***Memorandum***

To: Mark Hirota, PB

From: John Horne, Evan Garich

Date: May 31, 2011

Subject: Final Geotechnical Foundation Recommendations, TS&L Phase
SR-35, Columbia River Crossing Project

This memorandum has been developed to provide preliminary geotechnical recommendations to facilitate the TS&L bridge design efforts for the SR-35 Columbia River Crossing Project. This document supersedes the memorandum "Preliminary Geotechnical Foundation Recommendations" dated December 12, 2010 and February 25, 2011, and incorporates comments received by project team members.

A TS&L geologic profile at the proposed bridge alignment has been developed using historic construction documents, and project specific investigations which included two surveys and three geotechnical borings. The surveys include a bathymetric survey performed on July 14, 2010 and a geophysical survey performed on October 20, 2010. Barge mounted geotechnical drilling occurred from December 20 to 23, 2010.

The investigations were performed in order to develop a better understanding of the elevation of bedrock and thickness of alluvium along the alignment. The historic construction records and geophysical survey are in general agreement at the northerly and southerly margins of the project. However, there is divergence of the data sets from Sta. 33+00 to 51+00. The depth to bedrock is deeper than represented in historic construction records at geotechnical borings B-1 and B-2, however there is good agreement at B-3. The geophysical survey did not produce meaningful results from Sta. 33+00 to 51+00 due to the thickness of the alluvial package over bedrock and the limitations in the ability of the equipment to penetrate 100+ feet of sediment. The TS&L geologic profile is included as Attachment A. Although the bedrock elevation has been determined at the three boring locations and to a high degree of confidence at the southerly and northerly portions of the river crossing, significant uncertainty remains in between the boring locations from Sta. 33+00 to 50+00 and at the south abutment where bedrock may increase in depth again.

Preliminary foundation recommendations have been developed for driven piles and drilled shafts. Driven piles were analyzed for stratigraphies developed at B-1 and B-2, while drilled shafts were analyzed at B-3. It is presumed that driven piles would be more economical at locations of deep bedrock (±50 feet of sediment) while drilled shafts would be more economical in locations of shallow bedrock. Three sizes of open-ended pipe pile were analyzed: 24x0.5, 36x0.5 and 48x0.5. It was assumed all piles would be driven into bedrock and ultimate capacity would be limited by the structural capacity of the piles. In the field, it may not be possible to drive the piles to bedrock, however very high axial capacities will be achievable even if the piles are not tipped in bedrock.

Driven pile tip elevations should be a minimum of 20 feet below the maximum predicted liquefaction depth of 60 feet. Driven pile capacities at B-1 and B-2 are presented in Attachment B.

It is presumed drilled shafts would be socketed into bedrock and behave primarily as end bearing shafts. Shaft sizes of 6, 8, and 10 ft. in diameter were analyzed. Shafts should be socketed at least two diameters into rock. Axial capacity derived from the bedrock will be highly dependent on the overall strength/hardness, jointing characteristics, and degree of weathering at each shaft location. The bedrock at the project location is basalt of the Grande Ronde Formation. Basalt samples obtained from drilling ranged from weathered to fresh, with unconfined compressive strengths ranging from 1,500 to 22,000 psi. Low end strengths were used in the drilled shaft capacity calculations at B-3. Drilled shaft capacities at B-3 are presented in Attachment C.

Soil and rock parameters have been developed for lateral loading and deformation analysis. The recommended parameters are presented in Tables 1 and 2. The lateral parameters for rock were developed based on Unconfined Compressive Strength tests using Mohr-Coulomb failure criteria and accounting for potential jointing in the rock and the stresses acting on the rock.

**Table 1.** Lateral Analysis Parameters at B-1 and B-2

| Unit | 1 | | 2 | | 3 | 4 |
|---|---|---|---|---|---|---|
| Description | Loose Alluvial Sand | | Med-Dense Alluvial Sand | | Dense Alluvial Gravel | Basalt |
| B-1 Thickness | 40 ft | | 54 ft | | 26 ft | -- |
| B-2 Thickness | 68 ft | | 22 ft | | 13 ft | -- |
| Condition | Static | Liquefied | Static | Liquefied | Static/ Liquefied | Static/ Liquefied |
| Soil Type for LPILE Analysis | “Sand” | “Sand” | “Sand” | “Sand” | “Sand” | “Silt” (c-φ material) |
| Effective Unit Weight (pcf) | 38 | 38 | 53 | 53 | 68 | 83 |
| Φ (degrees) | 28 | 8 | 32 | 8 | 35 | 35 |
| Cohesion (psf) | 0 | 0 | 0 | 0 | 0 | 144,000 |
| Lateral p-y parameter “k” (pci)[1] | 20 | 4 | 60 | 4 | 125 | 4000 |
| Strain at 50% Maximum Stress | 0 | 0 | 0 | 0 | 0 | 0.005 |

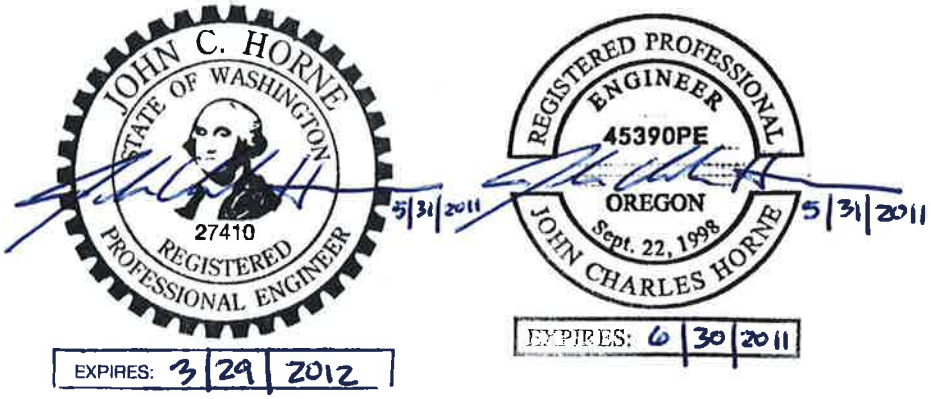
**Table 2.** Lateral Analysis Parameters at B-3

| Unit | 1 | | 2 | | 3 | 4 |
|---|---|---|---|---|---|---|
| Description | Soft Alluvial Silt | | Loose Alluvial Sand | | Weathered Basalt | Basalt |
| B-3 Thickness | 27 ft | | 3 ft | | 15 ft | -- |
| Condition | Static | Liquefied | Static | Liquefied | Static/ Liquefied | Static/ Liquefied |
| Soil Type for LPILE Analysis | "Clay" | "Sand" | "Sand" | "Sand" | "Sand" | "Silt" (c-φ material) |
| Effective Unit Weight (pcf) | 33 | 33 | 53 | 53 | 73 | 83 |
| Φ (degrees) | 0 | 8 | 28 | 8 | 40 | 35 |
| Cohesion (psf) | 100 | 0 | 0 | 0 | 0 | 13,000 |
| Lateral p-y parameter "k" (pci) | 20 | 4 | 20 | 4 | 125 | 4000 |
| Strain at 50% Maximum Stress | 0.02 | 0 | 0 | 0 | 0 | 0.002 |

Seismic design parameters have been developed following AASHTO LRFD Bridge Design Specifications, 5th Ed. Currently, ODOT specifies performance requirements for two ground motion events having recurrence intervals of approximately 500-years and 1,000-years based on USGS 2002 PSHA, while WSDOT has performance requirements for one event, the 1,000-year recurrence based on USGS 2008 PSHA. The USGS 2008 ground motions were found to be approximately 5 percent larger than those found using the 2002 data set. For this study, WSDOT seismic criteria were considered to control. Ground motions based on the USGS 2008 data at the rock/alluvium interface have been characterized and are presented in Attachment D.

The site is located within an area of moderate seismicity. No known active faults lie within 6 miles of the project site. A simplified liquefaction assessment of the soil columns at B-1, B-2, and B-3 is presented in Attachment D. The loose alluvium in the upper 60 feet at borings B-1 and B-2 is potentially liquefiable. The elastic silt present in boring B-3 would not be expected to liquefy, however, it may exhibit sensitive behavior which will result in strength loss during a seismic event. Although not directly analyzed, the south approach should be considered susceptible to liquefaction-induced lateral spreading. Mitigation involving ground improvement should be considered to reduce the effects of liquefaction-induced lateral spreading. The limits and type of ground improvement should be developed during subsequent design phases of the project.

Report prepared by:

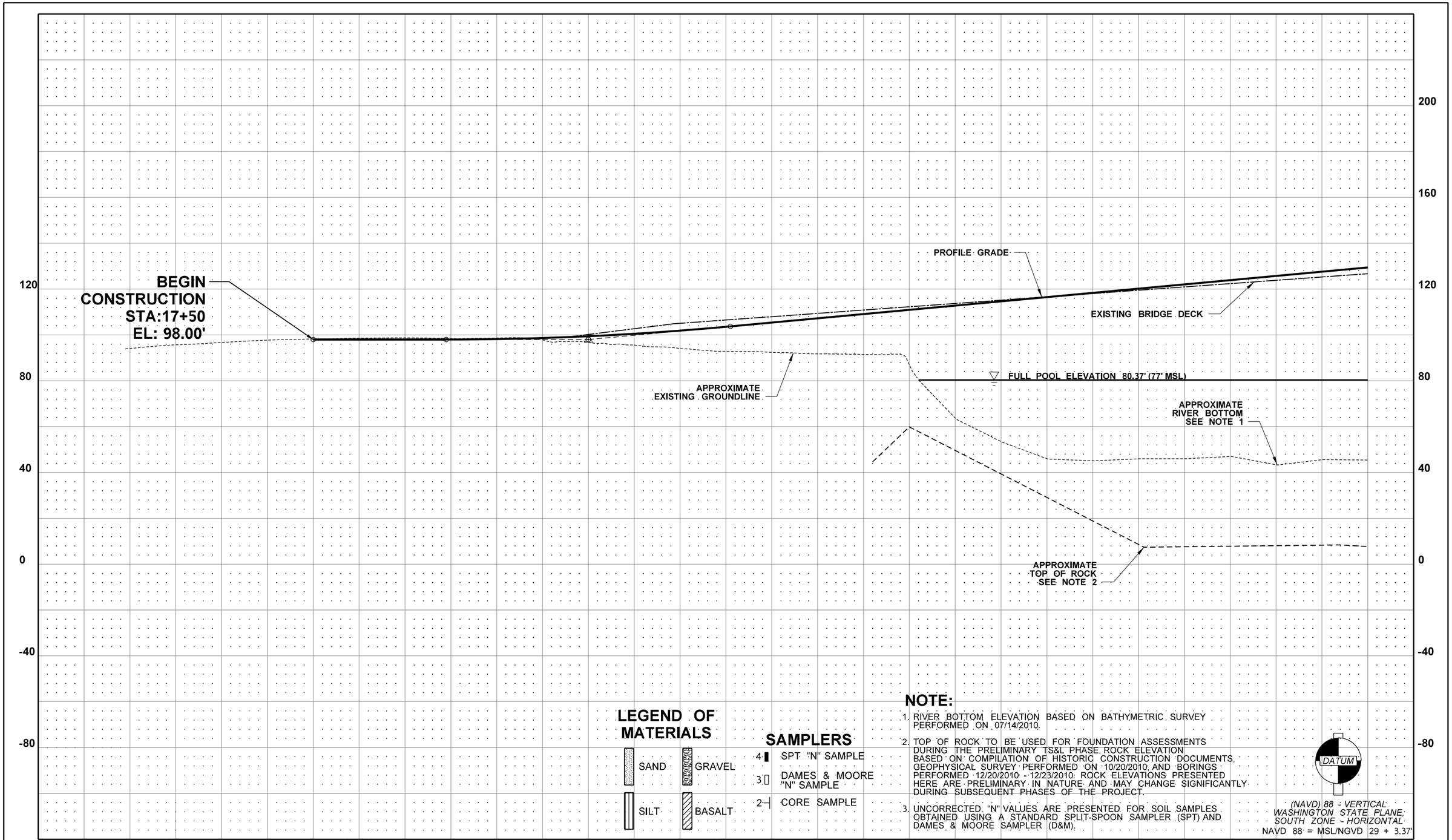



John Horne

Evan Garich

Attachments

Attachment A: TS&L Geologic Profile
Attachment B: Preliminary Driven Pile Capacities
Attachment C: Preliminary Drilled Shaft Capacities
Attachment D: Seismic Design Criteria




## LEGEND OF MATERIALS

SAND · GRAVEL · SILT · BASALT

## SAMPLERS

- 4 SPT "N" SAMPLE
- 3 DAMES & MOORE "N" SAMPLE
- 2 CORE SAMPLE

## NOTE:

1. RIVER BOTTOM ELEVATION BASED ON BATHYMETRIC SURVEY PERFORMED ON 07/14/2010.
2. TOP OF ROCK TO BE USED FOR FOUNDATION ASSESSMENTS DURING THE PRELIMINARY TS&L PHASE. ROCK ELEVATION BASED ON COMPILATION OF HISTORIC CONSTRUCTION DOCUMENTS, GEOPHYSICAL SURVEY PERFORMED ON 10/20/2010, AND BORINGS PERFORMED 12/20/2010 - 12/23/2010. ROCK ELEVATIONS PRESENTED HERE ARE PRELIMINARY IN NATURE AND MAY CHANGE SIGNIFICANTLY DURING SUBSEQUENT PHASES OF THE PROJECT.
3. UNCORRECTED "N" VALUES ARE PRESENTED FOR SOIL SAMPLES OBTAINED USING A STANDARD SPLIT-SPOON SAMPLER (SPT) AND DAMES & MOORE SAMPLER (D&M).

DATUM

(NAVD) 88 - VERTICAL
WASHINGTON STATE PLANE, SOUTH ZONE - HORIZONTAL
NAVD 88 = MSL/NGVD 29 + 3.37'

| | |
|---|---|
| FILE NAME | T:\80414S_SR35\CADD\SHEETS\GEO-PROFILE-Sheets.dgn |
| TIME | 2:22:48 PM |
| DATE | 2/23/2011 |
| PLOTTED BY | odonnella |
| DESIGNED BY | |
| ENTERED BY | |
| CHECKED BY | |
| PROJ. ENGR. | |
| REGIONAL ADM. | |

| REVISION | DATE | BY |
|---|---|---|
| | | |

| REGION NO. | STATE |
|---|---|
| 10 | WASH |

JOB NUMBER

CONTRACT NO.

FED.AID PROJ.NO.

LOCATION NO.

P.E. STAMP BOX — DATE

P.E. STAMP BOX — DATE

SR-35 Columbia River Crossing Study

PB PARSONS BRINCKERHOFF
400 S.W. Sixth Ave, Portland, OR 97204

# SR-35
# COLUMBIA RIVER CROSSING

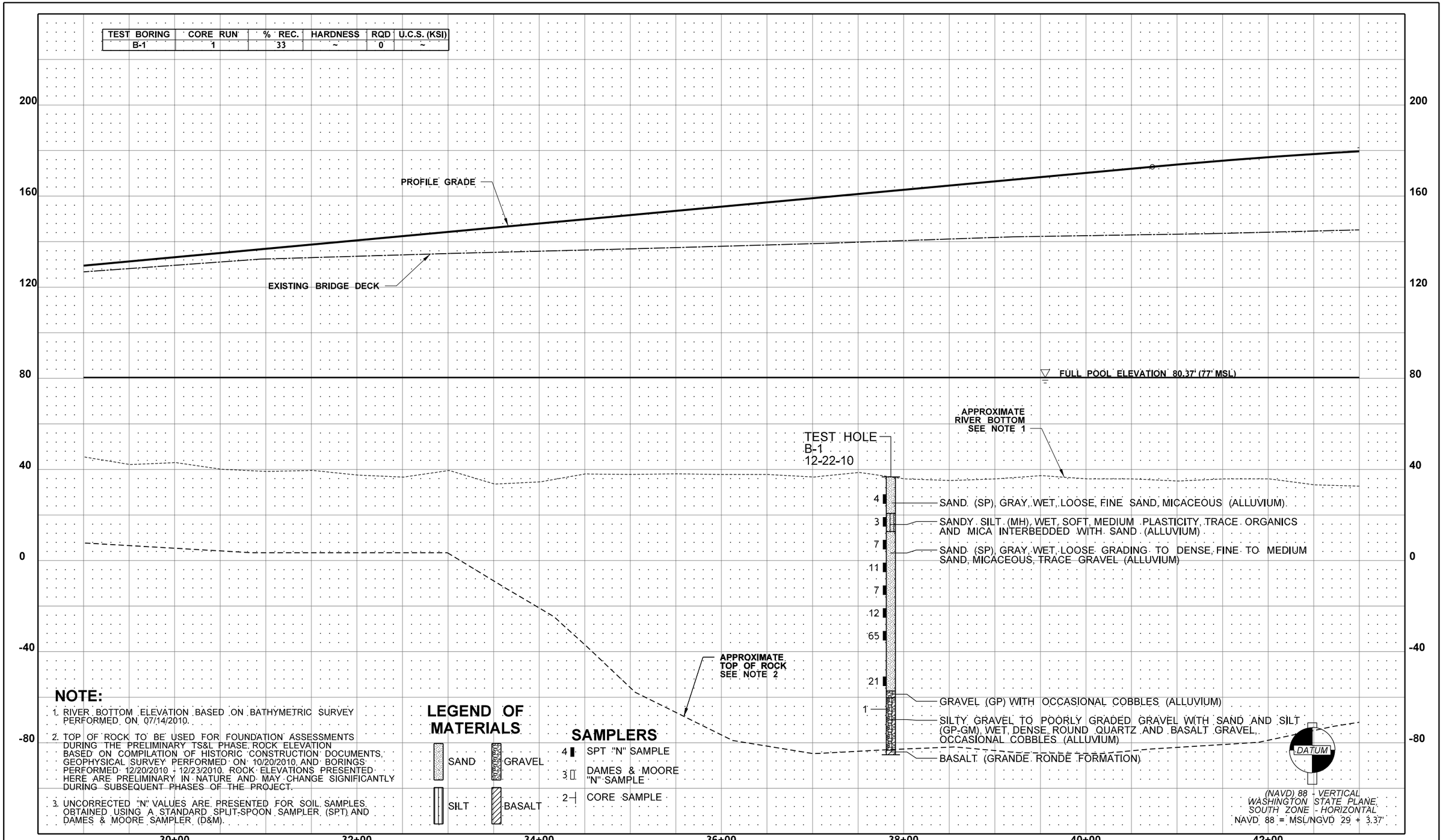
## PRELIMINARY GEOLOGIC PROFILE

Plot 1

PLAN REF NO

SHEET 1 OF 4 SHEETS

| TEST BORING | CORE RUN | % REC. | HARDNESS | RQD | U.C.S. (KSI) |
|---|---|---|---|---|---|
| B-1 | 1 | 33 | ~ | 0 | ~ |




## NOTE:

1. RIVER BOTTOM ELEVATION BASED ON BATHYMETRIC SURVEY PERFORMED ON 07/14/2010.
2. TOP OF ROCK TO BE USED FOR FOUNDATION ASSESSMENTS DURING THE PRELIMINARY TS&L PHASE. ROCK ELEVATION BASED ON COMPILATION OF HISTORIC CONSTRUCTION DOCUMENTS, GEOPHYSICAL SURVEY PERFORMED ON 10/20/2010, AND BORINGS PERFORMED 12/20/2010 - 12/23/2010. ROCK ELEVATIONS PRESENTED HERE ARE PRELIMINARY IN NATURE AND MAY CHANGE SIGNIFICANTLY DURING SUBSEQUENT PHASES OF THE PROJECT.
3. UNCORRECTED "N" VALUES ARE PRESENTED FOR SOIL SAMPLES OBTAINED USING A STANDARD SPLIT-SPOON SAMPLER (SPT) AND DAMES & MOORE SAMPLER (D&M).

## LEGEND OF MATERIALS

SAND, GRAVEL, SILT, BASALT

## SAMPLERS

4 SPT "N" SAMPLE
3 DAMES & MOORE "N" SAMPLE
2 CORE SAMPLE

| | |
|---|---|
| FILE NAME | T:\80414S_SR35\CADD\SHEETS\GEO-PROFILE-Sheets.dgn |
| TIME | 2:22:58 PM |
| DATE | 2/23/2011 |
| PLOTTED BY | odonnella |
| DESIGNED BY | |
| ENTERED BY | |
| CHECKED BY | |
| PROJ. ENGR. | |
| REGIONAL ADM. | |

| REVISION | DATE | BY |
|---|---|---|
| | | |

| REGION NO. | STATE |
|---|---|
| 10 | WASH |

JOB NUMBER

CONTRACT NO.

FED.AID PROJ.NO.

LOCATION NO.

P.E. STAMP BOX — DATE

P.E. STAMP BOX — DATE


PB PARSONS BRINCKERHOFF
400 S.W. Sixth Ave, Portland, OR 97204

# SR-35
# COLUMBIA RIVER CROSSING

## PRELIMINARY GEOLOGIC PROFILE

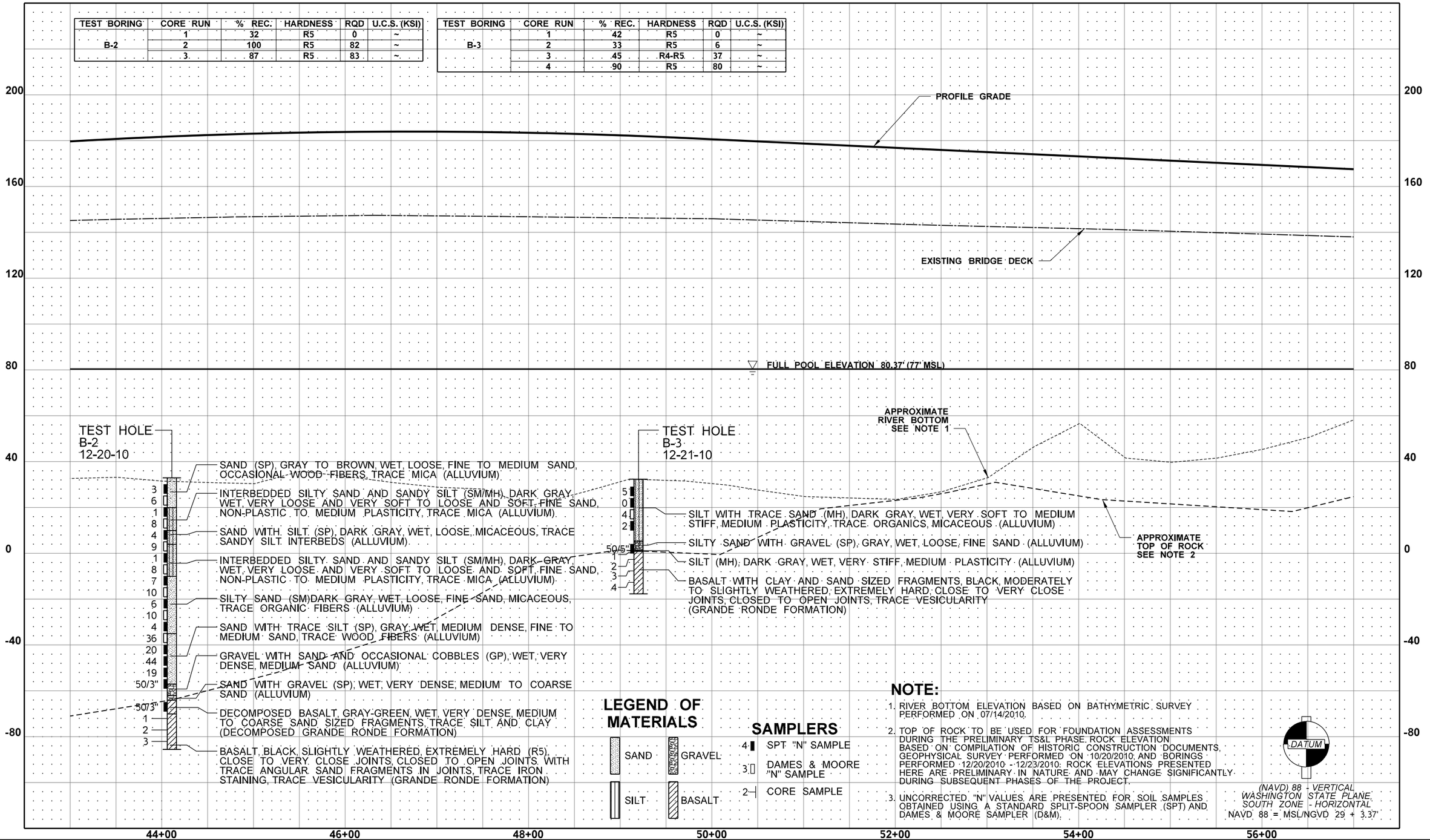
Plot 2

PLAN REF NO

SHEET 2 OF 4 SHEETS

| TEST BORING | CORE RUN | % REC. | HARDNESS | RQD | U.C.S. (KSI) |
|---|---|---|---|---|---|
| B-2 | 1 | 32 | R5 | 0 | ~ |
| | 2 | 100 | R5 | 82 | ~ |
| | 3 | 87 | R5 | 83 | ~ |

| TEST BORING | CORE RUN | % REC. | HARDNESS | RQD | U.C.S. (KSI) |
|---|---|---|---|---|---|
| B-3 | 1 | 42 | R5 | 0 | ~ |
| | 2 | 33 | R5 | 6 | ~ |
| | 3 | 45 | R4-R5 | 37 | ~ |
| | 4 | 90 | R5 | 80 | ~ |




## LEGEND OF MATERIALS

SAND · GRAVEL · SILT · BASALT

## SAMPLERS

4 SPT "N" SAMPLE

3 DAMES & MOORE "N" SAMPLE

2 CORE SAMPLE

## NOTE:

1. RIVER BOTTOM ELEVATION BASED ON BATHYMETRIC SURVEY PERFORMED ON 07/14/2010.
2. TOP OF ROCK TO BE USED FOR FOUNDATION ASSESSMENTS DURING THE PRELIMINARY TS&L PHASE. ROCK ELEVATION BASED ON COMPILATION OF HISTORIC CONSTRUCTION DOCUMENTS, GEOPHYSICAL SURVEY PERFORMED ON 10/20/2010, AND BORINGS PERFORMED 12/20/2010 - 12/23/2010. ROCK ELEVATIONS PRESENTED HERE ARE PRELIMINARY IN NATURE AND MAY CHANGE SIGNIFICANTLY DURING SUBSEQUENT PHASES OF THE PROJECT.
3. UNCORRECTED "N" VALUES ARE PRESENTED FOR SOIL SAMPLES OBTAINED USING A STANDARD SPLIT-SPOON SAMPLER (SPT) AND DAMES & MOORE SAMPLER (D&M).

DATUM

(NAVD) 88 - VERTICAL
WASHINGTON STATE PLANE, SOUTH ZONE - HORIZONTAL
NAVD 88 = MSL/NGVD 29 + 3.37'

| | |
|---|---|
| FILE NAME | T:\80414S_SR35\CADD\SHEETS\GEO-PROFILE-Sheets.dgn |
| TIME | 2:25:24 PM |
| DATE | 2/23/2011 |
| PLOTTED BY | odonnella |
| DESIGNED BY | |
| ENTERED BY | |
| CHECKED BY | |
| PROJ. ENGR. | |
| REGIONAL ADM. | |

| REVISION | DATE | BY |
|---|---|---|
| | | |

| REGION NO. | STATE | FED.AID PROJ.NO. |
|---|---|---|
| 10 | WASH | |
| JOB NUMBER | | |
| CONTRACT NO. | LOCATION NO. | |

P.E. STAMP BOX — DATE

P.E. STAMP BOX — DATE

SR-35 Columbia River Crossing Study

PB PARSONS BRINCKERHOFF
400 S.W. Sixth Ave, Portland, OR 97204

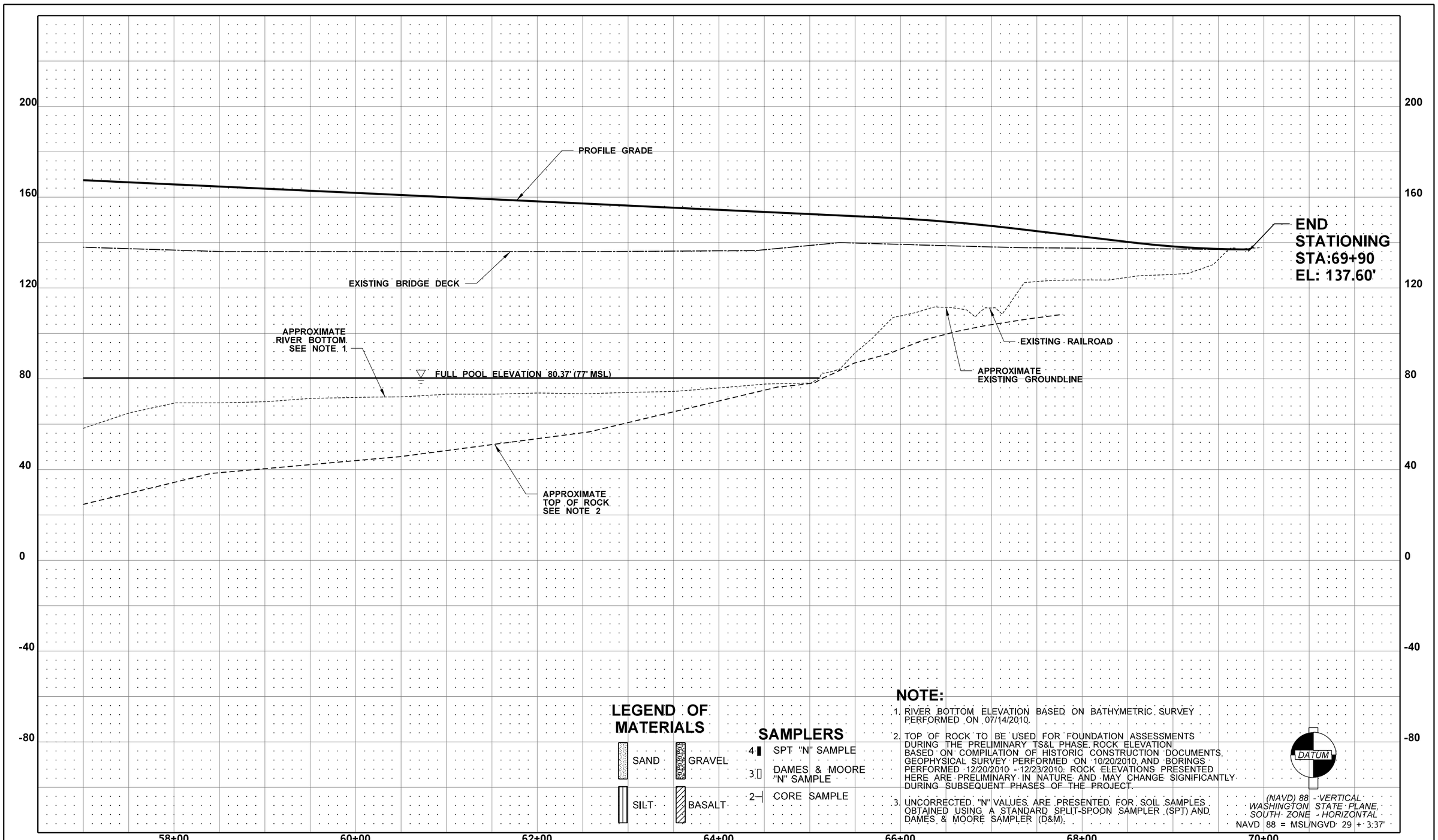
**SR-35**
**COLUMBIA RIVER CROSSING**

**PRELIMINARY GEOLOGIC PROFILE**

Plot 3

PLAN REF NO

SHEET 3 OF 4 SHEETS




## LEGEND OF MATERIALS

SAND · GRAVEL · SILT · BASALT

## SAMPLERS

4 SPT "N" SAMPLE

3 DAMES & MOORE "N" SAMPLE

2 CORE SAMPLE

## NOTE:

1. RIVER BOTTOM ELEVATION BASED ON BATHYMETRIC SURVEY PERFORMED ON 07/14/2010.
2. TOP OF ROCK TO BE USED FOR FOUNDATION ASSESSMENTS DURING THE PRELIMINARY TS&L PHASE. ROCK ELEVATION BASED ON COMPILATION OF HISTORIC CONSTRUCTION DOCUMENTS, GEOPHYSICAL SURVEY PERFORMED ON 10/20/2010, AND BORINGS PERFORMED 12/20/2010 - 12/23/2010. ROCK ELEVATIONS PRESENTED HERE ARE PRELIMINARY IN NATURE AND MAY CHANGE SIGNIFICANTLY DURING SUBSEQUENT PHASES OF THE PROJECT.
3. UNCORRECTED "N" VALUES ARE PRESENTED FOR SOIL SAMPLES OBTAINED USING A STANDARD SPLIT-SPOON SAMPLER (SPT) AND DAMES & MOORE SAMPLER (D&M).

DATUM

(NAVD) 88 - VERTICAL
WASHINGTON STATE PLANE, SOUTH ZONE - HORIZONTAL
NAVD 88 = MSL/NGVD 29 + 3.37'

| | |
|---|---|
| FILE NAME | T:\80414S_SR35\CADD\SHEETS\GEO-PROFILE-Sheets.dgn |
| TIME | 2:23:23 PM |
| DATE | 2/23/2011 |
| PLOTTED BY | odonnella |
| DESIGNED BY | |
| ENTERED BY | |
| CHECKED BY | |
| PROJ. ENGR. | |
| REGIONAL ADM. | |

| REVISION | DATE | BY |
|---|---|---|
| | | |

| REGION NO. | STATE |
|---|---|
| 10 | WASH |

JOB NUMBER

CONTRACT NO.

FED.AID PROJ.NO.

LOCATION NO.

P.E. STAMP BOX — DATE

P.E. STAMP BOX — DATE

SR-35 Columbia River Crossing Study

PB PARSONS BRINCKERHOFF
400 S.W. Sixth Ave, Portland, OR 97204

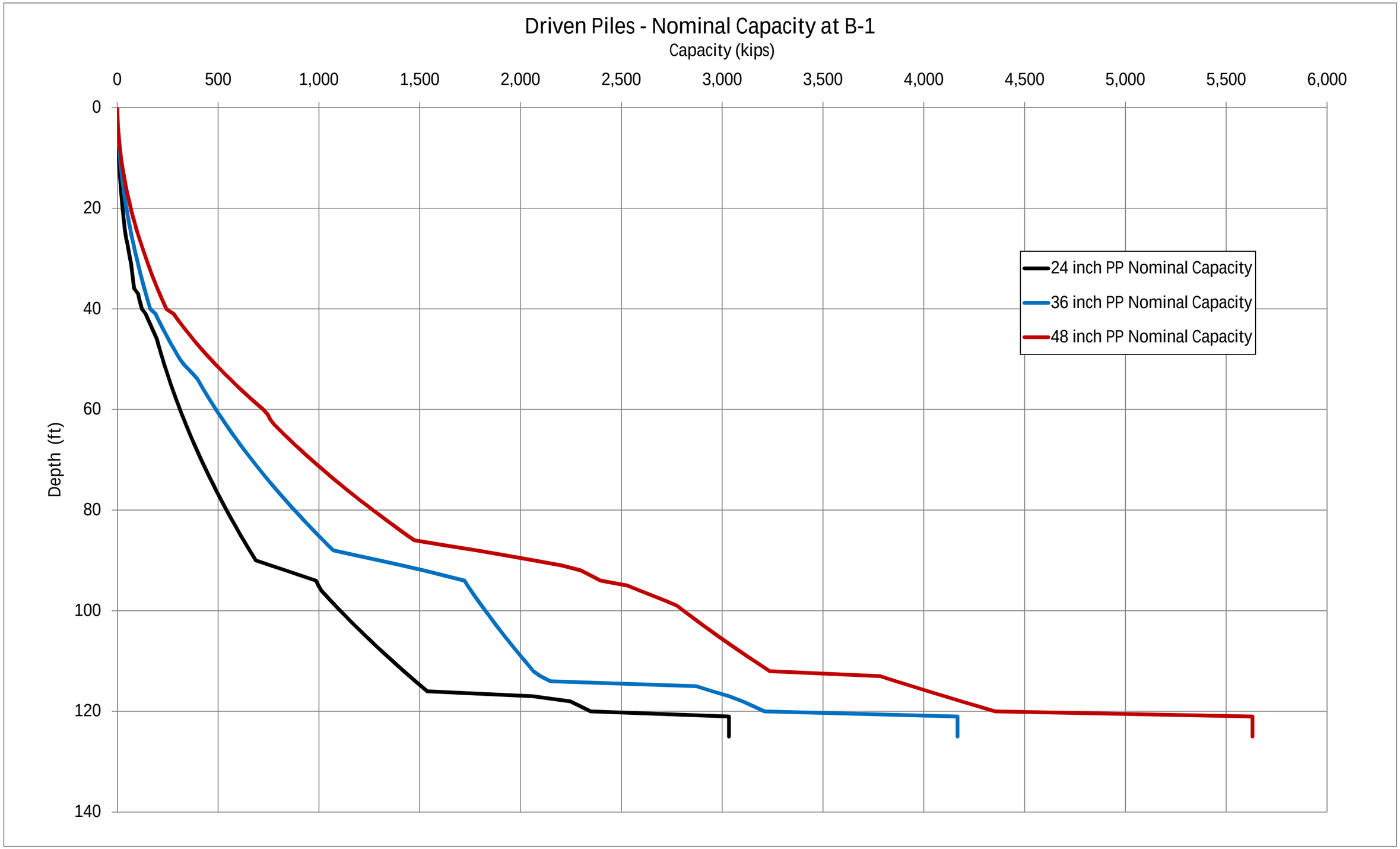
# SR-35
# COLUMBIA RIVER CROSSING

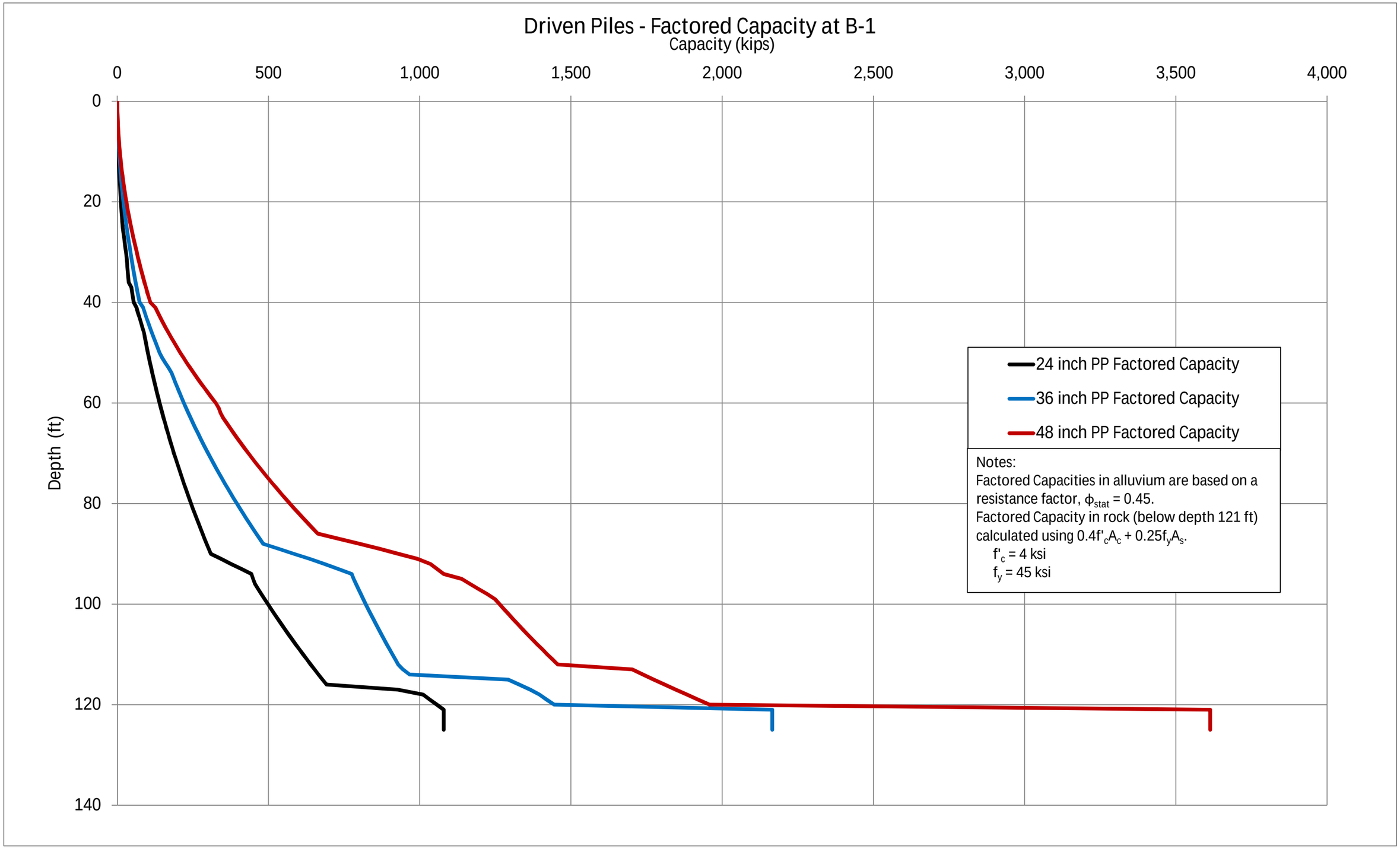
## PRELIMINARY GEOLOGIC PROFILE

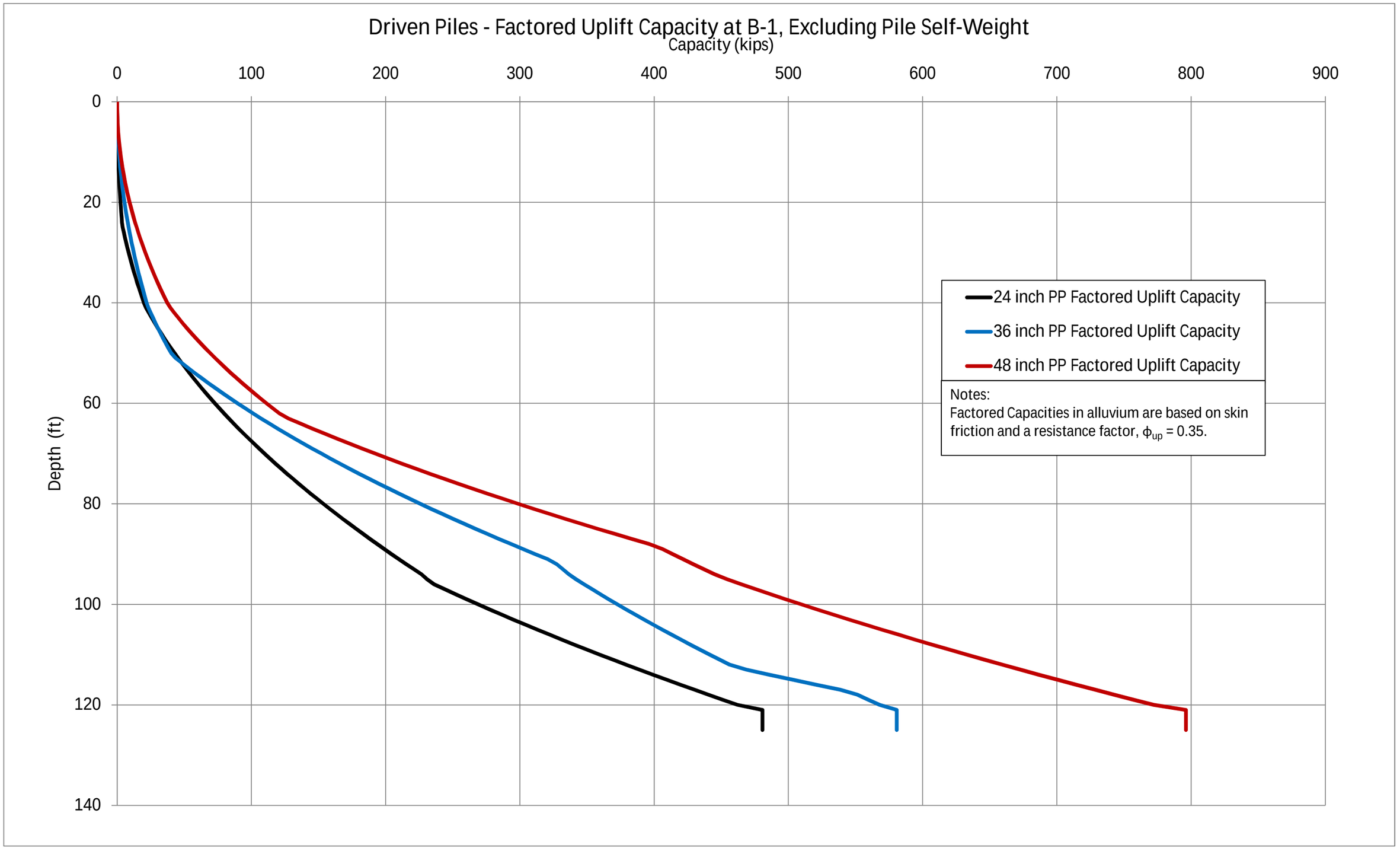
Plot 4

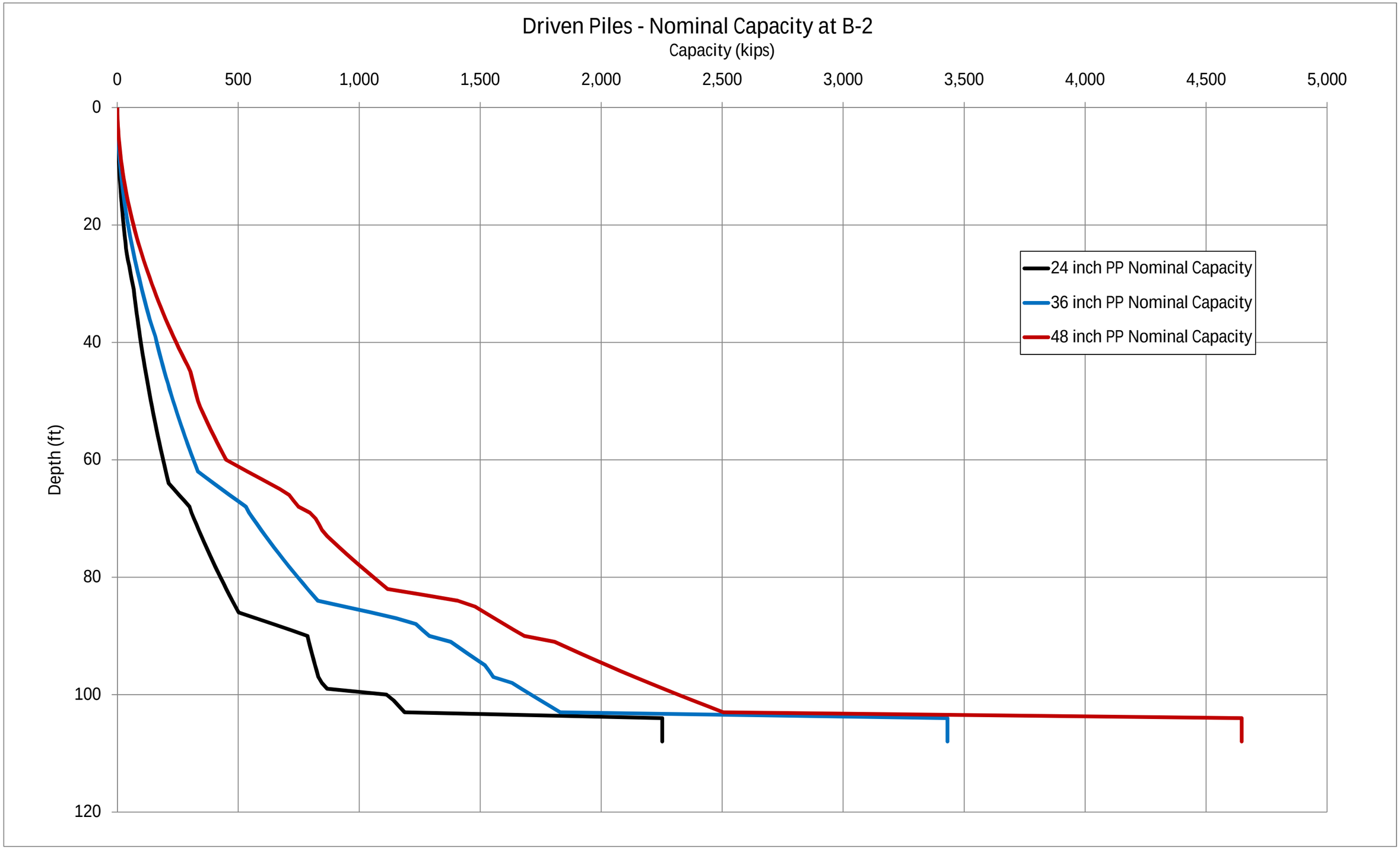
PLAN REF NO

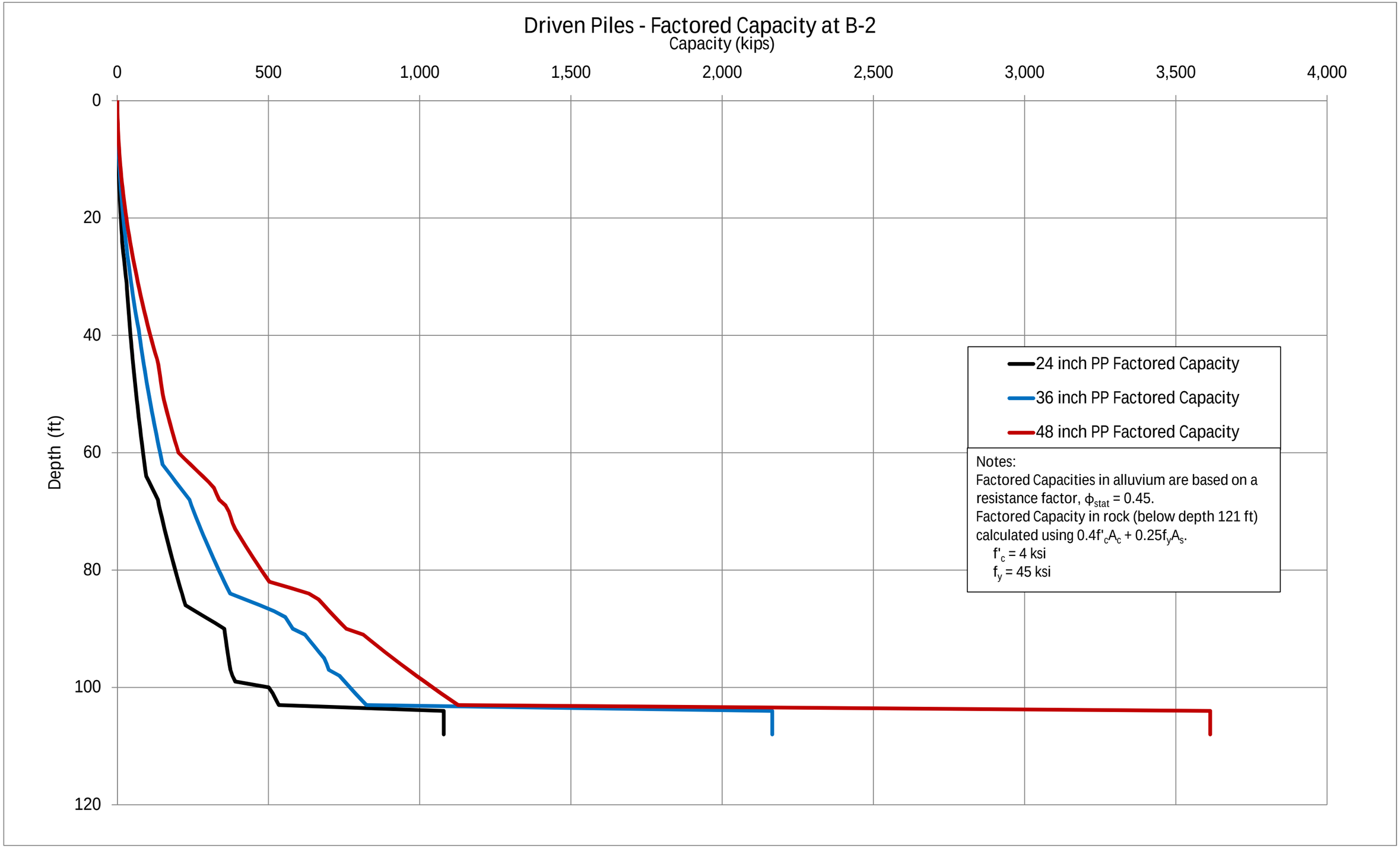
SHEET 4 OF 4 SHEETS


Driven Piles - Nominal Capacity at B-1
Capacity (kips)
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
4,500
5,000
5,500
6,000
Depth (ft)
0
20
40
60
80
100
120
140
24 inch PP Nominal Capacity
36 inch PP Nominal Capacity
48 inch PP Nominal Capacity

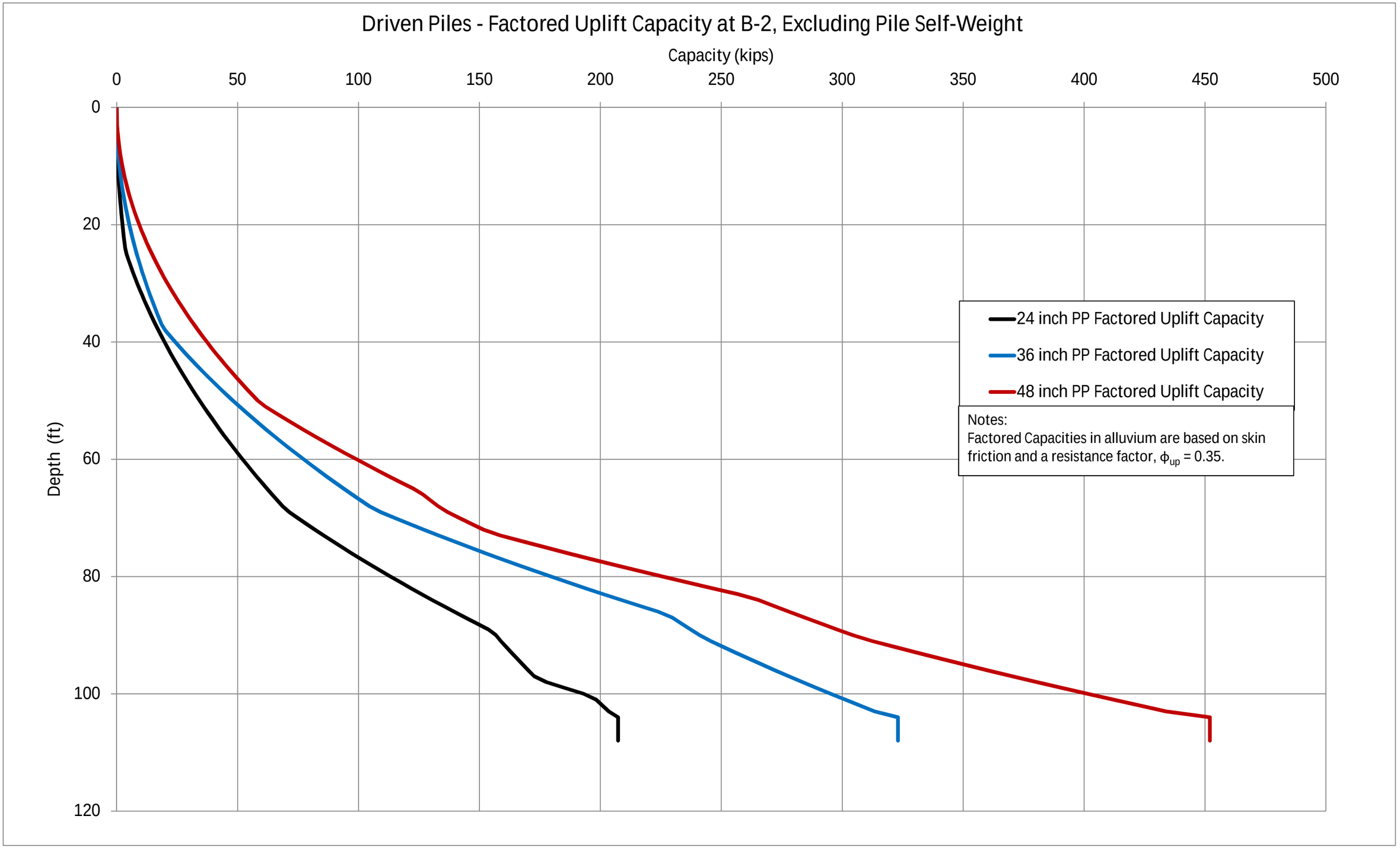

Driven Piles - Factored Capacity at B-1
Capacity (kips)
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
Depth (ft)
0
20
40
60
80
100
120
140
24 inch PP Factored Capacity
36 inch PP Factored Capacity
48 inch PP Factored Capacity
Notes:
Factored Capacities in alluvium are based on a resistance factor, $\phi_{stat}$ = 0.45.
Factored Capacity in rock (below depth 121 ft) calculated using $0.4f'_cA_c + 0.25f_yA_s$.
$f'_c$ = 4 ksi
$f_y$ = 45 ksi

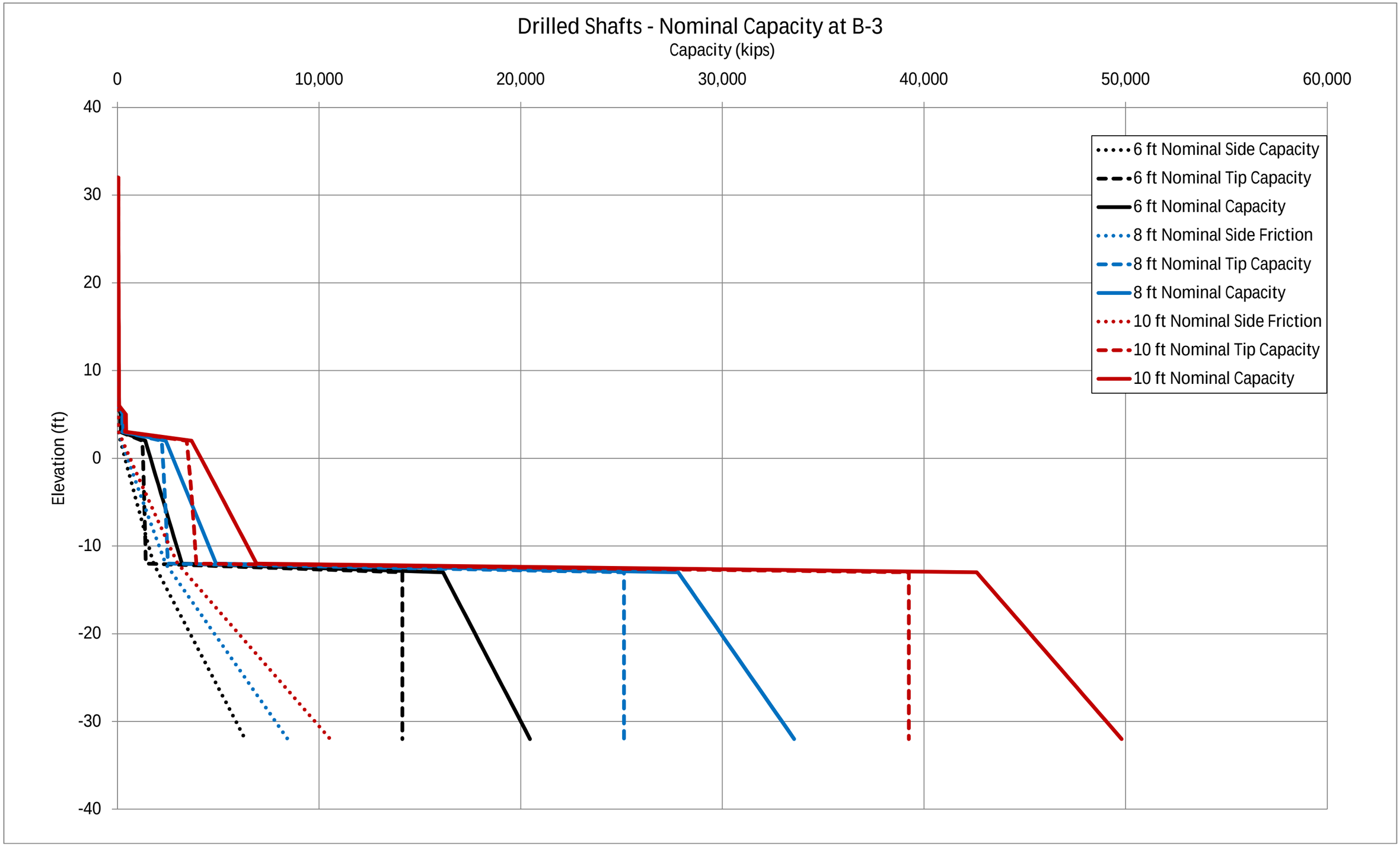

Driven Piles - Factored Uplift Capacity at B-1, Excluding Pile Self-Weight
Capacity (kips)
0
100
200
300
400
500
600
700
800
900
Depth (ft)
0
20
40
60
80
100
120
140
24 inch PP Factored Uplift Capacity
36 inch PP Factored Uplift Capacity
48 inch PP Factored Uplift Capacity
Notes:
Factored Capacities in alluvium are based on skin friction and a resistance factor, $\phi_{up}$ = 0.35.


Driven Piles - Nominal Capacity at B-2
Capacity (kips)
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
4,500
5,000
Depth (ft)
0
20
40
60
80
100
120
24 inch PP Nominal Capacity
36 inch PP Nominal Capacity
48 inch PP Nominal Capacity

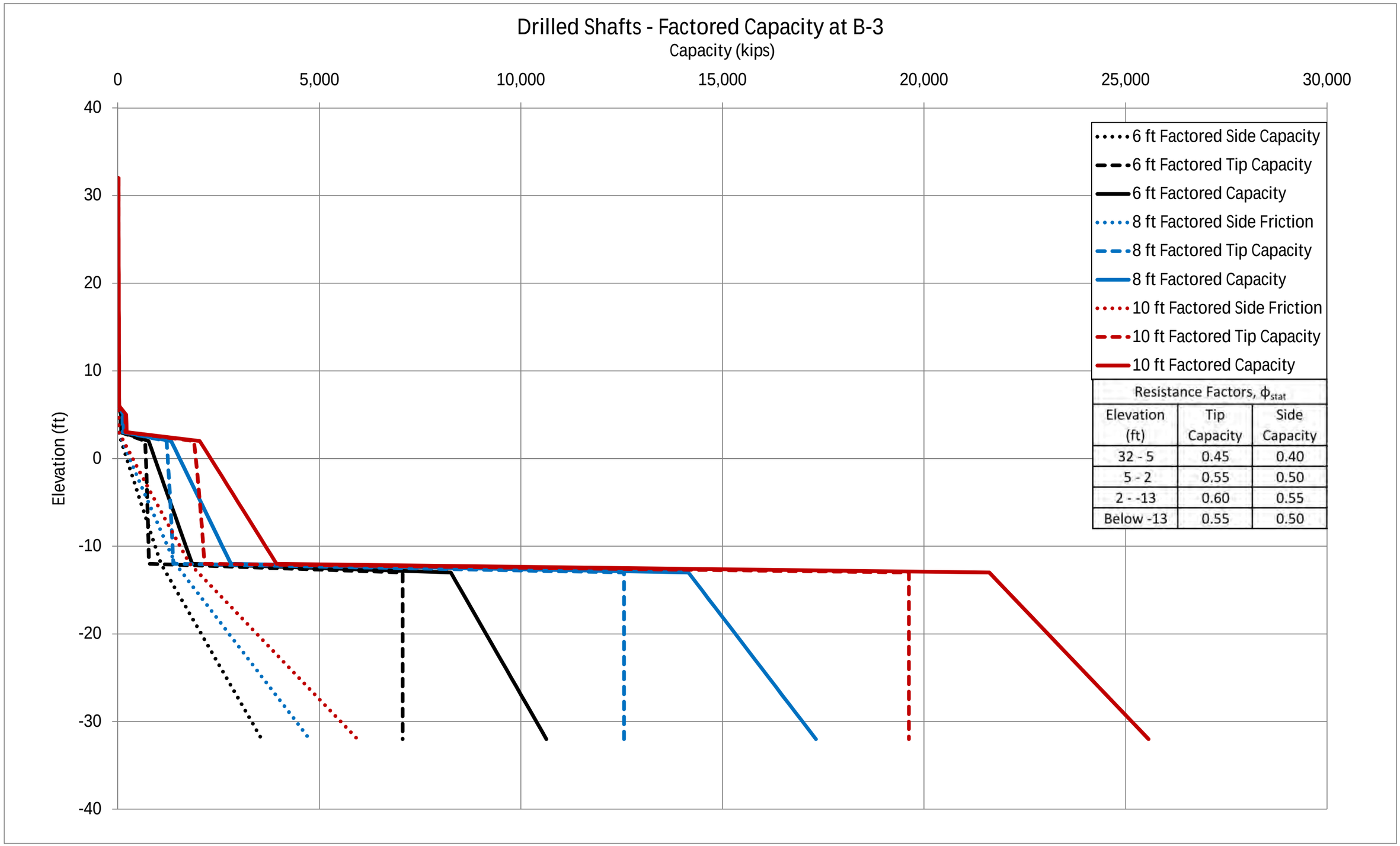

Driven Piles - Factored Capacity at B-2
Capacity (kips)
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
Depth (ft)
0
20
40
60
80
100
120
24 inch PP Factored Capacity
36 inch PP Factored Capacity
48 inch PP Factored Capacity
Notes:
Factored Capacities in alluvium are based on a resistance factor, $\phi_{stat}$ = 0.45.
Factored Capacity in rock (below depth 121 ft) calculated using $0.4f'_cA_c + 0.25f_yA_s$.
$f'_c$ = 4 ksi
$f_y$ = 45 ksi

## Driven Piles - Factored Uplift Capacity at B-2, Excluding Pile Self-Weight



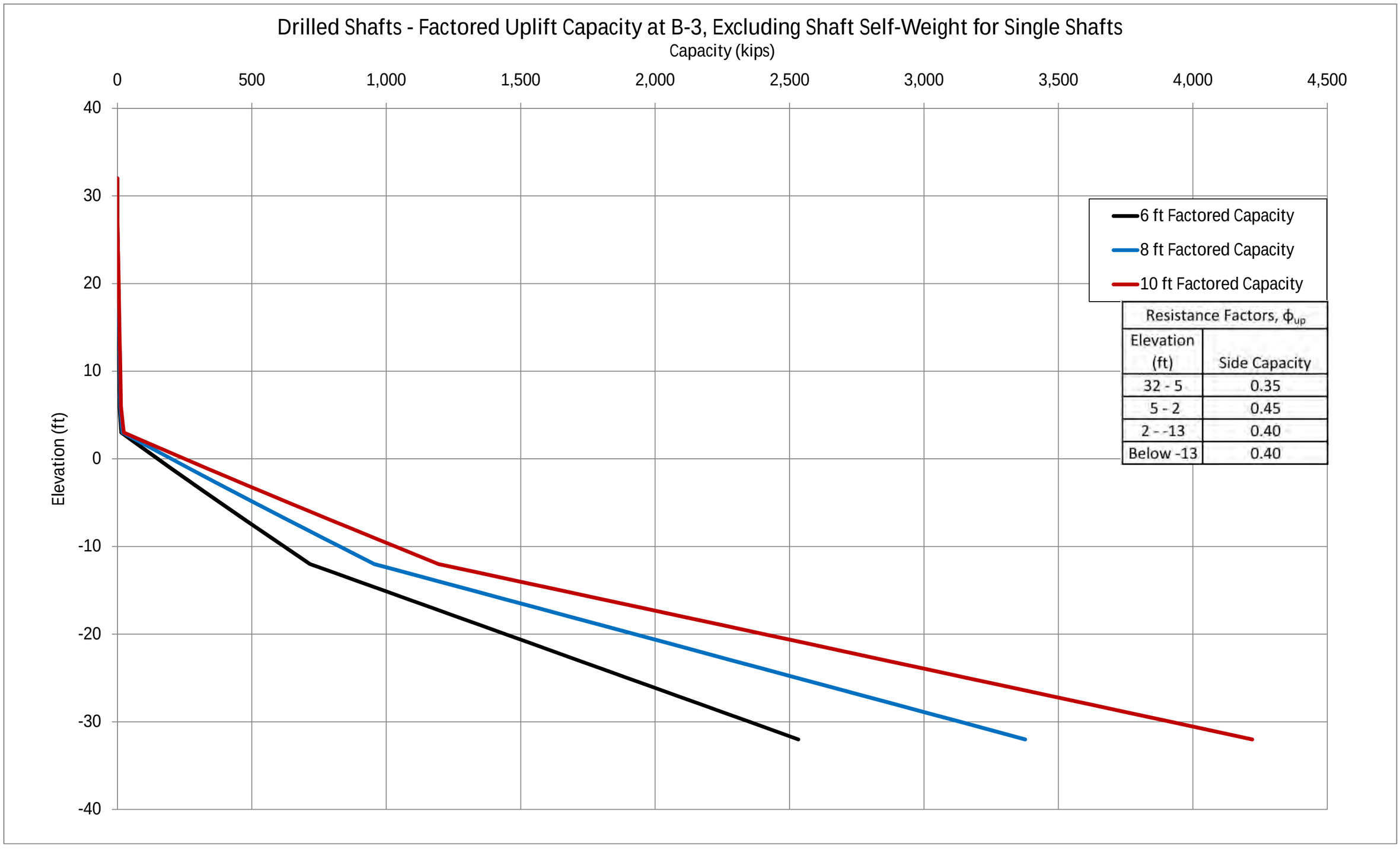

Drilled Shafts - Nominal Capacity at B-3
Capacity (kips)
0
10,000
20,000
30,000
40,000
50,000
60,000
Elevation (ft)
40
30
20
10
0
-10
-20
-30
-40
6 ft Nominal Side Capacity
6 ft Nominal Tip Capacity
6 ft Nominal Capacity
8 ft Nominal Side Friction
8 ft Nominal Tip Capacity
8 ft Nominal Capacity
10 ft Nominal Side Friction
10 ft Nominal Tip Capacity
10 ft Nominal Capacity

# Drilled Shafts - Factored Capacity at B-3




| Resistance Factors, $\phi_{stat}$ | | |
|---|---|---|
| Elevation (ft) | Tip Capacity | Side Capacity |
| 32 - 5 | 0.45 | 0.40 |
| 5 - 2 | 0.55 | 0.50 |
| 2 - -13 | 0.60 | 0.55 |
| Below -13 | 0.55 | 0.50 |

## Drilled Shafts - Factored Uplift Capacity at B-3, Excluding Shaft Self-Weight for Single Shafts




| Resistance Factors, $\phi_{up}$ | |
|---|---|
| Elevation (ft) | Side Capacity |
| 32 - 5 | 0.35 |
| 5 - 2 | 0.45 |
| 2 - -13 | 0.40 |
| Below -13 | 0.40 |

References


1) United States Geological Survey, 2008, Earthquake Hazards Program
2) AASHTO, 2010, AASHTO LRFD Bridge Design Specifications 5th Edition
3) AASHTO, 2009, Guide Specifications for LRFD Seismic Bridge Design, 1st Edition


Ground motion parameters shall be developed for two recurrence intervals - 500 and 1,000 years

Soil Site Classification at rock/alluvium interface - Site Class B
Seismic Design Category at rock/alluvium interface - SDC A

USGS 2008 accelerations on bedrock:

| 500 yr | |
|---|---|
| PGA | 0.114 |
| $S_s$ | 0.260 |
| $S_1$ | 0.096 |

| 1000 yr | |
|---|---|
| PGA | 0.158 |
| $S_s$ | 0.364 |
| $S_1$ | 0.142 |

AAHSTO 2009 ground motion parameters:

| 500 yr | |
|---|---|
| $F_{pga}$ | 1.00 |
| $F_a$ | 1.00 |
| $F_v$ | 1.00 |
| $A_s$ | 0.11 |
| $S_{DS}$ | 0.26 |
| $S_{D1}$ | 0.10 |
| $T_0$ | 0.07 |
| $T_S$ | 0.37 |

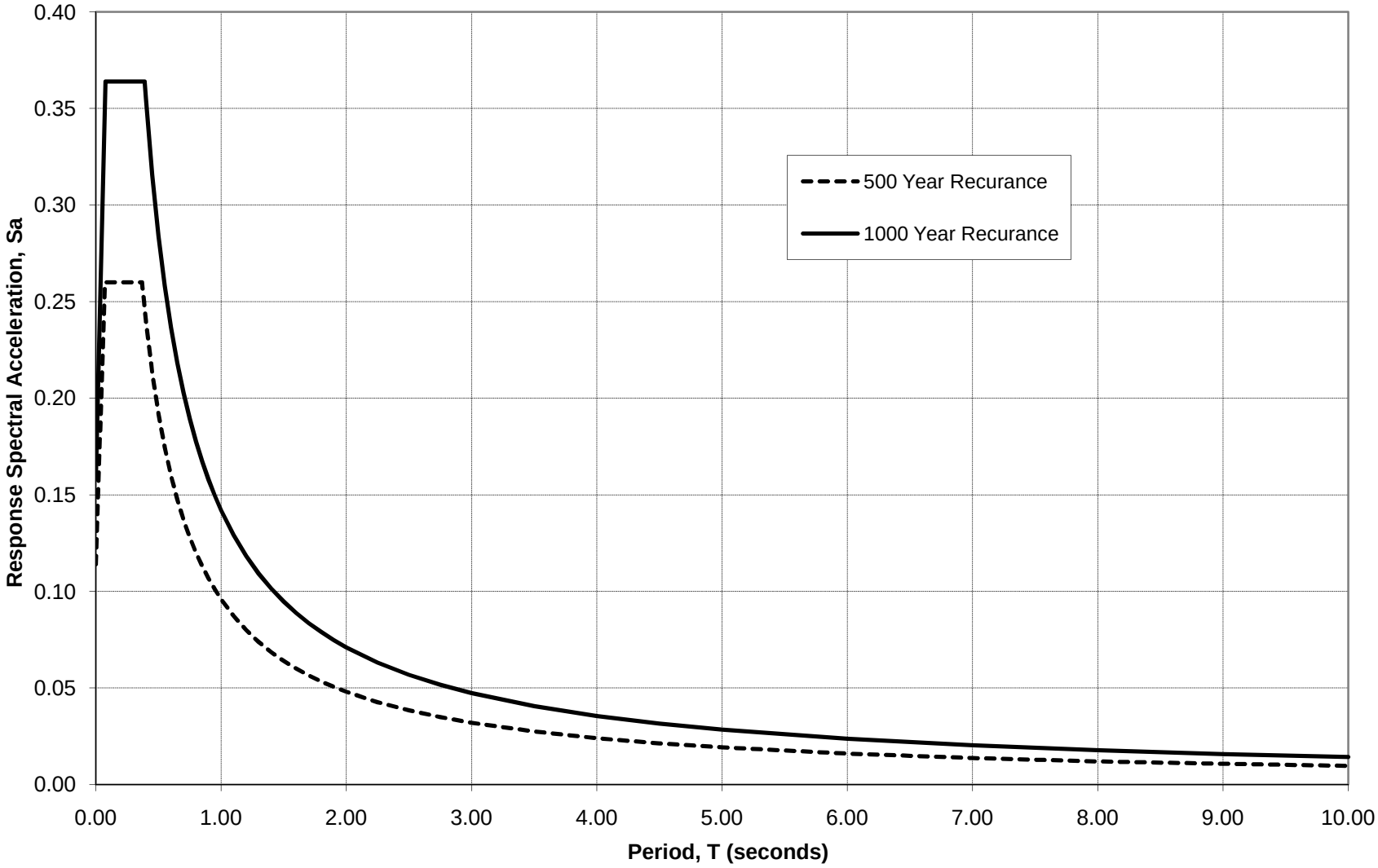
| 1000 yr | |
|---|---|
| $F_{pga}$ | 1.00 |
| $F_a$ | 1.00 |
| $F_v$ | 1.00 |
| $A_s$ | 0.16 |
| $S_{DS}$ | 0.36 |
| $S_{D1}$ | 0.14 |
| $T_0$ | 0.08 |
| $T_S$ | 0.39 |

Response Spectrum Values

| 500 yr | |
|---|---|
| T (sec) | $S_a$ |
| 0.00 | 0.11 |
| 0.07 | 0.26 |
| 0.37 | 0.26 |
| 0.40 | 0.24 |
| 0.45 | 0.21 |
| 0.50 | 0.19 |
| 0.55 | 0.17 |
| 0.60 | 0.16 |
| 0.65 | 0.15 |
| 0.70 | 0.14 |
| 0.75 | 0.13 |
| 0.80 | 0.12 |
| 0.85 | 0.11 |
| 0.90 | 0.11 |
| 0.95 | 0.10 |
| 1.0 | 0.10 |
| 1.1 | 0.09 |
| 1.2 | 0.08 |
| 1.3 | 0.07 |
| 1.4 | 0.07 |
| 1.5 | 0.06 |
| 1.6 | 0.06 |
| 1.7 | 0.06 |
| 1.8 | 0.05 |
| 1.9 | 0.05 |
| 2.0 | 0.05 |
| 2.3 | 0.04 |
| 2.5 | 0.04 |
| 2.8 | 0.03 |
| 3.0 | 0.03 |
| 3.5 | 0.03 |
| 4.0 | 0.02 |
| 4.5 | 0.02 |
| 5.0 | 0.02 |
| 6.0 | 0.02 |
| 7.0 | 0.01 |
| 8.0 | 0.01 |
| 9.0 | 0.01 |
| 10.0 | 0.01 |

| 1000 yr | |
|---|---|
| T (sec) | $S_a$ |
| 0.00 | 0.16 |
| 0.08 | 0.36 |
| 0.39 | 0.36 |
| 0.40 | 0.36 |
| 0.45 | 0.32 |
| 0.50 | 0.28 |
| 0.55 | 0.26 |
| 0.60 | 0.24 |
| 0.65 | 0.22 |
| 0.70 | 0.20 |
| 0.75 | 0.19 |
| 0.80 | 0.18 |
| 0.85 | 0.17 |
| 0.90 | 0.16 |
| 0.95 | 0.15 |
| 1.0 | 0.14 |
| 1.1 | 0.13 |
| 1.2 | 0.12 |
| 1.3 | 0.11 |
| 1.4 | 0.10 |
| 1.5 | 0.09 |
| 1.6 | 0.09 |
| 1.7 | 0.08 |
| 1.8 | 0.08 |
| 1.9 | 0.07 |
| 2.0 | 0.07 |
| 2.3 | 0.06 |
| 2.5 | 0.06 |
| 2.8 | 0.05 |
| 3.0 | 0.05 |
| 3.5 | 0.04 |
| 4.0 | 0.04 |
| 4.5 | 0.03 |
| 5.0 | 0.03 |
| 6.0 | 0.02 |
| 7.0 | 0.02 |
| 8.0 | 0.02 |
| 9.0 | 0.02 |
| 10.0 | 0.01 |

## Design Response Spectrum



A seismic hazard deaggregation was performed to identify the seismic sources that contribute the greatest hazard to the site. The sources were identified: 1) Shallow crustal faults, 2) Intraplate faulting, and 3) Cascadia Subduction Zone (CSZ) faulting. A M-R pair from each source which had the greatest contribution to the mean PGA was choosen to be included in the liquefaction analysis. These pairs are:

1) Shallow crustal - M = 5.40, R = 8.3 km
2) Intraplate - M = 7.01, R = 86.0 km
3) CSZ - M = 9.0, R = 179.7 km

Attenuation relationships were used to determine the PGA from each M-R pair at the site. For the shallow crustal faulting 3 NGA relationships (Boore and Atkinson (2008), Campbell and Bozorgnia (2008), and Chiou and Youngs (2008)) were equally weighted to evaluate PGA. For CSZ and Intraplate faulting Youngs et al. (1997) was used. Averaged PGA's are as follows:

1) Shallow crustal - PGA = 0.13 g
2) Intraplate - PGA = 0.11 g
3) CSZ - PGA = 0.10 g

The liquefaction analysis was performed using the software program LiquefyPro V.5.8f. This program utilizes Seed's Method to calculate the CSR and the CSR is determined from corrected SPT blow count data (Harder and Seed, 1986 and Harder, 1997). Fines content correction formulas developed by Idriss and Seed (1997) were used and the Ishihara/Yoshimine Method was used to calculate settlement. A anlaysis was performed at each boring using insitu and laboratory test data from the field explorations. Three earthquake scenerios were analyzed at each boring. The results of these analyses are presented on Plates B1-1 through B3-3 and summarized below.

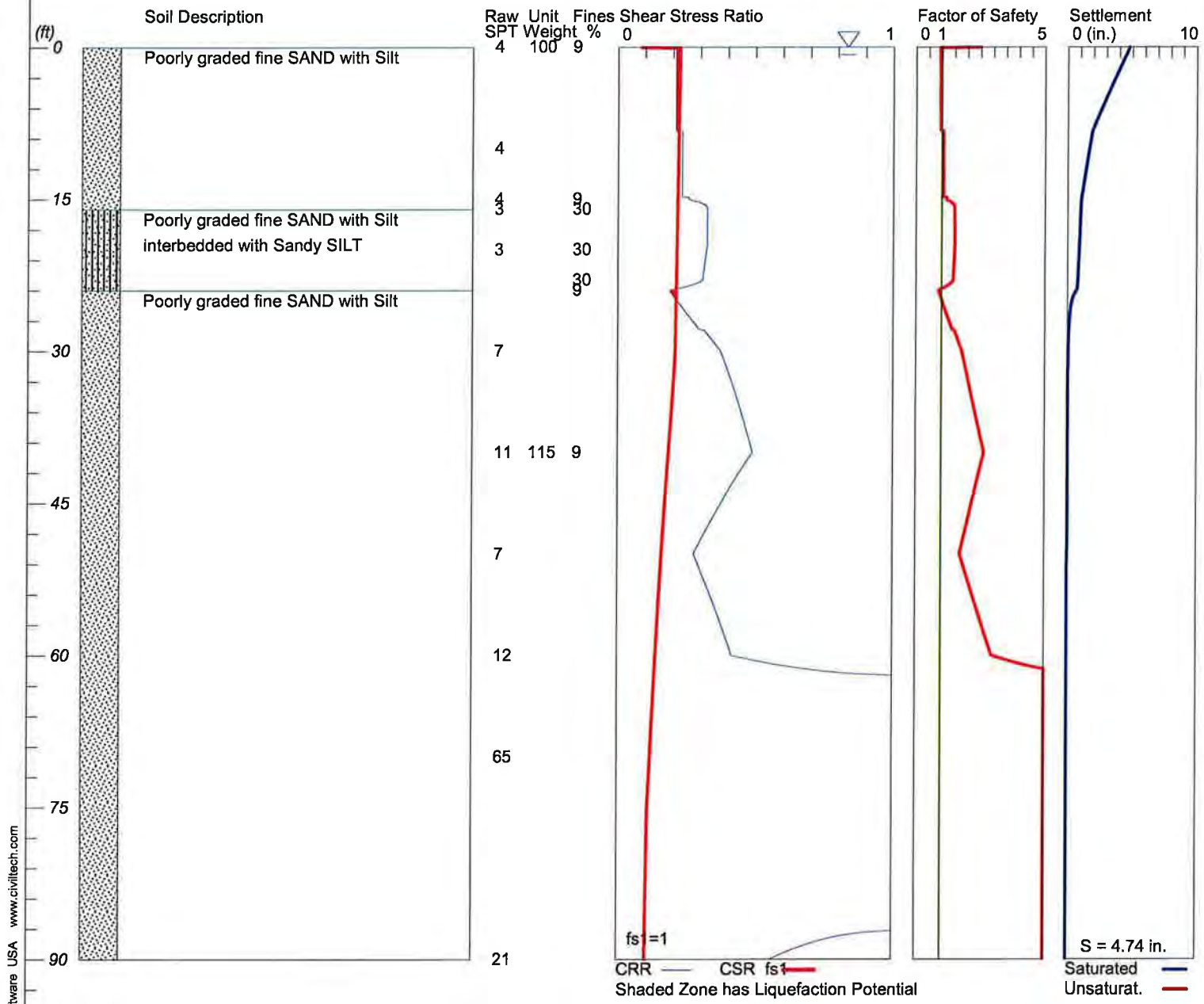
| Scenerio | Liquefaction? | Settlement Predicted (inches) |
|---|---|---|
| B-1 , Crustal | Yes | 5 |
| B-1, Intraplate | Yes | 13 |
| B-1, CSZ | Yes | 21 |
| B-2 , Crustal | Yes | 3 |
| B-2, Intraplate | Yes | 14 |
| B-2, CSZ | Yes | 24 |
| B-3 , Crustal | Potential | 4 |
| B-3, Intraplate | Potential | 10 |
| B-3, CSZ | Potential | 12 |

# LIQUEFACTION ANALYSIS

## SR-35 Liquefaction Analysis

***Hole No.=1  Water Depth=0 ft  Surface Elev.=36.7***

***Magnitude=5.4***
***Acceleration=0.13g***

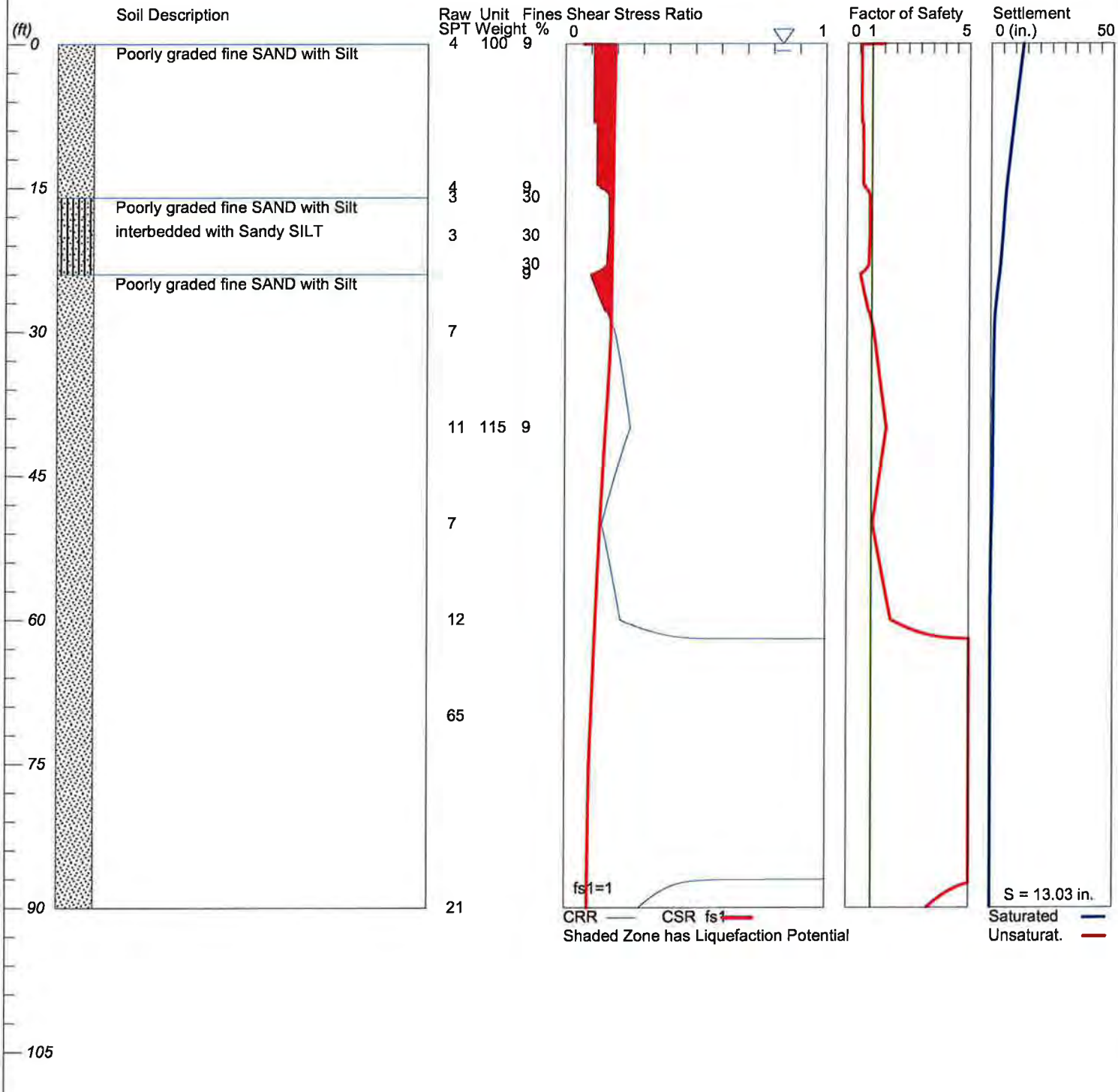


# LIQUEFACTION ANALYSIS

## SR-35 Liquefaction Analysis

***Hole No.=1 Water Depth=0 ft Surface Elev.=36.7***

***Magnitude=7.01***
***Acceleration=0.11g***

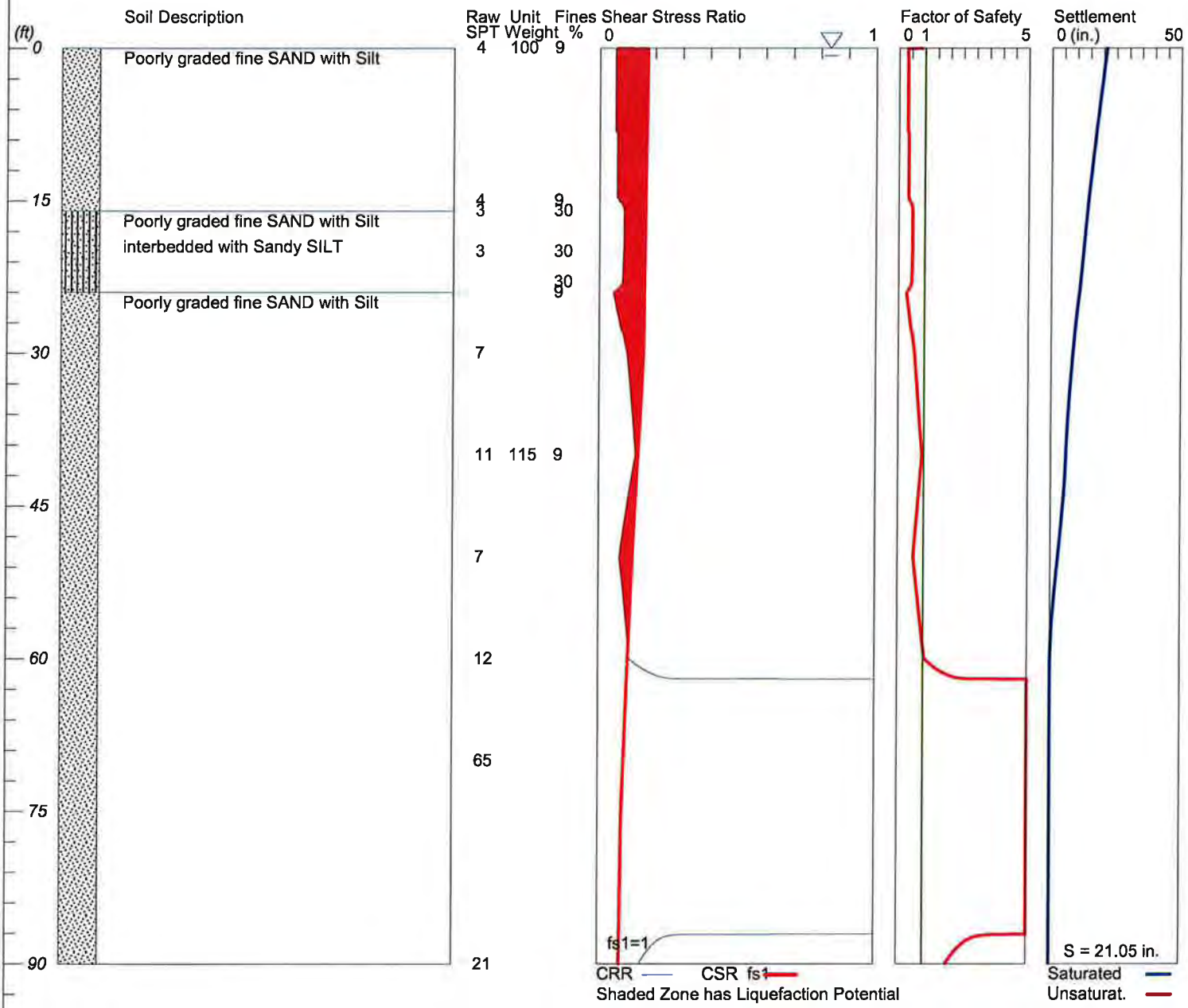


# LIQUEFACTION ANALYSIS

## SR-35 Liquefaction Analysis

***Hole No.=1 Water Depth=0 ft Surface Elev.=36.7***

***Magnitude=9***
***Acceleration=0.10g***

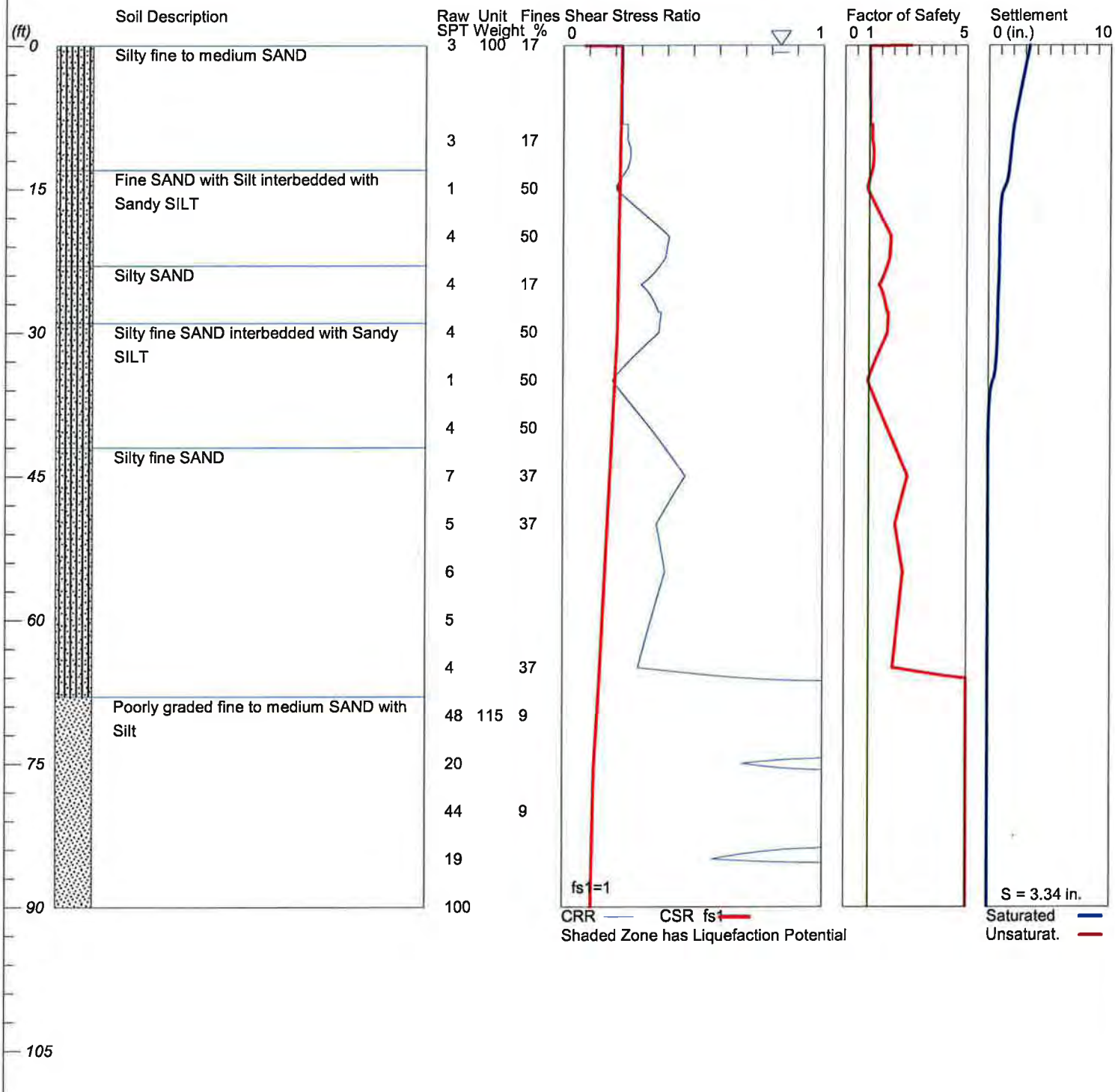


# LIQUEFACTION ANALYSIS

## SR-35 Liquefaction Analysis

***Hole No.=2 Water Depth=0 ft Surface Elev.=32.9***

***Magnitude=5.4***
***Acceleration=0.13g***

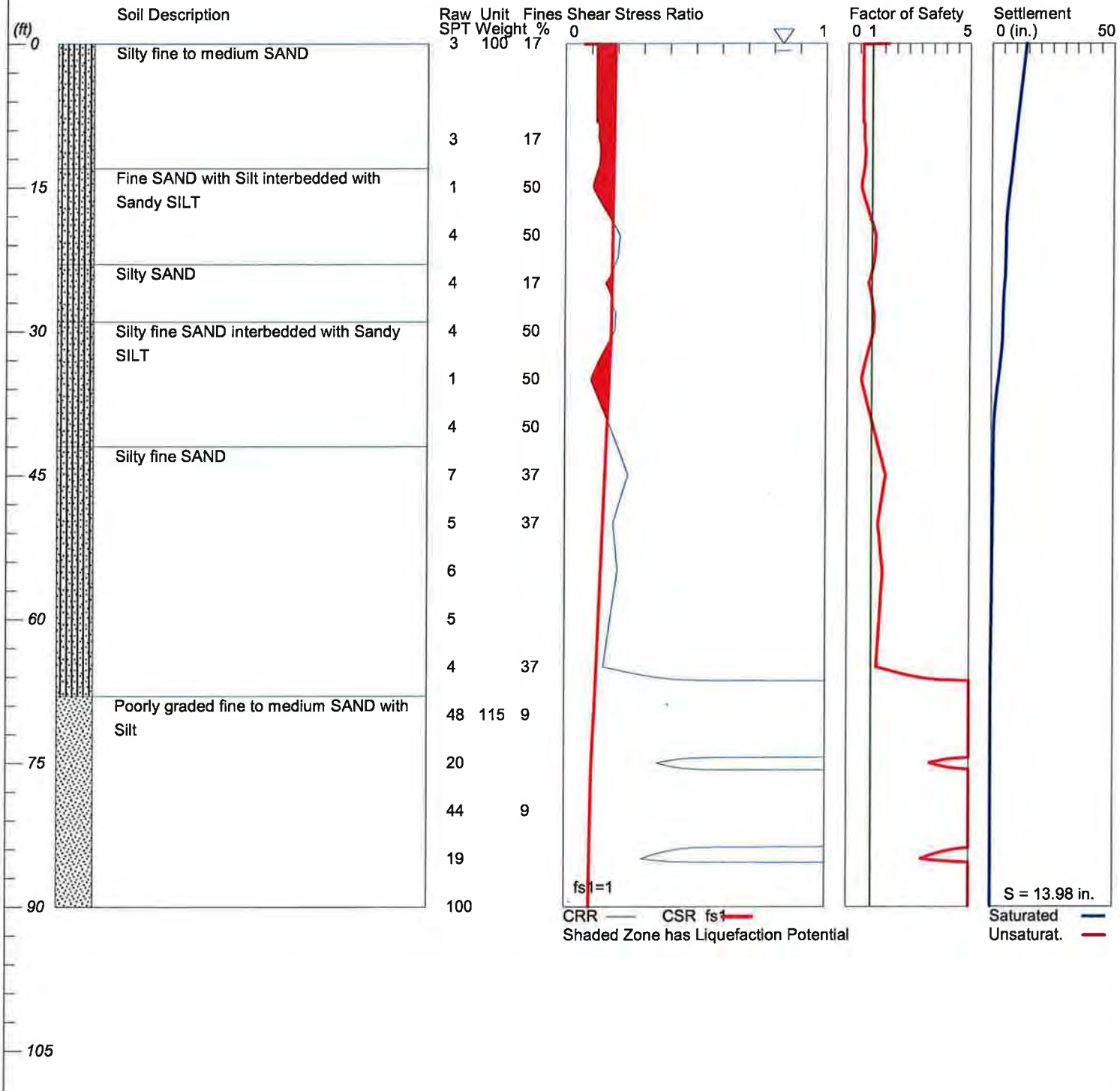


# LIQUEFACTION ANALYSIS

## SR-35 Liquefaction Analysis

***Hole No.=2 Water Depth=0 ft Surface Elev.=32.9***

***Magnitude=7.01***
***Acceleration=0.11g***

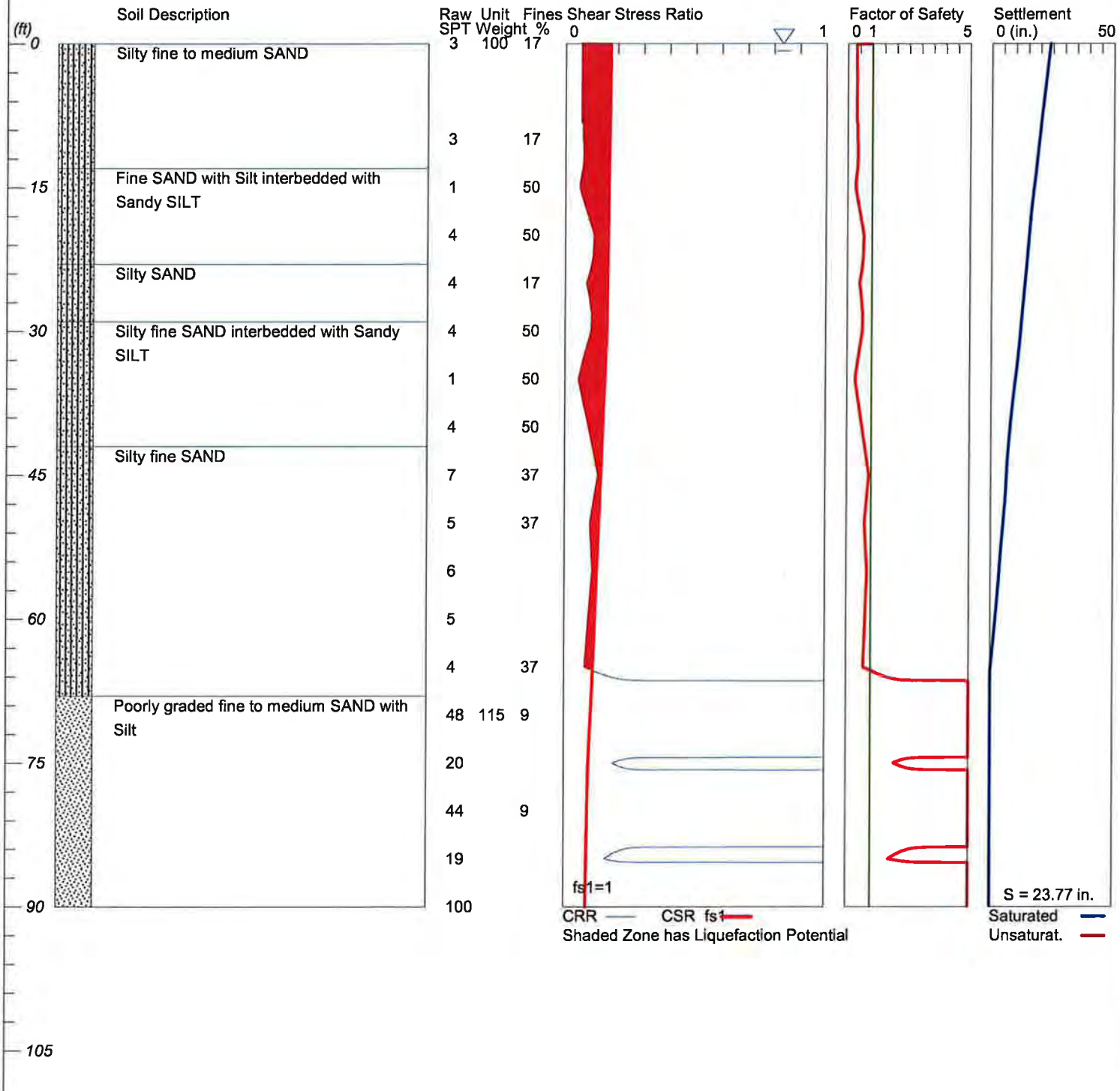


# LIQUEFACTION ANALYSIS

## SR-35 Liquefaction Analysis

***Hole No.=2 Water Depth=0 ft Surface Elev.=32.9***

***Magnitude=9.0***
***Acceleration=0.10g***

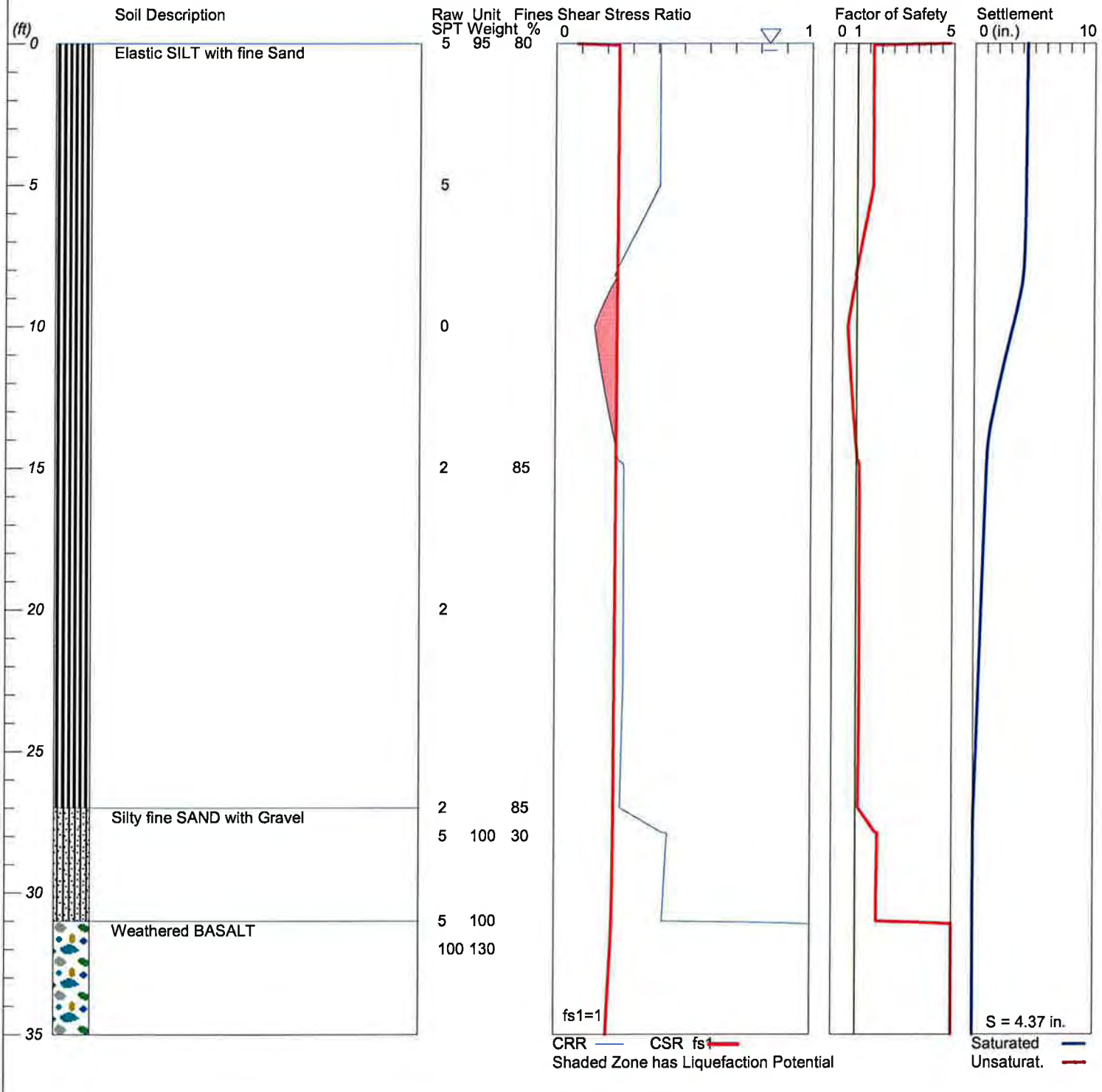


# LIQUEFACTION ANALYSIS

## SR-35 Liquefaction Analysis

***Hole No.=3 Water Depth=0 ft Surface Elev.=32.3***

***Magnitude=5.4***
***Acceleration=0.13g***

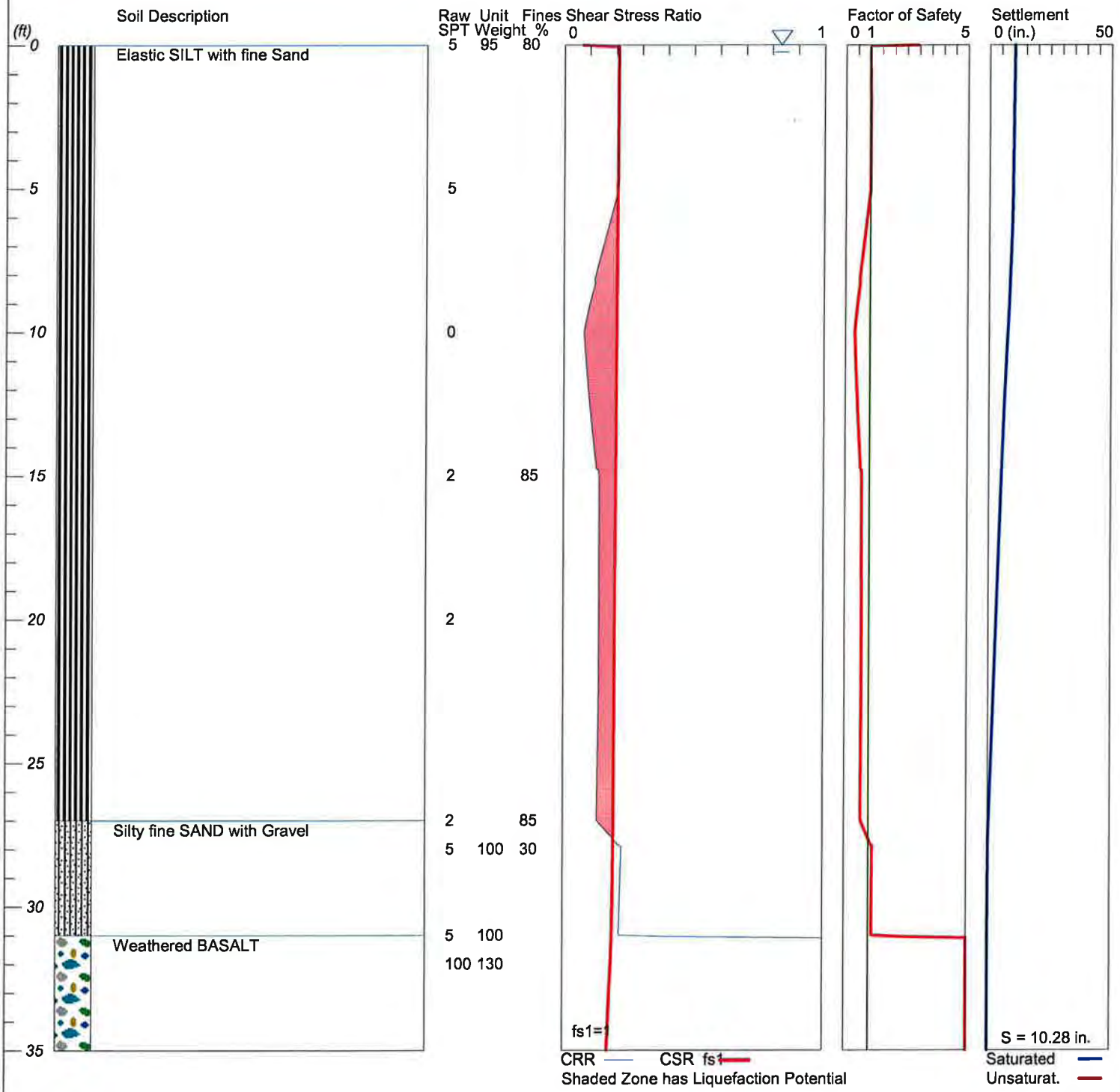


# LIQUEFACTION ANALYSIS

## SR-35 Liquefaction Analysis

***Hole No.=3 Water Depth=0 ft Surface Elev.=32.3***

***Magnitude=7.01***
***Acceleration=0.11g***



# LIQUEFACTION ANALYSIS

## SR-35 Liquefaction Analysis

***Hole No.=3 Water Depth=0 ft Surface Elev.=32.3***

***Magnitude=9***
***Acceleration=0.10g***