MEMORANDUM

Date: January, 2016
To: Office
From: Adam M. Dyer
Re: EE Memo 1 – Estimated Settlement and Stress on MMC from Development Fill
Wills Street Wharf Building and Ramp, Baltimore, MD
File: 12582B

MRCE has reviewed available subsurface information in the vicinity of the Wills Street Ramp and has estimated settlement resulting from fill placed for development. The purpose of these estimates is to determine if the proposed grading scheme will cause settlement or impose loads which may influence the integrity of the existing multi-media cap (MMC) and Head Maintenance System (HMS) components, including the Soil Bentonite Barrier (S-B Barrier).

Exhibits
Exhibits prepared to illustrate these reports are:

Sketch 1 Assessment of Fill Areas
Drawing GS-A Geologic Section A-A
Analysis 1 Wills Street Ramp
Analysis 2 Wills Street Turnaround
Analysis 3 Wills Street Turnaround in Area of Pre-Load
Analysis 4 Load impact on drainage net based on foundation type.

Appendix A Laboratory Data
Appendix B Assessment of Compressibility Characteristics

References


Site Description
The site straddles remedy Area 1 and 2 in the footprint of the Wills Street alignment and southern Wills Street extension. Generally, the existing ground surface for the proposed development slopes gently from Elev. +10 at the southern foot of Wills Street to Elev. +15 at the south end of the Plaza Garage. The proposed development raises grades for roadway, sloping from approximately Elev. +13 at the south end to Elev. +28 at the Plaza Garage. Retaining wall structures are required at the south, west and north sides to contain the fill. The east side contained by the Wills Street Wharf Building west foundation wall. Utilities will be buried in the fill below the street.

Subsurface Conditions
The southern portion of the site is underlain by the MMC remedy component, a layer of granular fill (Stratum F), and compressible organic clay (Stratum O) ranging in thickness from 6 to 20 ft. This compressible layer is generally described as a soft brown to black organic silty clay with trace vegetation and fine sand, and is typically given a USCS designation of OH or OL. Stratum O is underlain by a series of sand and silt layers (Strata S1, S2, S3, M, and S4). Bedrock is at approximately Elev. – 80. Groundwater is controlled by pumping; for design purposes the groundwater table is assumed at approximately Elev. 0. Abandoned foundations and waterfront structures are buried within Strata F and O.

Prior Remedial Earthwork
In preparation for construction of the MMC corrective measure during the 1990s Allied Signal placed a sheet pile retaining structure at the southern foot of Wills Street, constructed a rip-rap embankment, pre-loaded areas of potentially high settlement, and constructed the S-B Barrier, see Sketch 1.

Baltimore City Pier Pre-Load c. 1996:
The Baltimore City Pier was located at the foot of Wills Street in the vicinity of the proposed Wills Street Turnaround and consisted of a timber pile supported relieving platform and headwall. To make way for the MMC, the deck was removed and the timber piles were cut at Elev +1 and abandoned in place. The area was pre-loaded to Elev. +15. Pre-loading included installation of vertical wick drains between the piles.

This analysis assumes that the combination of pile support and soil support was effectively preloaded to Elev. +15. The pre-loading is significant when determining whether Stratum O will be in a recompression or virgin compression loading condition as a result of fill placement to achieve the proposed grades. If the proposed new grade is above that of the pre-load, a significant magnitude of settlement can be expected due to virgin compression of the underlying soil material. The timber pile hard points would reduce settlement magnitude but may cause areas of high strain due to localized differential settlement. If the proposed new grades are below the historic pre-load, only a negligible amount of settlement will occur, in re-compression.

S-B Barrier Construction c. 1999:
The S-B Barrier underlies the center of the proposed ramp and turnaround. A reinforced concrete bridge slab will be present (either existing or new after sheet pile is placed) in all areas where street traffic can travel.
MMC Construction c. 1999:
After completion of the S-B Barrier, the MMC was constructed, including cover soil to the present grade. The MMC contains a 60-mil LLDPE Geomembrane that is susceptible to strain from differential settlement. The performance of the MMC has two design conditions:

1. The Geomembrane covers the entirety of Area 1 and at its’ extents is embedded in the S-B Barrier. As described in EE Memo 1 for the Exelon Project (Ref 3), settlement of greater than 2 inches may cause strain that damages the Geomembrane. The Geomembrane is protected by the underlying crushed stone capillary break layer and the drainage net and the separation geotextile above which will help arch overburden loads over areas of soft support below. The 2 inches of allowable settlement is provided as a design guide and as a magnitude which can be practically estimated and observed.

2. Immediately overlying the Geomembrane is the Drainage Net which allows surface water infiltration to drain to the perimeter of the site and off of Area 1. Drainage Net flow is restricted when a stress greater 2,000 pounds per square foot (psf) is applied to it. However, reduced flow may be acceptable where the drainage basin upslope is covered by a roof or other structure which will manage storm water. As a general design guide, at final construction, total stress acting on the drainage net is limited to 2,000 psf.

Analysis and Assumptions
An overlay of proposed grades, existing conditions, prior remedial earthwork conditions, and buried structures was examined to analyze areas of settlement and loading concern. Three areas were identified as potentially impacting the corrective measures; areal extents are illustrated on Sketch 1.

These areas include:
1. Analysis 1 – Wills Street Ramp: This area is outside the limits of compressible materials.
2. Analysis 2 – Wills Street Turnaround: This area is within the limits of compressible materials and does not overlie an area of pre-loading.
3. Analysis 3 – Wills Street Turnaround in Area of Pre-Load: This area is within the limits of compressible materials and overlies an area of pre-loading.
4. Analysis 4 – Load impact on drainage net based on foundation type.

Settlement
In general, settlement is computed as the sum of three contributors: elastic compression, primary consolidation, and secondary compression. It was assumed that strata below the hard silty clay of Stratum M were incompressible under the potential loadings.

Elastic Compression

Primary Consolidation
Consolidation settlement of compressible strata were estimated using one-dimensional consolidation theory after Terzaghi (1947). Idealized profiles were determined for analysis based on the geologic sections presented on Drawing GS-A. The compressible stratum was divided into sub-layers no greater
than four feet in thickness. The groundwater table was assumed to be at El. 0. In areas where a preload was present, the maximum past pressure was calculated based on this preload. In locations where a preload was not present, the maximum past pressure ($P'_c$) was computed assuming existing conditions. Primary settlement was computed for each sub-layer, and a total primary settlement estimate at each section was determined.

Previous laboratory testing (Appendix A) indicates a correlation between natural water content & compression ratio and swell index & initial void ratio (Appendix B) for Stratum O Clay. Water contents reported in boring MR-505U before cap construction were used in the analyses.

**Secondary Compression**
Secondary compression was computed for a duration of 100 years after fill placement. Secondary compression was estimated in areas of compressible materials where the pre-load was not present.

**Analysis 1: Wills Street Ramp**
The area analyzed lies outside of the limits of the compressible strata and therefore settlement is expected to be less than ½ inch.

**Analysis 2: Wills Street Turnaround**
The area analyzed lies within the limits of compressible strata and outside the limits of pre-loading, therefore significant settlement will result from raising grades to accommodate the proposed turnaround. In this area, proposed fill height is about 3 feet and Stratum O is about 6 feet thick. The proposed fill height and stress history indicate that this area will be in virgin compression. It is estimated that total settlement, $\delta_T$ will be on the order of 1.5 to 2.0 inches and is therefore considered acceptable.

**Analysis 3: Wills Street Turnaround in Area of Pre-Load**
The area analyzed lies within the limits of the Baltimore City Pier pre-load and proposed fill will be below the pre-load of Elev. +15, therefore settlement is expected to be less than ½ inch.

**Additional Load on Drainage Net**

**Analysis 4: Load Impact on Drainage Net based on Foundation Type**
The drainage net in Area 1 has a bearing capacity limit of 2,000 psf. An estimate of shallow foundations supporting the retaining structures was performed to determine how high the wall can be before the toe bearing stresses exceeded the 2,000 psf bearing pressure and what wall height deep foundations would then have to be used.

A cantilever retaining wall with 8 foot wide by 2 foot thick footing and wall with 1.25 foot thick base was analyzed using regular weight fill having a unit weight of 125 pounds per cubic foot. It was estimated that the maximum top of wall elevation is 11 feet above the drainage net elevation for toe bearing stresses to be below 2,000 psf.
**Recommendations**

Settlement estimates show that proposed fill will not result in settlement that is detrimental to the Geomembrane. To confirm this, two permanent settlement plates should be installed in the area of the turnaround (within the area of Analysis 2) as follows:

1. Centered on the turnaround; and
2. South end of the turnaround.

Estimated additional loads planned require retaining wall foundation types:

1. Retaining walls bearing on shallow foundations may be used for up to a top of wall 11 feet above the drainage net elevation;
2. Retaining walls bearing on deep foundations may be used for top of wall between 11 and 16 feet above the drainage net elevation; and
3. Concrete platform bearing on deep foundations must be used for top of wall greater than 16 feet above the drainage net elevation.
NOTES:
1. Proposed grades shown are based on grading plan by MRA provided in October, 2015.
2. Elevations are based on Baltimore City and County Metropolitan Datum (BCCMD).

ANALYSES TO CHECK:
1. Ramp fill outside of organics falls under drainage net limitations, therefore assess retaining wall pressures.
2. Turnaround at foot of ramp is influenced by organics, therefore assess expected settlement using Section A-A.

WILLS STREET WHARF
ANALYSIS 1
Settlement Estimate of Area 1
SETTLEMENT CALCULATION (ANALYSIS AREA 1)

PURPOSE: DETERMINE TOTAL SETTLEMENT FOR ANALYSIS AREA 1

STRATIGRAPHY AND STRESS STATE:

$\gamma_w = 63$pcf

USING BORING MR-713

$\gamma = 125$pcf

$H = 13$ft

$\sigma_{v0}$

$\sigma_{vf}$

DEFINITIONS

F = GRANULAR FILL STRATUM

S2 = MEDIUM TO FINE SAND STRATUM

$H_n = $THICKNESS OF LAYER N

$\Delta\sigma = $CHANGE IN STRESS = $\sigma_{vf} - \sigma_{v0}$

$\sigma_{v0} = $EXISTING VERTICAL EFFECTIVE OBERBURDEN STRESS

$\sigma_{vf} = $FINAL VERTICAL EFFECTIVE OBERBURDEN STRESS
Settlement Calculation (Analysis Area 1)

Calculation of Settlement: \( S_T = S_I + S_c + S_s \)

Where:
- \( S_I = \sum \frac{H_i}{E_i} \) = "elastic" compression for granular, free draining
- \( S_c \) and \( S_s \) not applicable since there is no compressible layer.

Stratum M: Assumed to be heavily consolidated and hence
- \( P_{cm} > P_{co} \), \( C_m \leq C_0 \), \( C_m \leq C_s \)

Stratum F, S2: \( E_i = 740 \) KSF

Assumption based on "EPRI Manual on Estimating Soil Properties for Foundation Design," Table 5-5
(August 1990)

Definitions:
- \( S_T \) = total settlement
- \( S_I \) = immediate elastic settlement
- \( S_c \) = consolidation settlement
- \( S_s \) = secondary compression settlement
- \( e_0 \) = initial void ratio
- \( I \) = influence factor
- \( P_c' \) = maximum past vertical stress
- \( H_Dr \) = length of drainage path
CALCULATION OF IMMEDIATE SETTLEMENT, $S_I$:

$S_I = \Delta \sigma \cdot H \cdot \frac{s_{cr}}{E} \cdot \frac{1}{I} \cdot \frac{1}{E}$  \( I = 1.0 \) FOR 1D LOADING

$H = 25$ ft.

$S_I = 1625 \text{ psi} \cdot 25 \text{ ft} \cdot 1.0 \cdot 74000 = 0.055 \text{ ft} = 0.66 \text{ in}$

TOTAL SETTLEMENT, $S_T$:

$S_T = S_I + S_c + S_s = 0.66 \text{ in} + 0 + 0 = 0.66 \text{ in}$
ANALYSIS 2
Settlement Estimate of Area 2
PURPOSE: DETERMINE TOTAL SETTLEMENT AT KAMP OF ORGANICS LAYER

STRATIGRAPHY AND STRESS STATE:
(Existing and Proposed Conditions)

\( \gamma = 63 \text{pcf} \)

USING BORING MR-505U

\[ F \gamma = 125 \text{pcf} \]
\[ H_5 = 3 \text{ft} \]

\[ F \gamma = 120 \text{pcf} \]

Definitions:
- \( F = \text{GRANULAR FILL STRATUM} \)
- \( O = \text{ORGANIC CLAY STRATUM} \)
- \( S1 = \text{MEDIUM TO FINE SAND STRATUM} \)
- \( H_n = \text{THICKNESS OF LAYER N} \)
- \( \Delta \sigma = \text{CHANGE IN STRESS} = \sigma'_{\text{f}} - \sigma'_{\text{o}} \)
- \( \sigma'_{\text{o}} = \text{EXISTING VERTICAL EFFECTIVE OVERBURDEN STRESS} \)
- \( \sigma'_{\text{f}} = \text{FINAL VERTICAL EFFECTIVE OVERBURDEN STRESS} \)
CALCULATION OF SETTLEMENT: \( S_T = S_I + S_C + S_S \)

WHERE: \( S_I = \Delta \sigma \sum \frac{H_i}{E_i} \), "ELASTIC" COMPRESSION FOR GRANULAR, FREE DRAINING

FOR \( \sigma_v < P_c \): RECOMPRESSION ONLY

\[ S_C = \frac{H_i}{1 + C_0} \left[ C_{s_0} - 10 \log_{10} \left[ \frac{\sigma_v}{C_{s_0}} \right] \right] \]

FOR \( \sigma_v > P_c \): RECOMPRESSION + VIRGIN COMPRESSION

\[ S_C = \frac{H_i}{1 + C_0} \left[ C_{s_0} - 10 \log_{10} \left( \frac{\sigma_v}{C_{s_0}} \right) + C_{cl} - 10 \log_{10} \left( \frac{\sigma_v}{C_{s_0}} \right) \right] \]

\[ S_S = H_i C_0 \log_{10} \left( \frac{\Delta \sigma}{P} \right) \], SECONDARY COMPRESSION, NEGLIGIBLE FOR RECOMPRESSION

SETTLEMENT COMPUTED AFTER:

"AN ENGINEERING MANUAL FOR SETTLEMENT STUDIES"


ASSUME & NORMALLY CONSOLIDATED, I.E. \( \sigma_{v_0} = P_c \)

COMPRESSIBILITY PARAMETERS:

STRATUM 0: \( C_c \) & \( E_0 \) are based on correlations (see APPENDIX A),

\( C_c = 0.0114 \text{ Wn} \), \( E_0 = 0.0289 \text{ Wn} \)

\( Wn = 44\% \) (BASED ON BORING NR-5054)

\( C_{cl} = 0.0114 \text{ (44)} = 0.502 \text{ Wn} \), \( E_{cl} = 0.0289 \text{ (44)} = 1.272 \)

STRATUM M: ASSUMED TO BE HEAVILY CONSOLIDATED AND HENCE \( P_{cm} \gg P_{co} \), \( C_{sm} \ll C_{so} \)

STRATUM F, S1: \( E_1 = 740 \text{ ksf} \)

DEFINITIONS:

\( S_T = \text{TOTAL SETTLEMENT} \)

\( S_I = \text{IMMEDIATE ELASTIC SETTLEMENT} \)

\( S_C = \text{CONSOLIDATION SETTLEMENT} \)

\( S_S = \text{SECONDARY SETTLEMENT} \)

\( C_c = \text{VIRGIN COMPRESSION INDEX} \)

\( I = \text{INFLUENCE FACTOR} \)

\( Wn = \text{NATURAL WATER CONTENT} \)

\( C_s = \text{SWELL INDEX} \)

\( P_c = \text{MAXIMUM PAST VERTICAL STRESS} \)

\( \varepsilon_P = \text{SECONDARY COMPRESSION INDEX} \)

\( \varepsilon_P = \text{VOID RATIO AT END OF PRIMARY CONSOLIDATION} \)
SETTLEMENT CALCULATION (ANALYSIS AREA 2)

CALCULATION OF CONSOLIDATION SETTLEMENT, $S_c$:

$$S_c = \sum_{i=1}^{2} \frac{H_i}{k_i} \left[ C_{cl} \cdot \log_{10} \left( \frac{\sigma_{voi}}{\sigma_{vo}} \right) \right]$$

*COMPRESSIBLE LAYER IS IN VIRGIN COMPRESSION SINCE $\sigma_{vo}$ IS ASSUMED TO BE GREATER THAN THE PRE-LOAD
*ONLY STRATUM O IS COMPRESSIBLE

<table>
<thead>
<tr>
<th>LAYER</th>
<th>$H_i$ (ft)</th>
<th>ELEV. OF MIDPT (ft)</th>
<th>$\sigma_{voi}$ (psf)</th>
<th>$\sigma_{voi}^{%}$</th>
<th>$C_{cl}$</th>
<th>$E_{oi}$</th>
<th>$S_{ci}$ (in)</th>
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<tbody>
<tr>
<td>O₁</td>
<td>3</td>
<td>-23.5</td>
<td>2015</td>
<td>2390</td>
<td>44</td>
<td>0.502</td>
<td>1.272</td>
</tr>
<tr>
<td>O₂</td>
<td>3</td>
<td>-26.5</td>
<td>2096</td>
<td>2471</td>
<td>44</td>
<td>0.502</td>
<td>1.272</td>
</tr>
</tbody>
</table>

$$S_c = 1.16$$

EXAMPLE CALC. FOR LAYER O₁:

$$S_{ci} = \frac{3 \times 12''}{1 + 1.272} \cdot \left[ 0.502 \log_{10} \left( \frac{2471}{2015} \right) \right] = 0.59 \text{ in}$$

CALCULATION OF IMMEDIATE SETTLEMENT, $S_i$:

$$S_i = \Delta V \cdot H \cdot F \cdot I \cdot E$$

$I = 1.0$ FOR 1-D LOADING

$H_o = 28$ ft

$$S_i = 375 \text{ psf} \times 28 \text{ ft} \times 1 \times 100 = 0.144 \text{ ft} = 0.17 \text{ in}$$

CALCULATION OF SECONDARY COMPRESSION, $S_s$:

$$S_s = H \cdot C \cdot \log_{10} \left( \frac{t}{t_p} \right)$$

CALCULATED USING CONSOLIDATION TEST AT BORING MR-801 (SEE APPENDIX A)

$$C_o = 0.032$$

$$e_p = 1.708$$

$$C_x = \frac{C_o}{1 + e_p} = 0.012$$

$$H = 6 \text{ ft}$$

$$H_D = \frac{H}{2} = 3 \text{ ft}$$

$$t = 100 \text{ yrs} \ (AFTER \ PRIMARY)$$

$$S_s = (6 \text{ ft}) (0.012) \log \left( \frac{100 + 1.045}{1.045} \right)$$

$$S_s = 0.143 \text{ in}$$

$$C_v = 0.02 \text{ ft}^2/\text{day}$$
TOTAL SETTLEMENT, \( S_t \):

\[
S_t = S_I + S_C + S_8 = 0.17 + 1.16 + 0.14 = 1.47 \text{ in}
\]

Total estimated settlement at center of turn around is about, \( S_t = 1.5 \) to \( 2.0 \) in
ANALYSIS 3
Settlement Estimate of Area 3
SUBJECT: SETTLEMENT CALCULATION (ANALYSIS AREA 3)

PURPOSE: DETERMINE TOTAL SETTLEMENT FOR ANALYSIS AREA 3

STRATIGRAPHY AND STRESS STATES

\[ \gamma_w = 63 \text{pcf} \]

USING BORING MR-5085

\[ \gamma_{sc} = 120 \text{pcf} \]

\[ \gamma_{prop} = 125 \text{pcf} \]

\[ \gamma = 120 \text{pcf} \]

\[ 0.1 \gamma = 90 \text{pcf} \]

\[ 0.2 \gamma = 90 \text{pcf} \]

\[ \gamma_{pf} = \text{FINAL VERTICAL EFFECTIVE OVERBURDEN STRESS} \]

\[ \gamma_{ve} = \text{EXISTING VERTICAL EFFECTIVE OVERBURDEN STRESS} \]

\[ 0_{ve} = \text{STRESS (PSF)} \]

\[ 0_{pc} = \text{MAXIMUM PAST VERTICAL STRESS} \]

\[ \text{NOTE: } 0_{ve} < 0_{pc} \]

DEFINITIONS

\[ \gamma = \text{GRANULAR FILL STRATUM} \]

\[ \gamma_{sc} = \text{MAXIMUM PREVIOUS SUFCHARGE} \]

\[ \gamma_{prop} = \text{PROPOSED GRADE} \]

\[ \gamma_{ve} = \text{THICKNESS OF LAYER N} \]

\[ \Delta \sigma = \text{CHANGE IN STRESS} = \sigma_{ve} - \sigma_{ve} \]

\[ \sigma_{ve} = \text{EXISTING VERTICAL EFFECTIVE OVERBURDEN STRESS} \]

\[ \sigma_{pc} = \text{MAXIMUM PAST VERTICAL STRESS} \]
CALCULATION OF SETTLEMENT \( S_t = S_i + S_c + S_s \)

WHERE \( S_i = \frac{dS}{dL} \times \frac{H_i}{E_l} \); "PLASTIC" COMPRESSION FOR GRANULAR FOR \( dS/dL < P_c \) RECOMPRESSION ONLY

\[ S_c = \frac{H_i}{1+e_0} \left[ C_s = 1 - \log_{10} \left( \frac{S_v f}{S_v o} \right) \right] \]

FOR \( dS/dL > P_c \); RECOMPRESSION & VIRGIN COMPRESSION

\[ S_c = \frac{H_i}{1+e_0} \left[ C_s = 1 - \log_{10} \left( \frac{S_v f}{S_v o} \right) + C_c \cdot \log_{10} \left( \frac{S_v f}{S_v o} \right) \right] \]

\[ S_s = H_i \cdot \log_{10} \left( \frac{\Delta e_1}{\Delta P} \right) \]; SECONDARY COMPRESSION, NEGLIGIBLE (FOR RECOMPRESSION

SETTLEMENT COMPUTED AFTER:
"AN ENGINEERING MANUAL FOR SETTLEMENT STUDIES"

SINCE \( dS/dL < P_c \), SOIL IS UNDERGOING RECOMPRESSION

COMPRESSIBILITY PARAMETERS

STRATUM D: \( C_s \) INDEX IS BASED ON THE AVERAGE + ONE STANDARD DEVIATION OF ALL THE CONSOLIDATION TESTS AVAILABLE FOR THE D STRATUM (SEE APPENDIX A)

\( e_0 = 0.13 \)

\( \Delta e_0 = 0.0289 \) \( w_n = 0.0289(140) = 1.272 \)

(BASED ON BORING MAY 1980)

STRATUM M: ASSUMED TO BE HEAVILY CONSOLIDATED AND HENCE \( P_c(M) \geq P_c(M), C_m \geq C_c(M), C_m \leq C_c(0) \)

STRATUM F: \( e_1 = 740 \) KSF (BASED ON EPR MANUAL ON ESTIMATING SOIL PROPERTIES FOR FOUNDATION DESIGN, TABLES 5-5)

DEFINITIONS

\( S_i = \) IMMEDIATE SETTLEMENT

\( S_c = \) CONSOLIDATION SETTLEMENT

\( S_s = \) SECONDARY SETTLEMENT

\( S_t = \) TOTAL SETTLEMENT

\( I = \) INFLUENCE FACTOR

\( w_n = \) NATURAL WATER CONTENT

\( C_s = \) SWELL INDEX

\( P_c = \) MAXIMUM PAST VERTICAL STRESS

\( C_f = \) SECONDARY COMPRESSION INDEX

\( e_p = \) VOID RATIO AT END OF PRIMARY CONSOLIDATION

\( C_v = \) COEFFICIENT OF CONSOLIDATION

\( e_d = \) LENGTH OF DRAINAGE PATH

\( T_n = \) TIME FACTOR

\( U = \) DEGREE OF CONSOLIDATION

\( t_p = \) TIME FOR PRIMARY CONSOLIDATION TO OCCUR

\( t_e = \) TIME AFTER PRIMARY CONSOLIDATION

\( e_0 = \) INITIAL VOID RATIO

\( e_v = \) VIRGIN COMPRESSION INDEX
**SETTLEMENT CALCULATION (ANALYSIS AREA 3)**

### Calculation of Consolidation Settlement, $\delta_c$

$$\delta_c = \sum_{i=1}^{2} \frac{H_i}{\lambda_p^0} \left[ C_{s_i} \cdot \log_{10} \left( \frac{\sigma_{v_i}^{n,0}}{\sigma_{v_i}^{n,0}} \right) \right]$$

(STRATUM 0 ONLY)

<table>
<thead>
<tr>
<th>LAYER</th>
<th>$H_i$ (ft)</th>
<th>ELEV. OF MIDPT (ft)</th>
<th>$\sigma_{v_i}^{n,0}$ (PSF)</th>
<th>$\sigma_{v_i}^{n,0}$ (PSF)</th>
<th>$w_i$ (90)</th>
<th>$C_{s_i}$</th>
<th>$G_o$</th>
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<td>02</td>
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<td>2971</td>
<td>44</td>
<td>0.13</td>
<td>1.272</td>
<td>0.31</td>
</tr>
</tbody>
</table>

$\delta_c = 0.63$ in

Example Calculation for Layer 01:

$$\delta_{c_i} = \frac{3 \text{ ft} \cdot 12 \text{ in}}{1 + 1.272} \cdot \left[ 0.13 \cdot \log_{10} \left( \frac{2890}{2015} \right) \right] = 0.32 \text{ in}$$

### Calculation of Immediate Settlement, $S_i$

$$S_i = \delta_c \cdot H_F \cdot I \cdot \varepsilon$$

$I = 1.0 \text{ for } 1 \text{D loading}$

$H_F = 28 \text{ ft}$

$$S_i = 875 \text{ psf} \times 28 \text{ ft} \cdot 1 \text{ in} = 0.033 \text{ ft} = 0.397 \text{ in}$$

### Calculation of Secondary Compression, $S_s$

$$\sigma_{v_i}^{n} < p_c \quad S_s = 0 \text{ in} \quad (S_s \text{ is negligible in recompression})$$

### Total Estimated Settlement, $S_t$

$$S_t = S_i + \delta_c + S_s = 0.40 + 0.63 + 0 = 1.03 \text{ in}$$
ANALYSIS 4
Stress on Drainage Net
Subject: Wall Stability (Analysis Area 1)

Purpose: Determine maximum wall height due to bearing capacity of drainage net

\[
egin{align*}
E_l + 24 & \text{ ft} \\
\gamma & = 125 \text{ pcf} \\
\phi & = 30^\circ
\end{align*}
\]

\[
\text{CONCRETE WALL}
\]

\[
\text{CONCRETE FOOTING}
\]

\[
\text{SCALE: NOT TO SCALE}
\]

\[
\sigma'_{vo} = 125 \text{ pcf} \times 2 \text{ ft} = 250 \text{ psf}
\]

\[
\sigma'_{vo} + P_a = \sigma'_{v_{\text{max}}}
\]

\[
P_a = 0.875 \text{ tsf}
\]
Wall Design - Willis St. Wharf

Check Stability of Wall \( \gamma_c := 150 \text{pcf} \)

Top of Wall \( EL_t := 24 \text{ft} \) Bottom of Wall \( EL_b := 15 \text{ft} \)

**Self Weight of Cap**

Width of Cap \( b_{cap} := 8 \text{ft} \) Height of Cap \( d_{cap} := 1.5 \text{ft} \)

Weight of Cap \( W_{cap} := b_{cap} d_{cap} \gamma_c \)

\( W_{cap} = 1.80 \frac{\text{kip}}{\text{ft}} \)

**Self Weight of Wall**

Ave. Width \( b_w := 1.25 \text{ft} \) Height \( h_w := (EL_t - EL_b) - d_{cap} \)

\( h_w = 7.5 \text{ft} \)

**Self Weight of Retaining Wall**

\( W_{wall} := b_w h_w \gamma_c \)

\( W_{wall} = 1.41 \frac{\text{kip}}{\text{ft}} \)

**Self Weight of Soil** \( \gamma_s := 125 \text{pcf} \)

Soil Width \( b_s := b_{cap} - b_w \)

\( b_s = 6.75 \text{ft} \)

Height of soil \( h_s := h_w \)

\( h_s = 7.5 \text{ft} \)

Self Wt of Soil \( W_s := b_s h_s \gamma_s \)

\( W_s = 6.33 \frac{\text{kip}}{\text{ft}} \)

*Check Overturning*

Overturning Moment from Soil Pressure \( M_a := 5.06 \frac{\text{kip-ft}}{\text{ft}} \)

Resisting Moments:

Wt of wall: Eccen. \( e_w := \frac{b_w}{2} \)

\( e_w = 0.6 \text{ft} \)

Moment \( M_w := e_w W_{wall} \)

\( M_w = 0.9 \frac{\text{kip-ft}}{\text{ft}} \)

Wt of cap: Eccen. \( e_c := \frac{b_{cap}}{2} \)

\( e_c = 4.0 \text{ft} \)

Moment \( M_c := e_c W_{cap} \)

\( M_c = 7.2 \frac{\text{kip-ft}}{\text{ft}} \)

Wt of soil: Eccen. \( e_s := \frac{b_{cap} - b_s}{2} \)

\( e_s = 4.6 \text{ft} \)

Moment \( M_s := e_s W_s \)

\( M_s = 29.3 \frac{\text{kip-ft}}{\text{ft}} \)

Factor of Safety \( FS := \frac{M_w + M_c + M_s}{M_a} \)

\( FS = 7.38 \)

\( FS > 2.0 \) **OK**

*Check Sliding*

Friction Coeff. \( \mu_f := 0.4 \) (for concrete on fine sand)

Sliding Force \( P_{sl} := 1.69 \text{kifl} \)

Resisting Force w/ Passive \( F_{fr} := \mu_f (W_{wall} + W_{cap} + W_s) \)

\( F_{fr} = 3.81 \text{kifl} \)

Factor of Safety \( FS := \frac{F_{fr}}{P_{sl}} \)

\( FS = 2.26 \)

\( FS > 1.5 \) **OK**
Check Bearing Pressure on Soil  

Allowable Bearing pressure: \( p_a := 0.875 \text{ tsf} \)

Moments about Center of Cap

Overtuming Moment from Soil Pressure
\( M_a = 5.06 \frac{\text{kip-ft}}{\text{ft}} \)

Resisting Moments:
- Wt of wall: Eccen. \( e_w := \frac{b_{cap} - b_w}{2} \) \( e_w = 3.4 \text{ ft} \)  \( M_w := e_w \cdot W_{wall} \)  \( M_w = 4.7 \frac{\text{kip-ft}}{\text{ft}} \)
- Wt of cap: Eccen. \( e_c := 0 \text{ ft} \) \( e_c = 0.0 \text{ ft} \)  \( M_c := e_c \cdot W_{cap} \)  \( M_c = 0 \frac{\text{kip-ft}}{\text{ft}} \)
- Wt of soil: Eccen. \( e_s := \frac{b_{cap} - b_s}{2} \) \( e_s = 0.6 \text{ ft} \)  \( M_s := e_s \cdot W_s \)  \( M_s = 4 \frac{\text{kip-ft}}{\text{ft}} \)

Total Moment: \( M := M_a + M_w - M_c - M_s \) \( M = 5.85 \frac{\text{kip-ft}}{\text{ft}} \)

Total Force on Cap
\( P := W_{wall} + W_{cap} + W_s \) \( P = 9.53 \text{ klf} \)

Effective Eccentricity of Load
\( e_{eff} := \frac{M}{P} \) \( e_{eff} = 0.61 \text{ ft} \) \( < \frac{b_{cap}}{6} = 1.33 \text{ ft} \)

So the moment results in no uplift on one end of the footing

Effective Bearing Width
\( b_{eff} := \text{if} \left[ e_{eff} > \frac{b_{cap}}{6} \right] \left[ 3 \left( \frac{b_{cap}}{2} - e_{eff} \right) , b_{cap} \right] \) \( b_{eff} = 8.00 \text{ ft} \)

Effective Moment
\( M_{eff} := \text{if} \left[ e_{eff} > \frac{b_{cap}}{6} \right] \left[ \frac{b_{eff}}{6} , P \cdot \frac{b_{eff}}{6} \right] , M \) \( M_{eff} = 5.85 \frac{\text{kip-ft}}{\text{ft}} \)

Bearing Pressure on Fill
\( n := 1 \text{ ft (per ft width)} \)

Cap Section Modulus
\( S := \frac{1}{6} \cdot n \cdot b_{eff}^2 \) \( S = 10.7 \text{ ft}^3 \)

Bearing Pressures
\( p_{max} := \frac{P \cdot n}{b_{eff} \cdot n} + \frac{M_{eff} \cdot n}{S} \) \( p_{max} = 0.87 \text{ tsf} \) \( ~ p_a = 0.88 \text{ tsf} \) \text{ OK}

\( p_{min} := \frac{P \cdot n}{b_{eff} \cdot n} - \frac{M_{eff} \cdot n}{S} \) \( p_{min} = 0.32 \text{ tsf} \)
APPENDIX A

Assessment of Compressibility Characteristics
\[ C_\alpha = \frac{\Delta e}{\Delta t} = \frac{1.67 - 1.702}{\log(1000) - \log(100)} \]

\[ = 0.032 \]
APPENDIX B
Boring Logs
<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>NO.</th>
<th>DEPTH</th>
<th>BLOWS/6&quot;</th>
<th>SAMPLE DESCRIPTION</th>
<th>STRATA</th>
<th>DEPTH</th>
<th>BLOWS</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1D</td>
<td>5.0</td>
<td>4-4</td>
<td>2-10</td>
<td>Brown silty fine to medium sand, trace bricks, gravel, shells, coarse sand (Fill) (SM)</td>
<td>5</td>
<td>DPC (-)</td>
<td>Wood obstruction 8'-9''</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.0</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>2D</td>
<td>9.0</td>
<td>5-13</td>
<td>6-4</td>
<td>Gray silty coarse to fine sand, trace gravel, brick shells (Fill) (SM)</td>
<td>10</td>
<td>DPC (+)</td>
<td>3D: Wash sample. Fill running up casing. 90 gal. of mud lost down hole.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11.0</td>
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<td></td>
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<tr>
<td></td>
<td>17.0</td>
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</tr>
<tr>
<td>3D</td>
<td>15.0</td>
<td>11-8</td>
<td>1-1</td>
<td>Gray coarse to fine sand, some shells, silt, trace brick, gravel (Fill) (SM)</td>
<td>15</td>
<td>F</td>
<td>DPC (-)</td>
<td>3D: Wash sample. Fill running up casing, loosing mud down hole.</td>
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<tr>
<td></td>
<td>17.0</td>
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<tr>
<td></td>
<td>21.0</td>
<td>23-14</td>
<td></td>
<td>Gray coarse to fine sand, some shells, silt, trace gravel, brick (Fill) (SM)</td>
<td>20</td>
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<tr>
<td></td>
<td>24.0</td>
<td>1-WH</td>
<td>1-WH</td>
<td>No recovery</td>
<td>25</td>
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<tr>
<td></td>
<td>26.0</td>
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</tr>
<tr>
<td>4D</td>
<td>19.0</td>
<td>15-16</td>
<td></td>
<td>Gray coarse to fine sand, some shells, silt, trace gravel, brick (Fill) (SM)</td>
<td>28</td>
<td></td>
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<tr>
<td></td>
<td>21.0</td>
<td>23-14</td>
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</tr>
<tr>
<td>5D</td>
<td>30.0</td>
<td>1-WH</td>
<td>WH-WH</td>
<td>Soft dark gray organic clayey silt, trace fine to coarse sand, m'ca. vegetation (OH)</td>
<td>30</td>
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<td></td>
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</tr>
<tr>
<td>6U</td>
<td>33.0</td>
<td>PUSH=24*</td>
<td>REC=24*</td>
<td>Medium gray organic fine sandy silt, trace clay, mica interlayered with gray fine to coarse sand, trace clay packets (OL&amp;SP)</td>
<td>34</td>
<td>DPC (-)</td>
<td>WP=44%, pH=6.94</td>
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<tr>
<td></td>
<td>35.0</td>
<td></td>
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</tr>
<tr>
<td>7D</td>
<td>35.0</td>
<td>4-8</td>
<td>7-10</td>
<td>Gray medium to fine sand, trace coarse sand, silt, gravel (SP-SM)</td>
<td>39</td>
<td>S-1</td>
<td>pp=Pocket Penetrometer reading in tsf.</td>
<td></td>
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<tr>
<td></td>
<td>37.0</td>
<td></td>
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</tr>
<tr>
<td>8D</td>
<td>40.0</td>
<td>16-11</td>
<td>7-7</td>
<td>Brown yellow gravel and coarse to fine sand, trace silt (SP)</td>
<td>40</td>
<td>S-2</td>
<td>DPC (+)</td>
<td>Cobble 43.5' - 44.3'</td>
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<tr>
<td></td>
<td>42.0</td>
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<tr>
<td>9D</td>
<td>45.0</td>
<td>30-16</td>
<td>27-41</td>
<td>Top: Do 8D (SP) Bot: White medium to fine sand, trace silt, coarse sand (SP-SM)</td>
<td>45</td>
<td></td>
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<tr>
<td></td>
<td>47.0</td>
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<td>DAILY</td>
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<td>STRATA</td>
<td>CASING</td>
<td>REMARKS</td>
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<td>DEPTH</td>
<td>BLOWES</td>
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<tr>
<td>Cont'd</td>
<td>10D</td>
<td>50.0</td>
<td>54-37</td>
<td></td>
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<tr>
<td>Tuesday</td>
<td>51.8</td>
<td>53-75/3*</td>
<td></td>
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<tr>
<td>Partly</td>
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</tr>
<tr>
<td>Cloudy</td>
<td>65°F</td>
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</tr>
<tr>
<td>11D</td>
<td>55.0</td>
<td>22-31</td>
<td>Hard white silt, some fine sand, trace clay</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>56.8</td>
<td>(ML)</td>
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</tr>
<tr>
<td>12D</td>
<td>60.0</td>
<td>15-22</td>
<td>Hard pink white clayey silt, trace fine sand</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>07:00</td>
<td></td>
<td>66.4</td>
<td>75/5*</td>
<td></td>
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<tr>
<td>04-21-03</td>
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</tr>
<tr>
<td>Wednesday</td>
<td>13D</td>
<td>65.0</td>
<td>31-67</td>
<td>Yellow brown coarse to fine sand, trace gravel, silt (SP-SM)</td>
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<tr>
<td>Light</td>
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</tr>
<tr>
<td>Fan</td>
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<tr>
<td>60°F</td>
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<td></td>
</tr>
<tr>
<td>14D</td>
<td>70.0</td>
<td>92-100/5*</td>
<td>Do 13D, some gravel (SP-SM)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>70.9</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>15D</td>
<td>75.0</td>
<td>18-34</td>
<td>White tan silty fine to medium sand, some silt, trace mica seams (SM)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td>76.5</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13.00</td>
<td>1C</td>
<td>77.0</td>
<td>RUN=24*</td>
<td>Top 17*: Hard yellow silt, some gravel, fine to medium sand, trace coarse sand, clay (ML)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>79.0</td>
<td>REC=24*</td>
<td>Bot 7*: Yellow silty fine to medium sand, trace gravel, coarse sand, clay (SM)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Remarks:**
- **DPC (+)**
- **DPC (-)**
- **DPC (-)**, WC=14%
- **DPC (-)**, WC=21%, pH=6.45
- **DPC (+)**
- **S-4** 7.0  DPC (+), pH=7.51
- **DR** 7.5  DPC (-), WC=26%
- **MR-505U**

**Surfaces:**
- **WC=Water Content in percent of dry weight.**
- **pH=Soil pH by Method 9045 (EPA-SW846).**

**End of Boring at 79**
## Boring Log

**Project:** Harbor Point Area 2  
**Location:** Baltimore, MD

<table>
<thead>
<tr>
<th>SAMPLE NO.</th>
<th>DEPTH</th>
<th>BLOWS/&quot;</th>
<th>SAMPLE DESCRIPTION</th>
<th>STRATA</th>
<th>CASING DEPTH</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1D</td>
<td>1.0</td>
<td>2-4</td>
<td>Brown clayey fine to medium sand, some gravel, trace coarse sand (Fill) (SC)</td>
<td></td>
<td>DRILLED AHEAD 4&quot;</td>
<td>DPC=+, 11:45</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>11-7</td>
<td></td>
<td></td>
<td>DPC=+, 12.00</td>
<td>F</td>
</tr>
<tr>
<td>2D</td>
<td>3.0</td>
<td>7-16</td>
<td>Brown silty fine to coarse sand, some gravel, trace brick, cinder, wood (Fill) (SM)</td>
<td></td>
<td>DPC=+, 12:15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>46-52</td>
<td>Gray gravelly coarse to fine sand, trace brick, silt (Fill) (SP-SM)</td>
<td></td>
<td>DPC=+, 12:30</td>
<td></td>
</tr>
<tr>
<td>3D</td>
<td>5.0</td>
<td>5-10</td>
<td>Black silty fine to coarse sand, trace gravel, brick (Fill) (SM)</td>
<td></td>
<td>DPC=, 14:00</td>
<td></td>
</tr>
<tr>
<td>4D</td>
<td>7.0</td>
<td>6-7</td>
<td>Brown silty fine to medium sand, some gravel, trace brick (Fill) (SM)</td>
<td></td>
<td>DPC=, 14:45</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9.0</td>
<td>9-10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10.0</td>
<td>12-21</td>
<td>Brown coarse to fine sand, some gravel, trace silt (SP-SM)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>17.0</td>
<td>27-23</td>
<td></td>
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</tr>
<tr>
<td>5D</td>
<td>20.0</td>
<td>15-17</td>
<td>Brown fine to medium sand, trace silt (SP)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>22.0</td>
<td>21-27</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
| 6D         | 25.0  | 17-32   | Top: Stiff white clayey silt, trace fine sand seams, brown fine to medium sand layer (ML)  
Bot: Stiff white fine sandy silt (ML) |        |              | M       |
|            | 27.0  | 57-77   |                     |        | Top DPC=+, 15:30 |         |
| 7D         | 30.0  | 19-30   | Brown fine to medium sand, trace silt (SP) |        | DPC=+, 16:15  |         |
|            | 32.0  | 53-67   |                     |        | DPC=+, 16:40  |         |
| 8D         | 35.0  | 34-100/6" | Light brown and tan fine to medium sand, trace silt (SP-SM) |        |              | S3      |
|            | 36.0  | 56-100/6" |                     |        |              |         |
| 9D         | 40.0  | 21-36   | Tan fine to medium sand, trace silt (SP) |        |              |         |
|            | 42.0  | 47-89   |                     |        |              |         |
| 10D        | 45.0  | 19-21   | Top: Do 11D (SP)  
Bot: Red silty fine to medium sand, some red silty clay layers (SM) |        |              | M       |
|            | 46.3  | 100/4"  |                     |        | Top DPC=+, 08:30 |         |
| 11D        | 50.0  | 5-8     | Stiff red brown and white mottled silty clay (CL) |        |              |         |
|            | 52.0  | 10-14   |                     |        |              |         |

**Remarks:**
- DPC=+ indicates that the casing is above grade.
- DPC= indicates that the casing is below grade.
- AHEAD indicates the drilling progress."
<table>
<thead>
<tr>
<th>SAMPLE NO.</th>
<th>DEPTH</th>
<th>BLOWS/ft</th>
<th>SAMPLE DESCRIPTION</th>
<th>STRATA</th>
<th>DEPTH</th>
<th>CASING</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>14D</td>
<td>55.0</td>
<td>8-10</td>
<td>Stiff white clayey silt, trace red silty clay layers</td>
<td>55</td>
<td>DPC=+, 10:45</td>
<td>pp=2.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>57.0</td>
<td>21-38</td>
<td>(ML)</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>15D</td>
<td>60.0</td>
<td>5-8</td>
<td>Medium white fine sandy silt, trace fine sand</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>62.0</td>
<td>11-17</td>
<td>seams (ML)</td>
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<tr>
<td>16D</td>
<td>65.0</td>
<td>4-7</td>
<td>Medium white and fine sandy silt, trace red</td>
<td>65</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>67.0</td>
<td>9-17</td>
<td>brown clayey silt layer (ML)</td>
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<tr>
<td>17D</td>
<td>70.0</td>
<td>9-12</td>
<td>Light brown coarse to fine sand, some gravel,</td>
<td>70</td>
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<td></td>
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<tr>
<td></td>
<td>72.0</td>
<td>41-51</td>
<td>trace silt (SP-SM)</td>
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<tr>
<td>18D</td>
<td>75.0</td>
<td>19-27</td>
<td>Yellow brown coarse to fine sand, some</td>
<td>75</td>
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<tr>
<td></td>
<td>77.0</td>
<td>37-23</td>
<td>gravel, silt (SM)</td>
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<tr>
<td>19D</td>
<td>80.0</td>
<td>9-36</td>
<td>Light gray clayey silt, some gravel, trace brown</td>
<td>80</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>82.0</td>
<td>35-55</td>
<td>fine to medium sand (ML)</td>
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<tr>
<td>20D</td>
<td>85.0</td>
<td>100°</td>
<td>Brown and orange clayey fine to coarse sand,</td>
<td>85</td>
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<td></td>
<td>85.3</td>
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<td>sm tan silty clay'ys (Decomposed Rock) (SC)</td>
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<tr>
<td>21D</td>
<td>87.0</td>
<td>36-54</td>
<td>Green gray clayey fine to medium sand, some</td>
<td>86</td>
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<td></td>
<td>89.0</td>
<td>72-73</td>
<td>clay pockets (Decomposed Rock) (SC)</td>
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<tr>
<td>1C</td>
<td>59.0</td>
<td>92.0</td>
<td>Green gray clayey fine to medium sand (SC)</td>
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<tr>
<td>2C</td>
<td>92.0</td>
<td>95.0</td>
<td>Rec=33%</td>
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<td>95.0</td>
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<td>100.0</td>
<td>Rec=96%</td>
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<td>RQD=75%</td>
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</table>

**Remarks:**
- Top 1': Do 1C (SC)
- Bot 3': Intermediate moderately weathered green gray gneiss, jointed, weathered joints
- End of boring at 100'.

**BOARING NO.** MR-713