Stabilizing Slides in Pennington Formation with Drilled Ground Anchors

Site

Slope Stabilization @ I-40 WB MM 342, Roane Co.
Geotechnical Engineer: WSP\Golder
Contractor: Goettle
Contract: CNU 224

Presenter: Robert Jowers, PE

TN TDOT Department of Transportation

Photo Source: TDOT

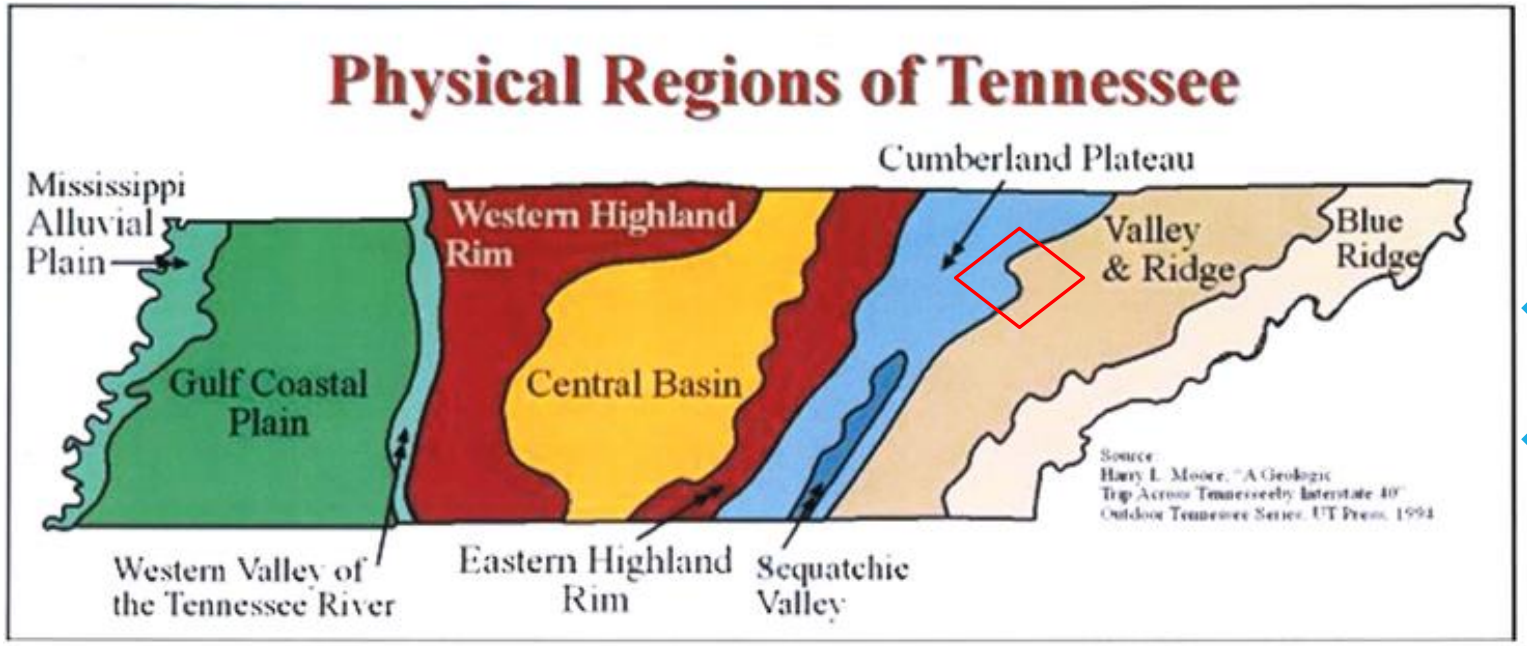
PIN 128729.00 GES 73240002 \ PHASE- 4

Photo Source: George Hornal\TDOT

Presentation Agenda

- TDOT geohazard
  - Pennington Formation colluvium
- Extensive site characterization and plans development effort
- System components used and schedule of progress
- Ground anchors could be a new slope stabilization tool at TDOT

Background



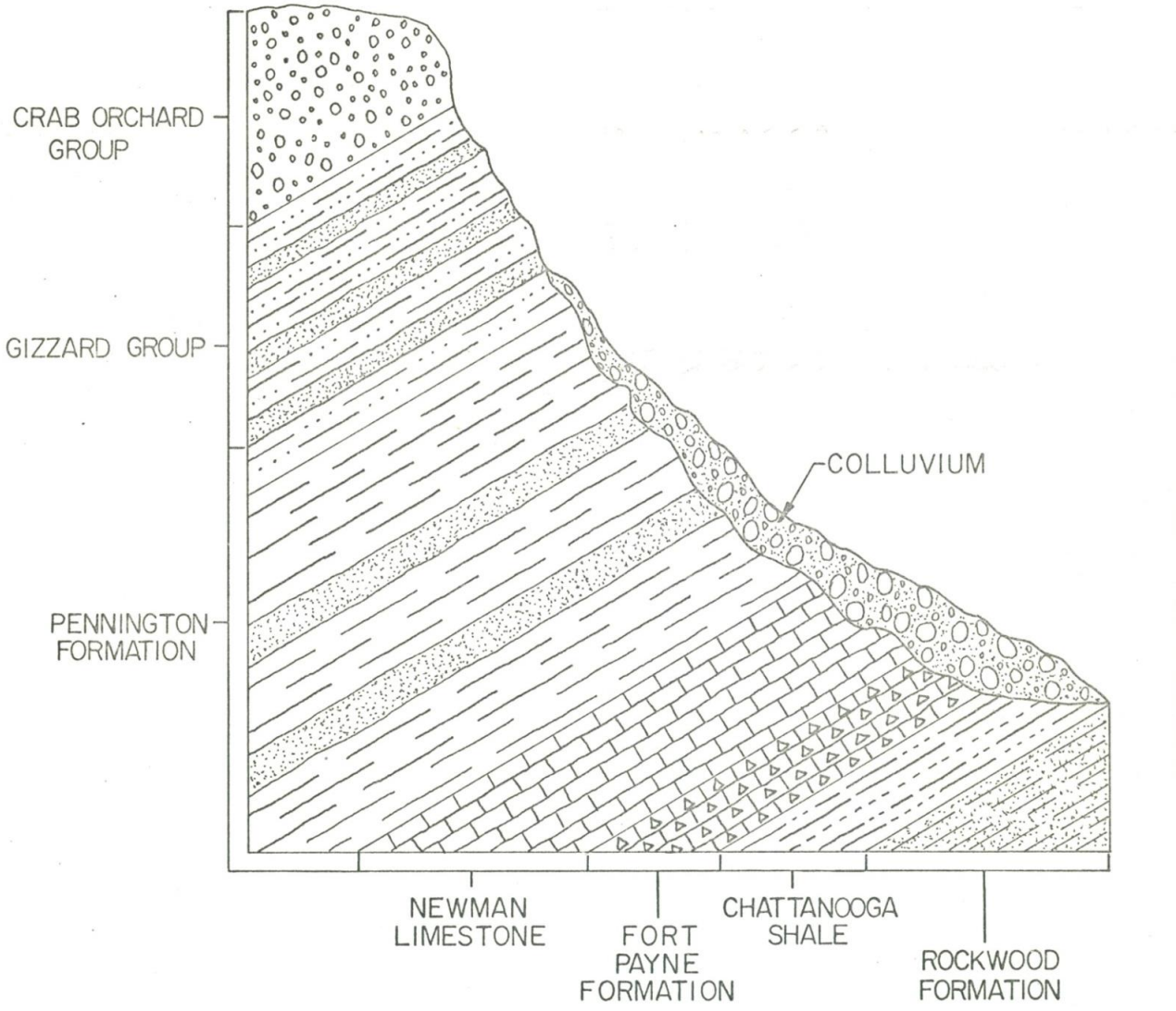
Source: Moore, H., “A Geologic Trip Across Tennessee Interstate 40”, University of Tennessee Press, 1994

- Geology \ Geography Creates Divisions
- TN contains nine physiographic regions

Geology

- Pennington Shale Formation Test Boring (1/3
- Notice the color on the drill matching the test boring samples

Source: TDOT



Source: David Grooms\David Royster\TDOT

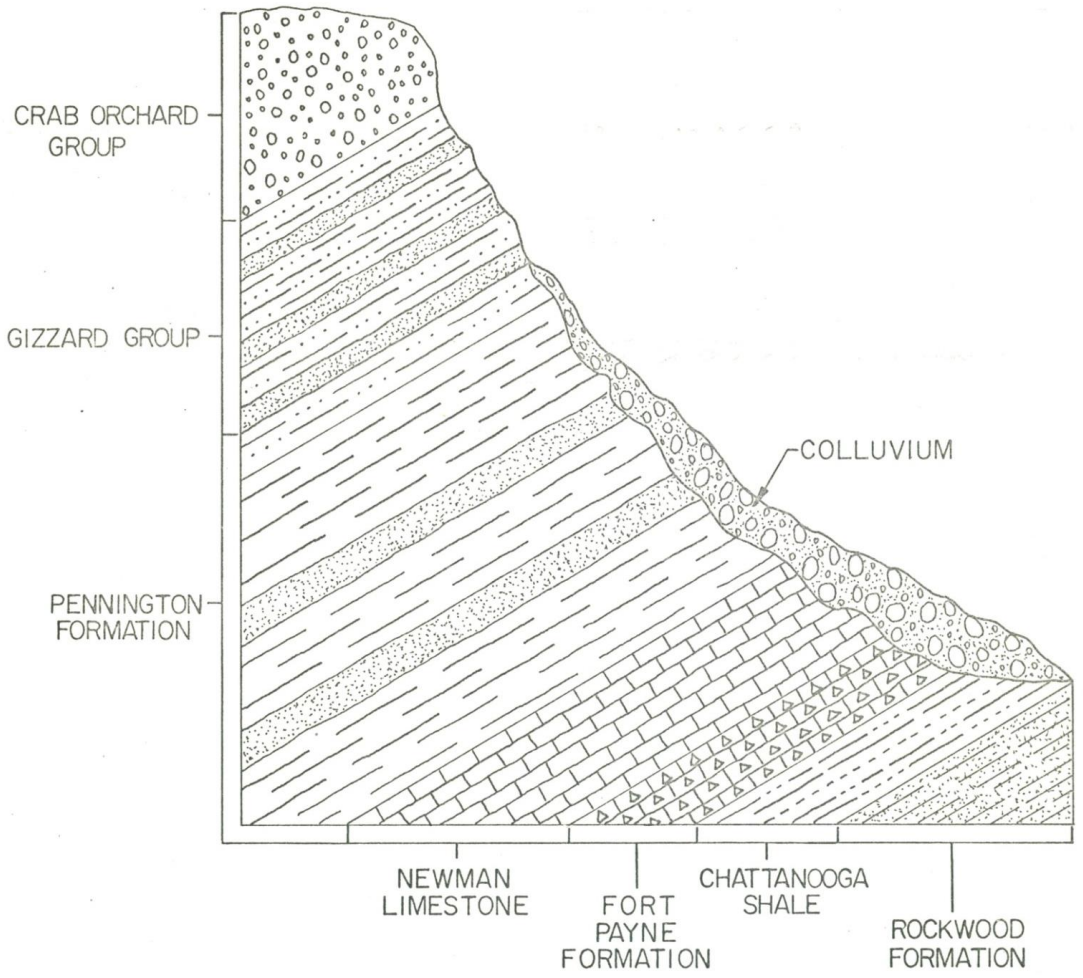
Geology

- Contains predominate shales that tend to weather differentially with overlying Gizzard Group Sandstone
- Creates unconsolidated colluvium, containing sandstone cobbles to boulders
- Through mapping, Golder identified an upper sandstone member, and a lower shale member
- The subject colluvium is more pervious than underlying strata – so trapped water pressures are created

Source: Golder \ TDOT

Geology

If there is a practical colluvium depth, the landslide can be stabilized practically.



Source: TDOT

Source: George Hornal\TDOT

I-40 Construction in 1968

- South of Walden Ridge, near the city of Rockwood
- Fill Slide proposed near MM 341.5-342
- Halted Construction

Source: George Hornal \ TDOT

I-40 Construction in 1968

- Entire corridor is built on unstable colluvial material
- Must contend with the Pennington Shale colluvium

Source: George Hornal \ TDOT

I-40 Rockwood Corridor Maintenance Time Line

- Slope movement continues
- 1970's TDOT later installed drilled horizontal drains
- 2012 Deep wells were installed
- 2017 Replaced pinched off inclinometers
- 2018 Future plan of action could be drastic \ significant - drilled ground anchors

Landslides Triggered Feb. 22, 2019

National Weather Service (2019). **Historic Flooding Across The Tennessee Valley**. Retrieved from https://www.weather.gov/mrx/hydroevent

Historic Flooding Across The Tennessee Valley

February 22-23, 2019

Radar loop of composite reflectivity

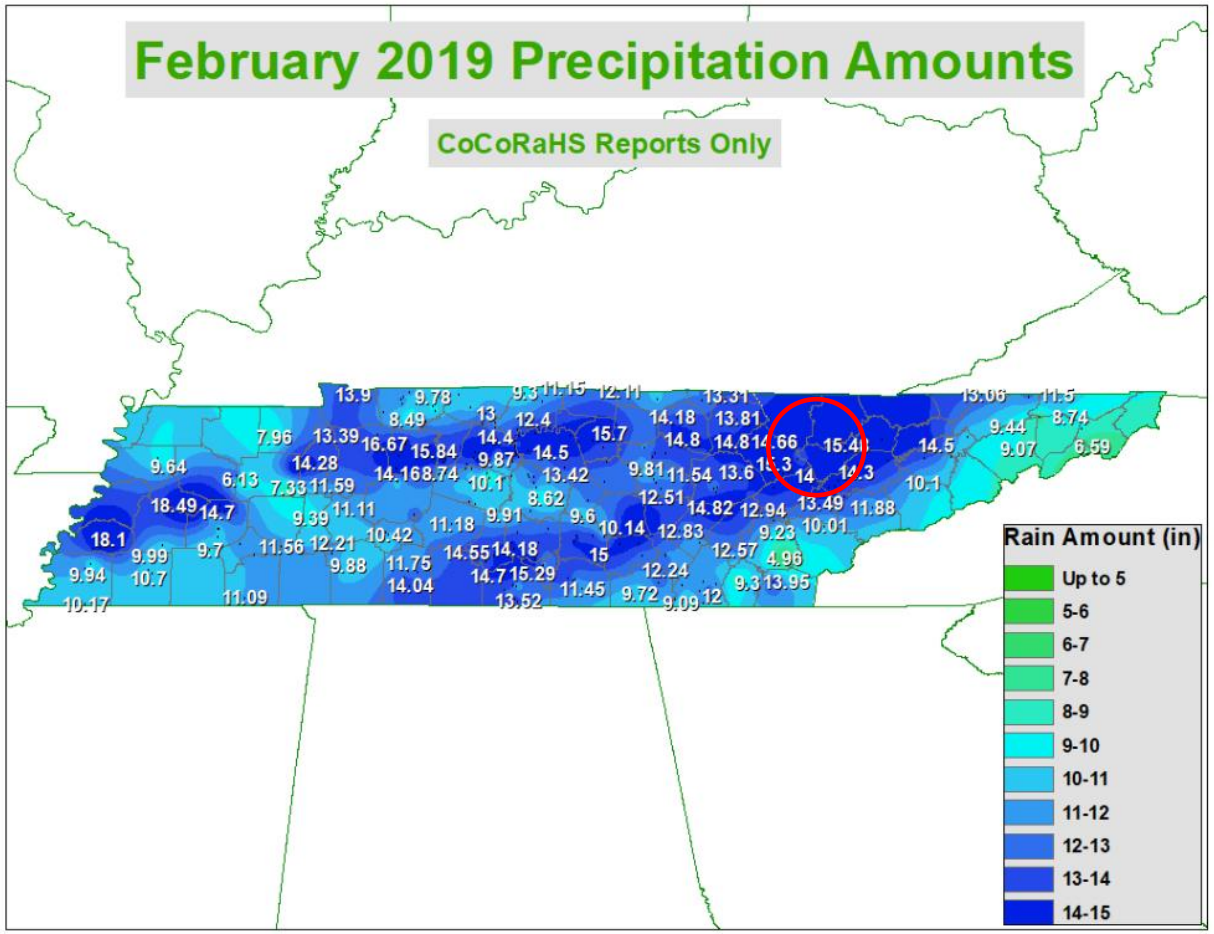
from early morning through mid afternoon (click to enlarge)

Landslides Triggered

- **Feb. 22, 2019 Rain Began**
- **Over 100 Landslides Occurred because of flooding**
- **Two Sites along EB and WB were identified that required immediate stabilization repair – Project Site**

National Weather Service (2019). **Historic Flooding Across The Tennessee Valley**. Retrieved from https://www.weather.gov/mrx/hydroevent

Landslides Triggered



- **I-40, Roane Co. Project Site shown in red circle**

National Weather Service (2019). *February 2019 Rainfall Compared to December 1926 Rainfall*. Retrieved from https://www.weather.gov/ohx/February2019vsDecember1926

Practical Landslide Stabilization

RESTRAINT

Practical Landslide Stabilization

Restraint

- Stone Buttress
- Soldier pile lagging retaining walls (often w\ drilled anchors)
- Reticulated micropiles (used to bridge terrain in Foothills Pkwy)

Royster, D. L. (1978). Landslide Remedial Measures. *Prepared for Presentation at the 37th Annual SASHTO Convention, October, 1978, Nashville, Tennessee*)

Restraint – Stone Buttress

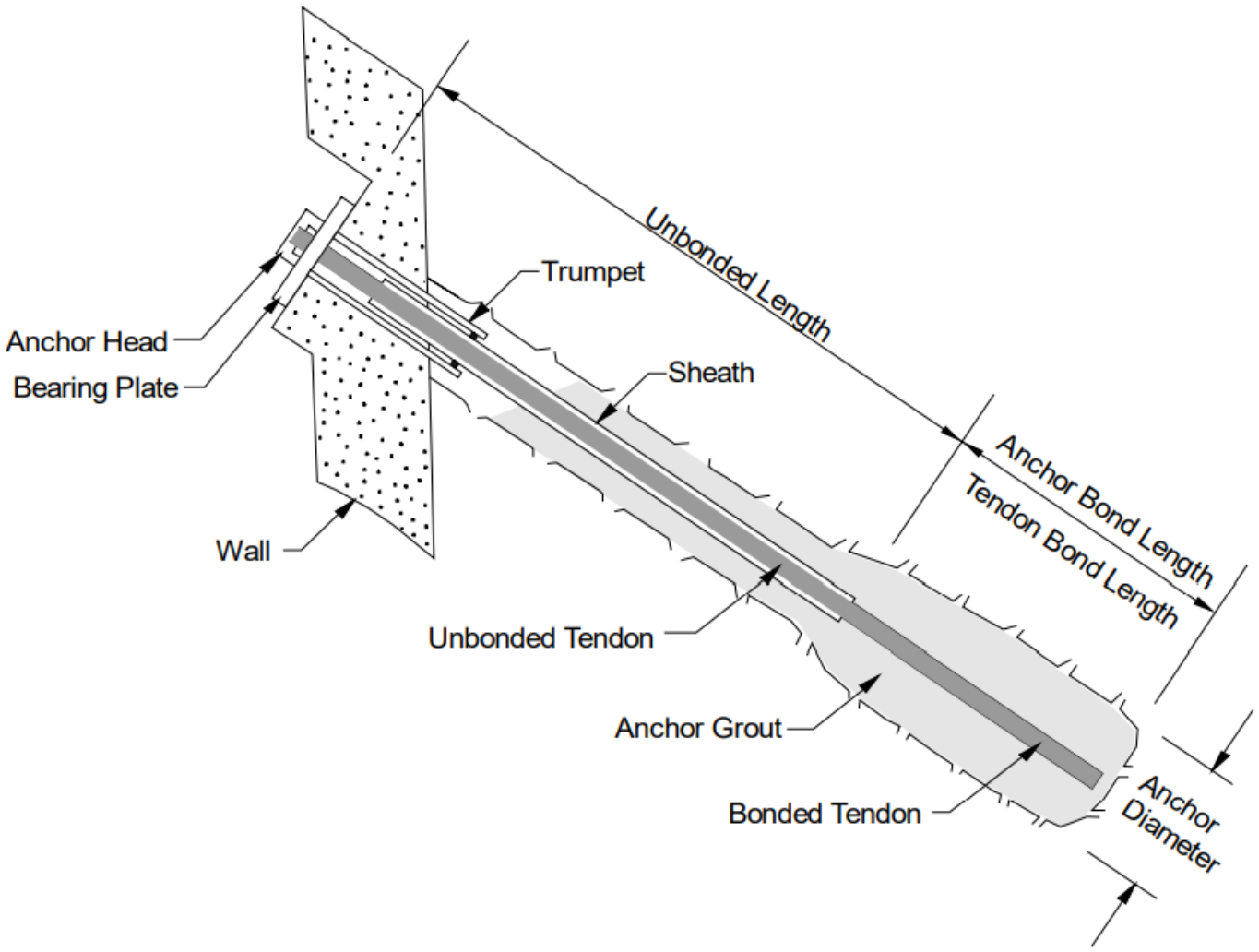
- Earthwork Volume excessive
- Practical if colluvium shallow
- Typically requires road closure
- Impractical in urban \ high ADT

Source: Barry McClendon, TDOT R2 Survey Office, August 6, 2019

Restraint – Stone Buttress

- SR-85, Fentress Co.

Source: Barry McClendon, TDOT R2 Survey Office, August 6, 2019

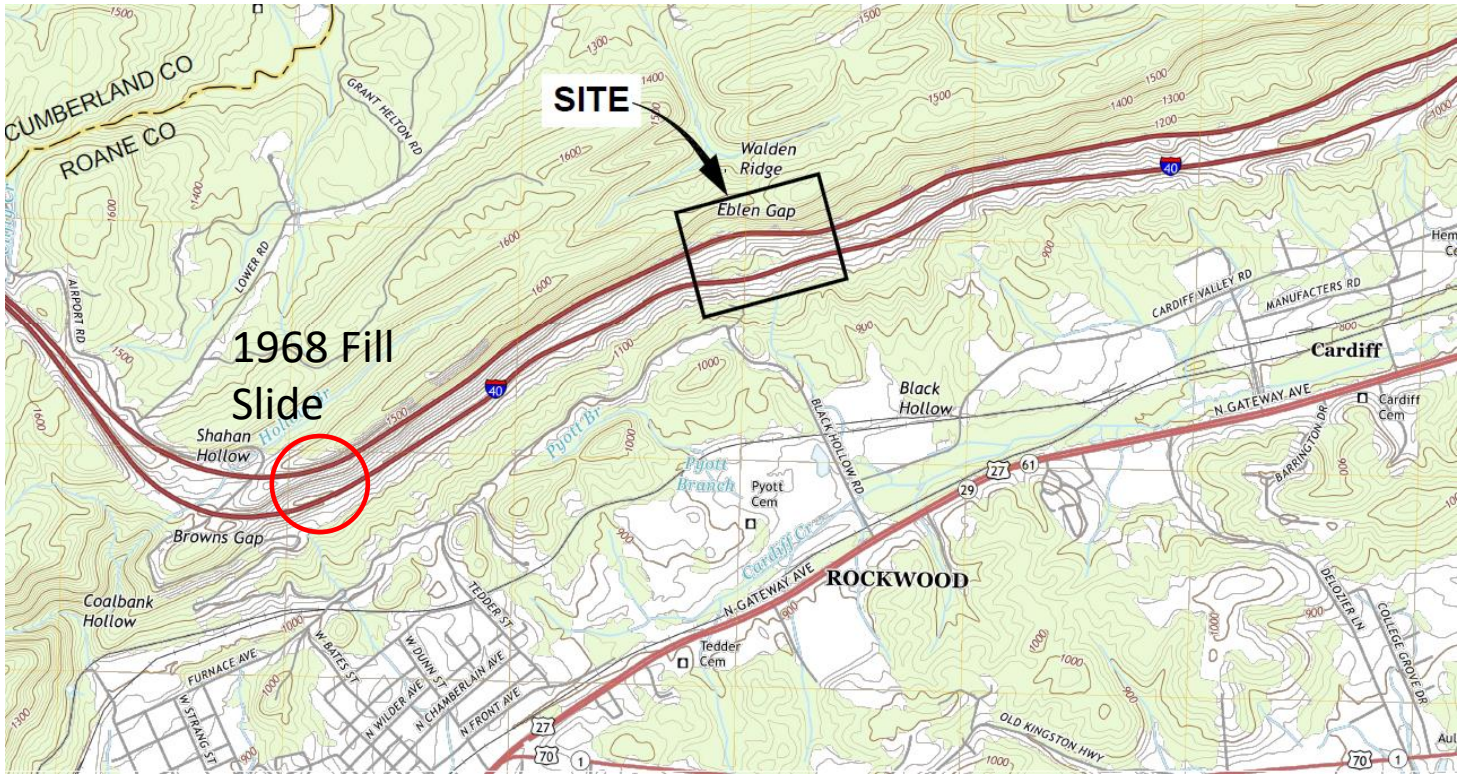


Source: FHWA, GEC Circular No. 4, Ground Anchors and Anchored Systems, 1999

Restraint – Drilled Anchors

- Practical – But major investment
- Costs and benefits warrants investment on interstate slopes

Project Vicinity



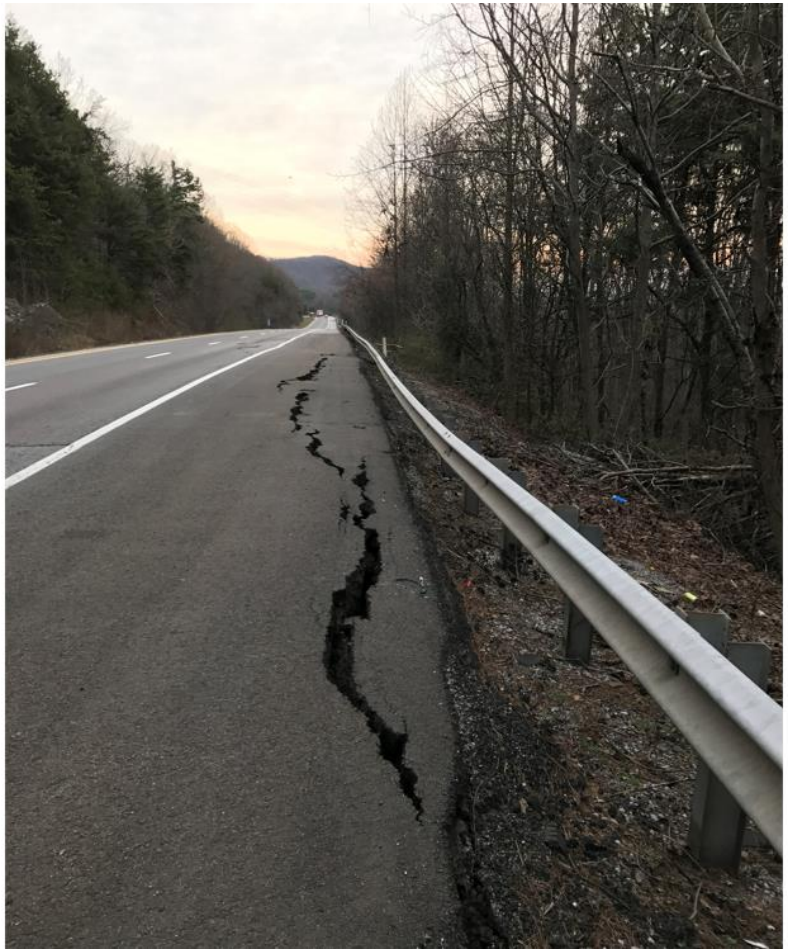
Source: Golder \ TDOT

Project Vicinity

- Slope movement occurs
- Further downhill 1.25 mi. – eastward
- Two separate slides
- KS Ware retained to develop plans I-40 EB MM 343 (+\-)
- Golder retained to develop plans I-40 WB MM 342 (+\-)

EB Project Design

- KS Ware's EB MM 343 site utilized ground anchors supporting a soldier pile \ lagging wall
- Bid just under $3.5
- Good administration
- Straight forward, single anchor row

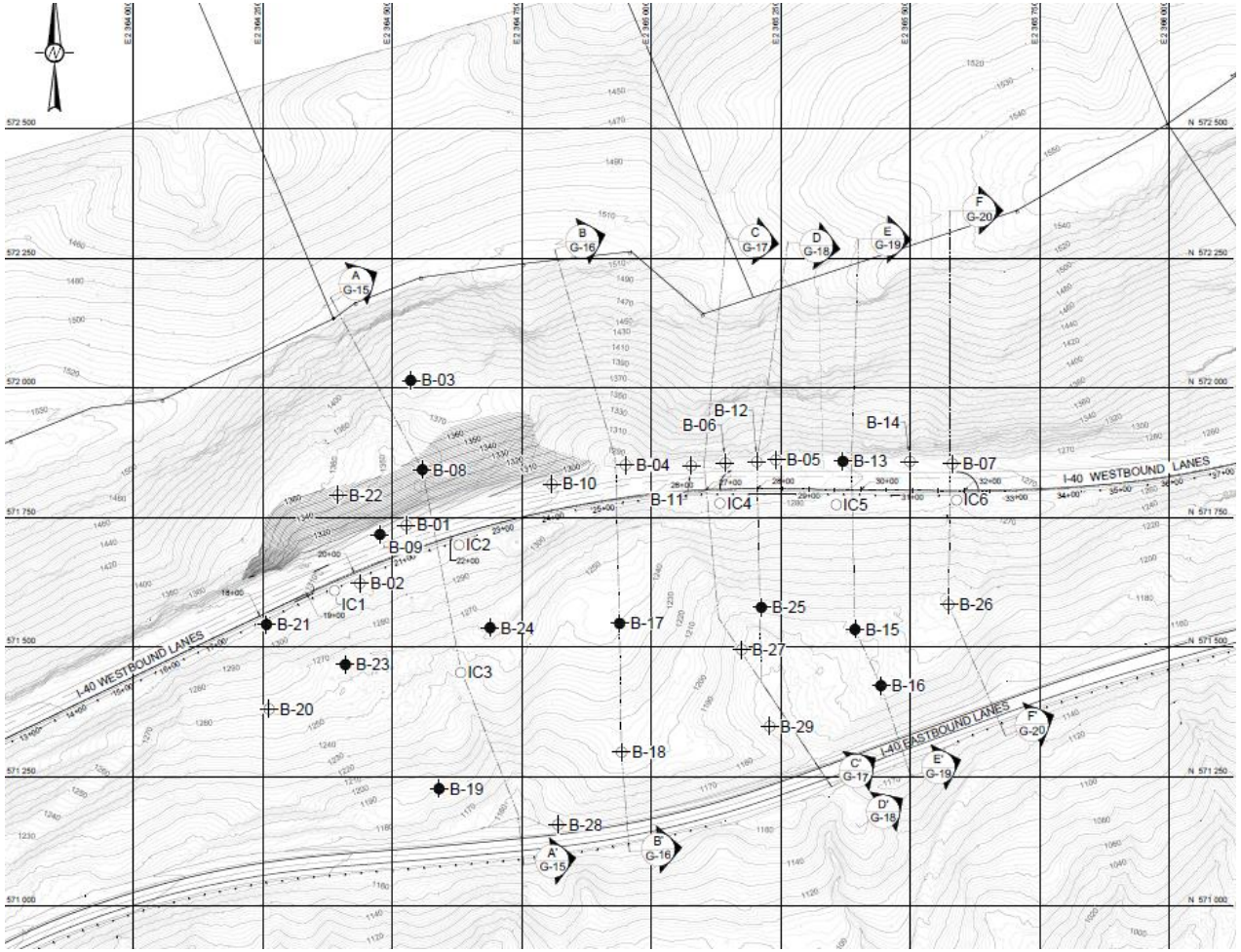


Source: TDOT

Source: TDOT

EB Project Construction Phase Retaining Wall Complete

November 2021

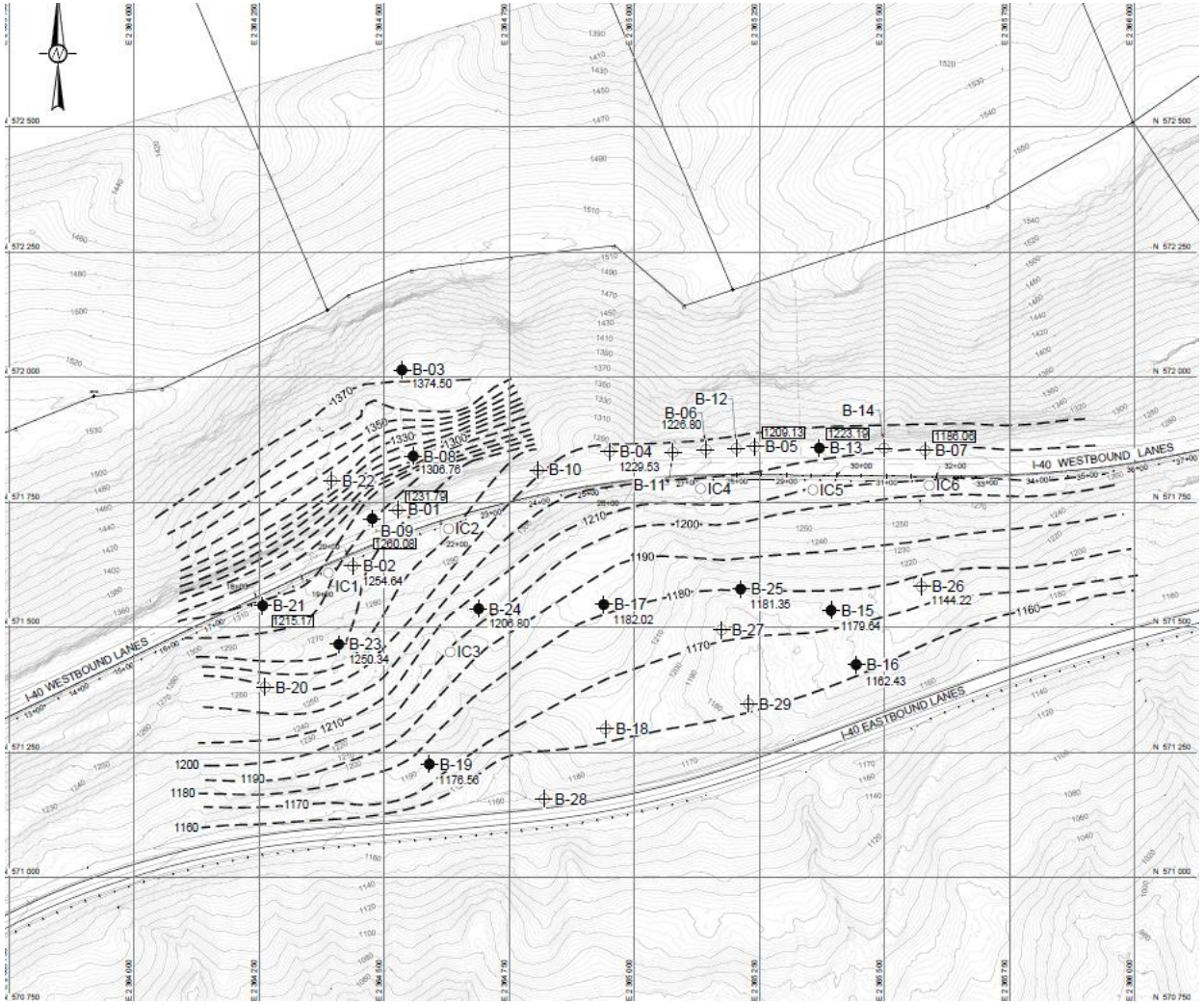


Source: Golder \ TDOT

WB Site Characterization

Much Larger Area

- Extensive Site Characterization Required
- Thirty-five test borings
- Developed six slope inclinometers

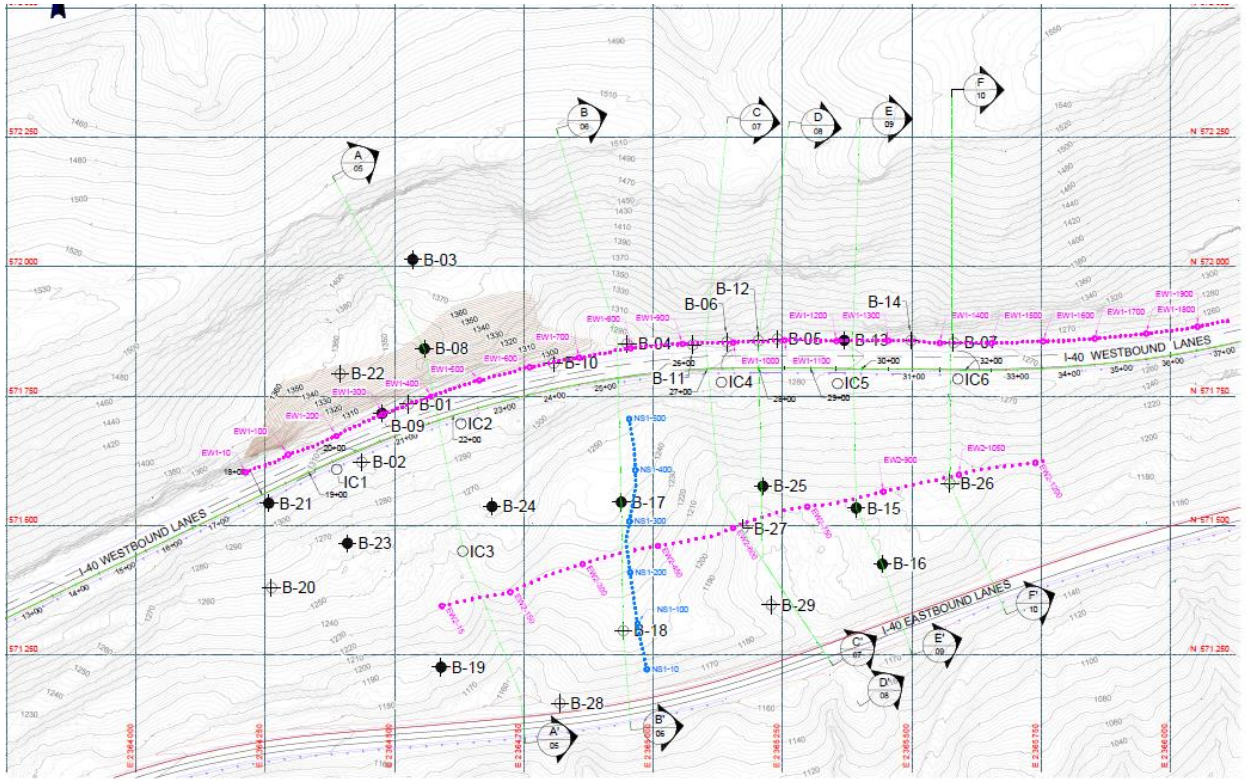


Source: Golder \ TDOT

WB Site Characterization

- Extensive Site Characterization Required

- Thirty-five test borings
- Developed six slope inclinometers
- Twenty-two vibrating wire piezometers

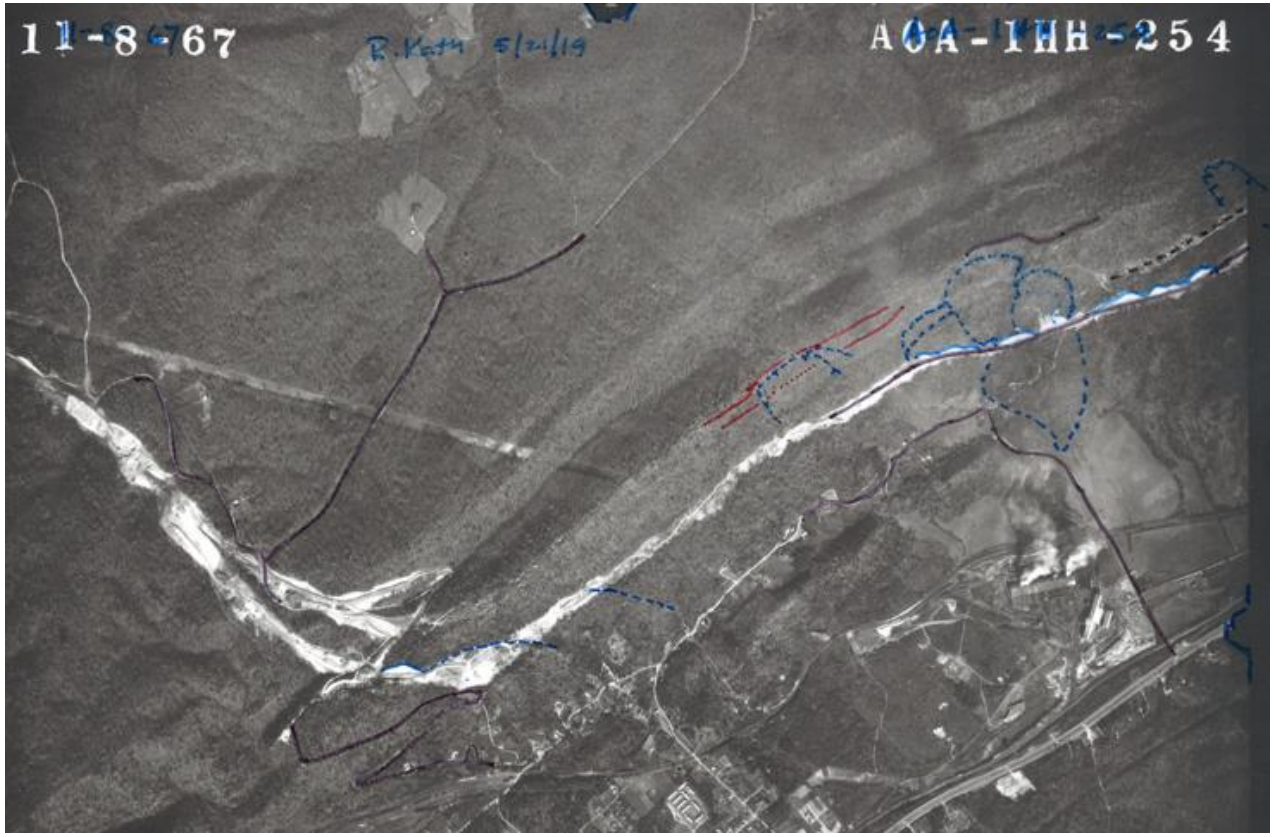


Source: Golder \ TDOT

WB Site Characterization

- Extensive Site Characterization Required

- Thirty-five test borings
- Developed six slope inclinometers
- Twenty-two vibrating wire piezometers
- Three electrical resistivity lines

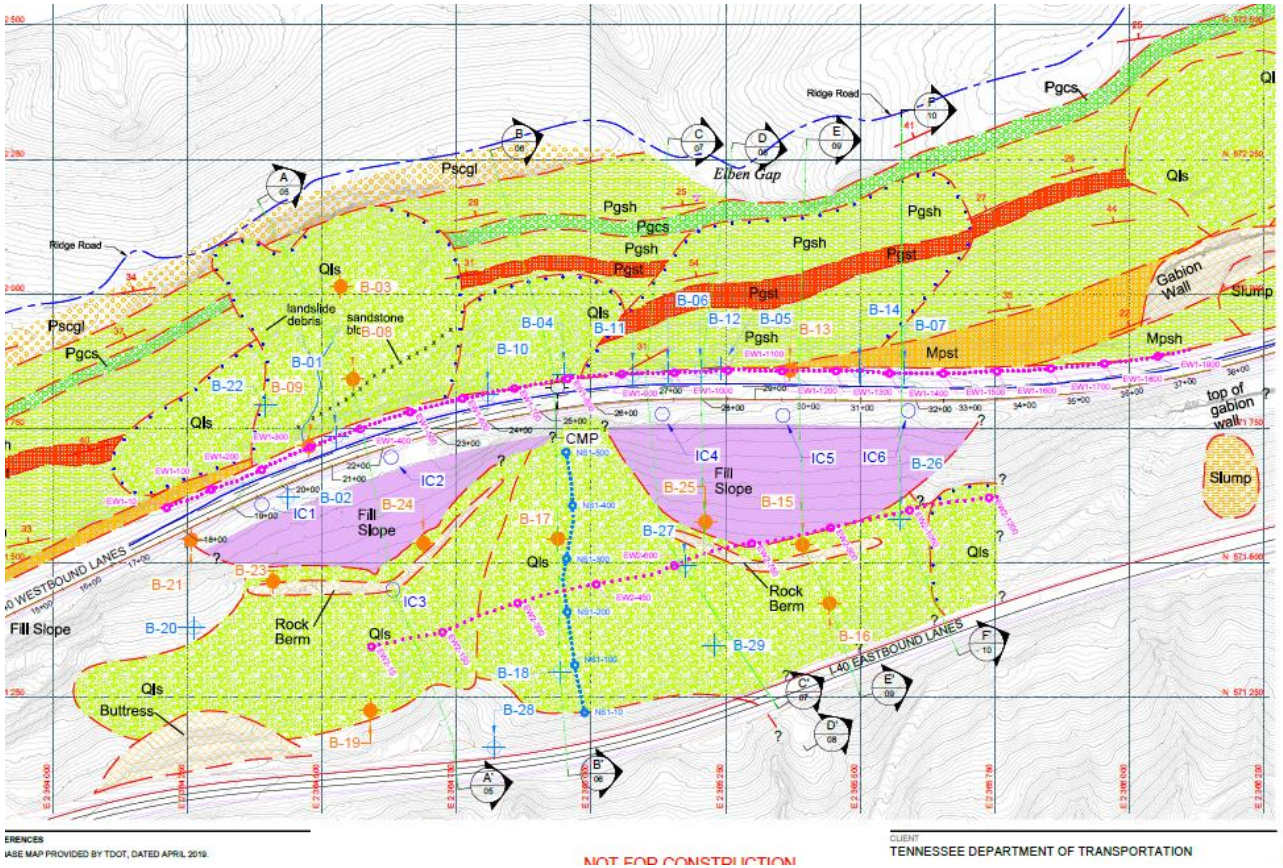


Source: Golder \ TDOT

WB Site Characterization

- Extensive Site Characterization Required

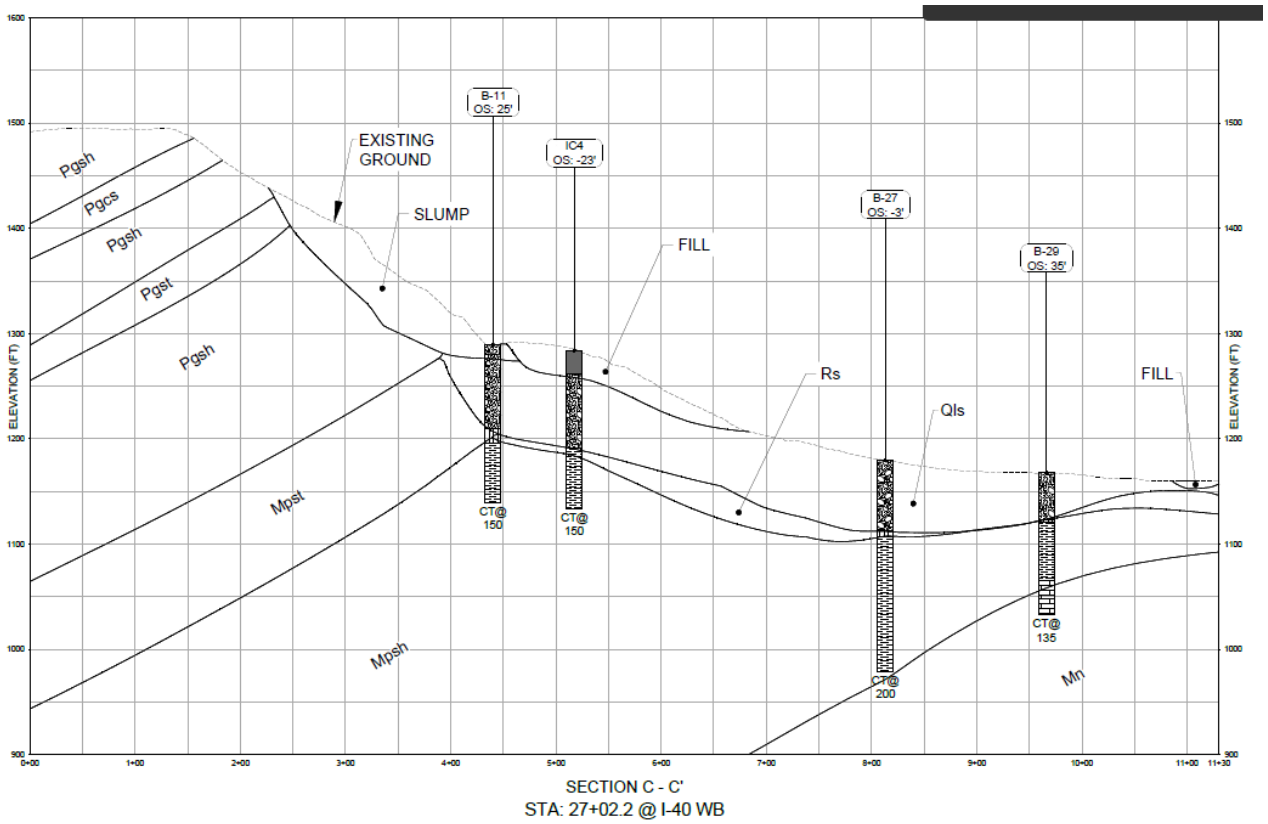
- Thirty-five test borings
- Developed six slope inclinometers
- Twenty-two vibrating wire piezometers
- Three electrical resistivity lines
- Detailed geological mapping



Source: Golder \ TDOT

WB Site Characterization

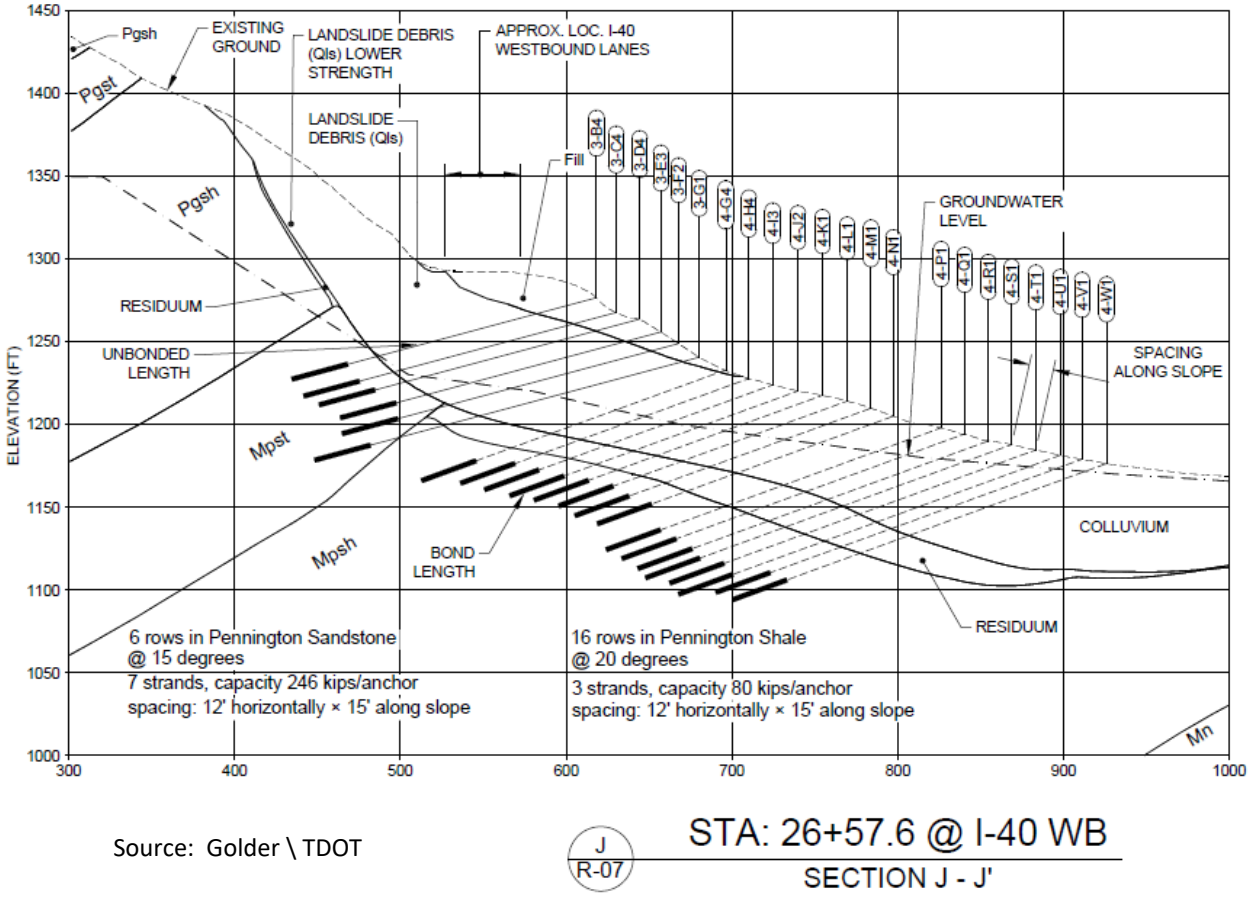
- Extensive Site Characterization Required
- Thirty-five test borings
- Developed six slope inclinometers
- Twenty-two vibrating wire piezometers
- Three electrical resistivity lines
- Detailed geological mapping
- Using sophisticated geologic modeling software - LeapFrog
- Identified Four significant slides



Source: Golder \ TDOT

WB Design Analyses

- Deep Colluvium – Significant
- Fifty-feet grid



Source: Golder \ TDOT

J
R-07

STA: 26+57.6 @ I-40 WB

SECTION J - J'

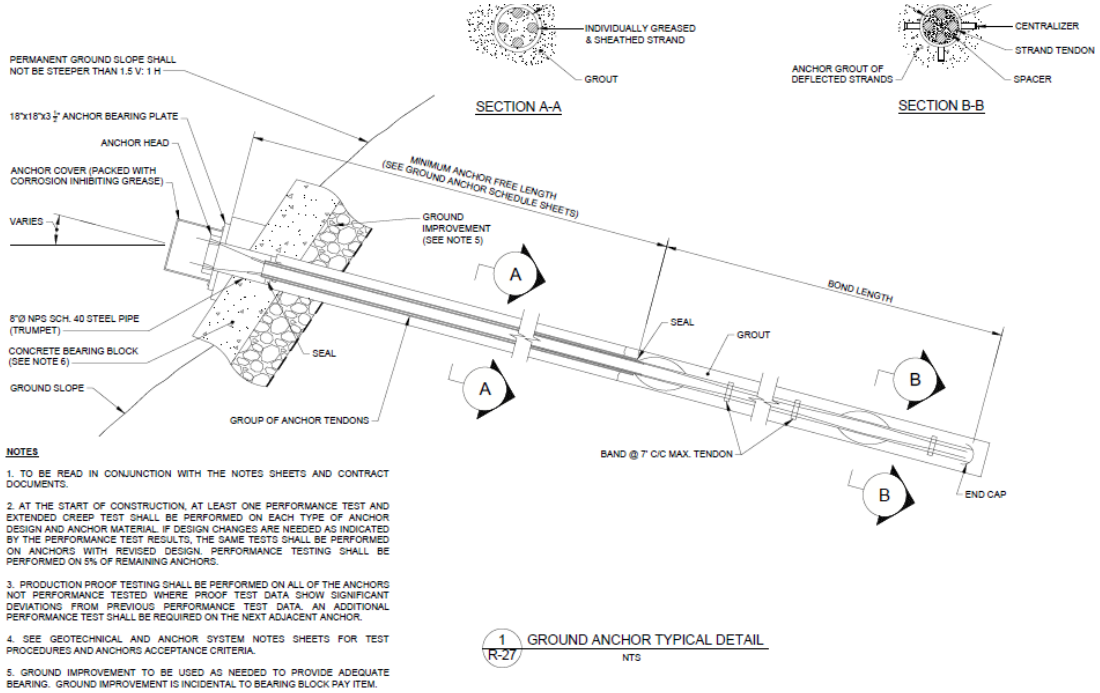
Contract Plans Design

- Acceptable Type of Earth Retention:

  Ground Anchors with
  Concrete Bearing Blocks

- Full Anchor Schedule Design – @ 1700!

- Drill depths between approx. 150 ft. and 250ft.



Source: Golder \ TDOT

WB Plans Design - Anchors

- Bid plans required 3, 7, and 9 Strand cable
- Design loads of 80 kip, 246 kip and 317 kip
- Drill depths between approx. 150 ft. and 250 ft.

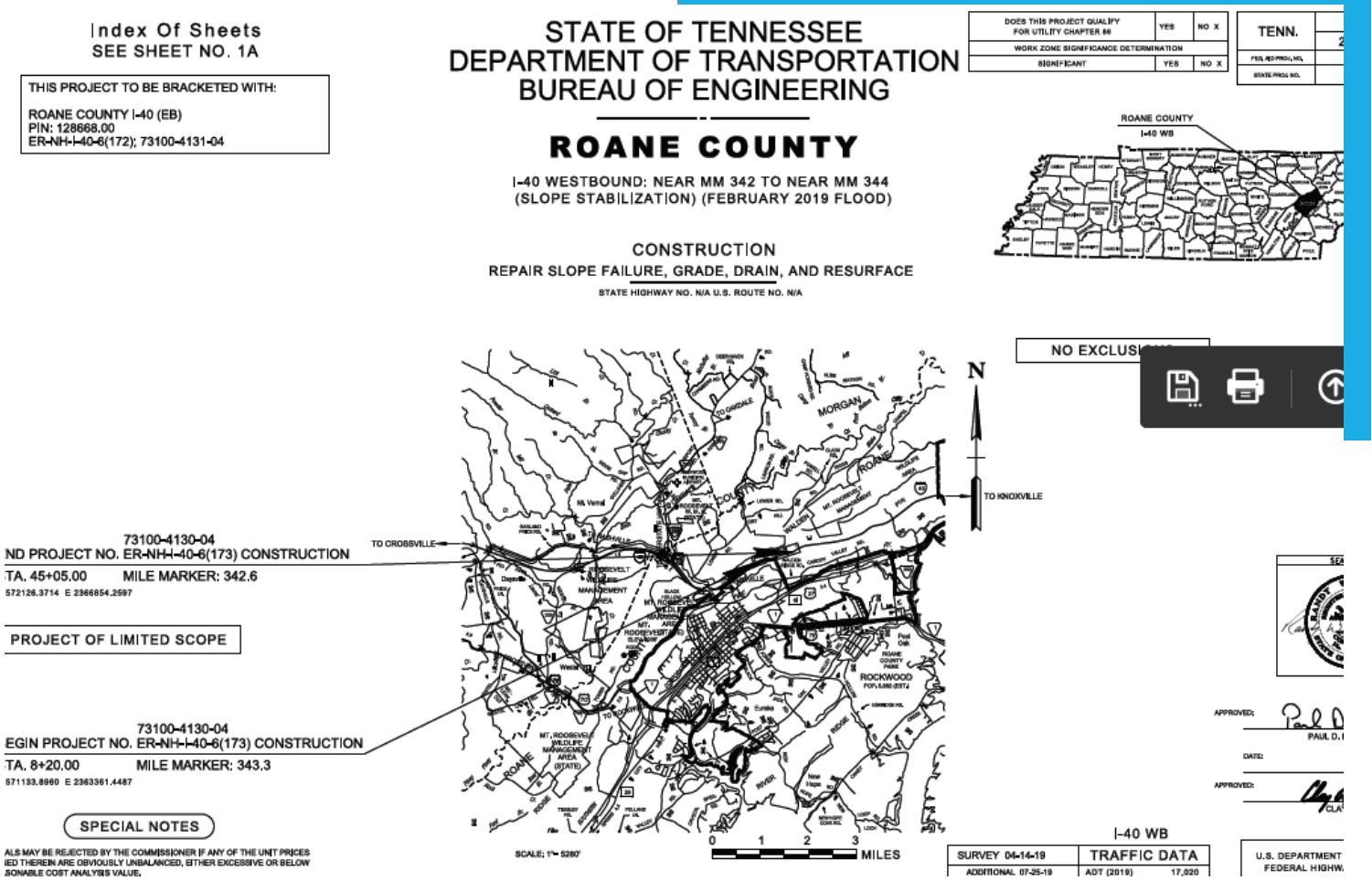
WB Plans Design – Concrete Blocks

Source: TDOT

- 1,700 Concrete Blocks
- Designed by Contractor using design guidance in plans
- Contractor to submit shop drawing design for approval to Engineer
- Foundation improvement specified incidental to cost of block item

Project Bid

- Two Sites combined & Bid
- Design-Bid-Build contract
- Bids Opened May 15th, 2020
- Apparent Low Bid of $33 M
- Awarded to Goettle, Inc.



Index Of Sheets
SEE SHEET NO. 1A

THIS PROJECT TO BE BRACKETED WITH:

ROANE COUNTY I-40 (EB)
PIN: 128668.00
ER-NHI-I-40-6(172); 73100-4131-04

STATE OF TENNESSEE
DEPARTMENT OF TRANSPORTATION
BUREAU OF ENGINEERING

ROANE COUNTY

I-40 WESTBOUND: NEAR MM 342 TO NEAR MM 344
(SLOPE STABILIZATION) (FEBRUARY 2019 FLOOD)

CONSTRUCTION
REPAIR SLOPE FAILURE, GRADE, DRAIN, AND RESURFACE

STATE HIGHWAY NO. N/A U.S. ROUTE NO. N/A

DOES THIS PROJECT QUALIFY FOR UTILITY CHAPTER 86 — YES / NO X
WORK ZONE SIGNIFICANCE DETERMINATION
SIGNIFICANT — YES / NO X

TENN.

ROANE COUNTY
I-40 WB

NO EXCLUSI

73100-4130-04
ND PROJECT NO. ER-NHI-I-40-6(173) CONSTRUCTION
TA. 45+05.00 MILE MARKER: 342.6
572126.3714 E 2366854.2597

PROJECT OF LIMITED SCOPE

73100-4130-04
EGIN PROJECT NO. ER-NHI-I-40-6(173) CONSTRUCTION
TA. 8+20.00 MILE MARKER: 343.3
571133.8960 E 2363361.4487

SPECIAL NOTES

ALS MAY BE REJECTED BY THE COMMISSIONER IF ANY OF THE UNIT PRICES
IED THEREIN ARE OBVIOUSLY UNBALANCED, EITHER EXCESSIVE OR BELOW
SONABLE COST ANALYSIS VALUE.

TO CROSSVILLE
TO KNOXVILLE
N
MORGAN
ROANE
ROCKWOOD
SCALE: 1" = 5280'
0 1 2 3 MILES

I-40 WB

SURVEY 04-14-19 | TRAFFIC DATA
ADDITIONAL 07-25-19 | ADT (2019) 17,020

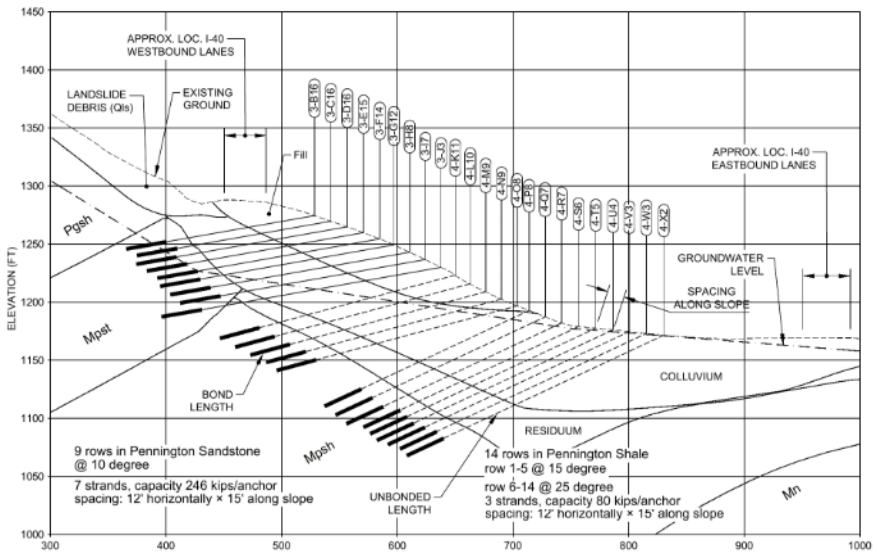
APPROVED:
DATE:
APPROVED:

U.S. DEPARTMENT
FEDERAL HIGHW

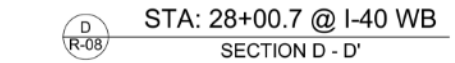
Source: TDOT

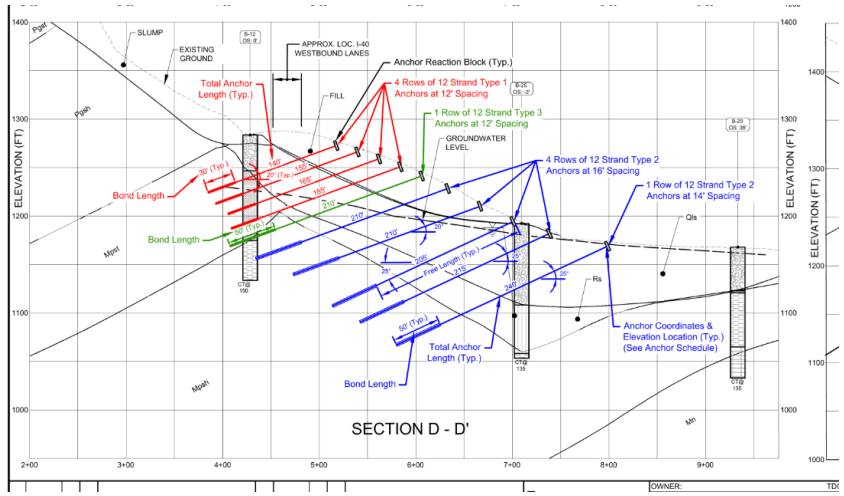
Project Const. Admin. - VECP

- Contractor presented Value Engineering Change Proposal
- Construction companies have different equipment available
- Different work schedules



Source: Golder \ TDOT





Project Const. Admin.-VECP

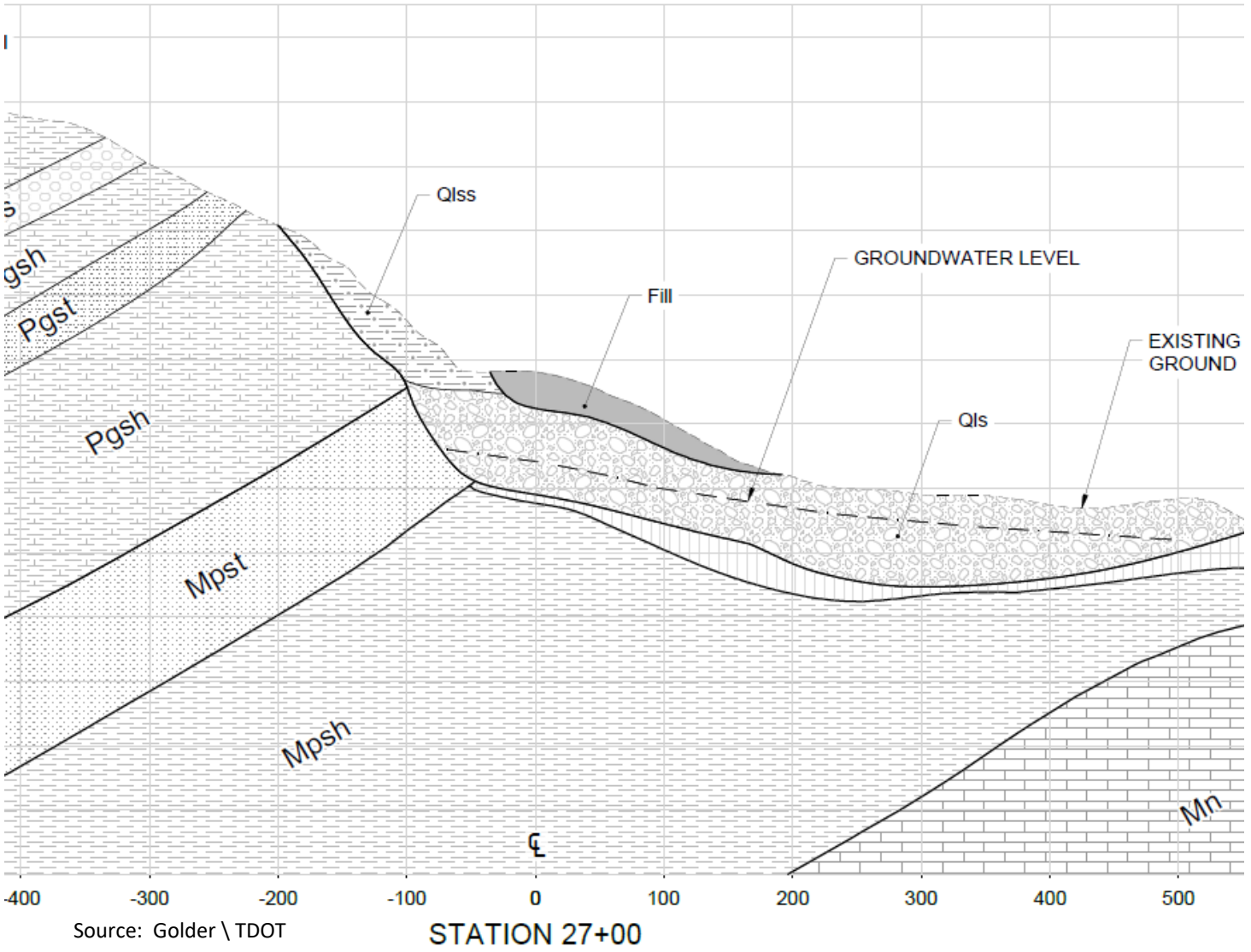
- Decrease number of concrete blocks to about 600
- Increase the tension load significantly
- Pennington Shale's ability to meet stress transfer
- No test load data
- Known knowns: Inaccessible and Tough Drilling

Source: *Shop Drawings Value Engineering Anchor Stabilization System, I-40 (WB) Near 342, June 17, 2022*, Goettle \ Burns Cooley Dennis, Inc. \ TDOT

Project Const. Admin - VECP

- Prior to consideration, TDOT required load tested anchors
- Design loads of 500 k were applied
- 12 strand anchors
- 8 in. diameter
- *VECP approved*

Source*: Shop Drawings Value Engineering Anchor Stabilization System, I-40 (WB) Near 342, June 17, 2022*, Geottle \ Burns Cooley Dennis, Inc. \ TDOT

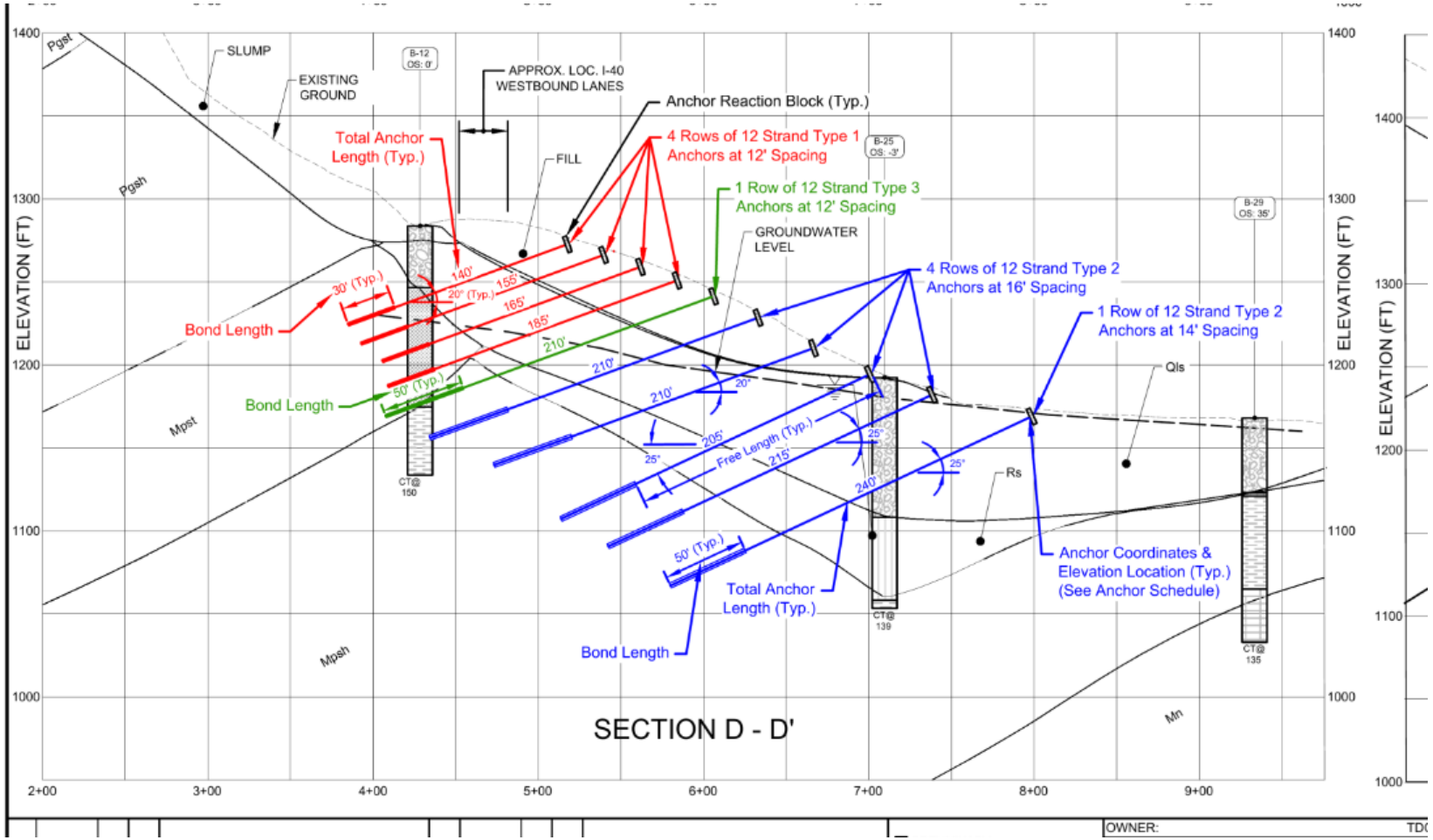


Source: Golder \ TDOT

Project Const. Admin - VECP

- Initial design based on quality site characterization
  - Added <u>value</u> to the project - solid
  - The slip surface \ minimum anchor free length evaluated
  - Strategic bearing strata location was evaluated

Anchor Drilling



Anchor Drilling

TYPICAL SECTION

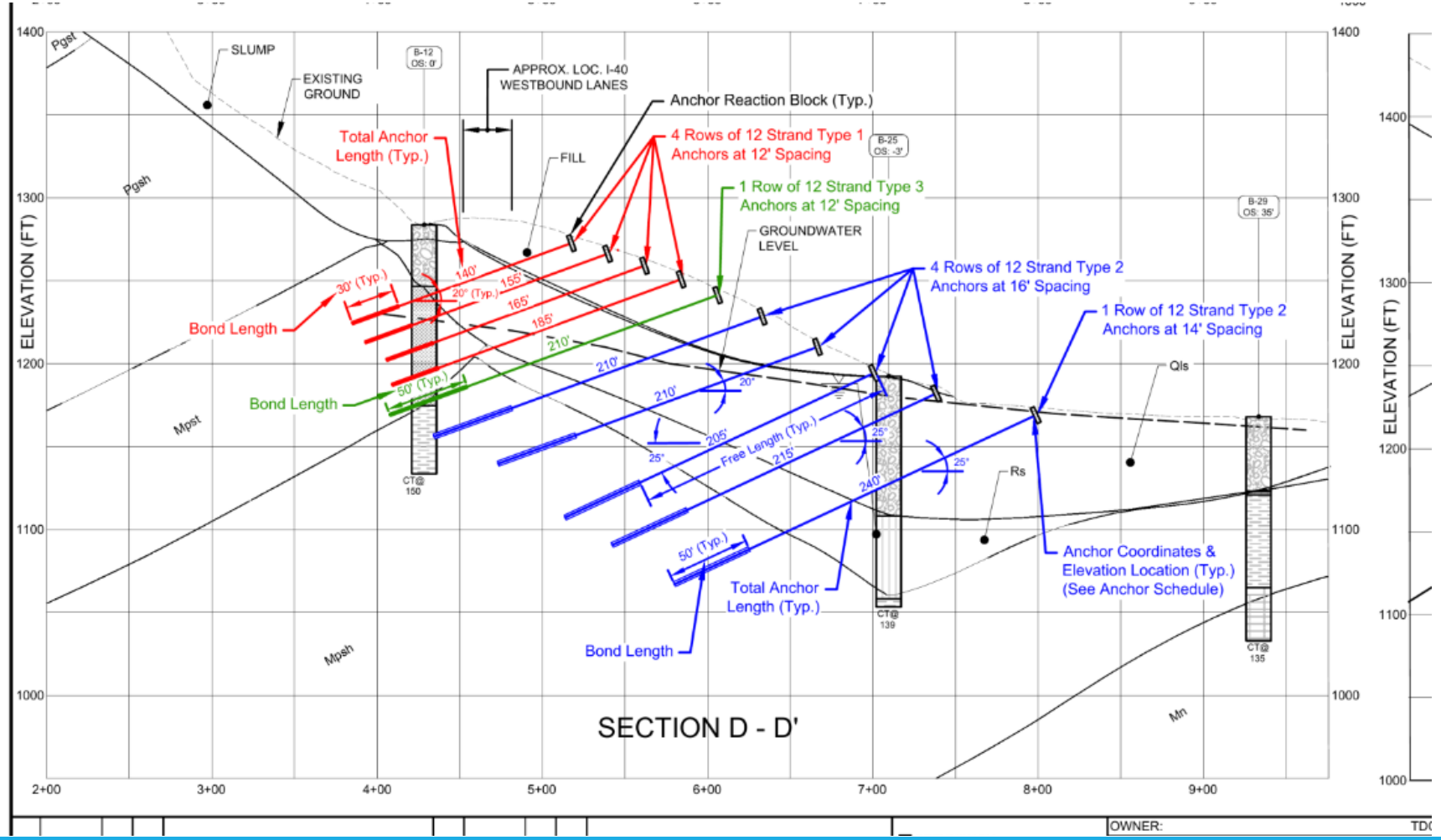
Anchor Drilling

Anchor Drilling

October 2021

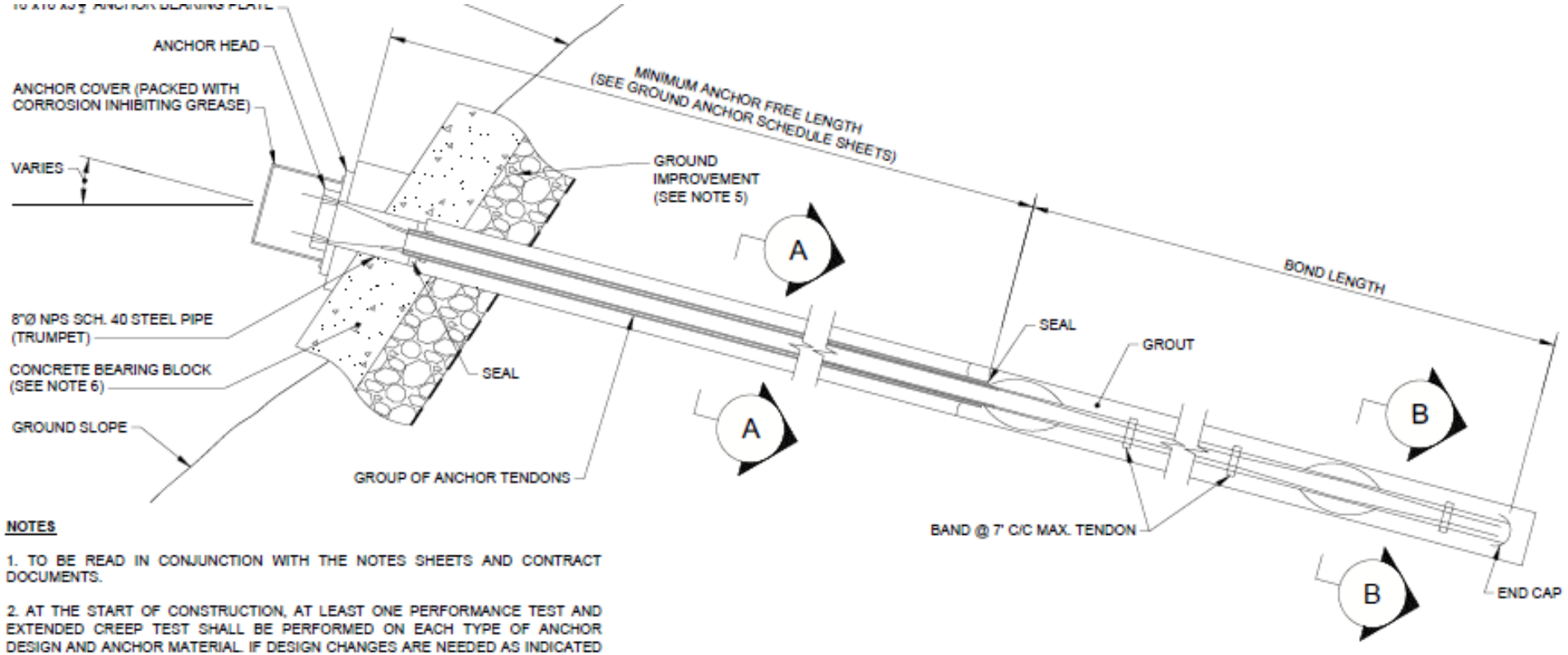
Anchor Drilling – Measuring Inclination

OCTOBER 2021



Anchor Drilling - Concept

TYPICAL DETAIL SECTION



NOTES

1. TO BE READ IN CONJUNCTION WITH THE NOTES SHEETS AND CONTRACT DOCUMENTS.

2. AT THE START OF CONSTRUCTION, AT LEAST ONE PERFORMANCE TEST AND EXTENDED CREEP TEST SHALL BE PERFORMED ON EACH TYPE OF ANCHOR DESIGN AND ANCHOR MATERIAL. IF DESIGN CHANGES ARE NEEDED AS INDICATED BY THE PERFORMANCE TEST RESULTS, THE SAME TESTS SHALL BE PERFORMED ON ANCHORS WITH REVISED DESIGN. PERFORMANCE TESTING SHALL BE PERFORMED ON 5% OF REMAINING ANCHORS.

Anchor Drilling - Strand Placement

TYPICAL DETAIL SECTION

Anchor Drilling - Strand Insertion

August 2021

Concrete Blocks

Concrete Blocks – Pre-Cast Site

December 2021

Concrete Blocks – Set In Place using Crane

October 2021

Concrete Block - Final Position

December 2021

Concrete Blocks – Next Bench Excavation

MAY 2022

Anchor Stressing & Load Testing

Anchor Stressing & Load Testing

December 2021

Source: TDOT

Anchor Stressing & Load Testing

December 2021

Source: TDOT

Anchor Stressing & Load Testing

Anchor Stressing & Load Testing

Anchor Proof Test

Stranded Anchors

Job No. 20001
Job Name CNU224
Location Harriman, TN
General Contractor Richard Goettle, Inc.
Anchor Contractor Richard Goettle, Inc.

Anchor Drill Date: 6-Oct-21
Test Date: 6-Nov-21
Anchor No.: 3B30
Anchor Zone: 3
Location: WB SLOPE
Anchor Block Lot #: 6
Anchor Block Size: 10' x 8'

Jack Capacity, tons: 600
Jack calibration date: 22-Jul-21
pump used: HP= 88
ram used: HR= 55
jack-ram set-up #: 1
max elongation, in 9.257

TENDON DATA			%DL	AL	25	50	75	100	120	133
ANCHOR DESIGN LOAD	421.9	Kips	LOAD	63.3	105.5	211.0	316.4	421.9	506.3	561.1
BOND LENGTH	30	ft	ELONG'N	-	0.820	2.210	3.736	6.272	8.882	7.886
FREE LENGTH + JACK SETUP (6 FT)	100.0	ft	d MIN (in)	0.000	0.546	1.910	3.275	4.639	5.730	6.440
TAIL LENGTH	10.0	ft	d MAX (in)	0.000	0.785	2.746	4.707	6.668	8.237	9.257
ANCHOR STRAND QUANTITY	12		gauge, psi	880	1,100	2,130	3,160	4,190	5,010	5,640
TOTAL STRAND AREA	2.60	in^2								
MODULUS OF ELASTICITY	28,500	ksi								

PERMANENT WALL

CREEP	TIME:	1	2	3	4	5	6	10	15	20	25	30	45	60
TEST	READING:	7.885	7.888	7.871	7.872	7.873	7.874	7.876	-	-	-	-	-	-
INFO	CREEP:	-	0.004	0.006	0.007	0.008	0.009	0.010	-	-	-	-	-	-

CREEP READINGS

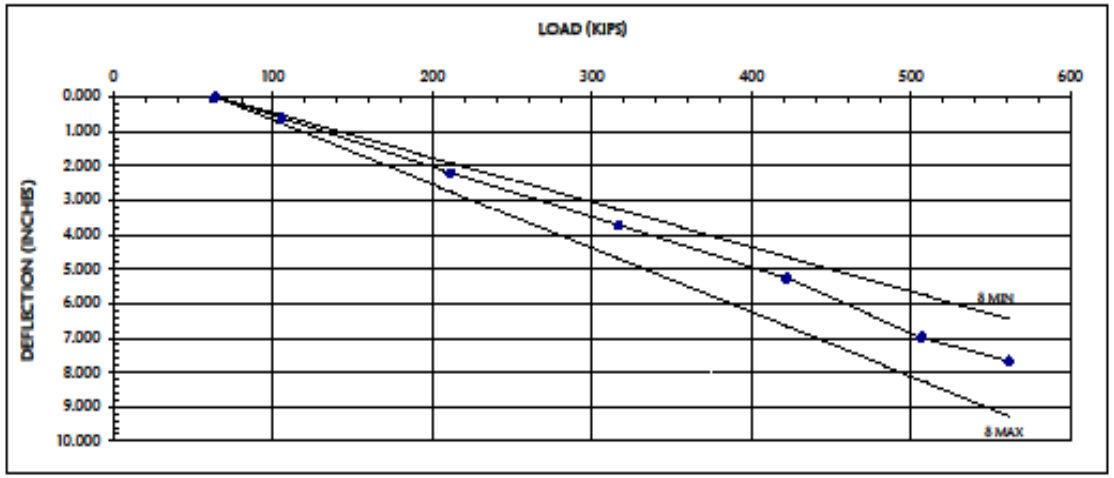
1 to 10	0.010	OK
6 to 60	-	-

LOCK-OFF (100 % D.L.)

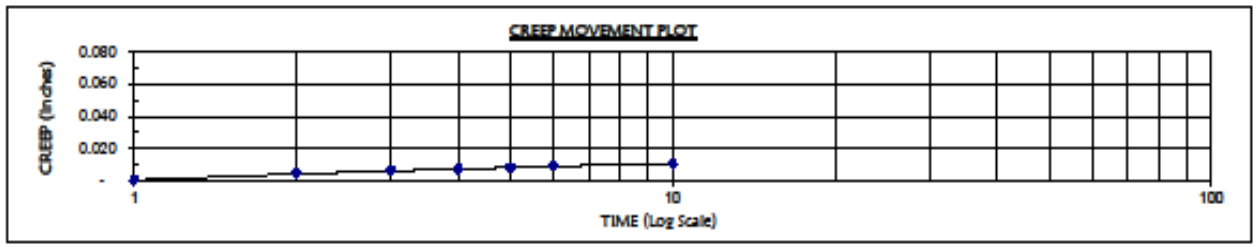
target	actual	
421.9	423	kips
4,190	4,200	psi

ELASTIC ELONGATION (in)

Total Elongation	7.665
AL After Backing Off MTL	0.469
Elastic Movement @ MTL	7.196



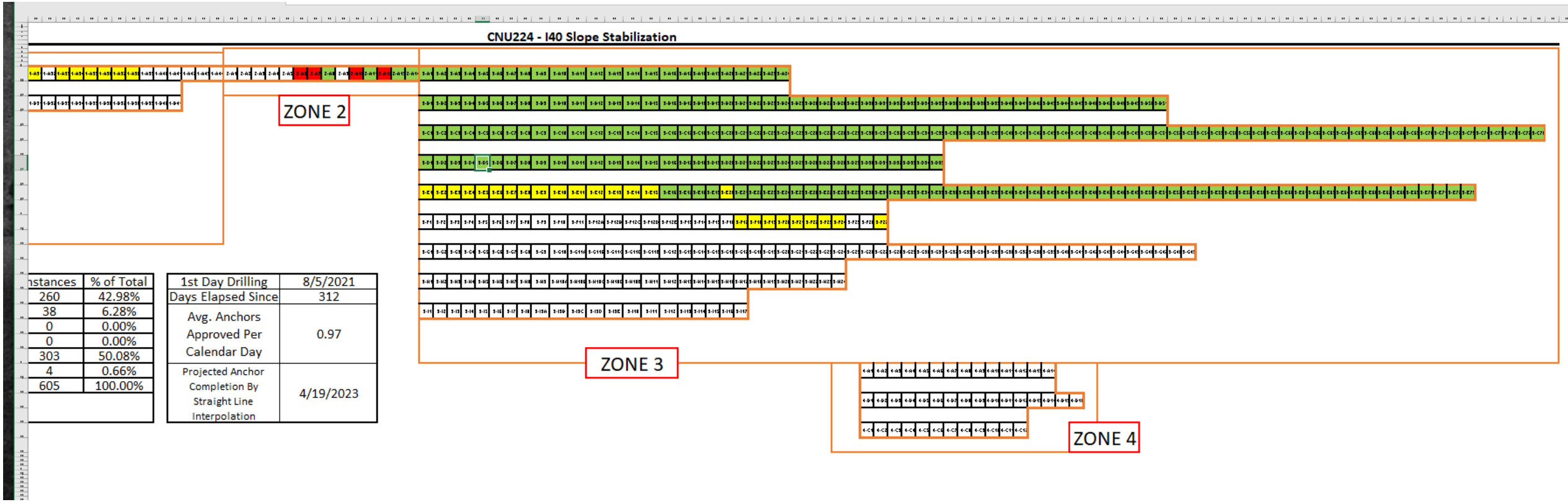
STRANDS E= 28,500
Unit Strand Area: 0.217 in^2



COMMENTS: -

Test Tech. Cody Schappacher

Anchor Stressing & Load Testing



nstances	% of Total
260	42.98%
38	6.28%
0	0.00%
0	0.00%
303	50.08%
4	0.66%
605	100.00%

1st Day Drilling	8/5/2021
Days Elapsed Since	312
Avg. Anchors Approved Per Calendar Day	0.97
Projected Anchor Completion By Straight Line Interpolation	4/19/2023

Anchor Stressing & Load Testing

Tracking Progress using Excel

19	1-A18	4	TDOT Acceptance	PAID	20	4/20/2022	
20	1-A19	4	TDOT Acceptance	PAID	20	4/20/2022	
21	1-A20	4	TDOT Acceptance	PAID	20	4/20/2022	
22	1-A21	4	TDOT Acceptance	PAID	20	4/20/2022	
23	1-A22	4	TDOT Acceptance	PAID	20	4/20/2022	
24	1-A23	4	TDOT Acceptance	PAID	20	4/21/2022	
25	1-A24	4	TDOT Acceptance	PAID	20	4/21/2022	
26	1-A25	4	TDOT Acceptance	PAID	20	4/21/2022	
27	1-A26	4	TDOT Acceptance	PAID	20	4/21/2022	
28	1-A27	4	TDOT Acceptance	PAID	20	4/21/2022	
29	1-A28	4	TDOT Acceptance	RRENT ESTIMA	21	5/19/2022	
30	1-A29	4	TDOT Acceptance	RRENT ESTIMA	21	5/19/2022	
31	1-A30	4	TDOT Acceptance	RRENT ESTIMA	21	5/19/2022	
32	1-A31	1	Installed, Not Tested	NOT PAID	NOT YET PAID		
33	1-A32	0	Not Installed	NOT PAID	NOT YET PAID		
34	1-A33	1	Installed, Not Tested	NOT PAID	NOT YET PAID		
35	1-A34	1	Installed, Not Tested	NOT PAID	NOT YET PAID		
36	1-A35	1	Installed, Not Tested	NOT PAID	NOT YET PAID		
37	1-A36	1	Installed, Not Tested	NOT PAID	NOT YET PAID		
38	1-A37	1	Installed, Not Tested	NOT PAID	NOT YET PAID		
39	1-A38	1	Installed, Not Tested	NOT PAID	NOT YET PAID		
40	1-A39	0	Not Installed	NOT PAID	NOT YET PAID		
41	1-A40	0	Not Installed	NOT PAID	NOT YET PAID		
42	1-A41	0	Not Installed	NOT PAID	NOT YET PAID		
43	1-A42	0	Not Installed	NOT PAID	NOT YET PAID		
44	1-A43	0	Not Installed	NOT PAID	NOT YET PAID		
45	1-A44	0	Not Installed	NOT PAID	NOT YET PAID		
46	1-B1	4	TDOT Acceptance	RRENT ESTIMA	21	5/18/2022	
47	1-B2	4	TDOT Acceptance	RRENT ESTIMA	21	5/18/2022	
48	1-B3	4	TDOT Acceptance	RRENT ESTIMA	21	5/13/2022	

Anchor Stressing & Load Testing

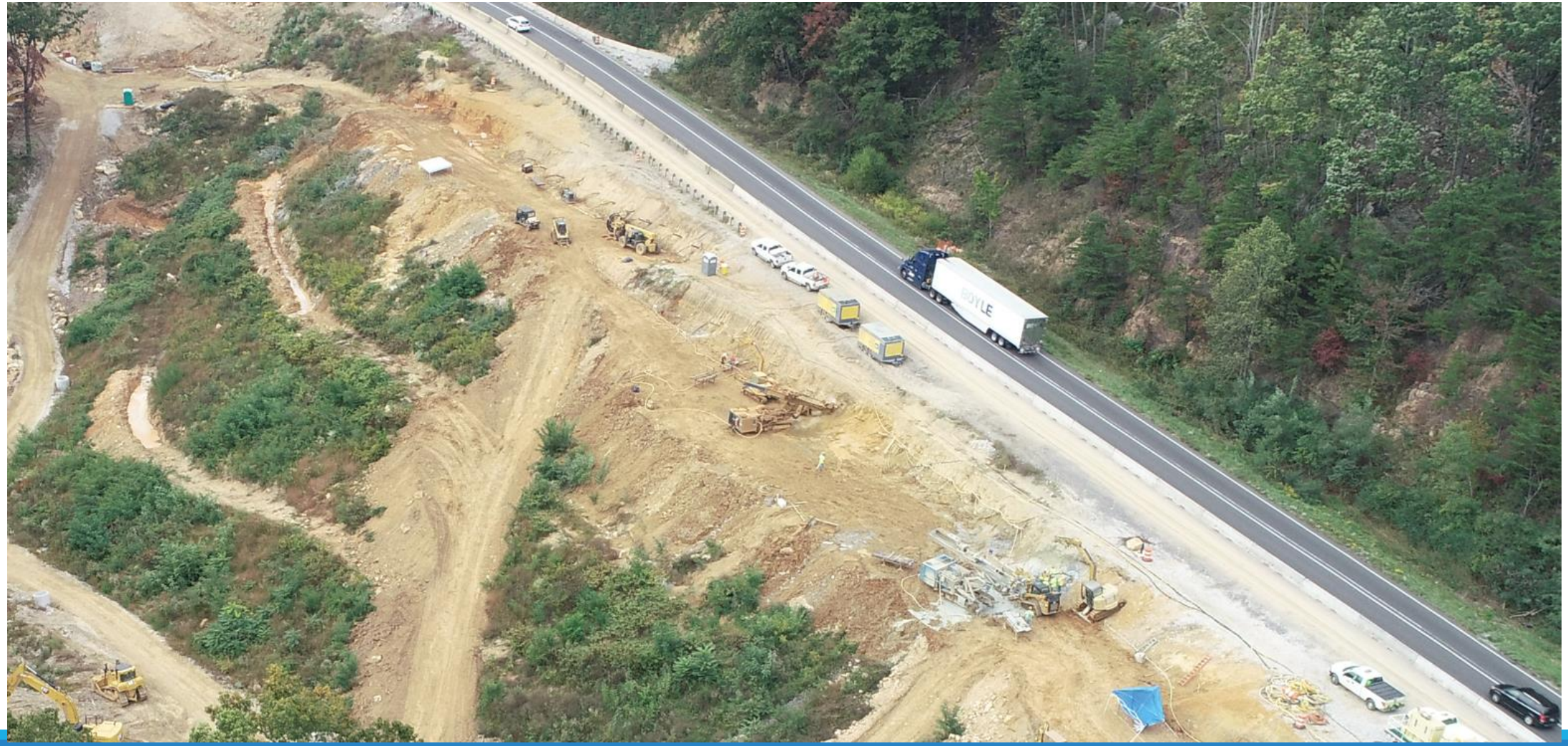
Tracking Progress using Excel

Progress Time Line

Progress Time Line

APRIL 2021

Source: TDOT



Source: TDOT

Progress Time Line

OCTOBER 2021

Source: TDOT

Progress Time Line

NOVEMBER 2021

Source: TDOT

Progress Time Line

JANUARY 25, 2022

Source: TDOT

Progress Time Line

MARCH 16, 2022

Progress Time Line

APRIL 19, 2022

Looking West at Zone 3

MAY 2022

Looking East at Zone 3

MAY 2022

Progress Time Line

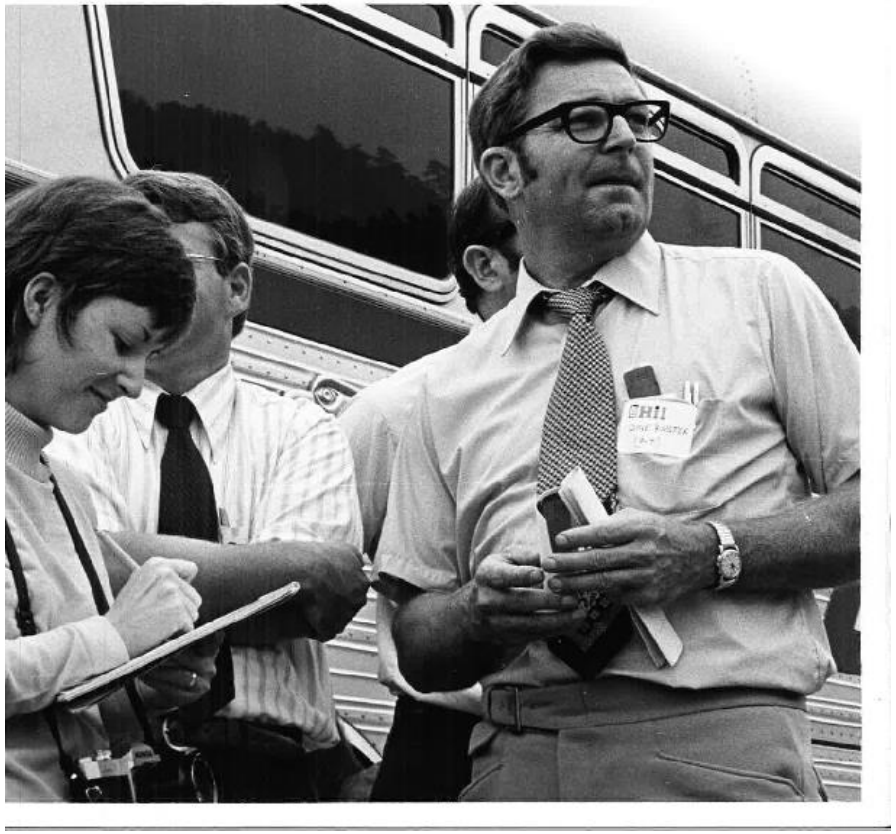
JUNE 14, 2022

Progress Time Line

AUGUST 16, 2022

Status Key	Status Number	Indication	Instances	% of Total
	0	Not Installed	57	9.42%
	1	Installed, Not Tested	37	6.12%
	2	Installed, Tested, Pending Test Submission	0	0.00%
	3	Pending TDOT Acceptance	0	0.00%
	4	TDOT Acceptance	511	84.46%
	5	Design Or Testing Issue	0	0.00%
			605	100.00%
Status Date		9/6/2022		

1st Day Drilling	8/5/2021
Days Elapsed Since	397
Avg. Anchors Approved Per Calendar Day	1.29
Projected Anchor Completion By Straight Line Interpolation	11/18/2022



End of Presentation – Time for Questions?