Initial Safety Factor Assessment
Nelsen Pond
Otter Tail Power Company – Coyote Station

Introduction
This report presents the initial safety factor assessment and certification of the Nelsen Pond at Coyote Station in Beulah, North Dakota. The Nelsen Pond is an "existing" surface impoundment.

Safety Factor Assessment
The Nelsen Pond 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 Nelsen Pond was analyzed according to the following conditions in accordance with §257.73(e)(1)(i) through (iv).

(i) **Condition 1**: The calculated static factor of safety under the long-term, maximum storage pool loading must equal or exceed 1.50.
(ii) **Condition 2**: The calculated static factor of safety under the maximum surcharge pool loading condition must equal or exceed 1.40.
(iii) The calculated seismic factor of safety must equal or exceed 1.00. This was conducted on both Condition 1 and 2.
(iv) 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 the Nelsen Pond were conducted through the critical cross section, located on the western side of the south dike. The stability calculations for all Conditions were conducted using circular failure modes to determine the global stability of the dike, to force a deep failure surface 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 Nelsen Pond at the critical section consists of 3H:1V slopes on both sides with a 10-foot wide top. A two-foot thick compacted clay liner is located on the bottom and inslopes of the pond.
- Circular failure analysis was used for both Conditions.
- 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, or ½ of 0.02386g (0.01193g) (Hynes-Griffin and Franklin 1984).

- The shear strength of undrained clays during a pseudo-seismic even was reduced by 20% (Hynes-Griffin and Franklin, 1984).
- As a conservative approach, undrained conditions were assumed.
- Conditions 1 and 2 were analyzed for global stability from left to right to determine the safety factor resistance to impounded water.
- The phreatic surface was input to preferentially flow through the re-compacted clay fill material and daylight at the toe of the dike slope.

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

Table 1: Material Geotechnical Properties

Material	Unit weight (pcf)	Friction Angle[4] (deg)	Cohesion (psf)[7]	Pseudo-seismic Cohesion (psf)
Coleharbor Till[1]	100.5	0	1800	1440
Re-Compacted Clay Fill[2]	105	0	230	184
Clay Liner[3]	119	0	230	184
Ash Slurry[5]	120	25	0	0
Topsoil[6]	119	35	0	0

Material Notes:
1. Material properties from the Coleharbor Till were taken from testing performed on material during hydrogeologic investigations of the Coleharbor Till. Cohesion was assumed to be typical for a clay classified as CL.
2. The embankment of the Nelsen Pond was constructed with compacted native clay soils generated from onsite excavation. The fill material soil parameters are typical for a soil classified as CL.
3. Material used for the clay liner consists of compacted onsite clay soils. The values provided use a conservative compaction estimate of 90% standard proctor maximum dry density.
4. Friction angles used are typical for the classified soil types with similar unit weights.
5. Values for the Ash Slurry were assumed using professional engineering judgement.
6. Topsoil is assumed to be a silty, sandy material. Soil properties provided are consistent for a soil classified as SP-SM.
7. It is assumed there is some cohesion of the clay at saturation. The value provided is taken from the typical saturated cohesion of a clay.

Compliance with §257.73(e)(1)(i) through (iii)

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
Condition 1 Long Term, Maximum Storage Pool Loading	**2.14**	1.50	**1.67**	1.00	Deep-Circular Failure
Condition 2 Maximum Surcharge Loading	**2.11**	1.40	**1.62**	1.00	Deep-Circular Failure

Compliance with §257.73(e)(1)(iv)

Using the initial liquefaction screening criteria from Seismic Design Guidance of Municipal Solid Waste Landfill Facilities, Office of Research and Development (US EPA, 1995), the potential for liquefaction of the soils is considered low. The soils onsite at the Coyote Station meet the following three criteria:

- Geologic Age: The Coleharbor Till formation is a Pleistocene-age deposit; pre-Holocene age deposits generally do not liquefy.
- Fines Content and Plasticity Index: Gradation and Atterberg limits have been determined for the Coleharbor Till. The till has greater than 70% fines, a liquid limit of approximately 40% or greater, and a moisture content less than 36%. Soils that have greater than 15% by weight fines, a liquid limit greater than 35%, and an insitu water content less than 0.9 times the liquid limit generally do not liquefy.
- Saturation: Surficial soils at the Coyote Station are dry, and the anticipated seasonal high water tables is located more than 40 feet below the ground surface. Therefore the potential for soils underneath the Nelsen pond to reach 80 to 85 percent saturation is low.

Summary

The factor of safety calculated for each of the critical conditions outlined in the 40 CFR Part 257.73(e) were found acceptable during static and seismic analyses.

Attachments

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.

John McCain, PE
License No. PE-4345

October 17, 2016
Date

References

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.

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

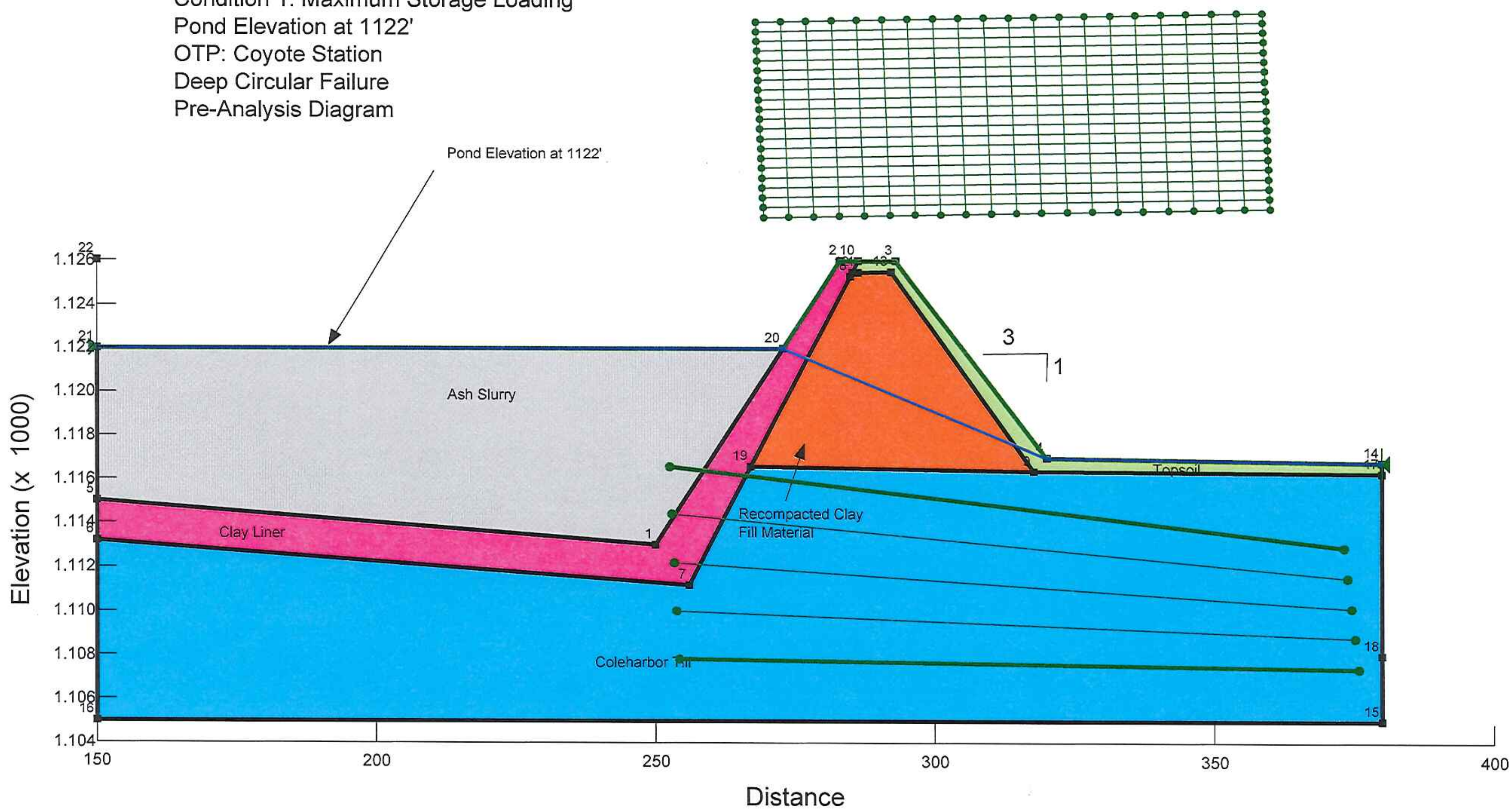
United States Society on Dams. Strength of Materials for Embankment Dams, February 2007.

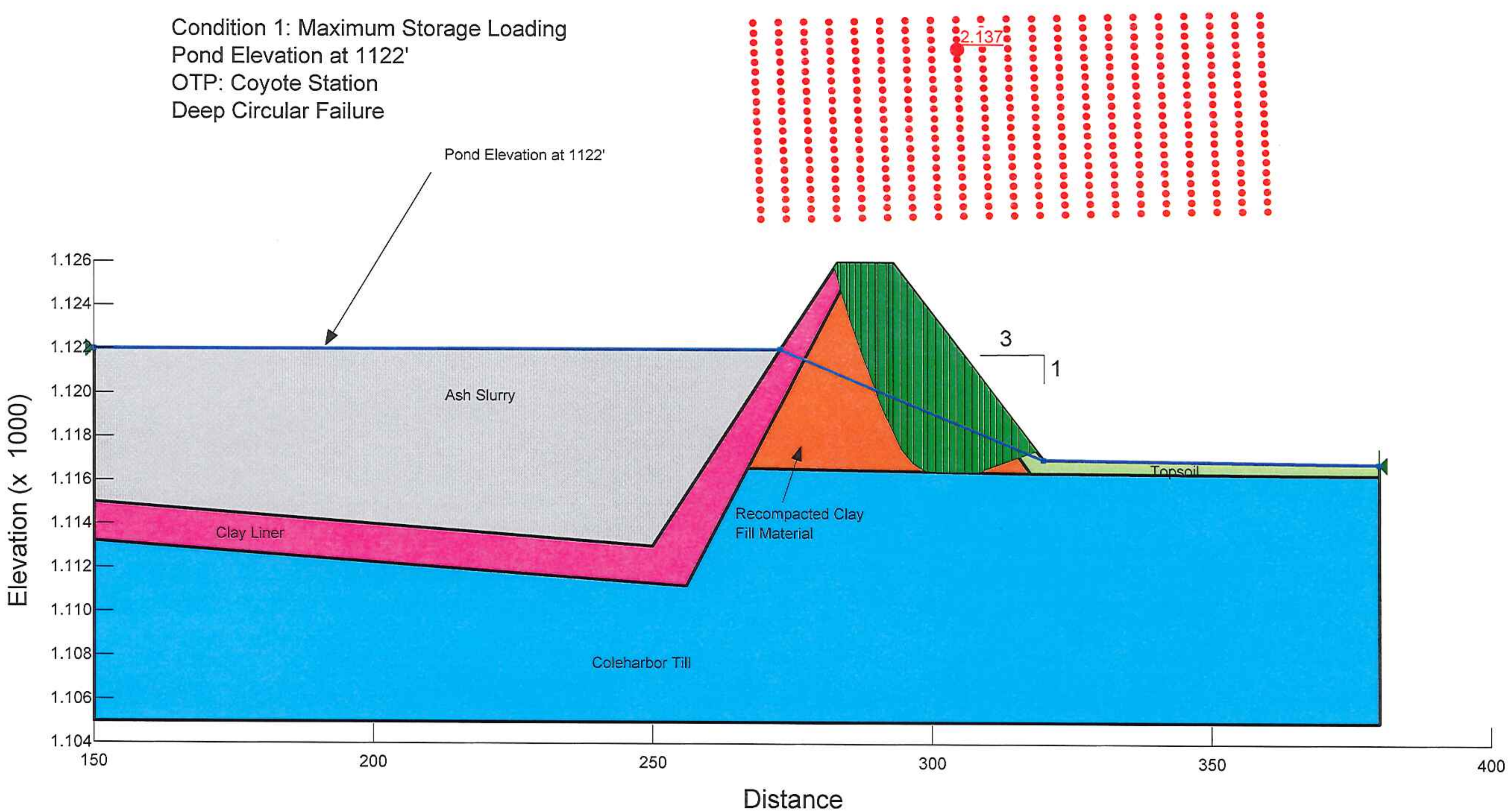
Slope/W Graphical Results

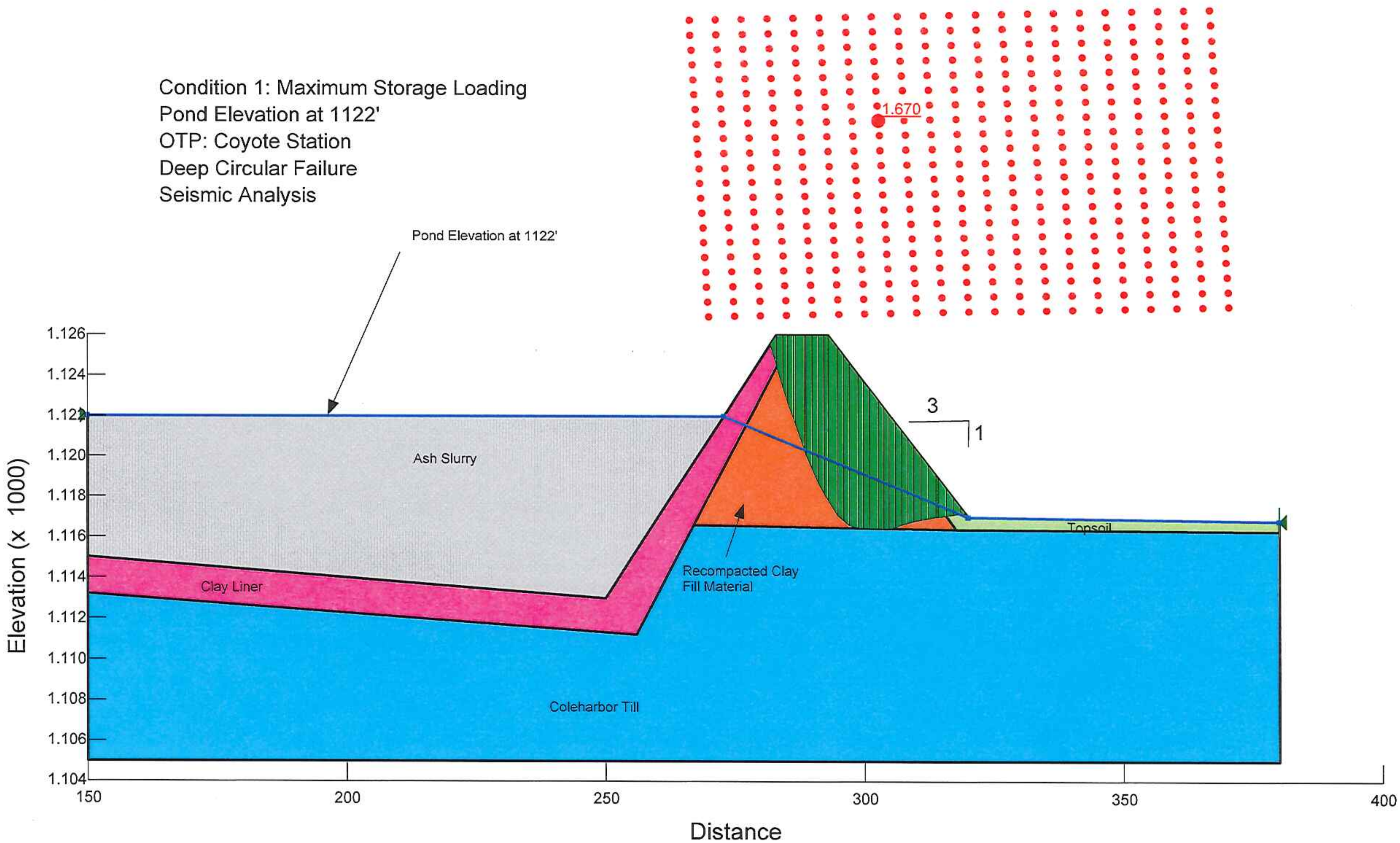
Condition 1

Long Term, Maximum, Storage Pool Loading

Condition 1: Maximum Storage Loading
Pond Elevation at 1122'
OTP: Coyote Station
Deep Circular Failure
Pre-Analysis Diagram

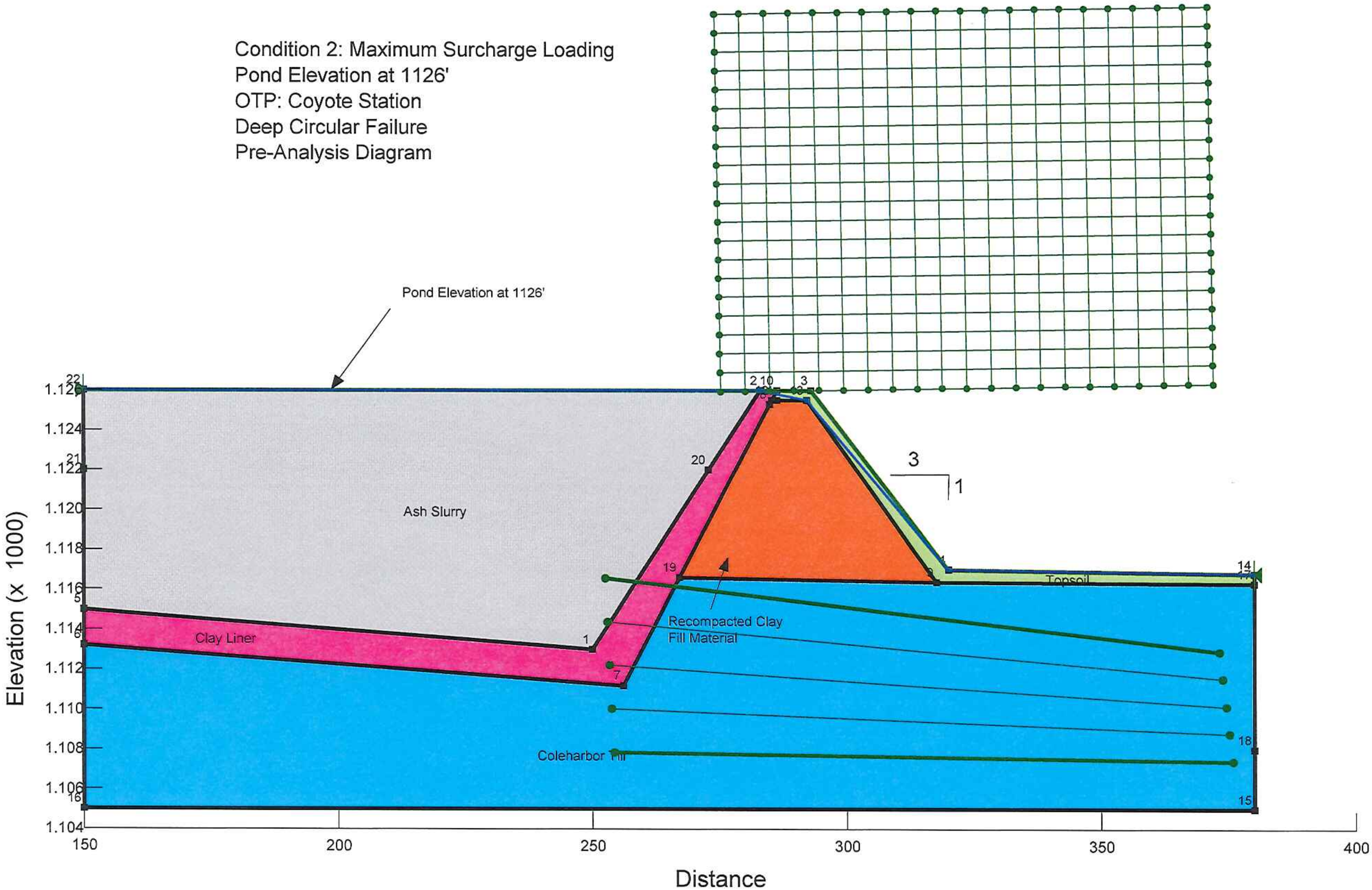



Condition 1: Maximum Storage Loading
Pond Elevation at 1122'
OTP: Coyote Station
Deep Circular Failure
Pond Elevation at 1122'
2.137
3
1
Ash Slurry
Clay Liner
Recompacted Clay
Fill Material
Topsoil
Coleharbor Till
Elevation (x 1000)
1.126
1.124
1.122
1.120
1.118
1.116
1.114
1.112
1.110
1.108
1.106
1.104
150
200
250
300
350
400
Distance

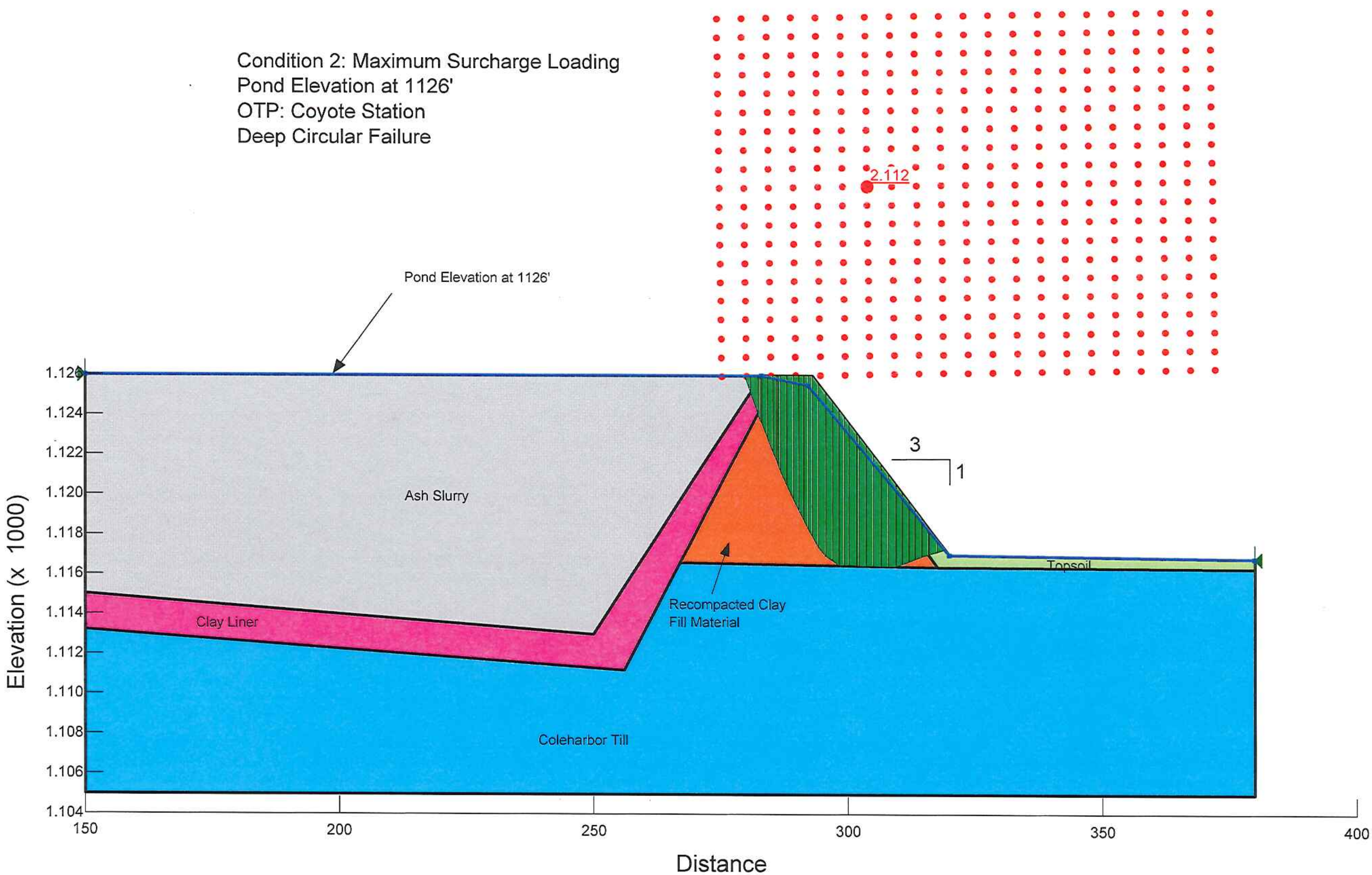

Condition 1: Maximum Storage Loading
Pond Elevation at 1122'
OTP: Coyote Station
Deep Circular Failure
Seismic Analysis
Pond Elevation at 1122'
1.670
3
1
Ash Slurry
Clay Liner
Recompacted Clay
Fill Material
Topsoil
Coleharbor Till
Elevation (x 1000)
1.126
1.124
1.122
1.120
1.118
1.116
1.114
1.112
1.110
1.108
1.106
1.104
150
200
250
300
350
400
Distance

Condition 2

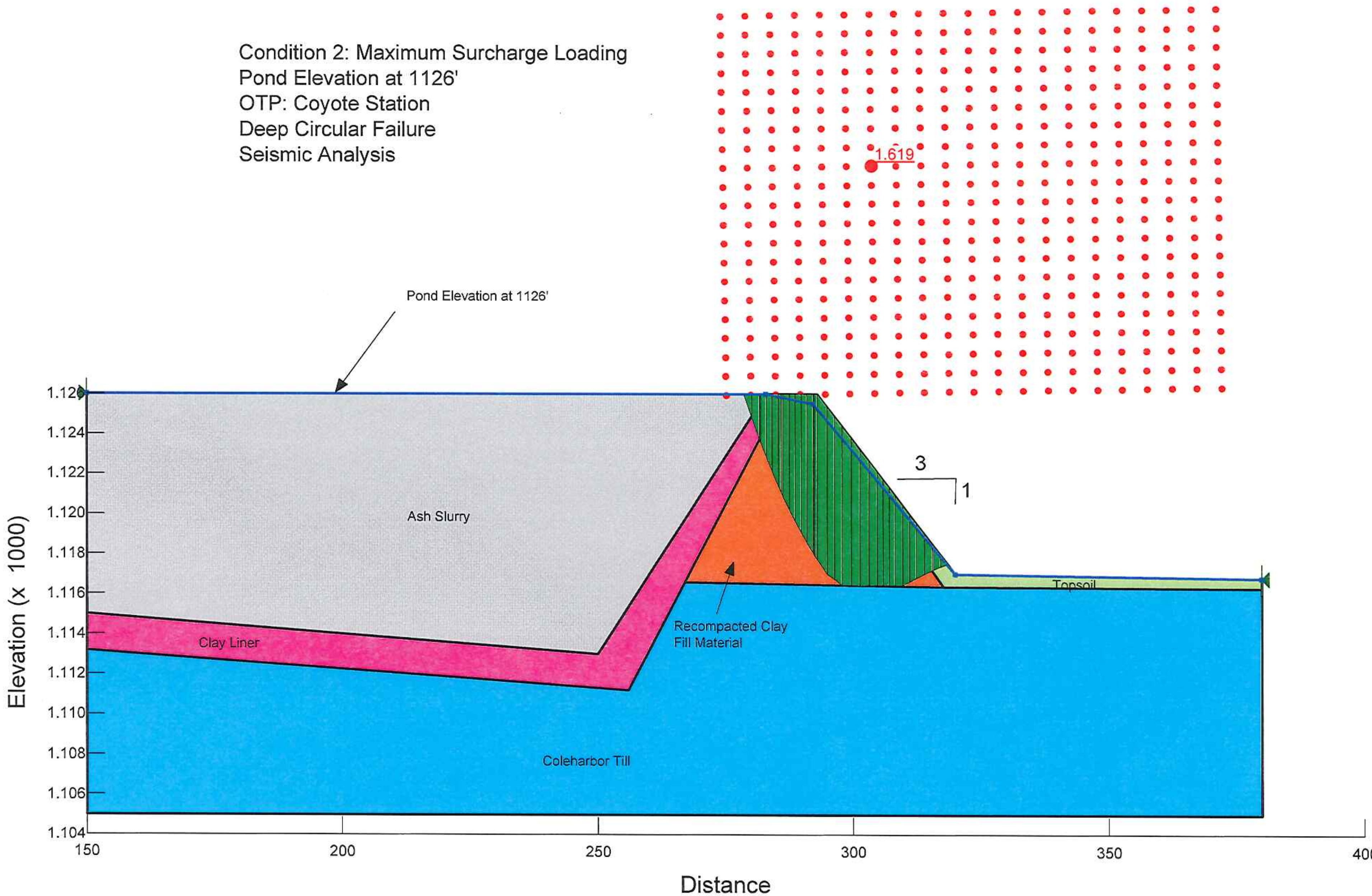
Maximum Surcharge Loading



Condition 2: Maximum Surcharge Loading
Pond Elevation at 1126'
OTP: Coyote Station
Deep Circular Failure
Pre-Analysis Diagram
Pond Elevation at 1126'
Ash Slurry
Clay Liner
Recompacted Clay
Fill Material
Topsoil
3
1
Elevation (x 1000)
Distance
150
200
250
300
350
400
1.124
1.122
1.120
1.118
1.116
1.114
1.112
1.110
1.108
1.106
1.104



Condition 2: Maximum Surcharge Loading
Pond Elevation at 1126'
OTP: Coyote Station
Deep Circular Failure
2.112
Pond Elevation at 1126'
3
1
Ash Slurry
Clay Liner
Recompacted Clay
Fill Material
Coleharbor Till
Elevation (x 1000)
1.124
1.122
1.120
1.118
1.116
1.114
1.112
1.110
1.108
1.106
1.104
150
200
250
300
350
400
Distance



Condition 2: Maximum Surcharge Loading
Pond Elevation at 1126'
OTP: Coyote Station
Deep Circular Failure
Seismic Analysis
1.619
Pond Elevation at 1126'
3
1
Ash Slurry
Clay Liner
Recompacted Clay
Fill Material
Topsoil
Coleharbor Till
Elevation (x 1000)
1.126
1.124
1.122
1.120
1.118
1.116
1.114
1.112
1.110
1.108
1.106
1.104
150
200
250
300
350
400
Distance