Initial Safety Factor Assessment
Bottom Ash Pond No. 2
Sherburne County Generating Plant

Introduction

This report presents the assessment and certification of the initial safety factor for the proposed Bottom Ash Pond No. 2 at the Sherburne County Generating Plant (Sherco) in Becker, Minnesota. Bottom Ash Pond No. 2 is a new surface impoundment that utilizes a composite liner compliant with 40 CFR part 257.70(c) on the bottom and each of the four (north, east, south, and west) slopes.

Safety Factor Assessment

The Bottom Ash Pond No. 2 (BAP 2) safety factor assessment was conducted using Slope/W slope stability analysis software developed by Geo-Slope International, LTD. All safety factors were determined using the Morgenstern-Price method, as this method satisfies vertical and horizontal force equilibrium and moment equilibrium and considers both inter-slice shear and normal forces.

The BAP 2 was analyzed according to the following conditions in accordance with §257.74(e)(1)(i) through (v).

(i) **Condition 1**: The calculated static factor of safety under the end of construction loading condition must equal or exceed 1.3.

(ii) **Condition 2**: The calculated static factor of safety under the long-term, maximum storage pool loading condition must equal or exceed 1.5.

(iii) **Condition 3**: The calculated static factor of safety under the maximum surcharge pool loading condition must equal or exceed 1.4.

(iv) The calculated seismic factor of safety must equal or exceed 1.00. This was conducted on both Conditions 1 through 3.

(v) For dikes constructed of soils that have susceptibility to liquefaction, the calculated liquefaction factor of safety must equal or exceed 1.20.

The analyses for BAP 2 were conducted through three critical cross sections: the west cross section is located through the western dike and illustrates the factor of safety with the shared dike of the Bottom Ash Pond 1; the southern cross section is located in the southern dike and analyzes the slope stability of the dike shared with closed Scrubber Solids Pond 2; and, the northern cross section located on the northern dike which represents the stability analysis of both the north and east dikes. A figure showing each critical cross section is included in the Attachments. The stability calculations for all Conditions were conducted using deep failure modes to determine the global stability for each dike, rather than localized sloughing that would not result in dike failure.

Assumptions:

The analysis of the critical section was based on the following assumptions:

- The geometry of the existing Bottom Ash Pond 1 at the western dike consists of a 2.5 horizontal(H):1 vertical(V) slope interior embankment with a 20-foot wide top. The clay core that runs through the embankment has been built with 1H:12V side slopes, a 10-foot wide top, and a 20-foot wide base.
- The BAP 2 will be lined with a needle-punched woven geocomposite liner (GCL) overlain by a 60-mil textured high density polyethylene (HDPE) geomembrane.
- The BAP 2 pond elevation for the maximum, long-term storage condition has been set at 993 feet above mean sea level (MSL), which corresponds to 2-feet below the top edge of the liner on the east embankment.
- The BAP 2 pond elevation for the maximum surcharge pool loading condition has been set at 995 feet, which is the maximum elevation of containment.
- A Circular failure analysis was used for each Condition.
- The water table was determined from the onsite monitoring wells measured on 10/29/2018.
- The seismic stability analysis was conducted using a seismic coefficient equal to one-half of the predicted peak bedrock acceleration during an earthquake with a 2% probability of exceedance in 50 years (Hynes-Griffin et al, 1984), or ½ of 0.022g (0.011g) (USGS, 2008).
- The western dike was analyzed for stability from left to right for Condition 1 and right to left for Conditions 2 and 3, the southern dike was analyzed for stability from left to right, and the northern dike was analyzed from right to left for Condition 1 and left to right for Conditions 2 and 3. In general, each condition was analyzed to determine the safety factor resistance to impounded water.
- The phreatic surface was input as shown with a near vertical downward flow based on the high transmissivity of the embankment fill.

Material Properties:

Soil material properties are taken from information provided in historical design and construction reports, and hydrogeologic site investigations. The results and assumptions for each soil are listed below.

Table 1: Material Geotechnical Properties

Material	Unit weight (pcf)	Friction Angle[1] (deg)	Cohesion (psf)	Pseudo-seismic Cohesion (psf)
Bottom Ash[2]	117	40	0	0
Clay Core – BAP 1[3]	119[4]	27	0	0
Clay – Scrubber Solids Pond 2[5]	127	30	0	0
Drainage Material[5]	120	30	0	0
Embankment Fill[6]	117[7]	30	0	0
Geomembrane/GCL[8]	58	23.8	0	0
Native Soils[9]	115	30	0	0
Scrubber Solids[5]	107	35	0	0

Material Notes:

1. Friction angles used are typical for the classified soil types with similar unit weights (Duncan et al, 2005) (Lindberg, 2001).
2. Geotechnical testing was completed on the former Bottom Ash Pond 1 during construction. Values are taken from the results of this testing.
3. The clay core was taken from an offsite borrow area and was typically classified as either CL, CL-SC, or SC-CL according to the Unified Soil Classification System (USCS). During construction of the clay core, 8-inch thick loose lifts were placed and compacted to at least 90% standard proctor density.
4. Compaction testing was completed on the clay core during construction. Average measured unit weights ranged between 118 and 121 pounds per cubic foot (pcf). This value takes into consideration both the average unit weights and the typical unit weight for soils classified as either CL, CL-SC, or SC-CL (USSD, 2007).
5. Previous slope stability analyses were completed on Scrubber Solids Pond 2 as part of final cover and closure activities. Material properties are taken from these analyses.
6. Embankment soils are typically classified as either SM, SP-SM, or SP under USCS. The embankment fill is taken from onsite excavation of native soils and is re-compacted to produce the embankments.
7. During construction of the former Bottom Ash Pond 1, compaction testing was completed on the embankment fill. Average measured unit weights during construction were between 116.5 and 118.5 pcf. This value takes into consideration the average unit weights for the embankment fill and the typical unit weight for a SM or SP-SM soil (USSD, 2007).
8. The unit weight for the geomembrane represents a typical unit weight for a 60-mil textured HDPE geomembrane. The friction angle for the geomembrane represents the critical interface friction angle between the embankment fill, GCL, and geomembrane (McCartney et al, 2009).
9. Native soils were collected during a previous Phase II hydrogeological Investigation completed near the proposed pond Site, and were tested in laboratory for unit weight, Atterberg limits, and soil classification. The native soil material properties are based on the laboratory results from the investigation (Carlson McCain, 2014).

Compliance with §257.74(e)(1)(i) through (iv)

The results of the static and seismic analyses are summarized below in Table 2. The full graphical results can be found in the Attachments.

Table 2: Slope Stability Results

Facility Phase	Static FOS	Minimum Allowable FOS	Pseudo Seismic FOS	Minimum Allowable FOS	Analysis Method
Western Dike					
Condition 1	1.67	1.3	1.61	1.0	Deep-Circular Failure
Condition 2	1.54	1.5	1.49	1.0	Deep-Circular Failure
Condition 3	1.53	1.4	1.48	1.0	Deep-Circular Failure

Facility Phase	Static FOS	Minimum Allowable FOS	Pseudo Seismic FOS	Minimum Allowable FOS	Analysis Method
Southern Dike					
Condition 1	1.65	1.3	1.60	1.0	Deep-Circular Failure
Condition 2	1.92	1.5	1.78	1.0	Deep-Circular Failure
Condition 3	1.94	1.4	1.80	1.0	Deep-Circular Failure
Northern Dike					
Condition 1	1.84	1.3	1.79	1.0	Deep-Circular Failure
Condition 2	2.47	1.5	2.38	1.0	Deep-Circular Failure
Condition 3	2.51	1.4	2.45	1.0	Deep-Circular Failure

Compliance with §257.74(e)(1)(v)

The potential for liquefaction of the soils is considered low based on the surficial geology (both age and soil composition of the Anoka Sand Plain) and the low probability of a large earthquake occurring in Minnesota. According to the Minnesota Geological Survey (MGS), Minnesota has one of the lowest probabilities for an earthquake occurring, and since 1860, only 20 small to moderate earthquakes have been documented (MGS, 2014). Furthermore, MGS identifies that the potential for a severe earthquake in Minnesota is low, and the Seismic Risk Zone assigned to Minnesota is also zero (meaning lowest risk possible).

Summary

The factor of safety calculated for each of the three critical conditions outlined in the 40 CFR Part 257.74(e) were found acceptable during static and seismic analyses.

Attachments
Critical Cross Sections Location Figure
Slope/W Graphical Results

Certification

I hereby certify under penalty of law that this report was prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based upon my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware there are significant penalties for submitting false information, including the possibility of fine and imprisonment.

March 18, 2019

Daniel J. Riggs, PE
License No. 49559

Date

References

Carlson McCain Phase II Hydrogeologic Investigation Report and Phase III Water Monitoring System Work Plan, Scrubber Solids Ponds 4 &5 Sherco Generating Plant, Becker, MN. December 2014.

Duncan, Michael J. & Wright, Stephen G. 2005. Soil Strength and Slope Stability. John Wiley & Sons, Inc.

Hynes-Griffin, M.E. & A.G. Franklin. 1984. Rationalizing the Seismic Coefficient Method. Department of the Army, Waterways Experiment Station.

Lindeburg, Michael R. Civil Engineering Reference Manual for the PE Exam, 8th edition. 2001.

Minnesota Division of Homeland Security and Emergency Management, Minnesota All-Hazard Mitigation Plan Update, 2011.

Minnesota Geological Survey, Minnesota at a Glance: Earthquakes in Minnesota, University of Minnesota, 2014.

McCartney, John, et al. Analysis of a Large Database of GCL-Geomembrane Interface Shear Strength Results. Journal of Geotechnical and Geoenvironmental Engineering, February 2009.

US EPA, RCRA Subtitle D (258) Seismic Design Guidance of Municipal Solid Waste Landfill Facilities, Officer of Research and Development, April 1995, Pages 74-80.

United States Geological Survey (USGS). 2008. PGA with 2% probability exceedance in 50 years

United States Society on Dams (USSD). Strength of Materials for Embankment Dams, February 2007.

Critical Cross Sections Location Figure

7/23/2020

P:\Projects\XCEL\3404-19 Bottom Ash Pond 2\2019 Services\Engineering Report\supporting docs\Figure 1 - Stability Analysis Cross Section.dgn

UNDERGROUND UTILITIES

NORTHERN DIKE SECTION

EXISTING BOTTOM ASH POND

BOTTOM ASH POND NO. 2

WESTERN DIKE SECTION

SOUTHERN DIKE SECTION

SCRUBBER POND NO. 2

Carlson McCain
ENVIRONMENTAL • ENGINEERING • SURVEYING

N

0 75 150
SCALE IN FEET

EXISTING CONTOURS FROM NOVEMBER 2014 LIDAR SURVEY

DESIGN CONTOURS REPRESENT LINER GRADES AND SUBGRADE, BELOW AND ABOVE LINER EDGE, RESPECTIVELY

FIGURE 1
SLOPE STABILITY SECTIONS

Slope/W Graphical Results

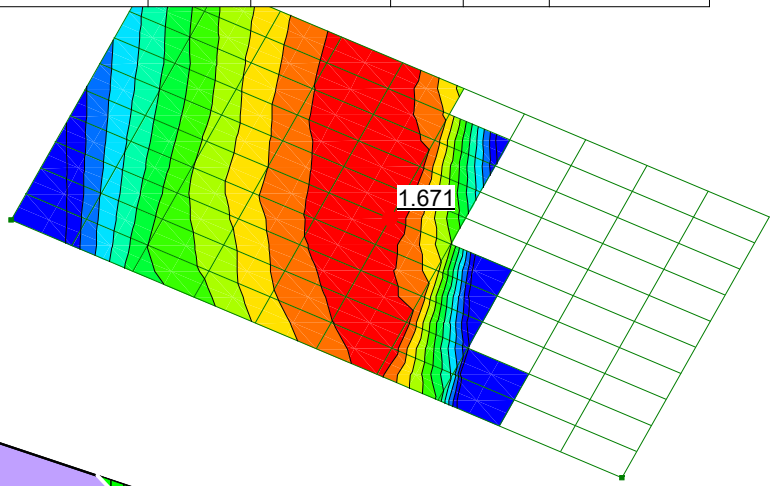
Western Dike

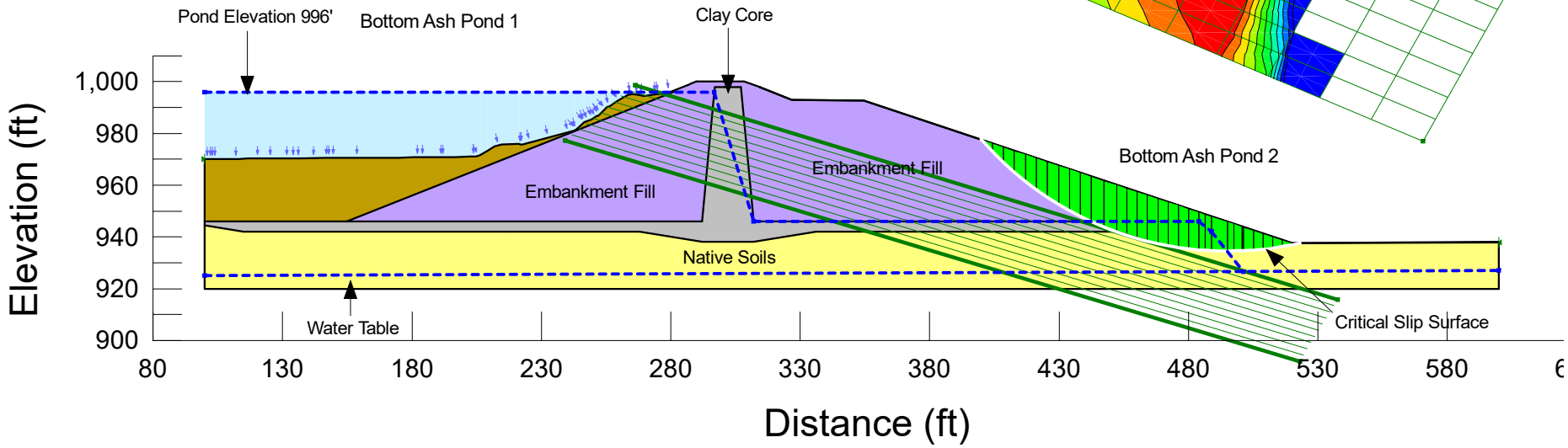
Condition 1

End of Construction

Condition 1: End of Construction
Western Dike Critical Cross Section
Global Stability
Xcel Sherco BAP 2
FS = 1.671

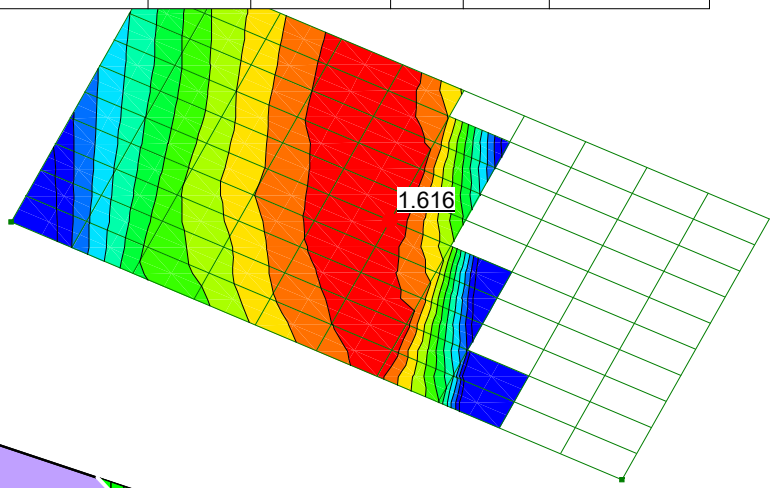
Color	Name	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)	Piezometric Line
	Bottom Ash	117	0	40	0	1
	Clay	119	0	27	0	1
	Embankment Fill	117	0	30	0	1
	Geomembrane/GCL	58	0	23.8	0	1
	Native Soils	115	0	30	0	1

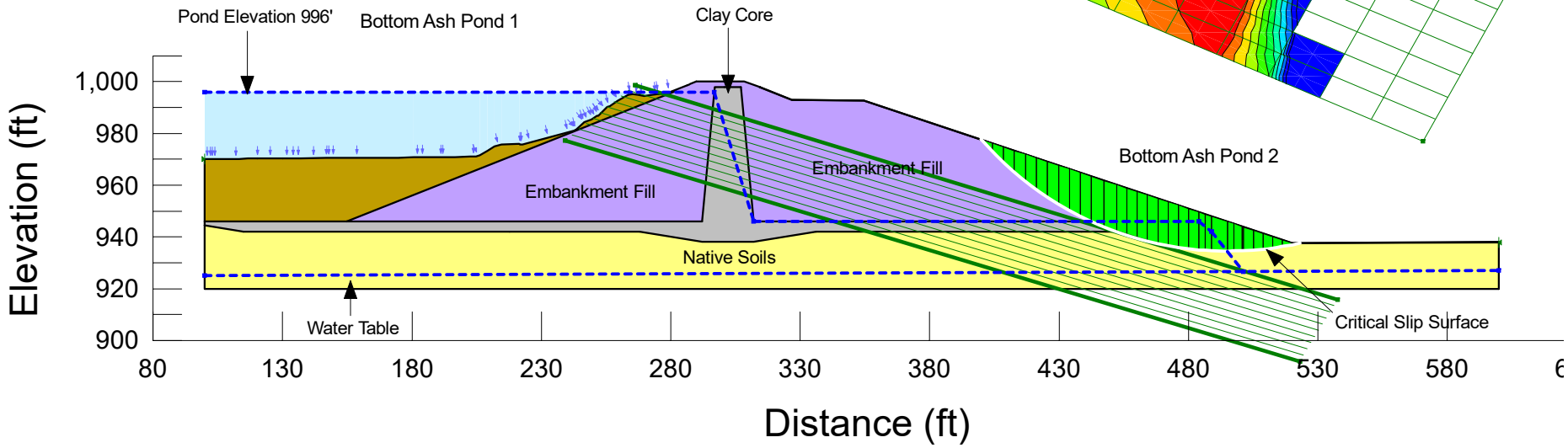




Seismic Condition 1: End of Construction
Western Dike Critical Cross Section
Global Stability
Xcel Sherco BAP 2
FS = 1.616

Color	Name	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)	Piezometric Line
	Bottom Ash	117	0	40	0	1
	Clay	119	0	27	0	1
	Embankment Fill	117	0	30	0	1
	Geomembrane/GCL	58	0	23.8	0	1
	Native Soils	115	0	30	0	1





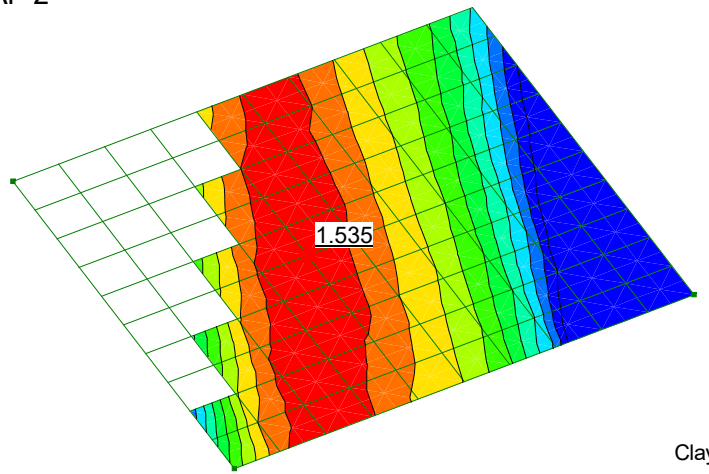
Western Dike

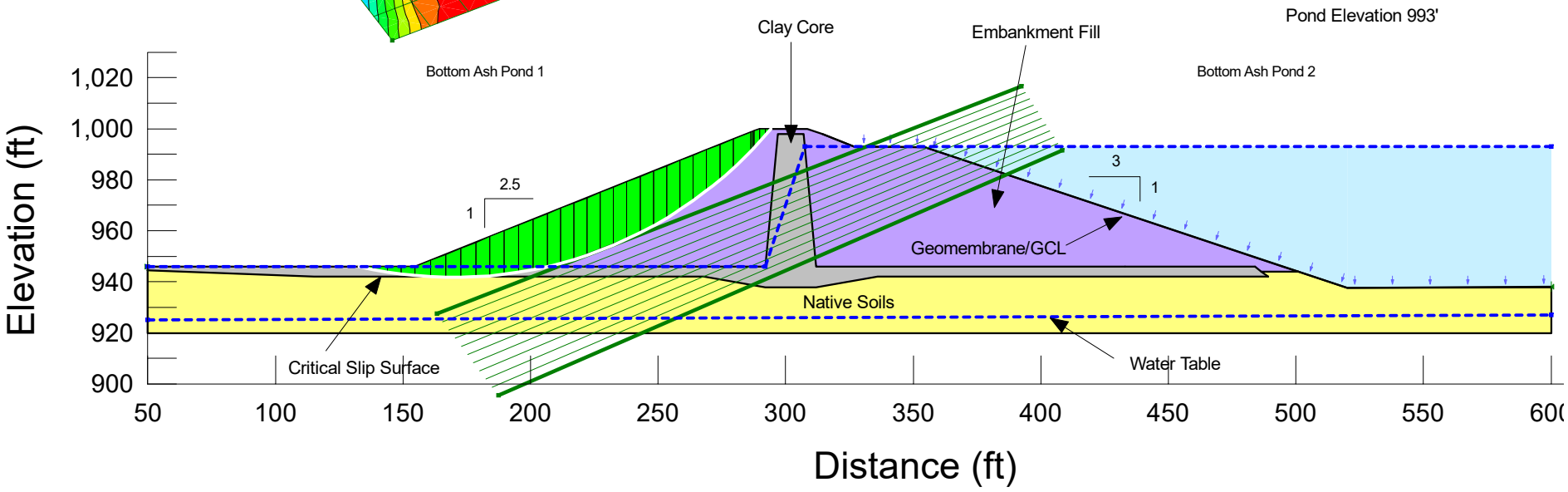
Condition 2

Long-Term, Maximum Storage Loading

Condition 2: Maximum Storage Loading
Western Dike Critical Cross Section
Global Stablity
Xcel Sherco BAP 2
FS = 1.535

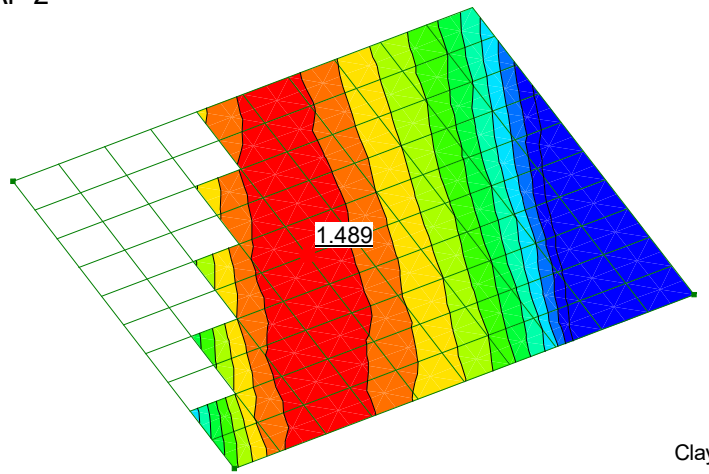
Color	Name	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)	Piezometric Line
	Clay	119	0	27	0	2
	Embankment Fill	117	0	30	0	2
	Geomembrane/GCL	58	0	23.8	0	2
	Native Soils	115	0	30	0	2

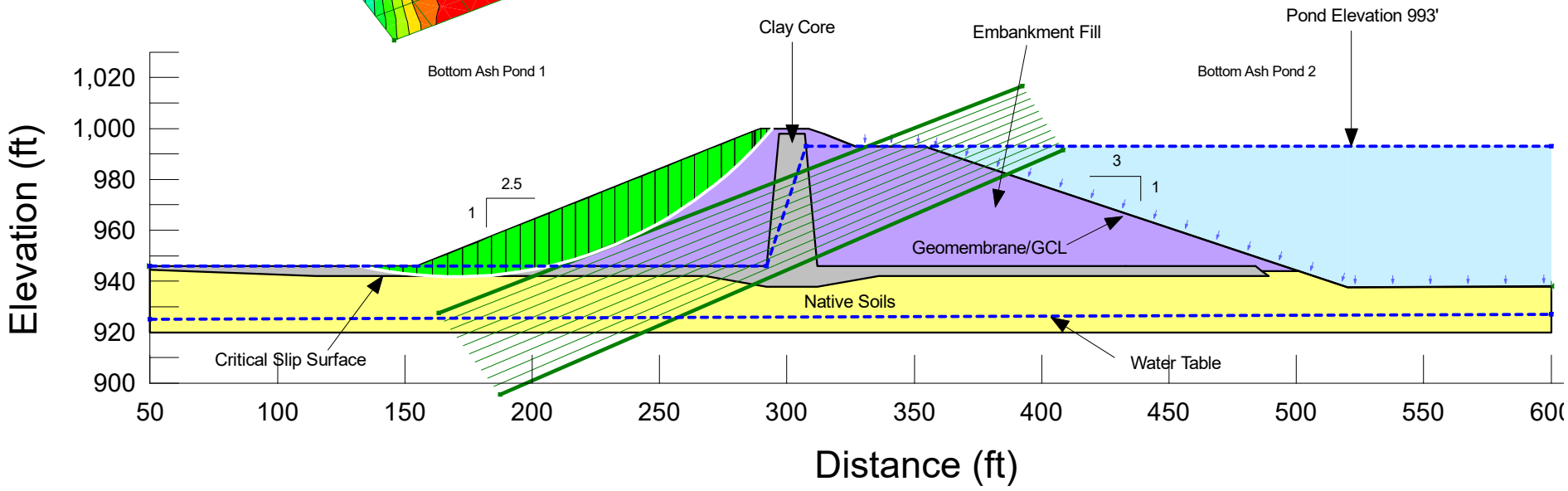




Seismic Condition 2: Maximum Storage Loading
Western Dike Critical Cross Section
Global Stablity
Xcel Sherco BAP 2
FS = 1.489

Color	Name	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)	Piezometric Line
	Clay	119	0	27	0	2
	Embankment Fill	117	0	30	0	2
	Geomembrane/GCL	58	0	23.8	0	2
	Native Soils	115	0	30	0	2





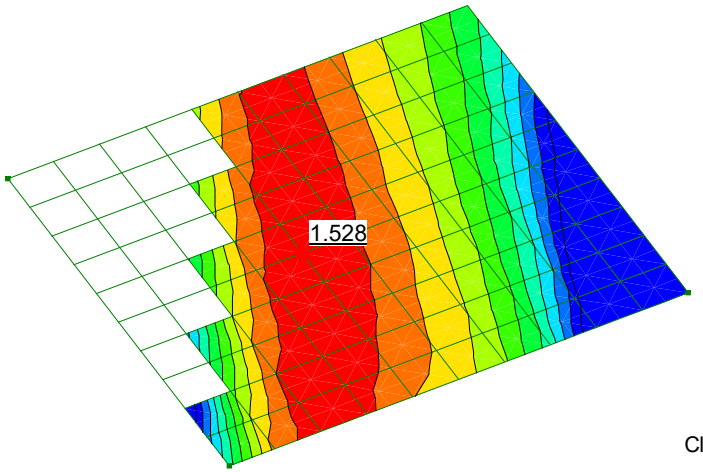
Western Dike

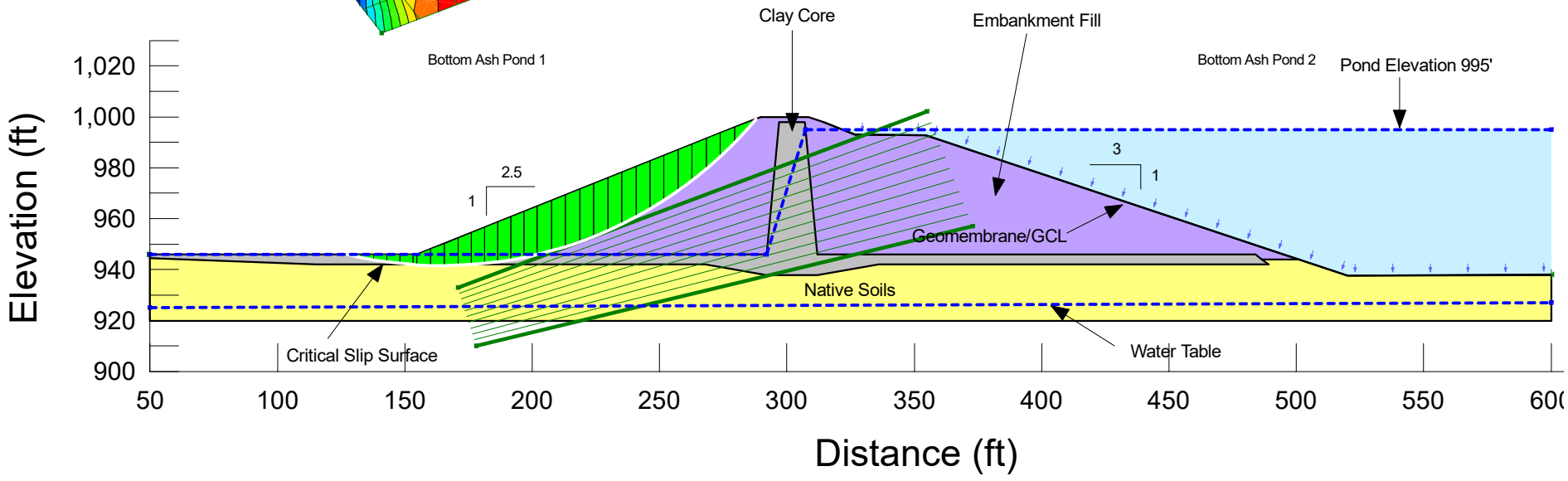
Condition 3

Maximum Surcharge Loading

Condition 3: Maximum Surcharge Loading
Western Dike Critical Cross Section
Global Stability
Xcel Sherco BAP 2
FS = 1.528

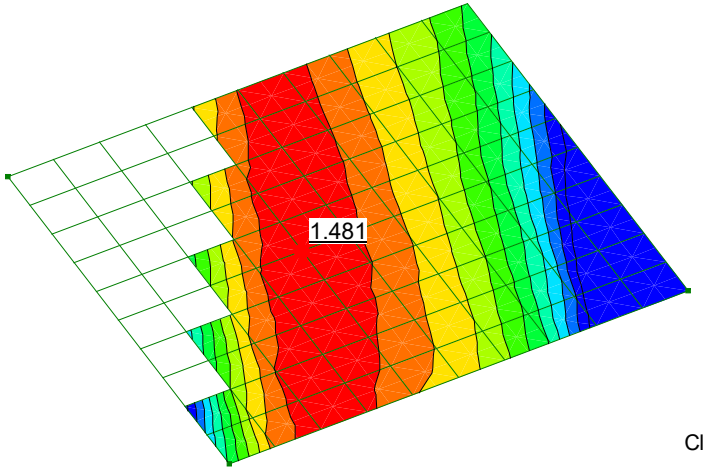
Color	Name	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)	Piezometric Line
	Clay	119	0	27	0	2
	Embankment Fill	117	0	30	0	2
	Geomembrane/GCL	58	0	23.8	0	2
	Native Soils	115	0	30	0	2

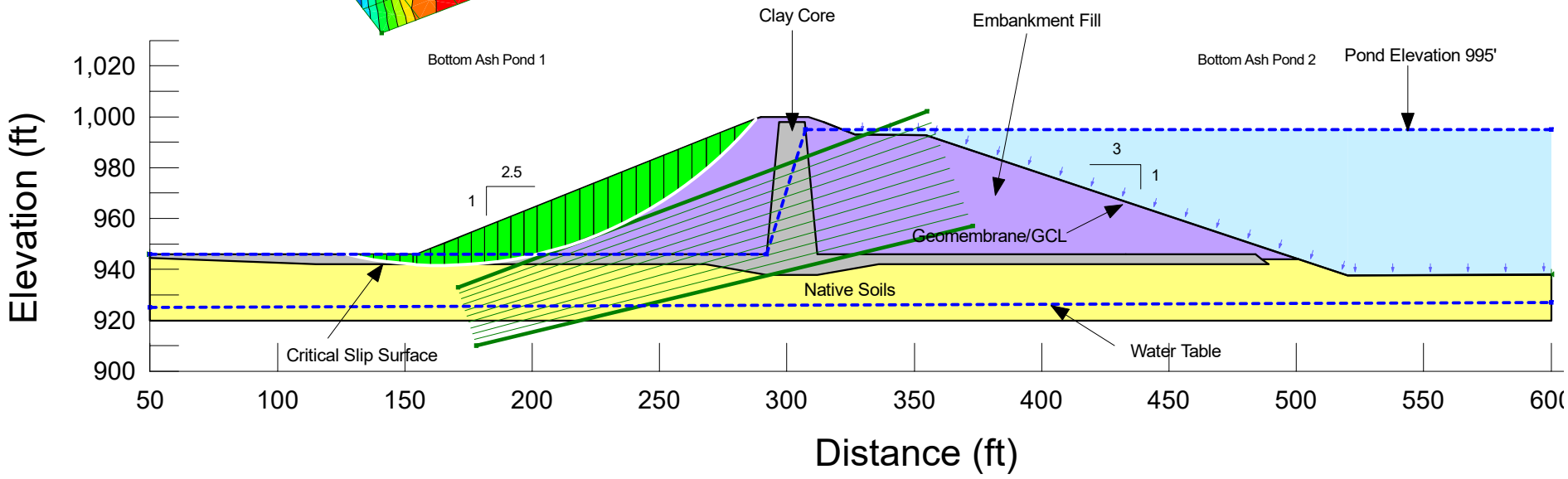




Seismic Condition 3: Maximum Surcharge Loading
Western Dike Critical Cross Section
Global Stability
Xcel Sherco BAP 2
FS = 1.481

Color	Name	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)	Piezometric Line
	Clay	119	0	27	0	2
	Embankment Fill	117	0	30	0	2
	Geomembrane/GCL	58	0	23.8	0	2
	Native Soils	115	0	30	0	2



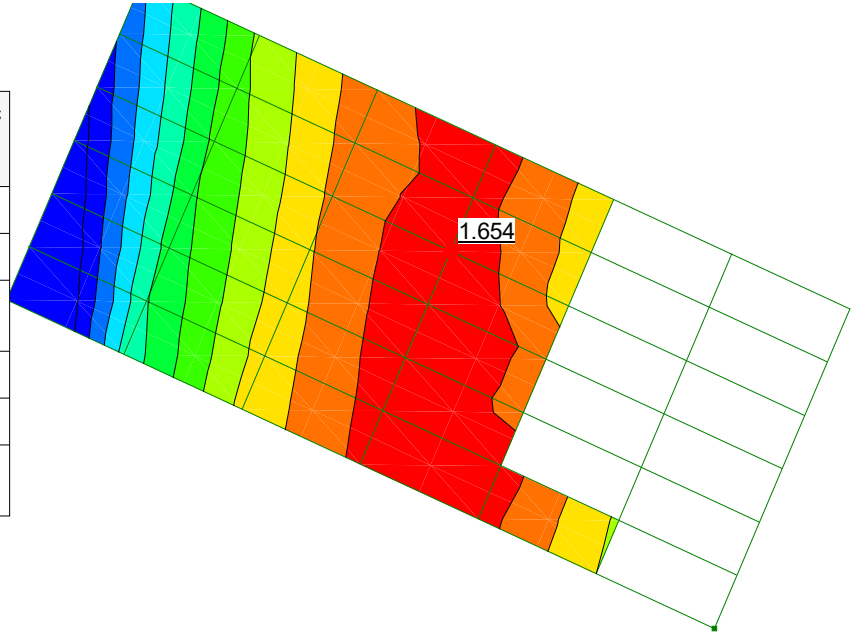


Southern Dike

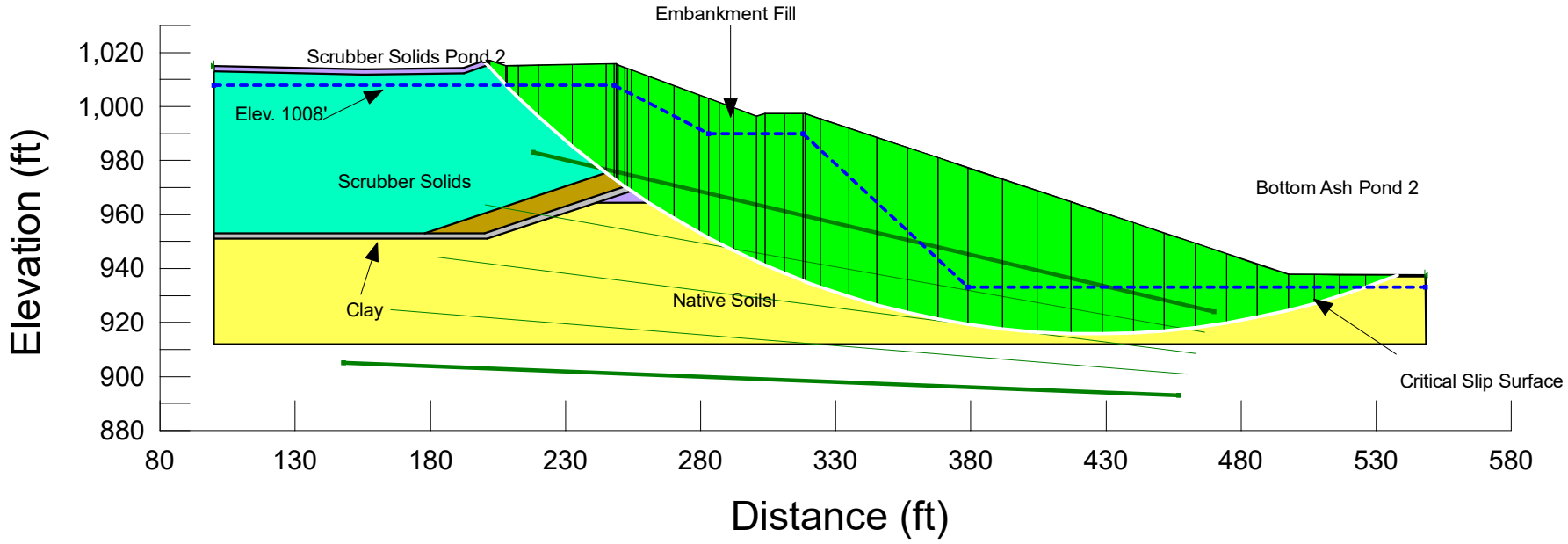
Condition 1

End of Construction

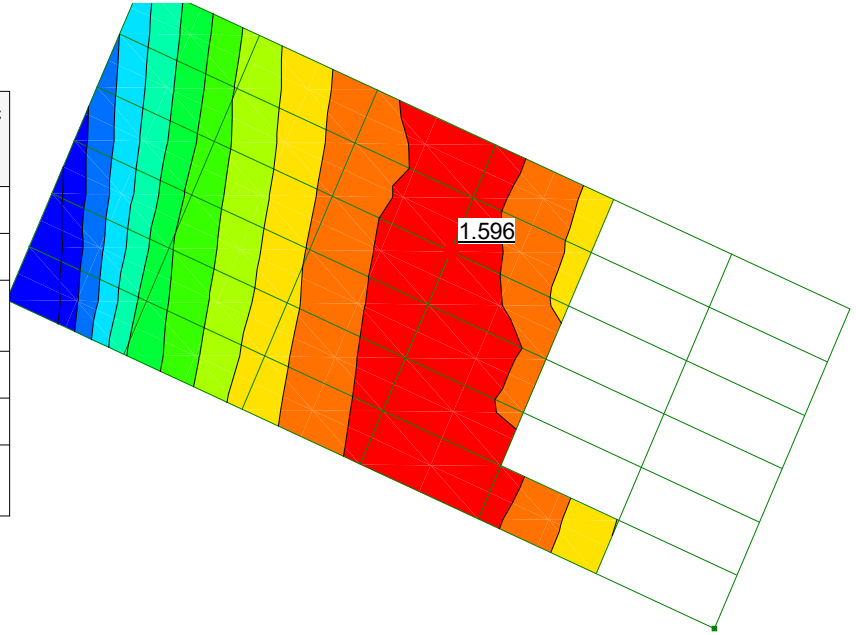
Color	Name	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)	Piezometric Line
	Bottom Ash	117	0	40	0	1
	Clay	127	0	30	0	1
	Embankment Fill	117	0	30	0	1
	Geomembrane/GCL	58	0	23.8	0	1
	Native Soils	115	0	30	0	1
	Scrubber Solids	107	0	35	0	1



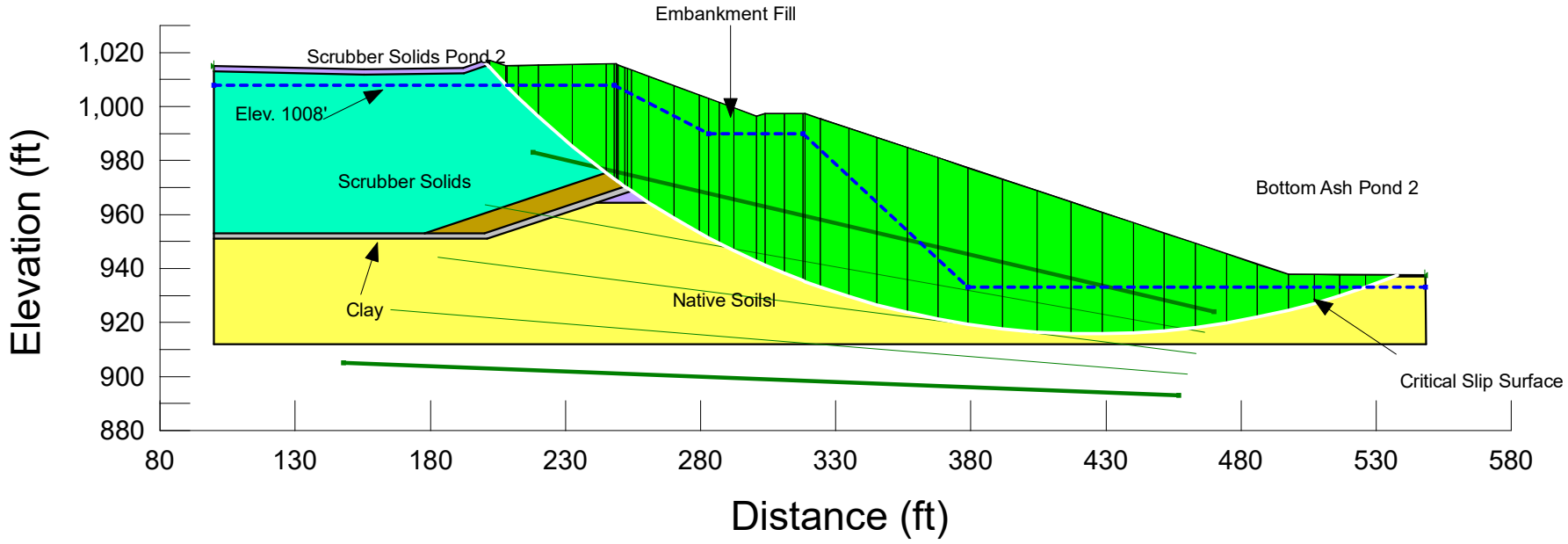
Condition 1: End of Construction
Southern Dike Critical Cross Section
Global Stability
Xcel Sherco BAP 2
FS = 1.654



Color	Name	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)	Piezometric Line
	Bottom Ash	117	0	40	0	1
	Clay	127	0	30	0	1
	Embankment Fill	117	0	30	0	1
	Geomembrane/GCL	58	0	23.8	0	1
	Native Soils	115	0	30	0	1
	Scrubber Solids	107	0	35	0	1



Seismic Condition 1: End of Construction
Southern Dike Critical Cross Section
Global Stability
Xcel Sherco BAP 2
FS = 1.596



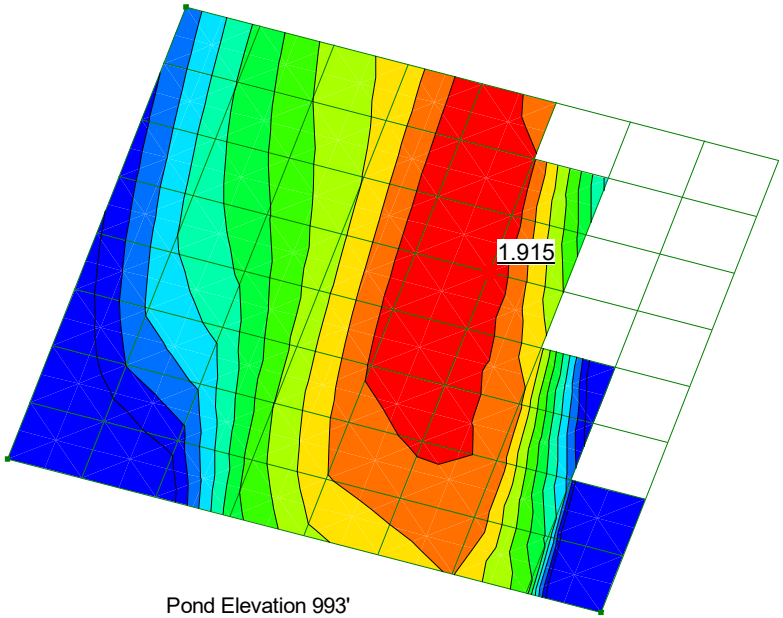
Southern Dike

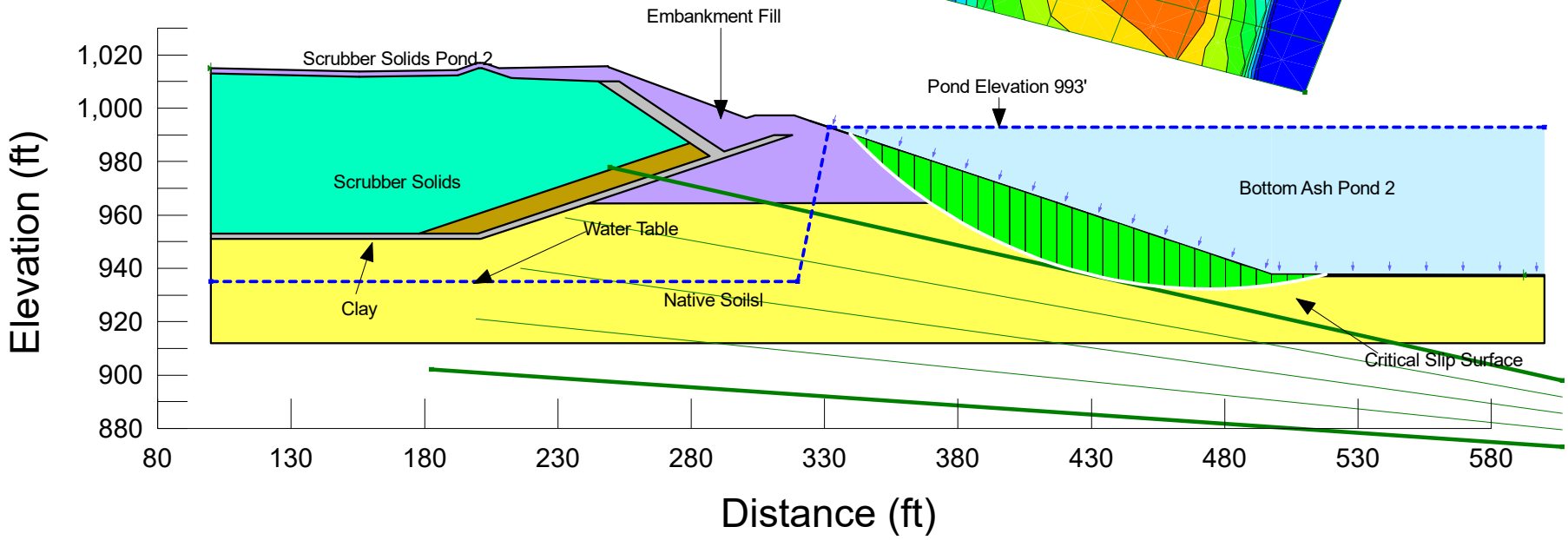
Condition 2

Long-Term, Maximum Storage Loading

Color	Name	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)	Piezometric Line
	Bottom Ash	117	0	40	0	1
	Clay	127	0	30	0	1
	Embankment Fill	117	0	30	0	1
	Geomembrane/GCL	58	0	23.8	0	1
	Native Soils	115	0	30	0	1
	Scrubber Solids	107	0	35	0	1

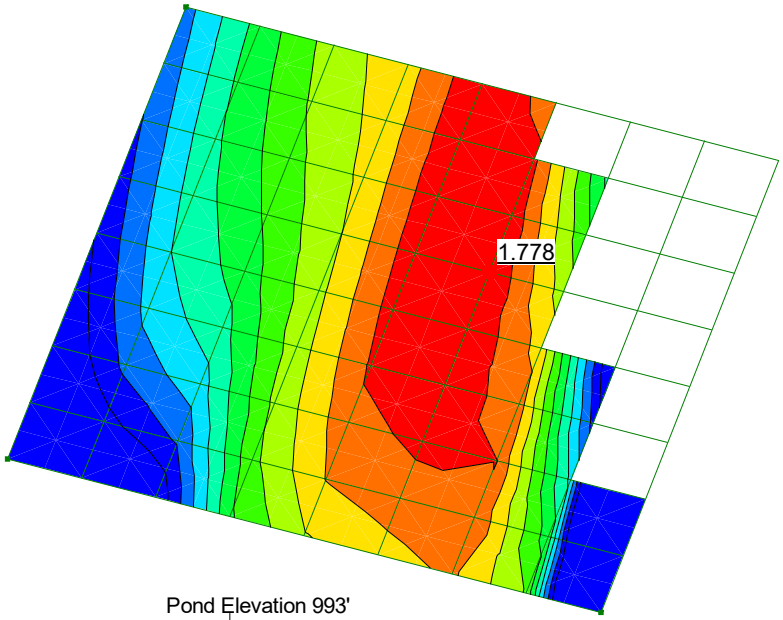
Condition 2: Maximum Storage Loading
Southern Dike Critical Cross Section
Global Stability
Xcel Sherco BAP 2
FS = 1.915

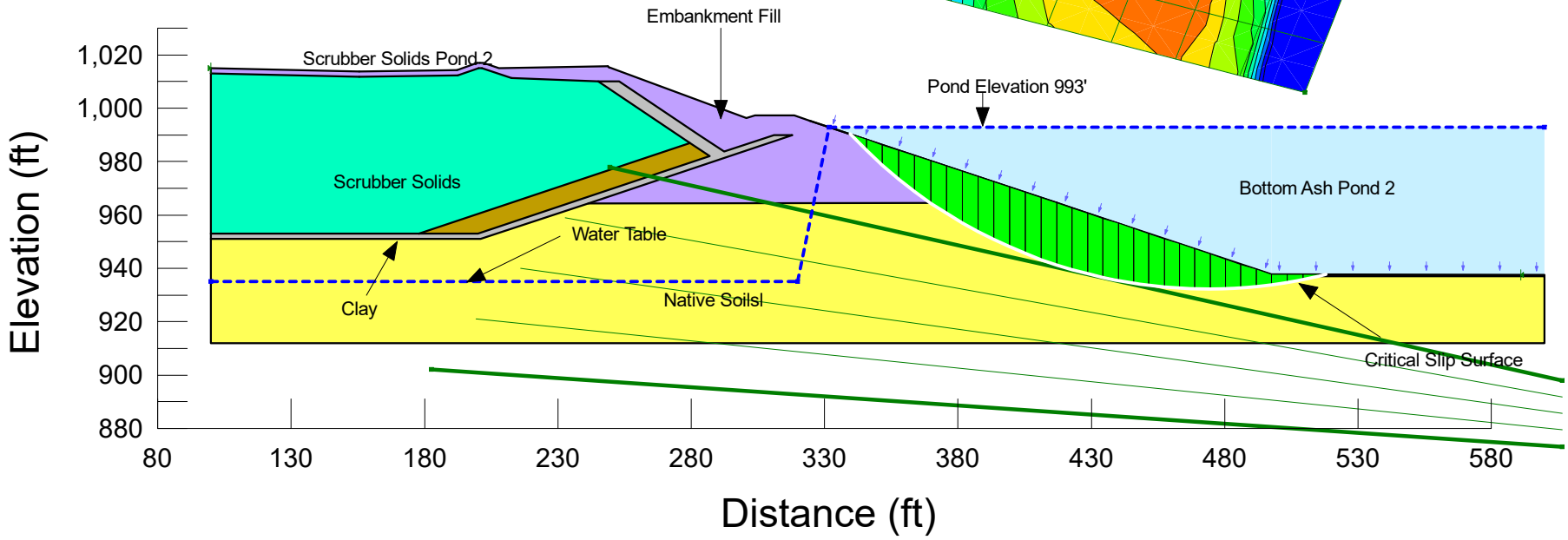




Color	Name	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)	Piezometric Line
	Bottom Ash	117	0	40	0	1
	Clay	127	0	30	0	1
	Embankment Fill	117	0	30	0	1
	Geomembrane/GCL	58	0	23.8	0	1
	Native Soils	115	0	30	0	1
	Scrubber Solids	107	0	35	0	1

Seismic Condition 2: Maximum Storage Loading
Southern Dike Critical Cross Section
Global Stability
Xcel Sherco BAP 2
FS = 1.778



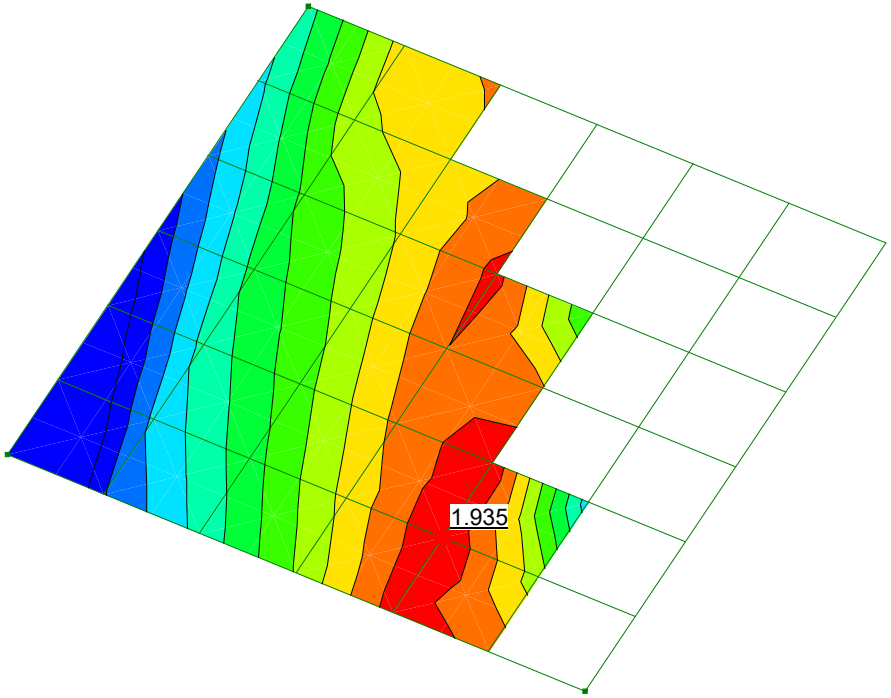


Southern Dike

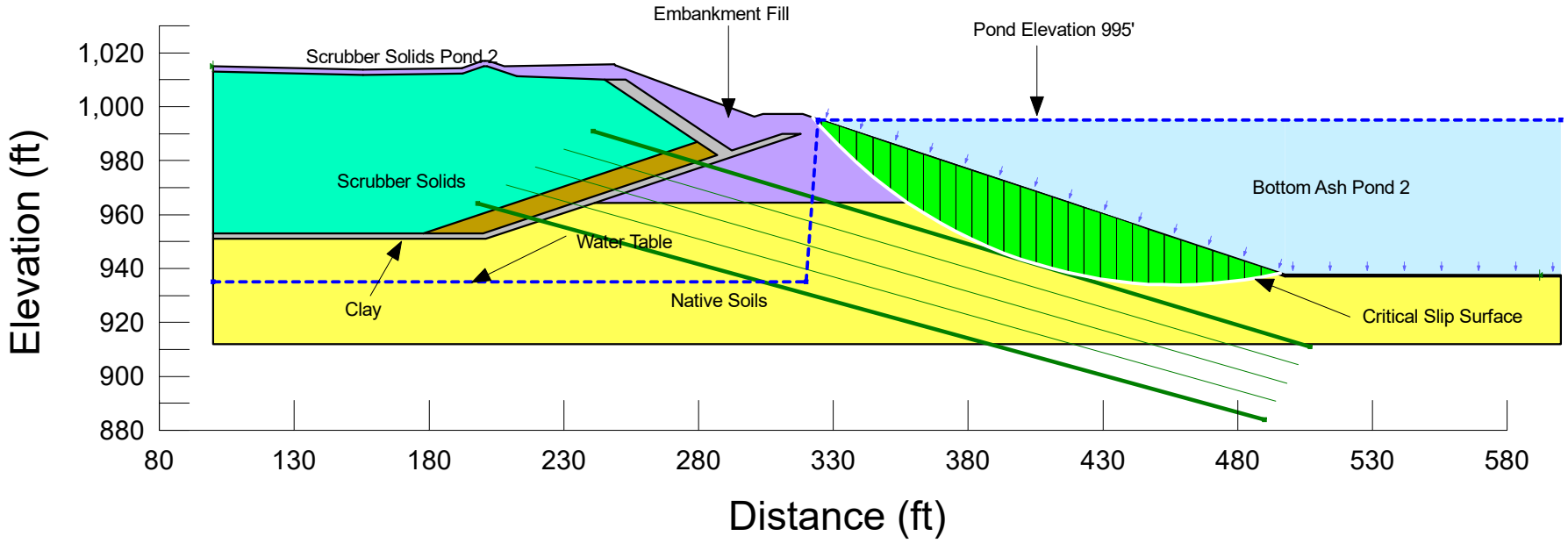
Condition 3

Maximum Surcharge Loading

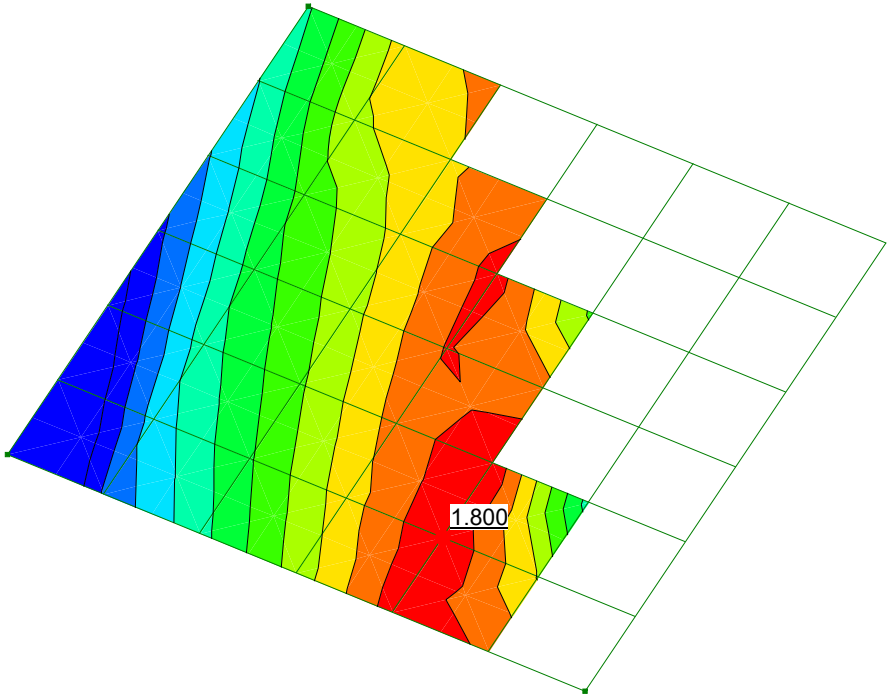
Color	Name	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)	Piezometric Line
	Bottom Ash	117	0	40	0	1
	Clay	127	0	30	0	1
	Embankment Fill	117	0	30	0	1
	Geomembrane/GCL	58	0	23.8	0	1
	Native Soils	115	0	30	0	1
	Scrubber Solids	107	0	35	0	1



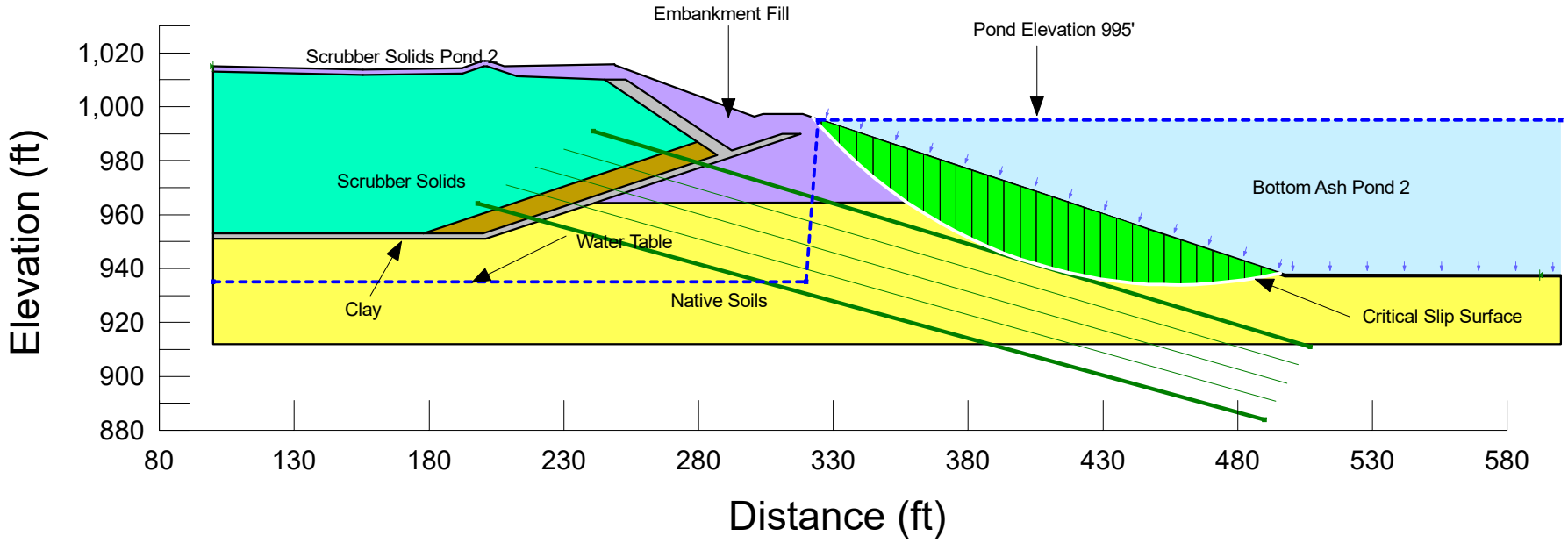
Condition 3: Maximum Surcharge Loading
Southern Dike Critical Cross Section
Global Stability
Xcel Sherco BAP 2
FS = 1.935



Color	Name	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)	Piezometric Line
	Bottom Ash	117	0	40	0	1
	Clay	127	0	30	0	1
	Embankment Fill	117	0	30	0	1
	Geomembrane/GCL	58	0	23.8	0	1
	Native Soils	115	0	30	0	1
	Scrubber Solids	107	0	35	0	1



Seismic Condition 3: Maximum Surcharge Loading
Southern Dike Critical Cross Section
Global Stability
Xcel Sherco BAP 2
FS = 1.800



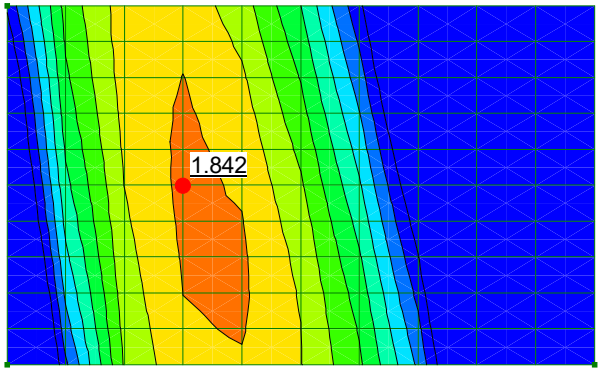
Northern Dike

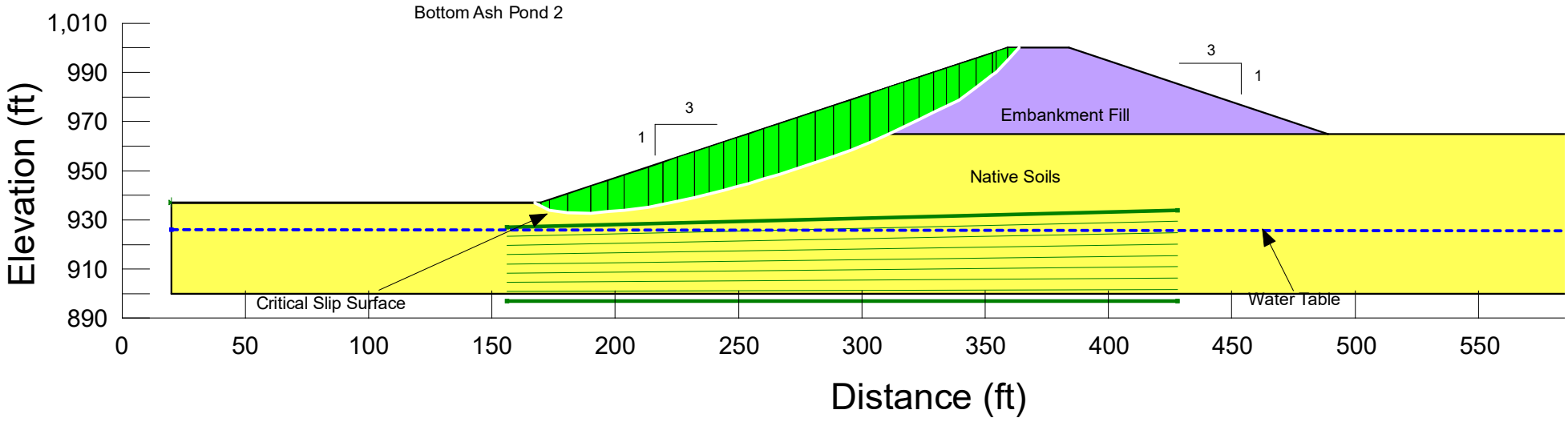
Condition 1

End of Construction

Condition 1: End of Construction
Northern Dike Critical Cross Section
Global Stability
Xcel Sherco BAP 2
FS = 1.84

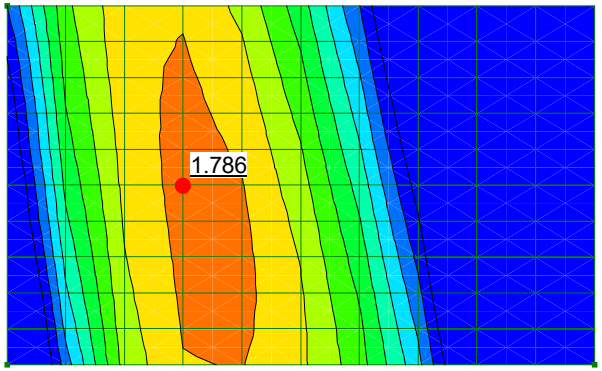
Color	Name	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)	Piezometric Line
	Engineered Embankment Fill	117	0	30	0	
	Geomembrane/GCL	58	0	23.8	0	
	Native Soils	115	0	30	0	1

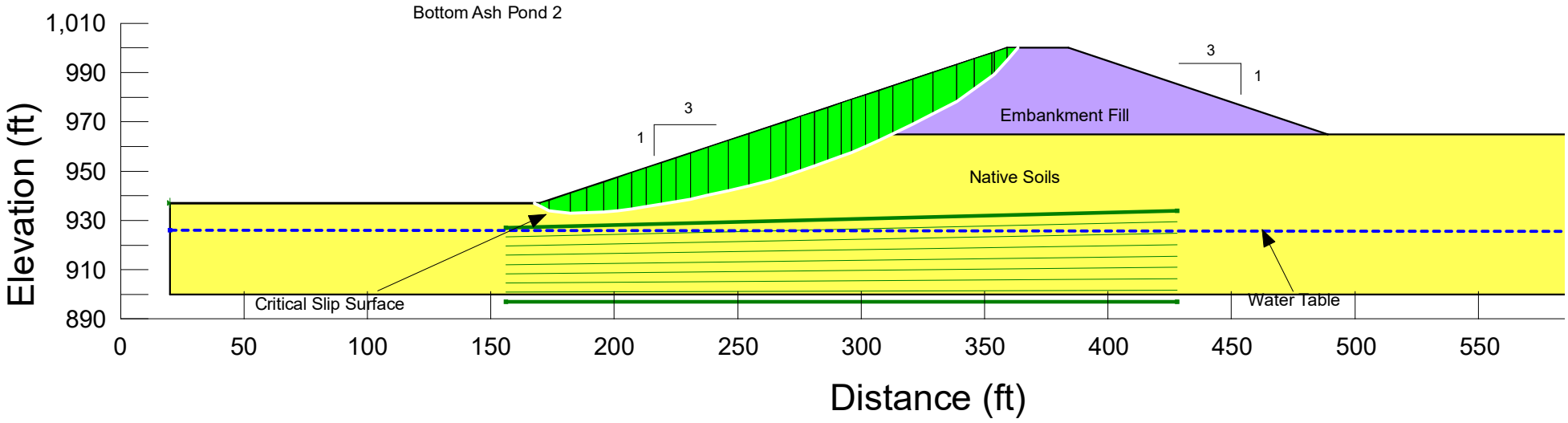




Seismic Condition 1: End of Construction
Northern Dike Critical Cross Section
Global Stability
Xcel Sherco BAP 2
FS = 1.79

Color	Name	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)	Piezometric Line
	Embankment Fill	117	0	30	0	
	Geomembrane/GCL	58	0	23.8	0	
	Native Soils	115	0	30	0	1





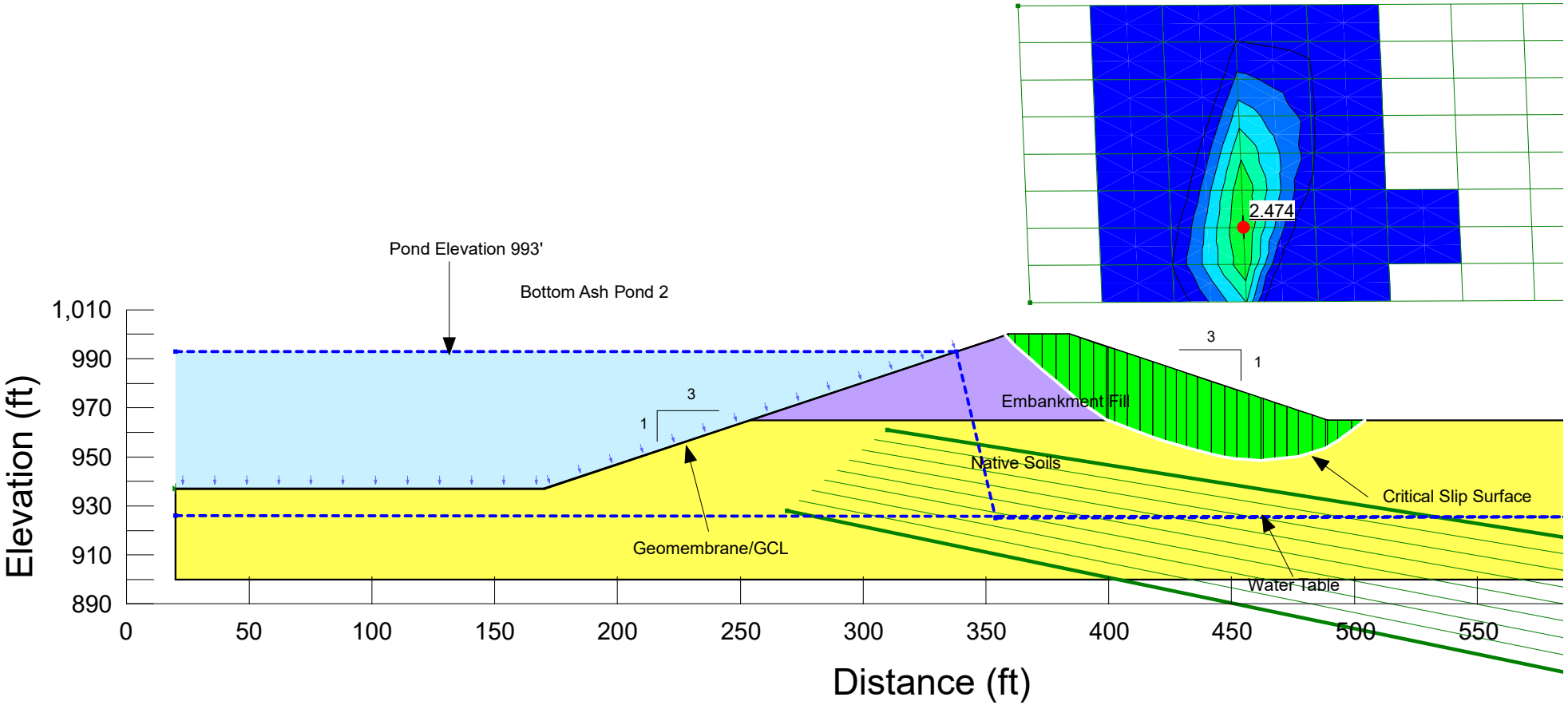
Northern Dike

Condition 2

Long-Term, Maximum Storage Loading

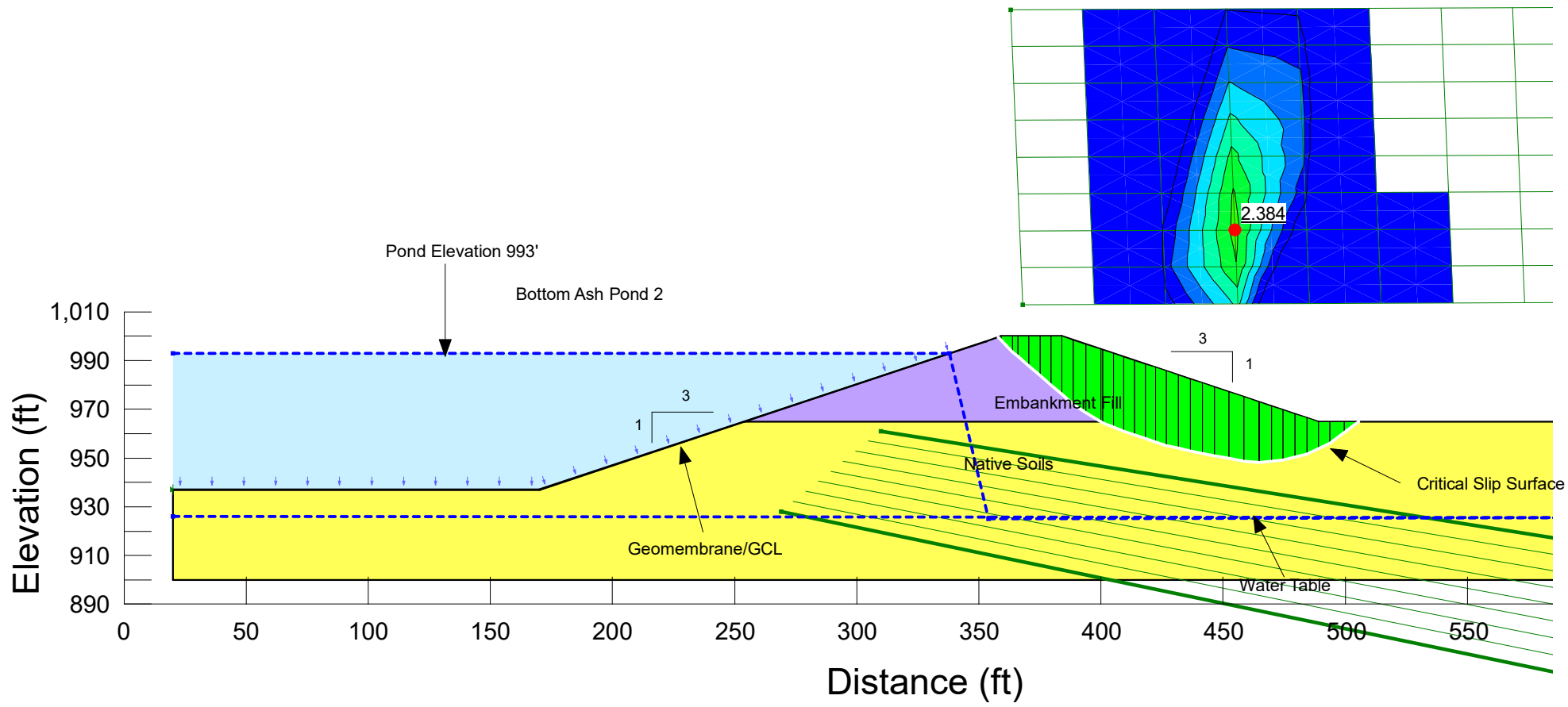
Condition 2: Max Storage
Northern Dike Critical Cross Section
Global Stability
Xcel Sherco BAP 2
FS = 2.474

Color	Name	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)	Piezometric Line
	Embankment Fill	117	0	30	0	2
	Geomembrane/GCL	58	0	23.8	0	2
	Native Soils	115	0	30	0	2



Seismic Condition 2: Max Storage
Northern Dike Critical Cross Section
Global Stability
Xcel Sherco BAP 2
FS = 2.38

Color	Name	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)	Piezometric Line
	Embankment Fill	117	0	30	0	2
	Geomembrane/GCL	58	0	23.8	0	2
	Native Soils	115	0	30	0	2



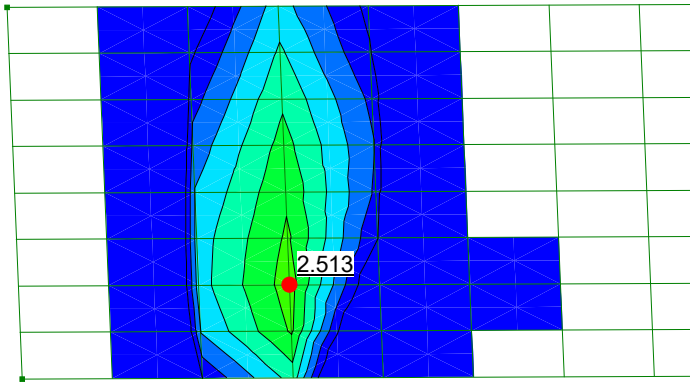
Northern Dike

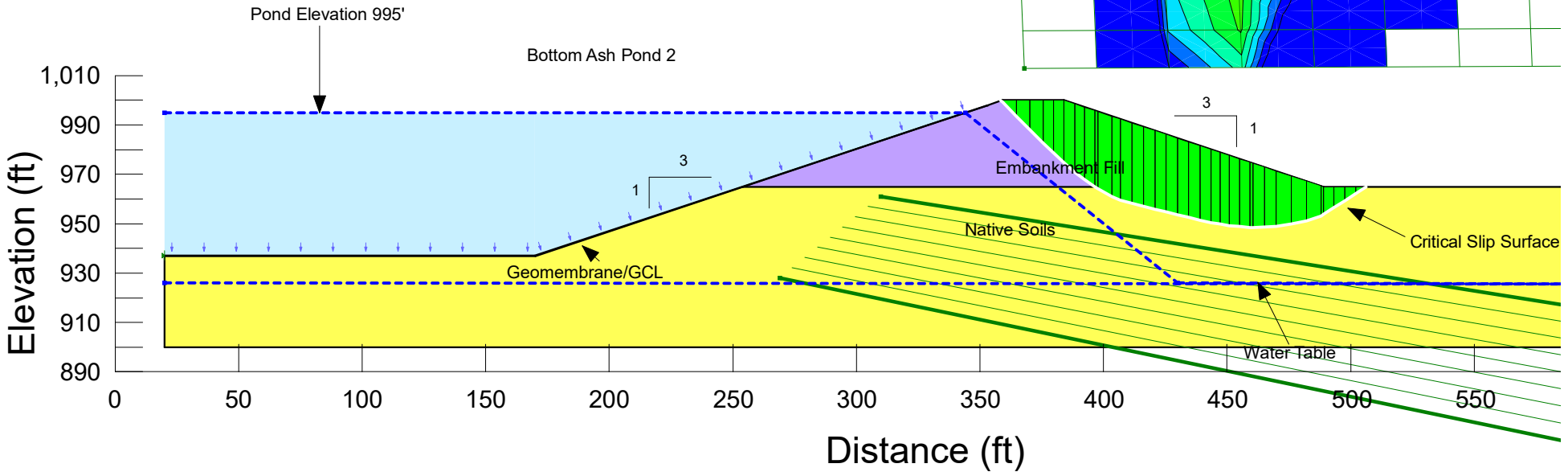
Condition 3

Maximum Surcharge Loading

Condition 3: Maximum Surcharge
Northern Dike Critical Cross Section
Global Stability
Xcel Sherco BAP 2
FS = 2.513

Color	Name	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)	Piezometric Line
	Embankment Fill	117	0	30	0	2
	Geomembrane/GCL	58	0	23.8	0	2
	Native Soils	115	0	30	0	2





Seismic Condition 3: Maximum Surcharge
Northern Dike Critical Cross Section
Global Stability
Xcel Sherco BAP 2
FS = 2.451

Color	Name	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)	Piezometric Line
	Embankment Fill	117	0	30	0	2
	Geomembrane/GCL	58	0	23.8	0	2
	Native Soils	115	0	30	0	2