Design and Construction of Drilled Shafts Wall for Landslides

106th Annual Road School 2020

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CONTENTS

Landslides Overview

- Even if foundation conditions are satisfactory, slopes may be unstable at the desired slope angle.
- For new construction, the cost of fill, right-of-way, and other considerations may make a steeper slope desirable.
- Existing slopes, natural or manmade, may also be unstable, as is painfully obvious when they fail.

Example of Landslide

Example of Landslide (2)

Example of Landslide (3)

Terzaghi and Peck (1967, 426) stated: "On shales of any kind, the decrease of the slope angle to its final equilibrium value takes place primarily by intermittent sliding. The scars of the slides give the slopes the hummocky, warped appearance known as "landslide topography"

SR 66 Spencer County, Indiana

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Example of Landslide (4)

Drilled Shaft Wall was Installed

SR 237 Perry County, Indiana

Example of Landslide (5)

Drilled Shaft Wall will be Installed
CR 875 Landslide Jackson County, Indiana

Example of Landslide (6)

Drilled Shaft Wall will be Installed

CR 100 Landslide
Jackson County, Indiana

Example of Landslide (7)

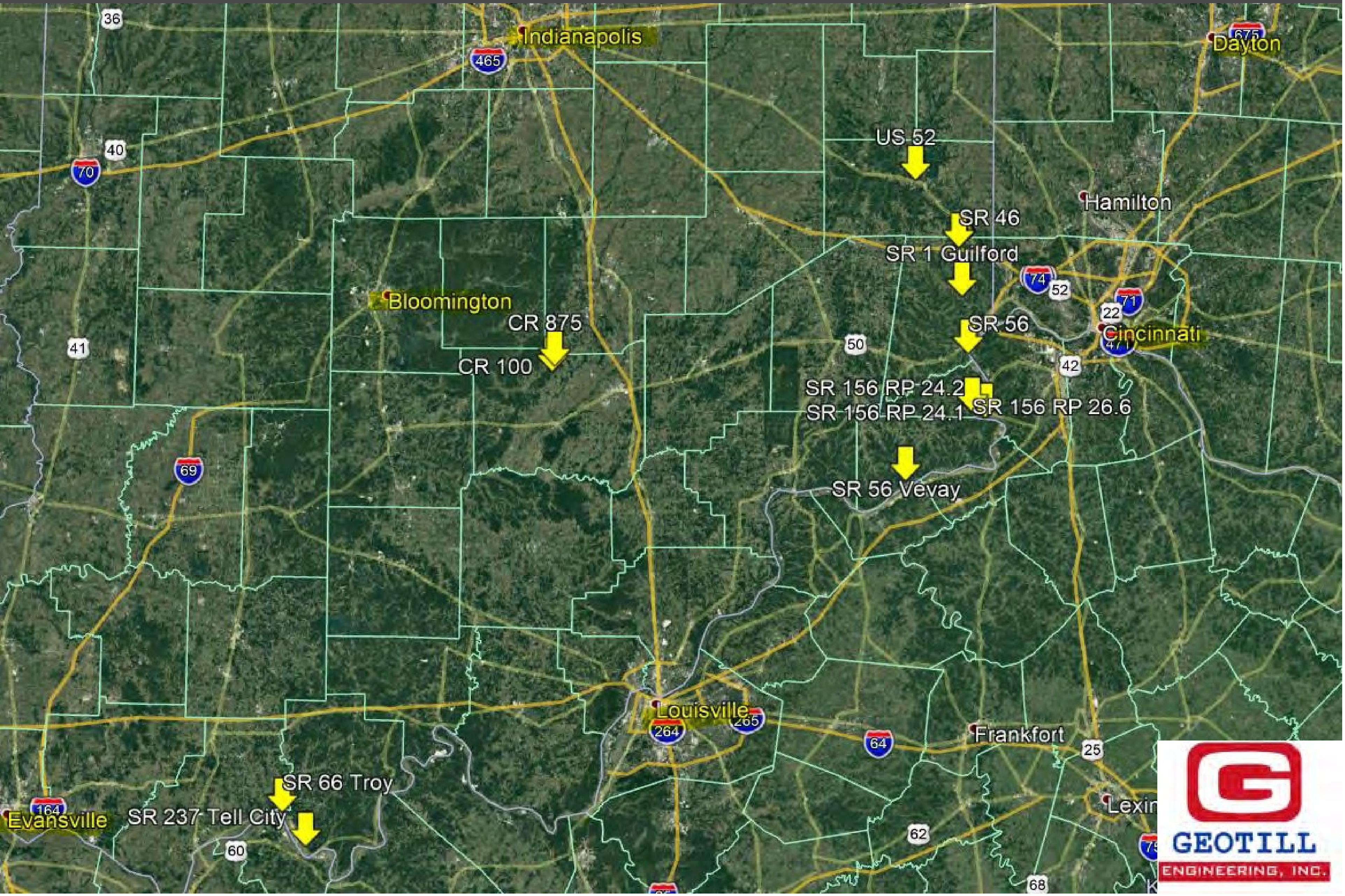
SR 62 Perry County, Indiana

Example of Landslide (8)

Massive landslides caught on camera

Drilled Shaft Wall Geometry with Tiebacks

Drilled Shaft Walls in Indiana



Drilled Shaft / Pier Wall Types

- Drilled Shaft with Lagging
- Drilled Shaft with Plugin Piles
- Drilled Shaft with Tiebacks
- Secant Drilled Shaft
- Tangent Drilled Shaft
- Drilled Shaft with Soldier Piles and Lagging
- Stub Drilled Shafts

SR 237

Drilled Shaft / Pier Wall Types

SR 156

Drilled shafts have been used in landslide stabilization schemes. A drilled shaft wall or even rows of shafts with space between rows can be constructed across a slip surface to provide a restraining force to a sliding soil mass.

Drilled Shaft / Pier Wall Types

Drilled Shaft Wall with Lagging

Drilled Shaft Wall Types

Drilled Shaft Wall with Lagging

- Backfill with structural concrete to bottom of lagging.
- Excavate to Install Lagging Panels.
- Reinforced Precast Concrete or Timber Panels.
- Backfill behind wall with free-draining aggregate.
- Regrade slope in front of wall

SR 66

Drilled Shaft / Pier Wall Types (2)

Drilled Shaft Wall with Plugin Piles

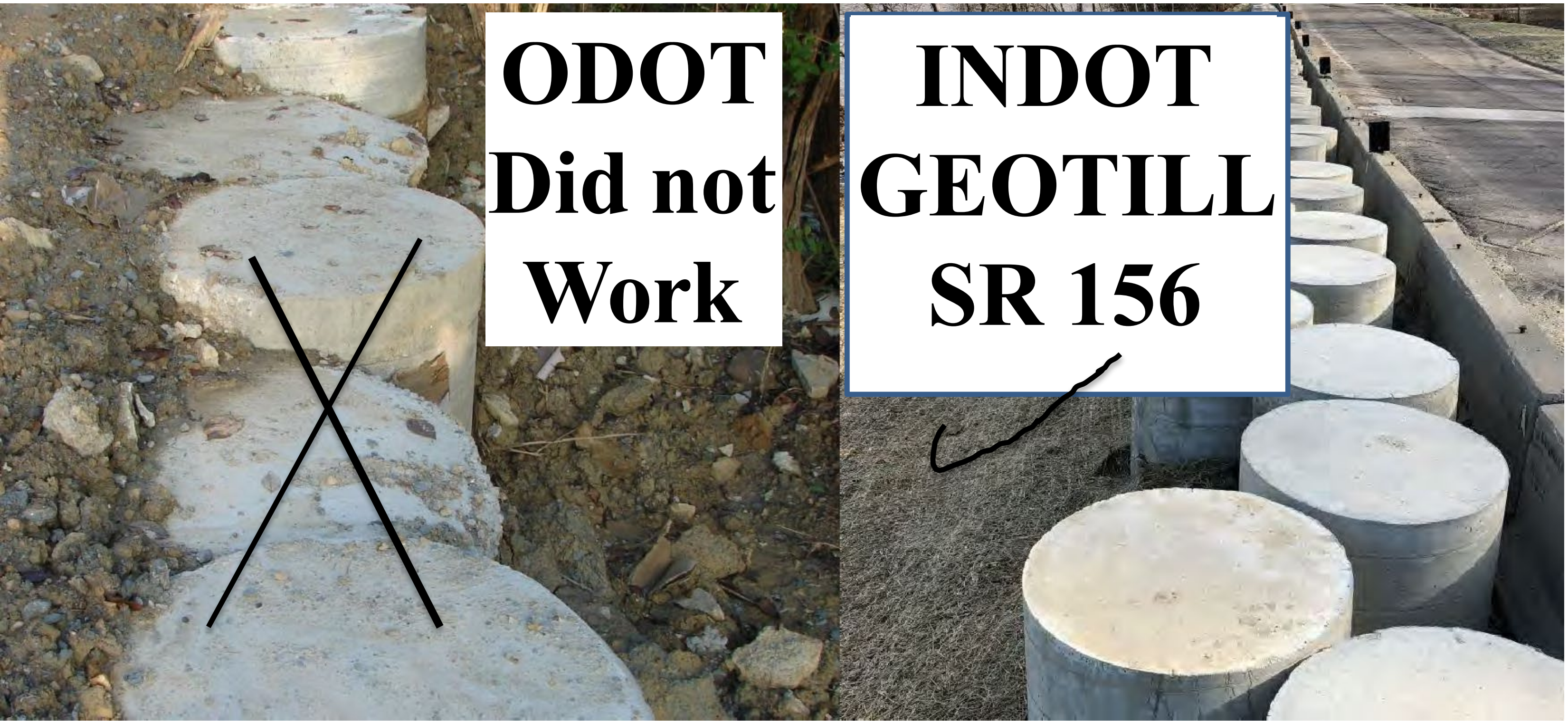
SR 156 RP 26.6

Ohio River

Drilled Shaft Wall Types (2)

Drilled Shaft Wall with Plugin Piles

- Similar to Tangent Pile Wall. However, every other shaft or every two shafts is reinforced.
- Unreinforced shafts are generally shorter (they do not penetrate into bedrock) and serve the purpose of lagging.
- Quick and easy wall.



Drilled Shaft / Pier Wall Types

Drilled Shaft Wall with Tiebacks

Drilled Shaft / Pier Wall Types (3)

Drilled shaft with tieback 4 ft in diameter - 7 ft center to center – 40 ft deep

Drilled Shaft Wall with Tiebacks

Drilled Shaft / Pier Wall Types (4)

Drilled Shaft Secant Wall

Drilled Shaft / Pier Wall Types (5)

Drilled Shaft Tangent Wall

Drilled Shaft Wall Types (3)

Drilled Shaft Tangent Wall

- Drilled shafts with a center-to-center spacing of one shaft diameter.
- With every shaft reinforced, this is the strongest type of drilled shaft retaining wall.
- Very expensive to construct.

Drilled Shaft / Pier Wall Types (6)

Drilled Shaft with Soldier Piles Wall and Lagging

14 HP - 410 ft long wall- spaced 6 ft center-to-center

Extend 10 ft into sound bedrock, drilled piers

DRILLED PIER WALL CONSTRUCTION PHOTOS

Drilled Shaft Wall Construction Sequence (2)

Drilled Shaft Wall Construction Sequence (3)

SR 66 Landslide, Perry County, Indiana

Drilled Shaft Wall Construction Sequence (4)

SR 66 Landslide, Perry County, Indiana

Drilled Shaft Wall Construction Sequence (5)

SR 66 Landslide, Perry County, Indiana

Drilled Shaft Wall Construction Sequence (6)

SR 66 Landslide, Perry County, Indiana

Drilled Shaft Wall Construction Sequence (7)

SR 66 Landslide, Perry County, Indiana

Drilled Shaft Wall Construction Sequence (8)

SR 66 Landslide, Perry County, Indiana

Drilled Shaft Wall Construction Sequence (9)

SR 66 Landslide, Perry County, Indiana

Drilled Shaft Wall Construction Sequence (10)

SR 66 Landslide, Perry County, Indiana

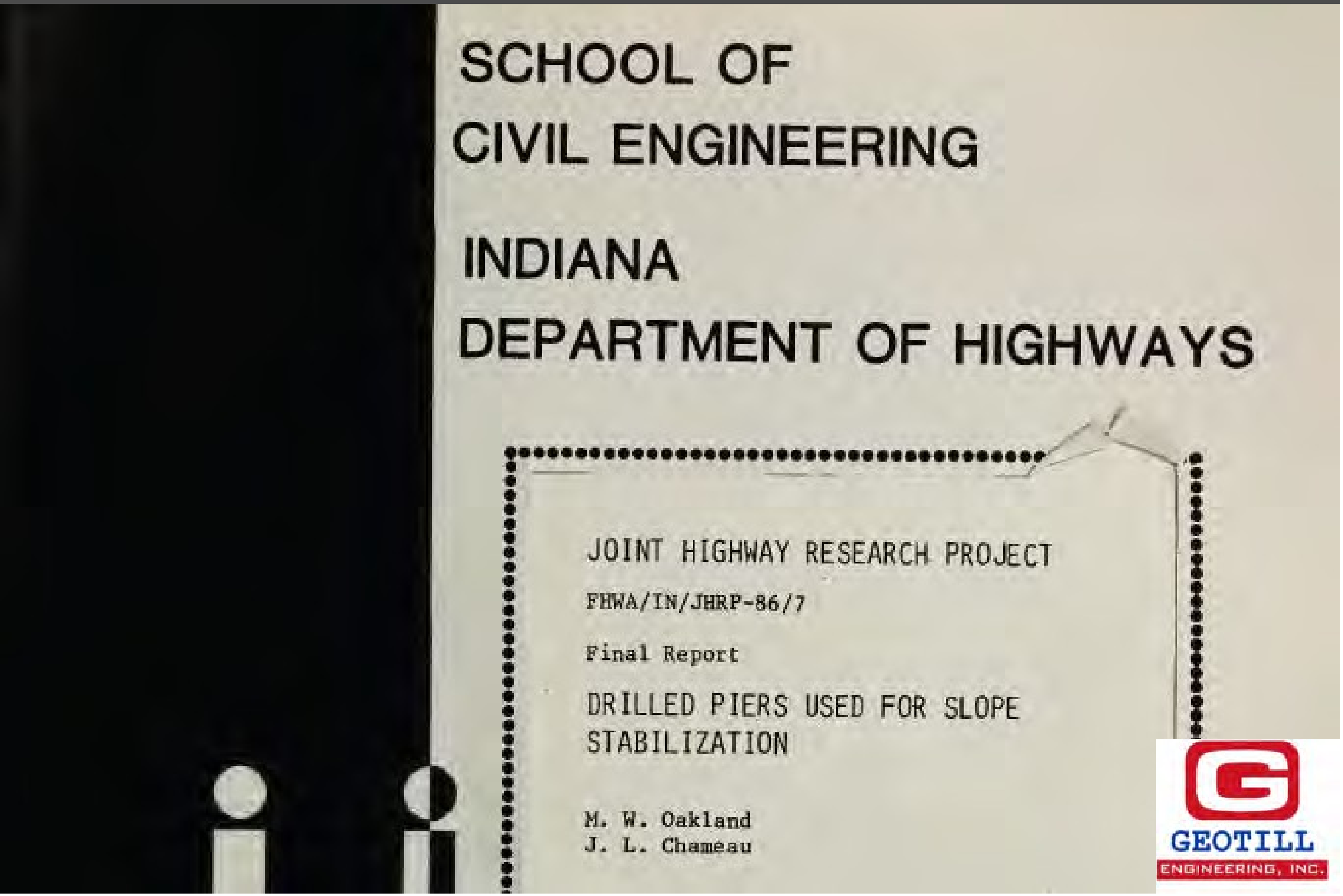
Drilled Shaft Wall Construction Sequence (11)

SR 66 Landslide, Perry County, Indiana

Drilled Shaft Wall Analysis and Design

- Past research relevant to the analysis of drilled shaft stabilized slopes include work by Merriam (1960), Andrews and Klasell (1964), Bulley (1965), Gould (1970), Ito and Matsui (1975), Oakland and Chameau at Purdue (1986), Reese (1992), Hassiotis et.al. (1997) Poulos (1999), and Liang and Zeng (2002).
- Slope stability is evaluated at the AASHTO (2014) Service I Load Combination relative to geotechnical resistance factors that are the inverse of the factor of safety (FS) computed by the various software available for slope analysis. In practice, the target geotechnical resistance factors (ϕ) of 0.75 and 0.65, as referenced in 11.6.2.3 of AASHTO (2014), are equal to a factor of safety (FS) of 1/Φ, or FS 1.33 and 1.53, respectively.
- Analyses of the overall slope may be performed using a limit equilibrium approach such as the Modified Bishop, Simplified Janbu, or Spencer methods, as available in several different geotechnical analysis software.
- If the existing slope is failing, the computed factor of safety should approximate 1.0, comparable to a geotechnical resistance factor of 1.0 for the Service Limit State, Should the computer simulated surface of failure differ significantly from the estimated shear failure surface based on surface observations and inclinometer data, the engineering properties, soil stratification and/or pore pressures within the slope should be adjusted in iterative "back-analyses" until the output from the computer analysis conforms to
- the observed conditions. A back-analysis that produces a geotechnical factor of safety of 1.0 (geotechnical resistance factor 1.0), but includes a calculated failure surface that is inconsistent with field observations should not be relied upon. All relevant parameters need to be consistent with observations.

Drilled Shaft Wall Analysis and Design (2)



SCHOOL OF
CIVIL ENGINEERING

INDIANA
DEPARTMENT OF HIGHWAYS

JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-86/7

Final Report

DRILLED PIERS USED FOR SLOPE
STABILIZATION

M. W. Oakland
J. L. Chameau

Drilled Shaft Wall Analysis and Design (3)

SR 156 Landslide RP 24.1

Drilled Shaft Wall Analysis and Design (4)

SR 156 Landslide RP 24.1

Drilled Shaft Wall Analysis and Design (5)

SR 156 Landslide RP 24.1

Drilled Shaft Wall Analysis and Design (6)

SR 156 Landslide RP 24.1 (Location of Test Borings)

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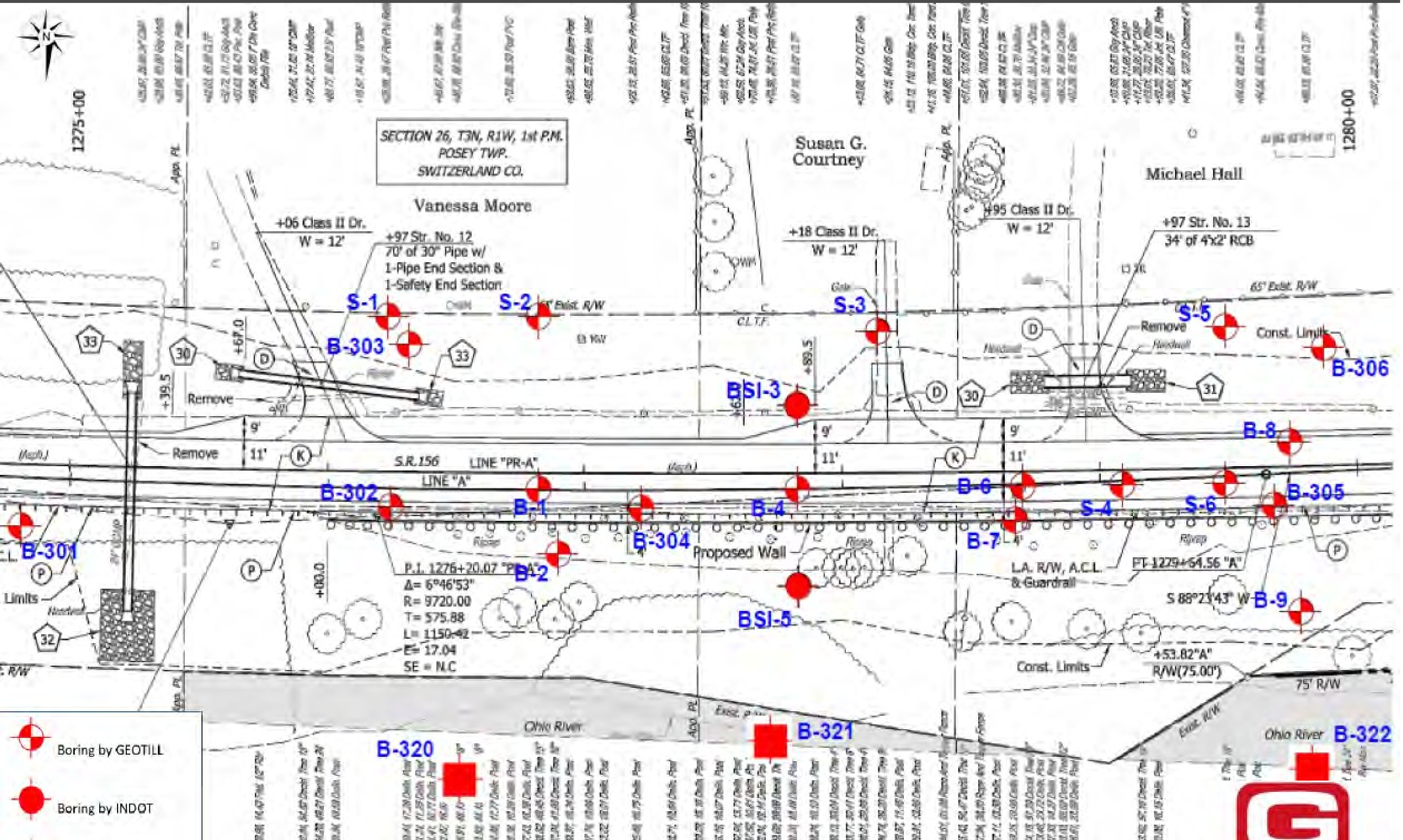
Drilled Shaft Wall Analysis and Design (7)

SR 156 Landslide RP 24.1 (Location of Test Borings)

Drilled Shaft Wall Analysis and Design (8)



SR 156 Landslide RP 24.1 (Location of Test Borings)

Drilled Shaft Wall Analysis and Design (9)

SR 156 Landslide RP 24.1 (Launching Rig in Ohio River)

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Drilled Shaft Wall Analysis and Design (10)

SR 156 Landslide RP 24.1 (Drilling in Ohio River)

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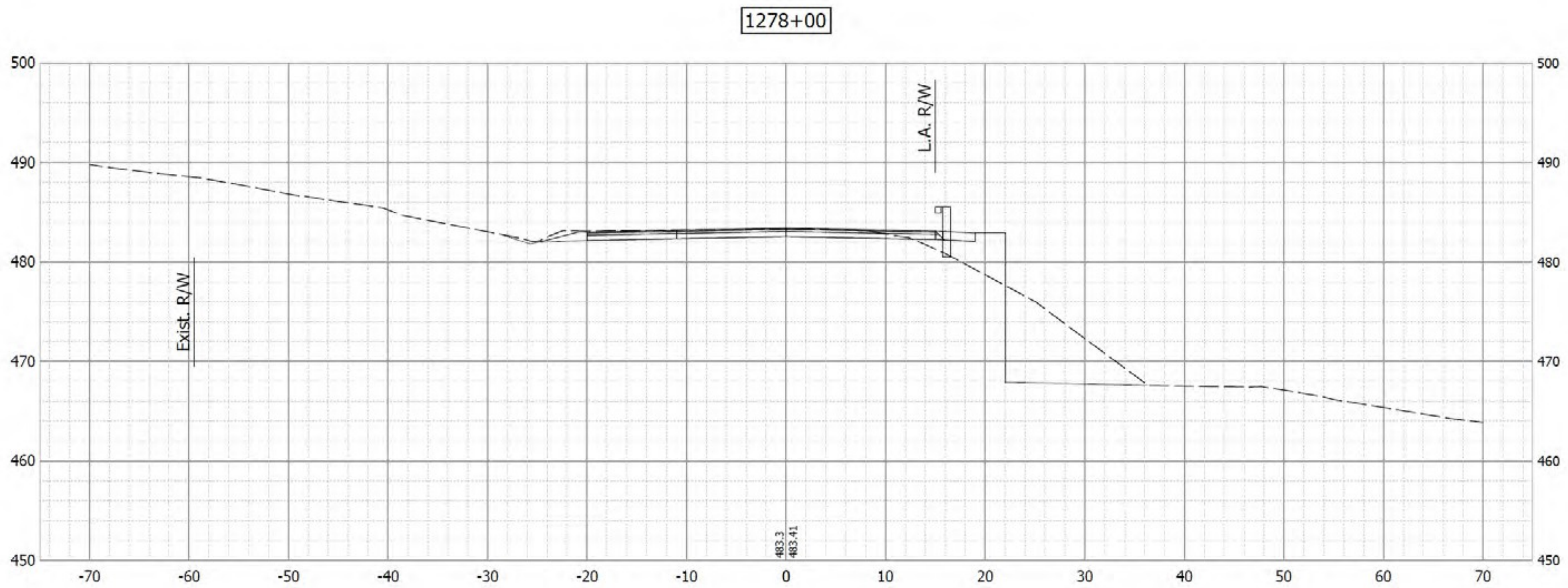
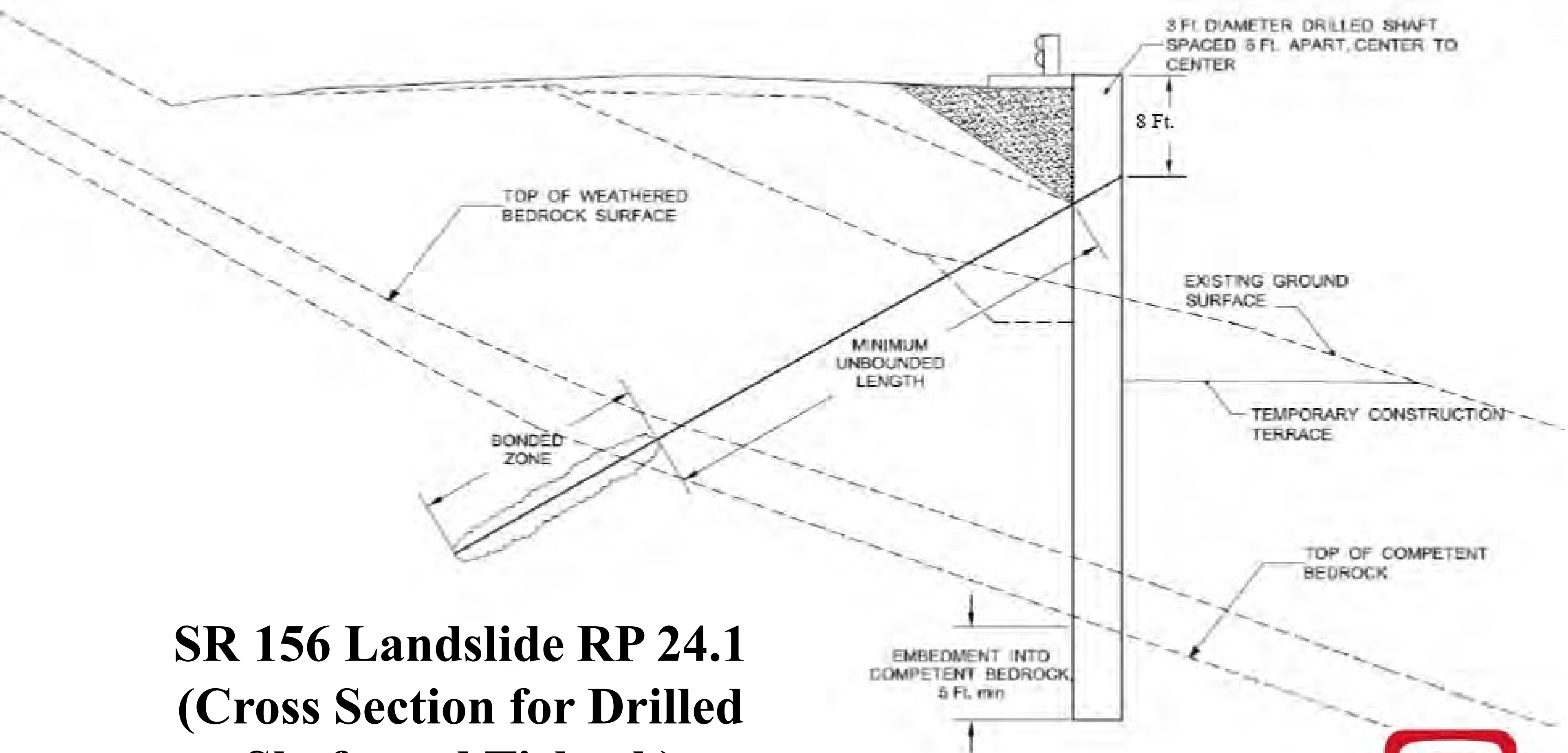
Drilled Shaft Wall Analysis and Design (11)



SR 156 Landslide RP 24.1 (Cross Section from Plans)

Drilled Shaft Wall Analysis and Design



SR 156 Landslide RP 24.1 (Cross Section for Drilled Shaft and Tieback)

Drilled Shaft Wall Analysis and Design (12)

SR 156 Landslide RP 24.1 (Soft Rock)

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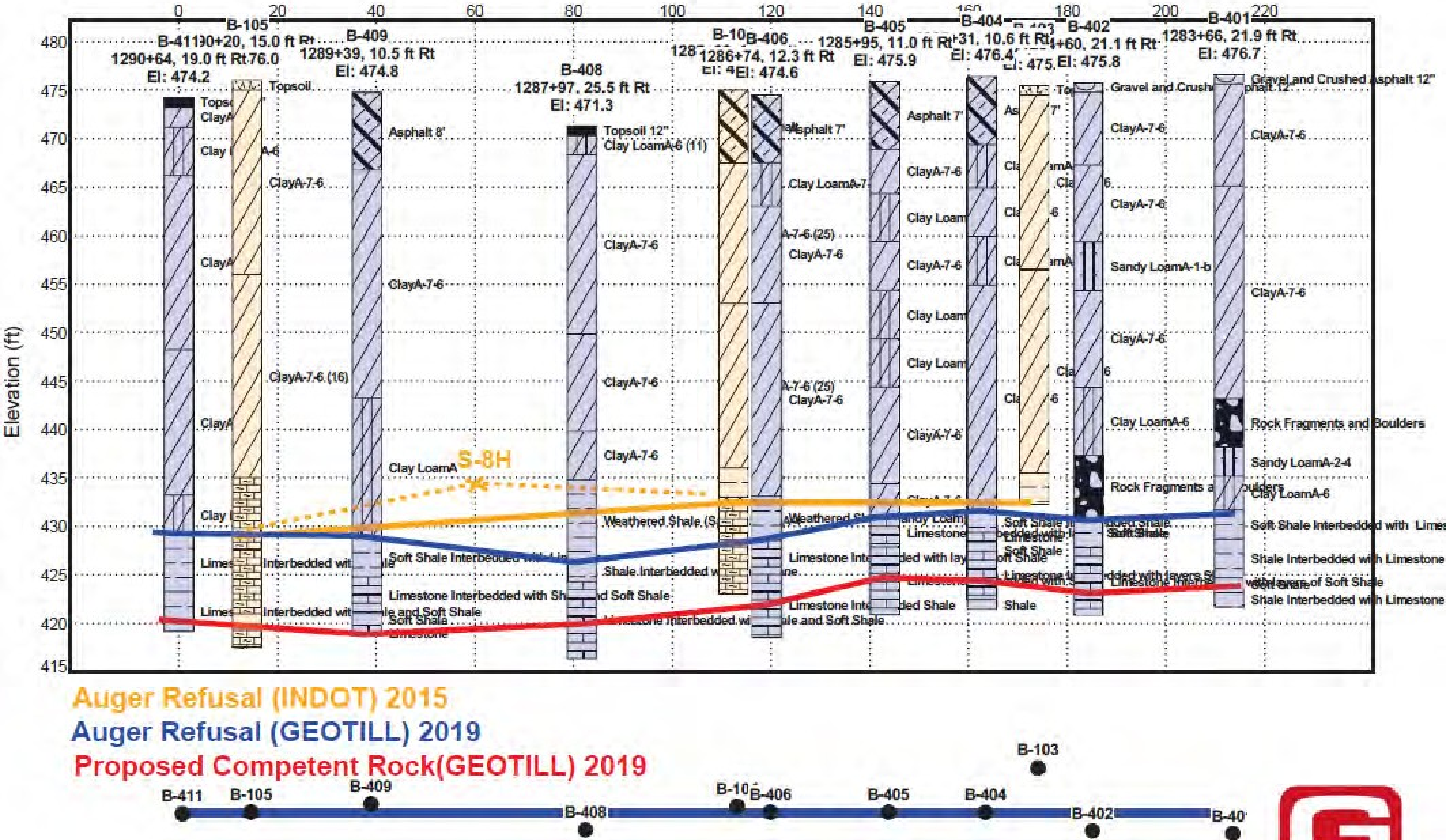
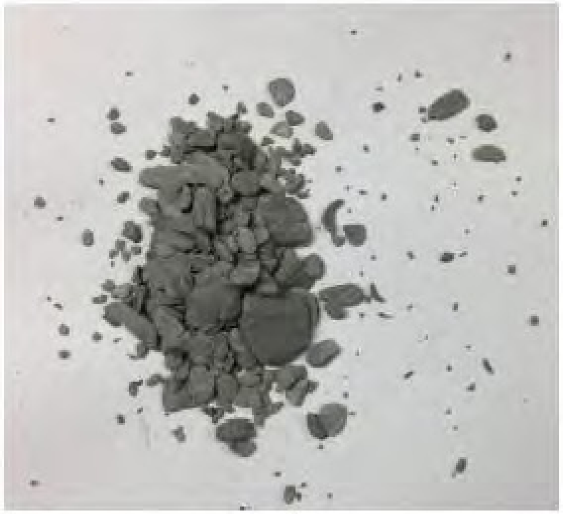
Drilled Shaft Wall Analysis and Design (13)



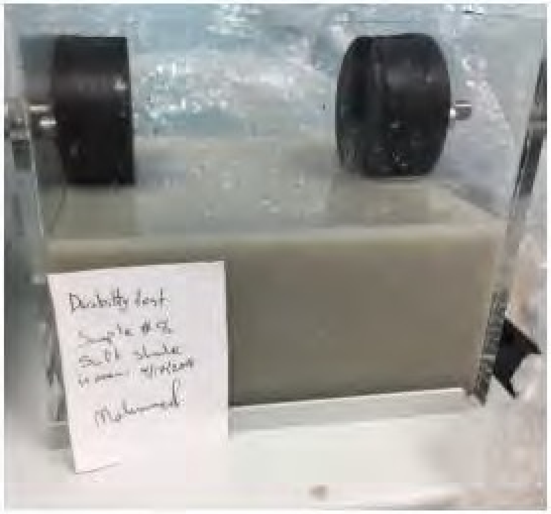
SR 156 Landslide RP 24.1 (Soft Rock)

Drilled Shaft Wall Analysis and Design (14)

Specimen before running the test



Turbidity of slake apparatus after running 2 cycles



Specimen after running 2 cycles

Elevation (ft)	Rock	Water Content (%)	Slake Durability Index	Type
435	Shale	4.6	32.6%	III

SR 156 Landslide RP 24.1
(Slake Durability Test for Soft Shale)

Drilled Shaft Wall Analysis and Design (15)

Specimen before running the test

Turbidity of slake apparatus after running 2 cycles

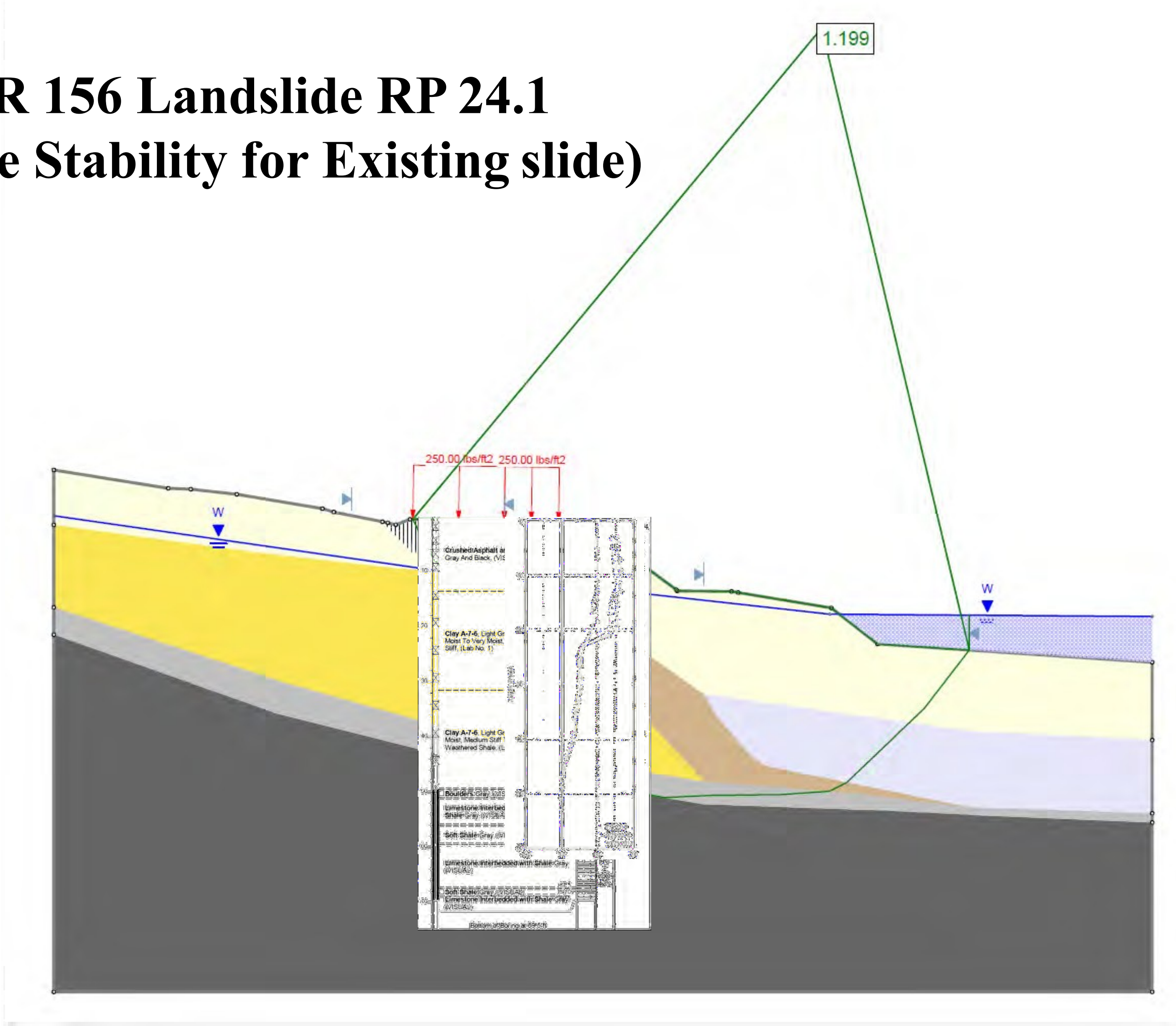
Specimen after running 2 cycles

Elevation (ft)	Rock	Water Content (%)	Slake Durability Index	Type
421	Hard Shale	2.4	83.1%	II

SR 156 Landslide RP 24.1
(Slake Durability Test for Hard Shale)

Drilled Shaft Wall Analysis and Design

SR 156 Landslide RP 24.1
(Slope Stability for Existing slide)



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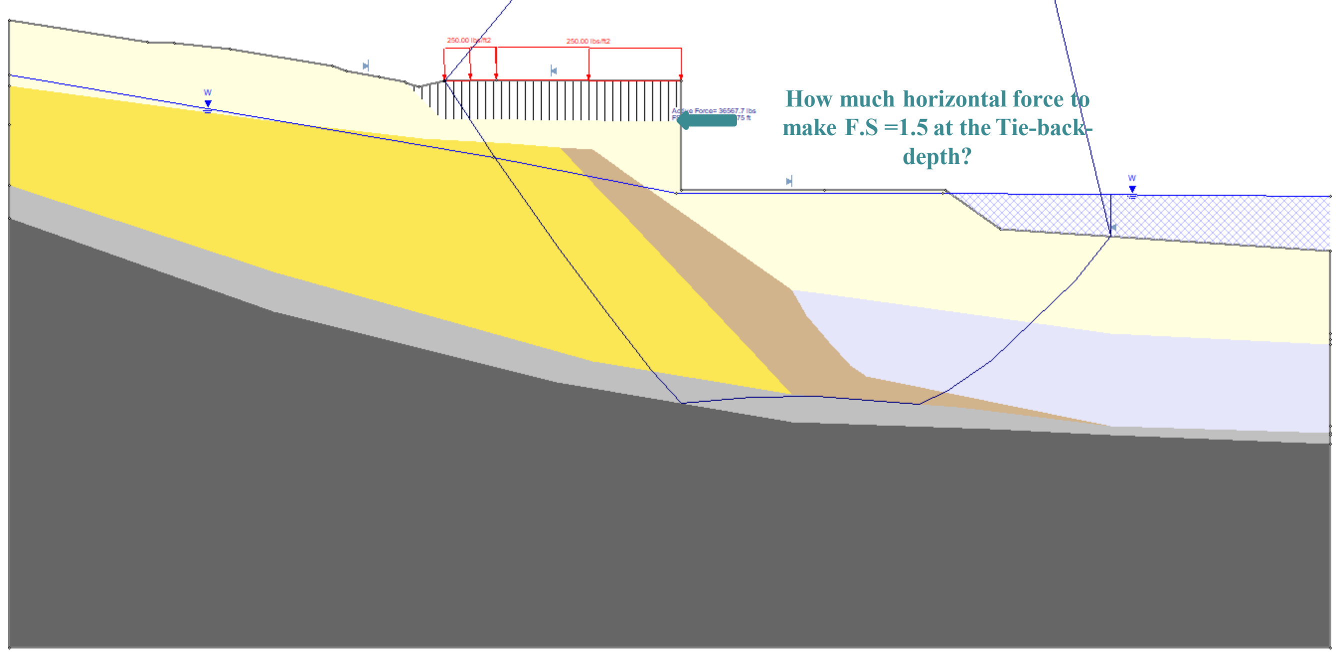
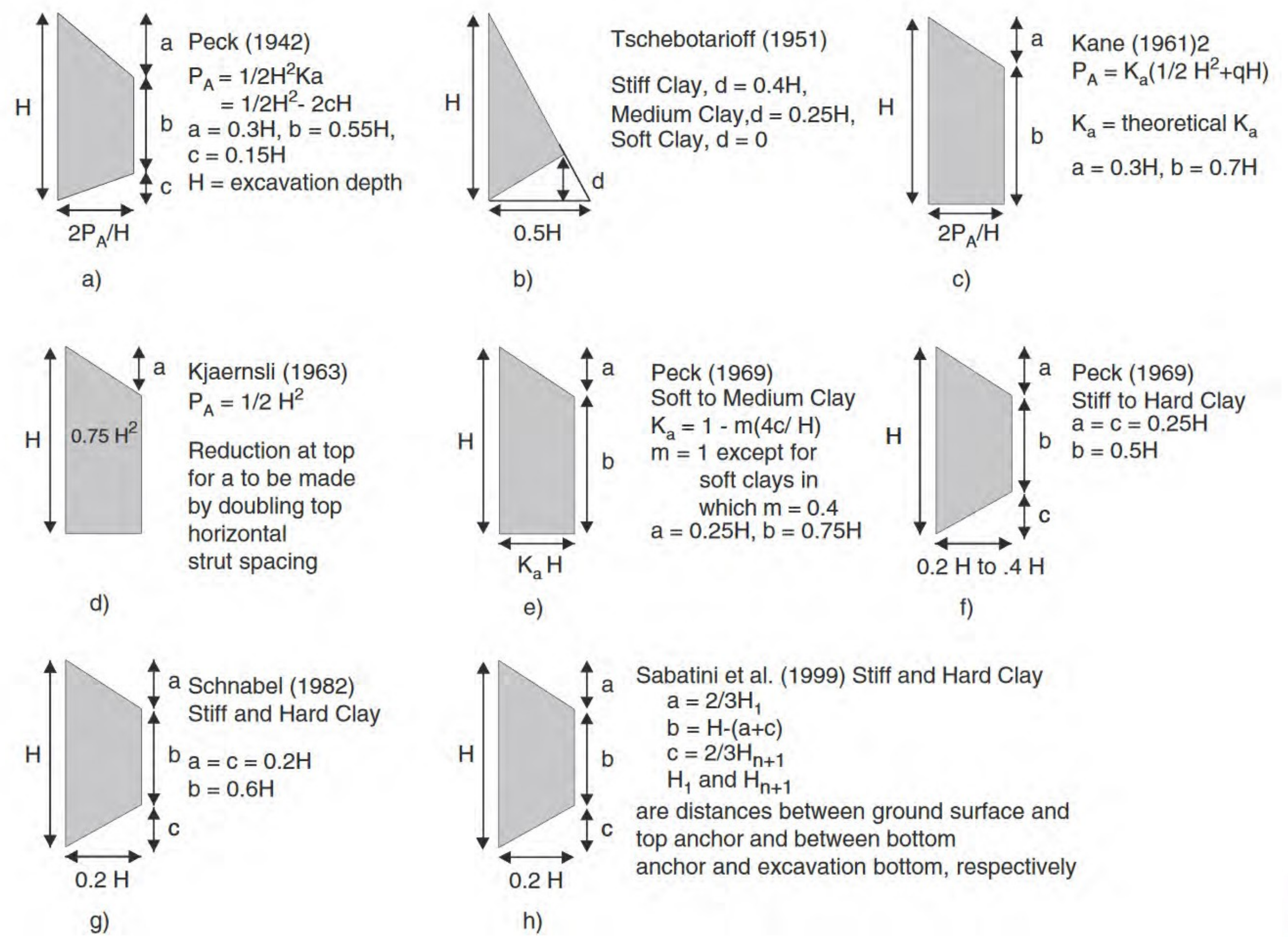
SR 156 Landslide RP 24.1 (Determine Horizontal Force Needed for FS = 1.5)



SR 156 Landslide RP 24.1(Apparent Earth Pressure Diagrams)



Drilled Shaft Wall Analysis and Design (17)

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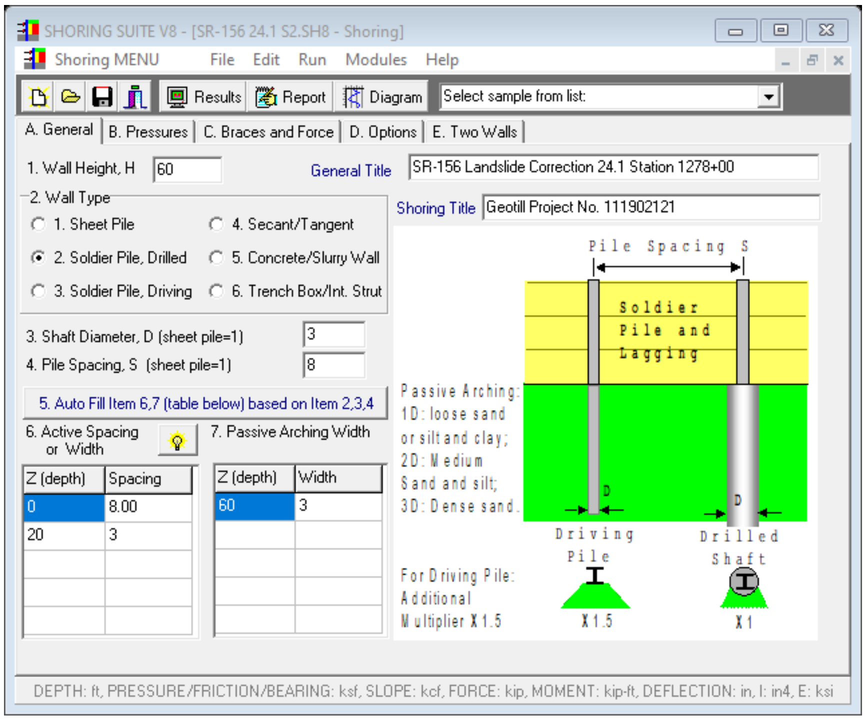

SR-156 Landslide Correction 24.1 Station 1278+00
Geotill Project No. 111902121

Wall Height=60.0 Pile Diameter=3.0 Pile Spacing=8.0 Wall Type: 2 Soldier Pile, Drilled

PILE LENGTH: Min. Embedment=0.92 (8~10 is recommended) Min. Pile Length=60.92
MOMENT IN PILE: Max. Moment=798.67 per Pile Spacing=8.0 at Depth=28.98

PILE SELECTION:
Request Min. Section Modulus = 242.0 in3/pile, Fy= 60 ksi = 414 MPa, Fb/Fy=0.66
User Input I (Moment of Inertia):
Top Deflection = -0.67(in) based on Elastic Module, E (ksi)= 3605.00 and Moment of Inertia, I (in4)/pile= 82447.0

BRACE FORCE: Strut, Tieback, Plate Anchor, and Deadman

No. & Type	Depth	Angle	Space	Total F	Horiz. F	Vert. F	L_free	Fixed Length
1. Tieback	8.0	30.0	8.0	172.2	149.1	86.1	26.8	23.4

UNITS: Width,Diameter,Spacing,Length,Depth,and Height - ft; Force - kip; Bond Strength and Pressure - ksf

DRIVING PRESSURES (ACTIVE, WATER, & SURCHARGE):

Z1	P1	Z2	P2	Slope
0.0	0.00	5.3	0.90	0.170
5.3	0.90	25.3	0.90	0.000
25.3	0.90	60.0	0.00	-0.026

PASSIVE PRESSURES: Pressures below will be divided by a Factor of Safety =2

Z1	P1	Z2	P2	Slope
60.0	20.00	999.0	20.00	0.000

ACTIVE SPACING:

No.	Z depth	Spacing
1	0.00	8.00
2	20.00	3.00

SR 156 Landslide RP 24.1
(Moment, shear force and deflection)

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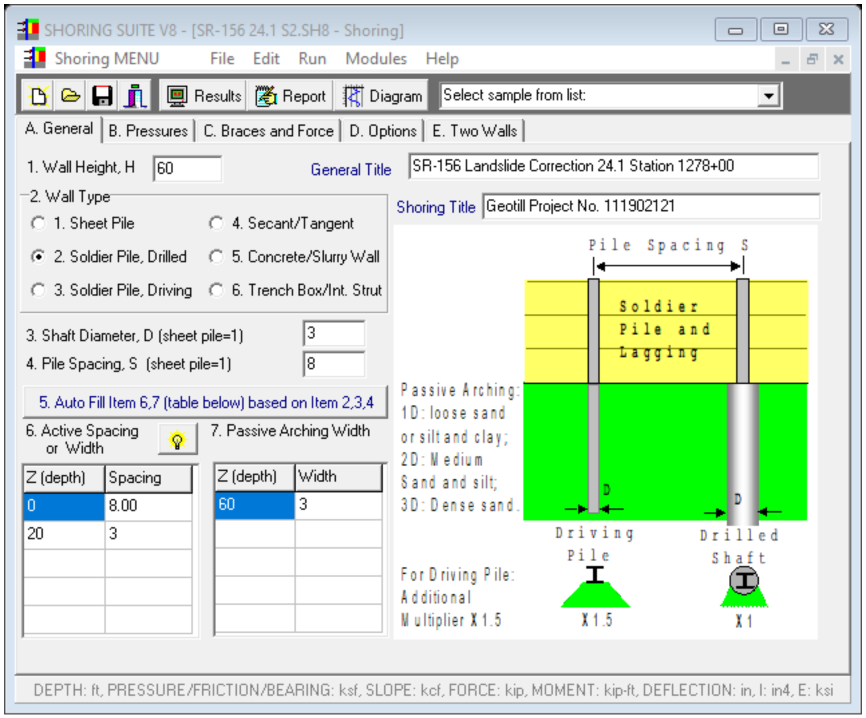
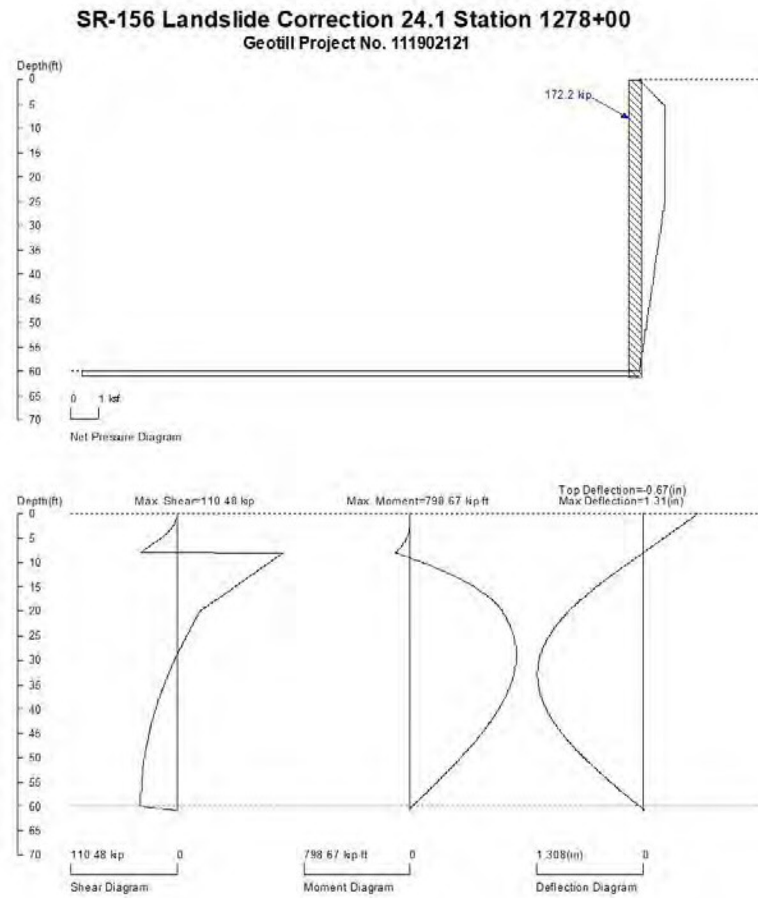
Drilled Shaft Wall Analysis and Design (18)

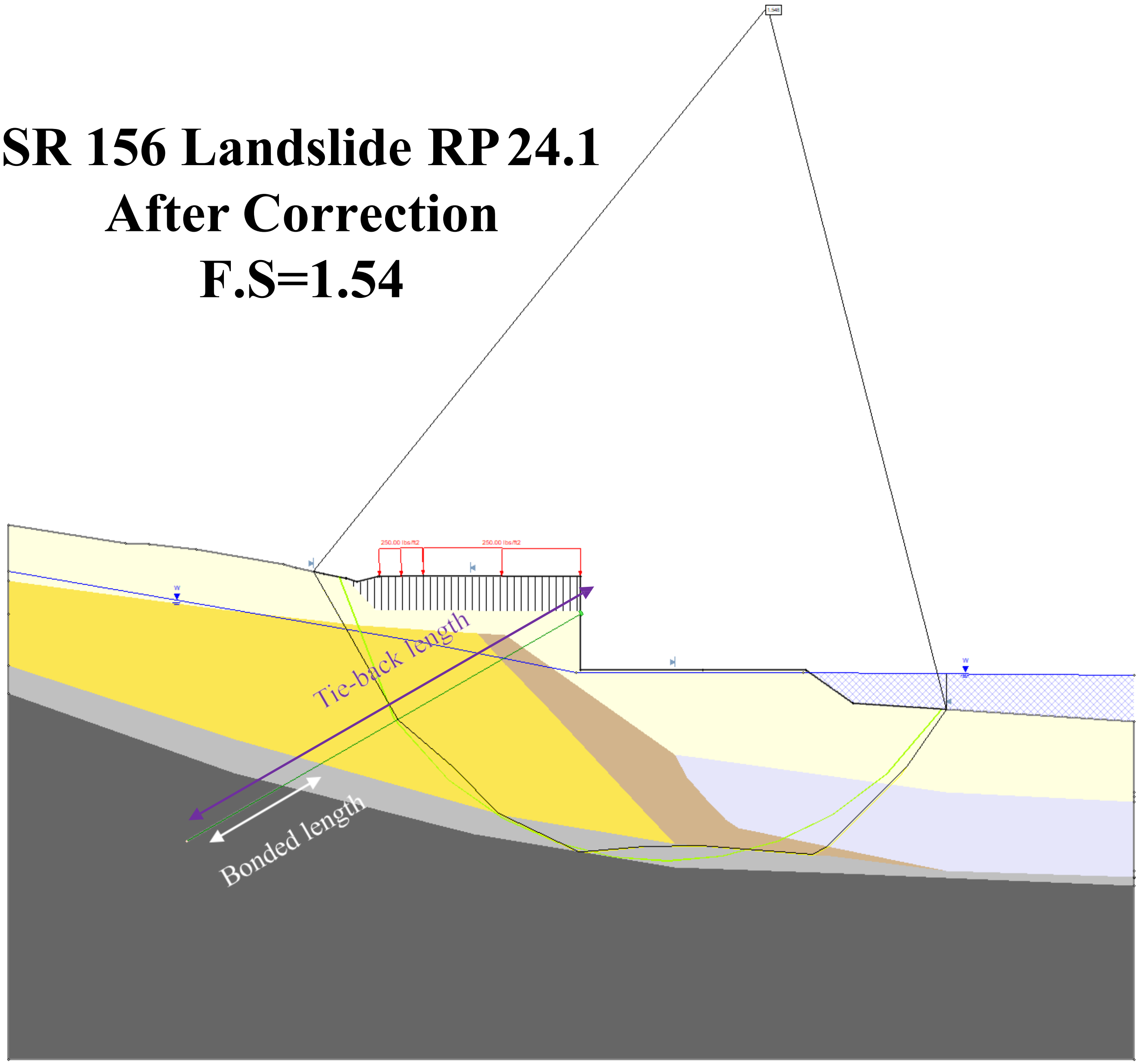




SR 156 Landslide RP 24.1
(Moment, shear force and deflection)

Drilled Shaft Wall Analysis and Design (19)

SR 156 Landslide RP 24.1
After Correction
F.S=1.54



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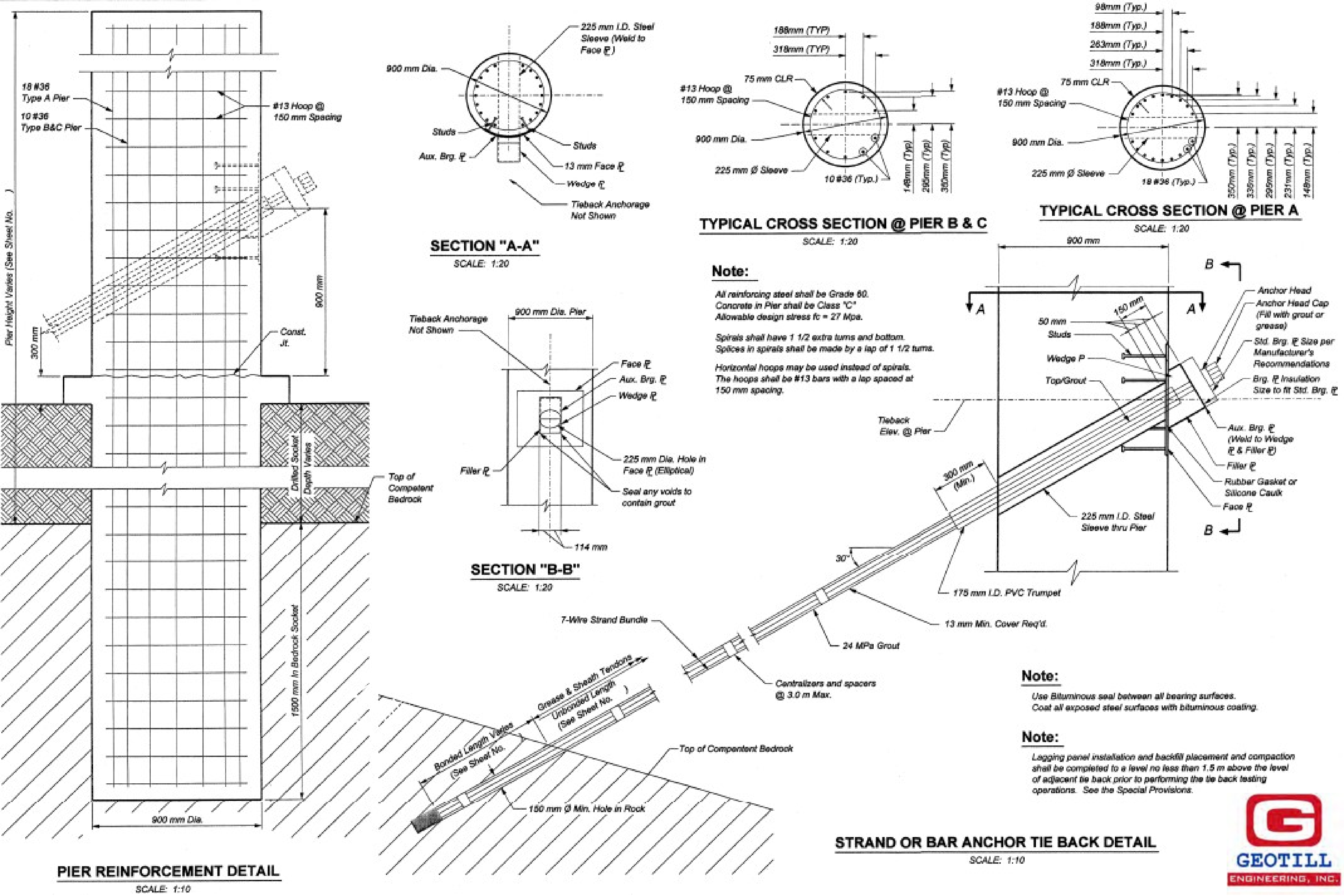
Drilled Shaft Wall Reinforcement



Drilled Shaft Wall SR 156 Case History

Drilled Shaft Wall SR 156 Case History

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Drilled Shaft Wall SR 156 Case History (2)

Drilled Shaft Wall SR 156 Case History (3)

Drilled Shaft Wall SR 156 Case History (4)

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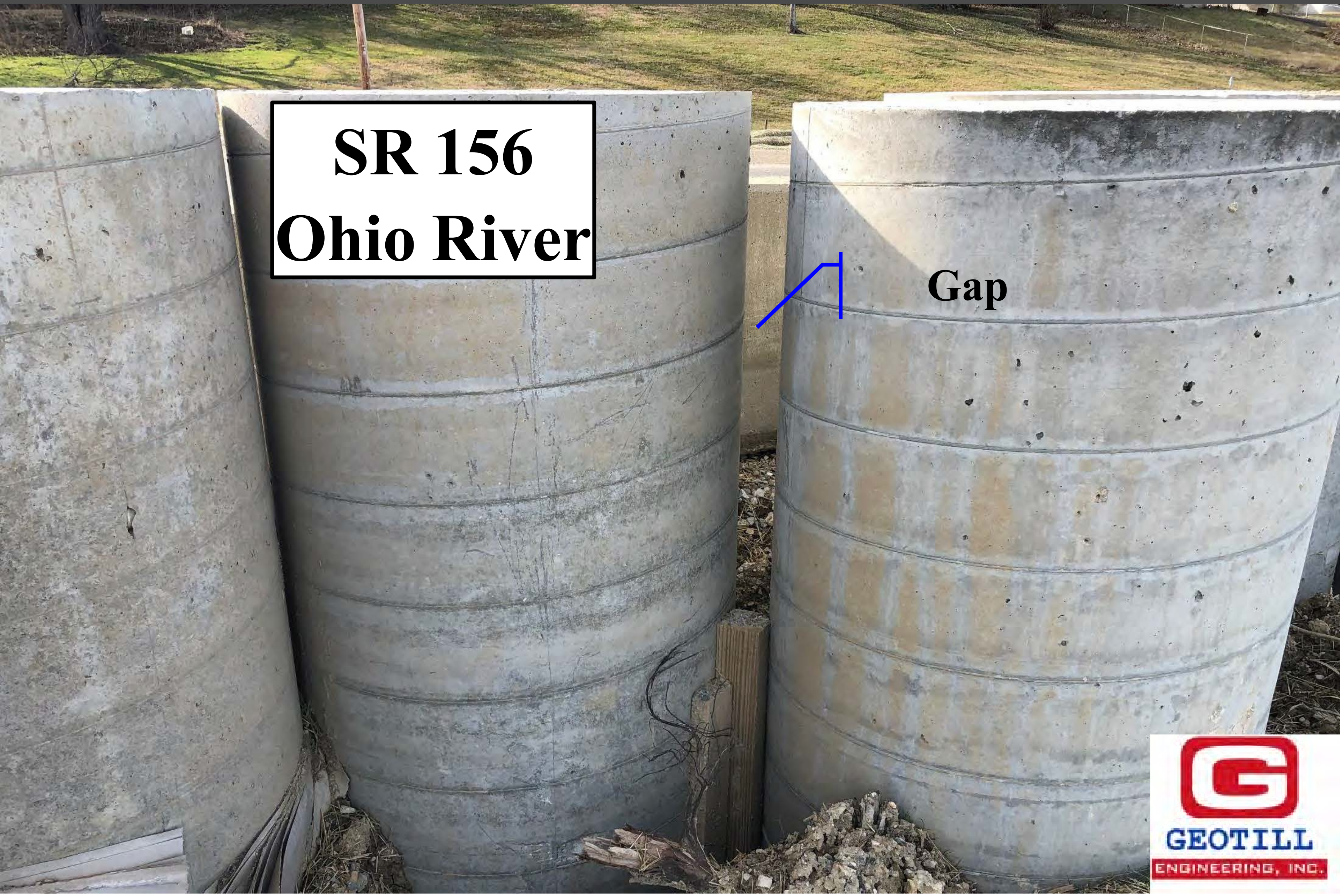
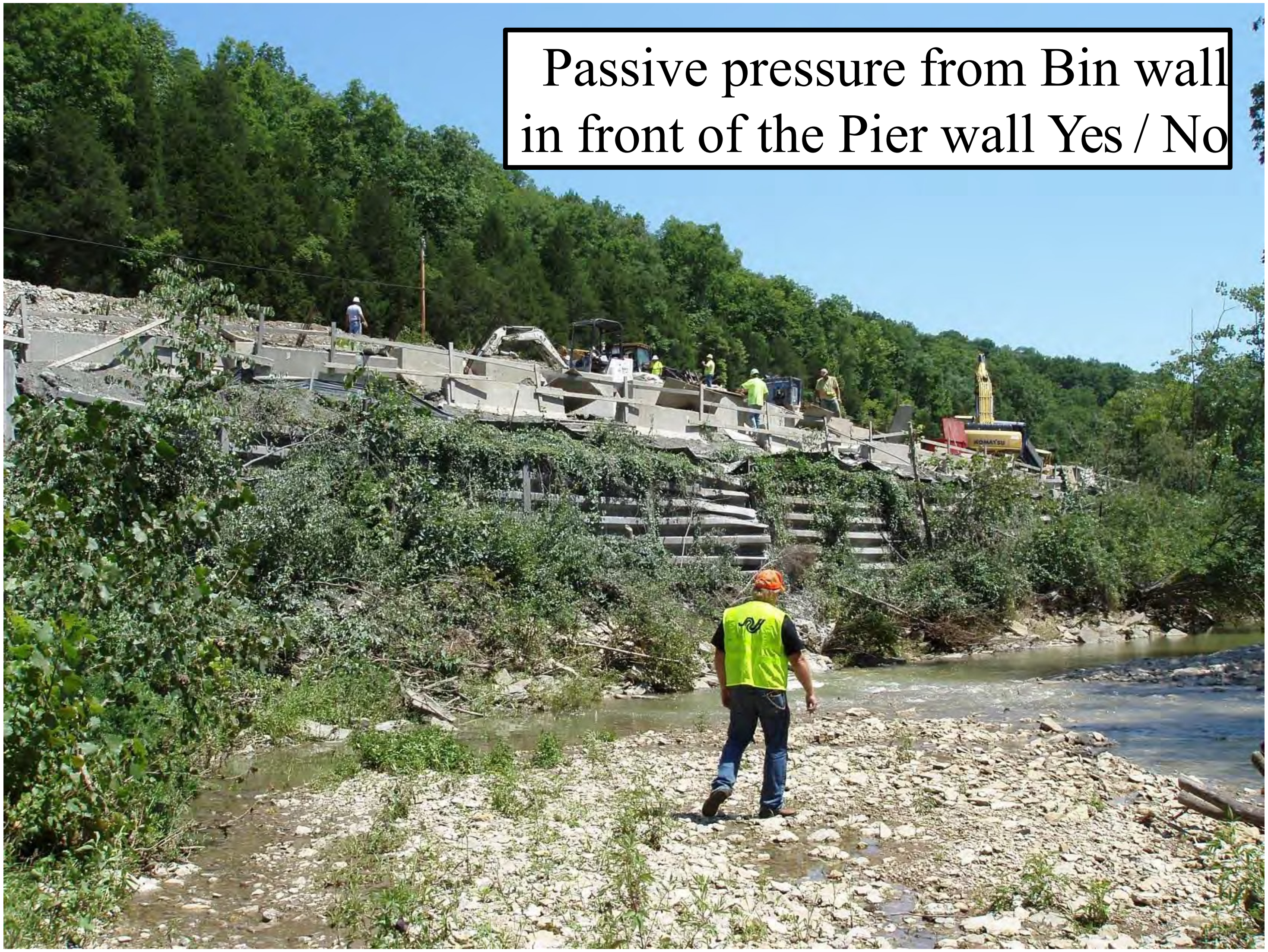
Drilled Shaft Wall SR 156 Case History (5)

Drilled Shaft Wall SR 156 Case History (6)

Drilled Shaft Wall SR 156 Case History (7)



Drilled Shaft Wall Design Considerations



In 1952 bin-wall was constructed

SR 46
RP 150
Dearborn County
Drilled Shaft Wall

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Drilled Shaft Wall Design Considerations

SR 46
RP 150
Dearborn
County
Drilled
Shaft
Wall

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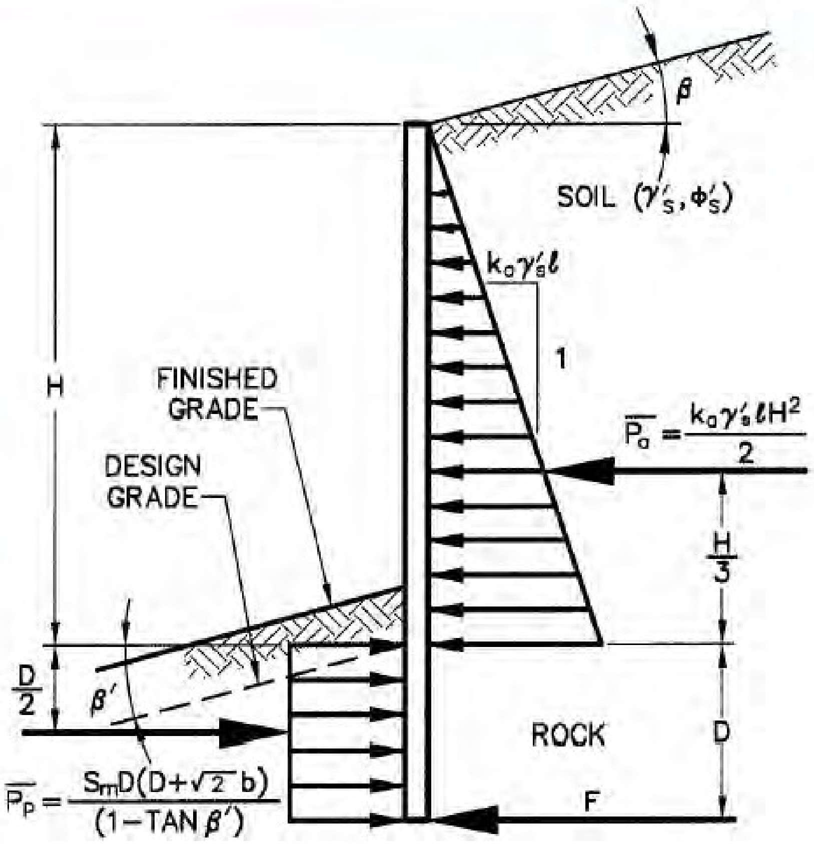
Drilled Shaft Wall Design Considerations



b = ACTUAL WIDTH OF EMBEDDED DISCRETE VERTICAL WALL ELEMENT BELOW DESIGN GRADE IN PLANE OF WALL (FT.).

Figure 3.11.5.6-2—Unfactored Simplified Earth Pressure Distributions for Permanent Nongravity Cantilevered Walls with Discrete Vertical Wall Elements Embedded in Rock

Passive pressure for drilled shaft wall embedded in Rock

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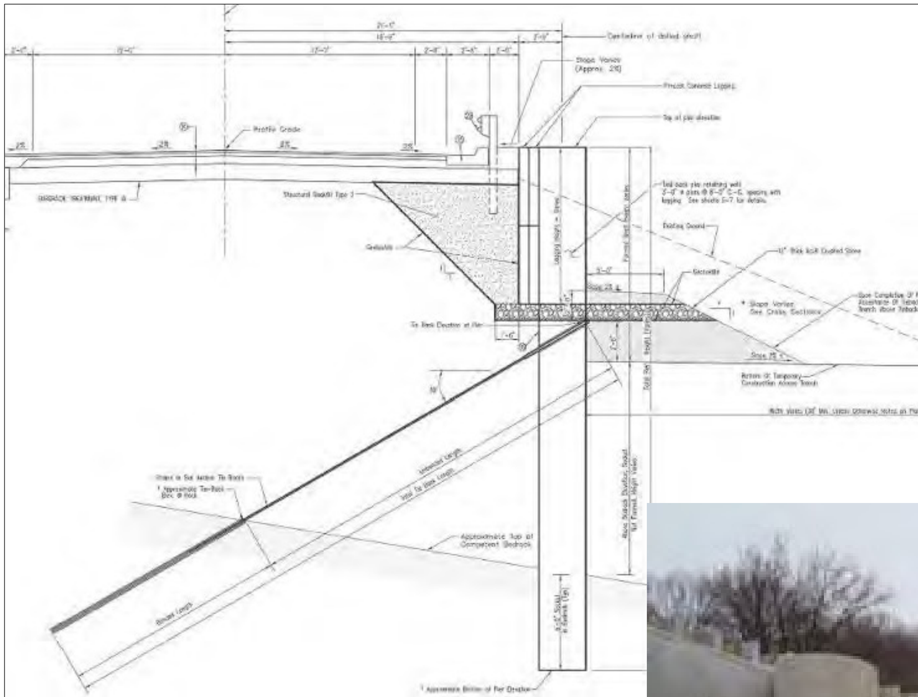
Drilled Shaft Wall Design Considerations (2)

- When piers are spaced 5 pier diameters or less apart, ground loads will tend to arch onto the stiff inclusions, as shown here.
- A semi-circular zone of tension will develop between the piers.

Drilled Shaft Wall Design Considerations (3)



During the design, it has been decided to shift the wall location, what you do about the Geotechnical Investigation that it has been already done?

2000 ft long wall
300 drilled shafts with tied-back
3 ft in diameter
8 ft center to center
5 ft into the bedrock

SR 56
Switzerland County
Vevay
Drilled Shaft Wall

Drilled Shaft Wall Design Considerations (4)

SR 56
Switzerland County
Vevay
Drilled Shaft Wall

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Drilled Shaft Wall Design Considerations

Drainage Design Issues

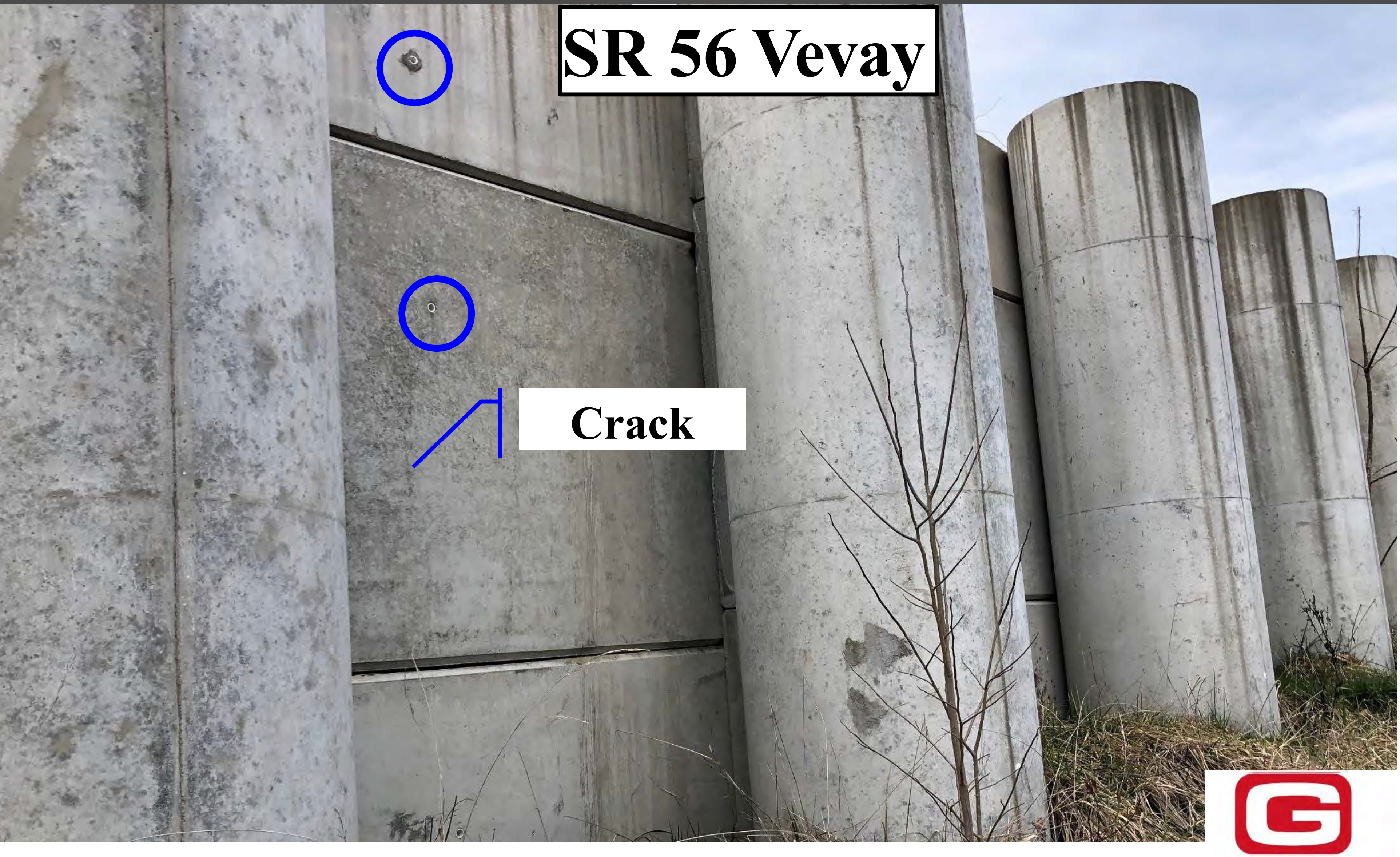
Drilled Shaft Wall Design Considerations (5)

Drainage Design Issues

Drilled Shaft Wall Design Considerations (6)

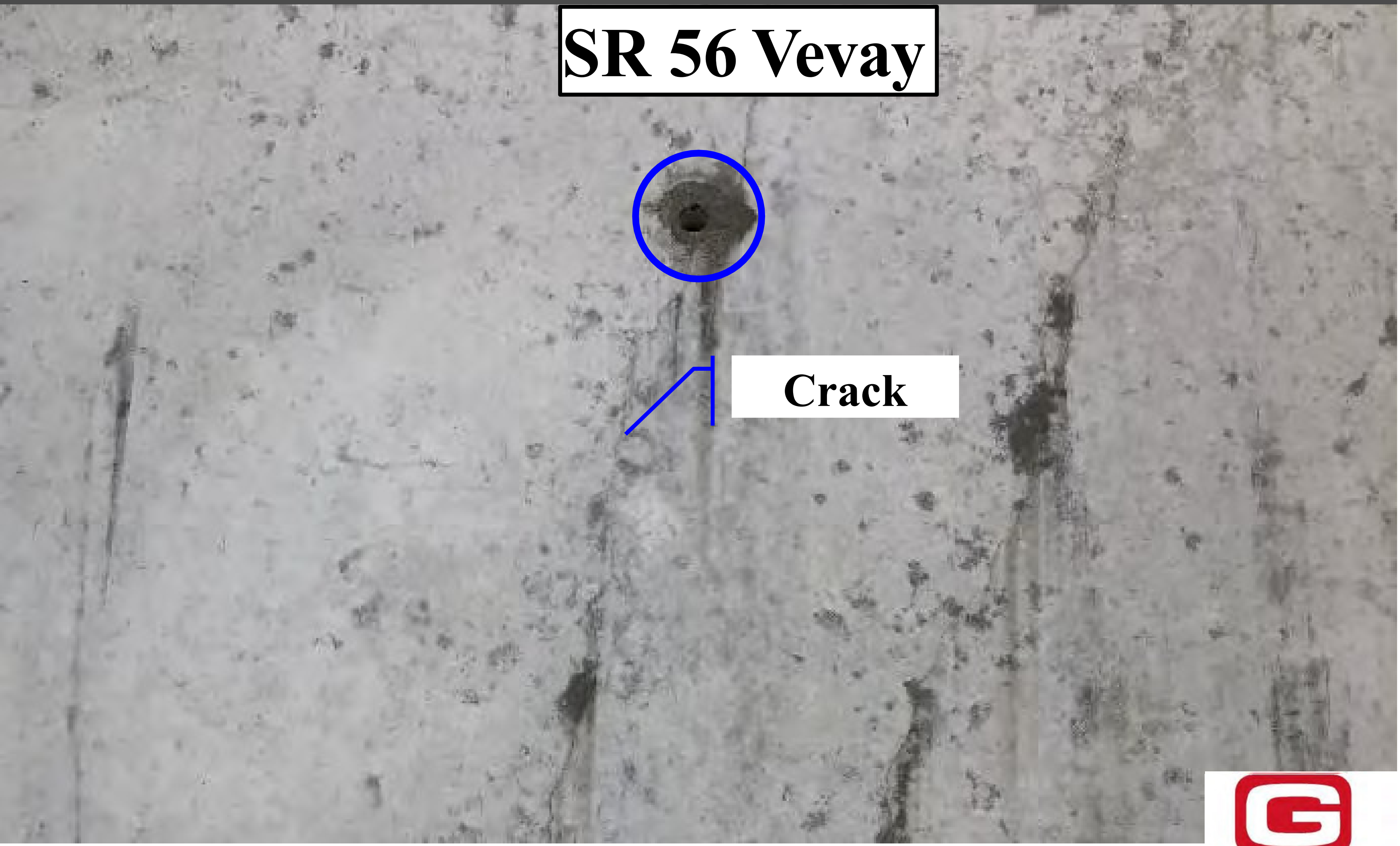
Drainage Design Issues

Drilled Shaft Wall Design Considerations (7)



Weep Hole Design Issues

Drilled Shaft Wall Design Considerations (8)

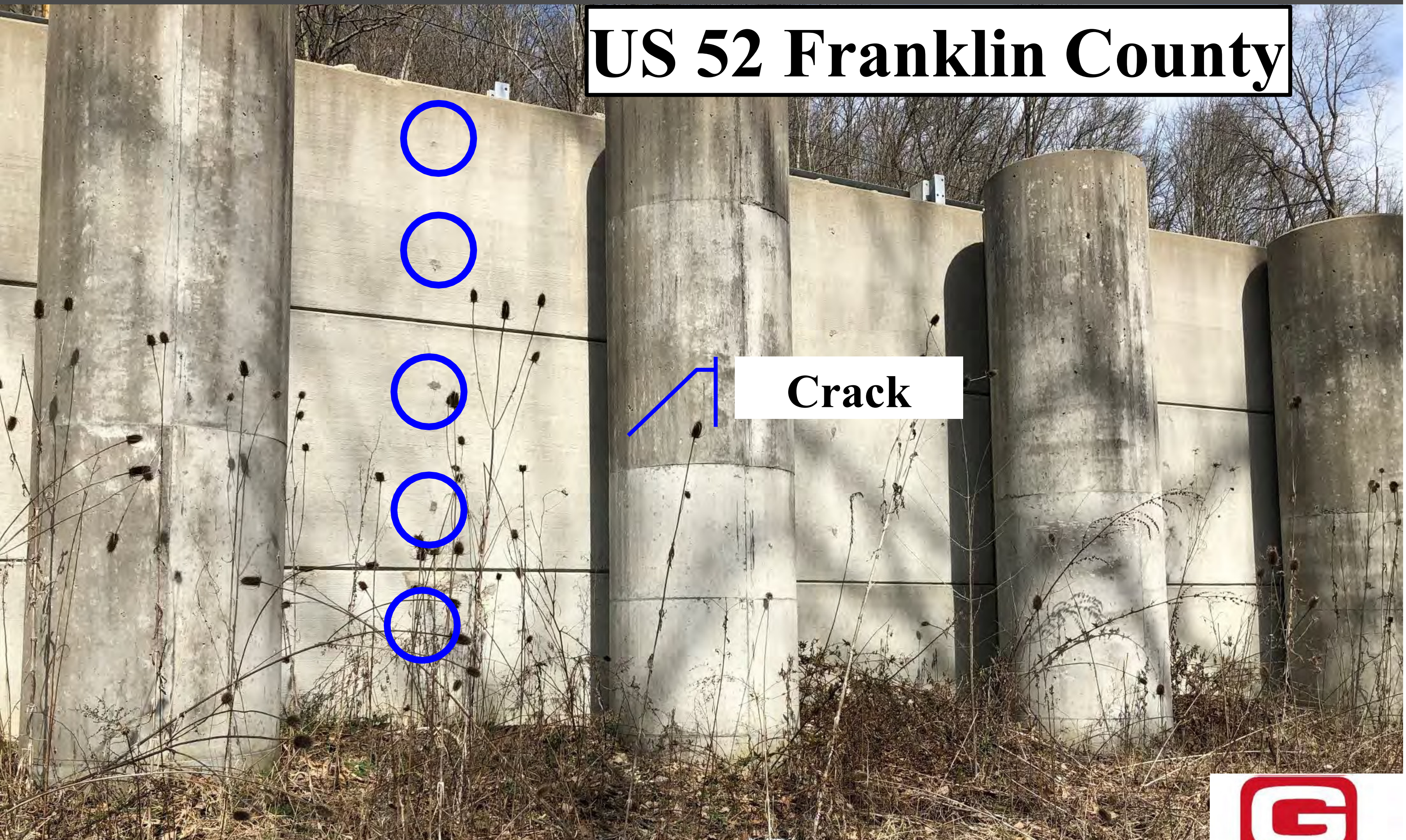


Weep Hole Design Issues

Drilled Shaft Wall Design Considerations (9)

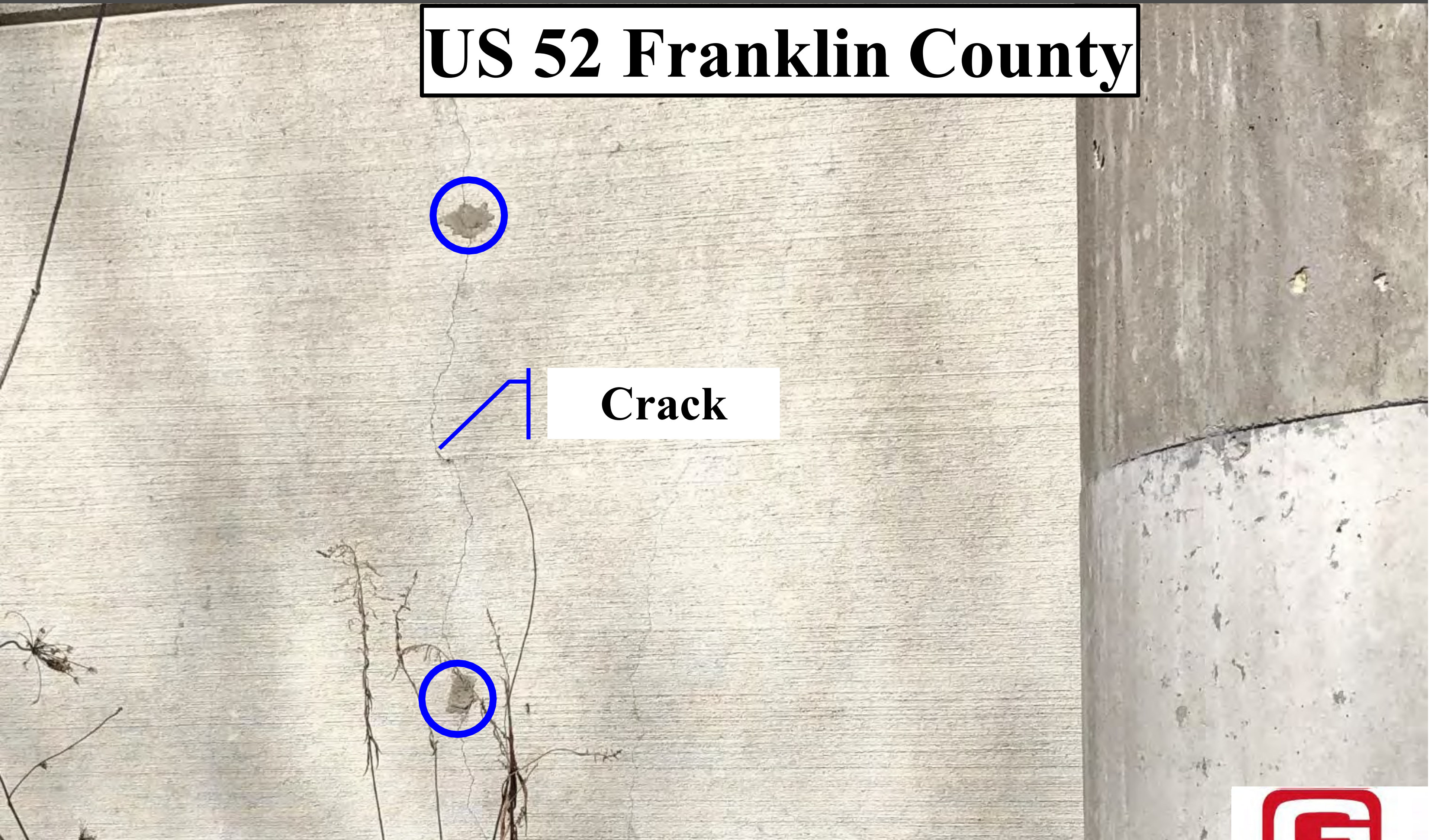
Weep Hole Design Issues

Drilled Shaft Wall Design Considerations (10)



Weep Hole Design Issues

Drilled Shaft Wall Design Considerations (11)



Weep Hole Design Issues

Questions ?

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