November 16, 2010

Virginia Department of Transportation
Norfolk Residency
1992 S. Military Highway
Chesapeake, VA 23320

Attn: Ian Johnston, P.E. – VDOT Project Manager

Subject: Summary of Geotechnical Stability and Settlement Analysis
PSA Greenwich Road, PSA Ramps and Channel, and PSA I-64, D7, and Bridge
I-64 / I-264 Interchange Project, Norfolk and VA Beach, VA

Dear Mr. Johnston,

In preparation for our meeting with VDOT and its designers for the above-referenced project scheduled for November 17, 2010, HDR is submitting this summary of our geotechnical stability and settlement analyses completed for the Greenwich Road Flyover Bridge, Ramps and Channel, and I-64, D7, and Bridge Project Study Areas (PSAs). Previously, HDR submitted our Draft Geotechnical Data packages for the Ramps and Channel and I-64, D7, and Bridge PSAs on November 1, 2010. Our draft Geotechnical Data Report for PSA Greenwich was provided on September 24, 2010.

In general, embankment and ramp widening and bridge approach fills of up to approximately 32 feet are planned as part of the proposed interchange improvements. To date, HDR has completed its proposed subsurface exploration programs at PSAs Greenwich Road and I-64, D7, and Bridge, and has completed most of its exploration for PSA Ramps and Channel. Following our exploration programs, HDR completed settlement and slope stability analyses to aid in evaluating the impacts that observed subsurface conditions might have on the proposed improvements. Table 1 provides a summary of the analyses completed for the three PSA's referenced above.

Table 1 – Geotechnical Analyses Completed for I-64/I-264 Interchange Project

PSA	Station	Proposed Fill Geometry	Slope Stability Analysis	Settlement Analysis
Greenwich Road	17+50	Fill Height = 23 ft Fill Width = 150 ft Slope	X	
	24+90	Fill Height = 30 ft Fill Width = 116 ft Slope / Wall	X	X
	32+50	Fill Height = 20 ft Fill Width = 116 ft Slope / Wall	X	X
Ramps and Channel	10+00	Fill Height = 32 ft Fill Width = 105 ft Wall	X	
	16+00	Fill Height = 26 ft Fill Width = 105 ft Wall / Slope		X

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Suite 103
Glen Allen, VA 23060

Phone: (804) 648-6630
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www.hdrinc.com

PSA	Station	Proposed Fill Geometry	Slope Stability Analysis	Settlement Analysis
Ramps and Channel	19+00	Fill Height = 15 ft Fill Width = 130 ft Wall	X	
	30+00	Fill Height = 27 ft Fill Width = 75 ft Wall / Slope	X	X
I-64, D7, and Bridge	18+00	Fill Height = 17 ft Fill Width = 45 ft Wall		X
	22+00	Fill Height = 28 ft Fill Width = 50 ft Wall	X	

Attached Drawings 1 through 3 show the locations of our analyses with respect to the proposed improvements and our recent subsurface explorations.

- Drawing 1 – PSA Greenwich Road – Locations of Geotechnical Analyses
- Drawing 2 – PSA Ramps and Channel – Locations of Geotechnical Analyses
- Drawing 3 – PSA I-64, D7, and Bridge – Locations of Geotechnical Analyses

Subsurface Conditions Impacting Construction

Attached Drawings 4 through 7 show subsurface cross sections and soil stratum boundaries interpreted by HDR. In our opinion, the cross sections show “representative” subsurface conditions at the different PSAs and in the vicinity of our settlement and stability analyses.

- Drawing 4 – PSA Greenwich Road – Subsurface Stratigraphy – Station 15+00 through 25+00
- Drawing 5 – PSA Ramps and Channel – Subsurface Stratigraphy – Station 16+00 through 22+00
- Drawing 6 – PSA Ramps and Channel – Subsurface Stratigraphy – Station 34+00 through 41+00
- Drawing 7 – PSA I-64, D7, & Bridge – Subsurface Stratigraphy – Station 15+00 through 25+00

The different soil strata are labeled on the drawings with names that are commonly referred to in our analyses (Upper Norfolk clays, Lower Norfolk clays, Yorktown Formation, etc.).

Slope Stability Analysis

HDR completed global stability analyses for soil slopes and vertical-faced walls in both the short-term (undrained) and long-term (drained) conditions at the locations shown in Table 1. To complete our analyses, we used the computer program Slope/W (2007, Version 7, Geo-Slope International). Strength parameters for the onsite soils were based on the soil test borings, CPT soundings, laboratory test results, and our experience with similar soils in the area. Based on experience with similar transportation projects, we recommend factors of safety (FS) against stability failure of FS = 1.3 for the short-term case and FS = 1.5 for the long-term case.

At PSA Greenwich, the currently proposed bridge approach embankments consist of a combination of soil slopes and vertical-faced walls (MSE walls). At PSA Ramps and Channel and I-64, D7, and Bridge, the proposed embankment and ramp widening will generally be constructed against the existing soil slopes and require a wall on the far side. Where vertical-faced walls were analyzed, HDR only evaluated slip surfaces located behind the anticipated reinforced zone of the MSE wall, which extends to a distance of approximately 0.7H behind the face (where H = total wall height).

The results of our analyses are summarized in the following attached sheets:

- Tables 2 and 3 – Summary of Stability Analyses
- Summary Points Related to Slope Stability
- Plots – Factor of Safety vs. Fill Pressure (3)
- Plots – Factor of Safety vs. Fill Unit Weight (2)

Settlement Analysis

HDR completed magnitude and time rate of settlement analyses for the proposed embankment fills shown in Table 1. Consolidation parameters for the onsite soils were based on laboratory 1-dimensional consolidation tests and our experience with similar soils in the area. We completed our magnitude and timerate analyses using the computer program CONSOL (version 3.0, CGPR, Virginia Tech).

In general, we plotted our settlement magnitude results against “fill pressure.” For the purposes of our analyses, we have defined fill pressure as the height of the fill multiplied by the unit weight of the fill. This gives the designer the flexibility to choose fill materials of various unit weights (expanded shale aggregate, VDOT No. 57 aggregate, etc.) and estimate the resulting settlement.

The results of our analyses are summarized in the following attached sheets:

- Table 4 – Summary of Settlement and Time Rate Analyses
- Summary Points Related to Settlement
- Plot – Fill Load vs. Embankment Height for Various Fill Soils (1)
- Plots – Settlement Magnitude and Timerate Results for Various Fill Heights (5 locations)
- Plot – Settlement Magnitude at Various Distances from Fill Centerline (1)
- Plot – Effect of Widening on Existing Embankment Settlement (1)

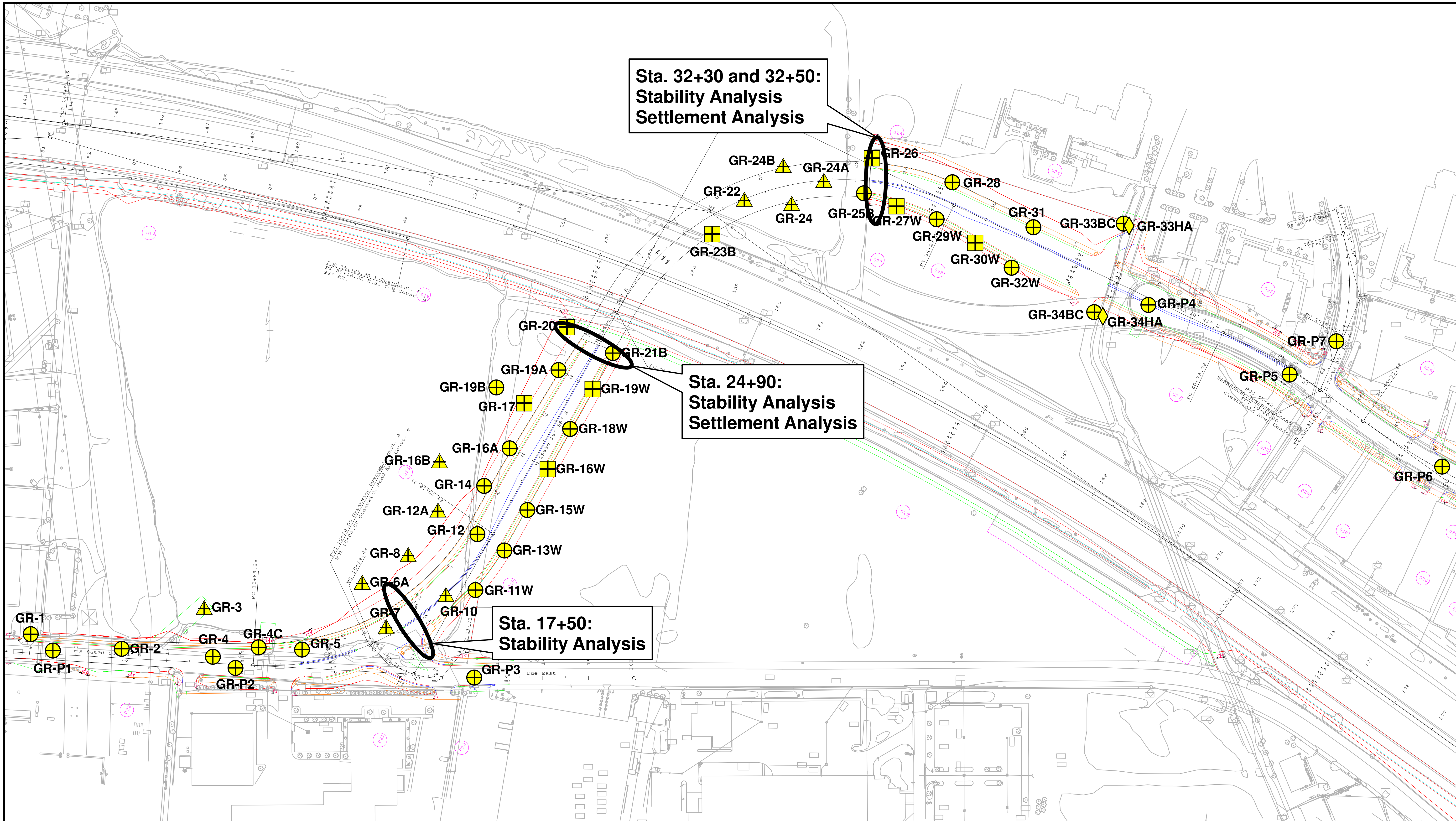
Conclusion

HDR completed slope stability and settlement analyses to aid in the evaluation of constructing the currently proposed fill / widening embankments at the three PSAs. Based on the results of the analyses, subsurface conditions at the project sites will present challenges in terms of both slope stability and settlement to the construction of tall embankment fills required for the proposed interchange improvements. We look forward to meeting with you on November 17 to discuss these challenges in an effort to provide future direction to the design team.

Regards,

Jesse N. Darden, P.E.
Geotechnical Project Manager

Aaron L. Zdinak, P.E.
Geotechnical Business Class Leader



N

0 100 200 Feet

Scale: 1" = 200'

Over Land (SPT) | Over Water (SPT/CPT) | Over Land (CPT) | Hand Auger

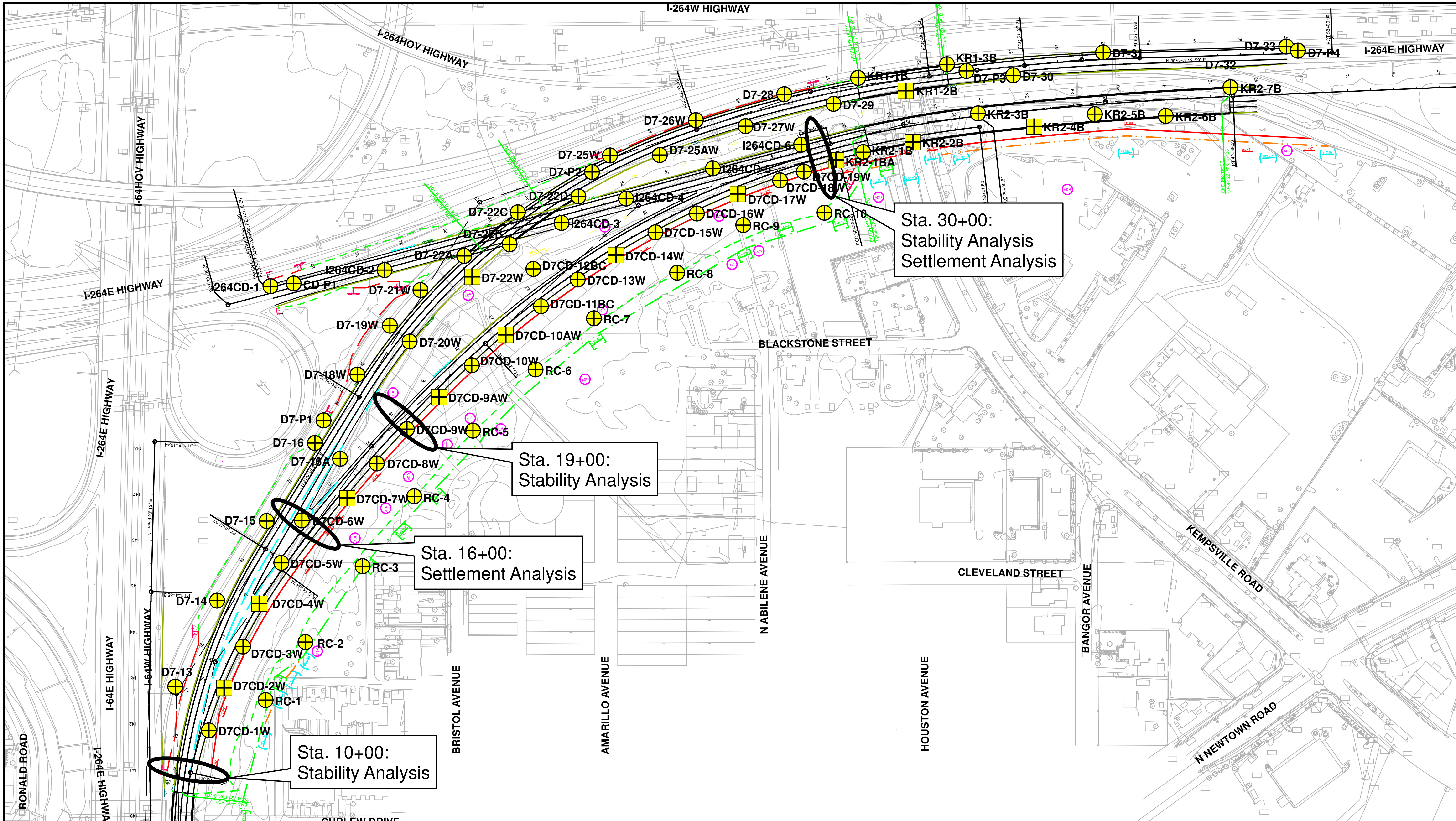
Prepared by: HDR Date: November 15, 2010

VDOT Virginia Department of Transportation

Project 0264-134-102
City of Virginia Beach

Project Study Area Greenwich

Drawing 1: Locations of Geotechnical Analyses



N

0 100 200 Feet

Scale: 1" = 200'

Ramps and Channel Borings

- Over Land (SPT)
- Over Land (CPT)

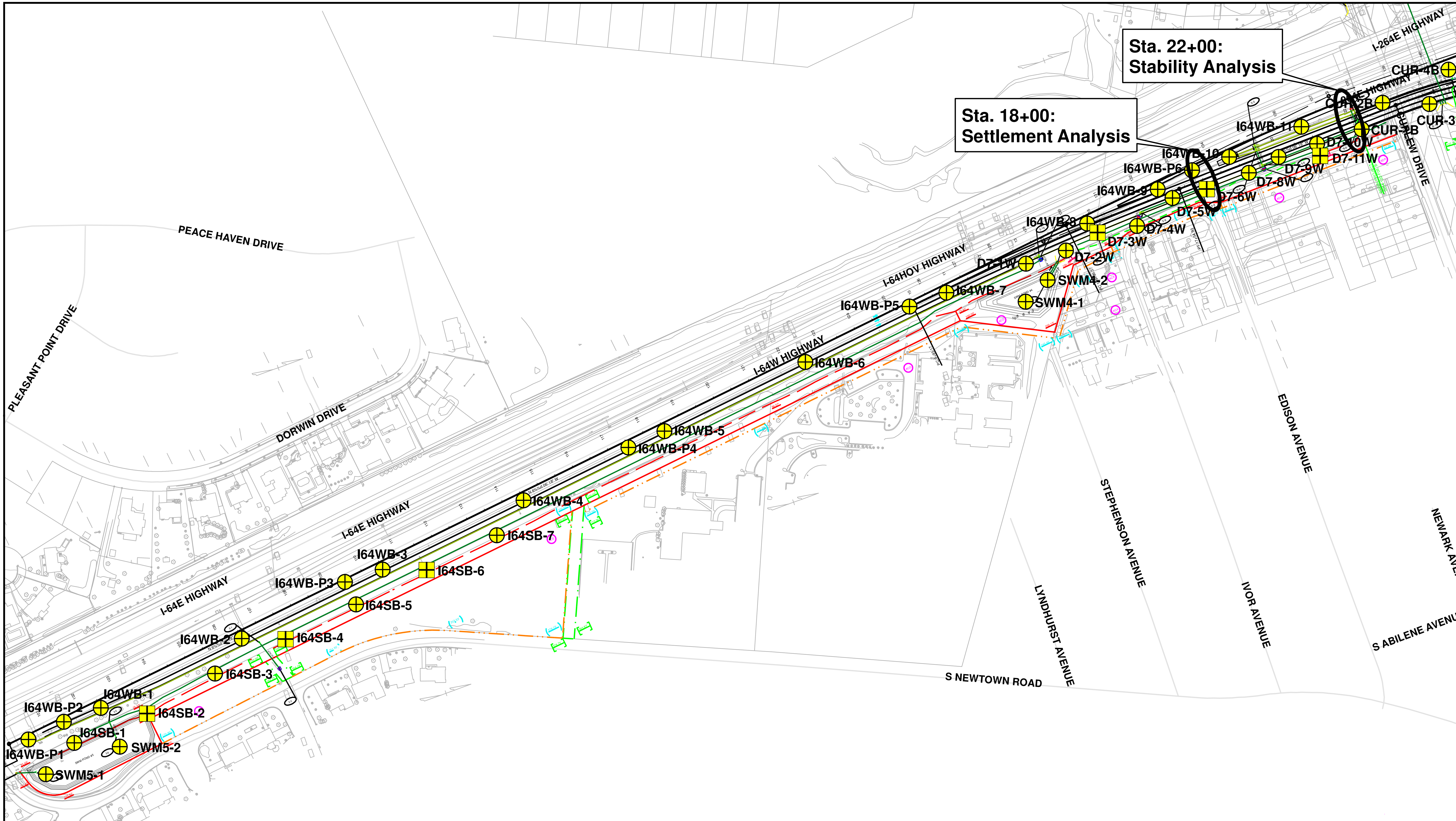
Prepared by: HDR Date: November 15, 2010

VDOT Virginia Department of Transportation

Project 0264-122-108
City of Norfolk

Project Study Area
Ramps and Channel

Drawing 2: Locations of Geotechnical Analyses



0 100 200 Feet

Scale: 1" = 200'

I64, D7, and Bridge Borings

- Over Land (SPT)
- Over Land (CPT)

Prepared by: HDR Date: November 15, 2010

VDOT Virginia Department of Transportation

Project 0264-122-108

City of Norfolk

Project Study Area

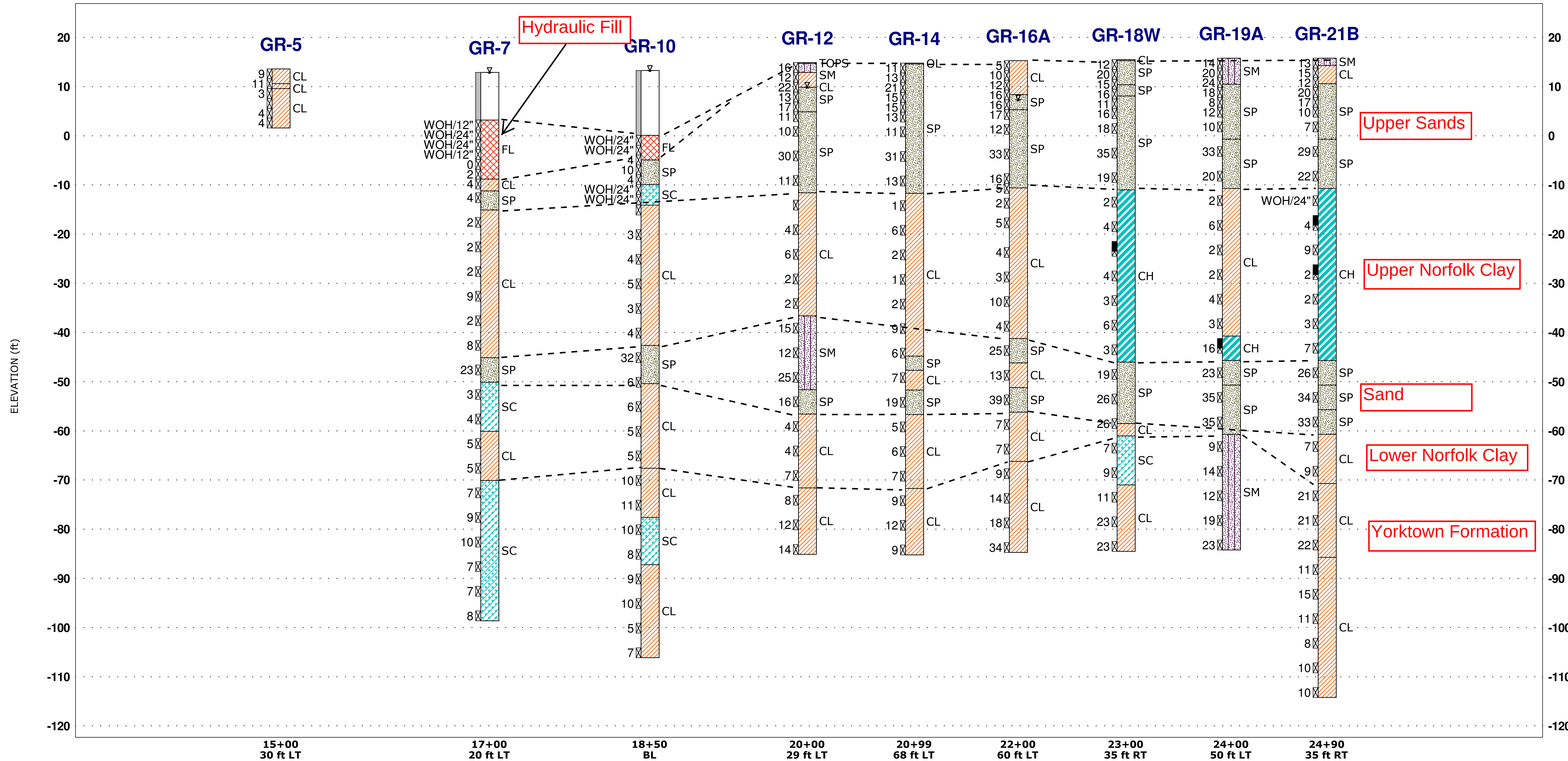
I64, D7, and Bridge

Drawing 3: Locations of Geotechnical Analyses

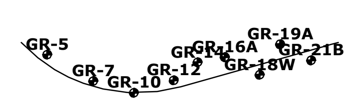
Drawing 4: PSA GREENWICH STRATIGRAPHY

FHWA REGION	STATE	FEDERAL AID ROUTE	FEDERAL AID PROJECT	STATE ROUTE	STATE PROJECT	SHEET NO.
3	VA.		STP-5403		0264-134-102	6-C

PSA GREENWICH
SOUTH APPROACH - BASELINE



Notes: See borehole logs for complete data
See Material and Sample Symbols List



LOCATION PLAN
(not to scale)

The subsurface information shown on the boring logs in these plans was obtained with reasonable care and recorded in good faith solely for use by the Department in establishing design controls for the project. The Department has no reason to suspect that such information is not reasonably accurate as an approximate indication of the subsurface conditions at the sites where the borings were taken. The Department does not in any way warrant or guarantee that such data can be projected as indicative of conditions beyond the limits of the borings shown; and any such projections by bidders are purely interpretive and altogether speculative. Further, the Department does not in any way guarantee, either expressly or by implication, the sufficiency of the information for bid purposes.

The boring logs are made available to bidders in order that they may have access to subsurface data identical to that which is possessed by the Department, and are not intended as a substitute for personal investigation, interpretation and judgment by the bidders.

No.	Description	Date
	Revisions	

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF TRANSPORTATION

MATERIALS DIVISION

0264-134-102
ENGINEERING GEOLOGY

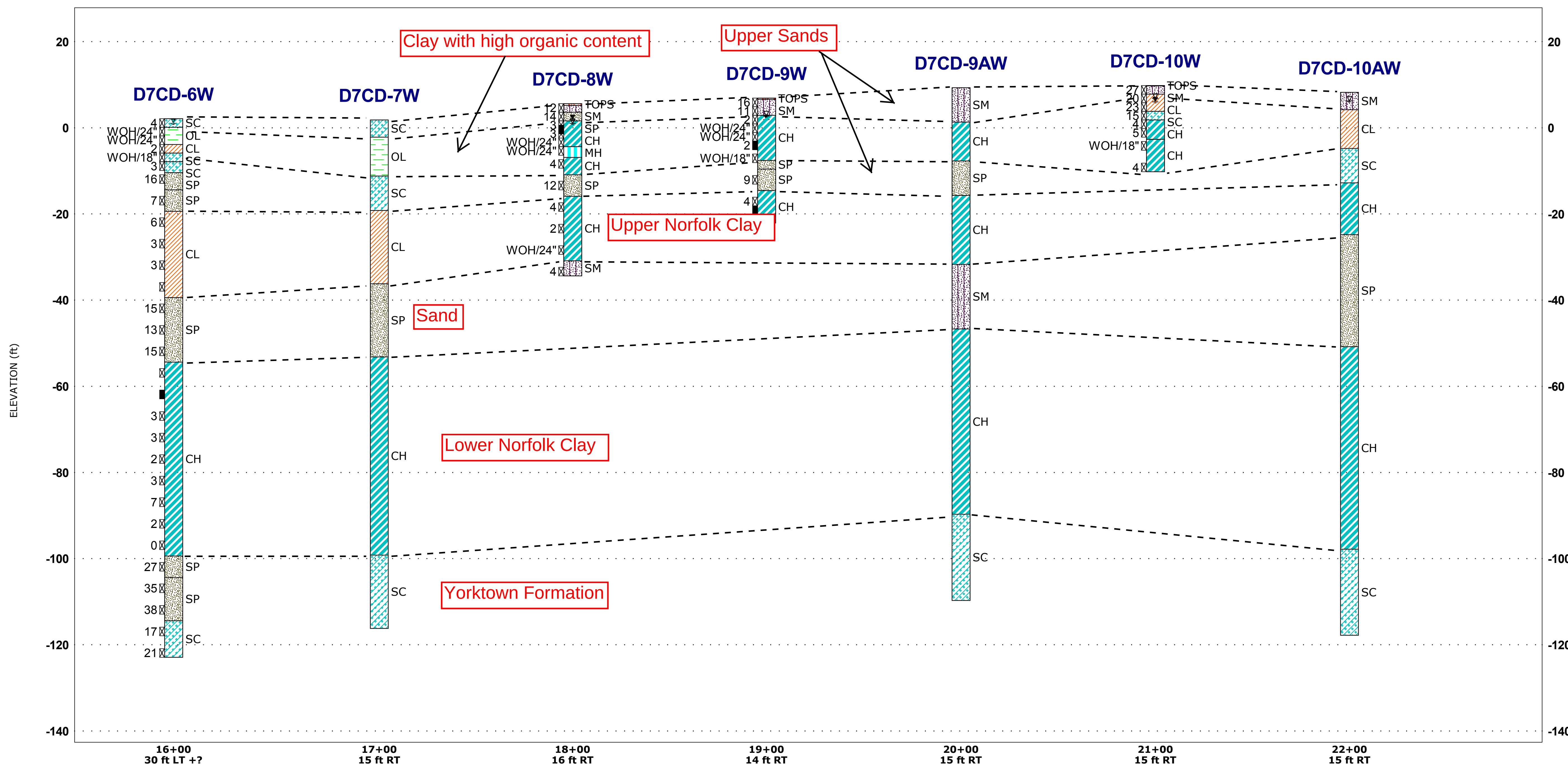
Data:	Date	Plan No.	Sheet No.
Drawn: KLH Checked: JND	10/4/2010	South-BL	6-C

Drawing 5: PSA RAMPS AND CHANNEL STRATIGRAPHY

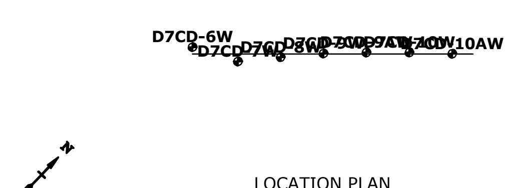
FHWA REGION	STATE	FEDERAL AID ROUTE	FEDERAL AID PROJECT	STATE ROUTE	STATE PROJECT	SHEET NO.
3	VA.		NH-264-6(098)		0264-122-108	6-A

PSA RAMPS AND CHANNEL

D7 CD WALL STA. 16+00 TO STA. 22+00



Notes: See borehole logs for complete data
See Material and Sample Symbols List



LOCATION PLAN
(not to scale)

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SPT_FENCE:PSA RAMPS AND CHANNEL BORING LOGS.GPJ;8.2.007-101609-10/29/10

No.	Description	Date
Revisions		

COMMONWEALTH OF VIRGINIA
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0264-122-108
ENGINEERING GEOLOGY

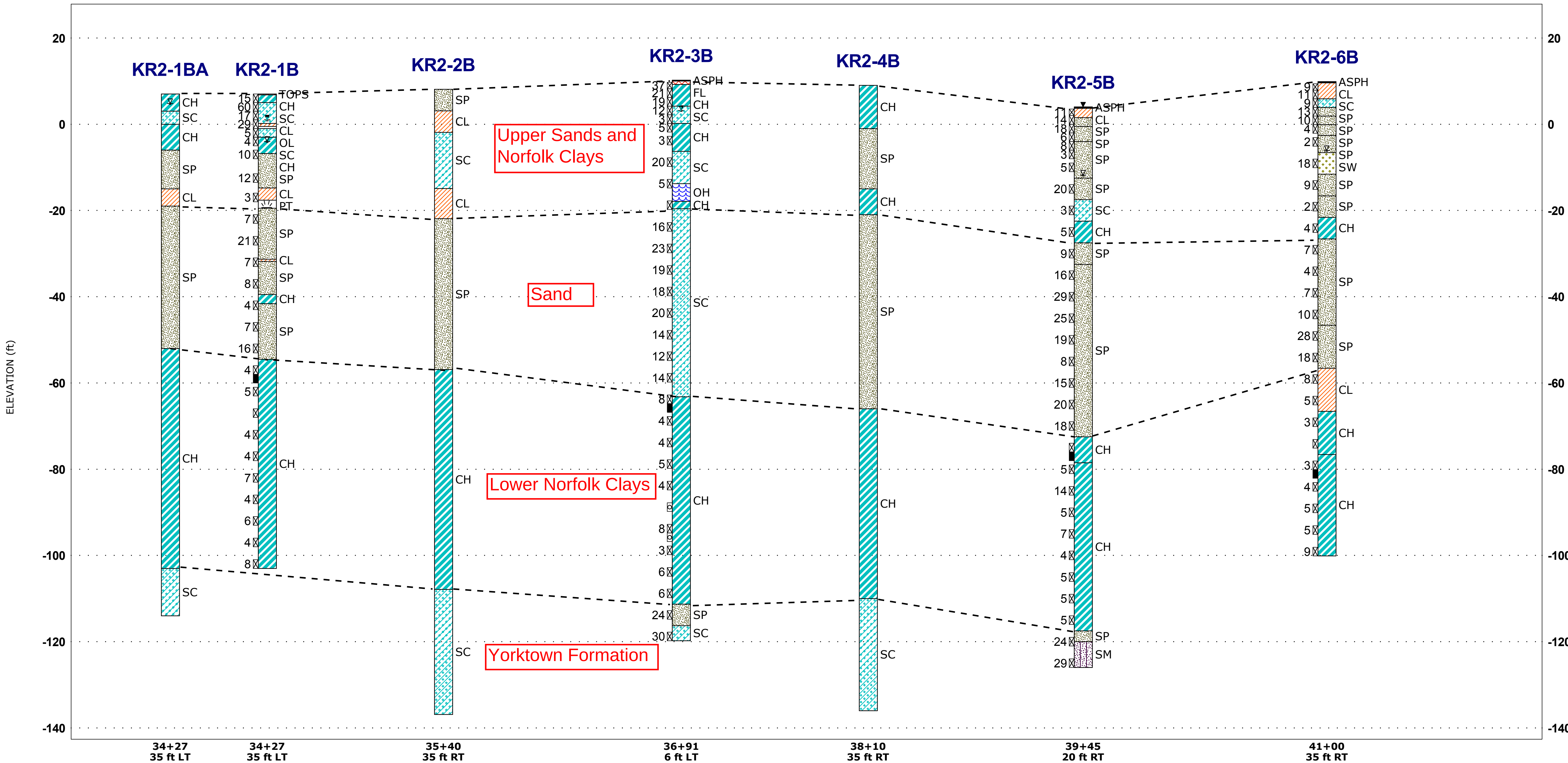
Data:	Date	Plan No.	Sheet No.
Drawn: MJS / Checked: JND	10/29/2010	D7 CD	6-A

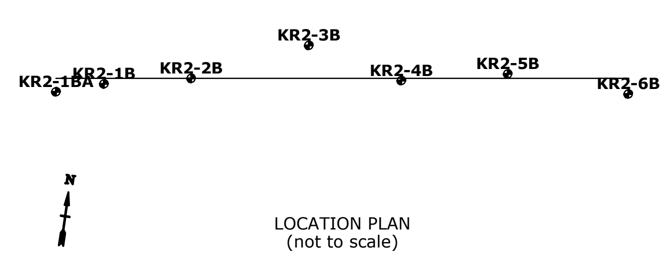
Drawing 6: PSA RAMPS AND CHANNEL STRATIGRAPHY II

FHWA REGION	STATE	FEDERAL AID ROUTE	FEDERAL AID PROJECT	STATE ROUTE	STATE PROJECT	SHEET NO.
3	VA.		NH-264-6(098)		0264-122-108	6-C

PSA RAMPS AND CHANNEL

BRIDGE: I264 EB CD AT KEMPSVILLE





LOCATION PLAN
(not to scale)

Notes: See borehole logs for complete data
See Material and Sample Symbols List

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SPT_FENCEAB:PSA RAMPS AND CHANNEL BORING LOGS.GPJ;8.2.007;10/1609;11/1/10

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DEPARTMENT OF TRANSPORTATION

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0264-122-108
ENGINEERING GEOLOGY

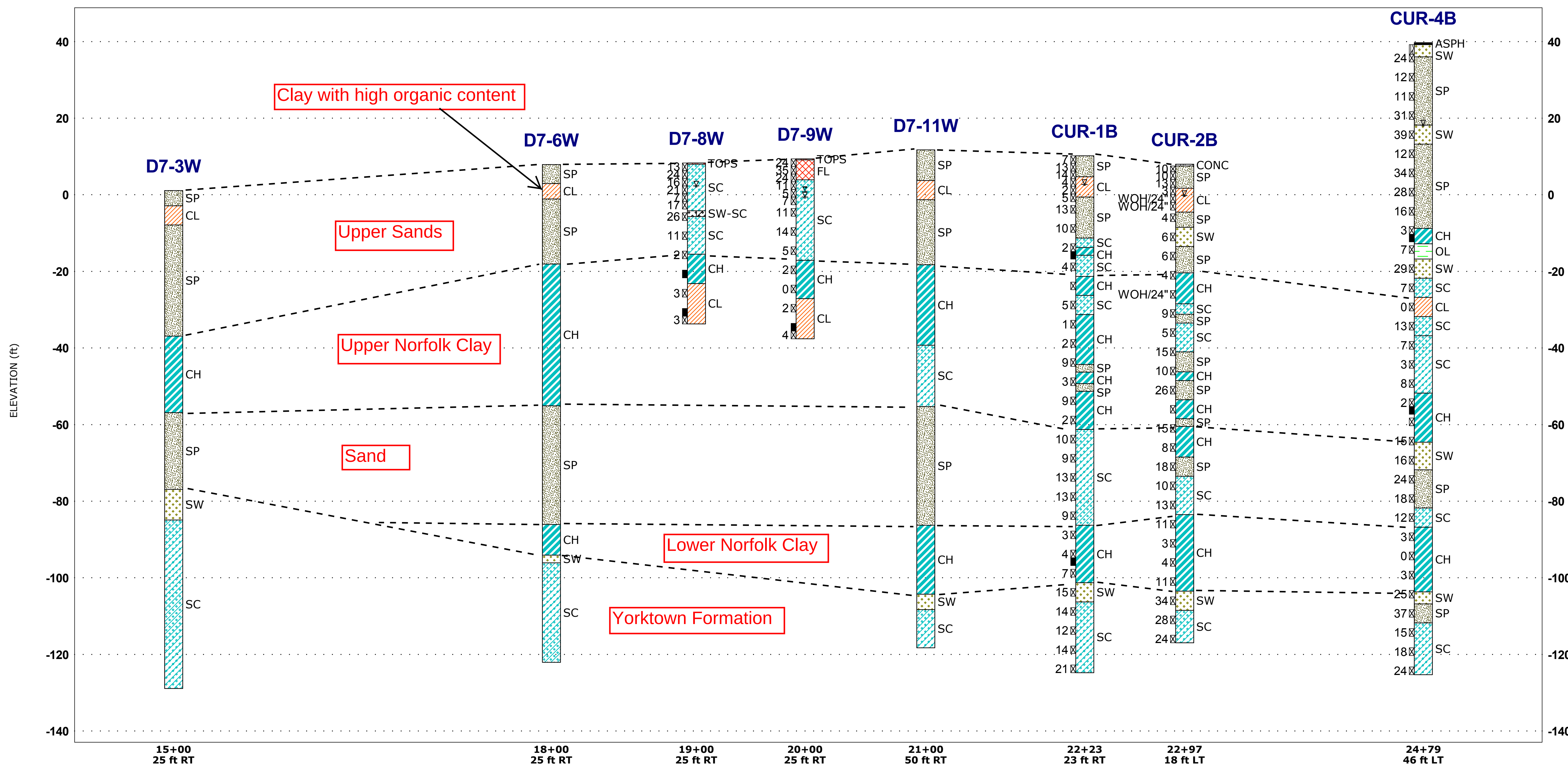
No.	Description	Date	Data:	Date	Plan No.	Sheet No.
Revisions			Drawn: MJS / Checked: JND	11/1/10	KR2	6-C

Drawing 7: PSA I64, D7, AND BRIDGE STRATIGRAPHY

FHWA REGION	STATE	FEDERAL AID ROUTE	FEDERAL AID PROJECT	STATE ROUTE	STATE PROJECT	SHEET NO.
3	VA.		NH-264-6(098)		0264-122-108	6A

PSA I64, D7, AND BRIDGE

D7 WALL AND BRIDGE



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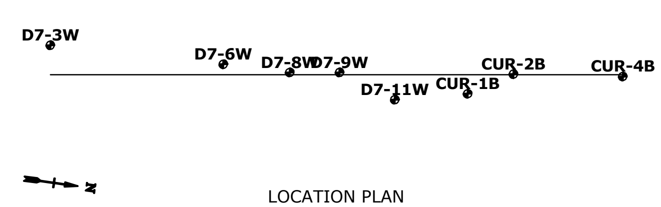


LOCATION PLAN
(not to scale)

Notes: See borehole logs for complete data
See Material and Sample Symbols List

SPT_FENCEAB:BORING LOGS I64 D7 AND BRIDGE.GPJ

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF TRANSPORTATION

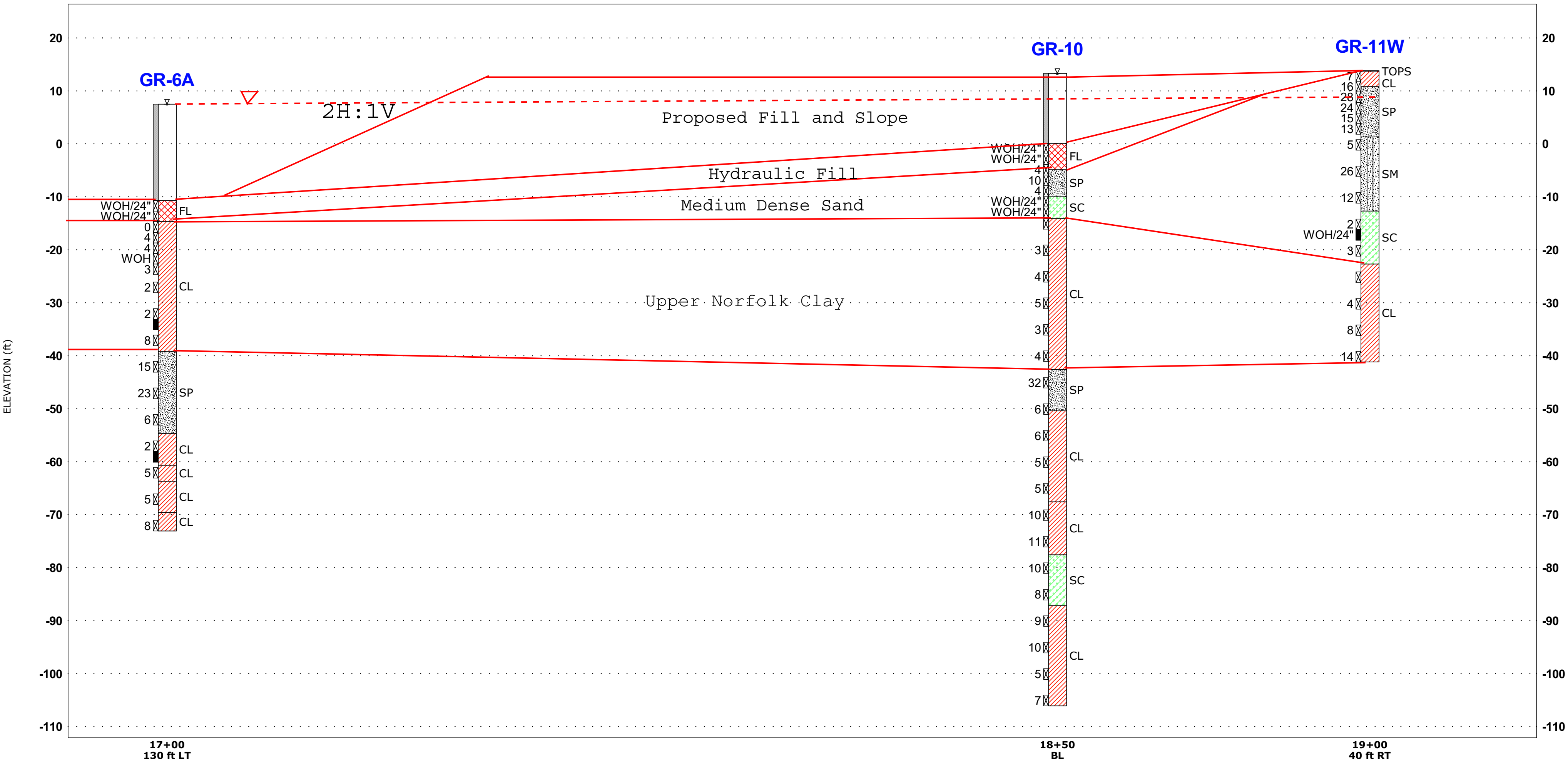
MATERIALS DIVISION

0264-122-108
ENGINEERING GEOLOGY

No.	Description	Date
Revisions		

Data:	Date	Plan No.	Sheet No.
Drawn: MJS / Checked: JND	10/29/2010	D7	6A

Drawing 8:PSA GREENWICH- STA. 17+50 SLOPE STABILITY



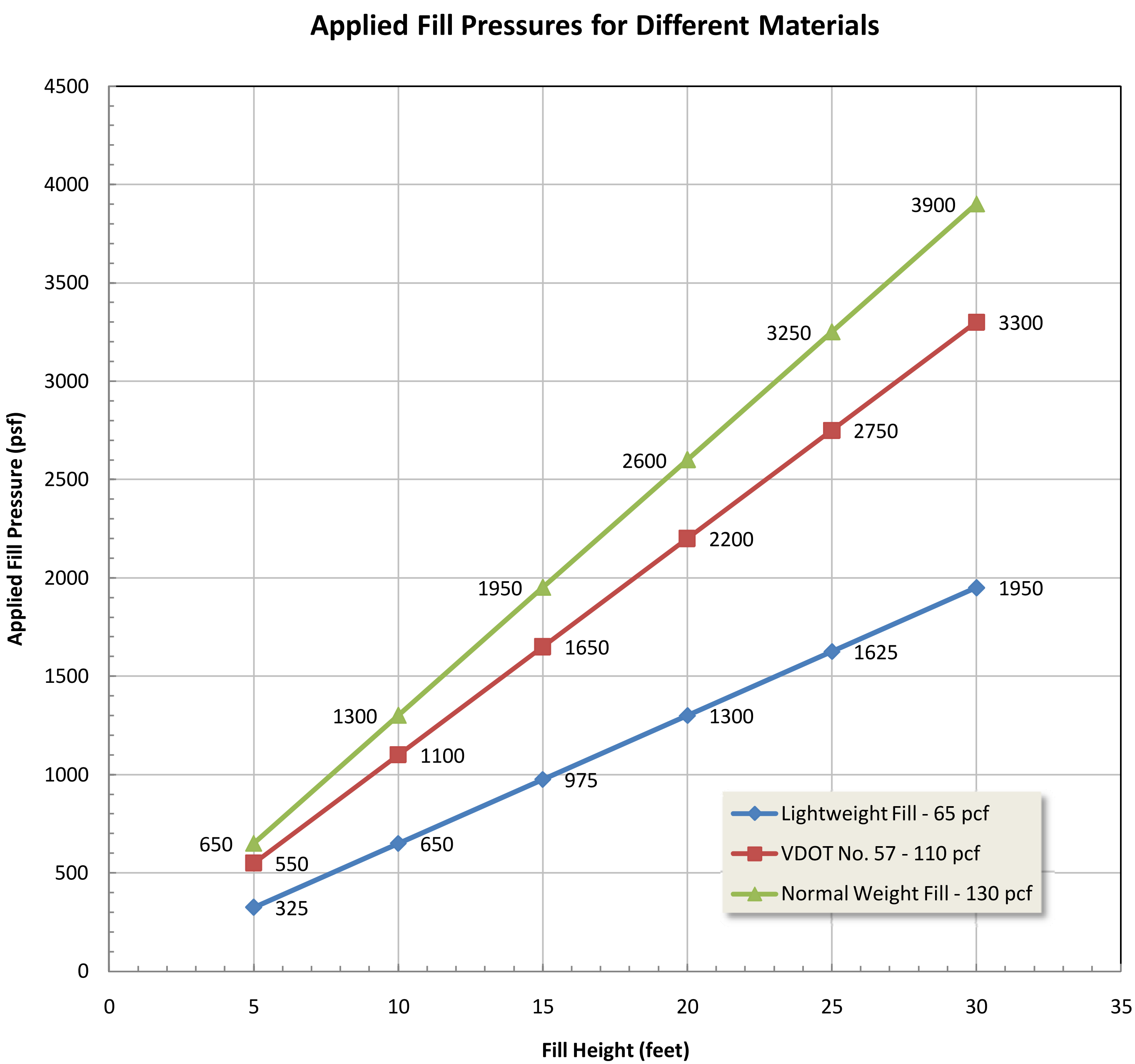

Applied Fill Pressures for Different Materials
Applied Fill Pressure (psf)
Fill Height (feet)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
0
5
10
15
20
25
30
35
650
1300
1950
2600
3250
3900
550
1100
1650
2200
2750
3300
325
650
975
1300
1625
1950
Lightweight Fill - 65 pcf
VDOT No. 57 - 110 pcf
Normal Weight Fill - 130 pcf

TABLE 2 – SUMMARY OF SLOPE (2H:1V) STABILITY ANALYSES FOR I-64/264 INTERCHANGE PROJECT USING CURRENT GEOMETRY AND NORMAL WEIGHT FILL (UNIT WEIGHT = 130 PCF)

PSA	Station	Proposed Fill Geometry	Susceptible Subsurface Conditions	Estimated Factor of Safety Against Slope Stability Failure	Comments
Greenwich	17+50 (South Abutment)	Fill Height = 23 ft Width of Fill = 150 ft Slope	• 5 ft of hydraulic fill • 25 ft of upper Norfolk clay	Short-term = 0.9 Long-term = 1.5	Hydraulic fill is weak material and susceptible to failure; long-term analysis predicated on assumption that strength of the hydraulic fill increases (ϕ=28°). See Drawing 8.
	17+50 Dredged (South Abutment)	Fill Height = 23 ft Width of Fill = 150 ft Slope	• 25 ft of upper Norfolk clay	Short-term = 1.5 Long-term = 1.5	Hydraulic fill has been removed. A flattened slope (2.5H:1V) is also recommended to ensure Long-term FS > 1.5. See Drawing 8.
	24+90 (South Abutment)	Fill Height = 30 ft Width of Fill = 116 ft Slope/Wall	• 26 ft of upper medium dense sand • 37 ft of upper Norfolk clay	Short-term = 1.8 Long-term = 2.5	Short and long-term factors of safety are higher than recommended values.
Note: The recommended factors of safety for short-term and long-term stability are 1.3 and 1.5 respectively.					

TABLE 3 – SUMMARY OF GLOBAL STABILITY ANALYSES OF MSE RETAINING WALLS FOR I-64/264 INTERCHANGE PROJECT USING CURRENT GEOMETRY AND NORMAL WEIGHT FILL (UNIT WEIGHT = 130 PCF)

PSA	Station	Proposed Fill Geometry	Susceptible Subsurface Conditions	Estimated Factor of Safety	Comments
Greenwich	24+90 (South Abutment)	Fill Height = 27 ft Width of Fill = 116 ft Slope/Wall	• 26 ft of medium dense sand • 37 ft of upper Norfolk clay	FS = 1.4 (short-term equals long-term)	Failure occurs through upper medium dense sand; short-term and long-term factors of safety are equal.
	32+30 (North Abutment-Along baseline)	Fill Height = 17 ft Fill runs length of road Slope/Wall	• 26 ft of medium dense sand • 37 ft of upper Norfolk clay	FS = 1.4 (short-term equals long-term)	Failure occurs through upper medium dense sand; short-term and long-term factors of safety are equal.
	32+50 (North Abutment-cross-section)	Fill Height = 15 ft Width of Fill = 116 ft Slope/Wall	• 26 ft of medium dense sand • 37 ft of upper Norfolk clay	FS = 1.6 (short-term equals long-term)	Failure occurs through upper medium dense sand; short-term and long-term factors of safety are equal.
Ramps and Channels	10+00	Fill Height = 32 ft Widening = 105 ft Wall	• 30 ft of interbedded medium dense sand and shallow clays with high organic concentrations • 8 ft of upper Norfolk clay	Short-term = 0.6 Long-term = 1.3	Failure occurs through shallow clays, retaining wall constructed into slope, and berm in front of wall in long-term.
	19+00	Fill Height =15 ft Width of Fill = 130 ft Wall	• 30 ft of interbedded medium dense sand and shallow clays with high organic concentrations • 8 ft of upper Norfolk clay	Short-term = 1.0 Long-term = 1.7	Failure occurs through shallow clays, retaining wall constructed away from slope, and berm in front of wall in long-term.
	30+00 (Kempsville Rd Bridge)	Fill Height = 23 ft Width of Fill = 75 ft Wall	• 30 ft of interbedded medium dense sand and shallow clays with high organic concentrations • 8 ft of upper Norfolk clay	Short-term = 0.9 Long-term = 1.4	Failure occurs through shallow clays, retaining wall constructed away from slope, and berm in front of wall in long-term.
I-64, D7, and Bridge	22+00	Fill Height = 28 ft Widening = 50 ft Wall	• 30 ft of interbedded medium dense sand and shallow clays with high organic concentrations • 8 ft of upper Norfolk clay	Short-term = 0.7 Long-term = 1.2	Failure occurs through shallow clays, retaining wall constructed into slope, and no berm in front of wall in long-term.
I-64, D7, and Bridge	22+00 (with Berm)	Fill Height = 28 ft Widening = 50 ft Wall	• 30 ft of interbedded medium dense sand and shallow clays with high organic concentrations • 8 ft of upper Norfolk clay	Short-term = 0.7 Long-term = 1.4	A berm that is 5-foot tall and 10-foot wide is constructed in front of wall.
Note: The recommended factors of safety for short-term and long-term stability are 1.3 and 1.5 respectively.					

SUMMARY OF POINTS RELATED TO SLOPE STABILITY

Susceptible Subsurface Conditions

- Hydraulic Fill (PSA Greenwich)
  - 5 to 15 feet thick (typical elevations between +16 ft and -10 ft)
  - Weak material
  - Susceptible to both short-term and long-term instability
- Shallow clays with high organic concentrations (Most prevalent in PSA Ramps and Channel)
  - 5 to 15 feet thick (typical elevations between +5 ft and -10 ft)
  - Very soft material with low shear strength
  - Susceptible to both short-term and long-term instability
- Medium dense sands (All PSAs)
  - 10 to 30 feet thick (typical elevations below +20 ft and above -20 ft)
  - Interbedded with shallow clays
  - Medium dense material with relatively low friction angle ($\phi = 32°$)
- Upper Norfolk clays (All PSAs)
  - 10 to 40 feet thick (typical elevations below -10 ft and above -50 to -60 ft)
  - Soft material
  - Based on current analysis, only impacts stability in PSA Greenwich where overlying medium dense sands have been excavated

Slope Stability Analysis- PSA Greenwich

- Short-term slope stability
  - Failure through hydraulic fill is major concern
  - Hydraulic fill is generally present in cross-sections where slope is constructed into lake especially Sta. 17+00 through Sta. 22+00
  - At higher fill heights (> 10 feet) with normal unit weight fill, estimated FS decreases and becomes less than recommended FS
  - Stability can be improved (dredging, staged construction, subgrade improvement, flatter slopes, lightweight materials, etc.)
- Long-term slope stability
  - Failure occurs through medium dense sand and/or hydraulic fill
  - Generally not a concern
  - Stability can be improved (flattening slope to 2.5H:1V, etc.)

Global Stability Analysis of MSE Retaining Walls- PSA Greenwich

- Short-term global stability
  - Failure generally occurs through medium dense sand
  - Equal to long-term FS
  - Estimated FS is generally above recommended FS
- Long-term global stability
  - Failure generally occurs through medium dense sand
  - Equal to short-term FS
  - At higher fill heights (> 15 feet) with normal unit weight fill, estimated FS decreases and becomes less than recommended FS
  - Stability can be improved (subgrade improvement, lightweight materials, etc.)

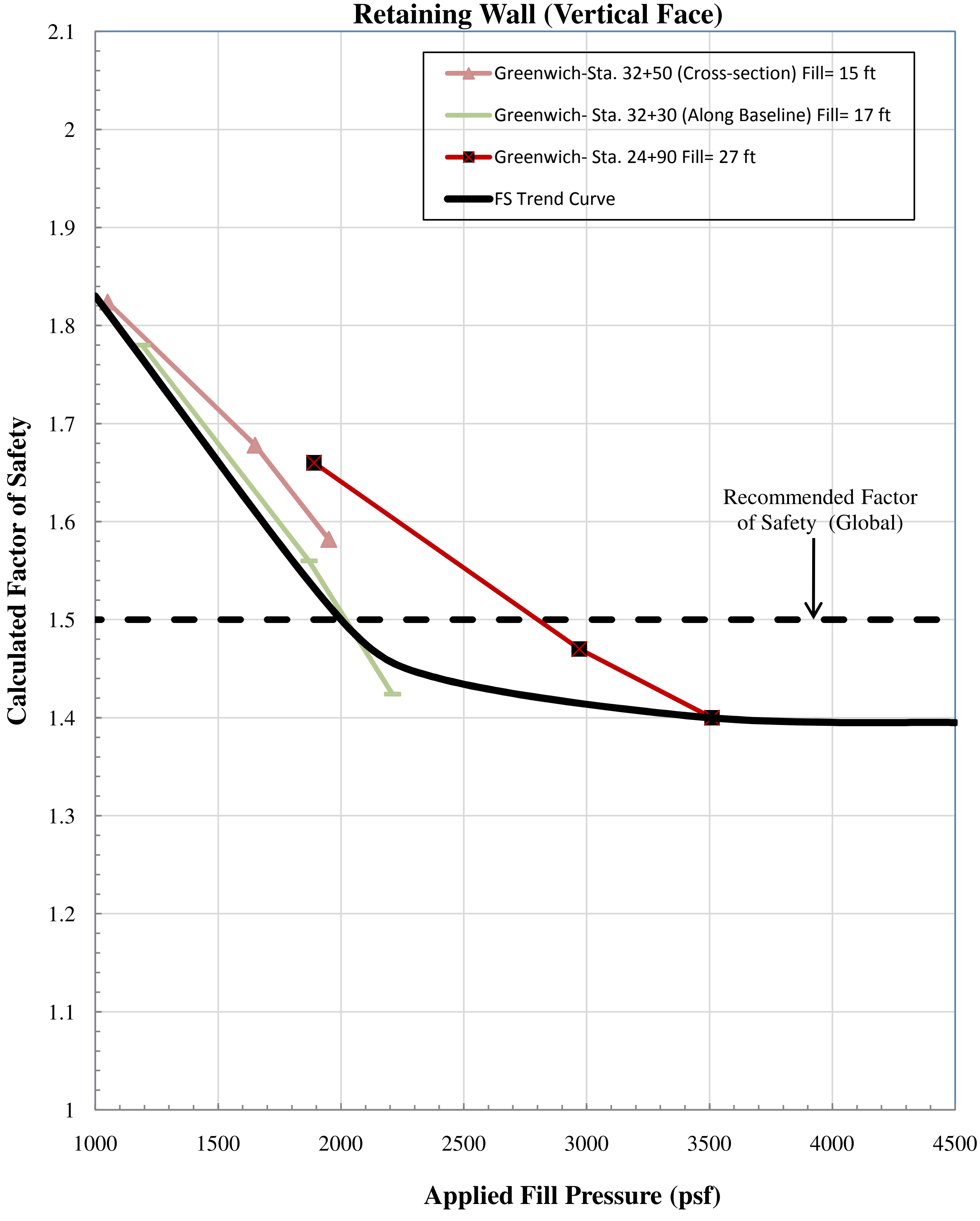
Global Stability Analysis of MSE Retaining Walls- PSA I64, D7, and Bridge and PSA Ramps and Channel

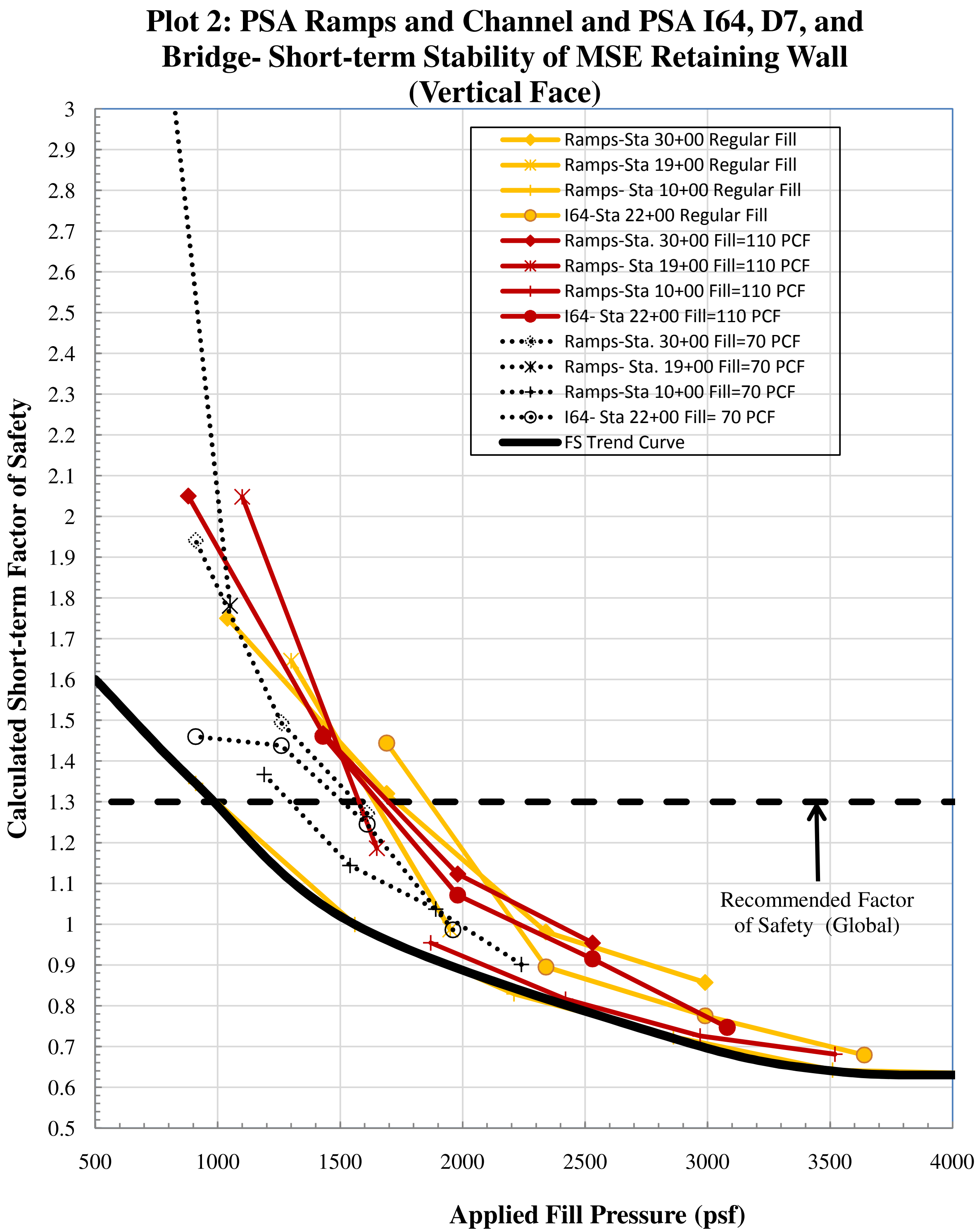
- Short-term global stability
  - Similar stratigraphy observed across both PSA I64, D7, and Bridge and PSA Ramps and Channel
  - Failure generally occurs through shallow clay with high organic content
  - At higher fill heights (> 8 feet) with normal weight fill, estimated FS decreases and becomes less than recommended FS
  - When the MSE Retaining Wall width is twice the MSE Retaining Wall height and fill with a unit weight of 70 PCF is used, the estimated short-term factor of safety is generally above 1.3
  - Stability can be improved (lightweight materials, subgrade improvement, widening the retaining wall, staged construction, construction of berms, etc.)
- Long-term slope stability
  - Similar stratigraphy observed across both PSA I64, D7, and Bridge and PSA Ramps and Channel
  - Failure generally occurs through shallow clay with high organic content
  - Berms constructed for relocated channel in front of retaining walls in PSA Ramps and Channel, but not PSA I64, D7, and Bridge
  - Stability improves with construction of berm in front of retaining wall in PSA I64, D7, and Bridge and may be necessary
  - At higher fill heights (> 20 feet) with normal weight fill, estimated FS decreases and becomes less than recommended FS
  - Long-term slope stability can be improved (subgrade improvement, lightweight materials, increasing width of retaining wall, construction of berms, etc.)

Examples of Usage of Lightweight Fill and Construction of Berm in Front of Retaining Walls

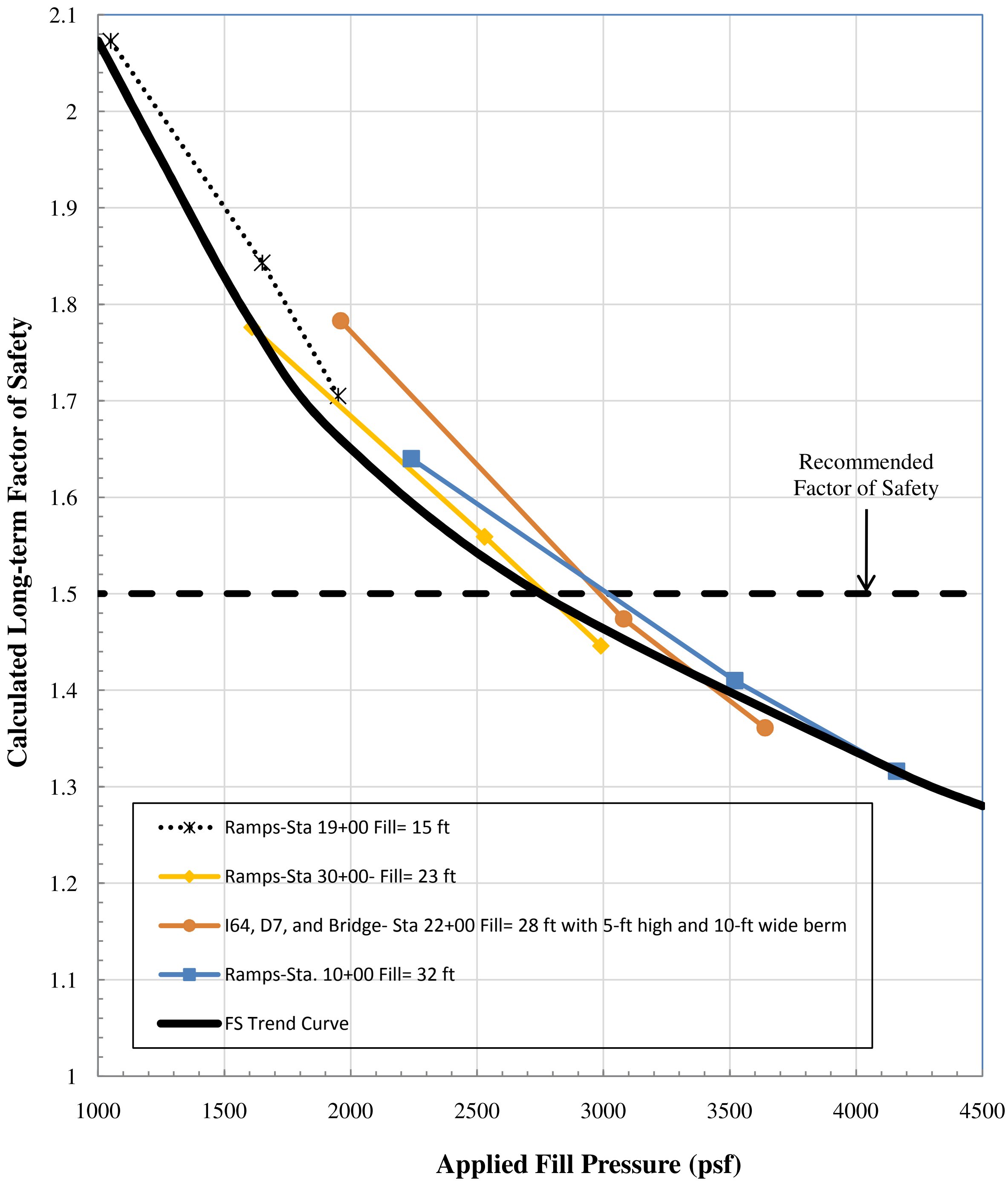
Location	**Short-term Factor of Safety**			**Long-term Factor of Safety**		
	Fill Wt = 130 PCF	**Fill Wt= 110 PCF**	**Fill Wt= 70 PCF**	**Fill Wt = 130 PCF**	**Fill Wt= 110 PCF**	**Fill Wt= 70 PCF**
Greenwich Rd Station 24+90 (South Abutment)	1.4	1.5	1.7	1.4	1.5	1.7
Ramps and Channel Station 30+00 (North Abutment)	0.9	1.0	1.3	1.4	1.6	1.8
Ramps and Channels Station 10+00	0.6	0.7	0.9	1.3	1.4	1.6
I64, D7, and Bridge Station 22+00 (no berm)	0.7	0.7	1.0	1.2	1.2	1.4
I64, D7, and Bridge Station 22+00 (with 5-ft high and 10-ft wide berm in front of wall for short and long-term analysis)	0.7	0.8	1.2	1.4	1.5	1.8
General Conclusion: Lightweight fill can be used in the construction of embankments to help increase the estimated factor of safety and decrease susceptibility to stability failure. Berms are present only in the long-term analysis at the Ramps and Channel Stations 30+00 and 10+00, but are not present at any other stations unless specifically stated.						

Plot 1: PSA Greenwich- Short and Long-term Stability of MSE Retaining Wall (Vertical Face)

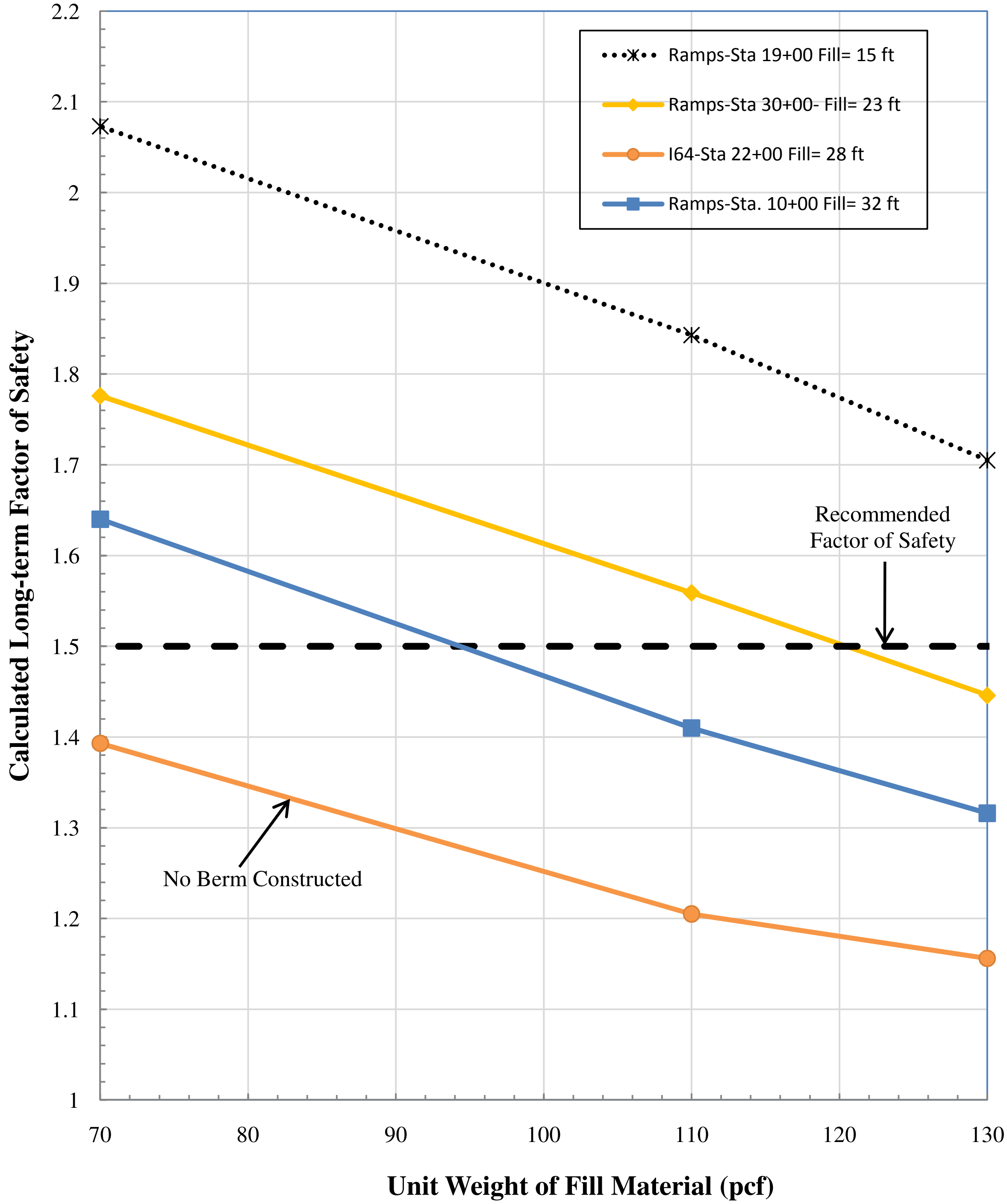



Plot 2: PSA Ramps and Channel and PSA I64, D7, and Bridge- Short-term Stability of MSE Retaining Wall (Vertical Face)
Calculated Short-term Factor of Safety
Applied Fill Pressure (psf)
Ramps-Sta 30+00 Regular Fill
Ramps-Sta 19+00 Regular Fill
Ramps- Sta 10+00 Regular Fill
I64-Sta 22+00 Regular Fill
Ramps-Sta. 30+00 Fill=110 PCF
Ramps- Sta 19+00 Fill=110 PCF
Ramps-Sta 10+00 Fill=110 PCF
I64- Sta 22+00 Fill=110 PCF
Ramps-Sta. 30+00 Fill=70 PCF
Ramps- Sta. 19+00 Fill=70 PCF
Ramps-Sta 10+00 Fill=70 PCF
I64- Sta 22+00 Fill= 70 PCF
FS Trend Curve
Recommended Factor of Safety (Global)
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
500
1000
1500
2000
2500
3000
3500
4000

Plot 3: PSA Ramps and Channel and PSA I64, D7, and Bridge-Long-term Stability of MSE Retaining Wall (Vertical Face)



Plot 4: PSA Ramps and Channel and PSA I64, D7, and Bridge-
Long-term Stability of MSE Retaining Wall (Vertical Face)



Plot 5: PSA Ramps and Channel and PSA I64, D7, and Bridge-
Long-term Stability of MSE Retaining Wall (Vertical Face)

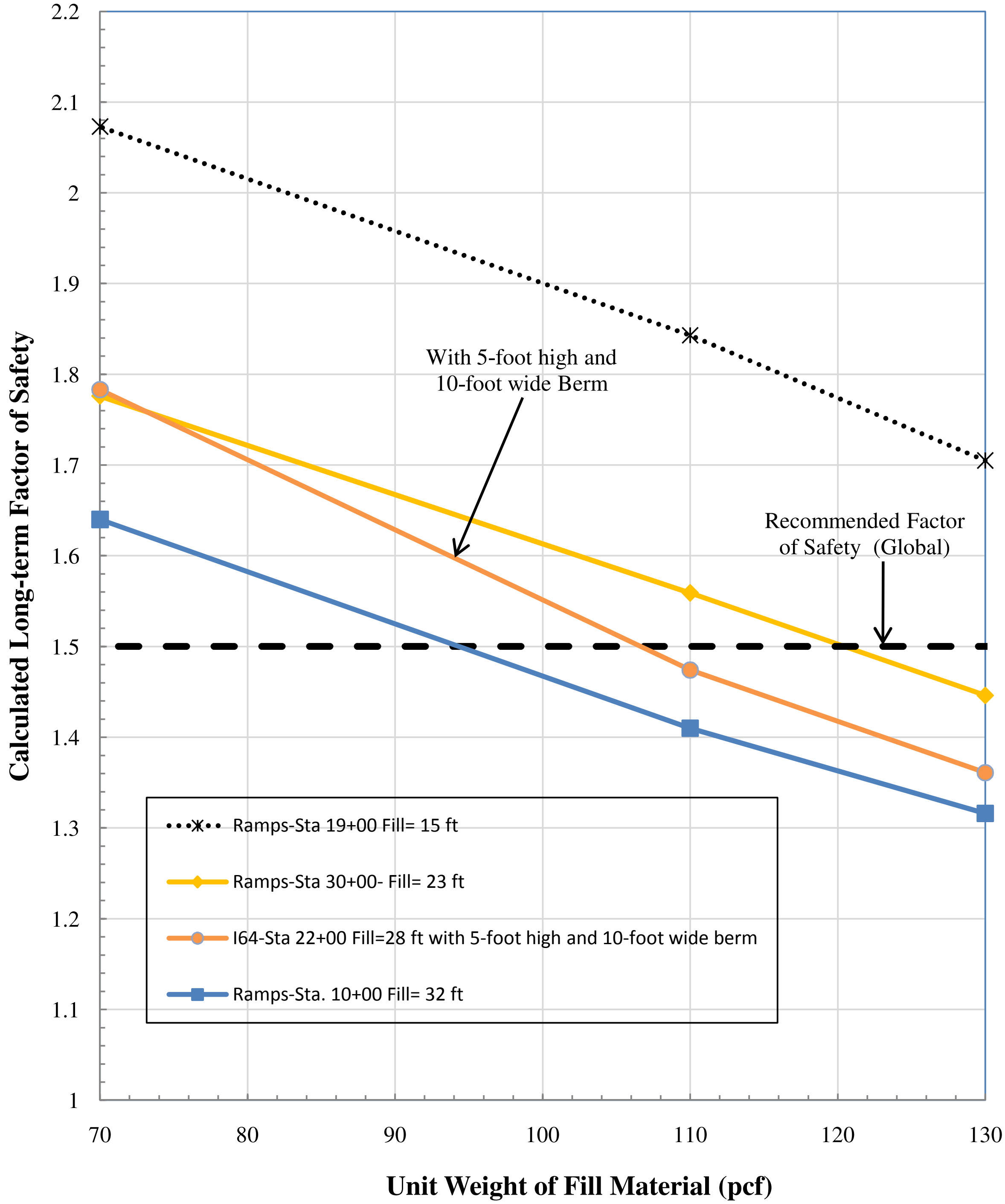


TABLE 4 – SUMMARY OF SETTLEMENT MAGNITUDE AND TIMERATE ANALYSES FOR I-64/264 INTERCHANGE PROJECT

PSA	Station	Proposed Fill Geometry	Compressible Subsurface Conditions	Representative Exploration	Estimated Maximum Settlement (Fill Wt = 130 pcf)	Estimated Time Rate of Settlement (No Improvement)	Comments on Settlement
Greenwich	24+90 (South Abutment)	• Fill Height = 30 ft • Width of Fill = 116 ft • Wall / Slope	• 37 ft of upper clay (with 2 sand seams) • 7 ft of lower clay • Yorktown at El. -68 ft	GR-19W	24 inches total 10 inches rapid 14 inches over time	t < 3 in = 7 months t < 1 in = 1.3 years	2 sand seams speed up consolidation
	32+50 (North Abutment)	• Fill Height = 20 ft • Width of Fill = 116 ft • Wall / Slope	• 36 ft of upper clay (with 1 sand seam) • 16 ft of lower clay • Yorktown at El. -66 ft	GR-26 and GR-27W	17 inches total 6 inches rapid 11 inches over time	t < 3 in = 1 year t < 1 in = 2.5 years	1 sand seam, slower compared to south side
Ramps and Channels	16+00	• Fill Height = 26 ft • Widening = 105 ft • Wall / Slope	• 29 ft of upper clay (interbedded with sand) • 44 ft of lower clay • Yorktown at El. -99 ft	D7CD-6W and D7CD-7W	30 inches total 8 inches rapid 22 inches over time	t < 3 in = 1 year t < 1 in = 2 years	Thinner upper clay than Greenwich, but no sand seams
	30+00 (West Abut. Kempsville Rd Bridge)	• Fill Height = 27 ft • Width of Fill = 75 ft • Wall / Slope	• 10 ft of upper clay (interbedded with sand) • 51 ft of lower clay • Yorktown at El. -103 ft	KR2-1BA	19 inches total 10 inches rapid 9 inches over time	t < 3 in = 2 months t < 1 in = 1 year	Relatively thin upper clay
I-64, D7, and Bridge	18+00	• Fill Height = 17 ft • Widening = 45 ft • Wall	• 37 ft of upper clay • 8 ft of lower clay • Yorktown at El. -94 ft	D7-6W	9 inches total 5 inches rapid 4 inches over time	t < 3 in = 1 month t < 1 in = 6 months	Relatively low fill height and narrow widening, limited influence

SUMMARY POINTS RELATED TO SETTLEMENT

Compressible Subsurface Conditions

- Shallow clays with high organic concentrations
    - 5 to 15 feet thick (typical elevations between +5 ft and -10 ft)
    - Observed most prevalently at Ramps and Channels
    - Highly compressible, most likely OCR = 1 to 2
    - Secondary compression can be an issue in organic clays
- Upper Norfolk clays
    - 10 to 40 feet thick (typical elevations below -10 ft and above -50 to -60 ft)
    - Observed at all PSAs
    - Moderately to highly compressible, preconsolidated to 3,000 to 4,000 psf (typical OCR = 1.2 to 2.2)
- Lower Norfolk clays
    - 5 to 50 feet thick (typical elevations below -50 to -60 ft and above Yorktown Formation)
    - Observed at all PSAs
    - Highly compressible, preconsolidated to 8,000 psf (typical OCR = 1.8 to 2.1)

Magnitude of Settlement- Example at Ramps and Channels, Station 16+00

- Total Settlement = 30 inches
    - Shallow clay w/organics = 13 inches = 43%
    - Upper Norfolk Clay = 7 inches = 23%
    - Lower Norfolk Clay = 4 inches = 13%
    - Sands (combined) = 6 inches = 21%
- Most settlement comes from upper clays (shallow organic + upper Norfolk) – about 65%
    - Embankment heights (normal weight fill) higher than about 10 to 15 feet push these clays into normally consolidated stress range and greater settlement
- Less settlement comes from lower clays – 15%
    - Tallest embankment heights (about 30 feet with normal weight fill) typically keep lower clays in recompression stress range and result in less settlement

Time Rate of Settlement

- Settlement occurs over time in soft, saturated clays as excess pore water pressure induced by stress increases is dissipated
    - Occurs slowly in thicker layers because drainage path is longer
    - Occurs slowly in clays in normally consolidated stress range, more quickly in recompression stress range
    - Sand seams interbedded in clay layers greatly accelerate time rate of settlement
- Note: Estimates are limited in their accuracy – actual settlements must be monitored in the field with settlement plates and accurate, timely survey measurements to adjust initial estimates
- Prefabricated Vertical (PV) Drains (wick drains) can be used to accelerate the time rate of settlement by providing shorter, lateral drainage paths

Examples of PV Drains at Three Locations

Location	Estimated Maximum Settlement (Fill Wt = 130 pcf)	Time to < 3 inches			Time to < 1 inch		
		No PV Drains	With PV Drains 5 ft spacing	% Increase in Rate	No PV Drains	With PV Drains 5 ft spacing	% Increase in Rate
Greenwich Rd Station 24+90 (South Abutment)	24 inches total 10 inches rapid 14 inches over time	7 months →	2 months	350 %	1.3 years →	3 months	500 %
Greenwich Rd Station 32+50 (North Abutment)	17 inches total 6 inches rapid 11 inches over time	1 year →	2 months	600 %	2.5 years →	4 months	750 %
Ramps and Channels Station 16+00	30 inches total 8 inches rapid 22 inches over time	1 year →	3 months	400 %	2 years →	4 months	600 %

General Conclusion: PV Drains can be installed through the upper clays at a reasonable spacing of about 5 feet to accelerate the time rate of settlement. The time to less than 3 inches of settlement should be less than about 3 months. The time to less than 1 inch of settlement might be less than about 6 months.

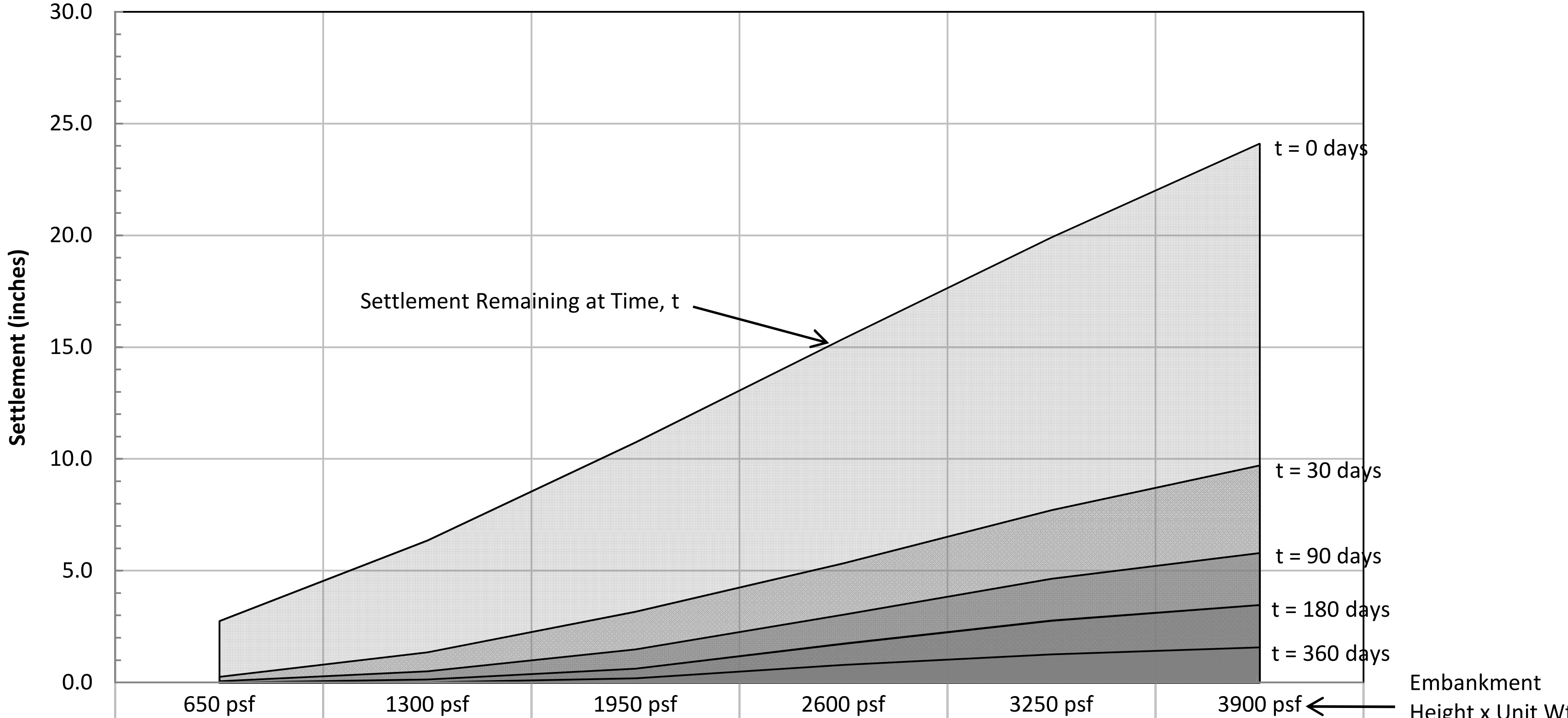
Secondary Compression

- Secondary compression occurs over long periods of time with no additional change in vertical stress, after primary consolidation settlements are complete (> 95% consolidation)
- Is generally an issue with normally consolidated clays, and more so with clay with high organic content
- Is not generally an issue with clays in the recompression range
- Is a function of the soil type, layer thickness, and time – but not the magnitude of the load

Example of Secondary Compression at PSA Ramps and Channels, Station 16+00:

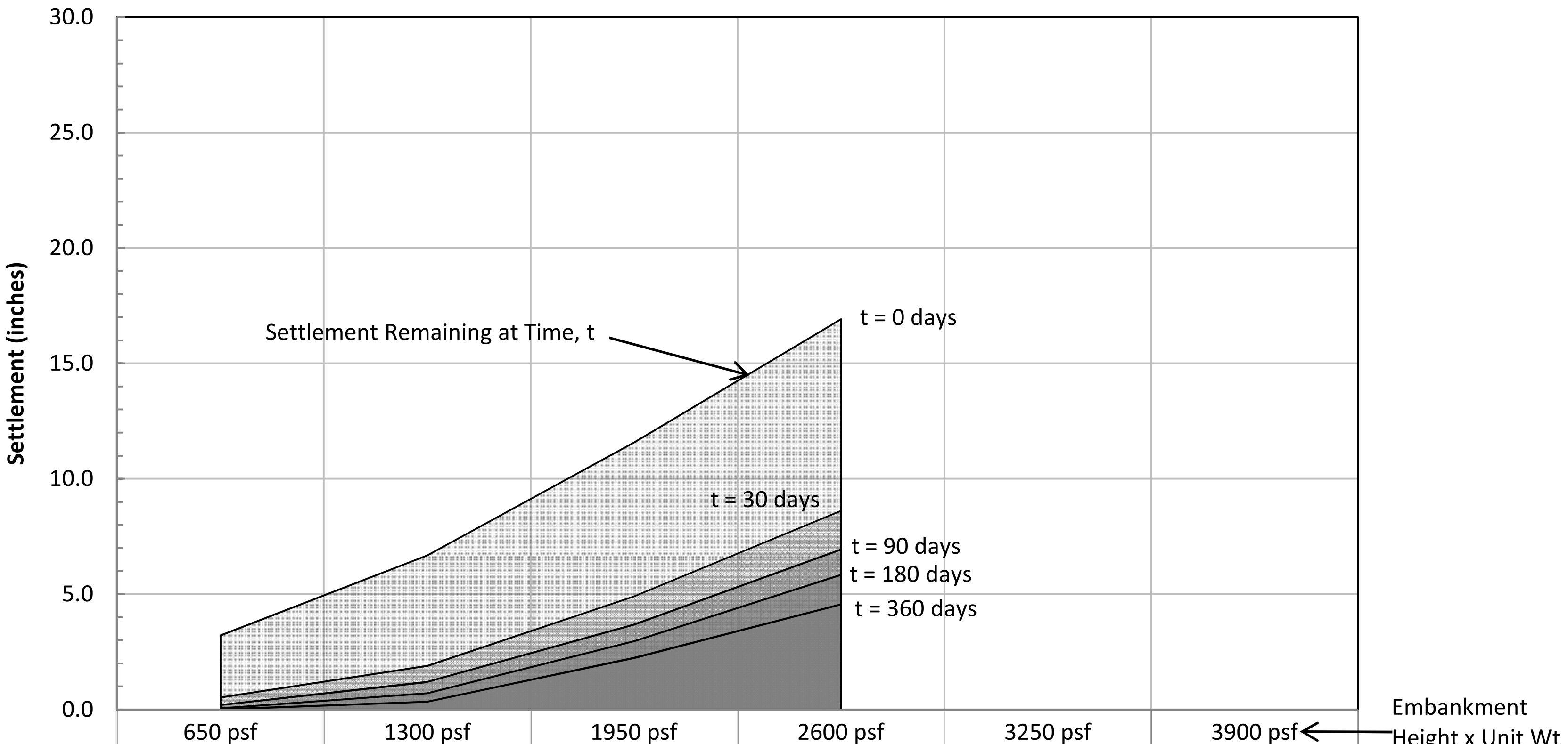
- 29 feet of upper clay (20 feet of upper Norfolk clay + 9 feet of clay with high organic content)
- Assume time to end of primary consolidation settlement with PV drains = 6 months
- Assume design life of embankment = 75 years
- Estimate secondary compression is approximately = 5 inches in 75 years

Timerate of Settlement Analysis
PSA Greenwich Rd Bridge / Station 24+90 (South Abutment)



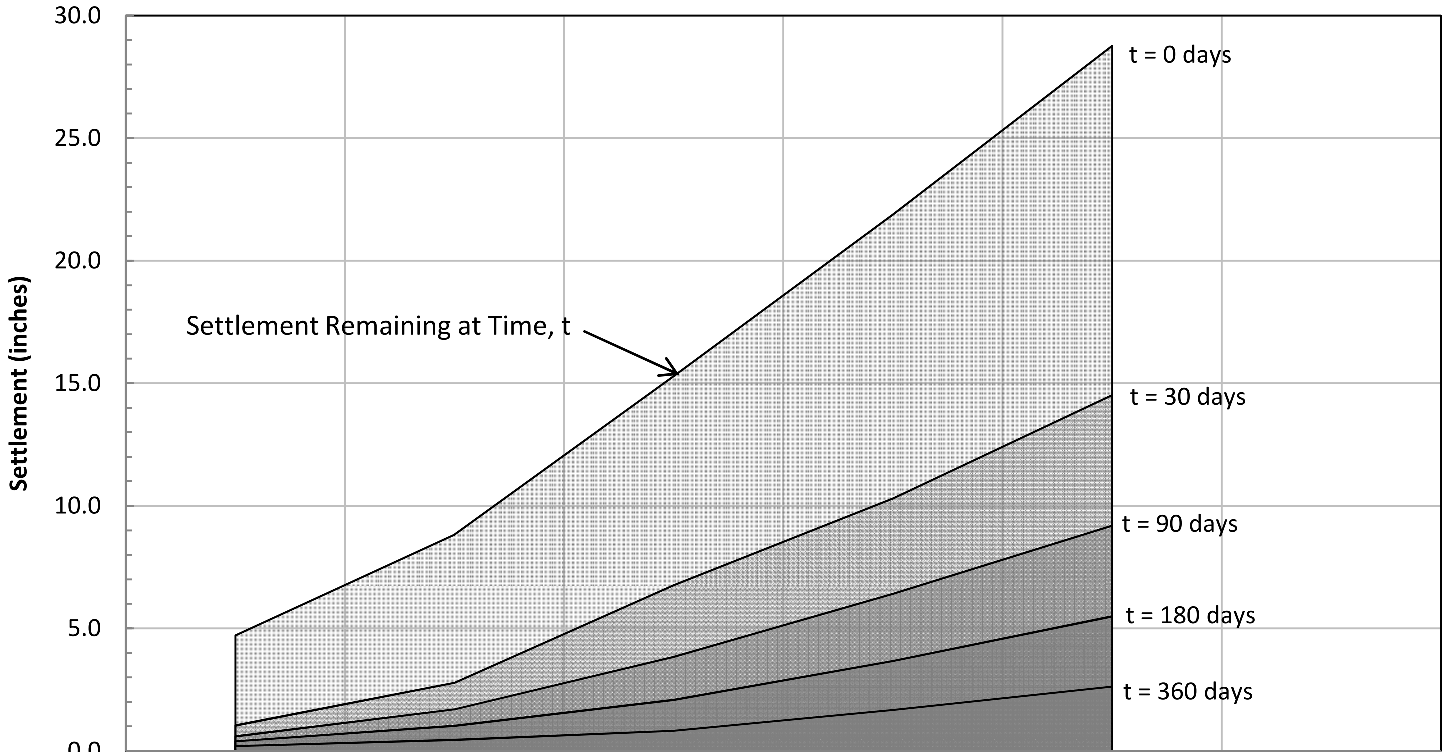
	650 psf	1300 psf	1950 psf	2600 psf	3250 psf	3900 psf
t = 0 days	2.7	6.4	10.7	15.4	19.9	24.1
t = 30 days	0.3	1.4	3.2	5.3	7.7	9.7
t = 90 days	0.1	0.5	1.5	3.0	4.6	5.8
t = 180 days	0.0	0.1	0.6	1.7	2.8	3.5
t = 360 days	0.0	0.0	0.2	0.8	1.3	1.6

Timerate of Settlement Analysis
PSA Greenwich Rd Bridge / Station 32+50 (North Abutment)



	650 psf	1300 psf	1950 psf	2600 psf	3250 psf	3900 psf
t = 0 days	3.2	6.7	11.6	16.9		
t = 30 days	0.5	1.9	4.9	8.6		
t = 90 days	0.2	1.2	3.7	6.9		
t = 180 days	0.1	0.7	3.0	5.8		
t = 360 days	0.0	0.3	2.2	4.6		

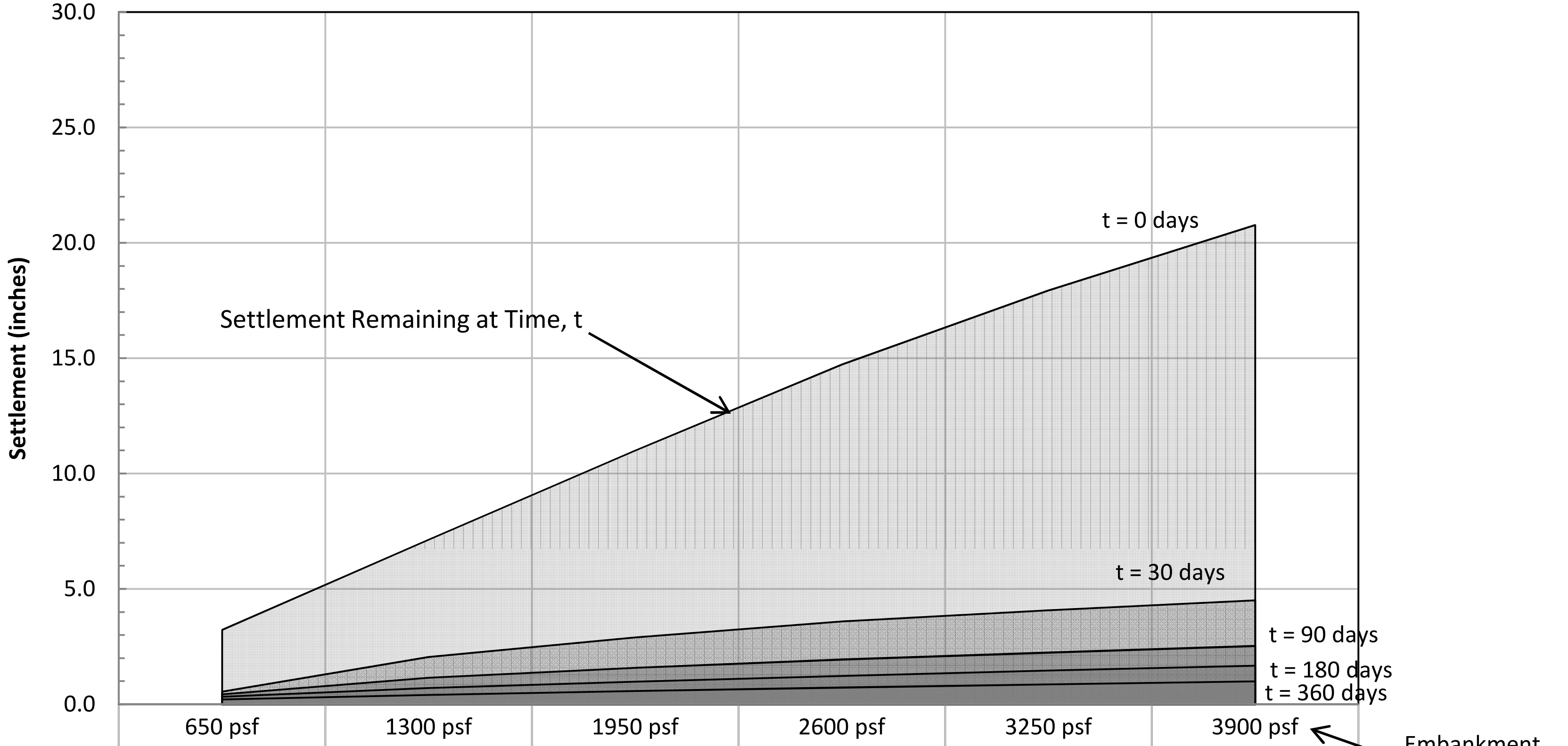
Timerate of Settlement Analysis
PSA Ramps and Channels / Station 16+00



	650 psf	1300 psf	1950 psf	2600 psf	3250 psf	3900 psf
t = 0 days	4.7	8.8	15.3	21.9	28.8	
t = 30 days	1.0	2.8	6.8	10.3	14.5	
t = 90 days	0.6	1.7	3.8	6.4	9.2	
t = 180 days	0.4	1.0	2.1	3.7	5.5	
t = 360 days	0.2	0.5	0.8	1.7	2.6	

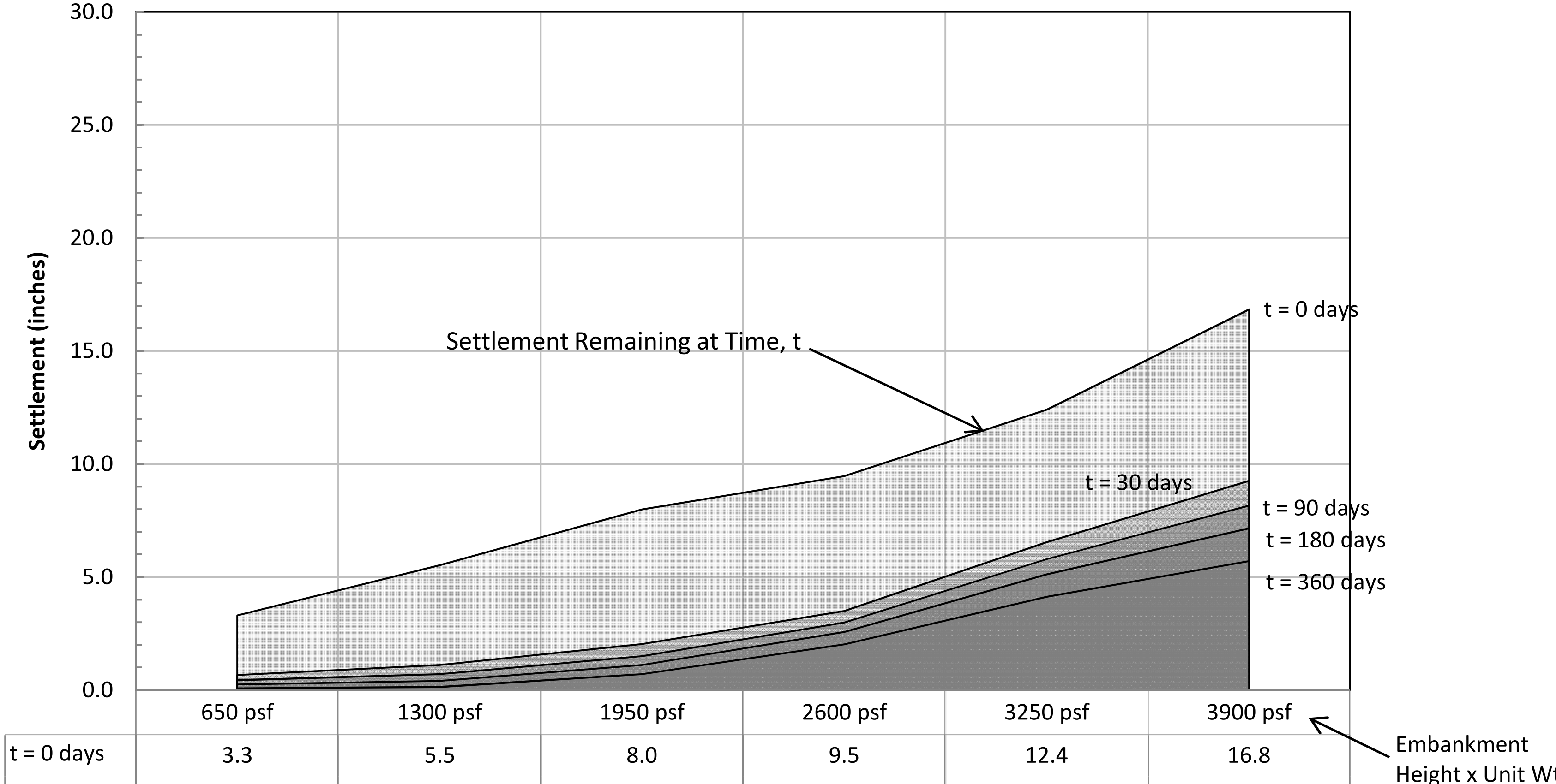
Embankment Height x Unit Wt

Timerate of Settlement Analysis
PSA Ramps and Channels / Station 30+00

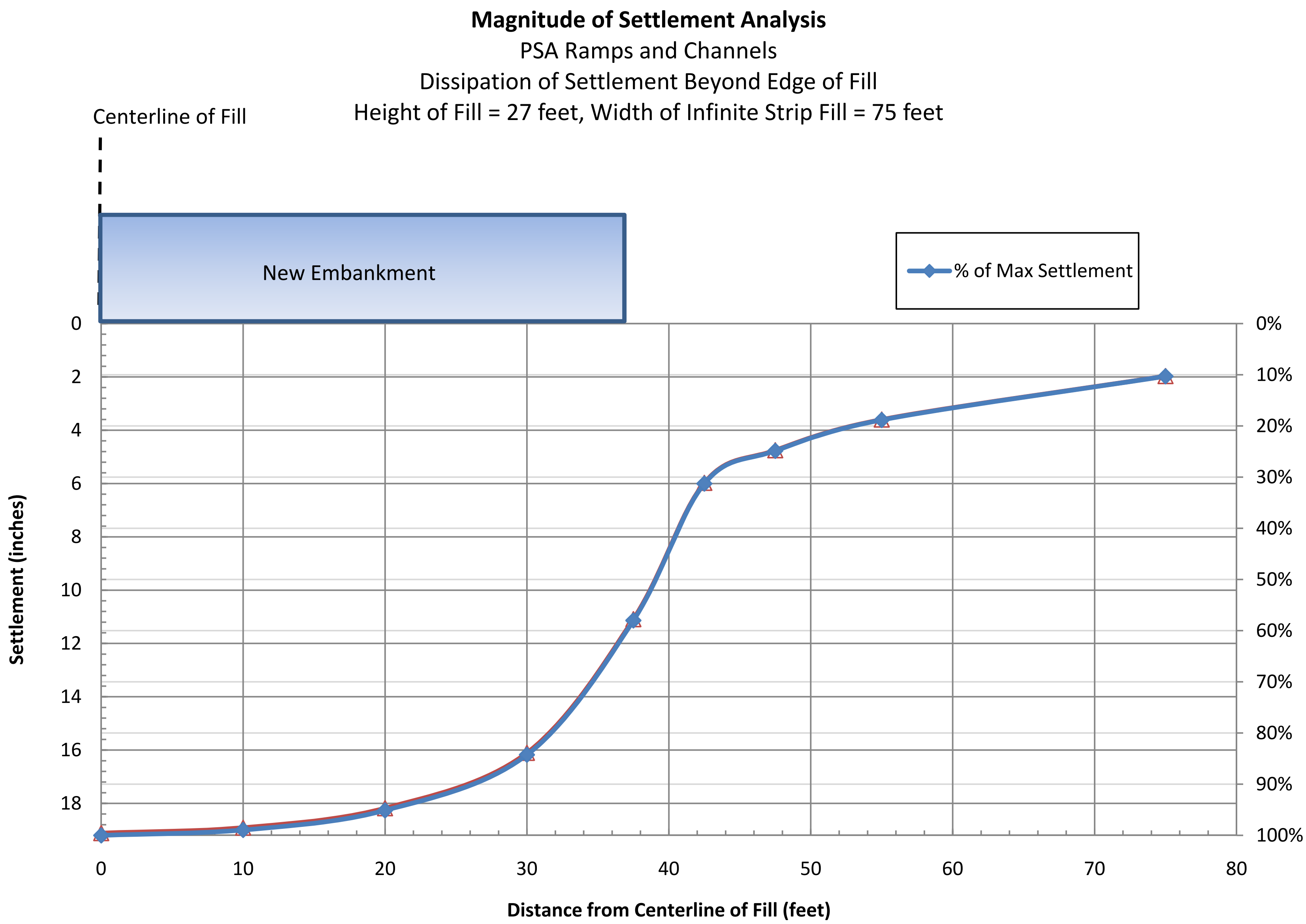


	650 psf	1300 psf	1950 psf	2600 psf	3250 psf	3900 psf
t = 0 days	3.2	7.1	11.0	14.7	17.9	20.8
t = 30 days	0.6	2.1	2.9	3.6	4.1	4.5
t = 90 days	0.4	1.2	1.6	1.9	2.2	2.5
t = 180 days	0.3	0.7	1.0	1.2	1.5	1.7
t = 360 days	0.2	0.4	0.6	0.7	0.9	1.0

Timerate of Settlement Analysis
PSA I-64, D7, and Bridge / Station 18+00



	650 psf	1300 psf	1950 psf	2600 psf	3250 psf	3900 psf
t = 0 days	3.3	5.5	8.0	9.5	12.4	16.8
t = 30 days	0.7	1.1	2.0	3.5	6.6	9.3
t = 90 days	0.4	0.7	1.5	3.0	5.8	8.2
t = 180 days	0.3	0.4	1.1	2.6	5.1	7.2
t = 360 days	0.1	0.1	0.7	2.0	4.1	5.7


Magnitude of Settlement Analysis
PSA Ramps and Channels
Dissipation of Settlement Beyond Edge of Fill
Height of Fill = 27 feet, Width of Infinite Strip Fill = 75 feet
Centerline of Fill
New Embankment
% of Max Settlement
Settlement (inches)
0
2
4
6
8
10
12
14
16
18
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
10
20
30
40
50
60
70
80
Distance from Centerline of Fill (feet)

Magnitude of Settlement Analysis

PSA Ramps and Channels

Effect of Widening on Existing Embankment Settlement

Height of Fill = 30 feet, Width of Widening = 95 feet