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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

1. "Corrective Measures Implementation Construction Completion Report, Phase I: Soil-Bentonite Hydraulic Barrier Wall, Phase II: Final Remedial Construction" prepared by Black and Veatch, Volumes I and II, February 2000.
2. "An Engineering Manual for Settlement Studies" by J.M. Duncan and A.L. Buchignani, June 1976, revised October 1987.
3. "EE Memo 1 – Estimated Settlement Under Development Fill Exelon Building & Plaza Garage, Baltimore, MD" by Mueser Rutledge Consulting Engineers, December 2013.
4. "Manual on Estimating Soil Properties for Foundation Design", by Cornell University for the Electric Power Research Institute, August 1990.

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 and 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

Elastic moduli of granular strata were estimated based on the EPRI *Manual on Estimating Soil Properties for Foundation Design*, Reference 4.

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, δ_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.

<u>Additional Load on Drainage Net</u>

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

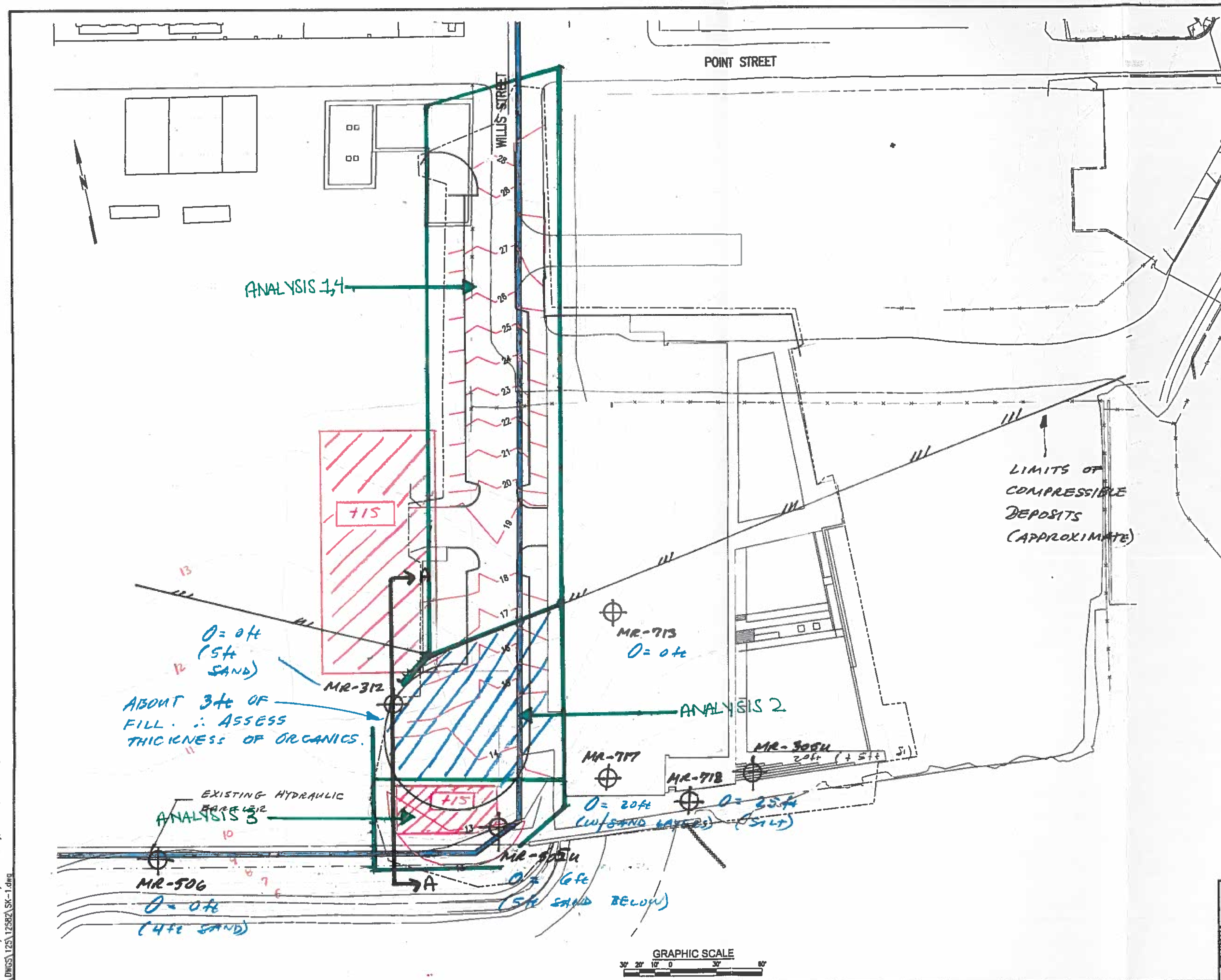
Settlement estimates show that proposed fill will not result in settlement that is detrimental to the Geomembrane. To confirm this, two permanent settlement plates should be installed in the area of the turnaround (within the area of Analysis 2) as follows:

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.

AMD: PWD\F:\125\12582\12582B\Task 110 - Settlement Analysis\Memo 1 Text - Site.docx



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).
3. SURCHARGES SHOWN ARE BASED ON PHASE II & III CONSTRUCTION COMPLETION REPORT BY BLACK & VEATCH DATED FEBRUARY, 2000.

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

BALTIMORE MARYLAND

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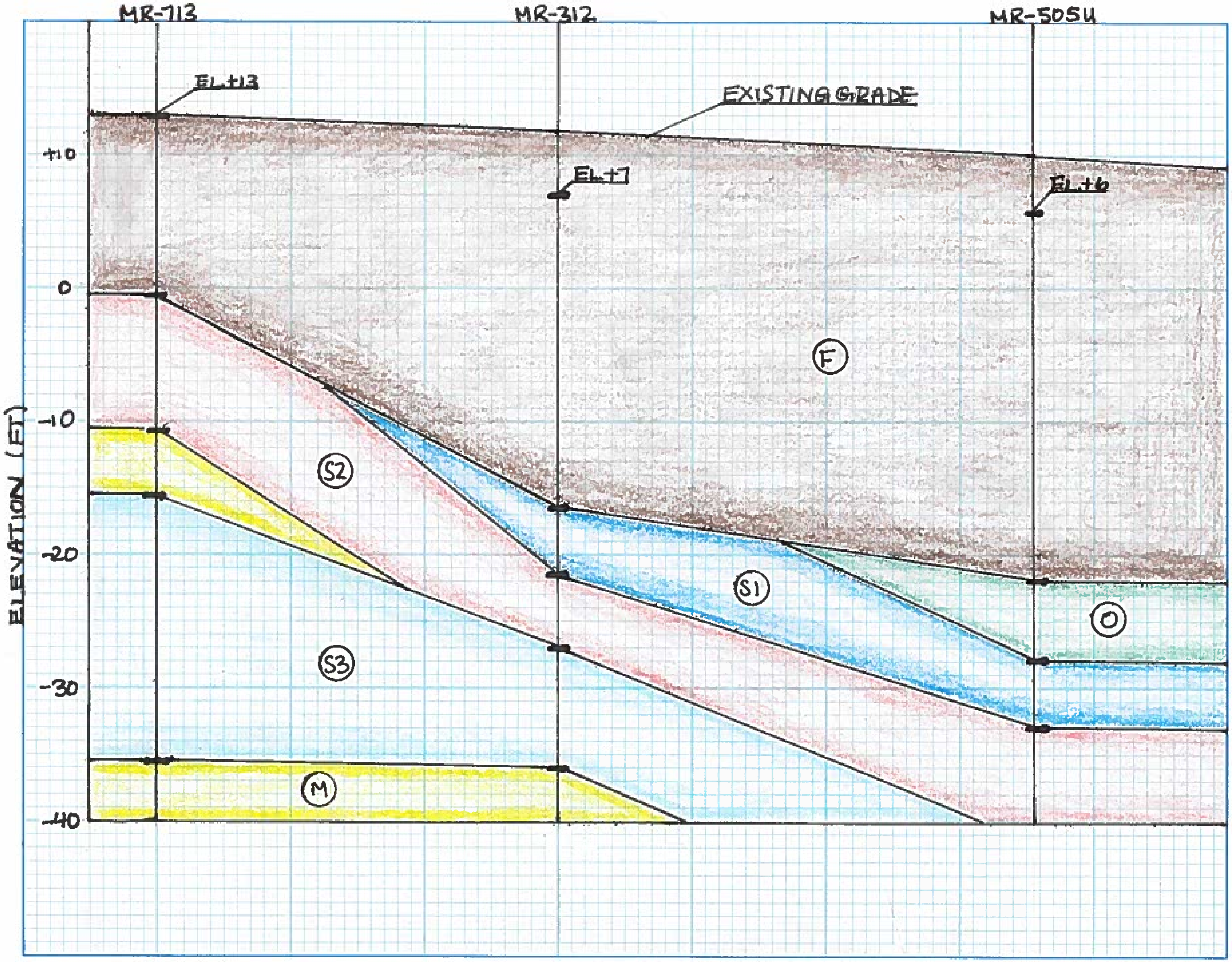

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PROJECT WILLS STREET WHARF

SUBJECT SETTLEMENT ANALYSIS SECTION A-A

SHEET ____ OF ____

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ANALYSIS 1

Settlement Estimate of Area 1

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SHEET 1 OF 3

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PROJECT WILLS STREET WHARF

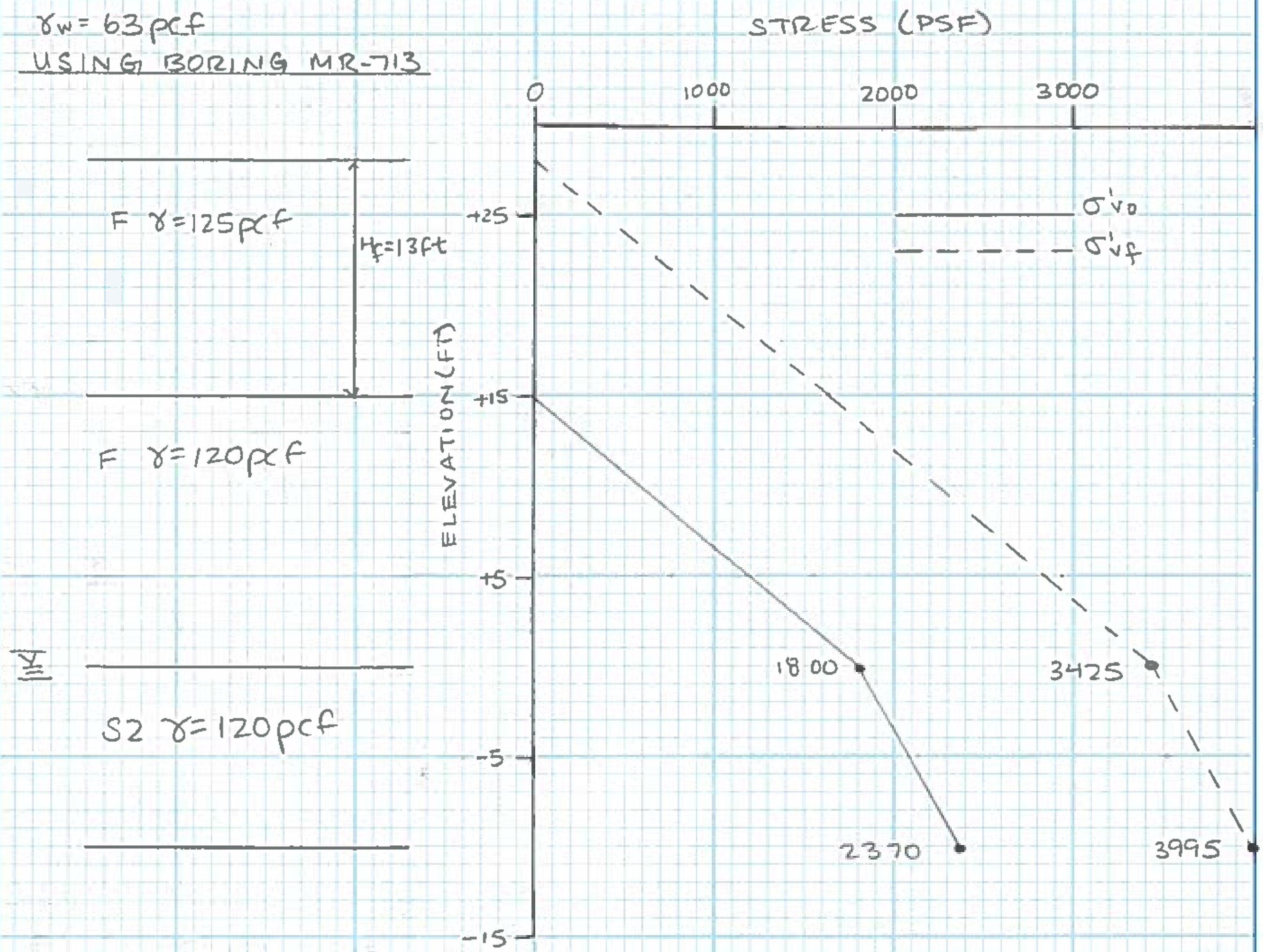
SUBJECT SETTLEMENT CALCULATION (ANALYSIS AREA 1)

PURPOSE: DETERMINE TOTAL SETTLEMENT FOR ANALYSIS AREA 1

STRATIGRAPHY AND STRESS STATE:

γ_w = 63 pcf

USING BORING MR-713



DEFINITIONS

F = GRANULAR FILL STRATUM

S2 = MEDIUM TO FINE SAND STRATUM

H_N = THICKNESS OF LAYER N

$\Delta\sigma$ = CHANGE IN STRESS = $\sigma'_{vf} - \sigma'_{vo}$

σ'_{vo} = EXISTING VERTICAL EFFECTIVE OVERBURDEN STRESS

σ'_{vf} = FINAL VERTICAL EFFECTIVE OVERBURDEN STRESS

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SUBJECT SETTLEMENT CALCULATION (ANALYSIS AREA 1)

CALCULATION OF SETTLEMENT: $\delta_T = \delta_I + \delta_c + \delta_s$

where: $\delta_I = \Delta\sigma \sum \frac{H_i I}{E_i}$; "ELASTIC" COMPRESSION FOR GRANULAR, FREE DRAINING

δ_c & δ_s NOT APPLICABLE SINCE THERE IS NO COMPRESSIBLE LAYER

STRATUM M: ASSUMED TO BE HEAVILY CONSOLIDATED AND HENCE $P'_{cM} \gg P'_{co}$, $C_{cM} \ll C_{co}$, $C_{sM} \ll C_{so}$

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

δ_T = TOTAL SETTLEMENT

δ_I = IMMEDIATE ELASTIC SETTLEMENT

δ_c = CONSOLIDATION SETTLEMENT

δ_s = SECONDARY COMPRESSION SETTLEMENT

e_o = INITIAL VOID RATIO

I = INFLUENCE FACTOR

P'_c = MAXIMUM PAST VERTICAL STRESS

H_{DR} = LENGTH OF DRAINAGE PATH

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SUBJECT SETTLEMENT CALCULATION (ANALYSIS AREA 1)

CALCULATION OF IMMEDIATE SETTLEMENT, δ_I:

$\delta_I = \Delta\sigma \cdot H_{F,S2} \cdot I / E$ $I = 1.0$ FOR 1D LOADING

$H_F \sim 25\,ft$

$\therefore\ \delta_I = 1625\,psf \times 25\,ft \times 1.0 / 740000 = 0.055\,ft = \underline{0.66\,in}$

TOTAL SETTLEMENT, δ_T:

$\delta_T = \delta_I + \delta_c + \delta_s = 0.66\,in + 0 + 0 = \underline{0.66\,in}$

ANALYSIS 2

Settlement Estimate of Area 2

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SUBJECT SETTLEMENT CALCULATION (ANALYSIS AREA 2)

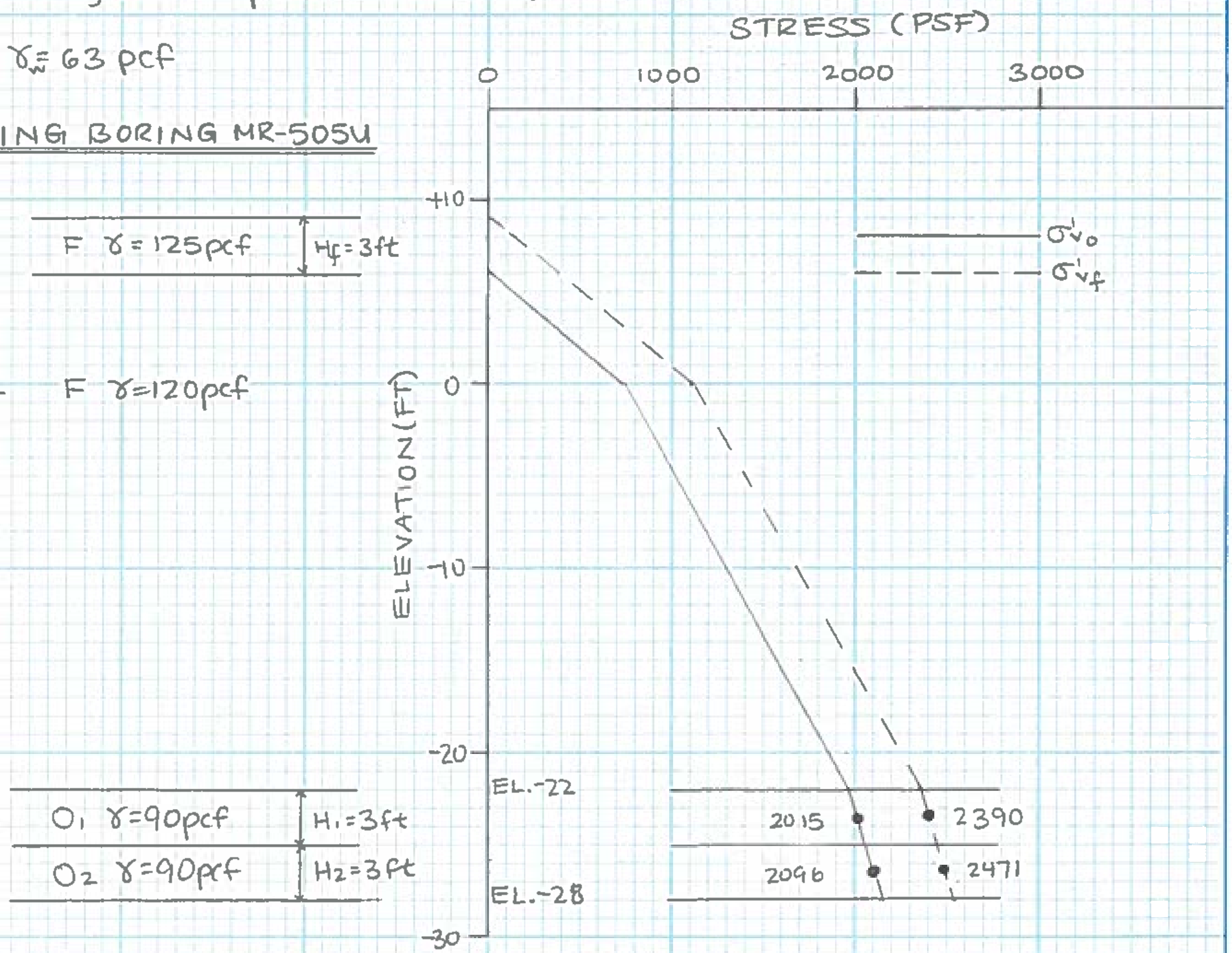
PURPOSE: DETERMINE TOTAL SETTLEMENT AT RAMP OF ORGANICS LAYER

STRATIGRAPHY AND STRESS STATE:

(Existing and Proposed Conditions)

$\gamma_w = 63$ pcf

USING BORING MR-505U



DEFINITIONS

F = GRANULAR FILL STRATUM

O = ORGANIC CLAY STRATUM

S1 = MEDIUM TO FINE SAND STRATUM

H_N = THICKNESS OF LAYER N

$\Delta\sigma$ = CHANGE IN STRESS = $\sigma'_{vf} - \sigma'_{vo}$

σ'_{vo} = EXISTING VERTICAL EFFECTIVE OVERBURDEN STRESS

σ'_{vf} = FINAL VERTICAL EFFECTIVE OVERBURDEN STRESS

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PROJECT WILLS STREET WHARF

SUBJECT SETTLEMENT CALCULATION (ANALYSIS AREA 2)

CALCULATION OF SETTLEMENT: $\delta_T = \delta_I + \delta_c + \delta_s$

where: $\delta_I = \Delta\sigma \sum \frac{H_i I}{E_i}$; "ELASTIC" COMPRESSION FOR GRANULAR, FREE DRAINING

FOR $\sigma'_{vf} < P'_c$: RECOMPRESSION ONLY

$$\delta_c = \frac{H_i}{1+e_o}\left[C_{si} \cdot \log_{10}\left[\frac{\sigma'_{vf}}{\sigma'_{vo}}\right]\right];$$

FOR $\sigma'_{vf} > P'_c$: RECOMPRESSION & VIRGIN COMPRESSION

$$\delta_c = \frac{H_i}{1+e_o}\left[C_{si} \cdot \log_{10}\left[\frac{\sigma'_{vf}}{\sigma'_{vo}}\right] + C_{ci} \cdot \log_{10}\left[\frac{\sigma'_{vf}}{\sigma'_{vo}}\right]\right];$$

$$\delta_s = H_i C_\alpha \log_{10}\left[\frac{\Delta t}{t_p}\right];$$ SECONDARY COMPRESSION, NEGLIGIBLE FOR RECOMPRESSION

SETTLEMENT COMPUTED AFTER:
• "AN ENGINEERING MANUAL FOR SETTLEMENT STUDIES" BY J.M DUNCAN AND A.L BUCHIGNANI (1981)

*ASSUME: NORMALLY CONSOLIDATED, i.e $\sigma'_{vo} \sim P'_c$

COMPRESSIBILITY PARAMETERS:

STRATUM O: C_c & e_o are based on correlations (see APPENDIX A)

$C_c = 0.0114\, W_n$ $e_o = 0.0289\, W_n$

$W_n = 44\%$ (BASED ON BORING MR-505U)

$C_{ci} = 0.0114(44) = 0.502$ $e_{oi} = 0.0289(44) = 1.272$

STRATUM M: ASSUMED TO BE HEAVILY CONSOLIDATED AND HENCE $P'_{cM} \gg P'_{cO}$, $C_{cM} \ll C_{cO}$, $C_{sM} \ll C_{sO}$

STRATUM F, S1: $E_i = 740$ Ksf

DEFINITIONS

δ_T = TOTAL SETTLEMENT
δ_I = IMMEDIATE ELASTIC SETTLEMENT
δ_c = CONSOLIDATION SETTLEMENT
δ_s = SECONDARY SETTLEMENT
C_c = VIRGIN COMPRESSION INDEX
I = INFLUENCE FACTOR
W_n = NATURAL WATER CONTENT
C_s = SWELL INDEX
P'_c = MAXIMUM PAST VERTICAL STRESS
C_α = SECONDARY COMPRESSION INDEX
e_p = VOID RATIO AT END OF PRIMARY CONSOLIDATION

C_v = COEFFICIENT OF CONSOLIDATION
H_{DR} = LENGTH OF DRAINAGE PATH
T_v = TIME FACTOR
U = DEGREE OF CONSOLIDATION
t_p = TIME FOR PRIMARY CONSOLIDATION TO OCCUR
t = TIME AFTER PRIMARY CONSOLIDATION
e_o = INITIAL VOID RATIO

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SUBJECT SETTLEMENT CALCULATION (ANALYSIS AREA 2)

CALCULATION OF CONSOLIDATION SETTLEMENT, δ_c:

$$\delta_c = \sum_{i=1}^{2} \frac{H_i}{1+e_{o_i}} \left[Cc_i \cdot \log_{10} \left[\frac{\sigma'_{vf_i}}{\sigma'_{vo_i}} \right] \right]$$

*COMPRESSIBLE LAYER IS IN VIRGIN COMPRESSION SINCE σ'_{vo} IS ASSUMED TO BE GREATER THAN THE PRE-LOAD
*ONLY STRATUM O IS COMPRESSIBLE

LAYER	H_i (ft)	ELEV. OF MIDPT (ft)	σ'_{voi} (psf)	σ'_{vfi} (psf)	w_i (%)	Cc_i	e_{oi}	δ_{ci} (in)
O_1	3	-23.5	2015	2390	44	0.502	1.272	0.59
O_2	3	-26.5	2096	2471	44	0.502	1.272	0.57
							δ_c=	1.16

EXAMPE CALC: FOR LAYER O_1

$$\delta_{ci} = \frac{3\text{ ft} \cdot 12\text{ in/ft}}{1+1.272} \cdot \left[0.502 \log_{10} \left[\frac{2390}{2015} \right] \right] = 0.59\text{ in}$$

CALCULATION OF IMMEDIATE SETTLEMENT, δ_I:

$\delta_I = \Delta\sigma \cdot H_F \cdot I / E$ $\quad$ $I = 1.0$ For 1-D loading

$H_F = 28$ ft

$\therefore \delta_I = 375\text{ psf} \times 28\text{ft} \times 1/740000 = 0.014\text{ft} = 0.17\text{ in}$

CALCULATION OF SECONDARY COMPRESSION, δ_s:

$\delta_s = H_i C_\alpha \log_{10}\left[\frac{t}{t_p}\right]$

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

$C_\alpha = 0.032$

$e_p = 1.708$

$C'_\alpha = \frac{C_\alpha}{1+e_p} = 0.012$

$H = 6$ ft

$H_{DR} = \frac{H}{2} = \frac{6\text{ ft}}{2} = 3\text{ ft}$

$T_v = 0.848$ @ $U = 90\%$

$C_v = 0.02\text{ ft}^2/\text{day}$

$t_p = \frac{H_{DR}^2 T_v}{C_v} = \frac{(3)^2(0.848)}{0.02} = 381.6\text{ days} = 1.045\text{ yrs.}$

USE $t = 100$ yrs (AFTER PRIMARY)

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

$\delta_s = 0.143$ in

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SUBJECT SETTLEMENT CALCULATION (ANALYSIS AREA 2)

TOTAL SETTLEMENT, δ_T:

$$\delta_T = \delta_I + \delta_C + \delta_S = 0.17 + 1.16 + 0.14 = 1.47 \text{ in}$$

∴ TOTAL ESTIMATED SETTLEMENT AT CENTER OF TURNAROUND IS ABOUT, δ_T = 1.5 to 2.0 in

ANALYSIS 3

Settlement Estimate of Area 3

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PROJECT WILLS STREET WHARF

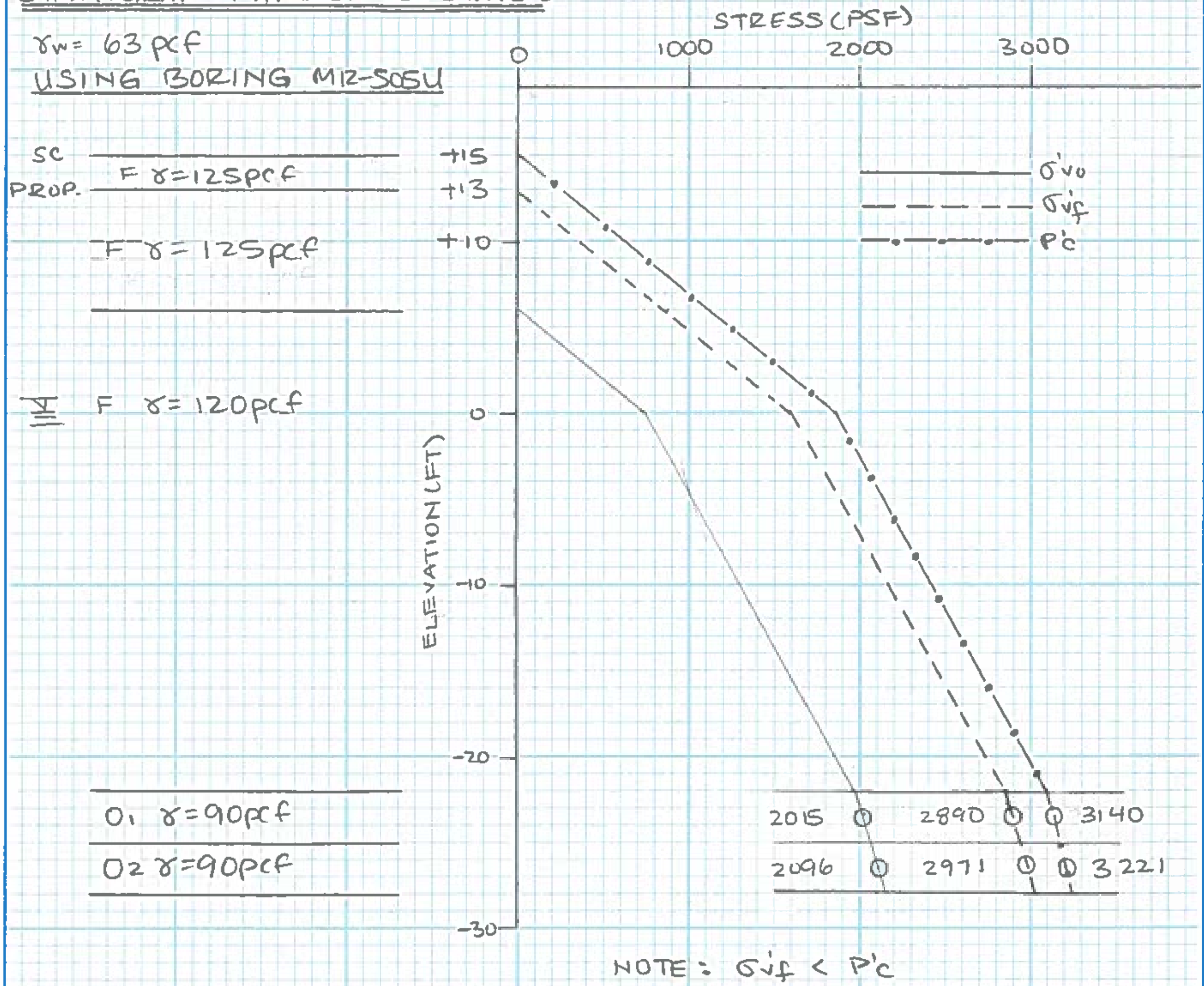
SUBJECT SETTLEMENT CALCULATION (ANALYSIS AREA 3)

PURPOSE: DETERMINE TOTAL SETTLEMENT FOR ANALYSIS AREA 3

STRATIGRAPHY AND STRESS STATES

$\gamma_w = 63$ pcf

USING BORING M12-505U



DEFINITIONS

F = GRANULAR FILL STRATUM

O = ORGANIC CLAY STRATUM

H_N = THICKNESS OF LAYER N

$\Delta\sigma$ = CHANGE IN STRESS = $\sigma'_{vf} - \sigma'_{vo}$

σ'_{vo} = EXISTING VERTICAL EFFECTIVE OVERBURDEN STRESS

σ'_{vf} = FINAL VERTICAL EFFECTIVE OVERBURDEN STRESS

P'_c = MAXIMUM PAST VERTICAL STRESS

SC = MAXIMUM PREVIOUS SURCHARGE

PROP. = PROPOSED GRADE

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SUBJECT SETTLEMENT CALCULATION (ANALYSIS AREA 3)

CALCULATION OF SETTLEMENT: $\delta_T = \delta_I + \delta_c + \delta_s$

where: $\delta_I = \Delta\sigma \sum \frac{H_i I}{E_i}$; "ELASTIC" COMPRESSION FOR GRANULAR FREE DRAINING

FOR $\sigma'_{vf} < P'_c$: RECOMPRESSION ONLY

$$\delta_c = \frac{H_i}{1+e_o}\left[C_{si} \cdot \log_{10}\left[\frac{\sigma'_{vf}}{\sigma'_{vo}}\right]\right];$$

FOR $\sigma'_{vf} > P'_c$: RECOMPRESSION & VIRGIN COMPRESSION

$$\delta_c = \frac{H_i}{1+e_o}\left[C_{si} \cdot \log_{10}\left[\frac{\sigma'_{vf}}{\sigma'_{vo}}\right] + C_{ci} \cdot \log_{10}\left[\frac{\sigma'_{vf}}{\sigma'_{vo}}\right]\right];$$

$\delta_s = H_i C_\alpha \log_{10}\left[\frac{\Delta t}{t_p}\right]$; SECONDARY COMPRESSION, NEGLIGIBLE FOR RECOMPRESSION

SETTLEMENT COMPUTED AFTER:
"AN ENGINEERING MANUAL FOR SETTLEMENT STUDIES"
BY J.M DUNCAN AND A.L BUCHIGNANI (1981)

SINCE $\sigma'_{vf} < P'_c$, SOIL IS UNDERGOING RECOMPRESSION

COMPRESSIBILITY PARAMETERS

STRATUM O: Cs index is based on the average + one stand. deviation of all the consolidation tests available for the O stratum (see APPENDIX A)
eo is based on correlations (see APPENDIX A)

$C_s = 0.13$ $e_o = 0.0289\, w_n = 0.0289(44) = 1.272$
(Based on Boring MR-505U)

STRATUM M: ASSUMED TO BE HEAVILY CONSOLIDATED AND HENCE $P'_{cM} \gg P'_{cO}$, $C_{cM} \ll C_{cO}$, $C_{sM} \ll C_{sO}$

STRATUM F: $E_i = 740$ KSF (BASED ON "EPRI MANUAL ON ESTIMATING SOIL PROPERTIES FOR FOUNDATION DESIGN", TABLE 5-5)

DEFINITIONS

δ_I = IMMEDIATE SETTLEMENT
δ_c = CONSOLIDATION SETTLEMENT
δ_s = SECONDARY SETTLEMENT
δ_T = TOTAL SETTLEMENT
I = INFLUENCE FACTOR
W_n = NATURAL WATER CONTENT
C_s = SWELL INDEX
P'_c = MAXIMUM PAST VERTICAL STRESS
C_α = SECONDARY COMPRESSION INDEX
e_p = VOID RATIO AT END OF PRIMARY CONSOLIDATION
C_v = COEFFICIENT OF CONSOLIDATION
H_{DR} = LENGTH OF DRAINAGE PATH

T_v = TIME FACTOR
U = DEGREE OF CONSOLIDATION
t_p = TIME FOR PRIMARY CONSOLIDATION TO OCCUR
t = TIME AFTER PRIMARY CONSOLIDATION
e_o = INITIAL VOID RATIO
C_c = VIRGIN COMPRESSION INDEX

SHEET 3 OF 3

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SUBJECT SETTLEMENT CALCULATION (ANALYSIS AREA 3)

CALCULATION OF CONSOLIDATION SETTLEMENT, δ_c:

$\sigma'_{vf} < P'_c \therefore \delta_c = \sum_{i=1}^{2} \frac{H_i}{1+e_{oi}} \left[C_{si} \cdot \log_{10}\left[\frac{\sigma'_{vfi}}{\sigma'_{voi}}\right]\right]$ (STRATUM O ONLY)

LAYER	H_i (ft)	ELEV. OF MIDPT (FT)	σ'_{voi} (PSF)	σ'_{vfi} (PSF)	w_i (%)	C_{si}	e_{oi}	δ_{ci} (in)
O_1	3	-23.5	2015	2890	44	0.13	1.272	0.32
O_2	3	-26.5	2096	2971	44	0.13	1.272	0.31

δ_c = 0.63

EXAMPLE CALC: FOR LAYER O_1

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

CALCULATION OF IMMEDIATE SETTLEMENT, δ_I:

$\delta_I = \Delta\sigma \cdot H_F \cdot I / E$ $\quad$ I = 1.0 FOR 1D LOADING

H_F = 28 ft

$\therefore \delta_I = 875\text{ psf} \times 28\text{ ft} \cdot 1/740000 = 0.033\text{ ft} = 0.397\text{ in}$

CALCULATION OF SECONDARY COMPRESSION, δ_s:

$\sigma'_{vf} < P'_c \therefore \delta_s \sim 0\text{ in}$ (δ_s IS NEGLIGIBLE IN RECOMPRESSION)

TOTAL ESTIMATED SETTLEMENT, δ_T:

$\delta_T = \delta_I + \delta_c + \delta_s = 0.40 + 0.63 + 0 = \underline{1.03\text{ in}}$

ANALYSIS 4

Stress on Drainage Net

SHEET 1 OF 1

MUESER RUTLEDGE CONSULTING ENGINEERS

FILE 12582

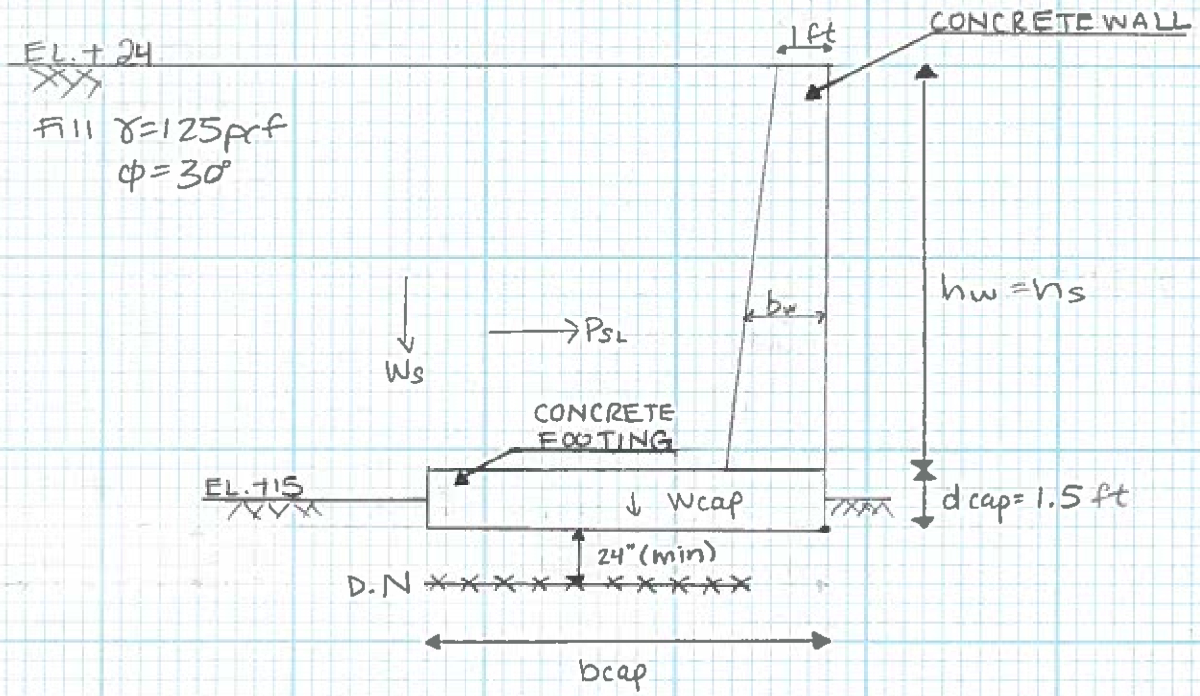
MADE BY APS DATE 10/27/15

PROJECT WILLS STREET WHARF

CHECKED BY ______ DATE ______

SUBJECT WALL STABILITY (ANALYSIS AREA 1)

PURPOSE: DETERMINE MAXIMUM WALL HEIGHT DUE TO BEARING CAPACITY OF DRAINAGE NET



SCALE: NOT TO SCALE

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

$\sigma'_{vmax} = 2000\text{ psf}$

$\sigma'_{vo} + P_a = \sigma'_{vmax}$

$\therefore \quad P_a = 0.875\text{ tsf}$

MUESER RUTLEDGE CONSULTING ENGINEERS

File: 12582

Made By: APS Date: 10/28/2015

FOR: WILLS STREET WHARF Checked By: ________ Date: ________

SUBJECT: RETAINING WALL STABILITY

Wall Design - Willis St. Wharf

Check Stability of Wall $\gamma_c := 150pcf$

Top of Wall $EL_t := 24ft$ Bottom of Wall $EL_b := 15ft$

Self Weight of Cap Width of Cap $b_{cap} := 8ft$ Height of Cap $d_{cap} := 1.5ft$

Weight of Cap $W_{cap} := b_{cap} \cdot d_{cap} \cdot \gamma_c$ $W_{cap} = 1.80 \frac{kip}{ft}$

Self Weight of Wall Ave. Width $b_w := 1.25ft$ Height $h_w := (EL_t - EL_b) - d_{cap}$ $h_w = 7.5\,ft$

Self Weight of Retaining Wall $W_{wall} := b_w \cdot h_w \cdot \gamma_c$ $W_{wall} = 1.41 \frac{kip}{ft}$

Self Weight of Soil $\gamma_s := 125pcf$ Soil Width $b_s := b_{cap} - b_w$ $b_s = 6.75\,ft$

Height of soil $h_s := h_w$ $h_s = 7.5\,ft$ Self Wt of Soil $W_s := b_s \cdot h_s \cdot \gamma_s$ $W_s = 6.33 \frac{kip}{ft}$

Check Overturning

Overturning Moment from Soil Pressure $M_a := 5.06 \frac{kip \cdot ft}{ft}$

Resisting Moments:

Wt of wall: Eccen. $e_w := \frac{b_w}{2}$ $e_w = 0.6\,ft$ Moment $M_w := e_w \cdot W_{wall}$ $M_w = 0.9 \frac{kip \cdot ft}{ft}$

Wt of cap: Eccen. $e_c := \frac{b_{cap}}{2}$ $e_c = 4.0\,ft$ Moment $M_c := e_c \cdot W_{cap}$ $M_c = 7.2 \frac{kip \cdot ft}{ft}$

Wt of soil: Eccen. $e_s := b_{cap} - \frac{b_s}{2}$ $e_s = 4.6\,ft$ Moment $M_s := e_s \cdot W_s$ $M_s = 29.3 \frac{kip \cdot ft}{ft}$

Factor of Safety $FS := \frac{M_w + M_c + M_s}{M_a}$ $\boxed{FS = 7.38}$ > 2.0 **OK**

Check Sliding

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

Sliding Force $P_{sl} := 1.69klf$

Resisting Force w/ Passive $F_{fr} := \mu_f \cdot (W_{wall} + W_{cap} + W_s)$ $F_{fr} = 3.81\,klf$

Factor of Safety $FS := \frac{F_{fr}}{P_{sl}}$ $\boxed{FS = 2.26}$ > 1.5 **OK**

MUESER RUTLEDGE CONSULTING ENGINEERS

File: 12582
Made By: APS Date: 10/28/2015
FOR: WILLS STREET WHARF Checked By: Date:

SUBJECT: RETAINING WALL STABILITY

Check Bearing Pressure on Soil Allowable Bearing pressure: $p_a := 0.875\text{tsf}$

Moments about Center of Cap

Overturning Moment from Soil Pressure $M_a = 5.06 \frac{\text{kip}\cdot\text{ft}}{\text{ft}}$

Resisting Moments:

Wt of wall: Eccen. $e_w := \frac{b_{cap} - b_w}{2}$ $e_w = 3.4\,\text{ft}$ Moment $M_w := e_w \cdot W_{wall}$ $M_w = 4.7 \frac{\text{kip}\cdot\text{ft}}{\text{ft}}$

Wt of cap: Eccen. $e_c := 0\text{ft}$ $e_c = 0.0\,\text{ft}$ Moment $M_c := e_c \cdot W_{cap}$ $M_c = 0 \frac{\text{kip}\cdot\text{ft}}{\text{ft}}$

Wt of soil: Eccen. $e_s := \frac{b_{cap} - b_s}{2}$ $e_s = 0.6\,\text{ft}$ Moment $M_s := e_s \cdot W_s$ $M_s = 4 \frac{\text{kip}\cdot\text{ft}}{\text{ft}}$

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

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

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

Bearing Pressure on Fill $n := 1\text{ft}$ (per ft width) Cap Section Modulus $S := \frac{1}{6}\cdot n \cdot b_{eff}^2$ $S = 10.7\,\text{ft}^3$

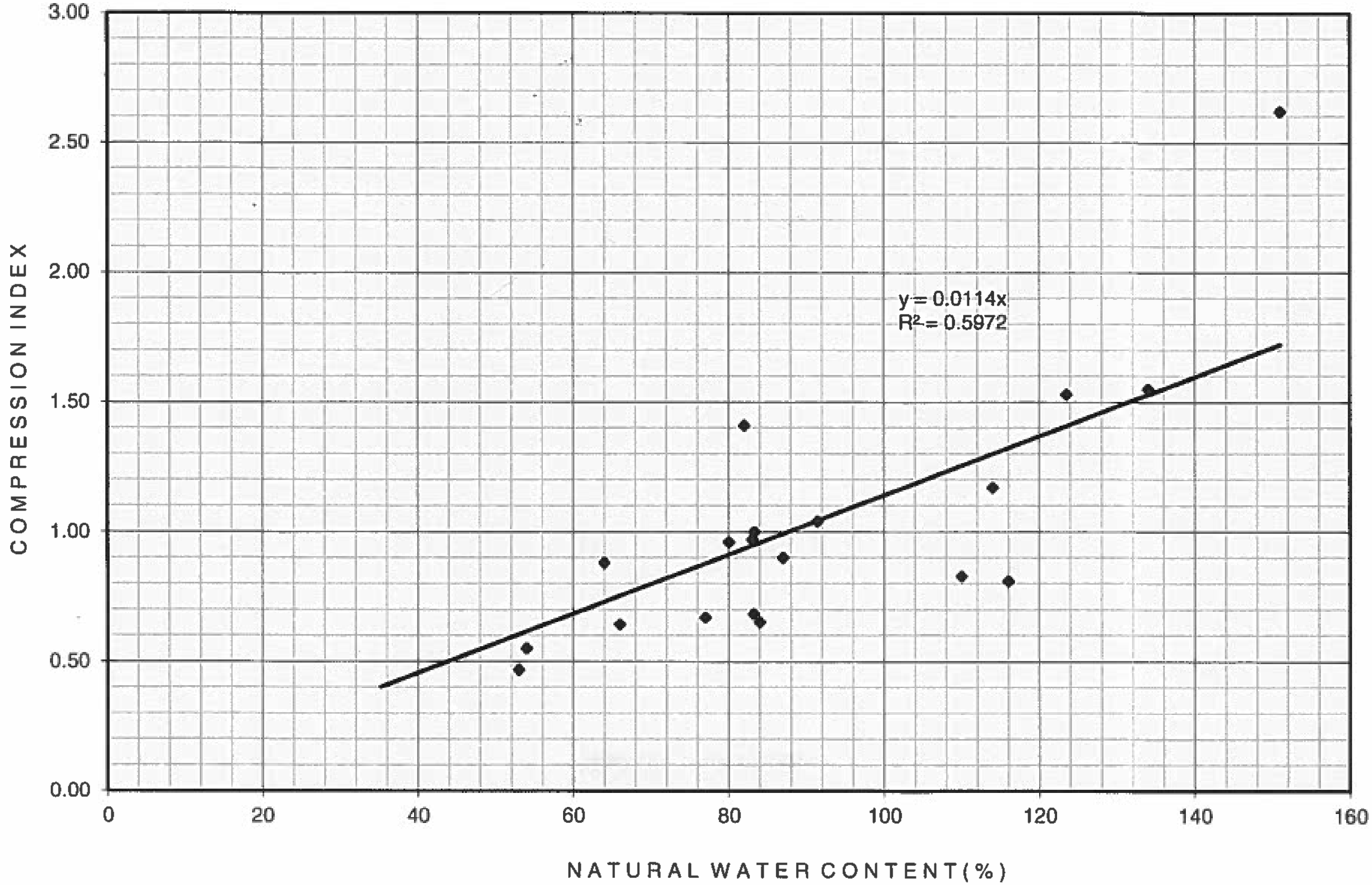
Bearing Pressures $p_{max} := \frac{P\cdot n}{b_{eff}\cdot n} + \frac{M_{eff}\cdot n}{S}$ $p_{max} = 0.87\,\text{tsf}$ ~ $p_a = 0.88\,\text{tsf}$ **OK**

$p_{min} := \frac{P\cdot n}{b_{eff}\cdot n} - \frac{M_{eff}\cdot n}{S}$ $p_{min} = 0.32\,\text{tsf}$

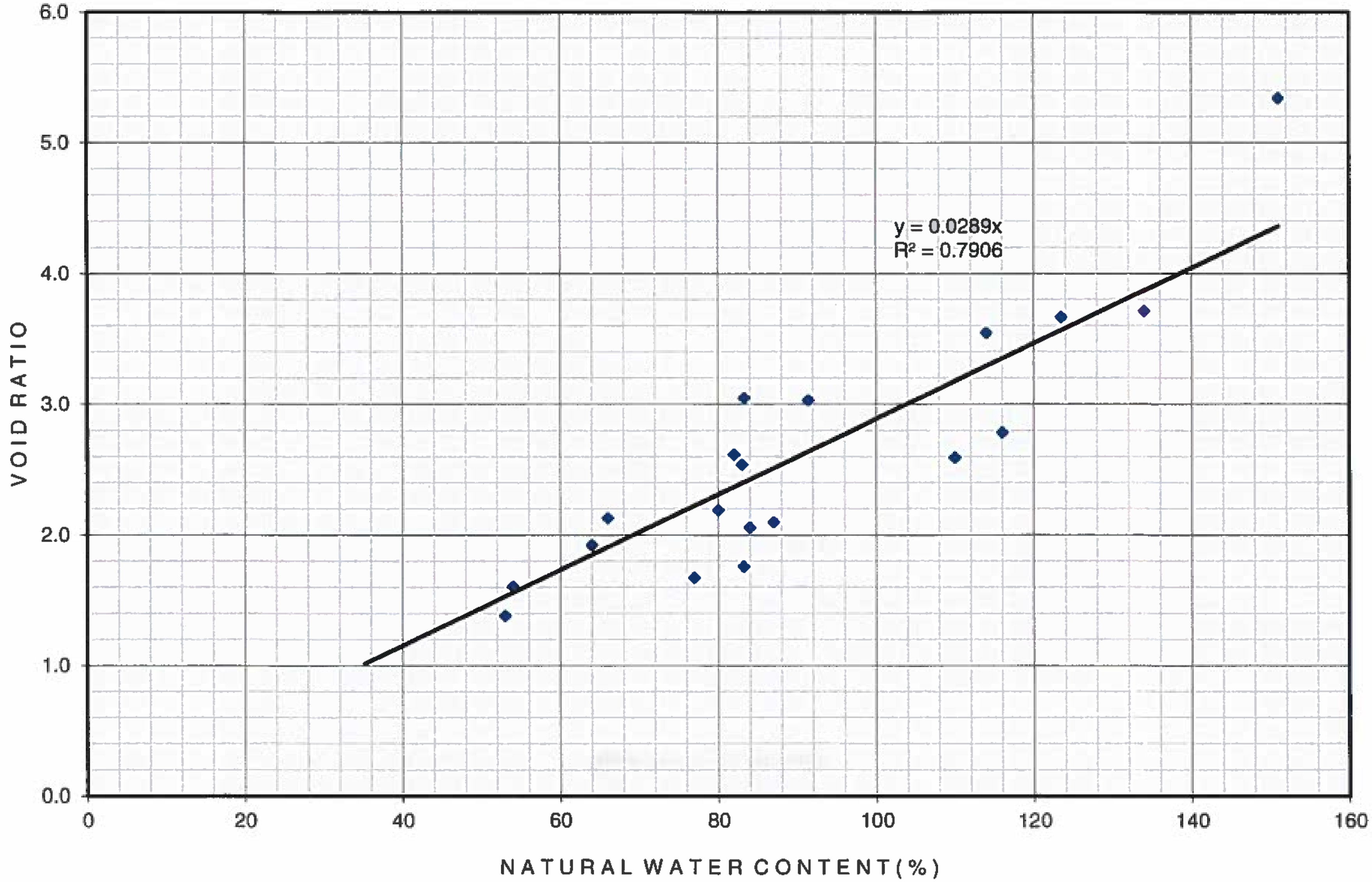
<u>APPENDIX A</u>

Assessment of Compressibility Characteristics

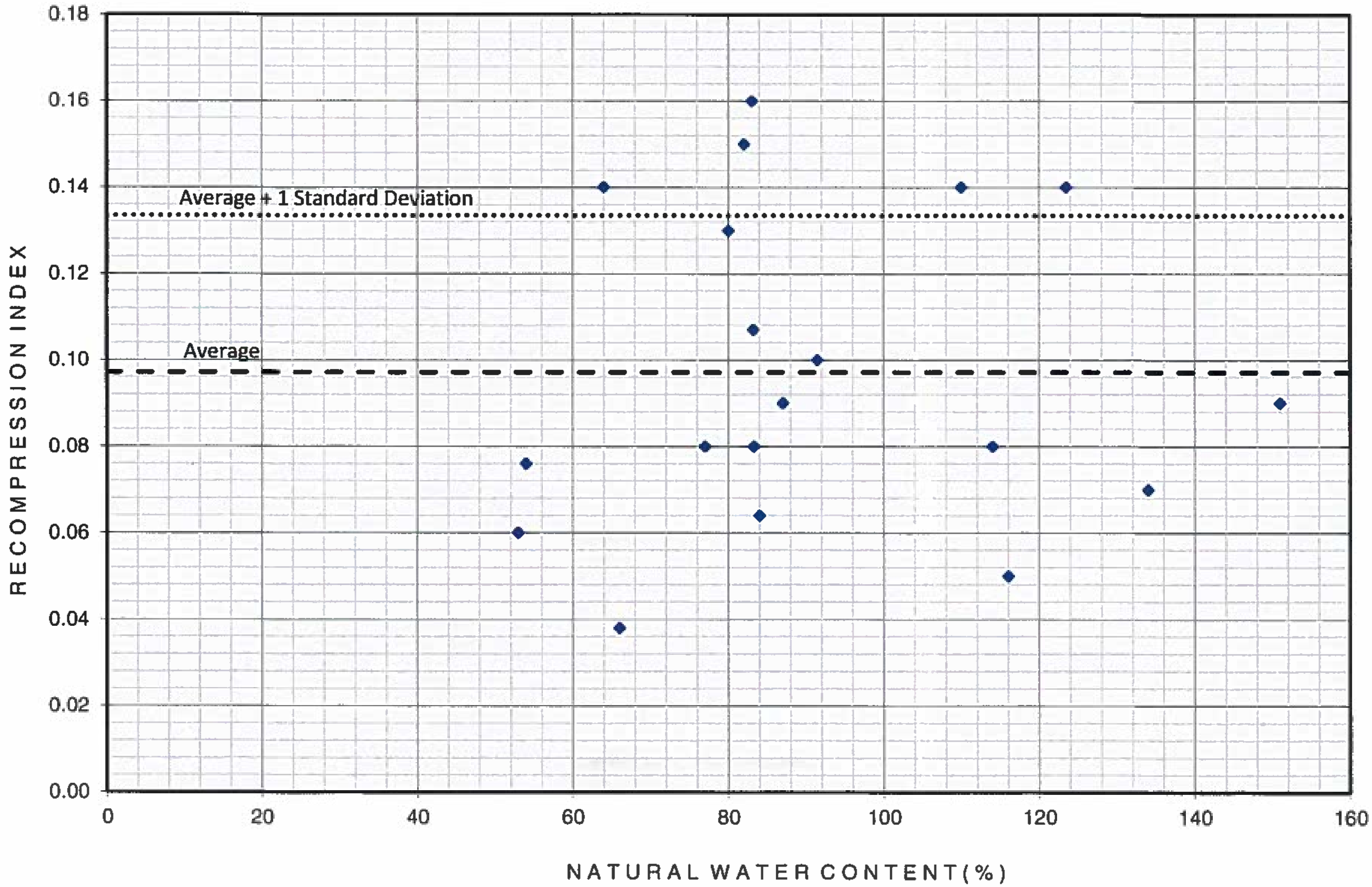
COMPRESSION INDEX VS. NATURAL WATER CONTENT



VOID RATIO VS. NATURAL WATER CONTENT

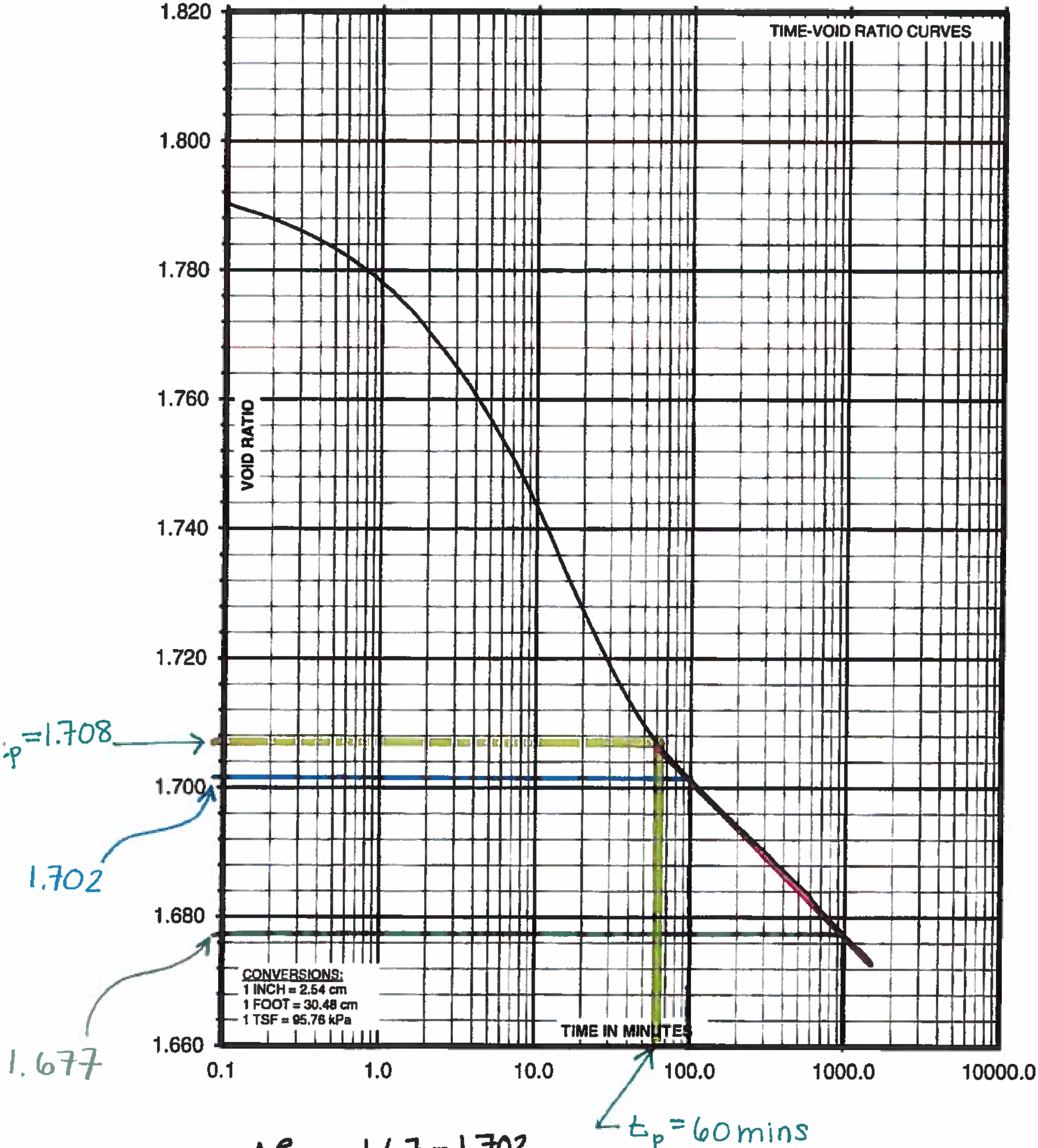


COMPRESSION INDEX VS. NATURAL WATER CONTENT



ATTACHMENT

VOID RATIO-TIME CURVE FOR MR-801



$$C_\alpha = \frac{\Delta e}{\Delta t} = \frac{1.67 - 1.702}{\log(1000) - \log(100)}$$

$$= 0.032$$

APPENDIX B

Boring Logs

MUESER RUTLEDGE CONSULTING ENGINEERS
BORING LOG

PROJECT: ALLIED BALTIMORE WORKS
LOCATION: BALTIMORE, MARYLAND

BORING NO. MR-505U
SHEET 1 OF 3
FILE NO. 6909
SURFACE ELEV. 5.89
RES. ENGR. M. KOLB

DAILY PROGRESS	SAMPLE NO.	SAMPLE DEPTH	BLOWS/6"	SAMPLE DESCRIPTION	STRATA	DEPTH	CASING BLOWS	REMARKS
15:30							CASING	12" of 1/2" gravel.
04-19-93								
Monday								
Partly								
Cloudy						5		
70°F	1D	5.0	4-4	Brown silty fine to medium sand, trace				DPC (-)
		7.0	2-10	bricks, gravel, shells, coarse sand (Fill) (SM)				
								Wood obstruction
								8'-9'.
	2D	9.0	5-13	Gray silty coarse to fine sand, trace gravel,		10		DPC (+)
		11.0	6-4	brick shells (Fill) (SM)				
								3D: Wash sample.
								Fill running up
								casing. 90 gal. of
17:00					F	15		mud lost down
07:00	3D	15.0	11-8	Gray coarse to fine sand, some shells, silt,				hole.
04-20-93		17.0	1-1	trace brick, gravel (Fill) (SM)				DPC (-)
Tuesday								3D:Wash sample.
Partly								Fill running up
Cloudy	4D	19.0	15-16	Gray coarse to fine sand, some shells, silt,		20		casing, loosing mud
65°F		21.0	23-14	trace gravel, brick (Fill) (SM)				down hole.
								4D: Wash sample.
								DPC (-), pH=6.37
	NR	24.0	1-WH	No recovery				Unsuccessful
		26.0	WH-1			25		attempt, 24'-26'
								made to recover
								sample. Dark
						28		gray organic silty
								clay in wash at 28'.
						30		
	5D	30.0	1-WH	Soft dark gray organic clayey silt, trace fine	O		REVERT	pp=0.6 tsf
		32.0	WH-WH	to coarse sand, mica, vegetation (OH)				
	6U	33.0	PUSH=24"	Medium gray organic fine sandy silt, trace				DPC (-),
		35.0	REC=24"	clay, mica interlayered with gray fine to		34		WC=44%, pH=6.94
				coarse sand, trace clay pockets (OL&SP)		35		
	7D	35.0	4-8	Gray medium to fine sand, trace coarse				DPC (-)
		37.0	7-10	sand, silt, gravel (SP-SM)	S-1			pp=Pocket
								Penetrometer
						39		reading in tsf.
						40		
	8D	40.0	16-11	Brown yellow gravel and coarse to fine				DPC (+)
		42.0	7-7	sand, trace silt (SP)				
								Cobble 43.5' -
					S-2			44.3'.
						45		
	9D	45.0	30-16	Top: Do 8D (SP)				DPC (+)
		47.0	27-41	Bot: White medium to fine sand, trace silt,				9D: 1 Jar.
				coarse sand (SP-SM)				
						50		

BORING NO. MR-505U

6' → 0

MUESER RUTLEDGE CONSULTING ENGINEERS
BORING LOG

BORING NO. MR-505U
SHEET 2 OF 3
FILE NO. 6909
SURFACE ELEV. 5.89
RES. ENGR. M. KOLB

PROJECT: ALLIED BALTIMORE WORKS
LOCATION : BALTIMORE, MARYLAND

DAILY PROGRESS	SAMPLE NO.	SAMPLE DEPTH	SAMPLE BLOWS/6"	SAMPLE DESCRIPTION	STRATA	DEPTH	CASING BLOWS	REMARKS
Cont'd	10D	50.0	54-37	Top: White red brown fine sandy silt, some			REVERT	DPC (+)
Tuesday		51.8	53-75/3"	clay, tr medium sand (ML)				10D Top: WC=13%
Partly				Bot: Hard white and red clayey silt, trace				10D Bot: WC=13%,
Cloudy				fine sand (MH)				pH=7.11
65°F						55		
	11D	55.0	22-31	Hard white silt, some fine sand, trace clay				DPC (-), WC=14%
		56.8	34-100/4"	(ML)				
					M			
						60		
	12D	60.0	15-22	Hard pink white clayey silt, trace fine sand				DPC (-),
17:00		62.0	29-49	(MH)				WC=21%, pH=6.45
07:00								
04-21-93								
Wednesday						65		
Light	13D	65.0	31-67	Yellow brown coarse to fine sand, trace		65.4		DPC (+)
Rain		66.4	75/5"	gravel, silt (SP-SM)				
60°F								
					S-4	70		
	14D	70.0	92-100/5"	Do 13D, some gravel (SP-SM)				DPC (+), pH=7.51
		70.9						
						73.8		
						75		
	15D	75.0	18-34	White tan silty fine to medium sand, some				DPC (-), WC=26%
		76.5	100	silt, trace mica seams (SM)	DR		↓	
							7*	
13:00	1C	77.0	RUN=24"	Top 17": Hard yellow silt, some gravel, fine		79	10*	DPC (-)
		79.0	REC=24"	to medium sand, trace coarse sand, clay		80	8*	*Coring time in
				(ML)				minutes per foot.
				Bot 7": Yellow silty fine to medium sand,				Bot: 1.5" crystalline
				trace gravel, coarse sand, clay (SM)				rock.
								End of Boring at
						85		79'.
								WC=Water Content
								in percent of dry
								weight.
						90		
								pH=Soil pH by
								Method 9045
								(EPA-SW846).
						95		
						100		

MUESER RUTLEDGE CONSULTING ENGINEERS

BORING LOG

PROJECT:	HARBOR POINT AREA 2
LOCATION:	BALTIMORE, MD
BORING NO.	MR-713
SHEET 1 OF	4
FILE NO.	1009A
SURFACE ELEV.	13.1
RES. ENGR.	M. QUASARANO

DAILY PROGRESS	SAMPLE NO.	SAMPLE DEPTH	BLOWS/6"	SAMPLE DESCRIPTION	STRATA	DEPTH	CASING BLOWS	REMARKS
11:30							DRILLED	
05-10-06	1D	1.0	2-4	Brown clayey fine to medium sand, some gravel, trace coarse sand (Fill) (SC)			AHEAD	DPC=-, 11:30
Wednesday		3.0	11-7				4"	
Clear	2D	3.0	7-16	Brown silty fine to coarse sand, some gravel, trace brick, cinder, wood (Fill) (SM)				DPC=-, 11:45
75°F		5.0	46-52			5		
	3D	5.0	17-100/5"	Gray gravelly coarse to fine sand, trace brick, silt (Fill) (SP-SM)				DPC=+, 12:00
		5.9			F			
	4D	7.0	5-10	Black silty fine to coarse sand, trace gravel, brick (Fill) (SM)				DPC=-, 12:15
		9.0	9-10					
						10		
	5D	10.0	6-7	Brown silty fine to medium sand, some gravel, trace brick (Fill) (SM)				DPC=-, 12:30
		12.0	9-10					
						13.5		
						15		
	6D	15.0	12-21	Brown coarse to fine sand, some gravel, trace silt (SP-SM)				DPC=-, 14:00
		17.0	27-23					
					S2			
						20		
	7D	20.0	15-17	Brown fine to medium sand, trace silt (SP)				DPC=-, 14:45
		22.0	21-27					
						23.5		
						25		
	8D	25.0	17-32	Top: Stiff white clayey silt, trace fine sand seams, brown fine to medium sand layer (ML)	M			Top DPC=-, 15:30
		27.0	57-77	Bot: Stiff white fine sandy silt (ML)				Bot DPC=+, 15:30
						28.5		
						30		
	9D	30.0	19-30	Brown fine to medium sand, trace silt (SP)				DPC=-, 16:15
		32.0	53-67					
						35		
	10D	35.0	34-100/6"	Light brown and tan fine to medium sand, trace silt (SP-SM)				DPC=-, 16:40
		36.0						
17:00					S3	40		
07:30	11D	40.0	21-36	Tan fine to medium sand, trace silt (SP)				DPC=+, 08:30
05-11-06		42.0	47-89					
Thursday								
Cloudy								
65°F						45		
	12D	45.0	19-21	Top: Do 11D (SP)				Top DPC=+, 09:15
		46.3	100/4"	Bot: Red silty fine to medium sand, some red silty clay layers (SM)				Bot DPC=+, 09:15
						48.5		
						50		
	13D	50.0	5-8	Stiff red brown and white mottled silty clay (CL)	M			DPC=+, 10:00
		52.0	10-14					pp=4.0

MRCE Form BL-1

BORING NO. MR-713

0' → 0

MUESER RUTLEDGE CONSULTING ENGINEERS

BORING LOG

PROJECT: HARBOR POINT AREA 2
LOCATION: BALTIMORE, MD

BORING NO. MR-713
SHEET 2 OF 4
FILE NO. 1009A
SURFACE ELEV. 13.1
RES. ENGR. M. QUASARANO

DAILY PROGRESS	SAMPLE NO.	SAMPLE DEPTH	BLOWS/6"	SAMPLE DESCRIPTION	STRATA	DEPTH	CASING BLOWS	REMARKS
Cont'd 05-11-06 Thursday Cloudy 65°F							DRILLED AHEAD 4"	
						55		
	14D	55.0 57.0	8-10 21-38	Stiff white clayey silt, trace red silty clay layers (ML)	M			DPC=+, 10:45 pp=2.5
						60		
	15D	60.0 62.0	5-8 11-17	Medium white fine sandy silt, trace fine sand seams (ML)				DPC=–, 11:20 pp=2.0 Sample recovered on 2nd attempt.
						65		
	16D	65.0 67.0	4-7 9-17	Medium white and fine sandy silt, trace red brown clayey silt layer (ML)				DPC=+, 11:50 (Very faint color, near red brown clay) pp=100
						68.5		
						70		
	17D	70.0 72.0	9-12 41-51	Light brown coarse to fine sand, some gravel, trace silt (SP-SM)	S4			DPC=+, 12.15
						75		
	18D	75.0 77.0	19-27 37-23	Yellow brown coarse to fine sand, some gravel, silt (SM)				DPC=+, 12.45
						78.5		
						80		
	19D	80.0 82.0	9-36 35-55	Light gray clayey silt, some gravel, trace brown fine to medium sand (ML)	DR			DPC=+, 13:45 (Faint color)
						85		
15:30	20D	85.0 85.3	100/3"	Brown and orange clayey fine to coarse sand, sm tan silty clay lyrs (Decomposed Rock) (SC)		86		DPC=+, 14:20
08:00 05-12-06	21D	87.0 89.0	36-54 72-73	Green gray clayey fine to medium sand, some clay pockets (Decomposed Rock) (SC)				DPC=–, 08:30
Friday Clear 75°F	1C	89.0 92.0	REC=53% RQD=0%	Green gray clayey fine to medium sand (SC)	TZ	90		
	2C	92.0 95.0	REC=33% RQD=0%	Do 1C (SC)				
						95		
	3C	95.0 100.0	REC=96% RQD=75%	Top 1': Do 1C (SC) Bot 3.8': Intermediate moderately weathered green gray gneiss, jointed, weathered joints	R	96		
18:00						100		End of boring at 100'.

MRCE Form BL-1

BORING NO. MR-713