MSE Wall Failures Lessons Learned

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MSE Wall Failures Lessons Learned

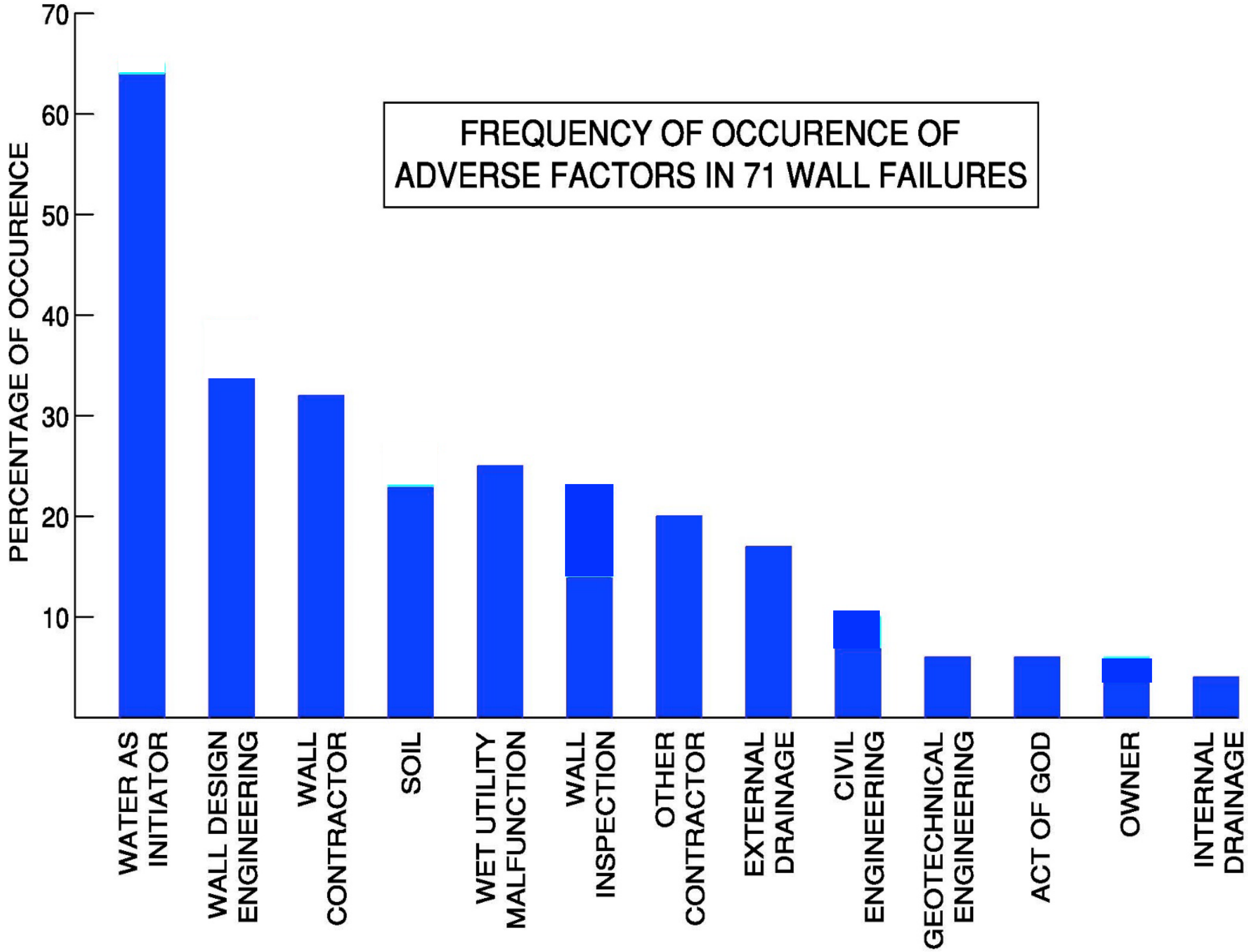
Forensic Evaluations

- Review of 71 failures (Collin and Valentine)
- Categorized the adverse factors that contributed to the failures/poor performance
- Evaluated the frequency with which each adverse factor occurred.

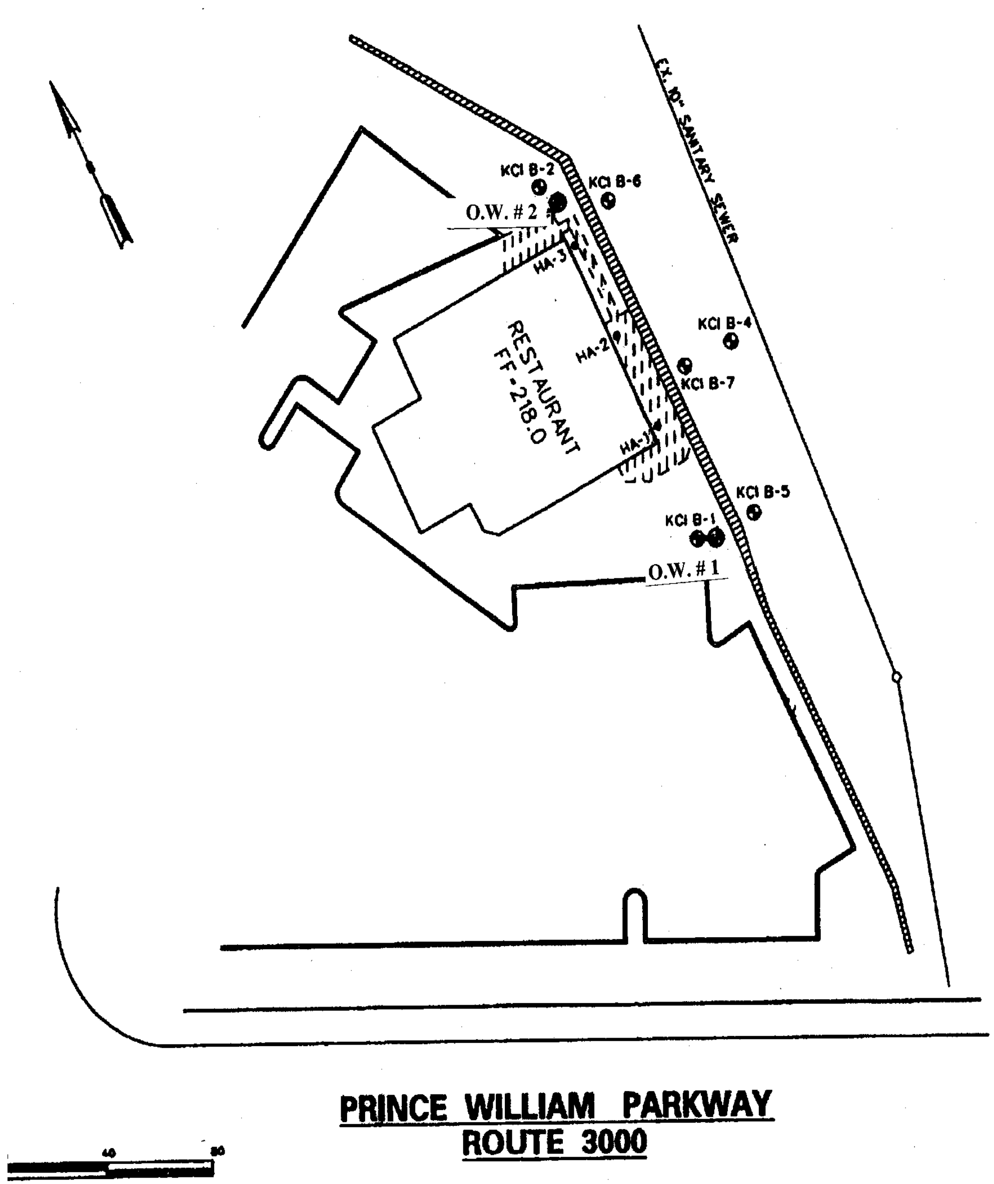
Twelve Adverse Factors

- Wall Contractor
- Other Contractor
- Soils
- Wall Engineering
- Wet Utility
- Internal Drainage
- External Drainage
- Owner
- Acts of God
- Construction Monitoring
- Civil Engineering
- Geotechnical Engineering

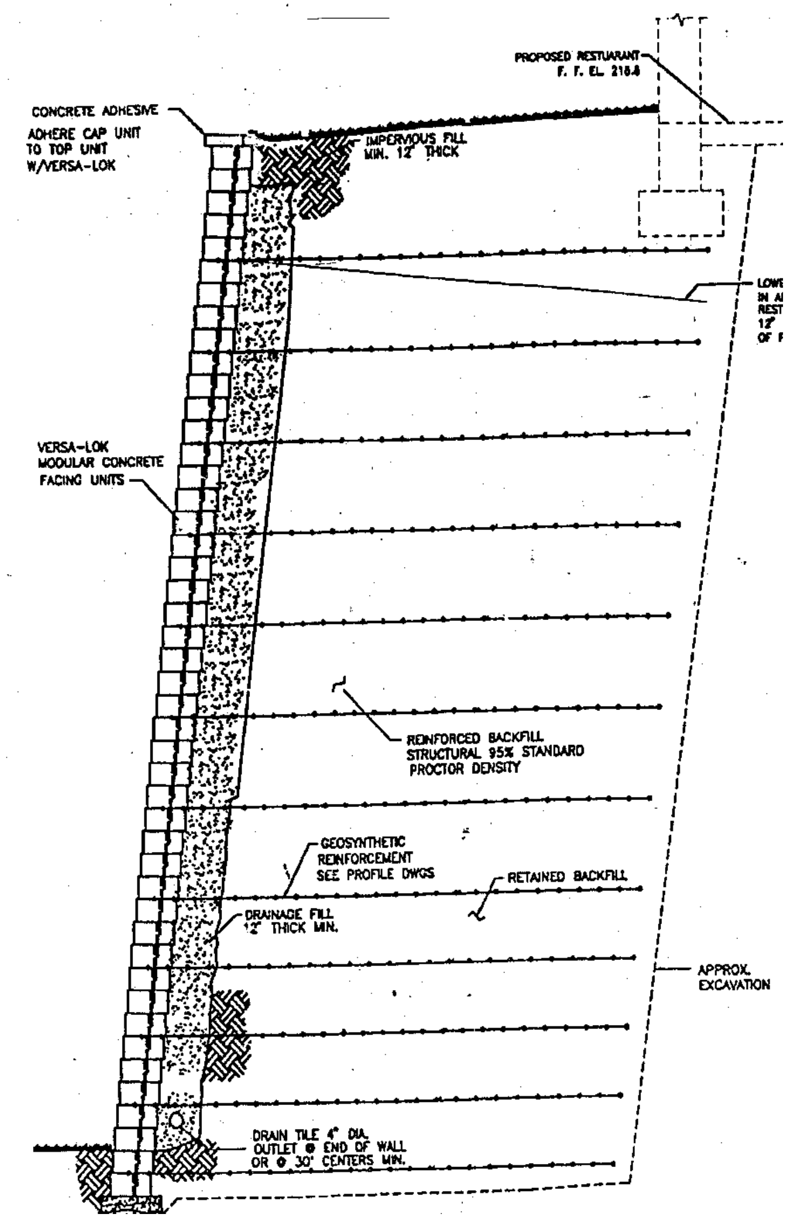
Findings


FREQUENCY OF OCCURENCE OF
ADVERSE FACTORS IN 71 WALL FAILURES
PERCENTAGE OF OCCURENCE
70
60
50
40
30
20
10
WATER AS INITIATOR
WALL DESIGN ENGINEERING
WALL CONTRACTOR
SOIL
WET UTILITY MALFUNCTION
WALL INSPECTION
OTHER CONTRACTOR
EXTERNAL DRAINAGE
CIVIL ENGINEERING
GEOTECHNICAL ENGINEERING
ACT OF GOD
OWNER
INTERNAL DRAINAGE

Case History I



SRW Cross-Section

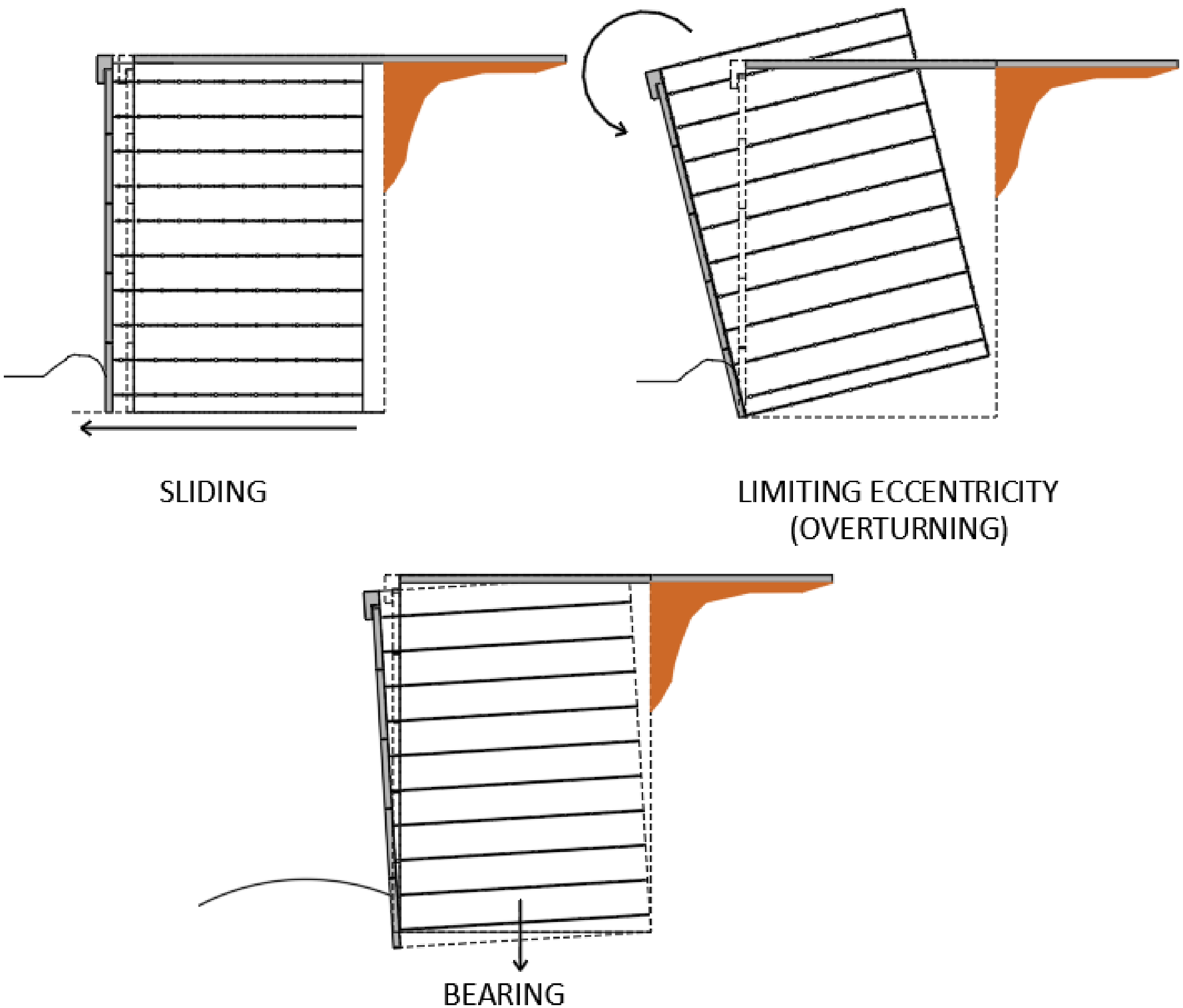


Case History II cont.

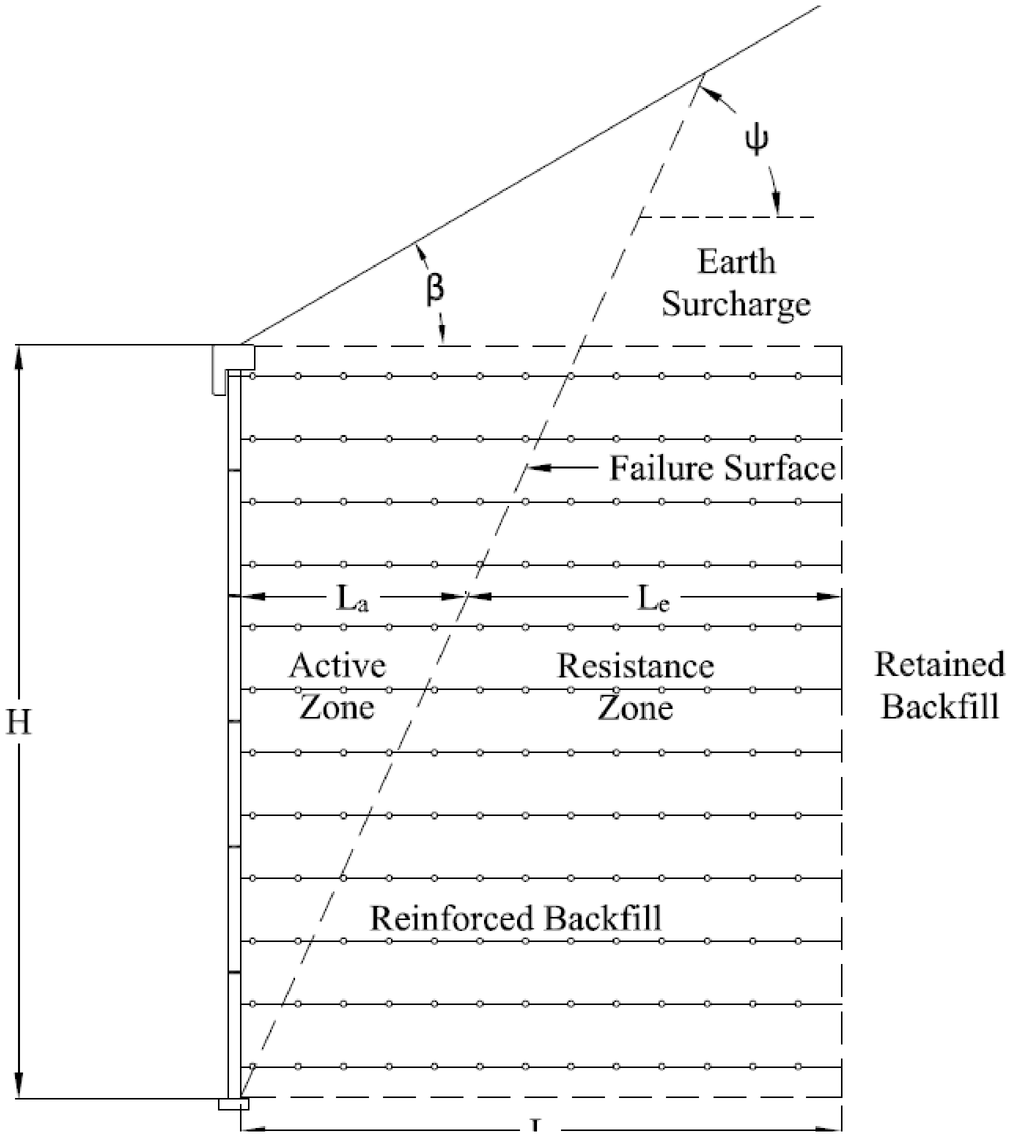
Signs of Distress

Signs of Distress

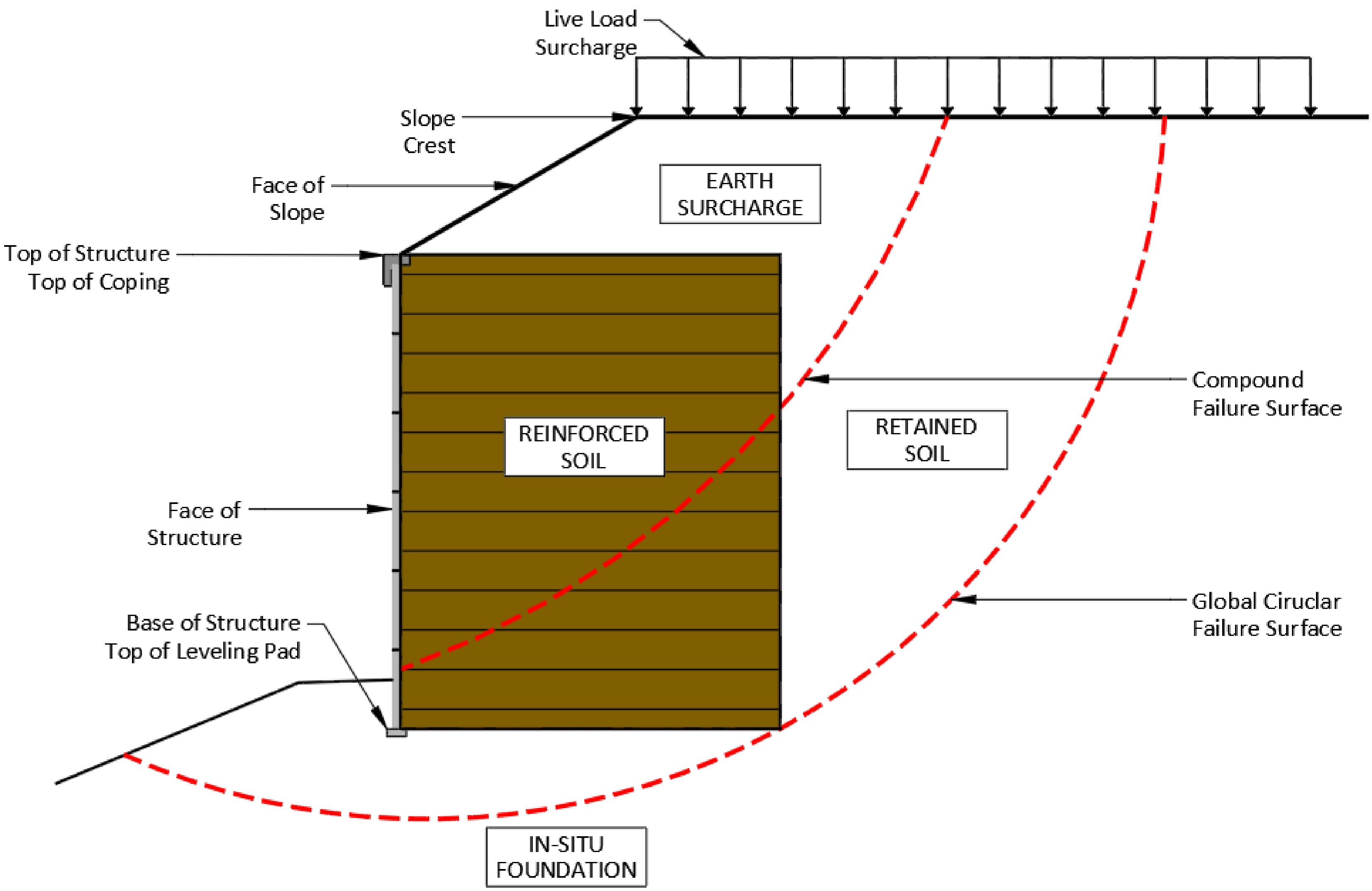
External Stability



Internal Stability – Rupture & Pullout



Global & Compound Stability



Site Differences Between Design Assumptions and As-Built Conditions

- Grade bottom of wall not level – slopes at 14°
- Soils used to construct wall are not free draining (35% fines), no external drainage was provided
- Direct shear testing of foundation soils peak effective friction angle of 28 degrees
- Shear strength of foundation soil (φ = 28°) is less than used in original design (φ = 30°)
- Surcharge from strip footing is greater than 100 psf assumed in design (actual 1000 psf)
- Post construction borings showed groundwater at the bottom of the wall, original design assumed no ground water

Design

- Internal Stability met industry standard factors of safety for both the as-design and as-built (i.e., rupture and pullout).

- External Stability met industry standard factors of safety for both the as-design and as-built (i.e., bearing capacity and sliding).

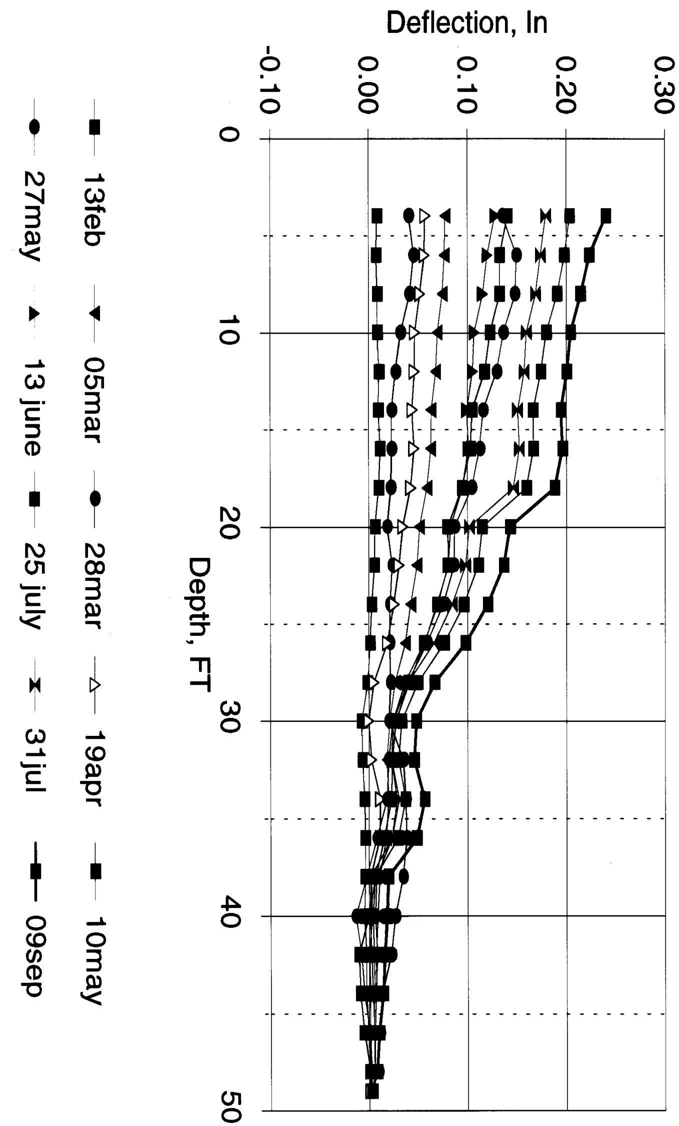
Soil Parameters for Global Stability Analysis

Material	Unit Weight (pcf)	φ(°)	Cohesion (psf)
Reinforced Fill	115	30	0
Retained Fill	115	30	0
Foundation Soil (Fill)	115	28	0
Residual Soil	120	34	0
Weathered Rock	120	36	0

Summary Stability Analysis

Description	φ_F	Sloping Toe	Surcharge	Water elev.	FS $_{global}$	FS $_{sliding}$	FS $_{overturn}$
As designed	30	no	100	170	1.3	>1.5	>2.0
As built	28	yes	100	170	1.25	>1.5	>2.0
As built	28	yes	100 + 1000 strip	170	1.14	>1.5	>2.0
As built water @ El 194	28	yes	100 + 1000 strip	194	0.89	>1.5	>2.0

Inclinometer Data

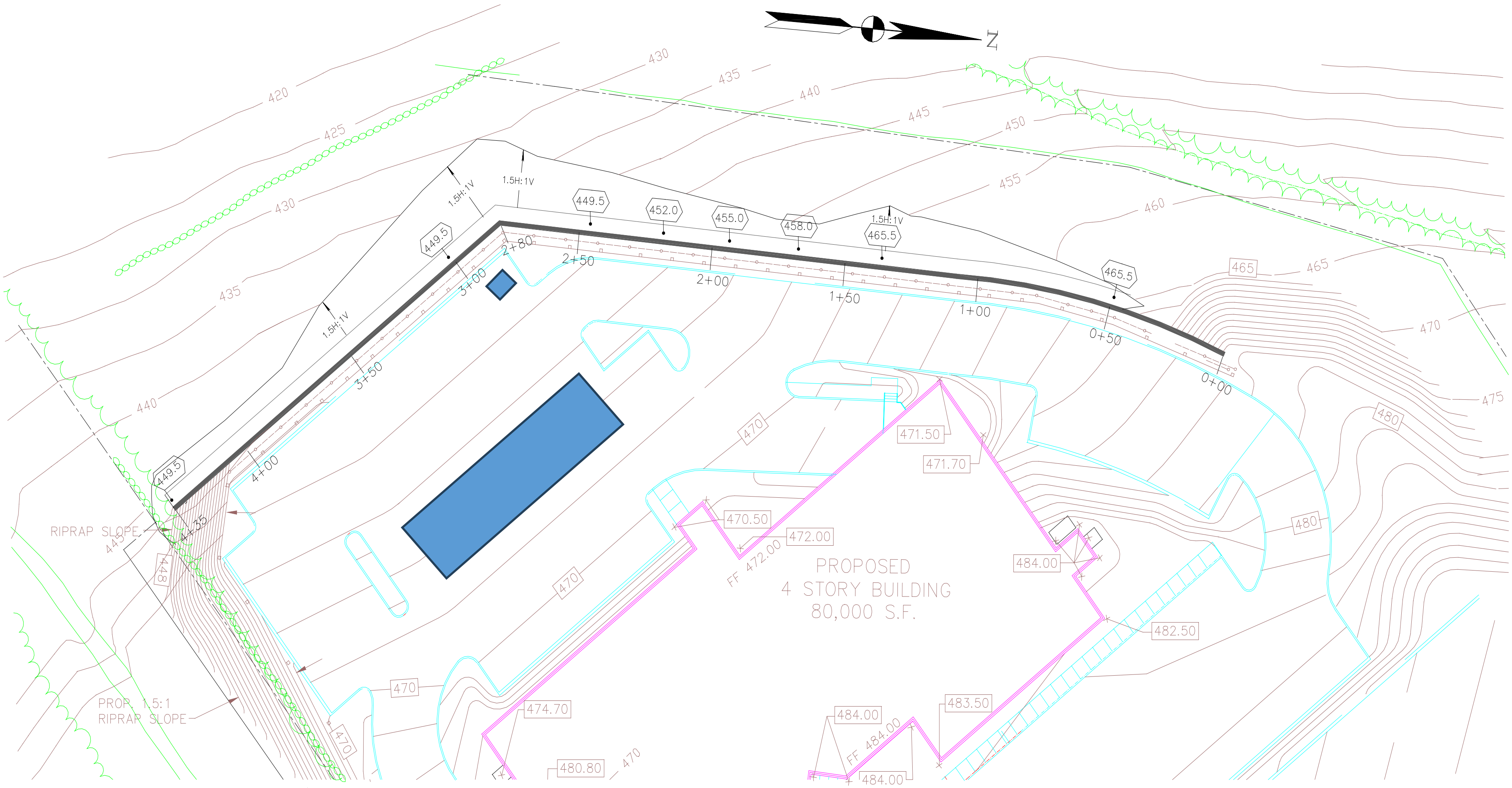


Remediation

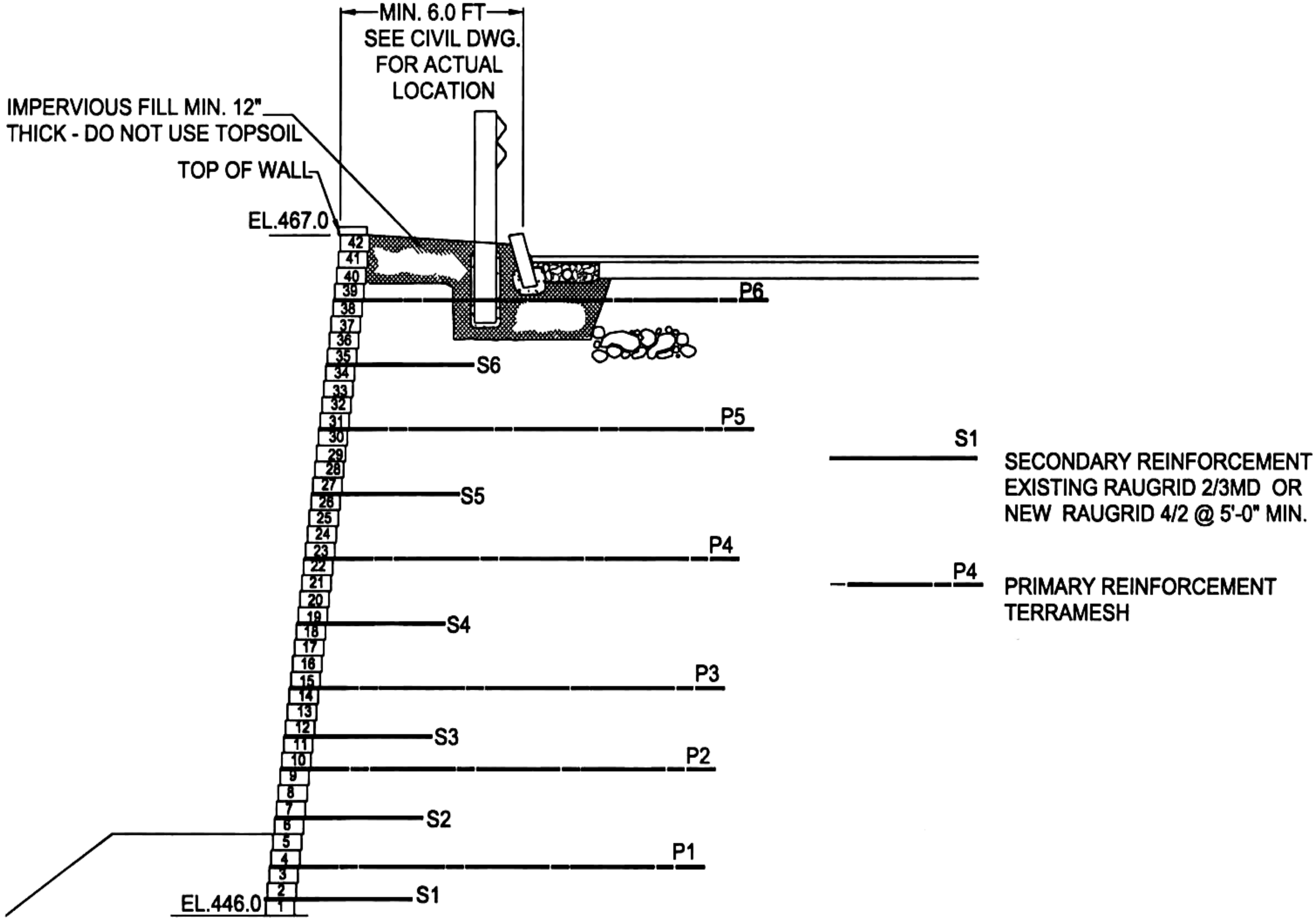
Lessons Learned from Case History I

- Water is the trigger to most failures
- Drainage structures should be included as part of the wall design
- Site conditions should be verified by the wall designer
- Global stability is a critical component of the design of an SRW
- Include instrumentation to monitor the structure during the remediation

Case History II



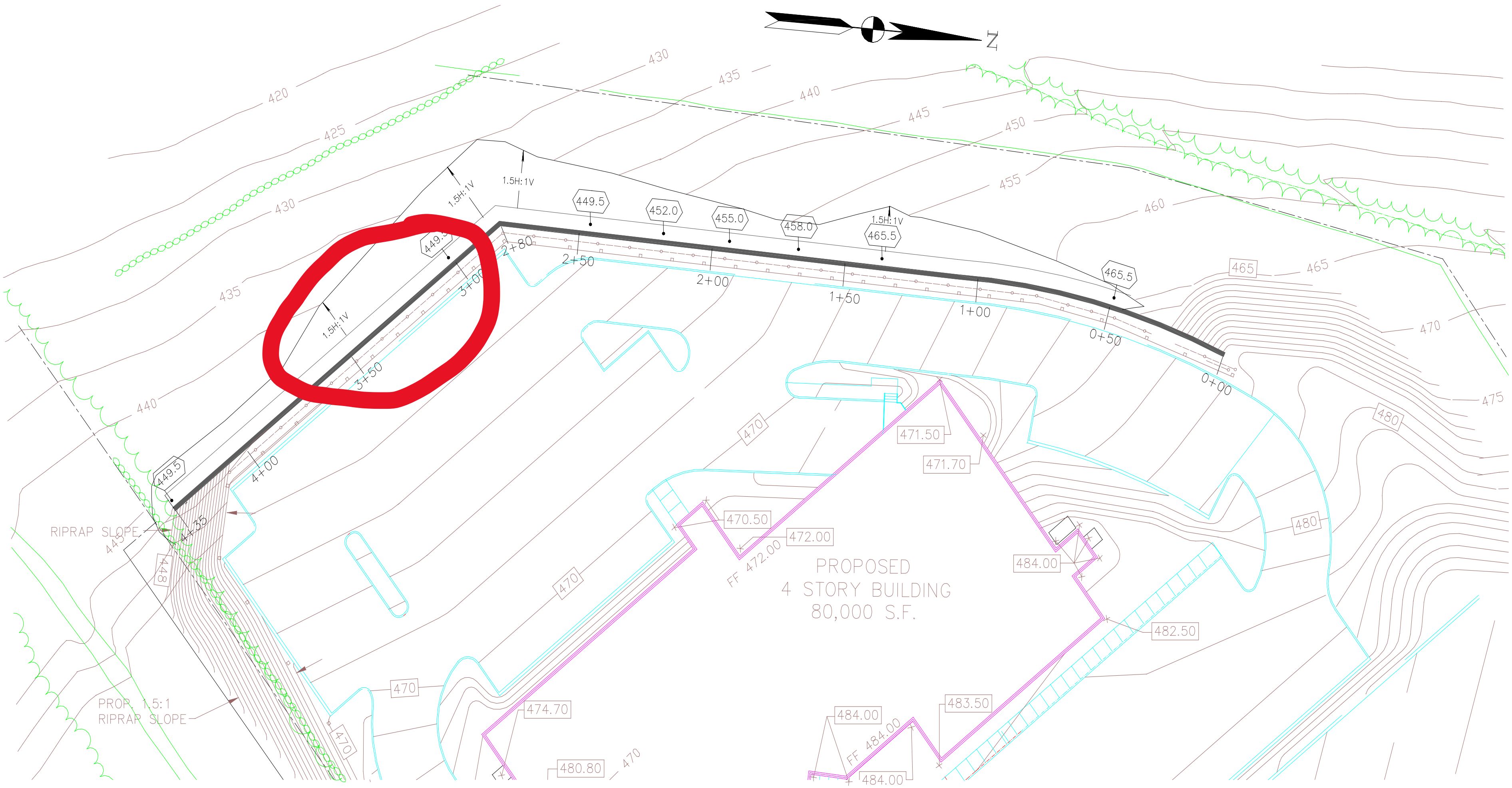
SRW Design Cross-Section



Construction November 1998

First Failure May 1999

Location of the failure



Observed Distress of Curb and Gutter

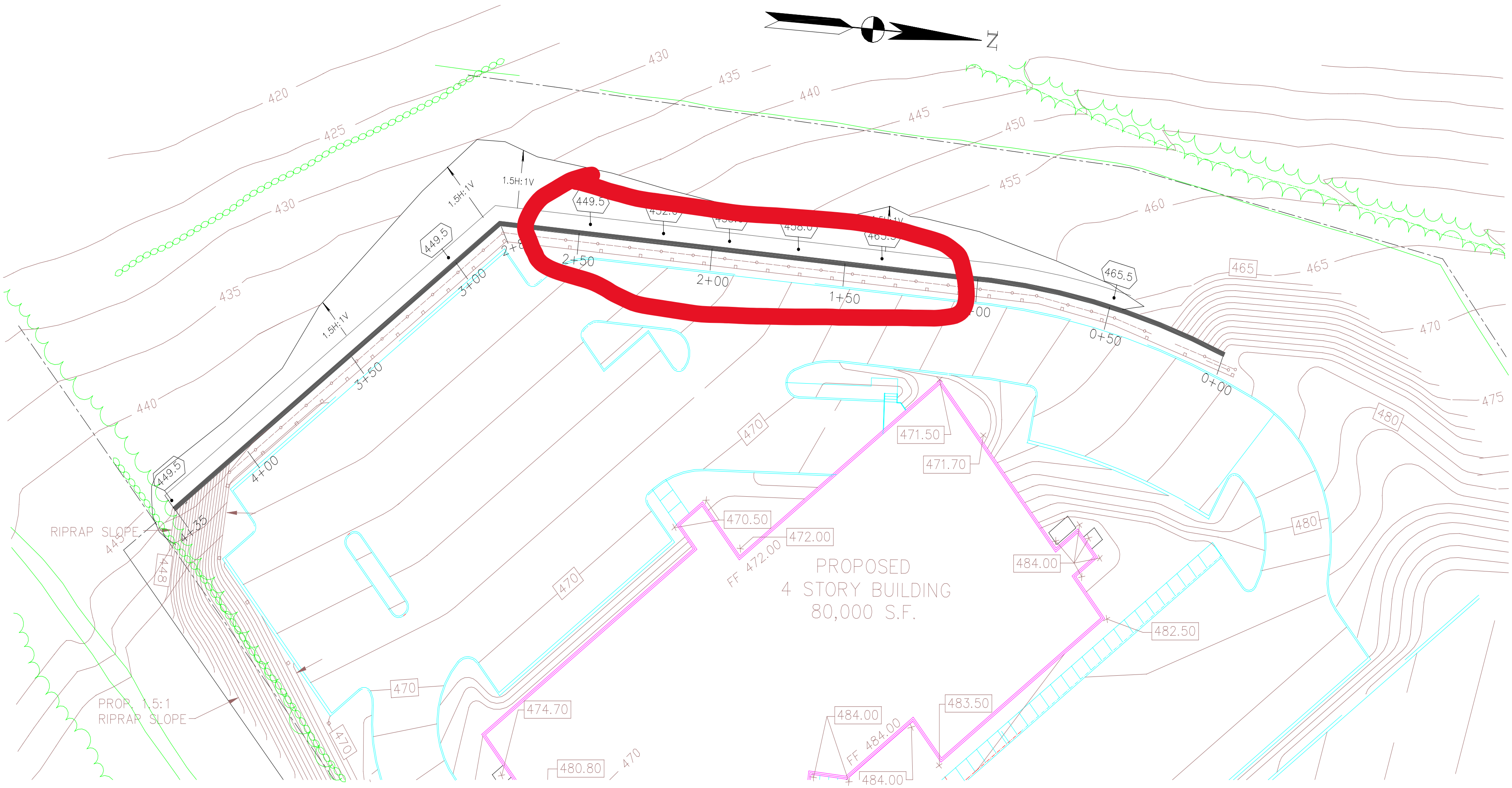
Observed Distress of Curb and Gutter

Observed Distress of Curb and Gutter

Hurricane Floyd – September 1999 – Over 5” of Rainfall

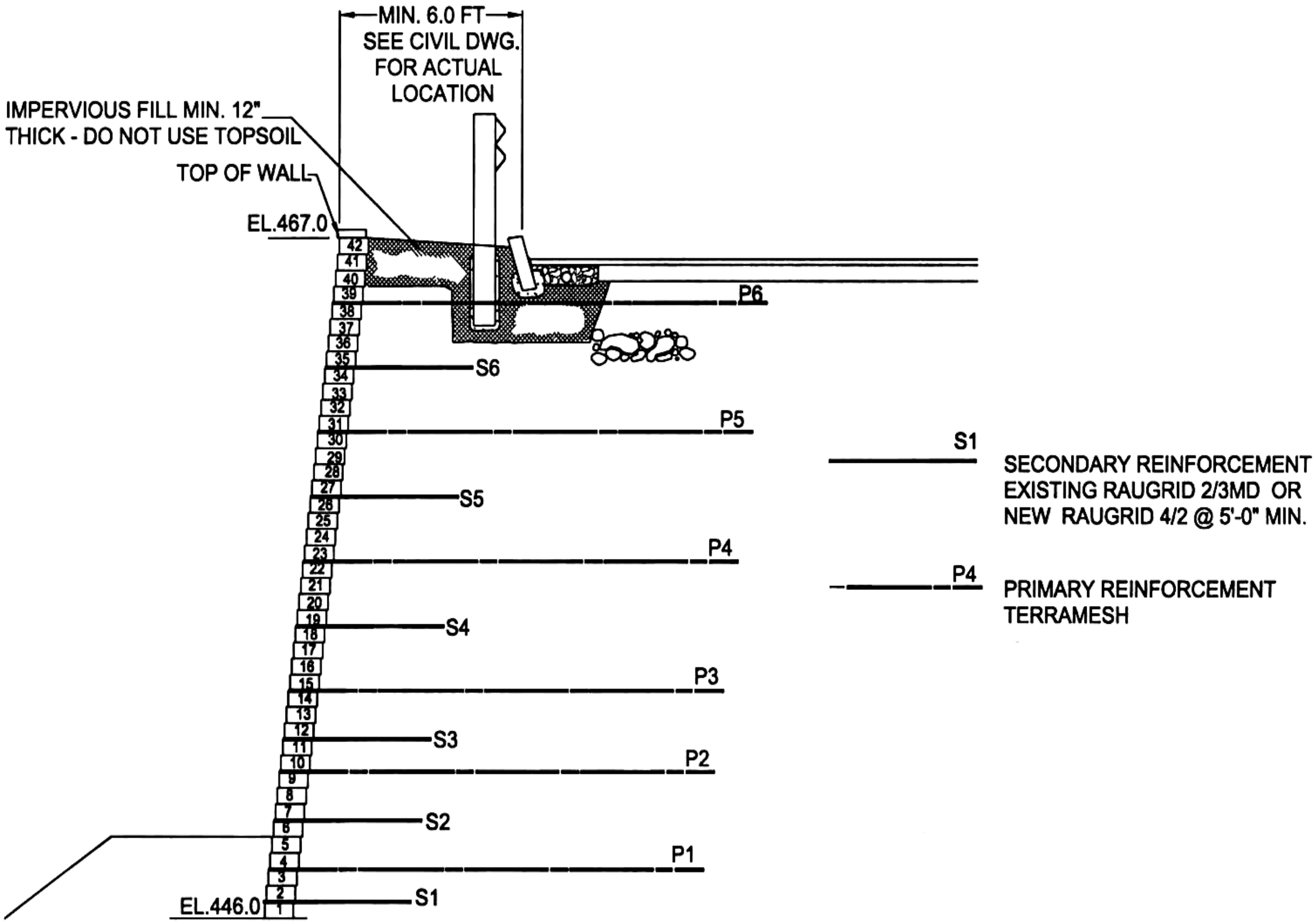
Second Failure

Location of Second Failure



Reinforcement Properties

Type	Aperture Size (in)	Tult (lbs/ft)	LTDS (lbs/ft)
PVC Coated Steel Mesh	3.25 x 4.5	na	2800
PVC Coated Polyester Geogrid	1.0 x 1.2	1400	740


MIN. 6.0 FT
SEE CIVIL DWG.
FOR ACTUAL
LOCATION
IMPERVIOUS FILL MIN. 12"
THICK - DO NOT USE TOPSOIL
TOP OF WALL
EL.467.0
P6
S6
P5
S5
P4
S4
P3
S3
P2
S2
P1
S1
EL.446.0
S1
SECONDARY REINFORCEMENT
EXISTING RAUGRID 2/3MD OR
NEW RAUGRID 4/2 @ 5'-0" MIN.
P4
PRIMARY REINFORCEMENT
TERRAMESH

Original Design – No Water

External Stability	Factor of Safety	NCMA Recommended Factor of Safety
FS Sliding	3.5	1.5
FS Overturning	6.0	2.0
FS Bearing Capacity	4.3	2.0

Original Design – Primary Grid

Layer #	FS Tensile	FS Pullout
10	3.0	3.8
9	2.0	6.4
8	1.9	11.4
7	1.9	15.5
6	1.8	20.6
5	2.1	28.1
4	2.2	35.4
3	2.0	37.3
2	2.2	47.7
1	3.2	73.6

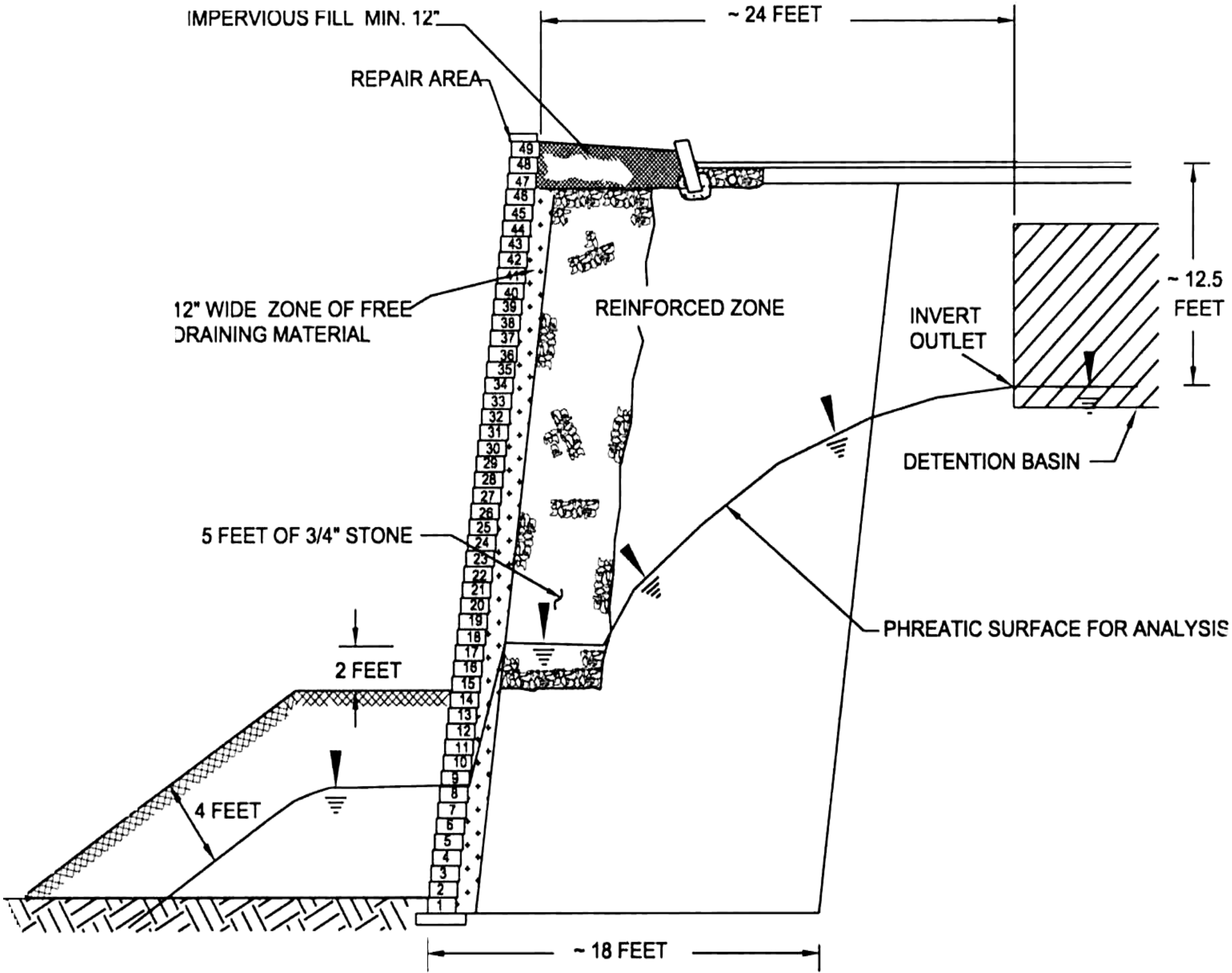
Original Design – Secondary Grid

Layer #	FS Connection
10	0.61
9	0.56
8	0.46
7	0.44
6	0.41
5	0.44
4	0.52
3	0.49
2	0.54
1	0.38

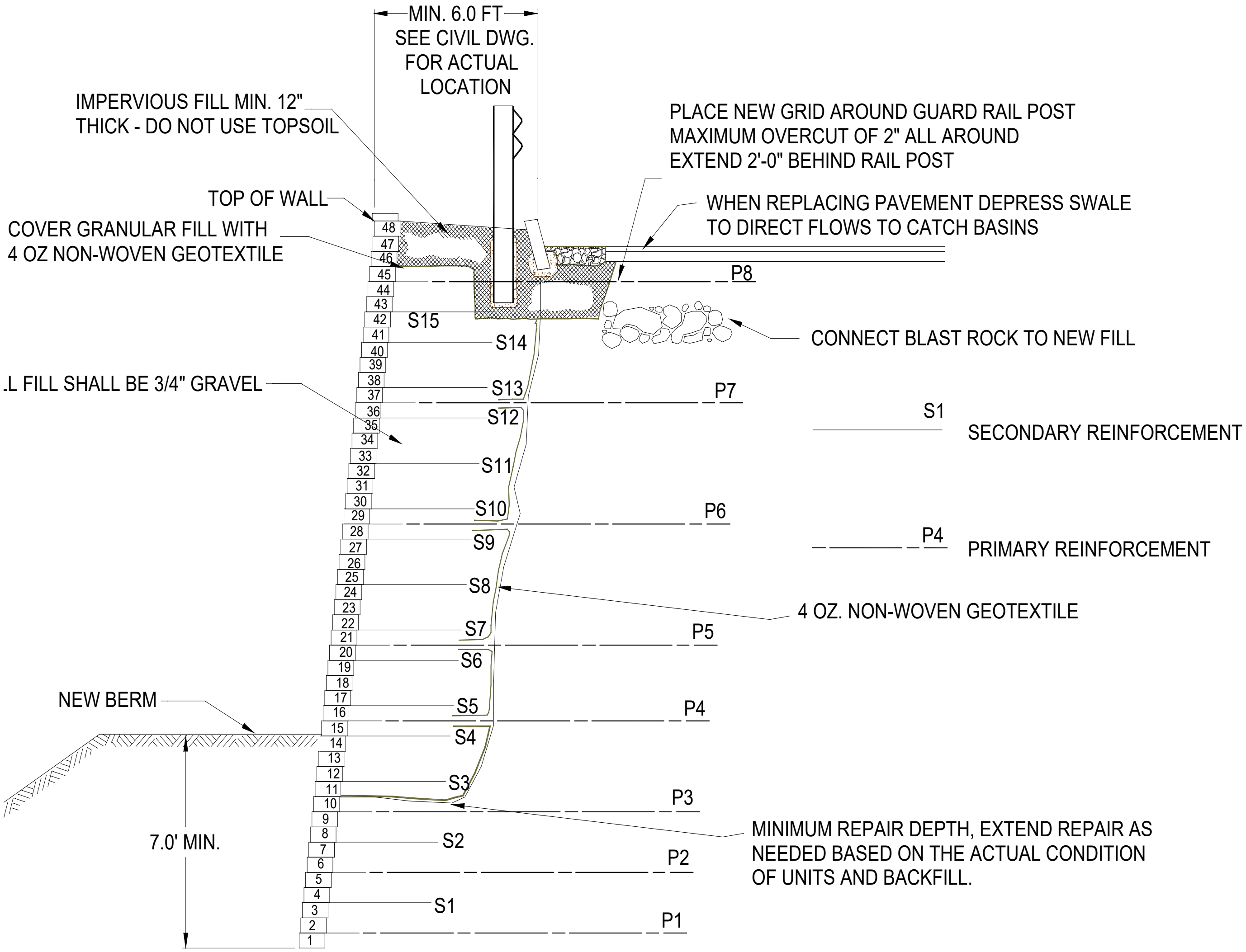
Original Design

- Did not consider connections
- Used proprietary software for one SRW system and substituted another system with different connection properties
- Did not consider hydrostatic effects on stability

Hydrostatic Pressure



Remedial Design



TYPICAL REPAIR SECTION

Remediation

Remediation cont.

Remediation cont.

Remediation cont.

Remediation cont.

Lessons Learned from Case History II

- Water is the trigger to most failures
- The load at the connection was 50% of that calculated using NCMA design procedure
- Connection loads although less than calculated must be considered in the design
- Understand the limitations of software packages
- Use generic software
- Consider the unique characteristics of the SRW selected in the design

Case History III

Case History III

Wall Construction

Wall Construction

First Failure of Wall

Construction of Wall a Second Time

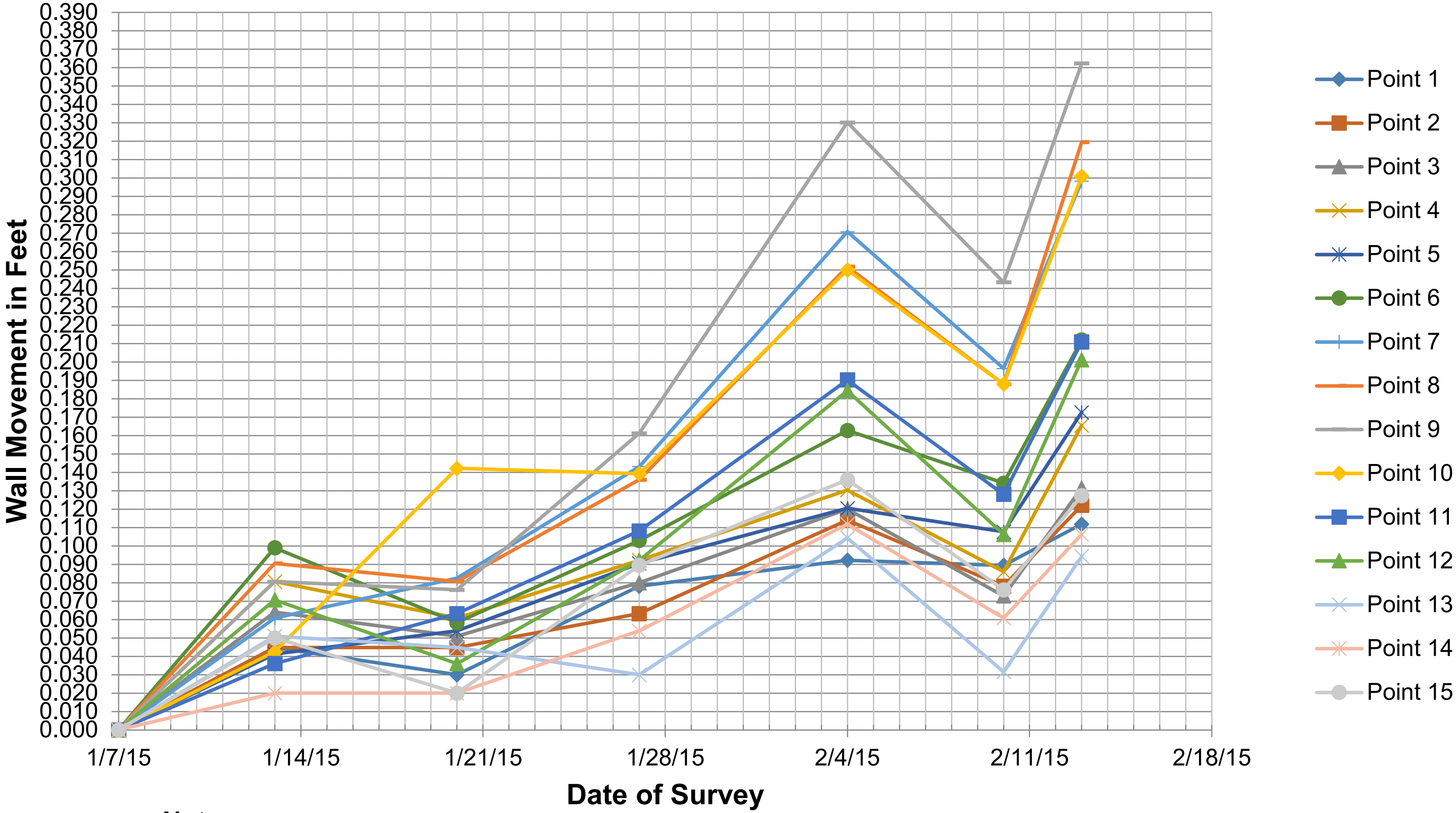
Construction of Walls a Second Time

Distress after rebuild

Distress after rebuild

Distress after rebuild

Top of Wall Movement Data

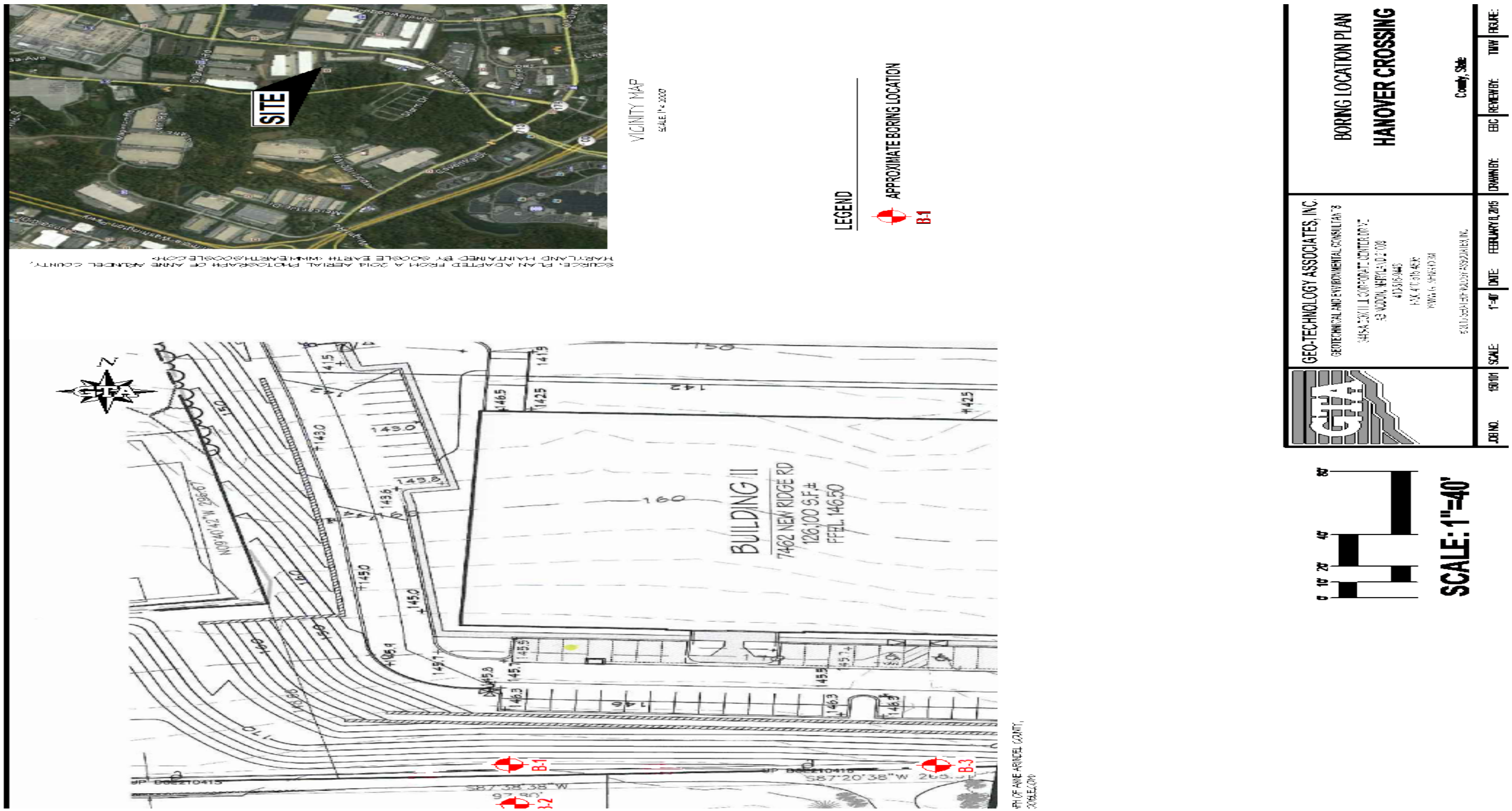


Notes:

1. All points are the calculated movement to the referecne point
2. Final point is the total movement at specified date


02/26/2015

Boring Location



LOG OF BORING NO. B-1

Sheet 1 of 2

PROJECT: **Hanover Crossing**
PROJECT NO.: **150101**
PROJECT LOCATION: **Anne Arundel County, Maryland**

WATER LEVEL (ft): **Dry** | **BOC**
DATE: 1/29/15
CAVED (ft): 33.5

DATE STARTED: **1/28/2015**
DATE COMPLETED: **1/29/2015**
DRILLING CONTRACTOR: **MDA Drilling, Inc.**
DRILLER: **D. Addison**
DRILLING METHOD: **HSA**
SAMPLING METHOD: **Split-Spoon**

WATER ENCOUNTERED DURING DRILLING (ft) **None**
GROUND SURFACE ELEVATION: **180**
DATUM: **Topo**
EQUIPMENT: **B-57**
LOGGED BY: **E. Kussman**
CHECKED BY: **T. Wirth**

SAMPLE NUMBER	SAMPLE DEPTH (ft.)	SAMPLE RECOVERY (in.)	SAMPLE BLOWS/6 inches	N (blows/ft.)	ELEVATION (ft.)	USCS	DESCRIPTION	REMARKS
S-1	0.0	8	28-11-4-4	15	180.0	SM	Brown, moist, loose, Silty SAND	
S-2	2.0	18	4-6-10-18	16			Orangish brown, moist, medium dense, Silty SAND	
S-3	4.0	18	16-14-10-18	24	176.0	SC	Light orangish brown, moist, medium dense, Clayey SAND	
S-4	6.0	14	12-16-20-25	36	174.0	CH	Red, dry to moist, hard, Fat CLAY	
S-5	8.0	16	11-14-17-25	31			Same	
S-6	10.0	14	11-17-18-21	35			Same	
S-7	12.0	20	8-11-17-20	28			Red, dry to moist, very stiff, Fat CLAY	
S-8	14.0	20	6-12-15-20	27			Same	
S-9	16.0	15					Shelby Tube	
S-10	18.0	20	15-20-26-40	46			Light reddish brown, moist, hard, Fat CLAY	
S-11	20.0	12	6-10-14-15	24			Light reddish brown, moist, very stiff, Fat CLAY	
S-12	22.0	20	7-11-15-21	26			Red, moist, very stiff, Fat CLAY	
S-13	24.0	20	7-11-21-23	32			Red, moist, hard, Fat CLAY	
S-14	26.0	20	7-12-24-28	36			Same	
S-15	28.0	22	7-12-24-30	36			Same	
S-16	30.0	24	15-18-27-40	45			Same	
S-17	32.0	20	15-27-40-50/5"	67			Same	
S-18	34.0	22	17-30-45-50/5"	75			Same	

NOTES: **Elevations and locations are approximate. BOC = Backfilled on completion.**

LOG OF BORING NO. B-1

Sheet 1 of 2

LOG OF BORING NO. B-1

Sheet 2 of 2

PROJECT: **Hanover Crossing**
PROJECT NO.: **150101**
PROJECT LOCATION: **Anne Arundel County, Maryland**

WATER LEVEL (ft): **Dry** | **BOC**
DATE: 1/29/15
CAVED (ft): 33.5

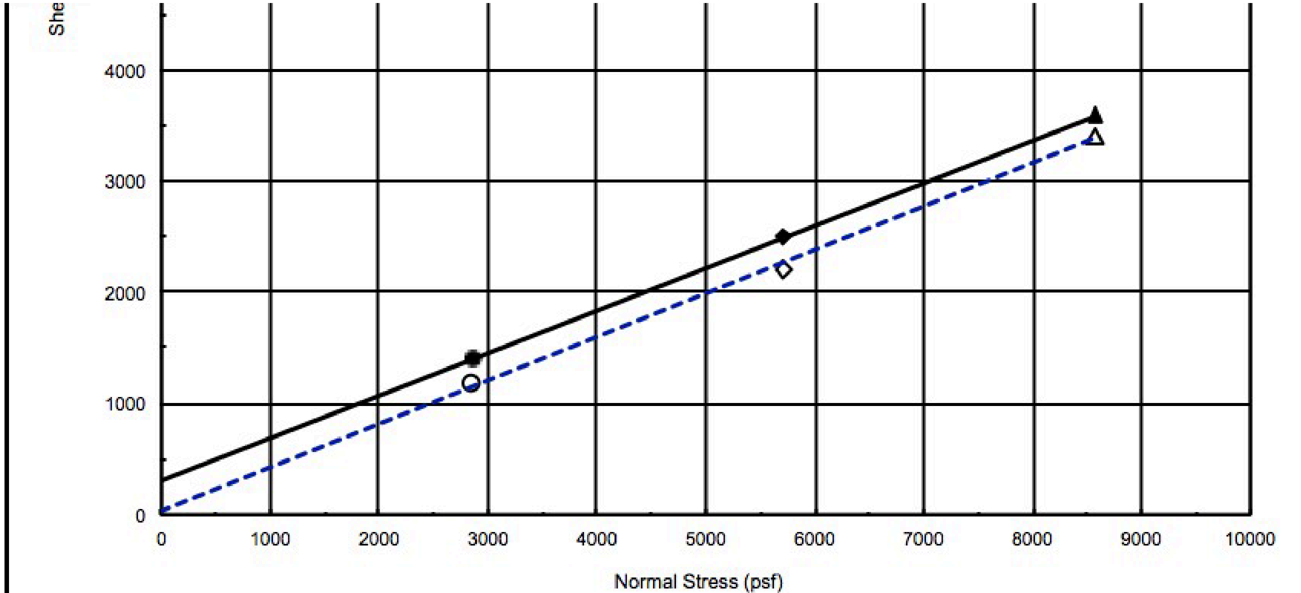
SAMPLE NUMBER	SAMPLE DEPTH (ft.)	SAMPLE RECOVERY (in.)	SAMPLE BLOWS/6 inches	N (blows/ft.)	ELEVATION (ft.)	USCS	DESCRIPTION	REMARKS
S-19	38.5	17	17-34-50/5"	84			Red, dry, hard, Fat CLAY	
S-20	43.5	5	50/5"				Gray, dry, hard, Fat CLAY	
S-21	48.5	2	50/2"				Same	
					130.0		Boring Terminated at 50 feet	

LOG OF BORING NO. B-1

Abingdon, MD 21009

Sheet 2 of 2

Direct Shear Peak Strength



Peak Values are : ● ,solid trend line   Ultimate Values are: ○ ,dashed trend line

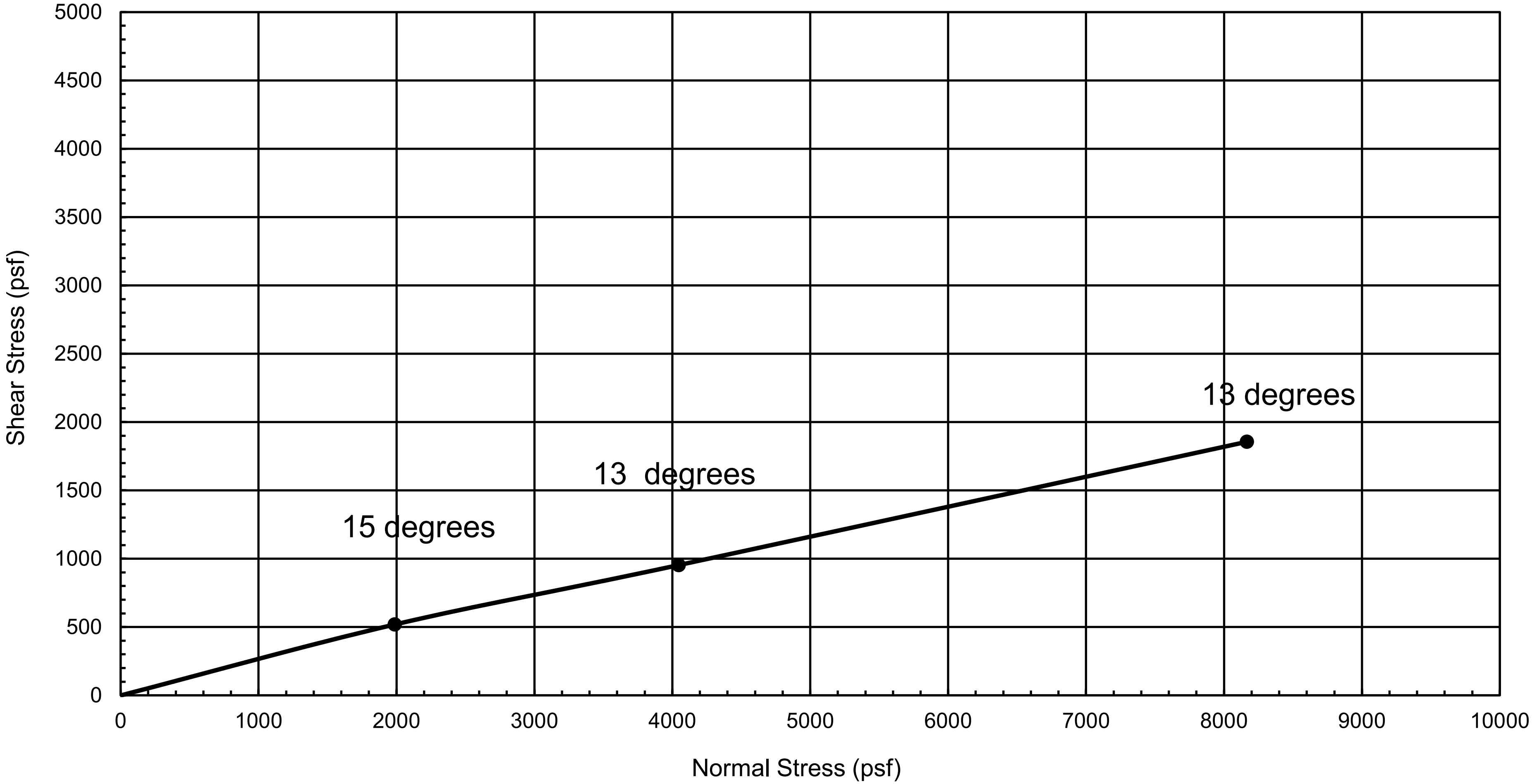
Exploration No.:	B-1		Strength Intercept (C) :	295.4	psf	Peak	28.8	psf	Ultimate
Sample No.:				14.1	kPa		1.4	kPa	
Depth (ft | m)	16.5	5.0	Friction Angle (ϕ) :	21	degree		21	degree	
Description:	**Red Clay (CH)**		Shear rate :	0.0010	(in/min) ,		0.0025	(cm/min)	

SYMBOL	% Water Content	Total Unit Weight (pcf)	Total Unit Weight (kN/m^3)	Dry Unit Weight (pcf)	Dry Unit Weight (kN/m^3)	Normal Stress (psf)	Normal Stress (kPa)	Peak Stress (psf)	Peak Stress (kPa)	Ultimate Stress (psf)	Ultimate Stress (kPa)
Initial / Set up	25.6	126.9	19.9	101.0	15.9	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
pre-shear ● spec. 1	32.7	131.1	20.6	98.8	15.5	2855	137	1391	67	1173	56
pre-shear ◆ spec. 2	30.0	133.5	21.0	102.7	16.1	5717	274	2492	119	2198	105
pre-shear ▲ spec. 3	27.8	132.0	20.7	103.3	16.2	8573	410	3587	172	3404	163

DIRECT SHEAR TEST

ASTM D 3080

Ring Shear – Residual Strength

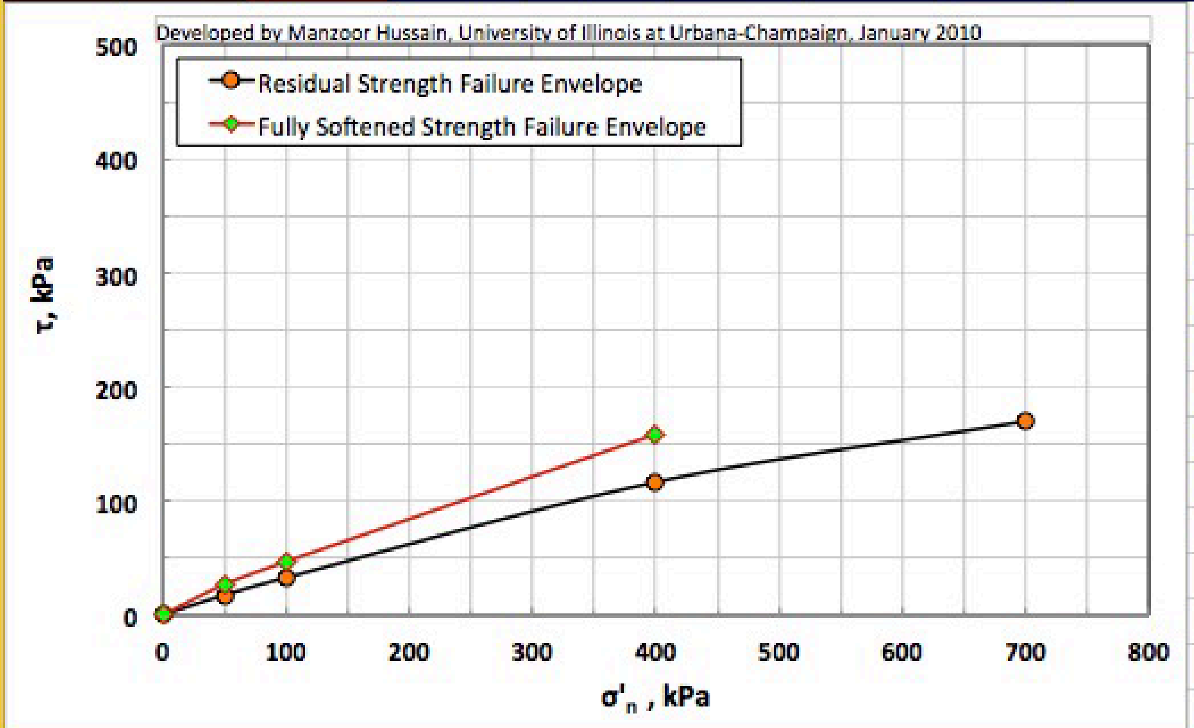


CL Properties

Drained Residual and Fully Softened Secant Friction Angles & Shear Stresses

Equations developed by Stark and Hussain (2010)

Input		Output	φ'$_r$, degrees				τ, kPa					
CF, %	LL, %		50	100	400	700	0	50	100	400	700	σ'$_n$, kPa
50	50		19.5	18.2	16.3	13.7	0.00	17.73	32.85	116.68	169.99	Residual
			28.4	25.2	21.6		0.00	27.06	46.96	158.73		Fully Softened



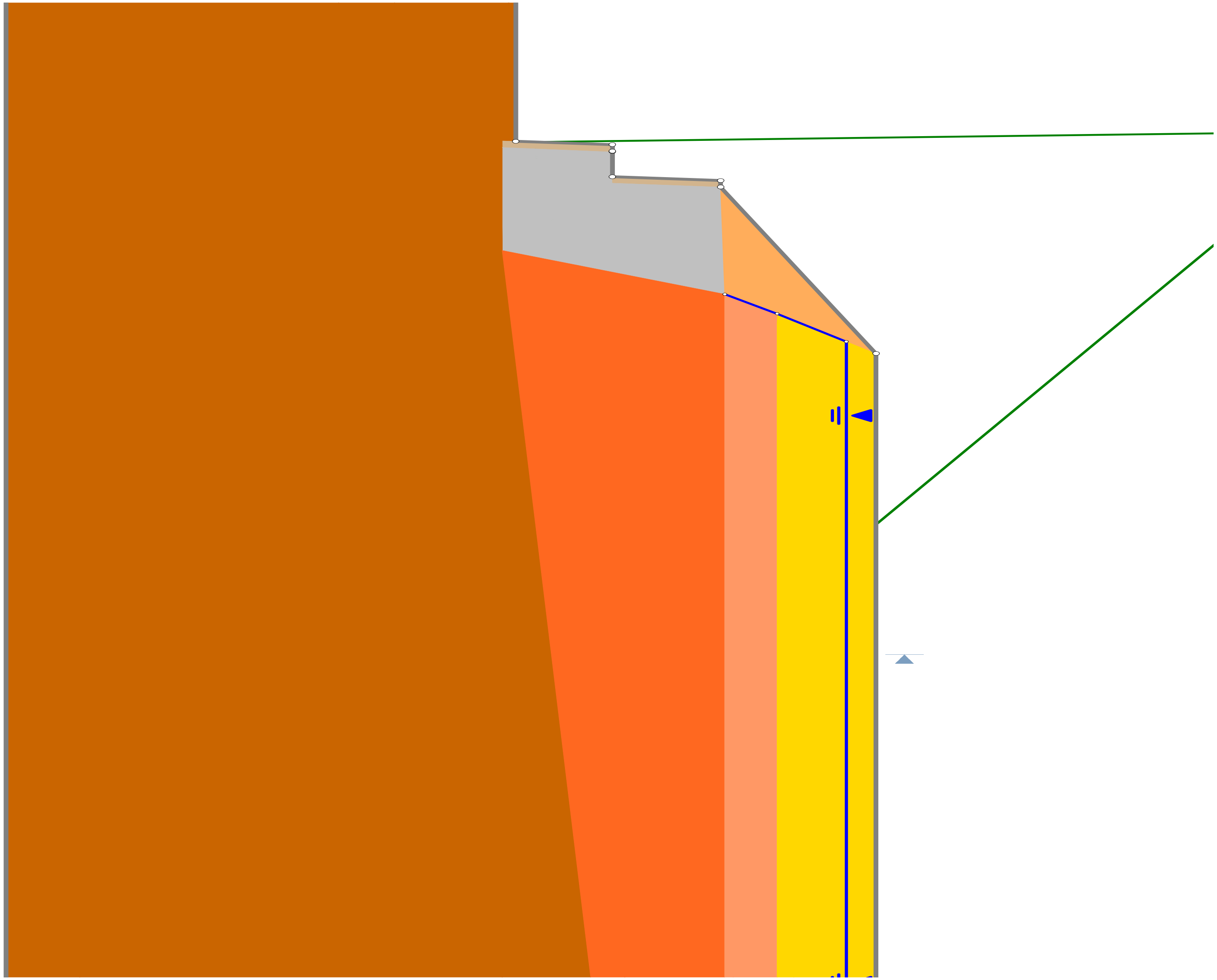
Important Note:

Valid for:	LL (%)	
	Minimum	Maximum
Fully Softened Strength		
Group #1 (CF ≤ 20%)	20	79
Group #2 (20%≤ CF ≤ 45%)	30	130
Group #3 (CF ≥ 50%)	30	300
Residual Strength		
Group #1 (CF ≤ 20%)	24	79
Group #2 (20%≤ CF ≤ 45%)	30	130
Group #3 (CF ≥ 50%)	40	300

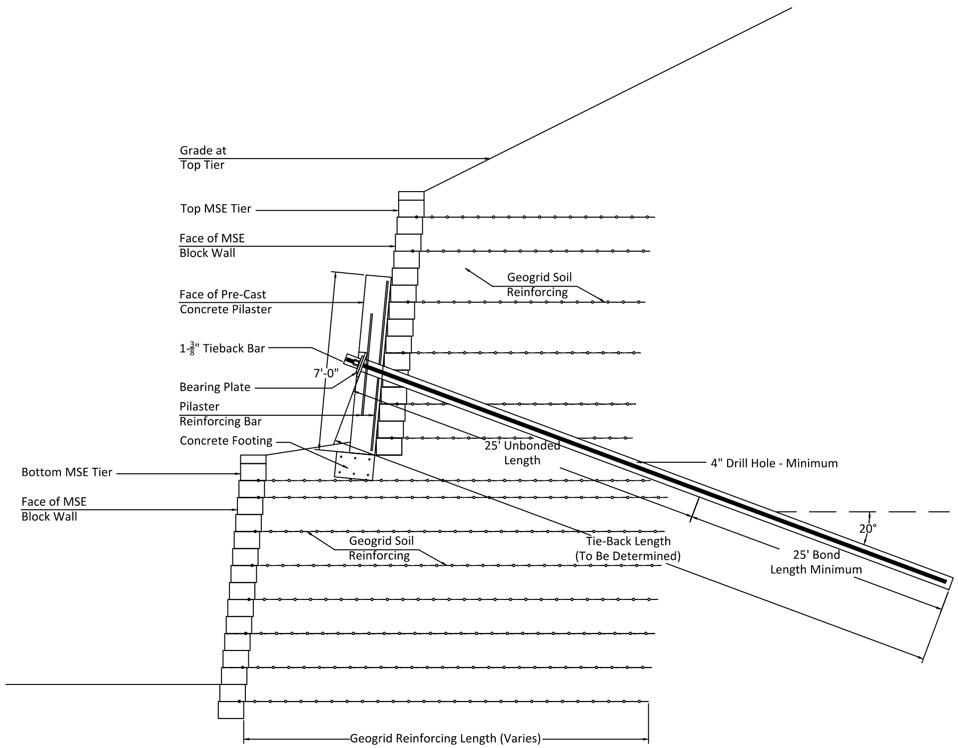
ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

CL directly below wall normal load 50 kPA use φ = 28°

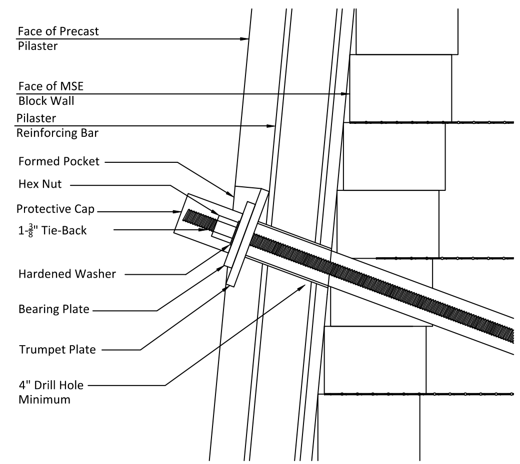
Section AA top of Slope EL 180 – Non-Circular Failure



Remediation Option 1



CROSS SECTION AT MSE STRUCTURE



CROSS SECTION AT TIE-BACK CONNECTION

Note: Tieback connection detail to be determined by Tieback Design Engineer and submitted to the Collin Group for Review and Approval

March 8, 2015 /ARCO_1_REV1.dwg

NUMBER	DATE	REVISIONS

Project Number
Date Drawn 03/08/15
Scale NTS
Designed By JGC
Drawn By TPT
Checked By JGC

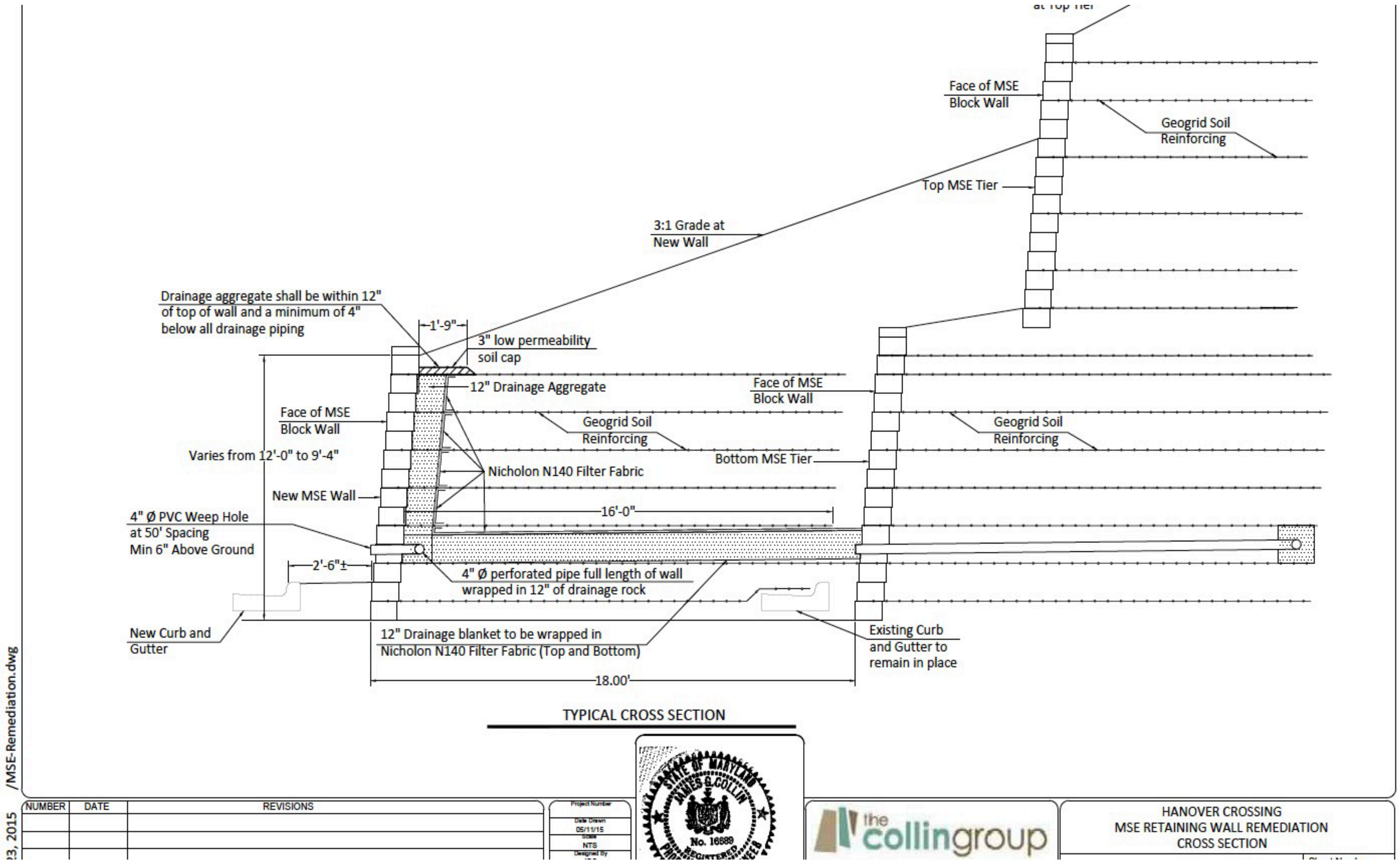
the collingroup
7445 Arlington Road - Bethesda, MD 20814
Tel. 301.907.9501 Fax 301.907.9502

HANOVER CROSSING
MSE RETAINING WALL REMEDIATION
CROSS SECTIONS

LOCALITY OF HANOVER
ANNE ARUNDEL CO. MARYLAND

Sheet Number 1 OF 8

Remediation Option 2



Lessons Learned from Case History III

- Don’t fix a failure until you know why it failed.
- Understanding the geology is critical to understanding the foundation conditions.

Questions????

Thank You for Attending!!!

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University of Illinois-FGI Online CQA Course & Certification

Feb. 4, 2025 12-1:30 p.m. CST - Manufacturing MQA & MQC

Feb. 5, 2025 12-1:30 p.m. CST - Subgrade Preparation & Inspection

Feb. 11, 2025 12-1:30 p.m. CST - Factory CQA & CQC

Feb. 12, 2025 12-1:30 p.m. CST - Field CQA & CQC

Feb. 18, 2025 12-1:30 p.m. CST - Post Installation Maintenance & Leak Location

Feb. 19 - 28, 2025 - University of Illinois-FGI CQA Online Certification Exam Available

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