SUBAQUEOUS SLOPE STABILITY ANLAYSIS REPORT

DIAMOND STATE PORT CORPORATION

WILMINGTON HARBOR – EDGEMOOR EXPANSION

February 2020

Prepared for:

Diamond State Port Corporation
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Wilmington, Delaware 19801

Prepared by:

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Project No. 11139.LH

TABLE OF CONTENTS

I. INTRODUCTION

Diamond State Port Corporation (DSPC) of Delaware (the applicant) has applied to the United States Army Corps of Engineers (USACE) for a Clean Water Act Section 404 permit, and a Rivers and Harbors Act Section 10 permit for dredging related to the construction of a primary harbor access channel and ship berth development ("proposed project") at the applicant's Edgemoor property ("Edgemoor Site"). The proposed project supports the redevelopment of the Edgemoor Site into a multi-user containerized cargo port.

The proposed project is located adjacent to and north of the Federal navigation channel, in the southern portion of Reach B of the Delaware River, at the intersection of the Cherry Island and Bellevue Ranges and is offshore of the applicant's property located along Hay Road, in Edgemoor, Delaware. The applicant proposes to deepen portions of the Delaware River adjacent to the Federal Navigation Channel to create a primary access channel that will serve the proposed berth construction at the Edgemoor Site.

The primary harbor access channel will provide access to an approximately 2,600 foot long wharf structure. Proposed construction of the berth and access channel calls for excavation to a 45-foot mean lower low water (MLLW) project depth. The 45-foot MLLW project depth matches the maintained depth of the Federal navigation channel of the Delaware River. The area expected to be dredged is approximately 4000 feet in length and a width extending from the boundary of the federal navigation channel to approximately 300 feet offshore of the site at MLLW. The total area is approximately 85 acres. The harbor layout and berth grading are shown in the project permit drawings titled "Port of Wilmington – Edgemoor Expansion, Permit Plans" prepared by Duffield Associates dated October, 2019.

The purpose of this evaluation was to analyze stability of the subaqueous slopes to be dredged as part of the proposed Berth and expanded Navigation Channel construction. It is proposed to widen the Delaware River Federal Navigation Channel (Federal Navigation Channel) to the proposed Edgemoor Expansion. The access channel slopes shown in the grading noted in the permit plans were analyzed considering the constructed slope configuration with 6:1 (Horizontal:Vertical) slopes away from the wharf and 3:1 slope under the high deck wharf.

The following report summarizes the results of Duffield Associates' (Duffield) slope stability analyses and provides discussion of the analyses and results.

II. FIELD EXPLORATION AND LABORATORY PROGRAM

In order to evaluate the stability of the excavated subaqueous slopes, Duffield performed three field programs which consisted of 10 test borings and 29 vibracore samples. As part of each field program, Duffield performed laboratory testing which in total consist of water content, gradational analysis without hydrometer methods, Atterberg Limits, Triaxial "Q" compression tests, Triaxial "R" compression tests, and Unconfined Compression tests.

The results of surface investigations are summarized in a report titled "Geotechnical Data Report, Port of Wilmington, Edgemoor Expansion, Edgemoor, New Castle County, Delaware," dated October 2019.

III. SLOPE STABILITY ANALYSIS

In general, the "factor of safety" referred to in slope stability analysis is the ratio of forces resisting failure to the driving forces (i.e., forces which would drive a failure). The driving forces typically consist of the weight of the embankment slope and in some cases the surcharge weight for future development, while the resisting forces are the strength of the soils beneath the embankment and to a lesser degree, the weight of the water acting against the slope.

The USACE guideline document, Engineer Manual for Confined Disposal of Dredged Material (EM-1110-2-5027), recommends a slope stability "factor of safety" of greater than, or equal to, 1.3 for the end-of-construction condition. In the case of this project, the end-of-construction conditions represents the end of initial dredging. In addition, to supporting the requirements of the 408 review, we evaluated "during" dredging slope stability cases. Although, there is no recommended factor of safety for "during" dredging, for the purpose of this evaluation, we have assumed a minimum factor of safety of 1.1.

A. STRENGTH PARAMETER SELECTION

Six design profiles were developed based on the strength parameters obtained from the field and laboratory testing during this evaluation. The estimated shear strengths used in the analyses reflect the existing conditions and do not consider strength gain, which may occur due to future consolidation of the soils under construction. The end-of-construction conditions following construction of the channel and berth slopes were analyzed for each of the four cross-sections. Two cases were evaluated for during construction conditions. Slope stability analyses were performed utilizing the reduced SPT and laboratory data. The subsurface soil parameters utilized in the analyses are provided in Table 1. Individual cross-sections and soil parameters can be located in Appendix B.

Shear strength parameters and internal friction angles were estimated for each stratum, based on the field and laboratory test data for the SPT borings performed in the vicinity of the subaqueous slopes. The unconsolidated undrained strength parameters were utilized for the existing and end-of-construction stability analysis. Consolidated drained characteristics were developed for analysis based on Duffield's past experience with similar soils along the Delaware River and test data developed during this evaluation.

Based on testing of similar soils, as well as the soil parameters obtained during the field and laboratory testing programs, the following strength parameters were utilized in analyzing the proposed access channel and berth slopes.

Table 1: Strength Parameters

STRATUM	Moist Unit Weight (pcf)	Cohesive or Undrained Shear Strength (psf)	Internal Friction Angle (ϕ)
Fluvial Silt Deposits	110	300	0
Alluvial Sands	120	0	32
Embankment Potomac Clays	115	600	0
Foundation Potomac Clays	120	1,300	0

B. CHANNEL AND BERTH CROSS-SECTION DESIGN AND STABILITY ANALYSIS

Due to its comprehensive search capabilities, the ReSSA+ (Stability Analysis of Geosynthetic Reinforced Soil Structures, 2001 - 2019) computer program was utilized to locate the critical failure surfaces for the end-of-construction rotational analyses and optimize the cross-section configurations. ReSSA is a Windows-based program developed and written by ADAMA Engineering, Inc. of Newark, Delaware, to analyze and design earthen embankments and walls. The program utilizes the Comprehensive Bishop's method for analyzing rotational slope stability.

C. END-OF-CONSTRUCTION STABILITY CASES

As part of this evaluation, slope stability analyses were performed utilizing anticipated slope configurations along the access channel and for the proposed berth and the subsurface conditions developed during this evaluation. The analyses were performed assuming that the proposed bottom of slope embankments will be -45 feet MLLW to provide access from the Delaware River Channel to the DSPC Edgemoor Port Facility.

End-of-construction stability analyses were performed on all of the cross-sections using the undrained strength parameters and a water elevation of 0 feet MLLW. It was important to analyze the stability of these slopes since failure would result in excess soils within both the access channel and the Delaware River navigation channel.

Both access channel cross-sections (upriver and downriver) were analyzed assuming a proposed slope configuration with 6:1 slopes (horizontal:vertical), and a bottom elevation of -45 feet MLLW. Typically, each cross-section was selected to represent the design case for each section because it presented the "worst-case" design scenario along that section.

Two separate cross-sections were analyzed for the proposed berth, with assumed slope configurations of 3:1. Similar to the access channel slopes, analysis assumed the embankments would be terminated at -45 feet MLLW to provide access to the facility.

The berth construction will impact the long term stability of these berth cross-sections. The as-constructed condition will result in a slow extending from -45 feet MLLW graded to an effective 3 horizontal to 1 vertical slope, which transmission to a structural retaining wall at elevation -12 feet along the rear of the berth structure. The retaining wall extends from the top up the slope -12 feet to proposed grade at elevation +18 feet and will structurally support the grade retention and surcharge loads. It is assumed that, at a minimum, the structure of the wall will extend to a depth corresponding to the exposed height of the wall (or 30 feet below the toe grade), corresponding to elevation -42 feet. The wall installation will effectively reduce the stability driving force on the wall increasing the stability.

It is proposed that this wall will be constructed prior to dredging. The stability analysis was performed based on the 3:1 grades extending to match current grade without consideration of the future wall, which is conservative.

Table 2: Factors of Safety for End-of-Construction Cases

Case No.	Cross Section	Proposed Subaqueous Slope (horizontal : vertical)	Factor of Safety
Downriver Access Channel	A – A	6:1	➢ 3.0
Downriver Berth w/ surcharge	B – B	3:1	1.93
Upriver Berth w/ surcharge	C – C	3:1	1.66
Upriver Access Channel	D – D	6:1	➢ 3.0

The final end-of-construction configurations recommended for each cross-section were developed to satisfy the required minimum “factors of safety” for the end of construction (1.3). “Safety Maps” summarizing the results of the slope stability are also included in Attachment B.

D. DURING CONSTRUCTION STABILITY CASES

As part of this evaluation and in support of 408 review, slope stability analyses were performed utilizing anticipated during construction slope configurations for the proposed berth and the subsurface conditions developed during this evaluation. Two separate cross-sections were analyzed with assumed slope configurations of 1:1.

Table 3: Factors of Safety for During Dredging Cases

Case No.	Cross Section	Proposed Subaqueous Slope (horizontal : vertical)	Factor of Safety
Downriver Access Channel	A – A	1:1	> 3.0
Upriver Access Channel	D – D	1:1	> 3.0

Review of the results indicate that the slope conditions during construction, appear to remain stable. However, the results of some instability are assumed to be minor, because as the material is dredged in passes, material sloughs in from the sides during dredging until a stable configuration is reached. "Safety Maps" summarizing the results of the slope stability are also included in Attachment B.

E. RAPID DRAWDOWN STABILITY

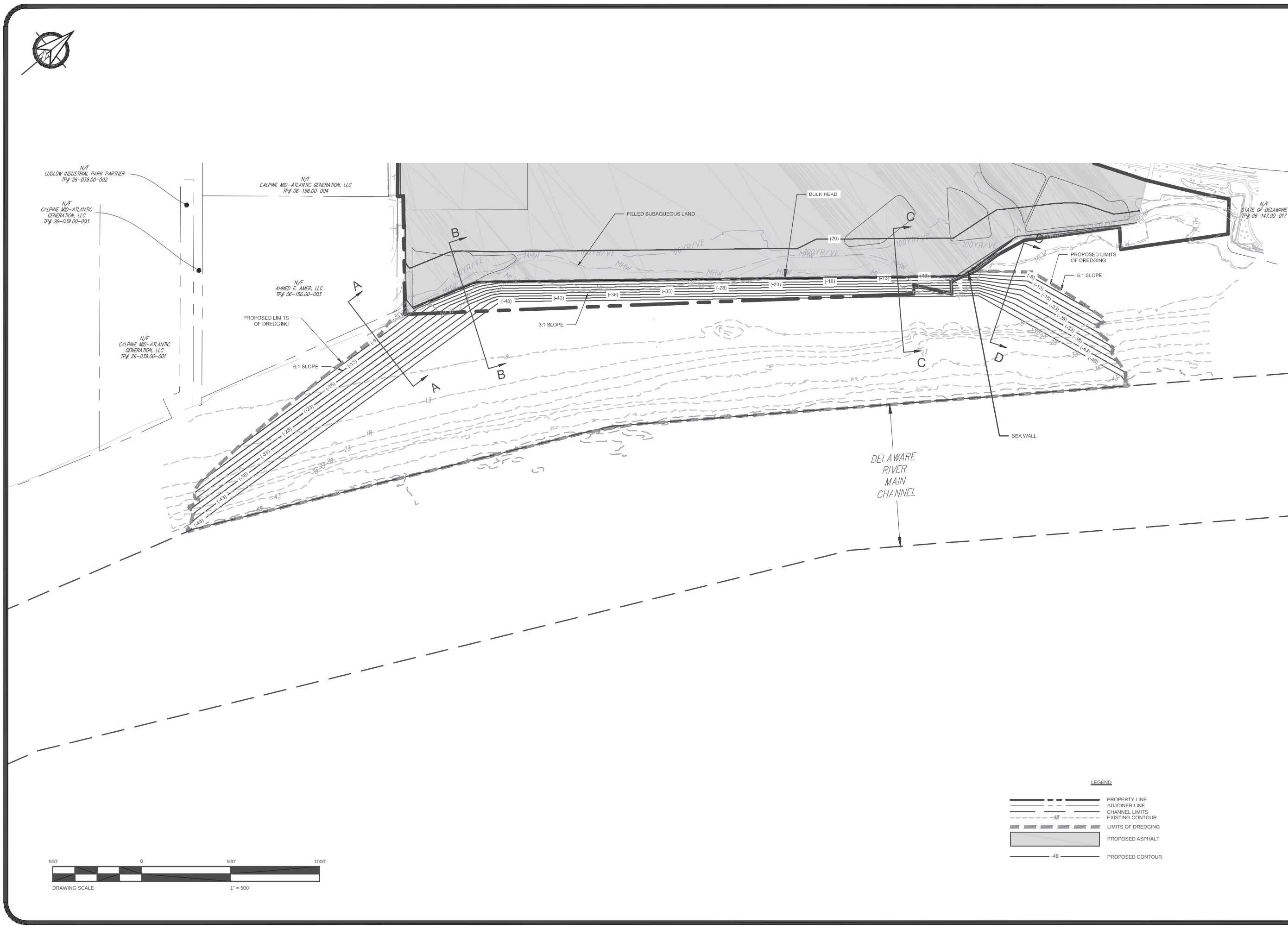
The "rapid drawdown" conditions generally corresponds to the removal of water (pore pressure) from portions of the system (e.g. if a pond or river was suddenly dry). For this tidal application, a "rapid drawdown" case for the subaqueous slope is unlikely to occur as tidal fluctuations would limit the full removal of water from the river.

Along the bulkhead, there is the potential for excess pore pressures to develop during fill placement which may remain during dredging. This condition is likely to represent an effective "draw-down" which would impact the bulkhead structure. This condition will be analyzed in full detail, during the design of the bulkhead and addressed at that time to reduce the potential for instability of the bulkhead, but is not anticipated to influence the separated subaqueous slopes in front of the wall.

This report has been prepared according to generally accepted soil engineering standards and is based on the samples provided for testing. Interpretation of this data should consider the requested scope of services and the conditions encountered at the site as a whole. In the event that changes in the presentation of this data are proposed, this report will not be considered valid unless the changes have been reviewed and the recommendations of this report modified and re-approved in writing by Duffield Associates, Inc.

APPENDIX A

SITE SKETCH
WITH CROSS-SECTIONS



DUFFIELD ASSOCIATES
Soil, Water & the Environment

DESIGNED BY: MRB

DRAWN BY: MH

CHECKED BY: BJD

FILE: PRMT-Grading-11139LH

PERMIT PLAN
BERTH GRADING PLAN

PORT OF WILMINGTON EDGEMOOR EXPANSION

BRANDYWINE HUNDRED ~ NEW CASTLE COUNTY ~ DELAWARE

DATE: JANUARY 2019

SCALE: 1" = 500'

PROJECT NO. 11139.LH

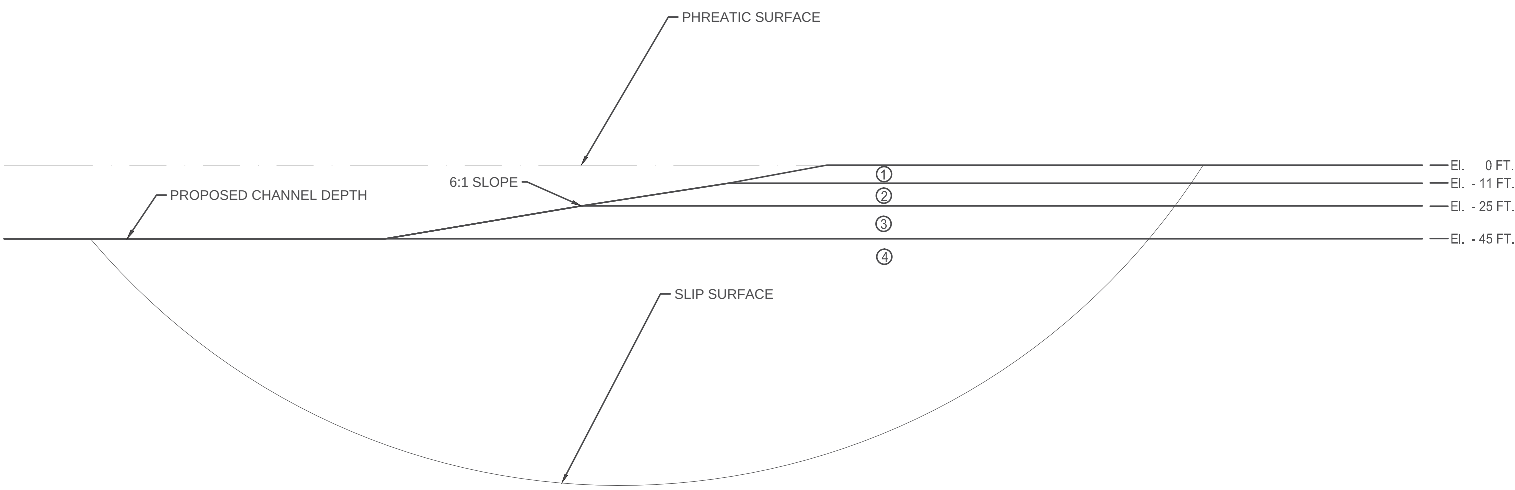
SHEET: 6 OF 17

APPENDIX B

DESIGN CASES AND SAFETY MAPS

CROSS SECTION A - A : DOWNRIVER CHANNEL SECTION: STABILITY ANALYSIS

SCALE: NOT TO SCALE



FACTOR OF SAFETY

MINUMUM FACTOR OF SAFETY = 3.38

SOIL LAYERS

1. FLUVIAL SILT DEPOSITS: γ = 110 PCF φ = 0 ° C = 330 PSF
2. ALLUVIAL SANDS: γ = 120 PCF φ = 32 ° C = 0 PSF
3. STIFF POTOMAC CLAY: γ = 115 PCF φ = 0 ° C = 600 PSF
4. STIFF POTOMAC CLAY γ = 120 PCF φ = 0 ° C = 1,370 PSF

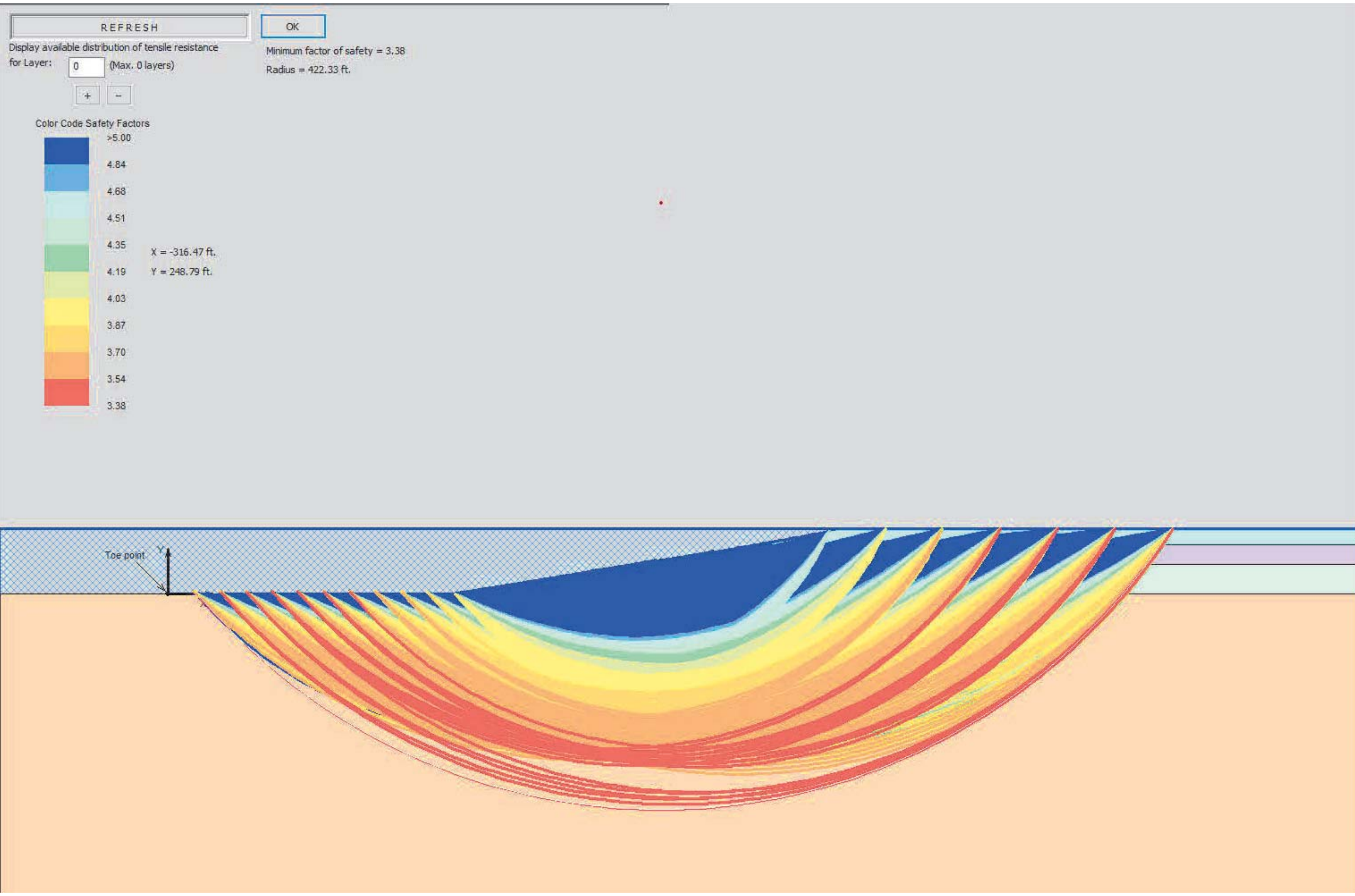
LEGEND:

γ - MOIST UNIT WEIGHT

φ - INTERNAL ANGLE OF FRICTION

C - COHESIVE OR UNDRAINED SHEAR STRENGTH

DUFFIELD ASSOCIATES, INC.
PROJECT No.: 11139.LH
JANUARY 2019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+
-
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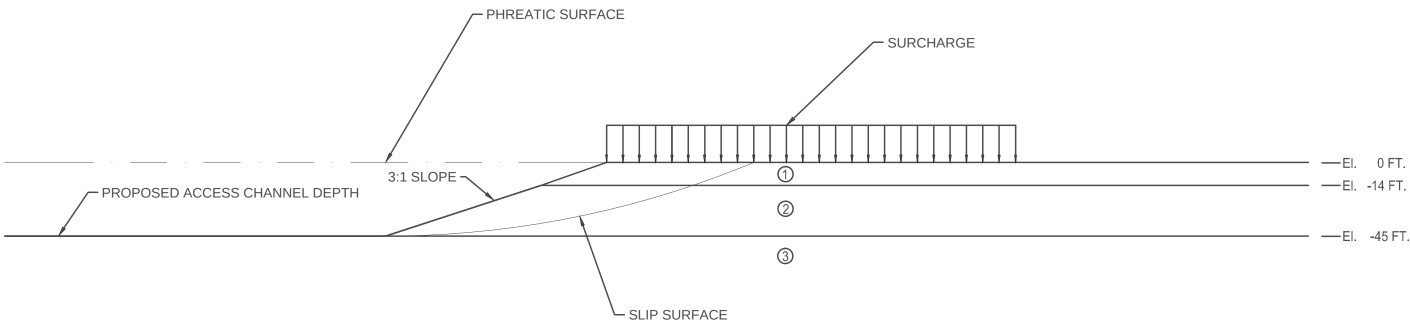
4.68
4.51
4.35
4.19
4.03
3.87
3.70
3.54
3.38
X = -316.47 ft.
Y = 248.79 ft.
Toe point
Y

CROSS SECTION B - B: DOWNRIVER BERTH SECTION: STABILITY ANALYSIS

SCALE: NOT TO SCALE



FACTOR OF SAFETY

MINUMUM FACTOR OF SAFETY = 1.93

SURCHARGE

UNIFORM SURCHARGE = 1,000 PSF

SOIL LAYERS

1. FLUVIAL SILT DEPOSITS: γ = 110 PCF φ = 0 ° C = 330 PSF
2. STIFF POTOMAC CLAY: γ = 115 PCF φ = 0 ° C = 600 PSF
3. STIFF POTOMAC CLAY γ = 120 PCF φ = 0 ° C = 1,370 PSF

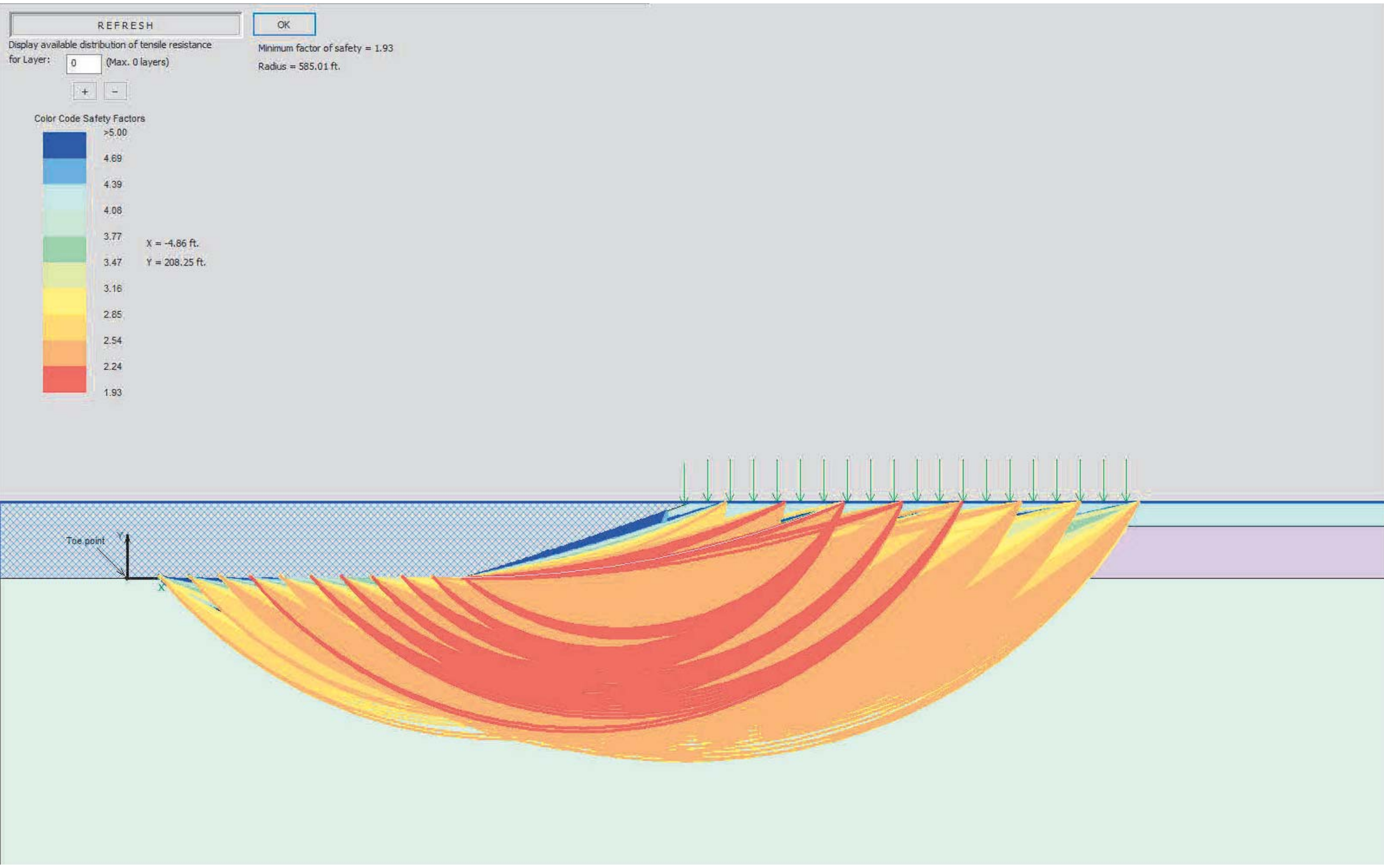
LEGEND:

γ - MOIST UNIT WEIGHT

φ - INTERNAL ANGLE OF FRICTION

C - COHESIVE OR UNDRAINED SHEAR STRENGTH

DUFFIELD ASSOCIATES, INC.
PROJECT No.: 11139.LH
JANUARY 2019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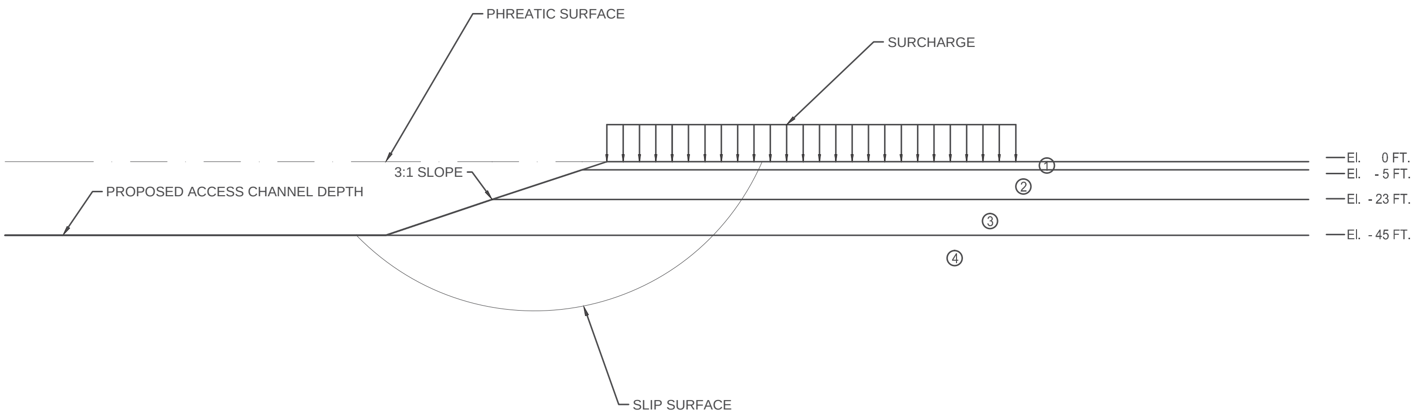
4.39
4.08
3.77
3.47
3.16
2.85
2.54
2.24
1.93
X = -4.86 ft.
Y = 208.25 ft.
Toe point
Y
X

CROSS SECTION C - C : UPRIVER BERTH SECTION: STABILITY ANALYSIS

SCALE: NOT TO SCALE



FACTOR OF SAFETY

MINUMUM FACTOR OF SAFETY = 1.66

SURCHARGE

UNIFORM SURCHARGE = 1,000 PSF

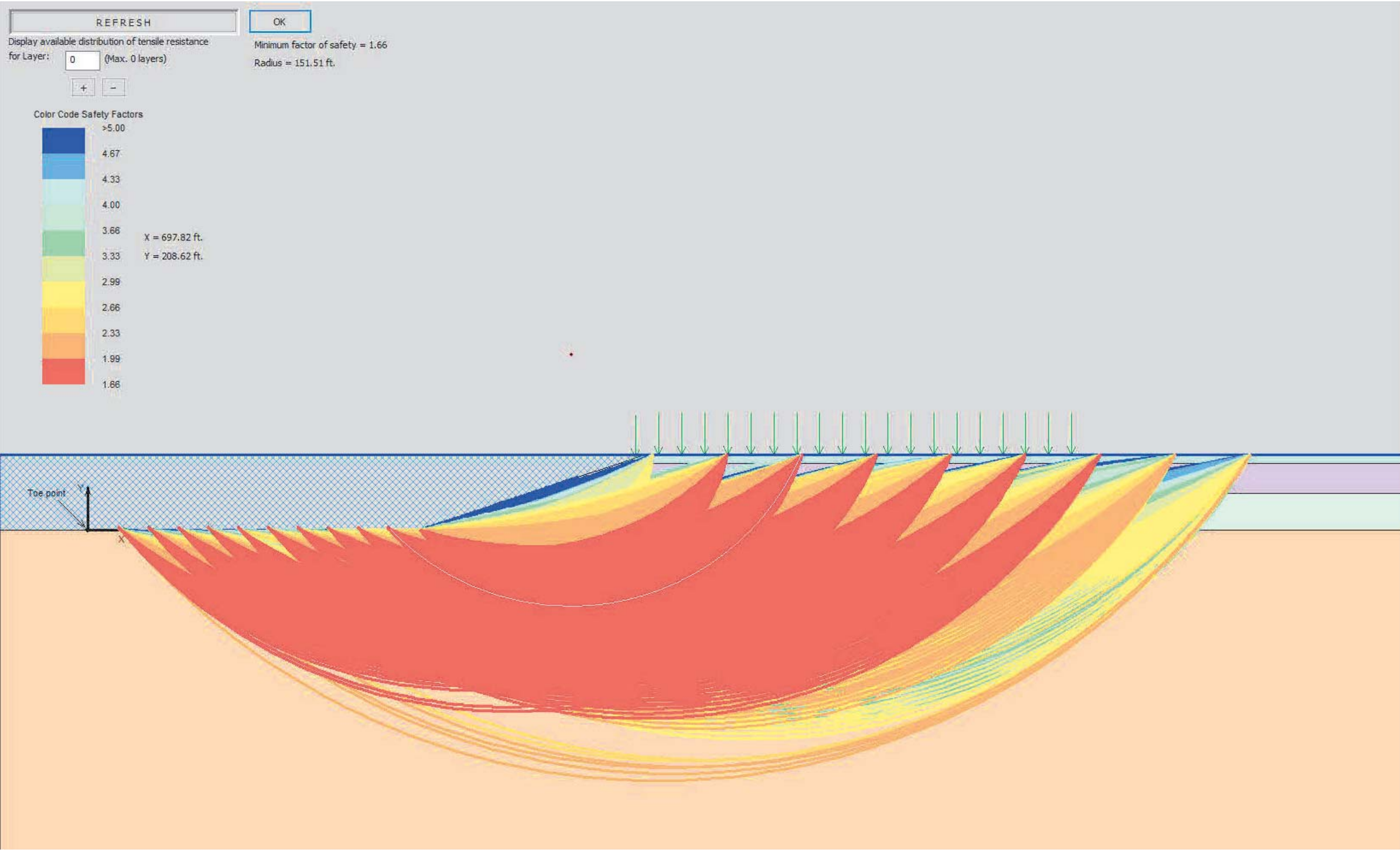
SOIL LAYERS

1. FLUVIAL SILT DEPOSITS: γ = 110 PCF φ = 0 ° C = 330 PSF
2. ALLUVIAL SANDS: γ = 120 PCF φ = 32 ° C = 0 PSF
3. STIFF POTOMAC CLAY γ = 115 PCF φ = 0 ° C = 600 PSF
4. STIFF POTOMAC CLAY γ = 120 PCF φ = 0 ° C = 1,370 PSF

LEGEND:

γ - MOIST UNIT WEIGHT
φ - INTERNAL ANGLE OF FRICTION
C - COHESIVE OR UNDRAINED SHEAR STRENGTH

DUFFIELD ASSOCIATES, INC.
PROJECT No.: 11139.LH
JANUARY 2019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(Max. 0 layers)
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4.33
4.00
3.66
3.33
2.99
2.66
2.33
1.99
1.66
X = 697.82 ft.
Y = 208.62 ft.
Toe point

CROSS SECTION D - D : UPRIVER CHANNEL SECTION: STABILITY ANALYSIS

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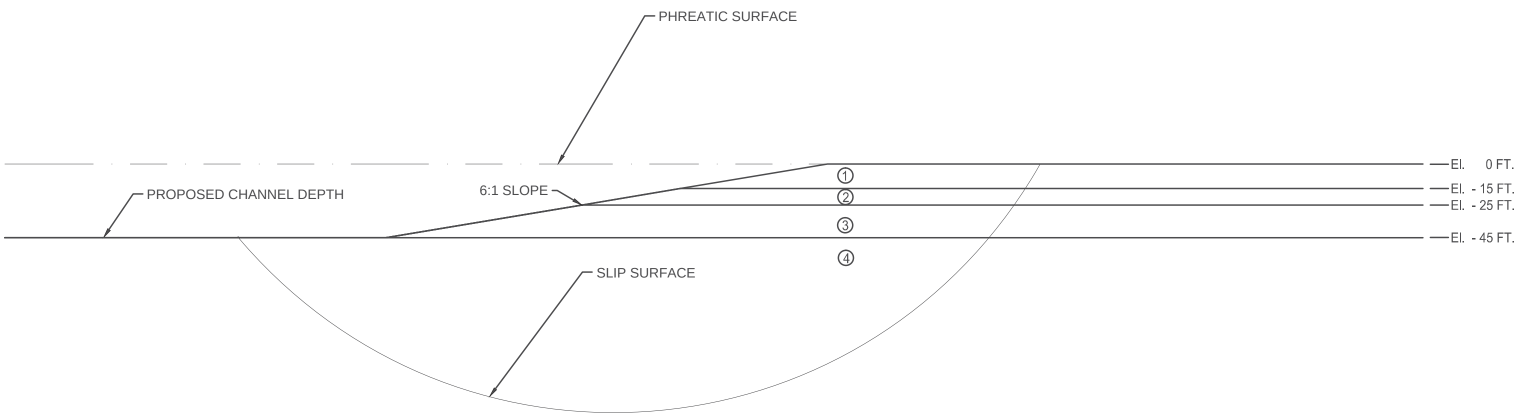


FACTOR OF SAFETY

MINUMUM FACTOR OF SAFETY = 3.53

SOIL LAYERS

(1) FLUVIAL SILT DEPOSITS: γ = 110 PCF φ = 0 ° C = 330 PSF

(2) ALLUVIAL SANDS: γ = 120 PCF φ = 32 ° C = 0 PSF

(3) STIFF POTOMAC CLAY: γ = 115 PCF φ = 0 ° C = 600 PSF

(4) STIFF POTOMAC CLAY γ = 120 PCF φ = 0 ° C = 1,370 PSF

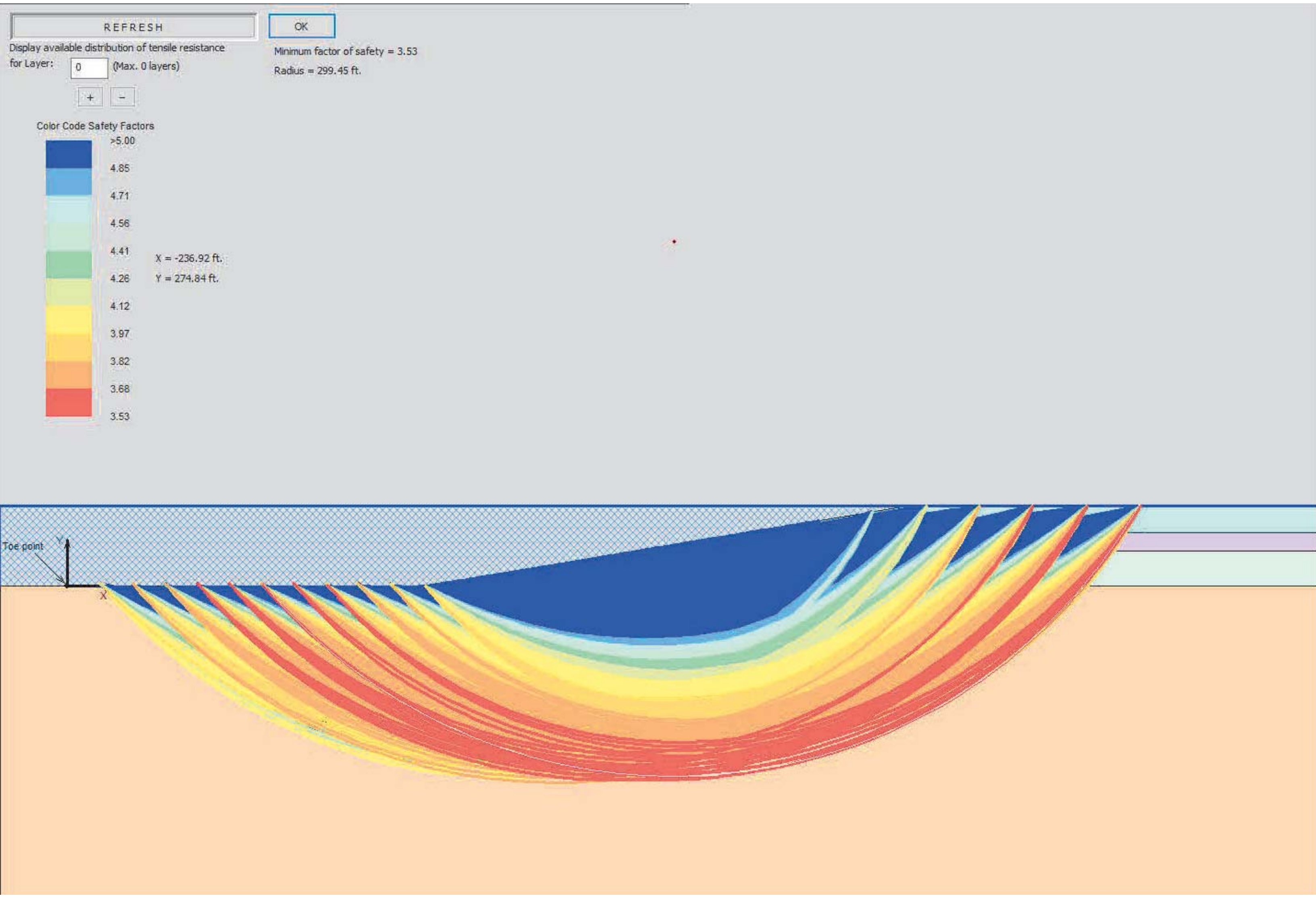
LEGEND:

γ - MOIST UNIT WEIGHT

φ - INTERNAL ANGLE OF FRICTION

C - COHESIVE OR UNDRAINED SHEAR STRENGTH

DUFFIELD ASSOCIATES, INC.
PROJECT No.: 11139.LH
JANUARY 2019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4.85
4.71
4.56
4.41
4.26
4.12
3.97
3.82
3.68
3.53
X = -236.92 ft.
Y = 274.84 ft.
Toe point
Y
X