Slope Stabilization using Drilled Shafts: Design and Long-Term Monitoring

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Presentation Outlines

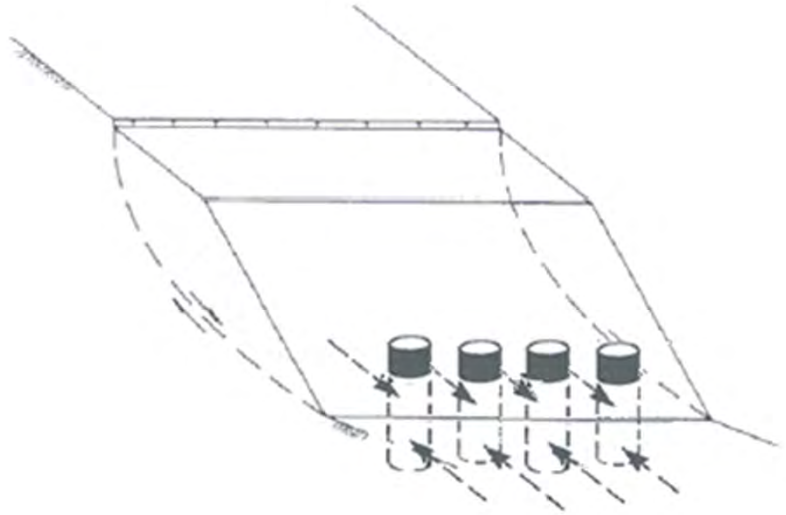
- Introduction
- Geotechnical Analysis
- Structural Design
- Instrumentation & Long-Term Monitoring
- Summary and Conclusions

Introduction

1. Slope remediation using drilled shafts
2. Single row of drilled shafts
   - Inexpensive
   - Various techniques and equipments
   - Has been successfully used
   - Simple to design

Geotechnical Elements

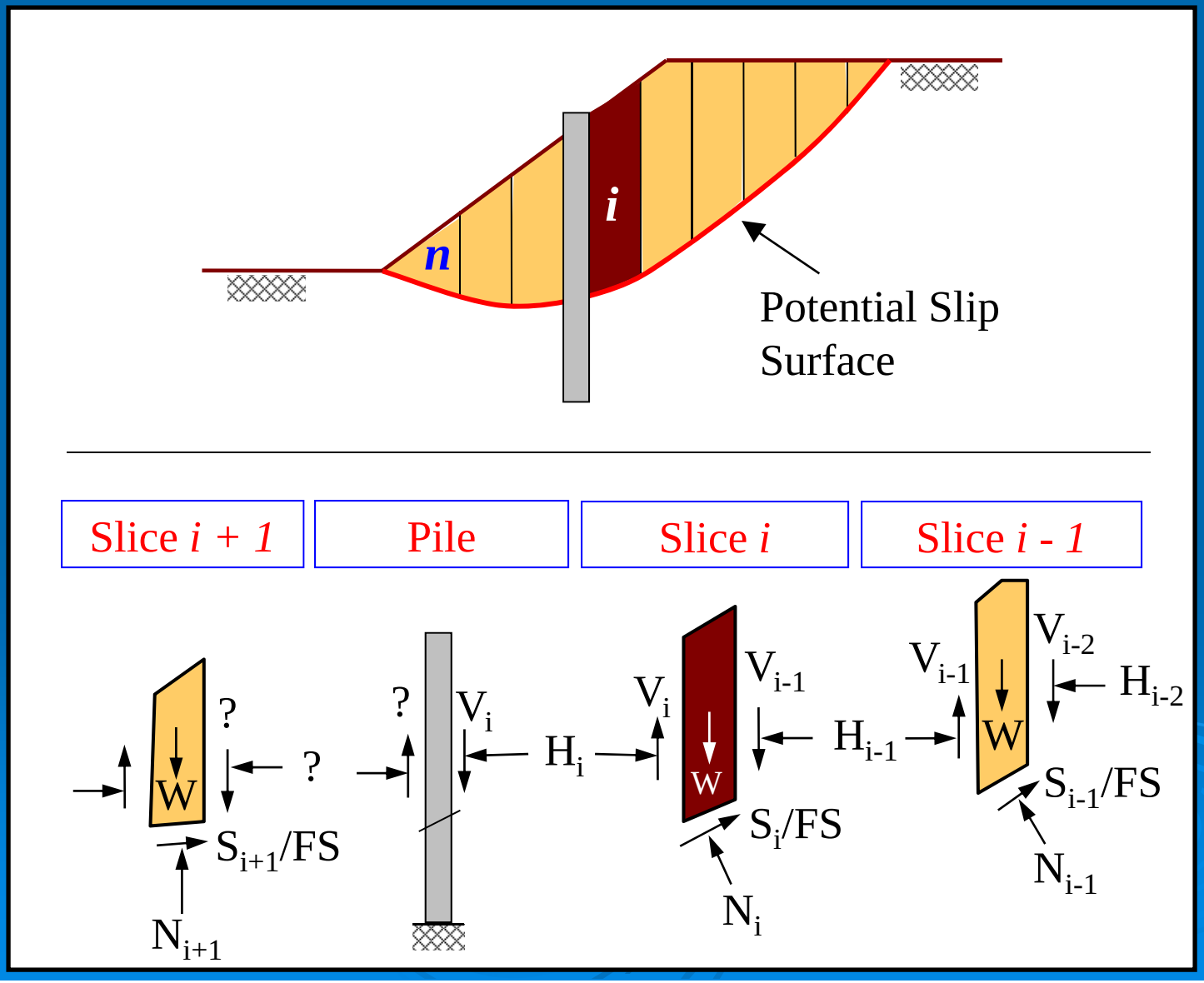
- Geometry
- FS improvement
- Shaft force
- Soil Arching



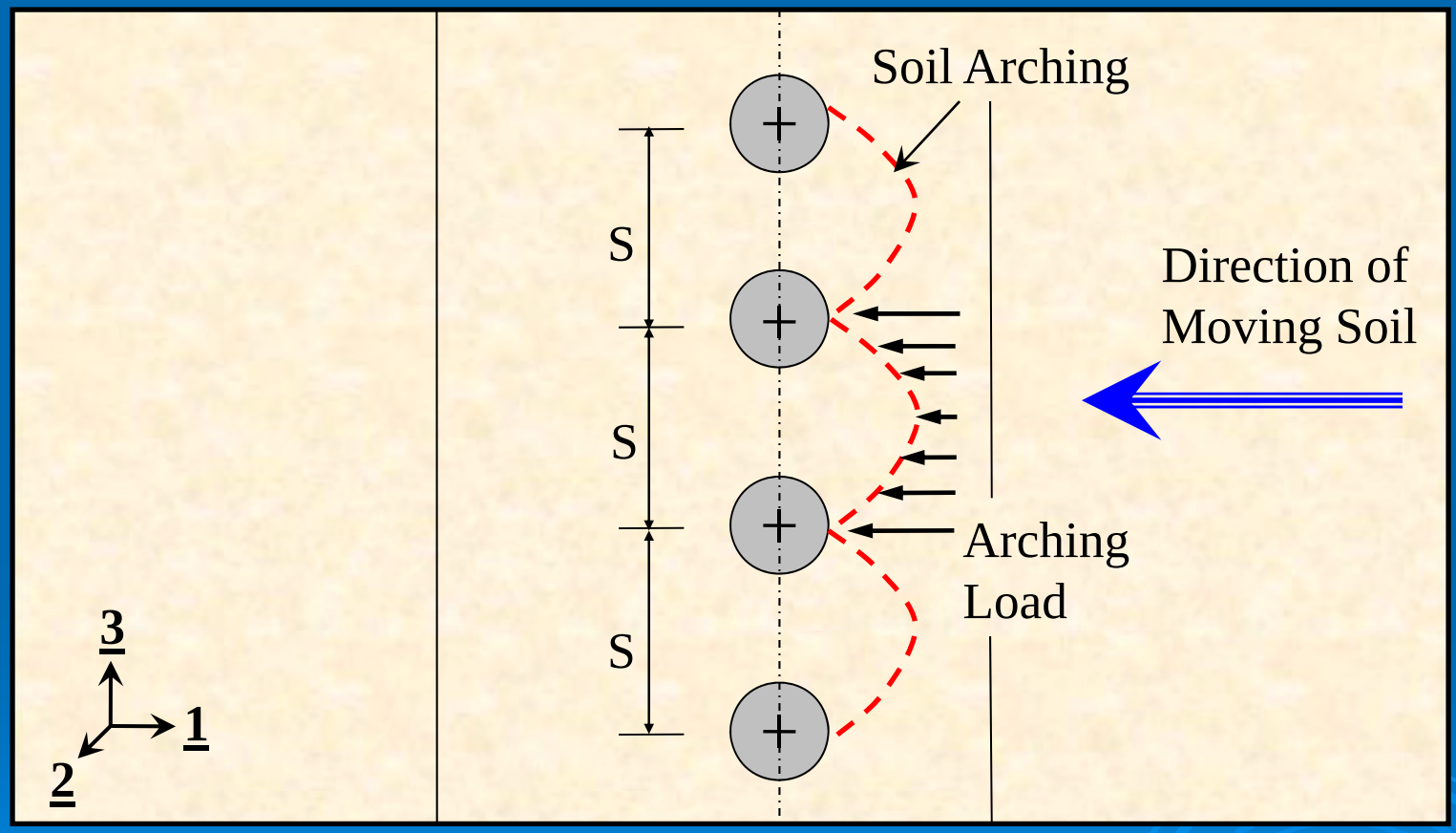
Analysis Methodology

- Define Geometry
- Define Stratigraphy and Material Properties
- Initial Slope Stability Analysis (no stabilization)
  - Determine the need and location of stabilization Elements
  - Assume Shafts diameter, length, and spacing
  - Verify/modify assumed shaft parameters
- Verify Shaft Structural adequacy (Lateral Analysis)

Stability Analysis: Limiting Equilibrium (Method of Slices)

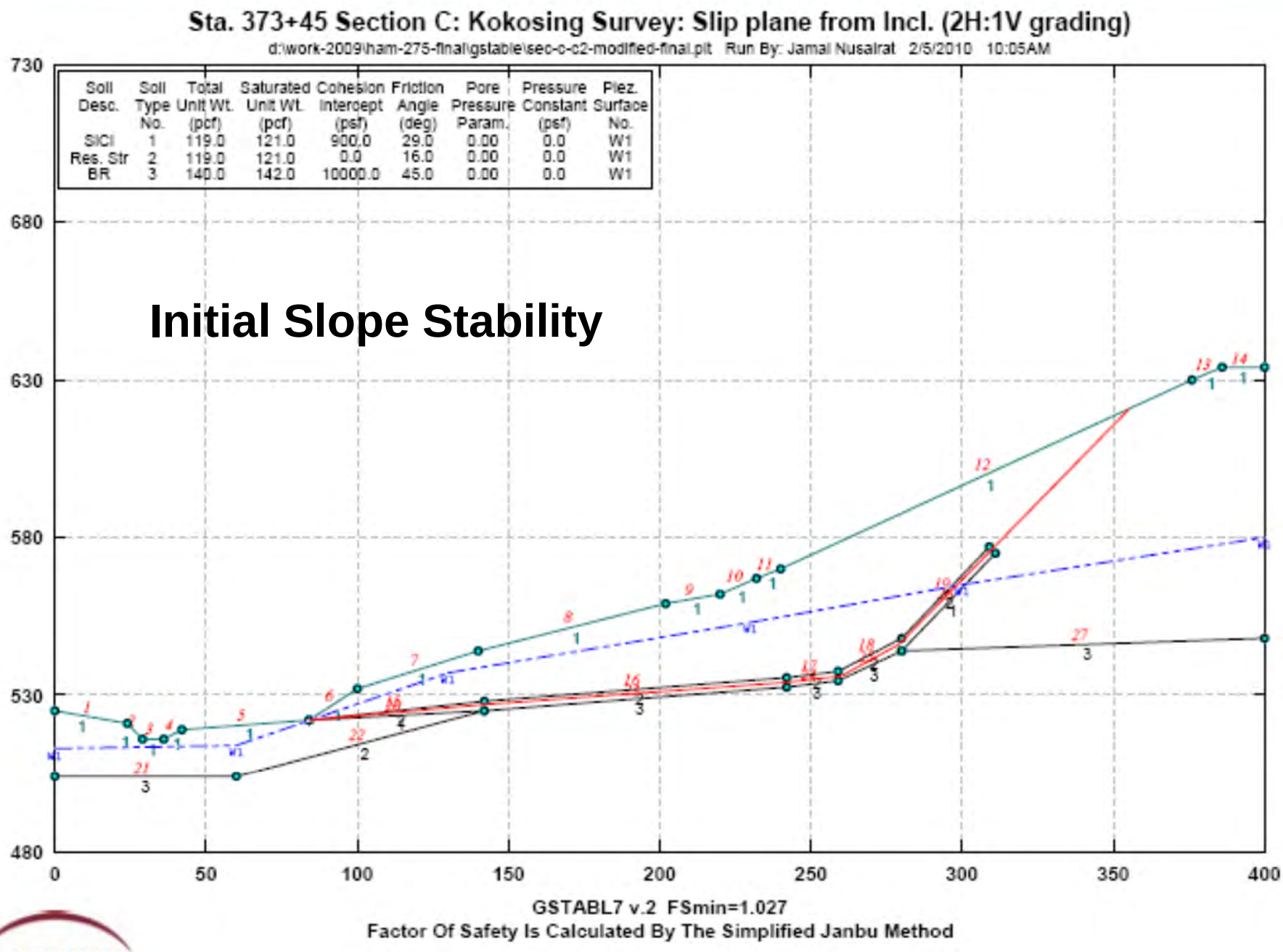


Arching Mechanism
Liang and Zeng (2002)

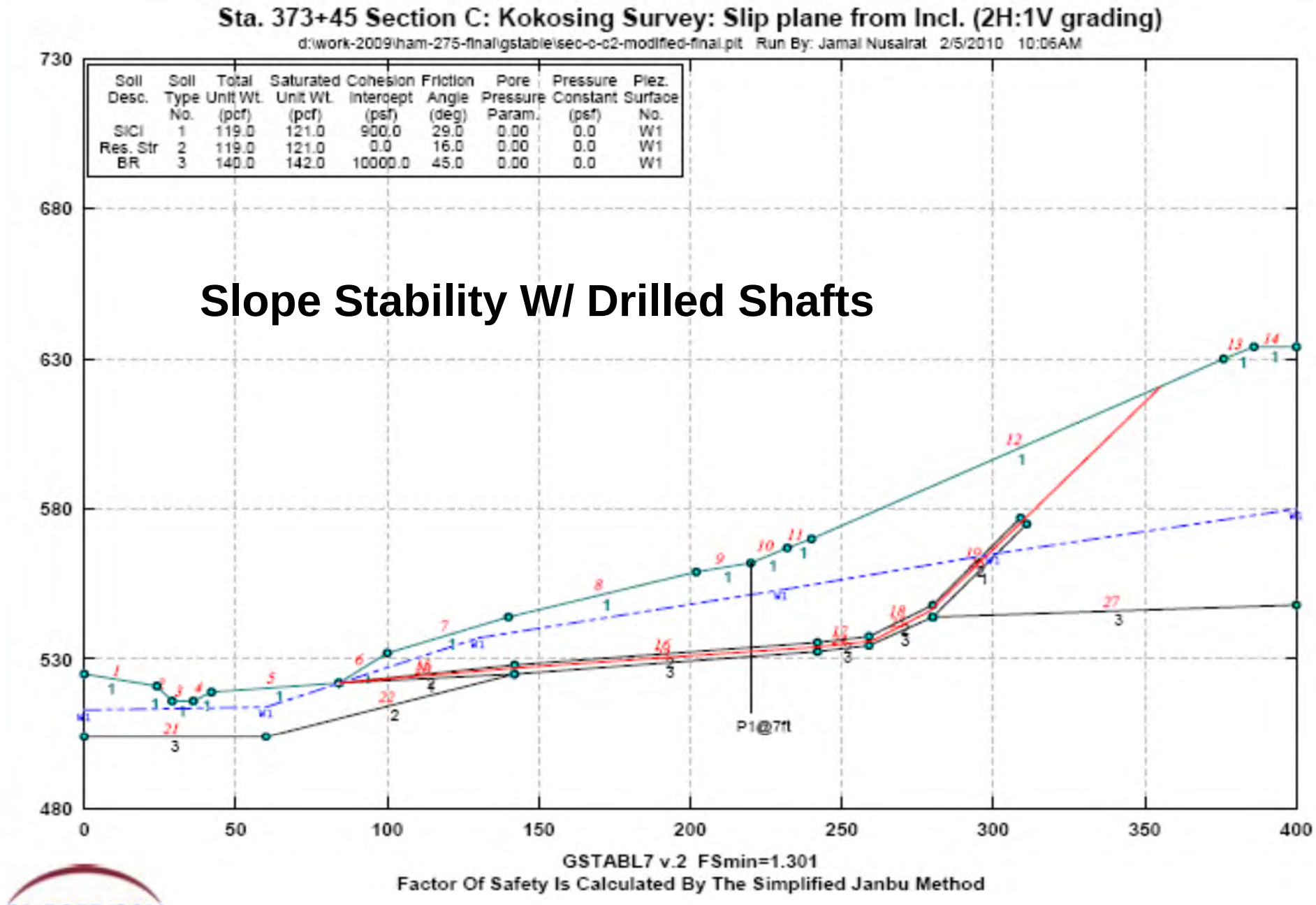


ODOT Research Report: Drilled Shaft Foundations for Noise Barrier Walls and Slope Stabilization (2002)

UA Slope Program
to
Design Landslides using Drilled Shafts



E.L.ROBINSON
the Challenge, the Choice


Sta. 373+45 Section C: Kokosing Survey: Slip plane from Incl. (2H:1V grading)
d:\work-2009\ham-275-final\gstable\sec-c-c2-modified-final.plt Run By: Jamal Nusairat 2/5/2010 10:06AM
Soil Desc. | Soil Type No. | Total Unit Wt. (pcf) | Saturated Unit Wt. (pcf) | Cohesion Intercept (psf) | Friction Angle (deg) | Pore Pressure Param. | Pressure Constant (psf) | Piez. Surface No.
SICI | 1 | 119.0 | 121.0 | 900.0 | 29.0 | 0.00 | 0.0 | W1
Res. Str | 2 | 119.0 | 121.0 | 0.0 | 16.0 | 0.00 | 0.0 | W1
BR | 3 | 140.0 | 142.0 | 10000.0 | 45.0 | 0.00 | 0.0 | W1
Slope Stability W/ Drilled Shafts
P1@7ft
730
680
630
580
530
480
0
50
100
150
200
250
300
350
400
GSTABL7 v.2 FSmin=1.301
Factor Of Safety Is Calculated By The Simplified Janbu Method

Inputs and Outputs for the Slope Stability Analysis

General information | Slope profile and soil property | Interslice force distribution

Unit
- (•) English
- ( ) Metric

Cross sectios X and Y

Vertical Section numbers: 18

Soil layer numbers: 4

Slip surface

Number of points: 5

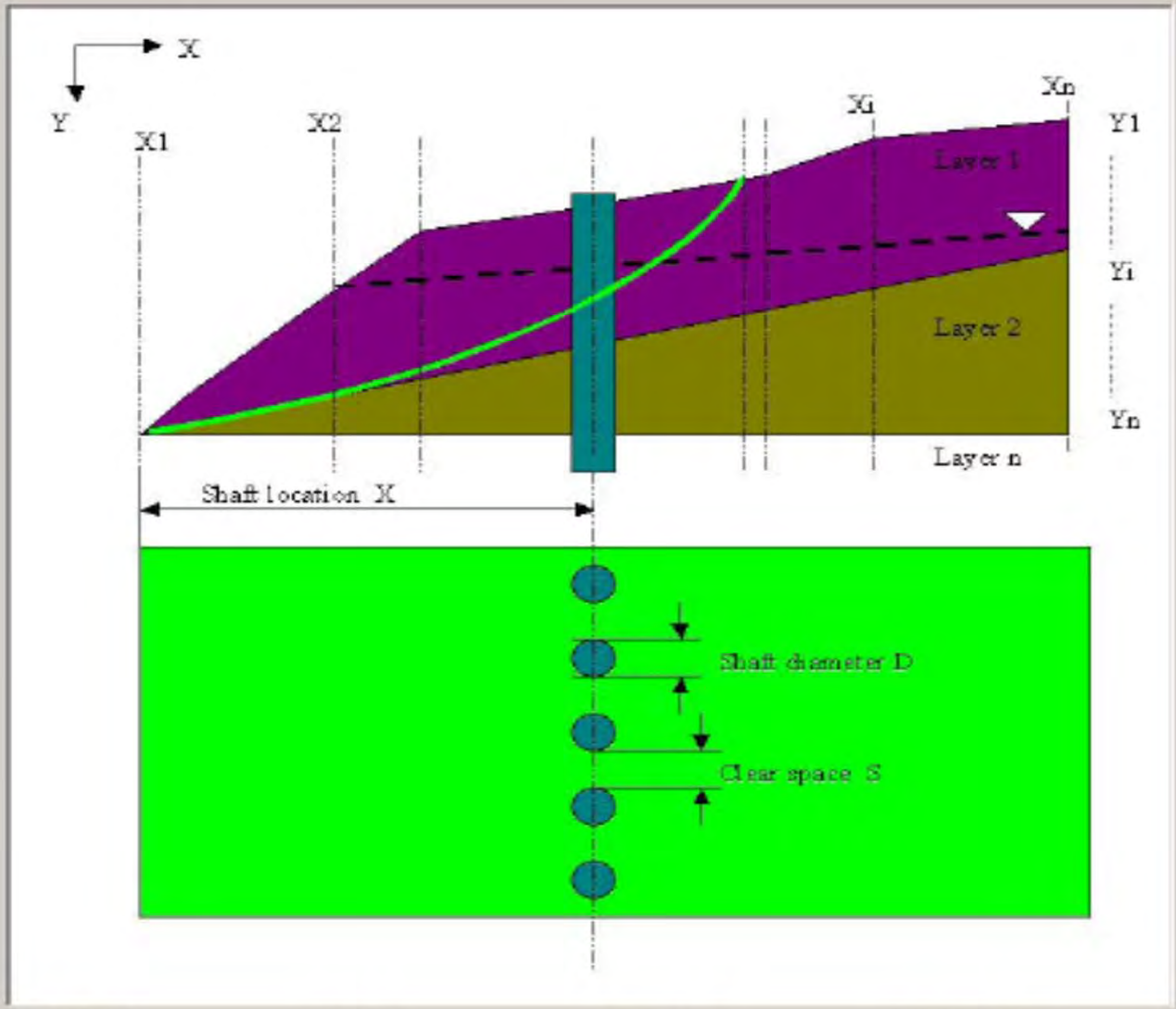
Pore pressure options
- ( ) No pore pressure
- ( ) Constant pore pressure ratio
- (•) Specified phreatic surface

Numbers of points: 5

Analysis methods
- (•) Effective stress method
- ( ) Total stress method

Pile information

Pile location X	180
Pile diameter D	4
Clear space S	2

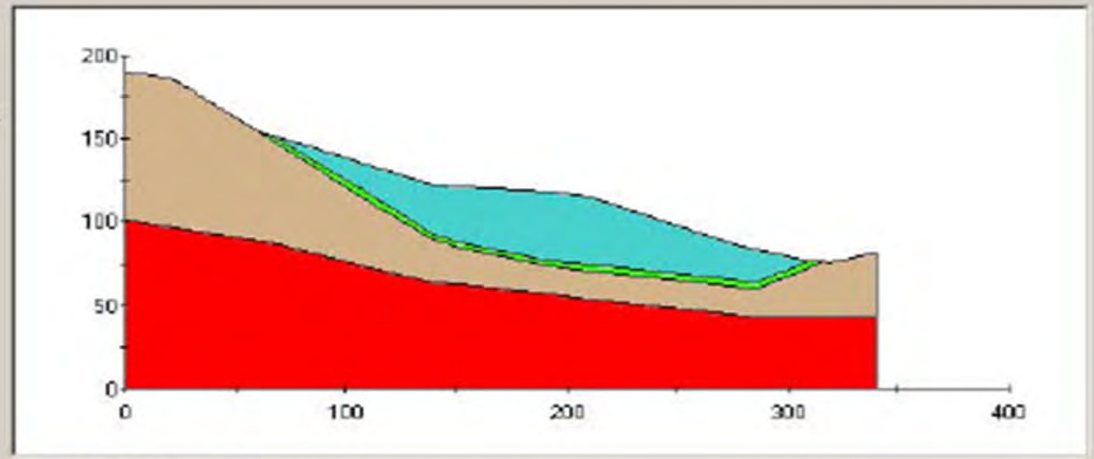


Length: ft Force: lb Pressure: psf Unit weight: pcf

Cancel OK

Inputs and Outputs for the Slope Stability Analysis

General information | Slope profile and soil property | Interslice force distribution



Calculated Result

Factor of Safety	1.34
Force per shaft	144564.74
Acting point X	180
Acting point Y	108.687

Drill shaft effect

- Not considered
- Auto calculated
- Manual input

Reduction factor [ ] %

Slope profile specification

Vertical sections. (Yi = top boundary position of each layer

YVX	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14
X	0	13.2	23	61.2	65.9	96.1	108	139.8	151.5	192.1	210	274.1	285.2	309.8
Y1	10	11.7	14.7	45.7	47.6	60	64.9	78	78.9	91.8	94.8	112.9	116.1	123.3
Y2	10	11.7	14.7	45.7	47.6	71.8	81	107	112	122.9	125.5	134.8	136.4	123.3
Y3	10	11.7	14.7	45.7	51.1	75.5	85.1	110.8	115	126.2	128.9	138.4	140.1	127.1
Y4	98.8	101.5	103.4	111.1	112	122	126	136	137	143.2	145.9	155.4	157.1	157.1
Y5	200	200	200	200	200	200	200	200	200	200	200	200	200	200

Soil property

C:cohesion; F:friction angle; U:U.W

L\P	C	F	U
layer1	900	29	120
layer2	0	16	120
layer3	900	29	120
layer4	10000	45	140

Slip surface specification

Number of points [5] Change

YVX	X1	X2	X3	X4	X5
X	61	152.2	167.9	285.2	312
Y	45.7	117.2	120.9	137.9	124

Phreatic surface specification

Number of points [5] Change

YVX	X1	X2	X3	X4	X5
X	0	110.1	210	280.1	340
Y	80.5	81	95.9	126	127.7

Update Graphics

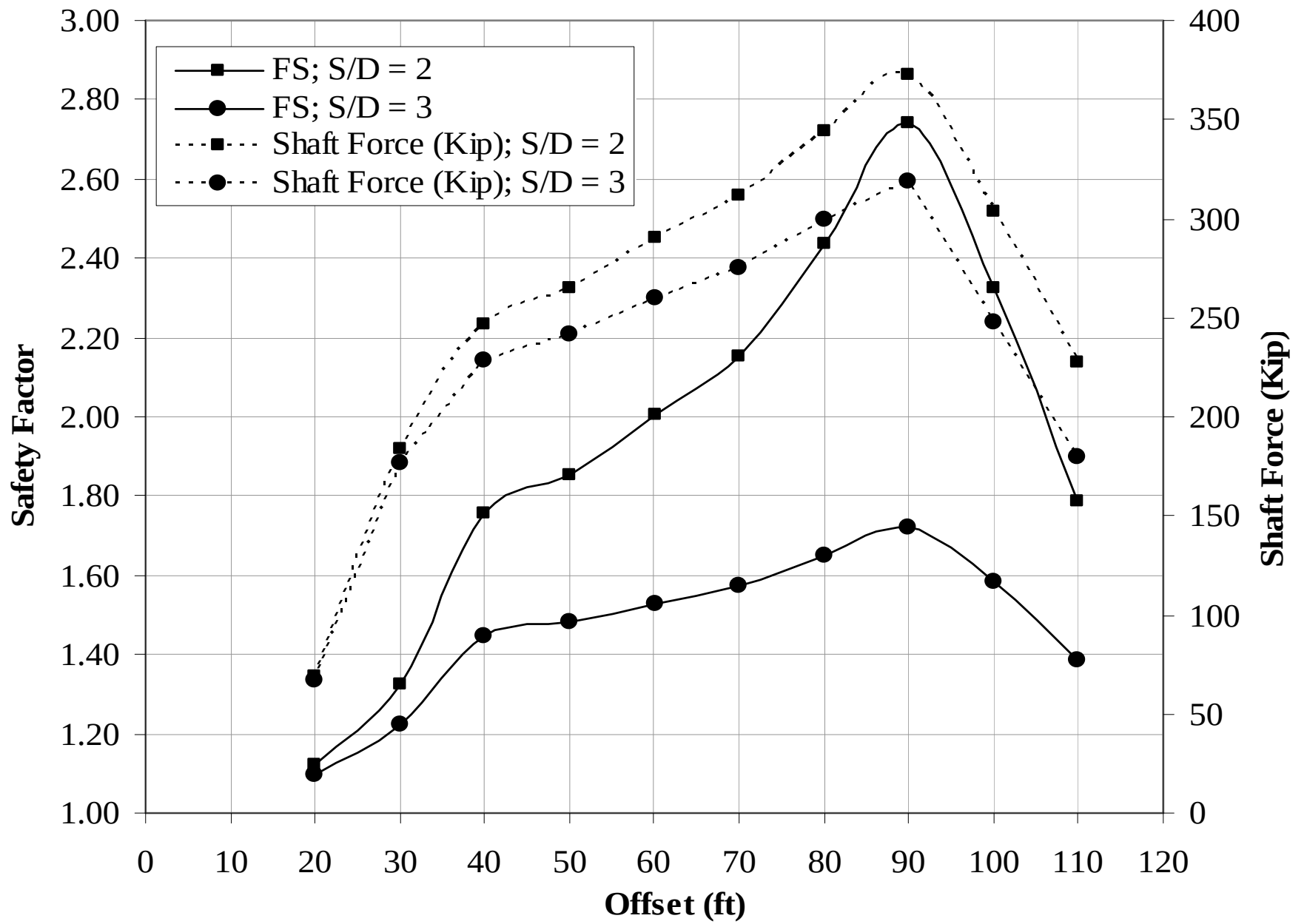
View Slip and Phreatic surfaces

Save

Compute

Cancel

OK


FS; S/D = 2
FS; S/D = 3
Shaft Force (Kip); S/D = 2
Shaft Force (Kip); S/D = 3
Safety Factor
Shaft Force (Kip)
Offset (ft)
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
400
350
300
250
200
150
100
50
0
0
10
20
30
40
50
60
70
80
90
100
110
120

Lateral Analysis Results

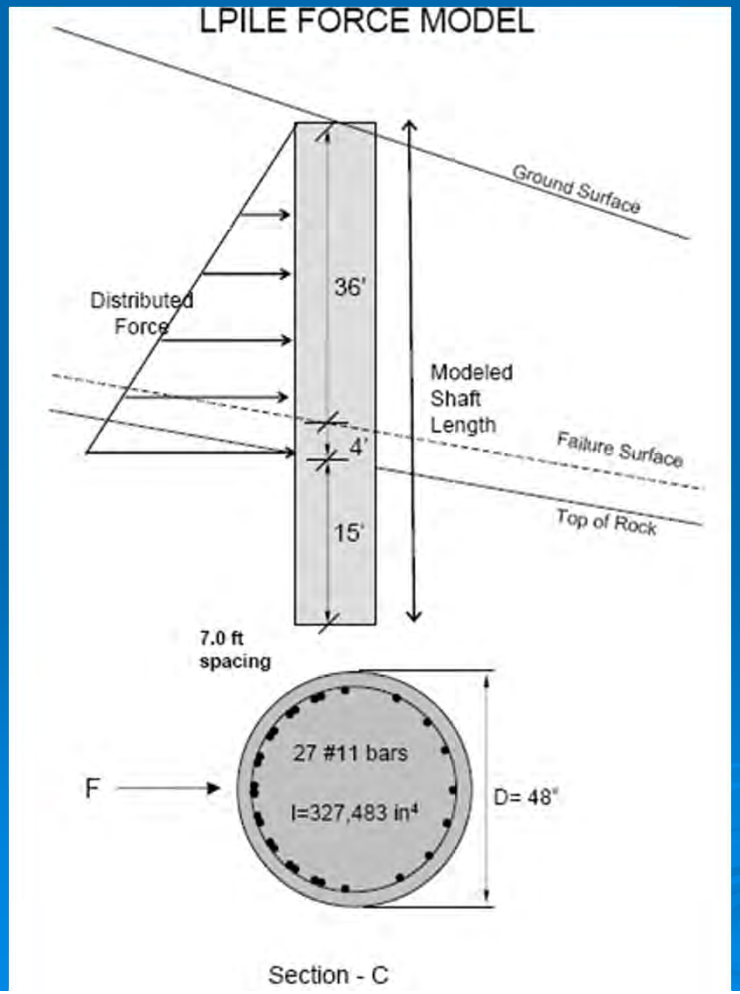
- Assumed Shaft diameter, Reinforcement, and concrete strength.
- Defined loads from Slope Stability Analysis (UA Slope, FEM…)
- Run Lateral Analysis (L-Pile, COM624, FB-Multi Pier, FEM…)

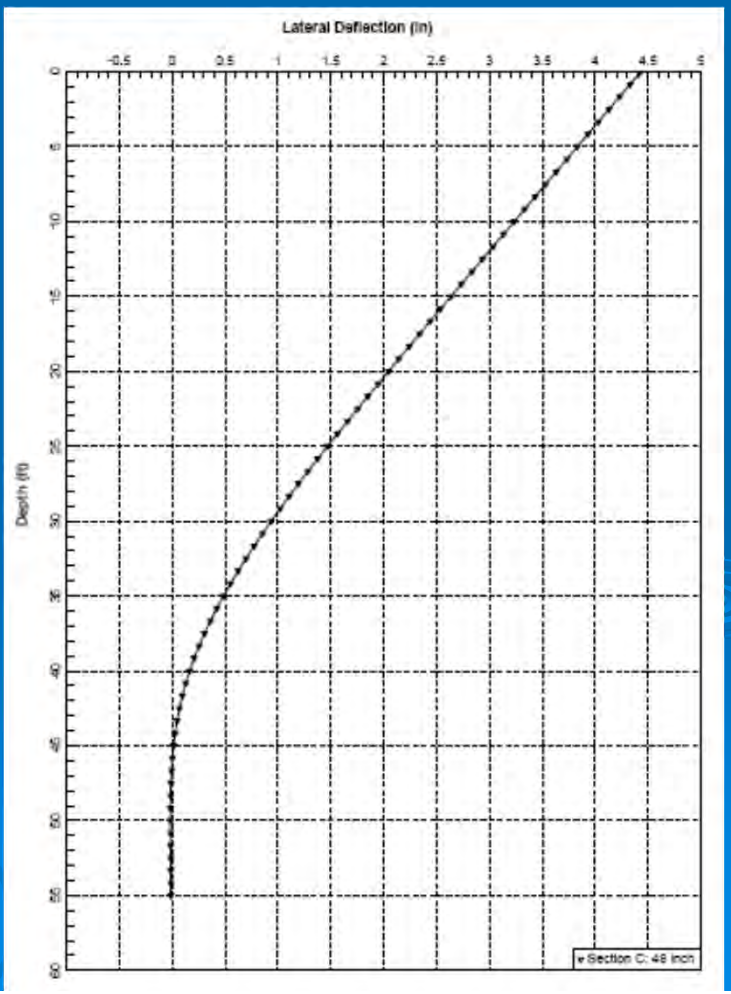
Results

- Deflection
- Moment
- Shear → verify/modify section

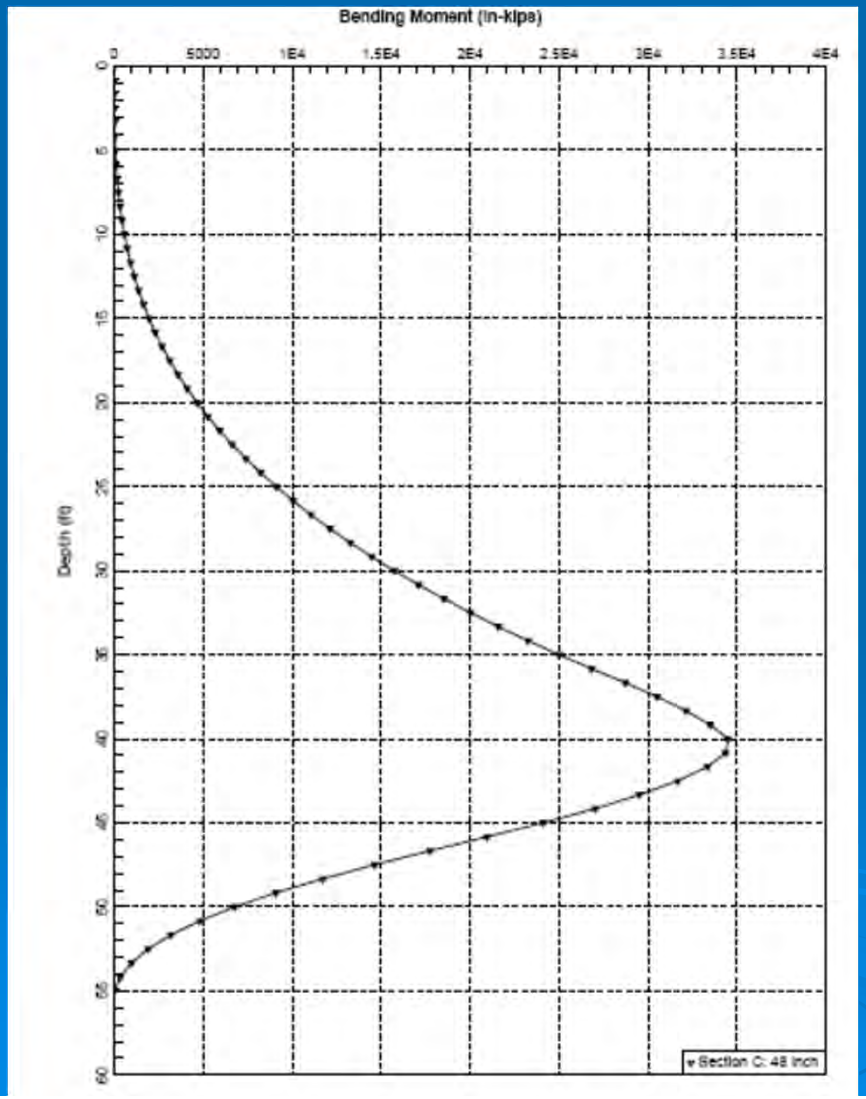
Perform Lateral Analysis

Verify assumed diameter, spacing, and length of shaft

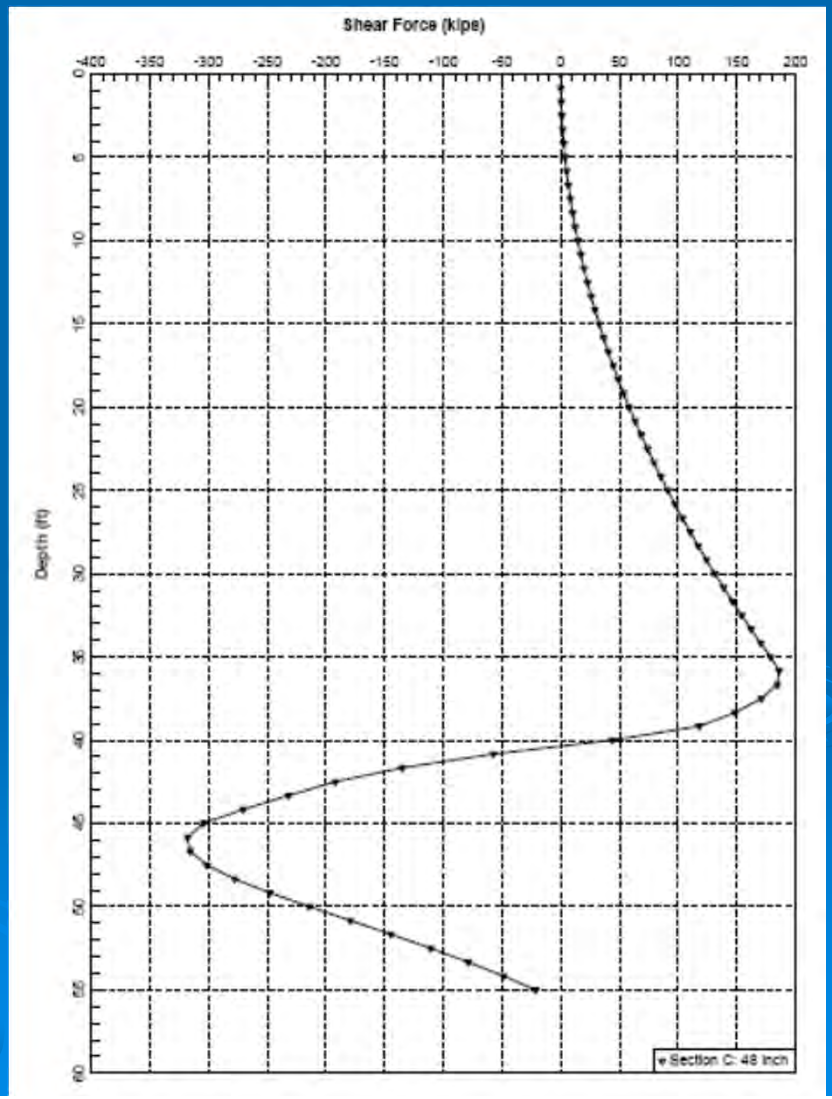




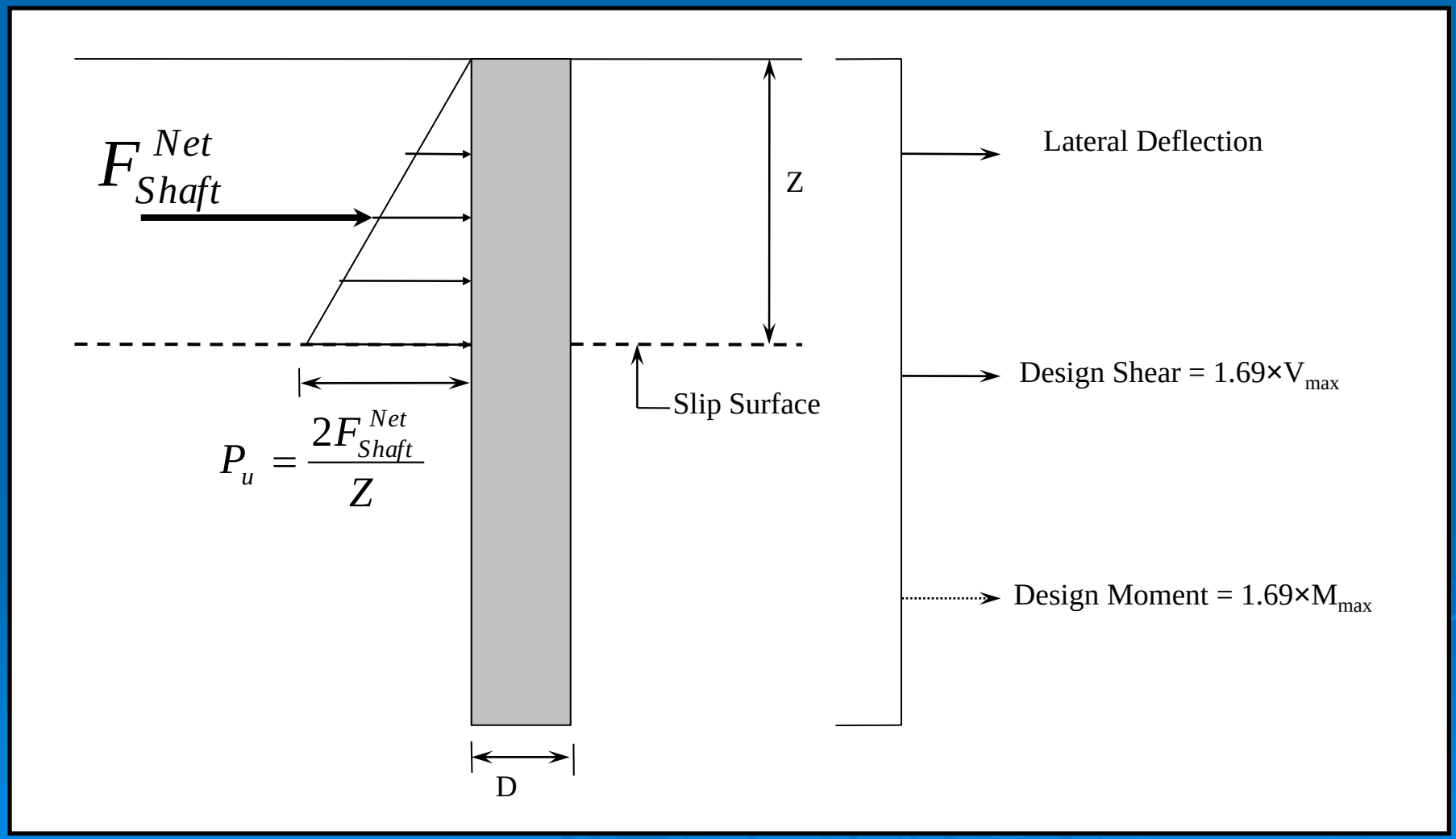
Moment

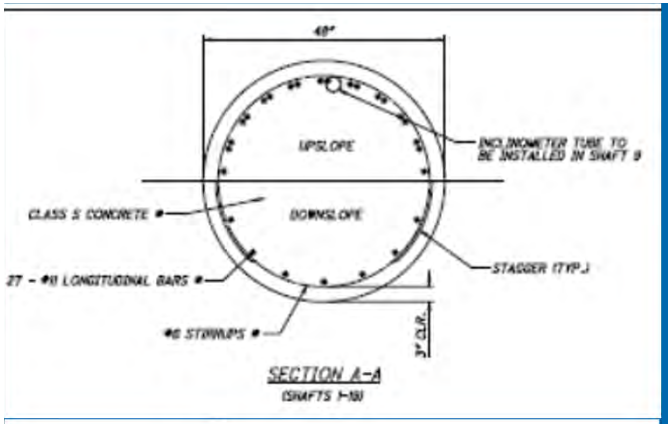


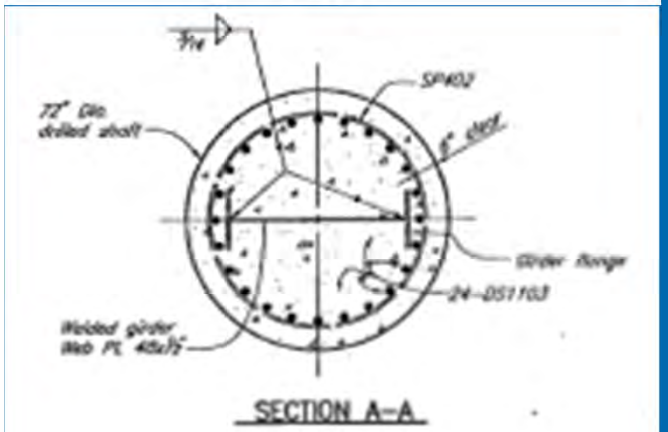
Shear

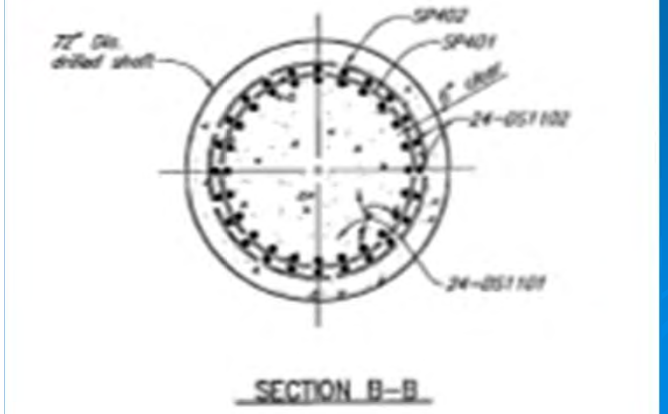


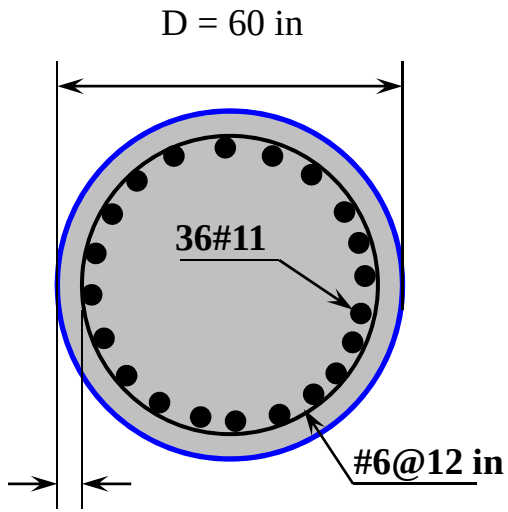
Structural Design of Drilled Shaft



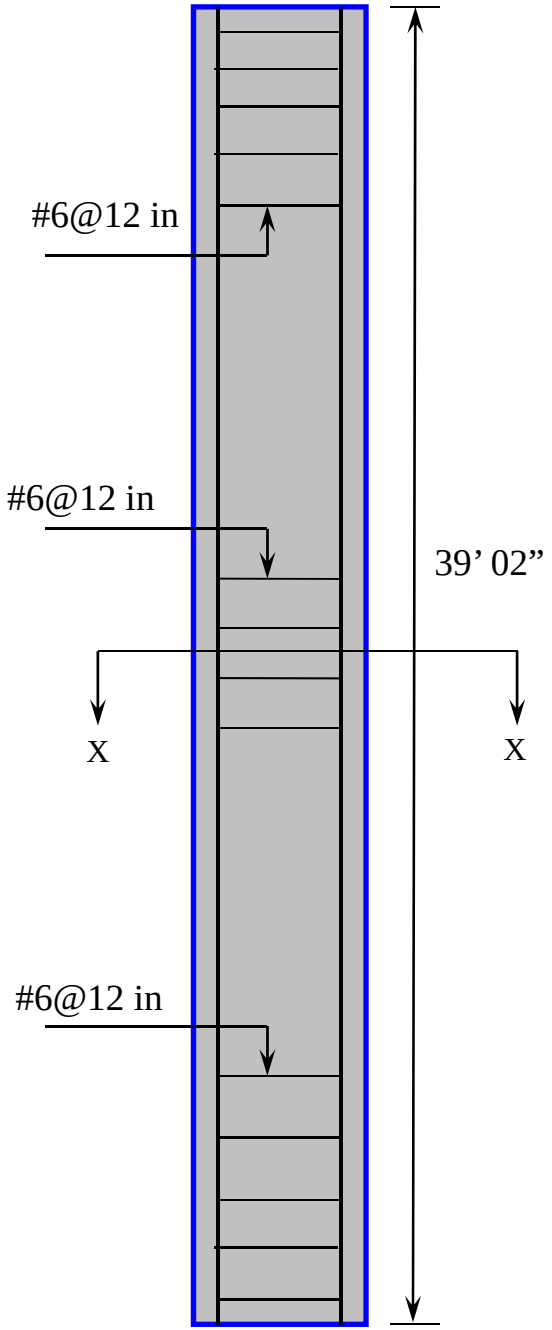

48"
UPSLOPE
INCLINOMETER TUBE TO BE INSTALLED IN SHAFT 9
CLASS S CONCRETE
DOWNSLOPE
STAGGER (TYP.)
27 - #11 LONGITUDINAL BARS
#6 STIRRUPS
3" CLR.
SECTION A-A
(SHAFTS 1-10)


72" Dia. drilled shaft
SP402
Girder flange
24-D51103
Welded girder Web PL 45x1/2"
SECTION A-A


72" Dia. drilled shaft
SP402
SP401
24-D51102
24-D51101
SECTION B-B

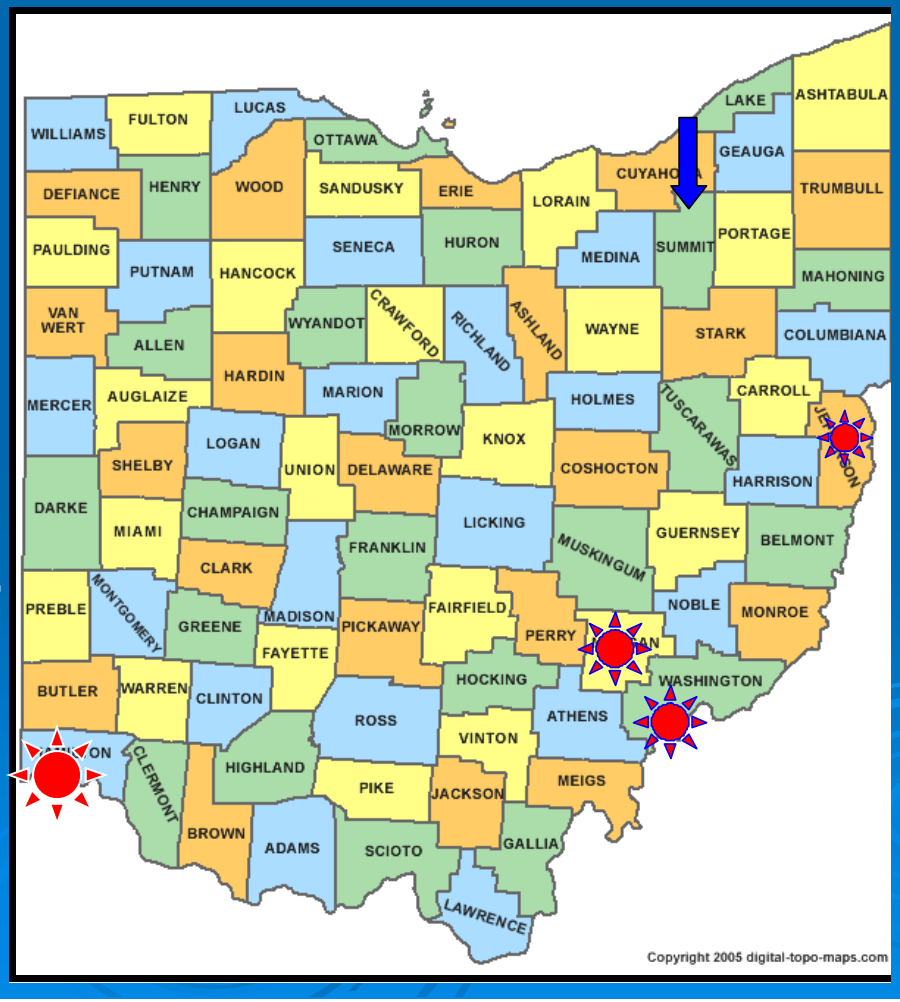

D = 60 in
36#11
#6@12 in
3 in cover

X - X


#6@12 in
#6@12 in
39' 02"
X
X
#6@12 in

Field Instrumentation and Monitoring

- JEF-152-1.3
- WAS-7-47.9
- MRG-376-1.1
- HAM-275-7.02

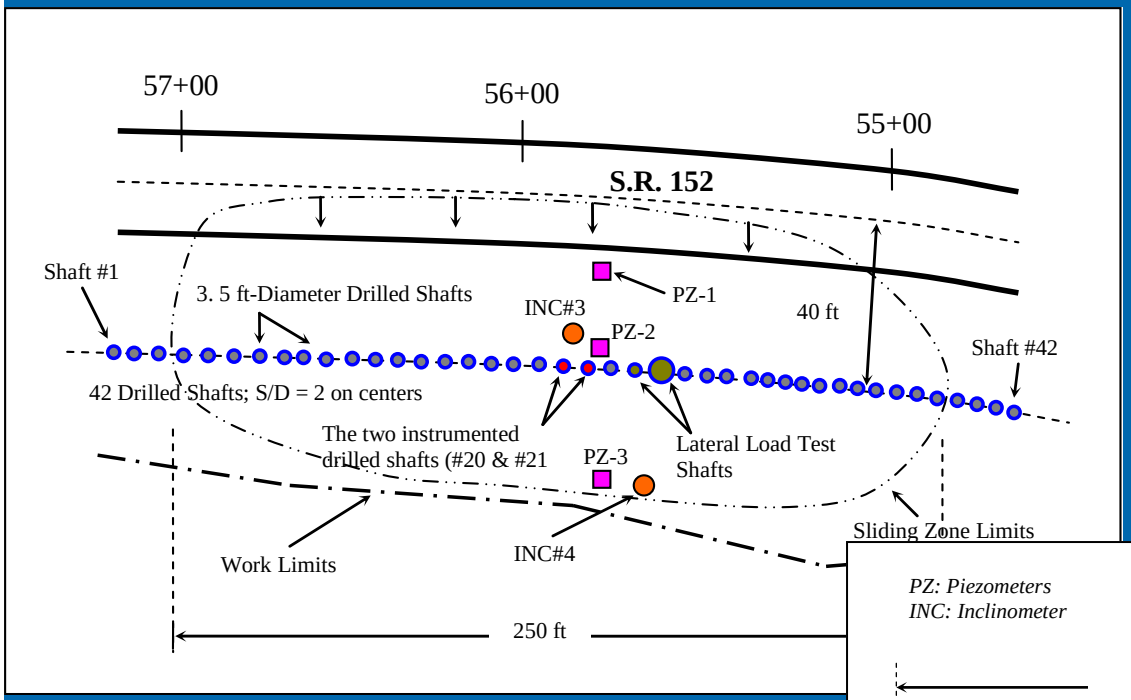


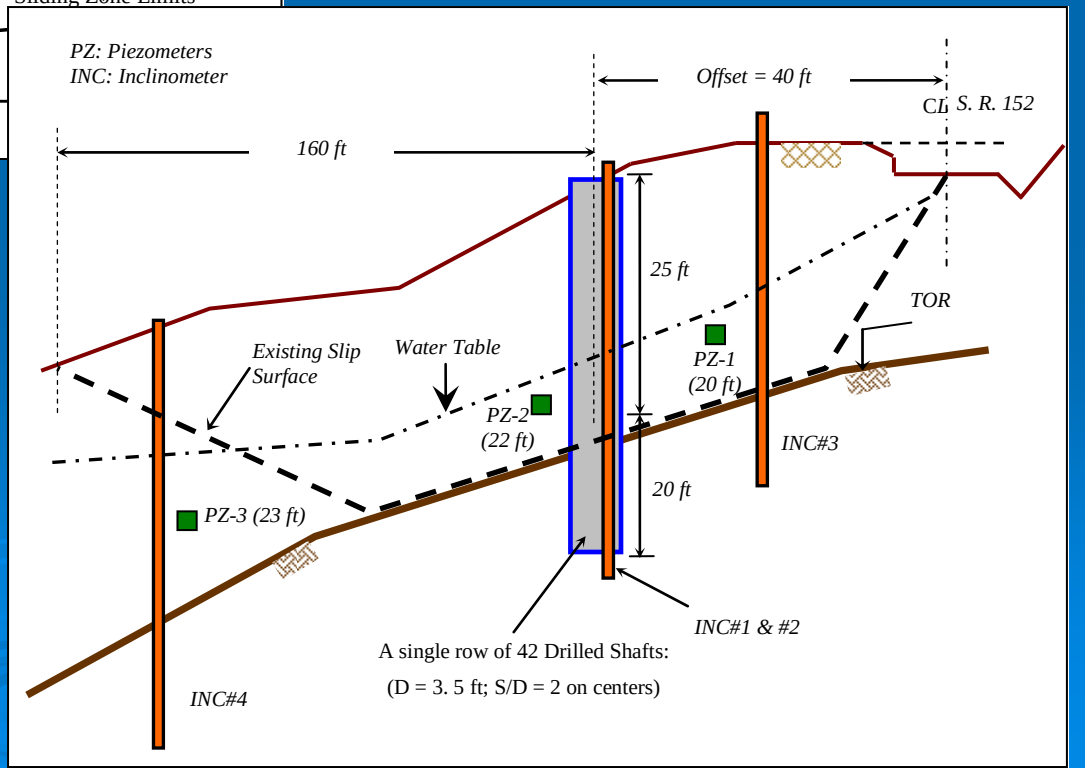
Projects Design Summary

Site	D (ft)	S/D (ft/ft)	Lp (ft)	Lr (ft)	Fshaft (kips)	# of Shafts	Offset (ft)
JEF-152-1.30	**3.5**	**2**	**45**	**20**	**100**	**42**	**40**
WAS-7-47.90	**4**	**2, 3**	**40**	**10**	**200**	**128**	**90**
MRG-376-1.1	**4**	**2**	**40**	**18**	**165**	**23**	**20**
HAM-275-7.02	**4**	**2**	**55**	**15**	**165**	**54**	**180**

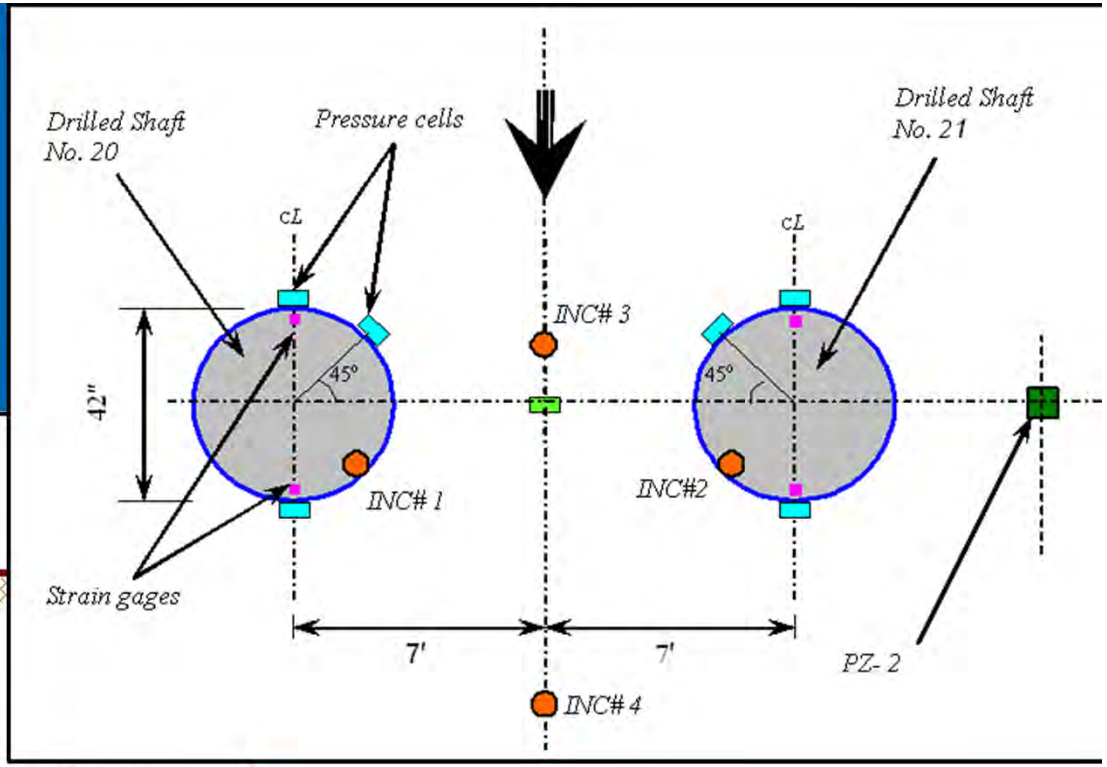
JEFF – 152-1.3

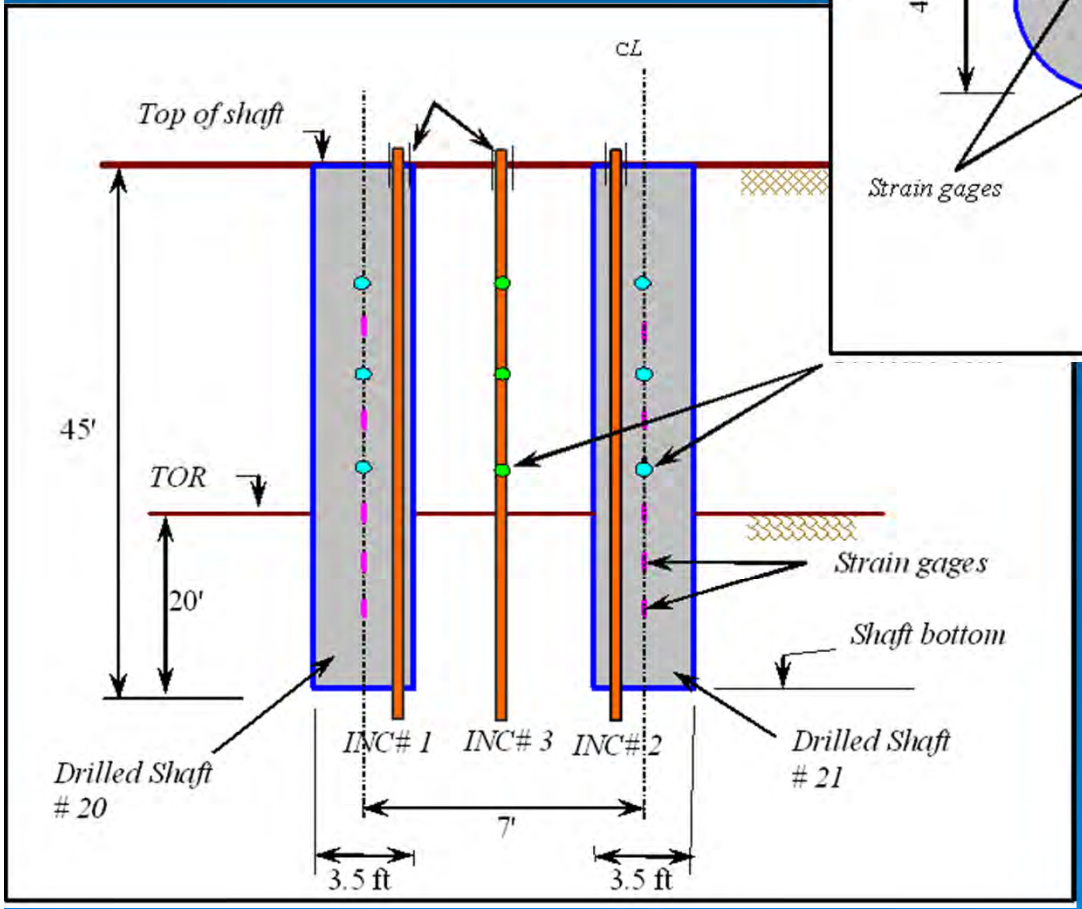
Instrumentation Plans/Slope Section





Instrumentation/Shafts





JEF-152-1.30

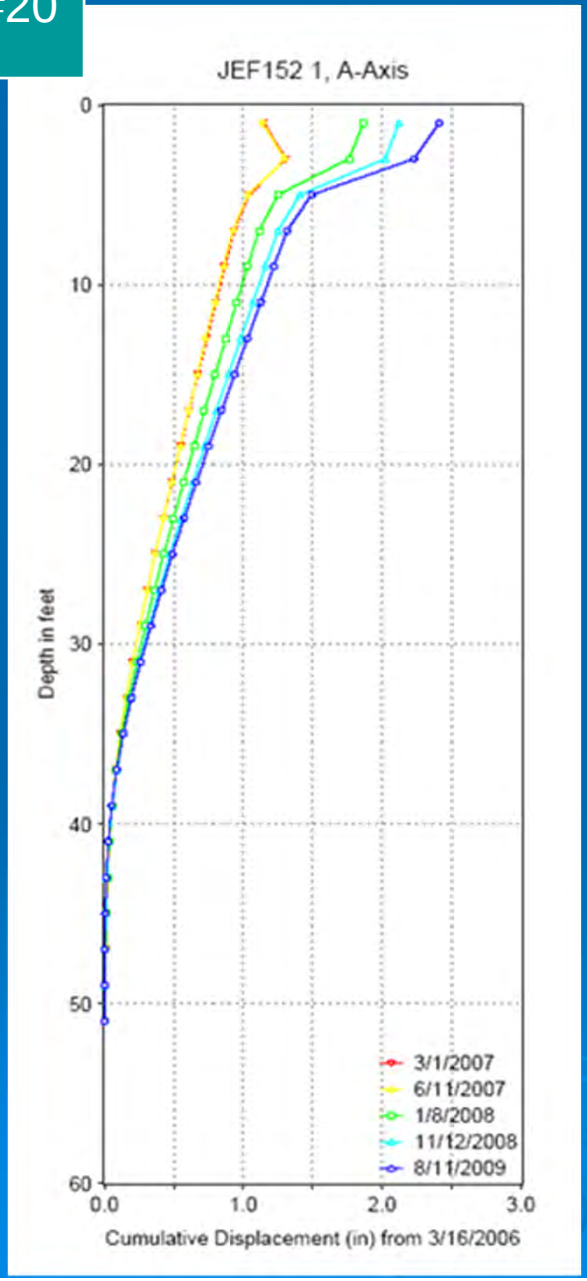
Shaft Properties

D (ft)	Reinforc.	Moment capacity (k-f)	Load kips	Max Deflection (in)
3.5	26 #11	2,824	102	3.2

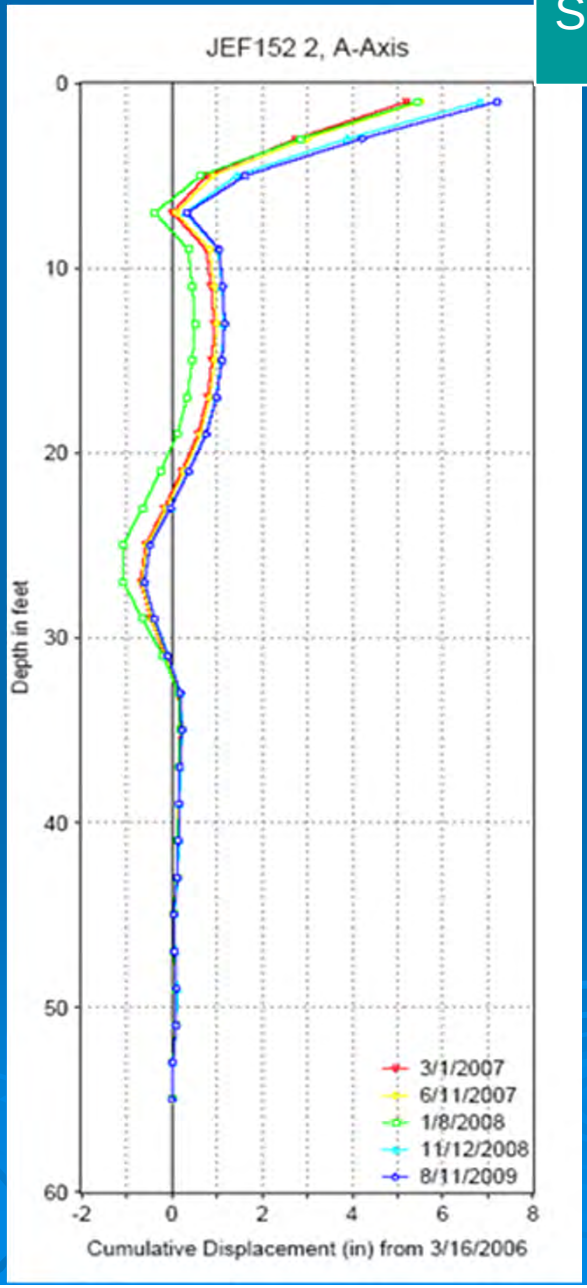
Max. Deflection: LPILE Analysis
Load : UA Slope Analysis

Drilled Shafts Deflection

SH#20

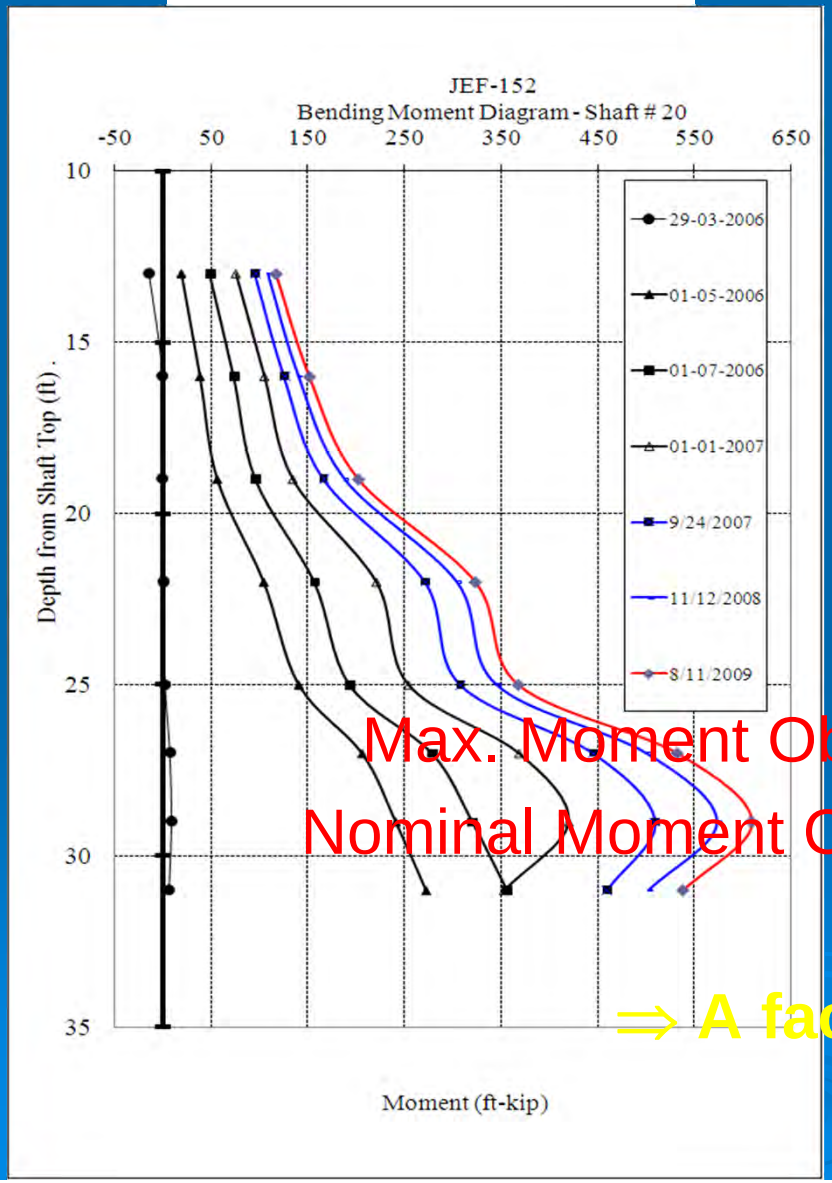


SH#21

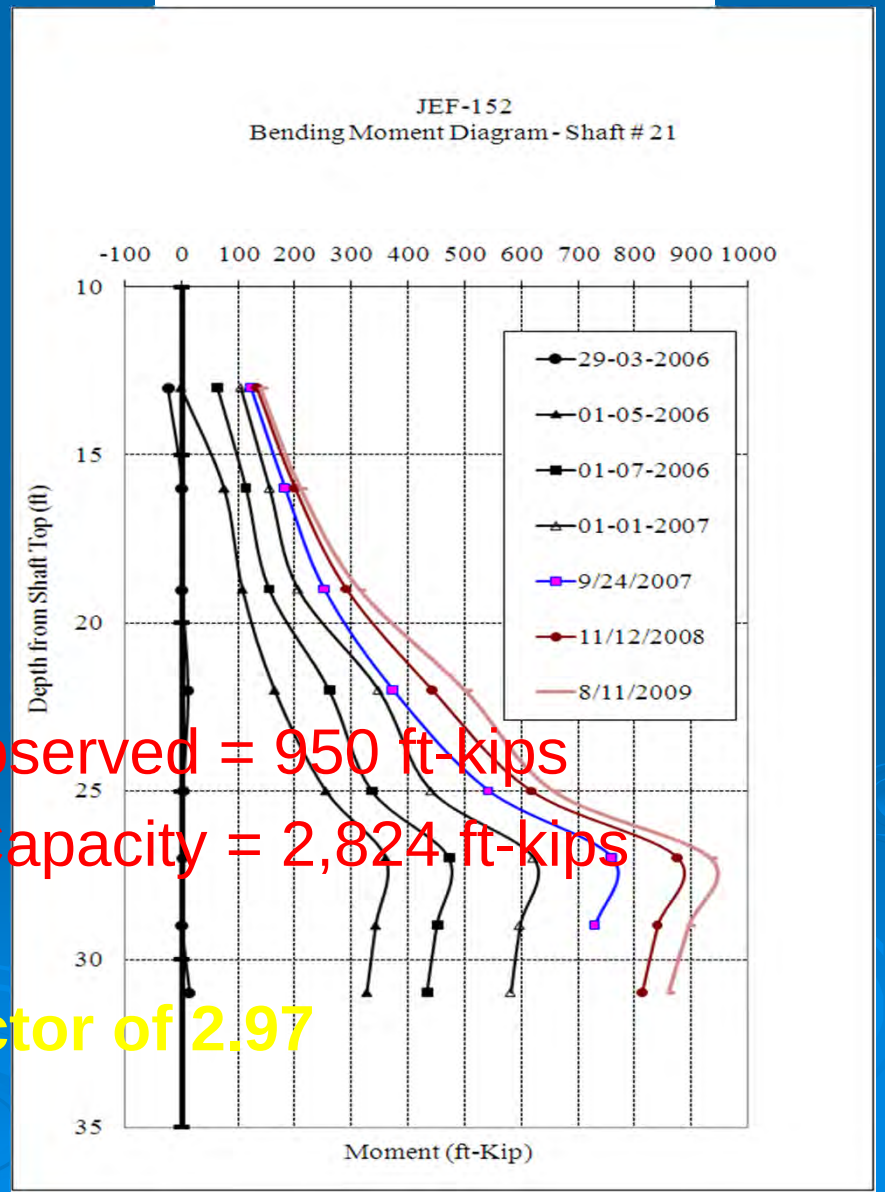


Moments in Shaft #20 and Shaft #21

Moment in SH#20



Moment in SH#21



Max. Moment Observed = 950 ft-kips

Nominal Moment Capacity = 2,824 ft-kips

⇒ A factor of 2.97

WAS – 7-47.9

Shaft Properties

D (ft)	Reinforc.	Moment capacity (k-f)	Load kips	Max Deflection (in)
4.0	32 #14	4,918	63	2.6

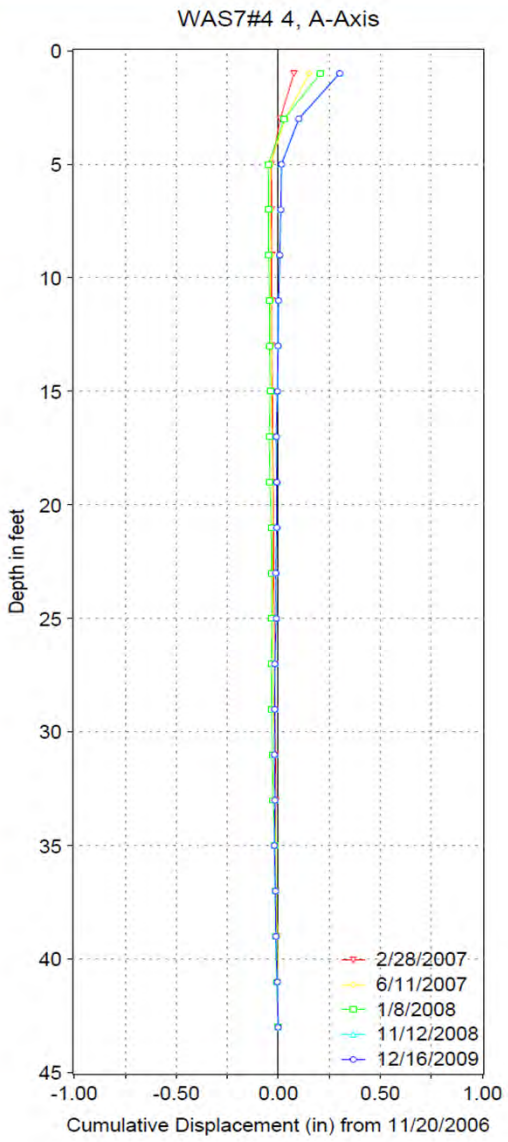
Max. Deflection: LPILE Analysis
Load : UA Slope Analysis

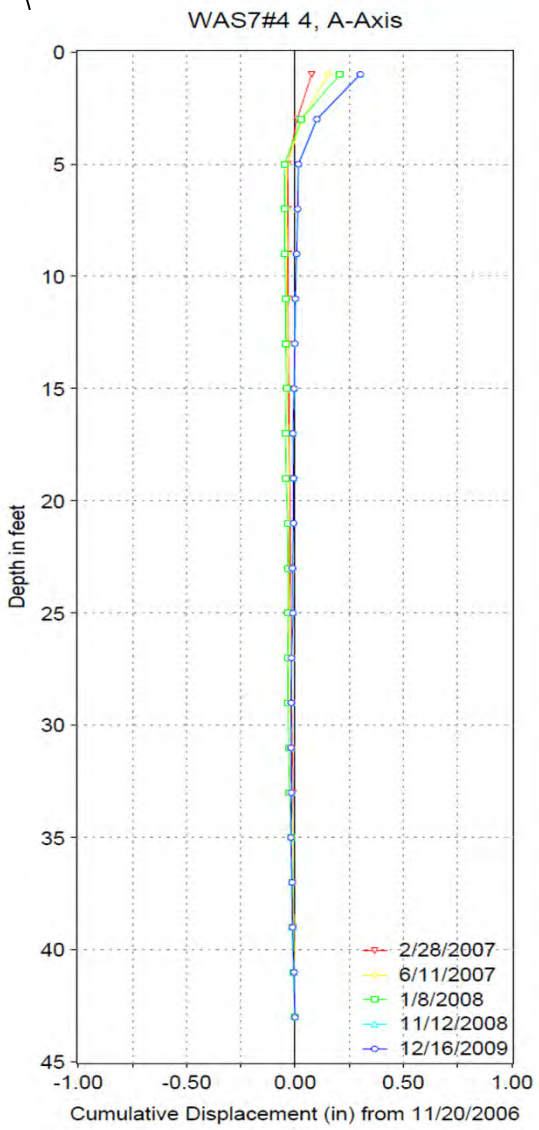
Soil Movement

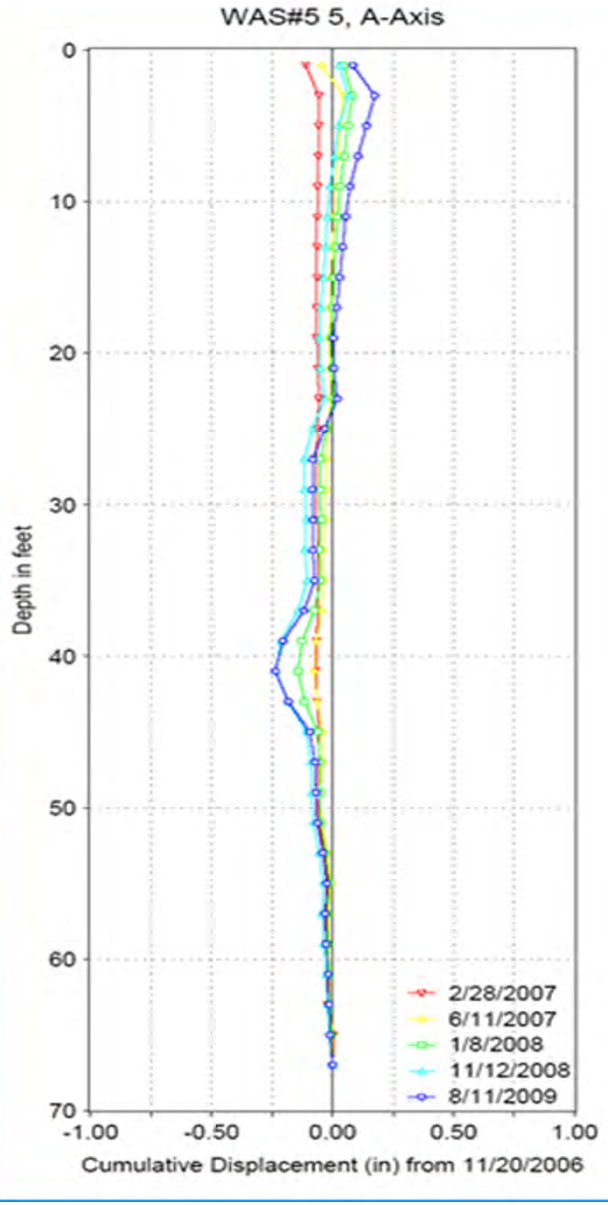
Up-Slope

In-between

Down-Slope

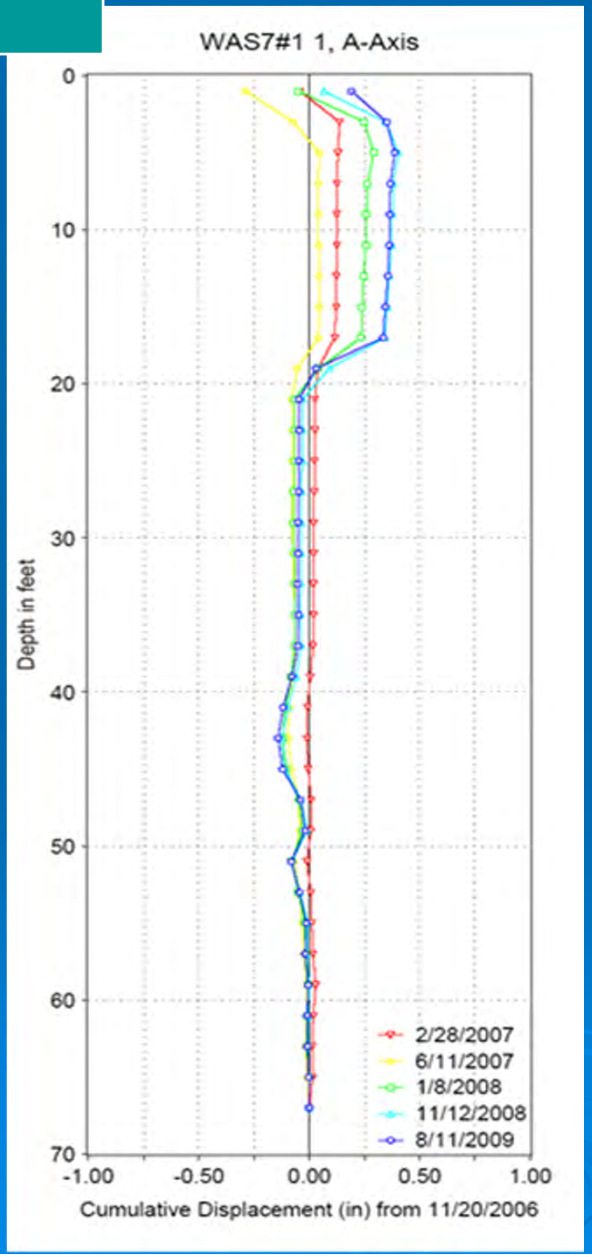




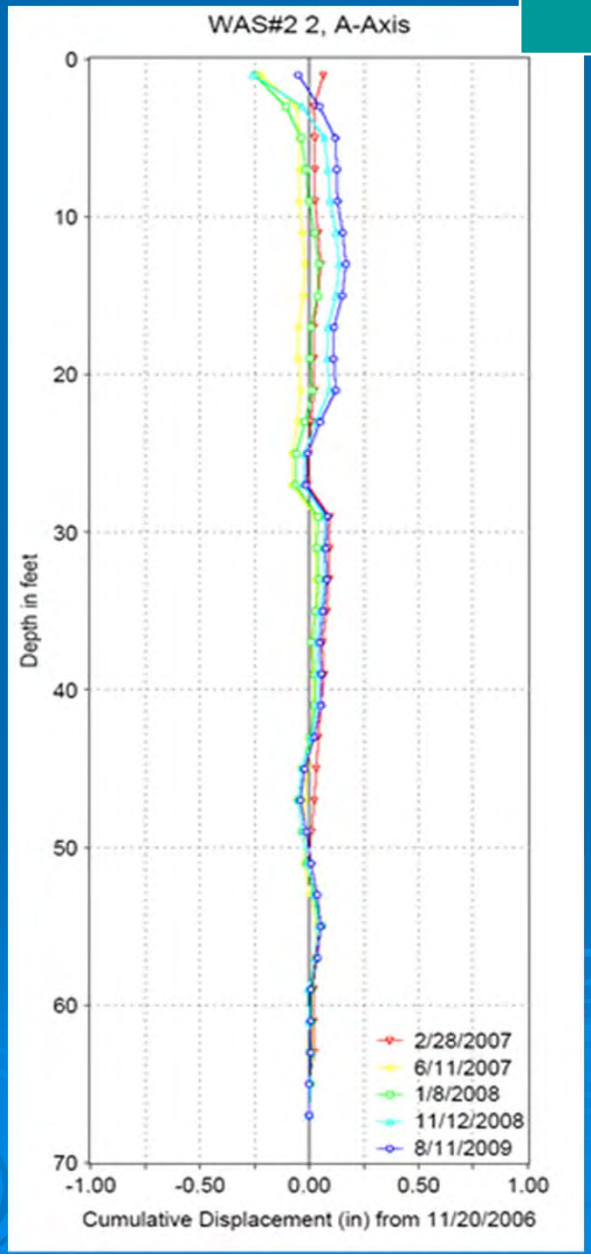


Drilled Shafts Deflection

SH#53

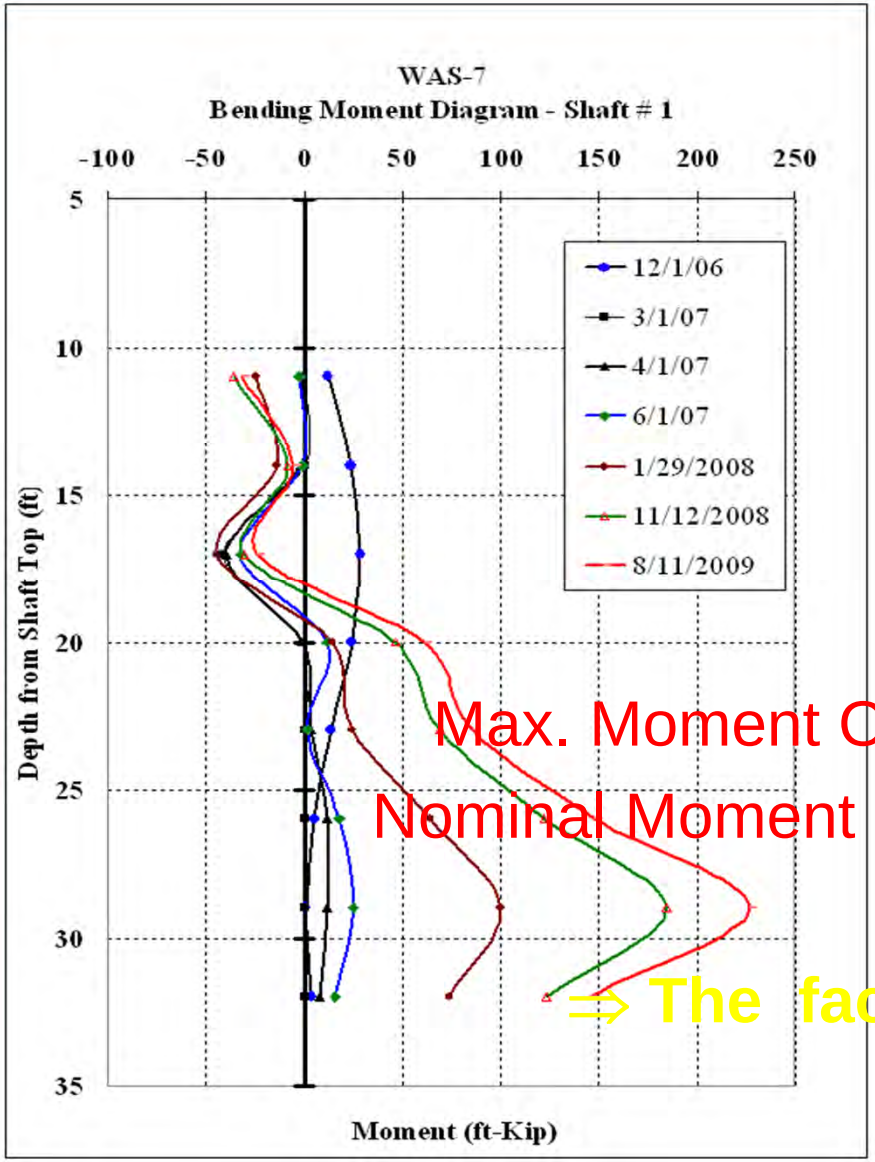


SH#54

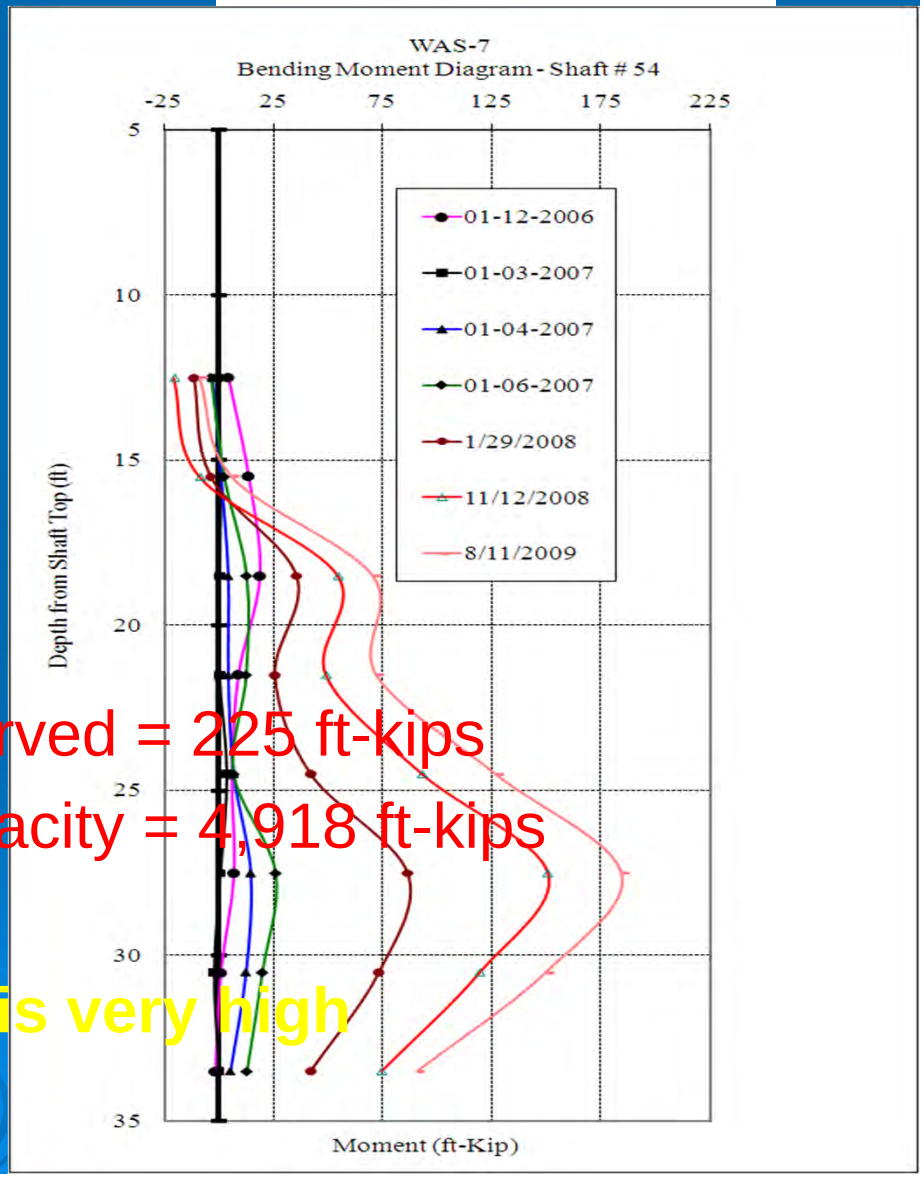


Moments in Shaft #20 and Shaft #21

Moment in SH#53



Moment in SH#54



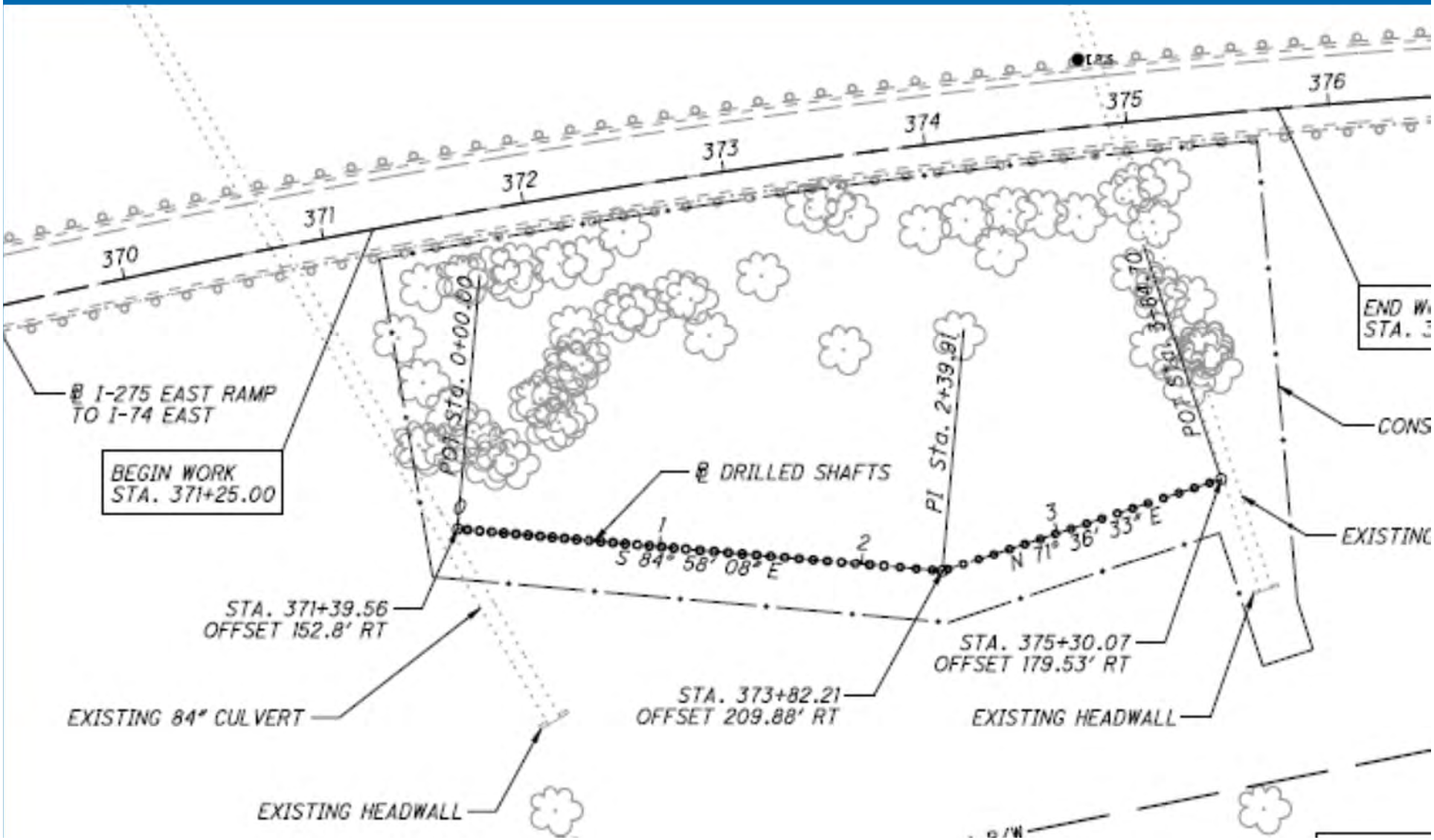
Max. Moment Observed = 225 ft-kips

Nominal Moment Capacity = 4,918 ft-kips

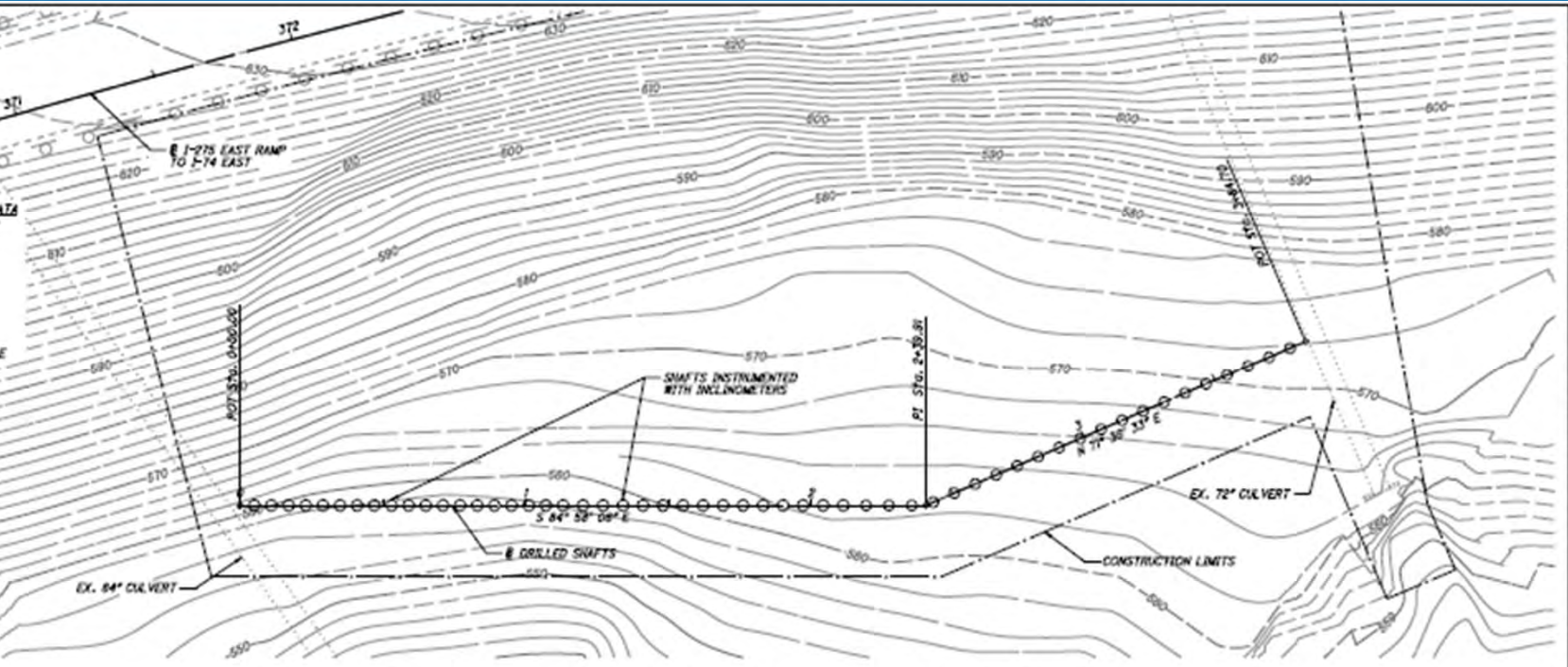
⇒ The factor is very high

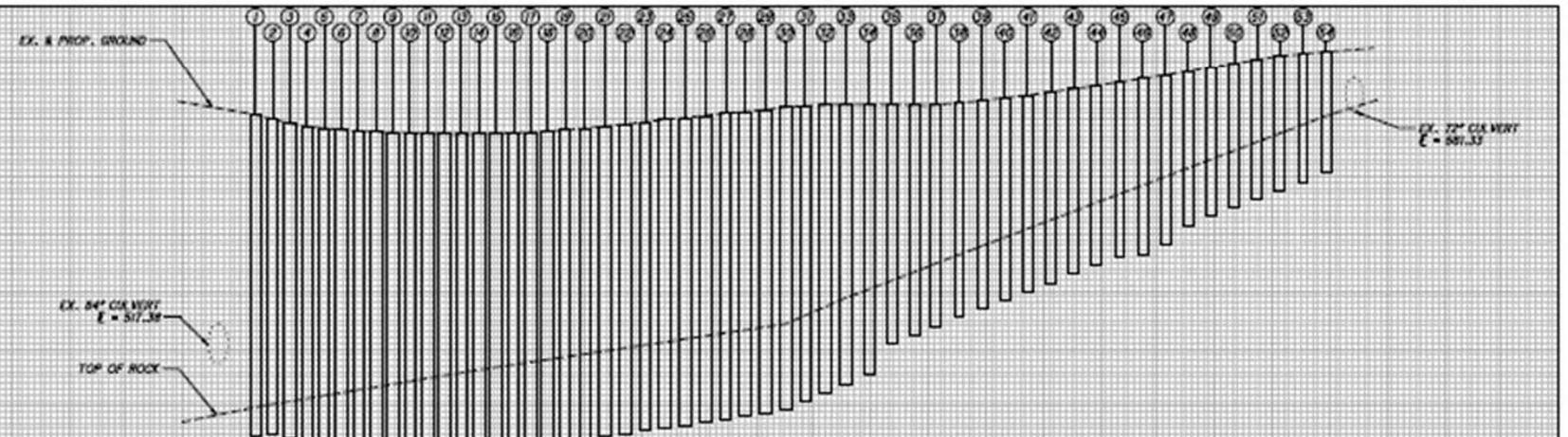
HAM-275-7.02

HAM-275-7.02


370
371
372
373
374
375
376
℄ I-275 EAST RAMP
TO I-74 EAST
BEGIN WORK
STA. 371+25.00
POT Sta. 0+00.00
℄ DRILLED SHAFTS
PI Sta. 2+39.91
POT Sta. 3+64.70
END W
STA. 3
CONS
EXISTING
S 84° 58' 08" E
N 71° 36' 33" E
STA. 371+39.56
OFFSET 152.8' RT
STA. 373+82.21
OFFSET 209.88' RT
STA. 375+30.07
OFFSET 179.53' RT
EXISTING 84" CULVERT
EXISTING HEADWALL
EXISTING HEADWALL

HAM-275-7.02

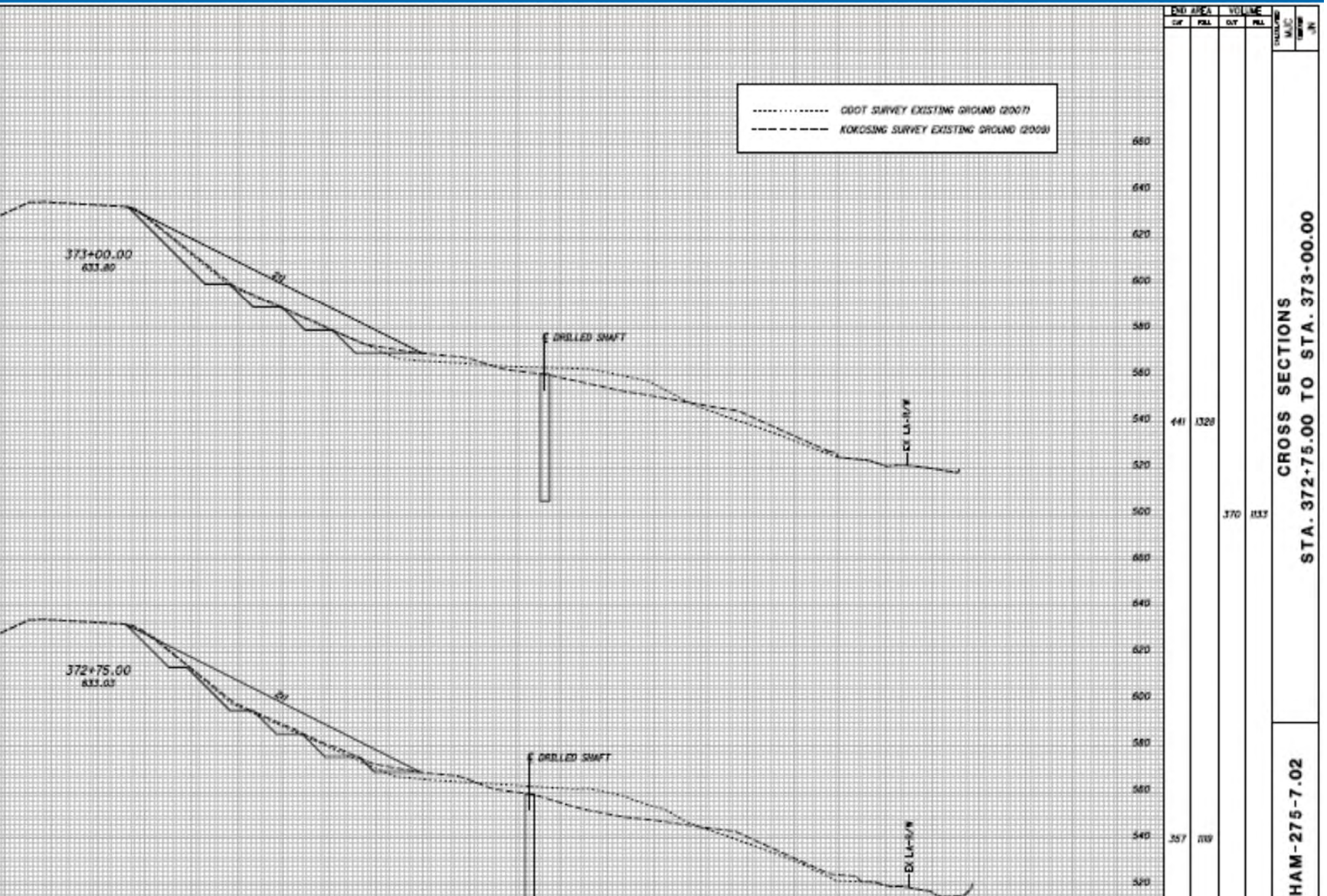




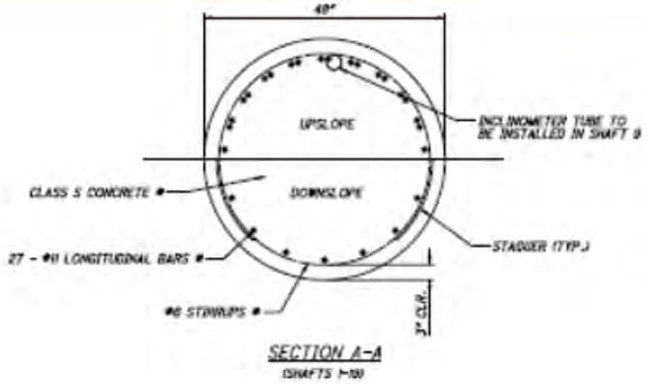
DRILLED SHAFTS - PLAN AND PROFILE
STA. 0+00 TO STA. 3+84.70

HAM-275-7.02

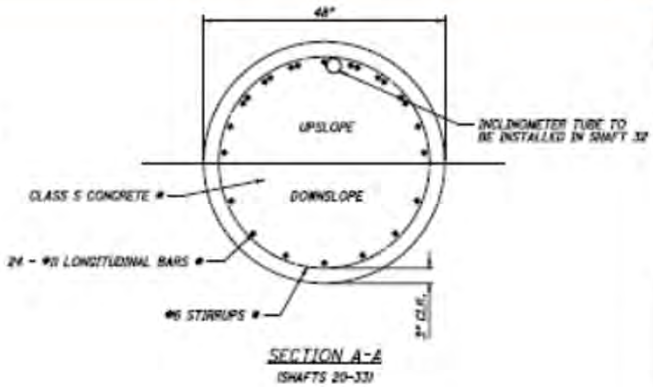
HAM-275-7.02


ODOT SURVEY EXISTING GROUND (2007)
KOKOSING SURVEY EXISTING GROUND (2009)
373+00.00
633.80
2%
℄ DRILLED SHAFT
EX LT-R/W
372+75.00
633.03
2%
℄ DRILLED SHAFT
EX LT-R/W
660
640
620
600
580
560
540
520
500
660
640
620
600
580
560
540
520
END AREA
CUT
FILL
441
1328
357
1119
VOLUME
CUT
FILL
370
1133
CROSS SECTIONS
STA. 372+75.00 TO STA. 373+00.00
HAM-275-7.02

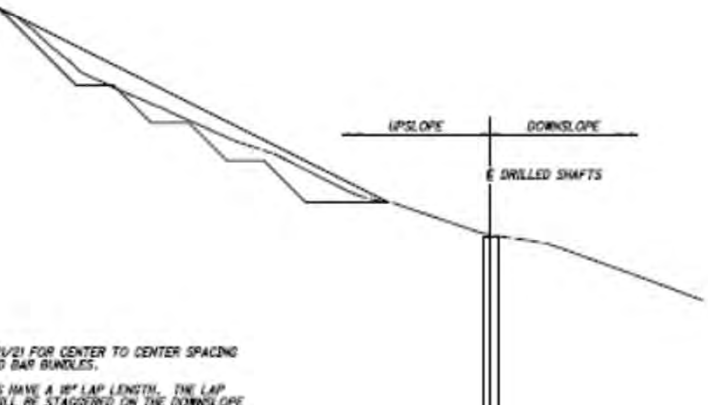
HAM-275-7.02

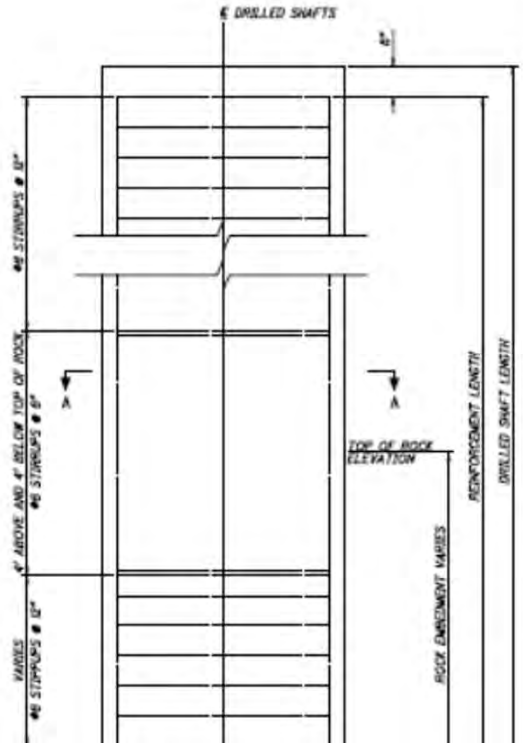


SECTION A-A
(SHAFTS 1-19)



SECTION A-A
(SHAFTS 20-33)





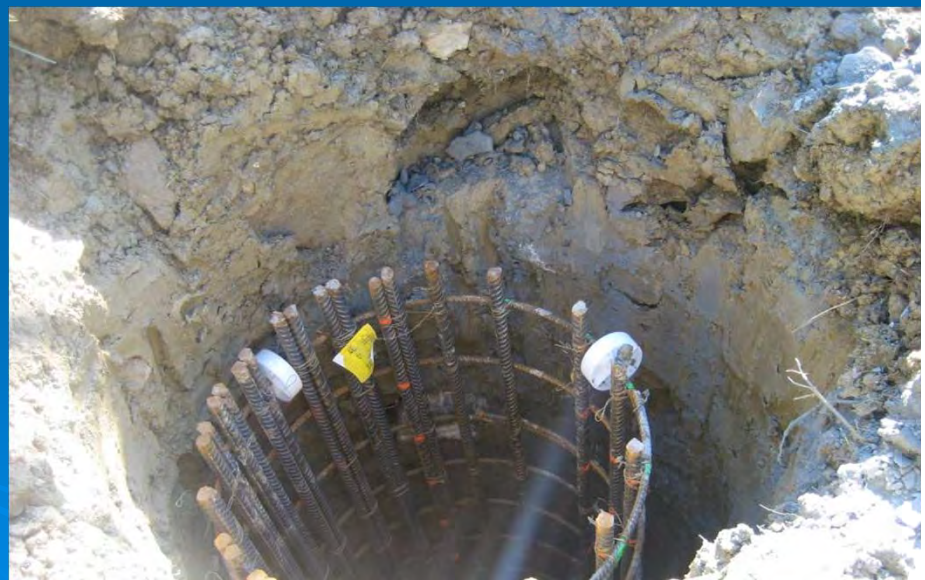
V/21 FOR CENTER TO CENTER SPACING
D BAR BUNDLES.
S HAVE A 18" LAP LENGTH. THE LAP
LL BE STAGGERED ON THE DOWNSLOPE

CALCULATED DTA
CHECKED JN

48" DRILLED SHAFT DETAILS

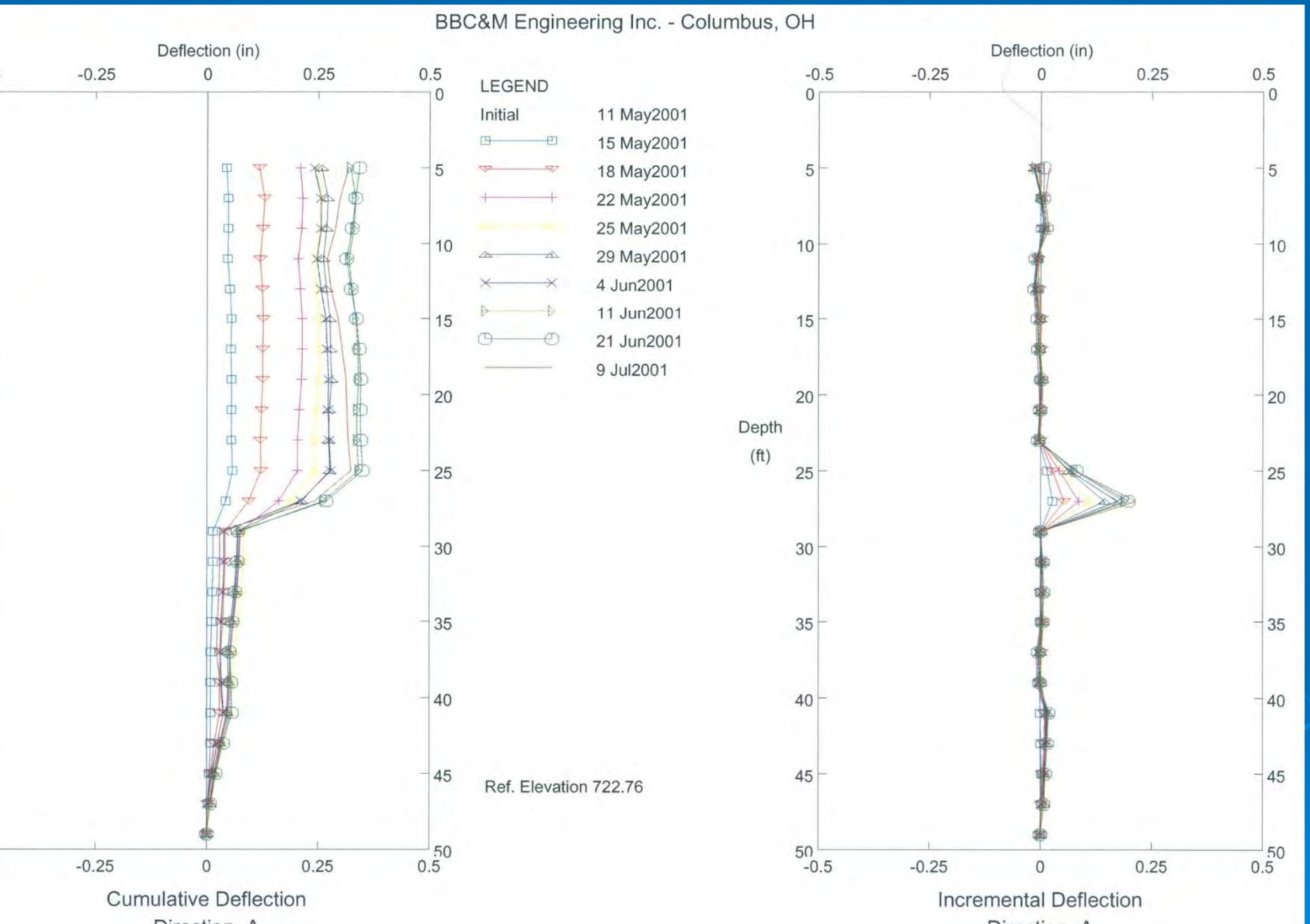
HAM-275-7.02

HAM-275-7.02

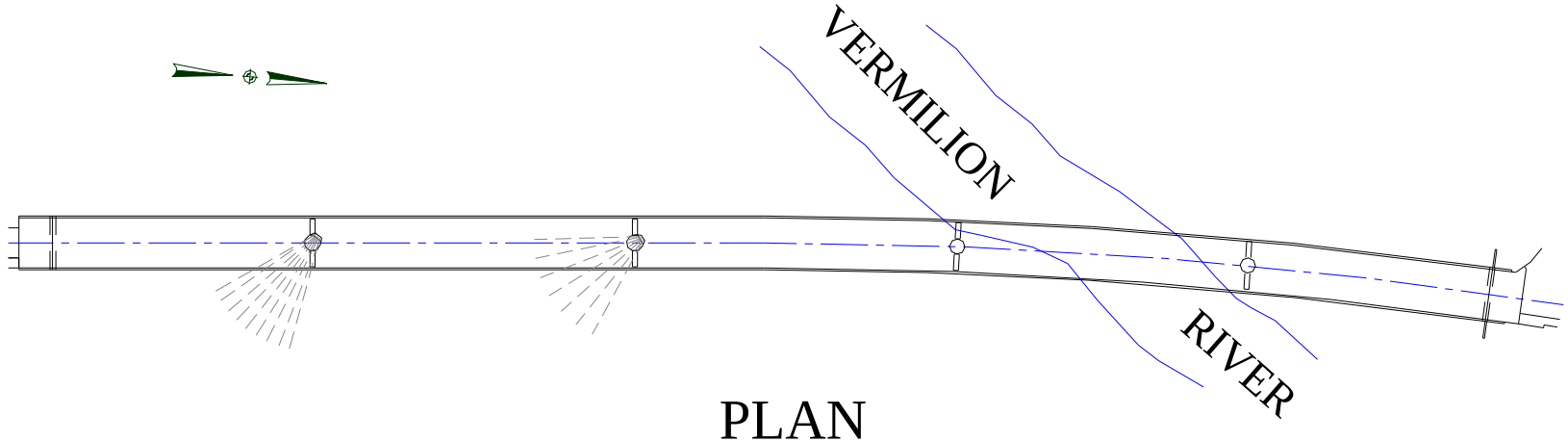



ERI-60-0227 over Vermillion River

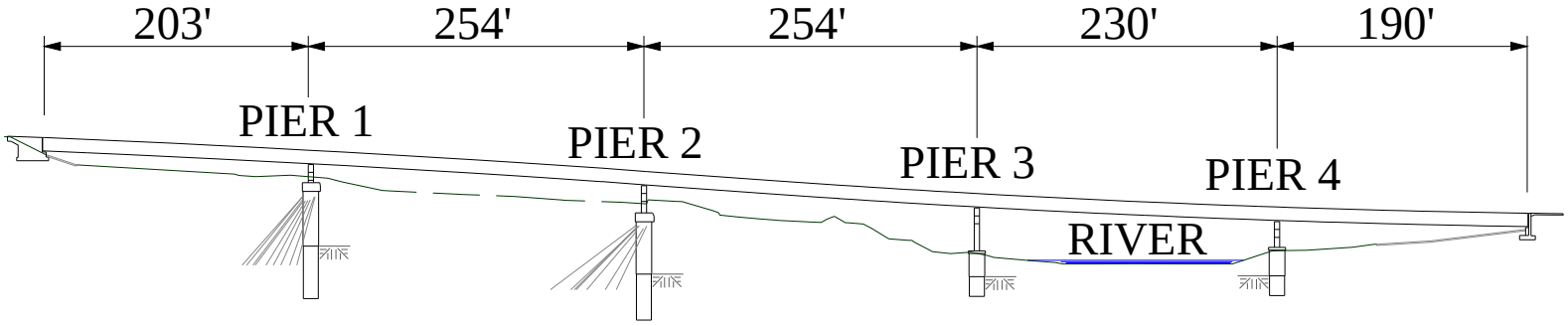
ERI-60-0227 over Vermillion River



ERI-60-0227 over Vermillion River



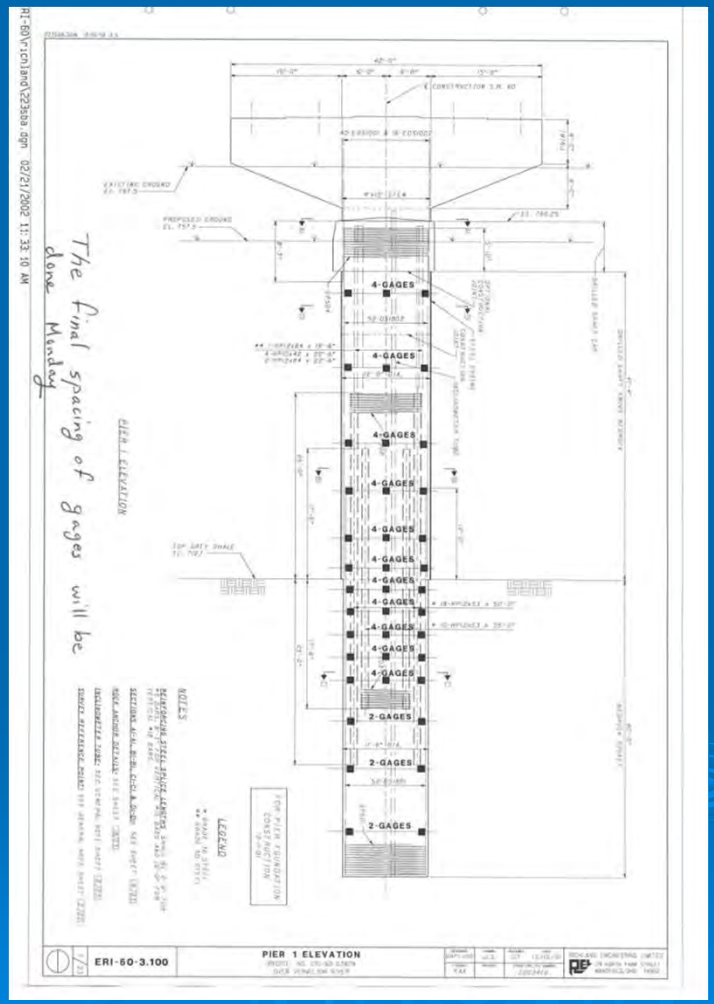
PLAN



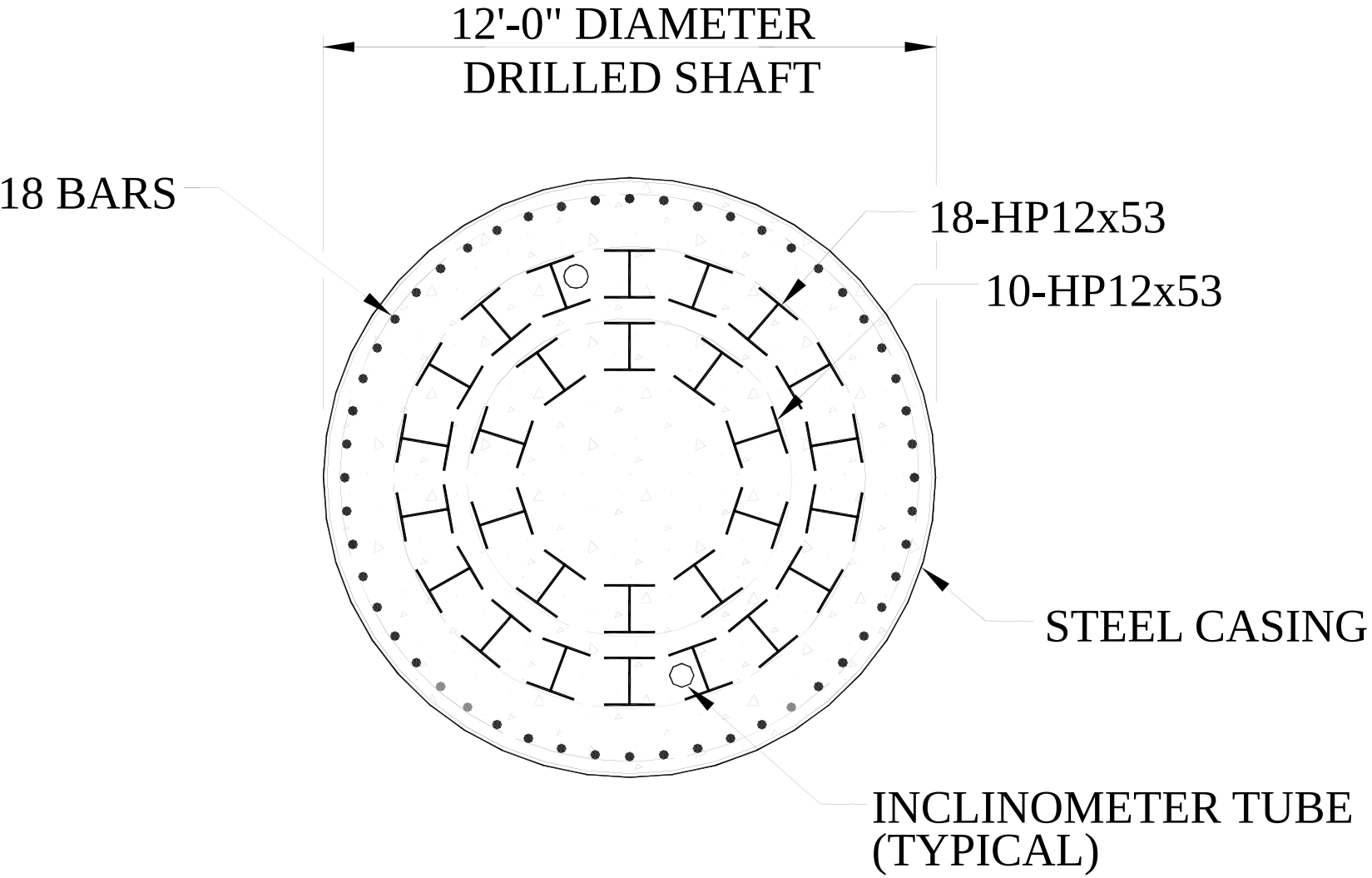
ELEVATION

60 Over
milion River

ERI-60-0227 over Vermillion River



ERI-60-0227 over Vermillion River

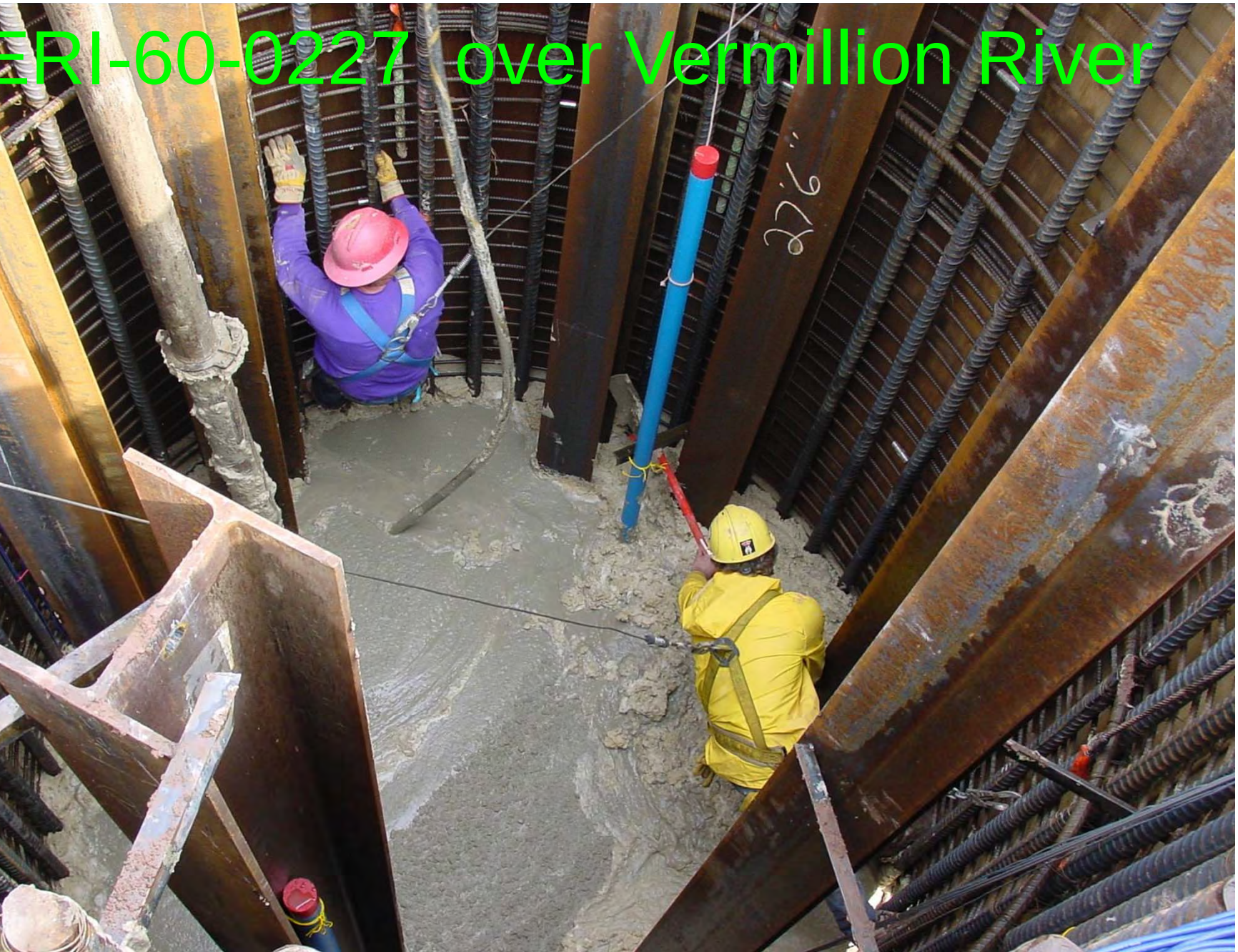


Section Through Drilled

ERI-60-0227 over Vermillion River

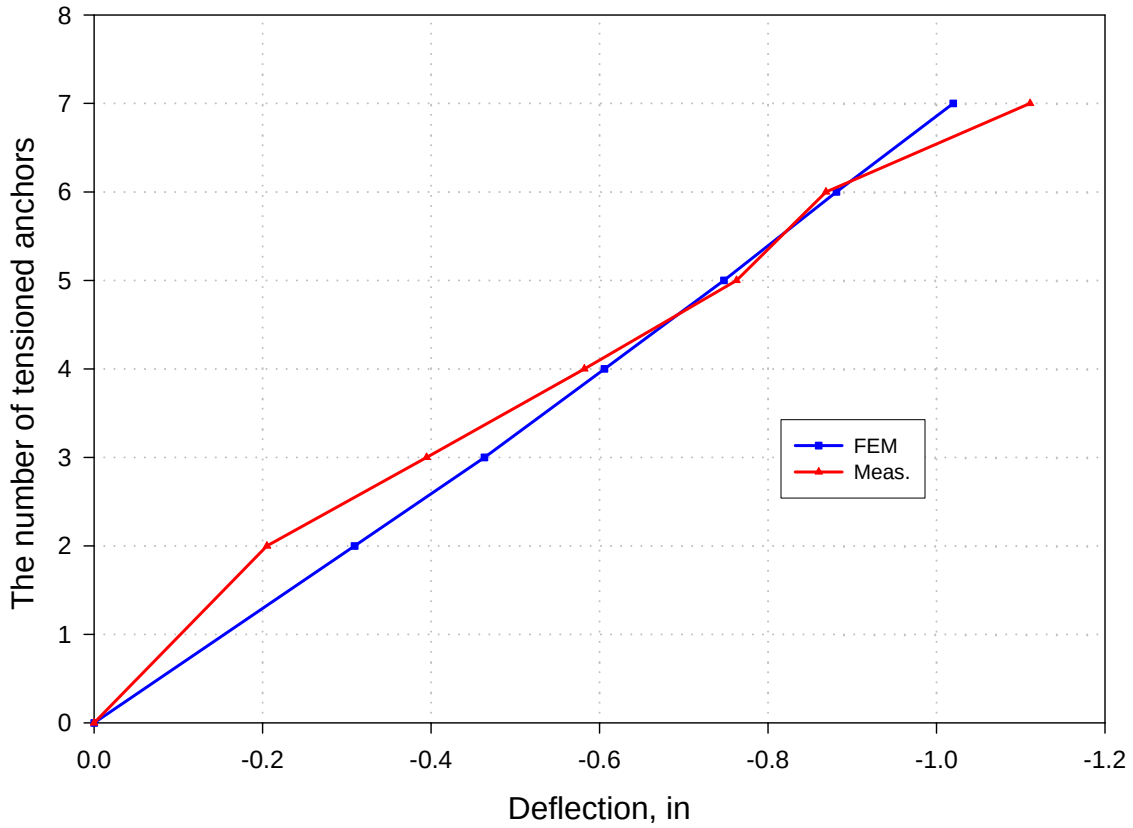

ERI-60-0227 over Vermillion River

ERI-60-0227 over Vermillion River


ERI-60-0227 over Vermillion River

ERI-60-0227 over Vermillion River

ERI-60-0227 over Vermillion River



The deflection at the top of drilled shaft pier #2

ERI-60-0227 over Vermillion River

ERI-60-0227 over Vermillion River


ERI-60-0227 over Vermillion River

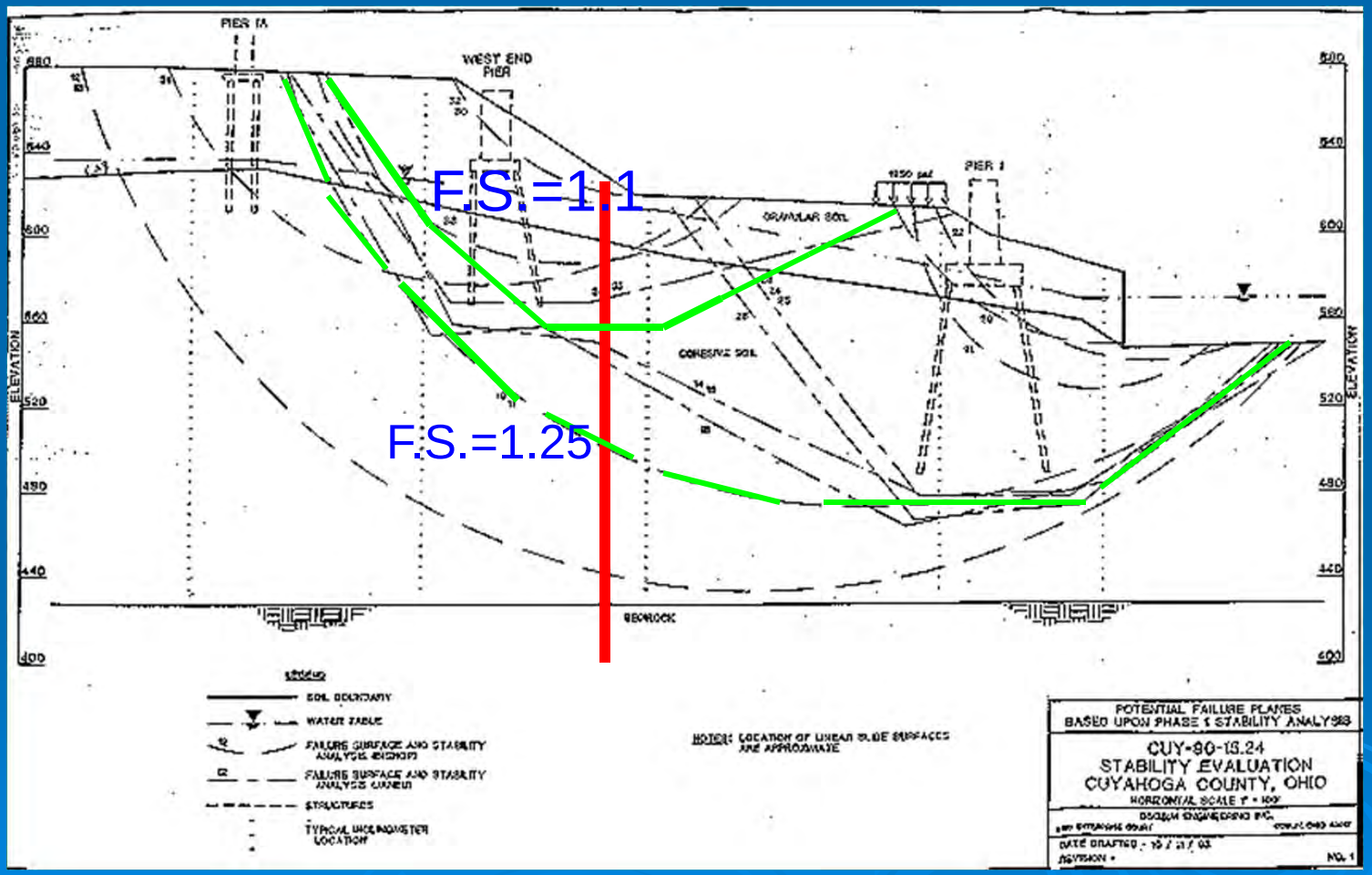
CUY-90-15.24


Road
Aerial
Crown Ave
W 14th St
University Rd
171
90
2
90
University Rd

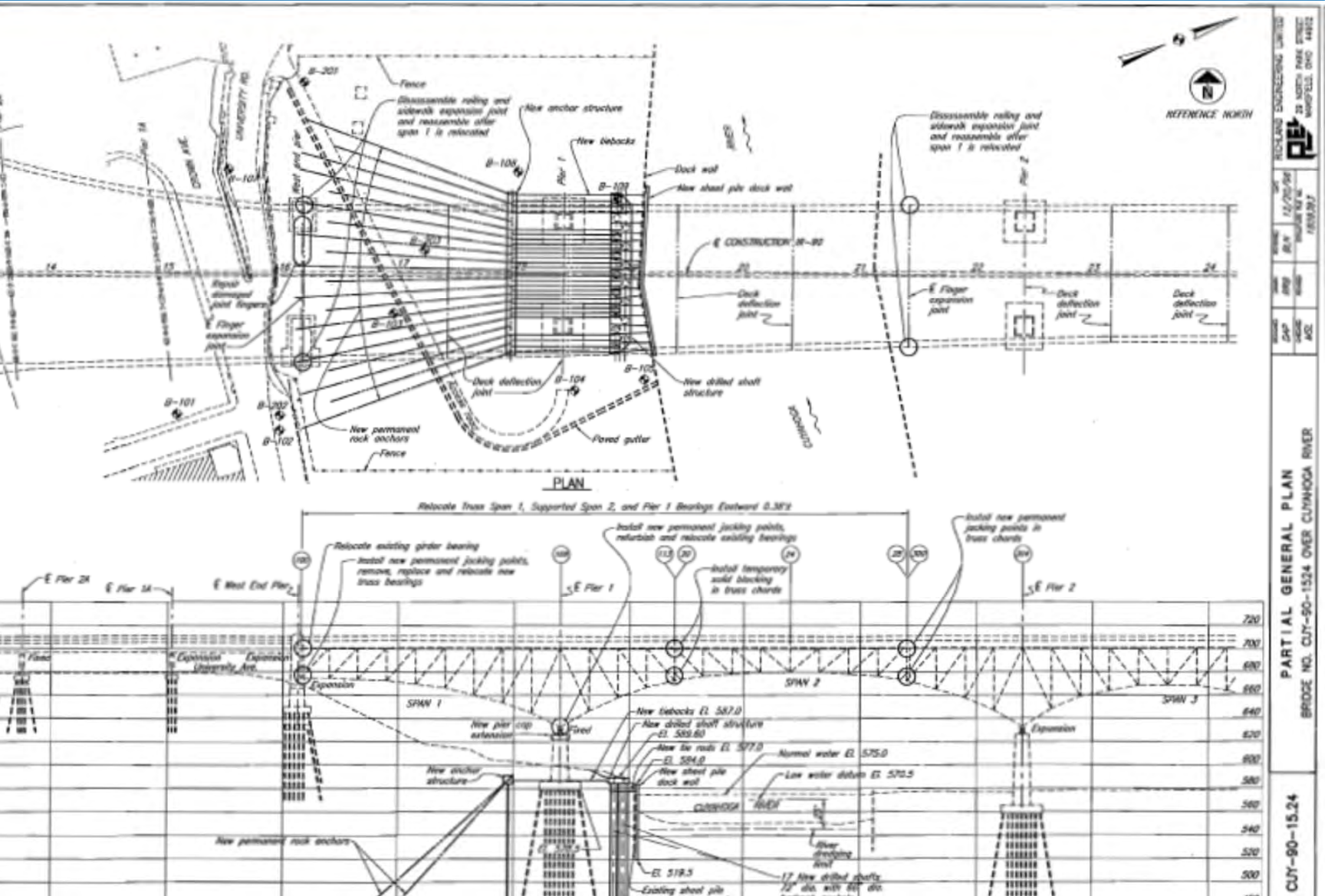
CUY-90-15.24

Site Condition Prior to Construction

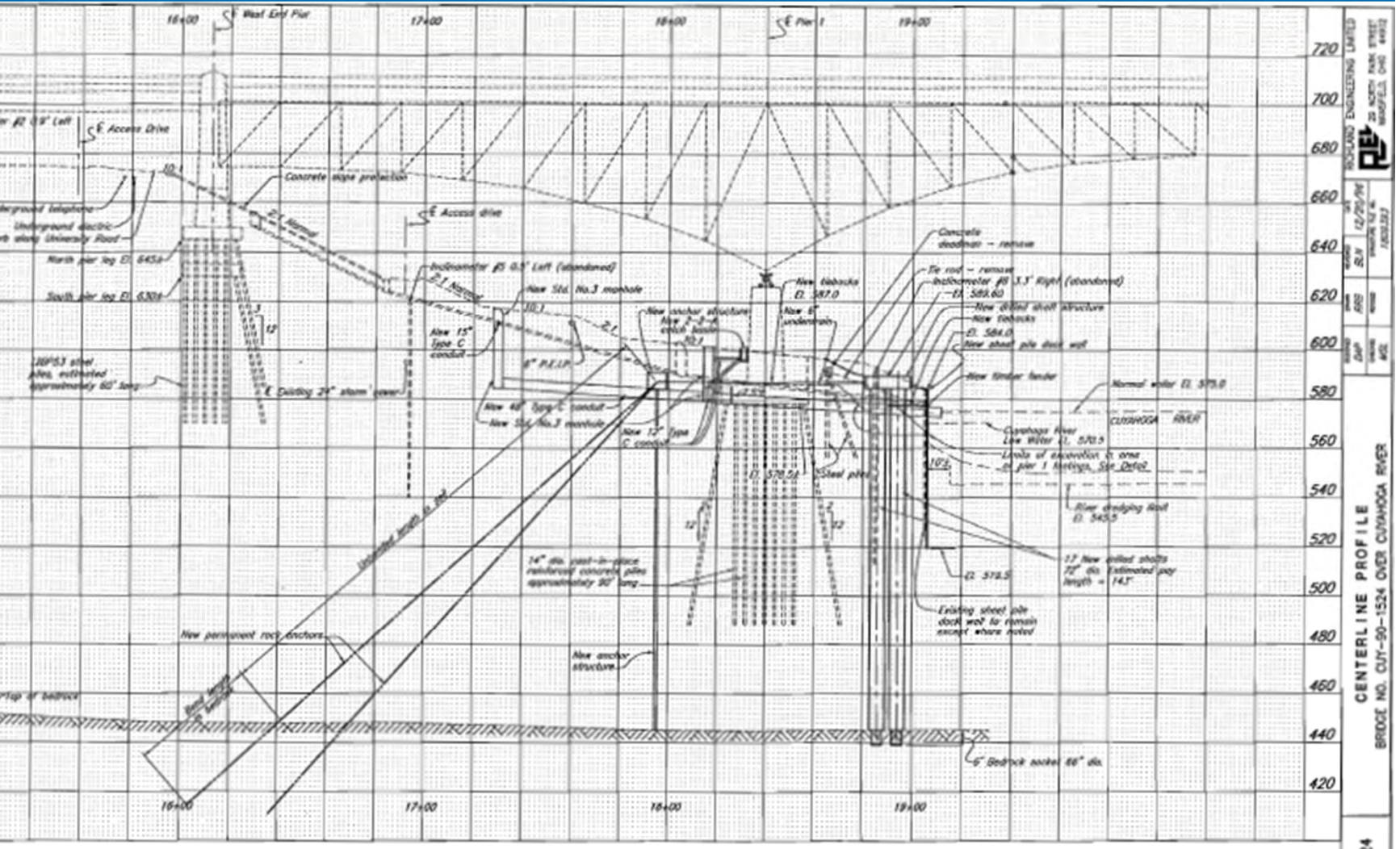
CUY-90-15.24


PIER 1A
WEST END PIER
PIER 1
F.S.=1.1
F.S.=1.25
GRANULAR SOIL
COHESIVE SOIL
BEDROCK
ELEVATION
SOIL BOUNDARY
WATER TABLE
STRUCTURES
POTENTIAL FAILURE PLANES
BASED UPON PHASE 1 STABILITY ANALYSES
CUY-90-15.24
STABILITY EVALUATION
CUYAHOGA COUNTY, OHIO

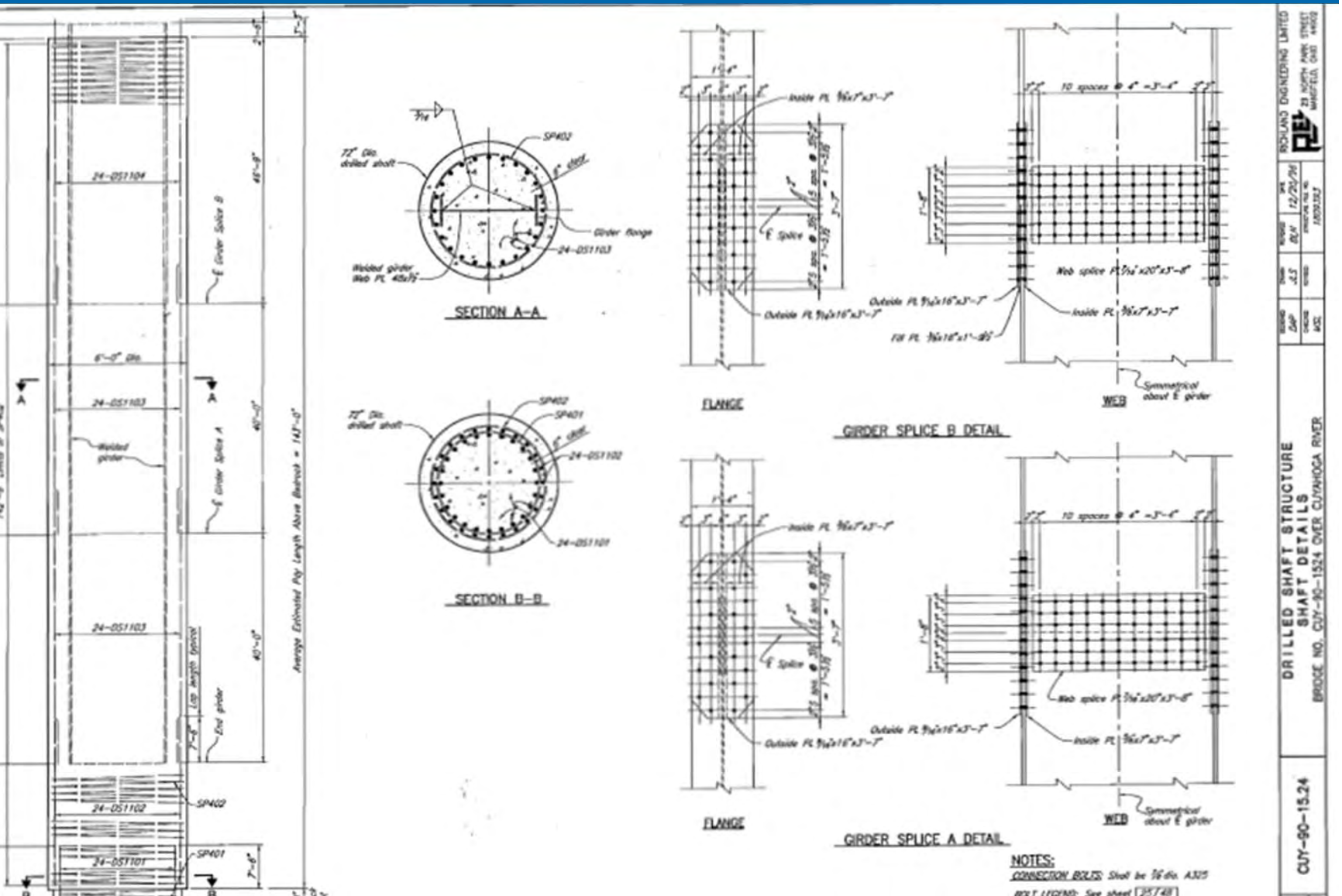
CUY-90-15.24


PLAN
REFERENCE NORTH
PARTIAL GENERAL PLAN
BRIDGE NO. CUY-90-1524 OVER CUYAHOGA RIVER
CUY-90-15.24
RICHLAND ENGINEERING LIMITED
SPAN 1
SPAN 2
SPAN 3
CUYAHOGA RIVER
Fence
Dismantle railing and sidewalk expansion joint and reassemble after span 1 is relocated
New anchor structure
New tiebacks
Dock wall
New sheet pile dock wall
New drilled shaft structure
Deck deflection joint
Finger expansion joint
New permanent rock anchors
Paved gutter
Relocate Truss Span 1, Supported Span 2, and Pier 1 Bearings Eastward 0.38'±
Relocate existing girder bearing
Install new permanent jacking points, remove, replace and relocate new truss bearings
Install new permanent jacking points, refurbish and relocate existing bearings
Install temporary solid blocking in truss chords
Install new permanent jacking points in truss chords
New pier cap extension
New anchor structure
New permanent rock anchors
Normal water El. 575.0
Low water datum El. 570.5
River dredging limit
El. 519.5
Existing sheet pile
17 New drilled shafts 72" dia. with 60" dia.

CUY-90-15.24


CENTERLINE PROFILE
BRIDGE NO. CUY-90-1524 OVER CUYAHOGA RIVER
CUY-90-15.24
CUYAHOGA RIVER
Concrete slope protection
New 15" Type C conduit
New 48" Type C conduit
New 12" Type C conduit
New permanent rock anchors
New anchor structure
14" dia. cast-in-place reinforced concrete piles approximately 90' long
17 New drilled shafts 72" dia. Estimated pay length = 14.5'
Existing sheet pile dock wall to remain except where noted
6' Bedrock socket 66" dia.
Steel piles
Concrete deadman - remove
Tie rod - remove
New drilled shaft structure
New timber fender
Normal water El. 575.0
Cuyahoga River Low Water El. 570.5
River dredging limit El. 545.5
Existing 24" storm sewer
New Std. No.3 manhole
Anchor structure
Total 6,600,000 pounds
Permanent rock anchors
Tiebacks
Drilled shaft structure (no vertical load)
Total 9,344,000 pounds at 45° angle
NOTES
LIMITS OF EXCAVATION: See Section C-C on sheet 27/48
VERIFICATION OF PIER TOP OF FOOTING:

CUY-90-15.24


SECTION A–A
SECTION B–B
FLANGE
WEB
GIRDER SPLICE B DETAIL
GIRDER SPLICE A DETAIL
NOTES:
DRILLED SHAFT STRUCTURE
SHAFT DETAILS
BRIDGE NO. CUY-90-1524 OVER CUYAHOGA RIVER
CUY-90-15.24
ROBLAND ENGINEERING LIMITED

Summary and Conclusions

- ✓ The use of drilled shafts to stabilize slopes demonstrated to be an effective method
- ✓The design process is an optimization of the drilled shaft size, spacing, location along the slip plane, and length
- ✓ The factor of safety was enhanced in all the cases
- ✓The calculated shaft deflection is always more than the field measured deflection

Thank You

QUESTIONS?