPICAL TREATMENT OF MINE VOIDS COVERED WITH EMB. DETAIL



TYPICAL TREATMENT OF MINE VOIDS
TO BE COVERED WITH EMBANKMENT

S&ME

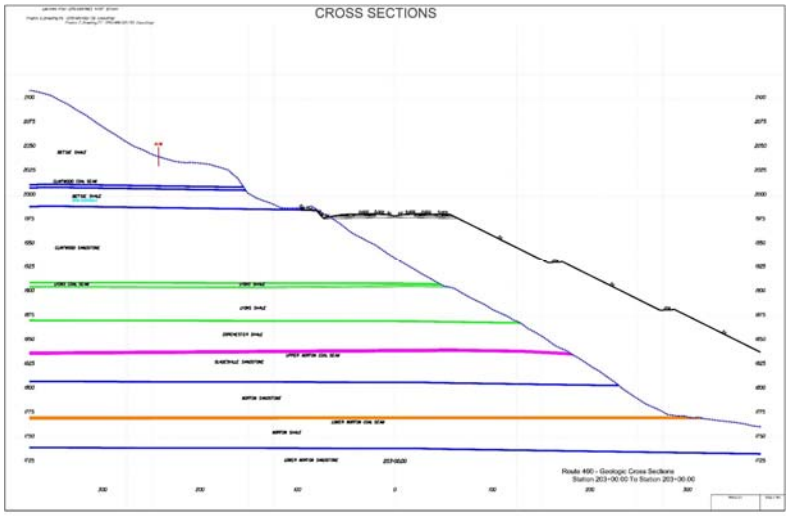
EXISTING HIGHWALL MITIGATION DETAIL



HIGHWALL MITIGATION DETAIL
STATION 216+00 TO STATION 217+25
STATION 311+00 TO STATION 313+25

S&ME

GEOLOGIC CROSS SECTION



S&ME

LESSONS LEARNED

- **DATA POINT LOCATIONS**
- **SOME WORK WILL STILL BE DONE THE "OLD FASHIONED" WAY**

QUESTIONS?