Appendix E
SLOPE/W Analysis

Re-Analyzing Section F Using SLOPE/W and Slide (09-2012)

CH2M HILL

Table 4-4 Summary of BCF Soil Properties for Limit-Equilibrium and Deformation Analyses

								Seaside (TXE[1])				Landside (TXC[1])			
Analysis Section[3]	Analysis Condition[4]	Unit weight (pcf)	ϕ	μ	Landside Dredge Depth (ft)	Wall Height (ft)[5]	C_o and E_o Elev. (ft)	C_o (psf)	C_{inc} (psf/ft)	E_o[2] (ksf)	E_{inc} (ksf/ft)	C_o (psf)	C_{inc} (psf/ft)	E_o[2] (ksf)	E_{inc} (ksf/ft)
A	Short-Term (End of Construction)	120	0	0.35	-50	65	-50	1500	9	1200	6	2000	9	1200	6
	Long-Term Seismic Long-Term Static	120	0	0.35	-50	65	-50	1500	9	1200	6	2800	18	2200	11
B/D	Short-Term (End of Construction)	120	0	0.35	-60	75	-60	1600	13	1200	9	2100	15	1200	9
	Long-Term Seismic Long-Term Static	120	0	0.35	-60	75	-60	1600	13	1200	9	3000	18	2400	11
C/E	Silty Sand with Gravel (El. -45 to -65)	130	40	0.3	-45	75	N.A.	0	0	3000	0	0	0	3000	0
	Short-Term (End of Construction)	120	0	0.35	-45	75	-65	1500	10	1200	7	2000	12	1200	7
	Long-Term Seismic Long-Term Static	120	0	0.35	-45	75	-65	1500	10	1200	7	3100	18	2500	11
F	Short-Term (End of Construction)	120	0	0.35	-50	75	-50	1600	17	1200	13	2100	23	1200	13
	Long-Term Seismic Long-Term Static	120	0	0.35	-50	75	-50	1600	17	1200	13	2800	18	2300	11
G	Short-Term (End of Construction)	120	0	0.35	-25	65	-25	2300	10	1800	6	2800	9	1800	6
	Long-Term Seismic Long-Term Static	120	0	0.35	-25	65	-25	2300	10	1800	6	3300	18	2700	11
H	Silty Sand with Gravel (El -10 to -50)	120	40	0.3	-10	55	N.A.	0	0	3000	0	0	0	3000	0
	Short-Term (End of Construction)	120	0	0.35	-10	55	-50	1600	17	1300	13	2100	26	1300	15
	Long-Term Seismic Long-Term Static	120	0	0.35	-10	55	-50	1600	17	1300	13	3000	21	2600	12
J	Short -Term (End of Construction)	120	0	0.35	-10	55	-50	1600	17	1300	13	2100	26	1300	15
	Long-Term Seismic Long-Term Static	120	0	0.35	-10	55	-50	1600	17	1300	13	3000	21	2600	12

1. TXE = triaxial extension TXC = triaxial compression
2. Eo ~ 600 C_o (short-term TXC) and 800 C_o (long-term TXC)
3. See Figures 6.1-6.7.
4. Short-term strength and long-term strength on the seaside is derived from CPT data. Long-term strength (landside) is derived from SHANSEP equation.
5. Wall height is calculated from the top of sheet pile wall to the bottom of the seaside excavation.

N.A. No analysis

Figure E1. Assumed properties of the seaside and landside BCF clay for Section F (PND, 2008).

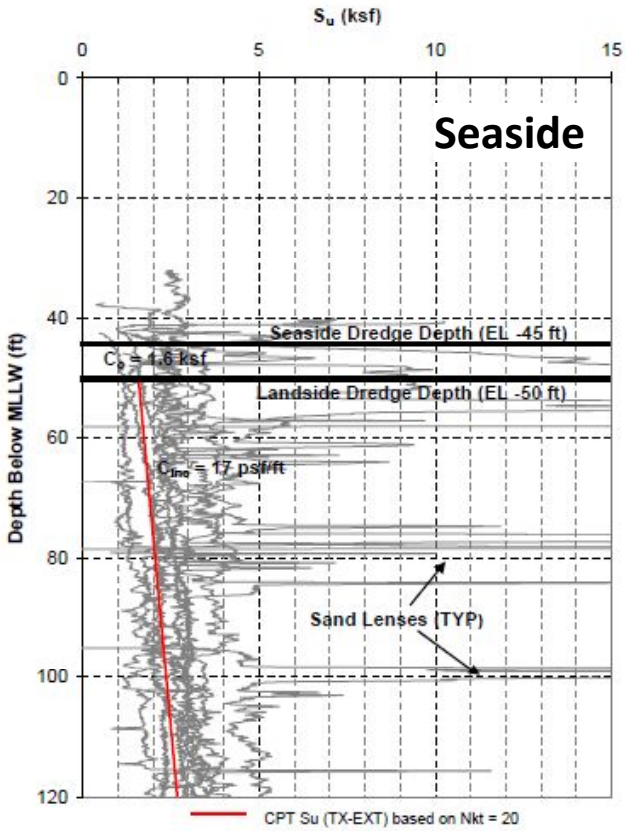


Figure 4.23 Undrained-Shear Strength Profile from CPT (TXE) Short-Term Static, Long-Term Static, and Seismic Conditions for Analysis Section F

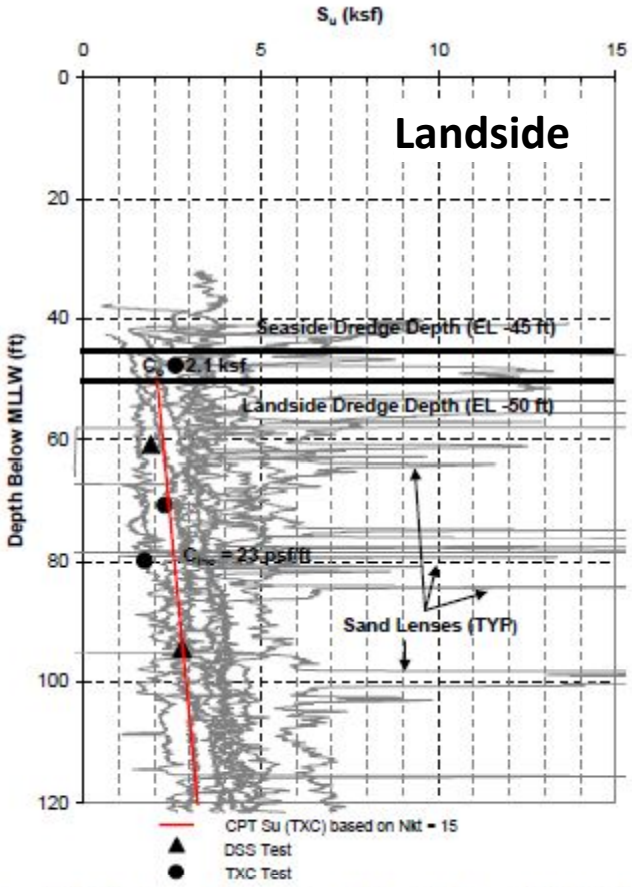


Figure 4.17 Undrained-Shear Strength Profile from CPT (TXC) Short-Term Static Conditions for Analysis Section F

Figure E2. Assumed shear strength profiles of the seaside and landside BCF clay for Section F in short-term (EOC) condition for Section F (PND, 2008).

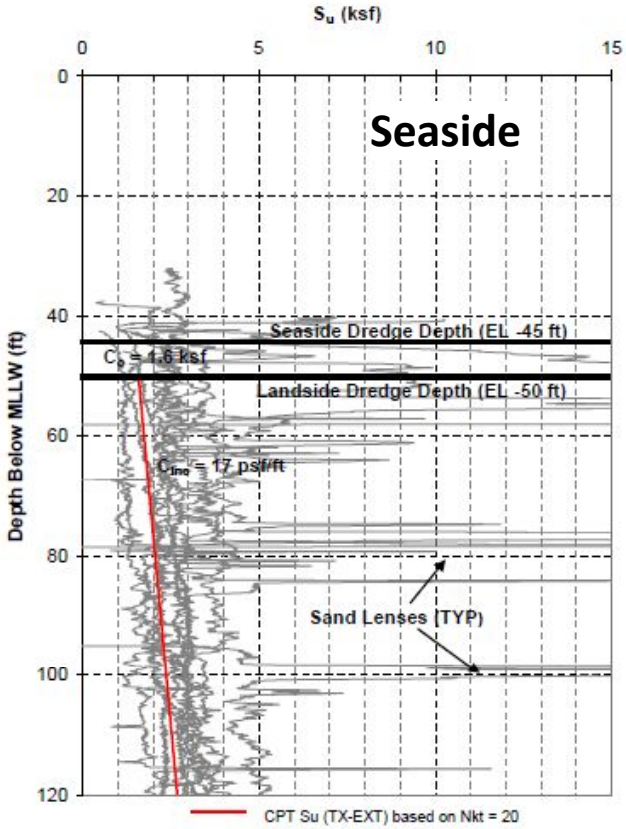


Figure 4.23 Undrained-Shear Strength Profile from CPT (TXE) Short-Term Static, Long-Term Static, and Seismic Conditions for Analysis Section F

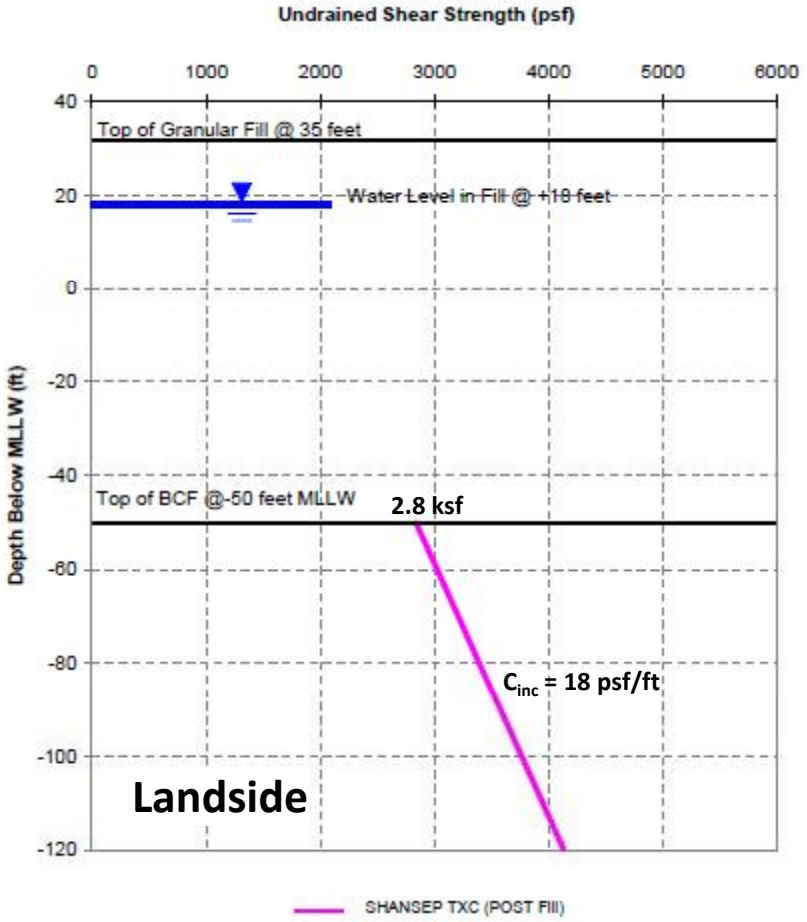


Figure 4.30 Undrained-Shear Strength Profile Based on SHANSEP-TXC Equation – Long-Term Static and Seismic Conditions for Analysis Section F

Figure E3. Assumed shear strength profiles of the seaside and landside BCF clay in long-term and seismic conditions for Section F (PND, 2008).

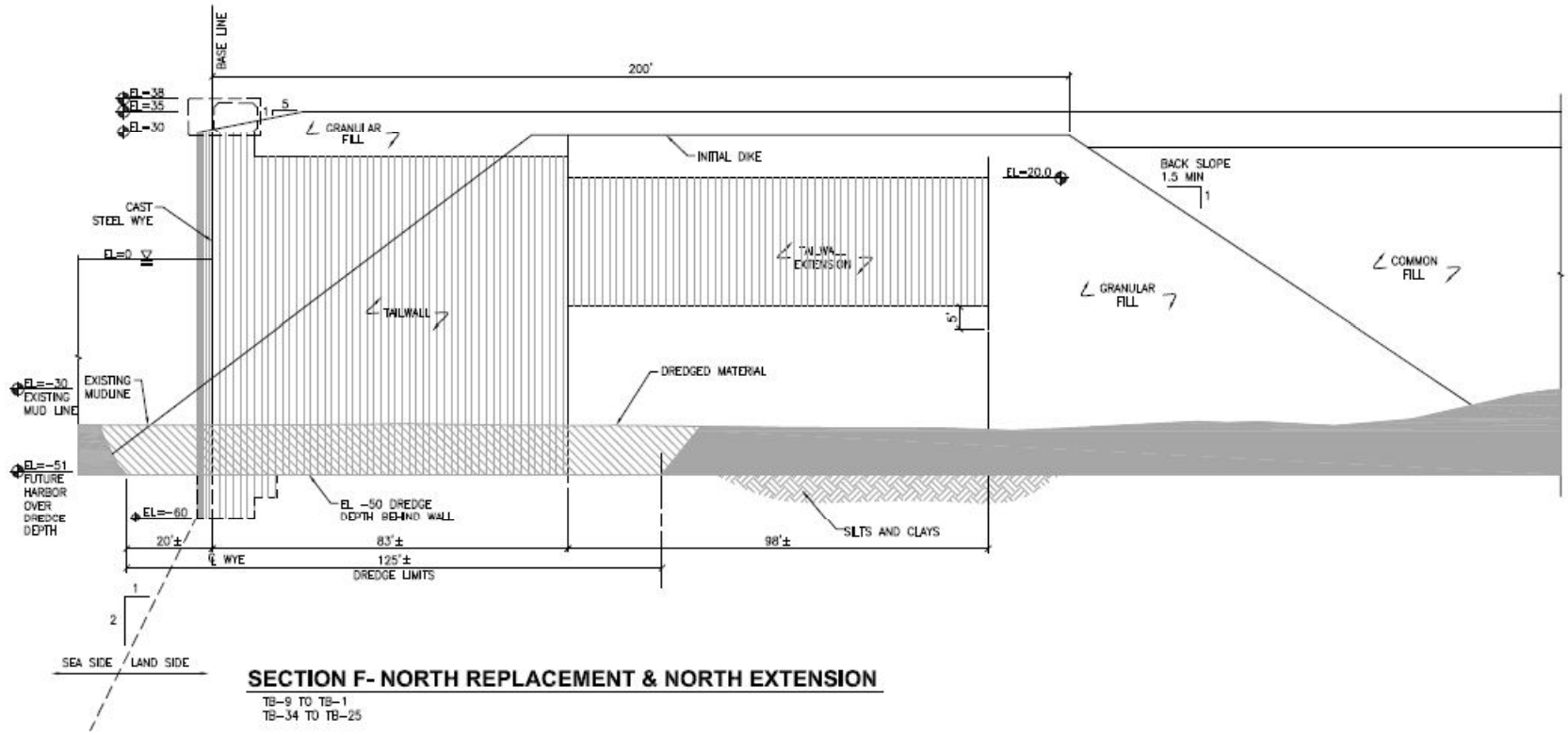
Table 4-3 Fill Properties for Analysis

	Unit weight (pcf)	ϕ	μ	E_o Elevation (ft)	C_o (psf)	C_{inc} (psf/ft)	E_o (ksf)	E_{inc} (ksf/ft)
Granular Fill Uncompacted	120	32	0.3	30	0	n/a	300	5.7
Granular Fill Compacted	130	36	0.3	30	0	n/a	1000	10
Common Fill Uncompacted	110	28	0.3	30	0	n/a	300	5.7
Common Fill Compacted	115	32	0.3	30	0	n/a	500	10

Long-term Static & Pseudo-Static

Short-term Static

Figure E4. Assumed properties of the granular and common fills (PND, 2008).



SECTION F- NORTH REPLACEMENT & NORTH EXTENSION

TB-9 TO TB-1
TB-34 TO TB-25

Figure E5. Geometry of Section F (PND, 2008).

Table 6-2 Factor of Safety Results

AREA (SECTION) See Figures 6.1-6.7	Dredge Elevation (ft MLLW)		LOAD CASE[2]				
	Outside[6]	Inside	Short-Term Static DL + LL + PH	Long-Term Static DL + LL + PH	Long-Term Seismic DL + OLE[5]	Long-Term Seismic DL + CLE[5]	Long-Term Seismic DL + MCE[5]
South Extension (A)[3]	-35	-50	1.2	1.5	1.3	1.2	1.0
South Replacement (B/D)	-45	-60	1.3	1.5	1.3	1.2	1.0
South Replacement (C)[4]	-45	-45	1.3	1.6	1.4	1.2	1.0
North Replacement (E)[4]	-45	-45	1.3	1.6	1.4	1.2	1.0
North Replacement (F)	-45	-50	1.3	1.5	1.3	1.1	0.9
North Extension (F)	-45	-50	1.3	1.5	1.3	1.1	0.9
North Extension (G)[3]	-35	-25	1.6	1.8	1.7	1.5	1.2
Barge Berths (H)[3,4]	-25	-10	1.5	1.6	1.7	1.5	1.3
Barge Berths (J)[3,4]	0	0	2.4	2.6	2.1	1.8	1.5
Required Factor of Safety	---	---	1.3	1.5	1.2	1.1	1.0

Terms:
DL—Dead Load; Soil Load and Pavement load
LL—Live Load; 200-psf within 200-ft of face, 1000-psf thereafter
PH—Phreatic Load; El. +18-ft MLLW inside wall, El. -5-ft MLLW outside wall
OLE—Operating Level Earthquake, Avg. MHEA = 0.20g
CLE—Contingency Level Earthquake, Avg. MHEA = 0.27g
MCE—Maximum Considered Earthquake, Avg. MHEA = 0.41g
MHEA—Maximum Horizontal Earthquake Acceleration

Notes:
(1) Limit equilibrium global stability analysis performed using Spencer method in Slope/W 2004 program.
(2) Pseudostatic analysis for seismic load cases; acceleration of 1/2*MHEA applied for analysis.
(3) Designated essential facility, designed for MCE seismic event. Other results (grey) for information only.
(4) Section contains silty-sand and gravel layer below granular fill.
(5) Basic phratic water level for seismic load cases is El. 16.5-ft inside and outside wall, but see sensitivity analysis (Section 6.7 case 10).
(6) Maintenance overdredge of 6-ft analyzed for factors of safety shown.

These FS values were later revised in Appendix N (PND 2008)

Figure E6. Original FS values calculated for Section F (PND, 2008 – Appendix J).

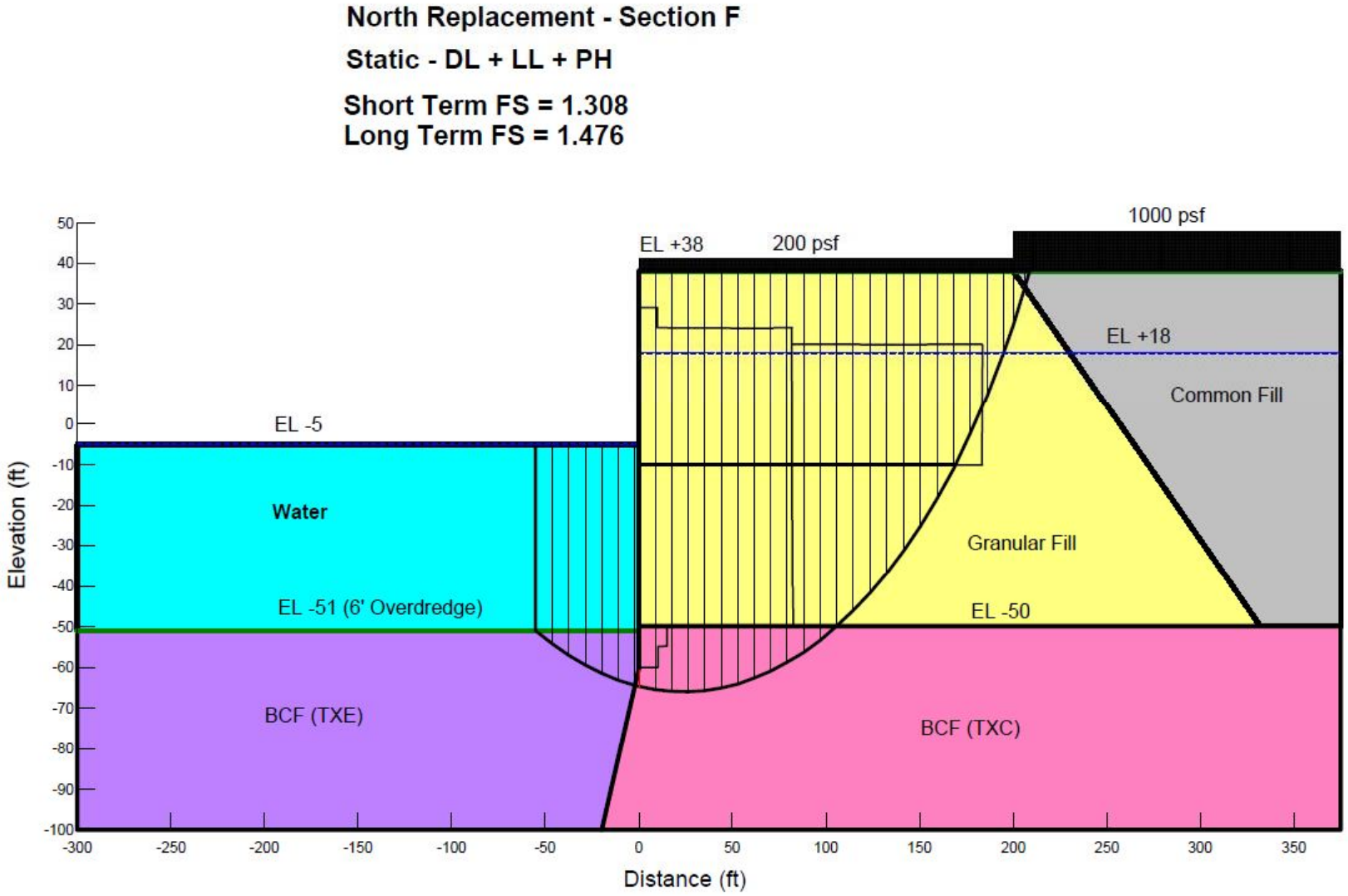


Figure E7. SLOPE/W model of Section F in short-term (EOC) and long-term static loading conditions (PND, 2008).

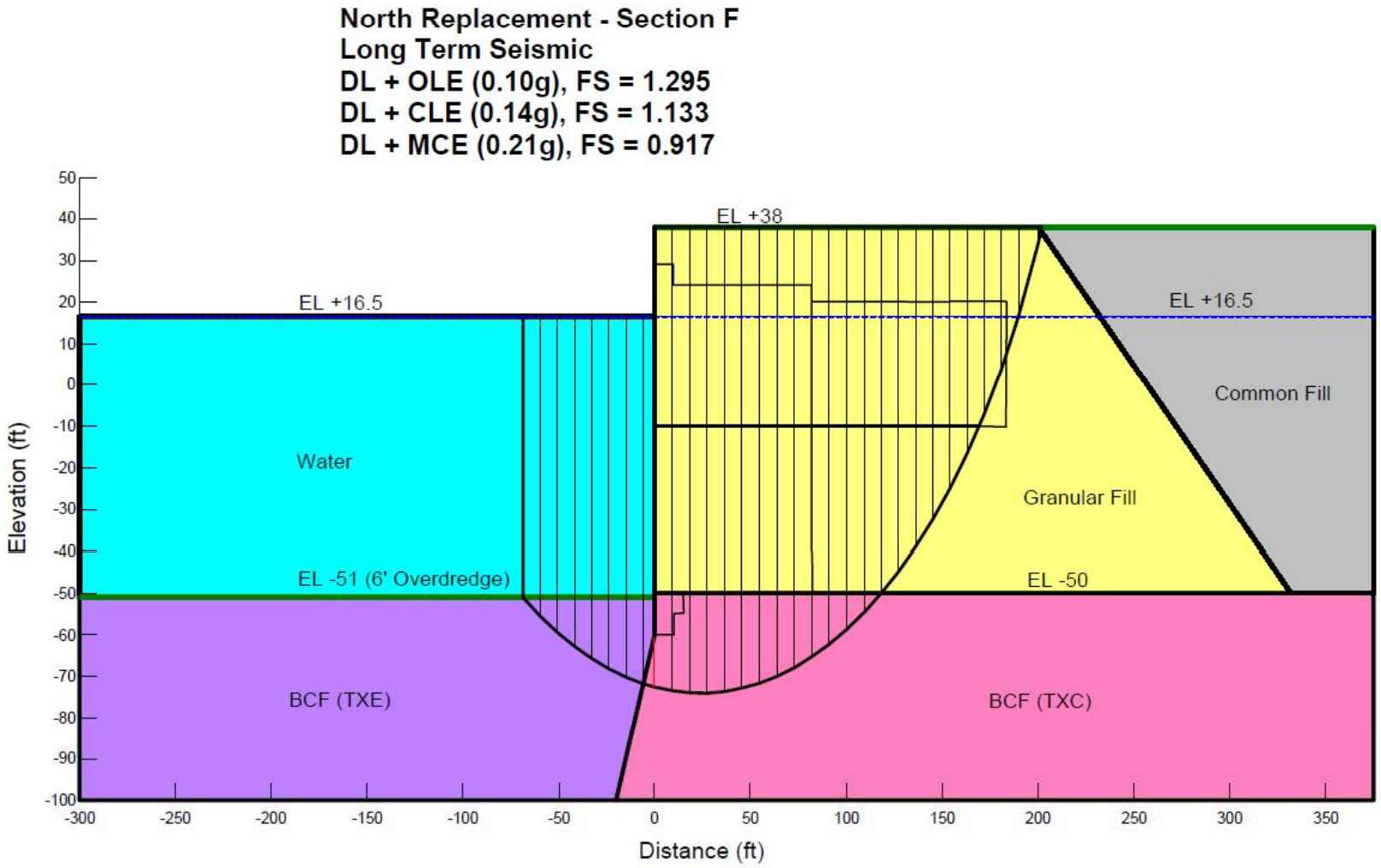


Figure E8. SLOPE/W model of Section F in pseudo-static loading condition (PND, 2008).

Table N7. Summary of Average Maximum Horizontal Equivalent Acceleration (MHEA) Section F

Earthquake Level	Earthquake Name	MHEA at A	MHEA at B	MHEA at C	MHEA at D	MHEA Average	
OLE	1965 Puget Sound	0.07	0.10	0.10	0.07	**0.09**	
	1974 Peru Coast	0.07	0.11	0.09	0.07	**0.09**	PND used k_h = 0.05g
	1997 Michoacan	0.07	0.11	0.08	0.07	**0.08**	
CLE	2001 Nisqually_000	0.15	0.24	0.18	0.15	**0.18**	
	2001 Nisqually_090	0.22	0.21	0.19	0.14	**0.19**	
	1997 Michoacan	0.19	0.21	0.17	0.11	**0.17**	
	1949 Western Washington	0.16	0.19	0.18	0.12	**0.16**	PND used k_h = 0.09g
	Synthetic Cascadia EQ_005	0.13	0.18	0.21	0.13	**0.16**	
	Synthetic Cascadia EQ_009	0.14	0.18	0.20	0.10	**0.16**	
MCE	2001 Nisqually_000	0.29	0.30	0.32	0.25	**0.29**	
	2001 Nisqually_090	0.22	0.29	0.31	0.22	**0.26**	
	1997 Michoacan	0.29	0.27	0.23	0.22	**0.25**	
	1949 Western Washington	0.22	0.26	0.29	0.20	**0.24**	PND used k_h = 0.13g
	Synthetic Cascadia EQ_005	0.24	0.26	0.28	0.22	**0.25**	
	Synthetic Cascadia EQ_009	0.22	0.25	0.25	0.20	**0.23**	

Figure E9. Revised seismic lateral coefficient (k_h) values for Section F (PND, 2008 – Appendix N).

Results from Global Stability Analysis

In general, the updated time histories produced lower accelerations in Section F and variable accelerations in Section G when compared to the original ground motions. All three seismic load cases in Section F had lower accelerations. In Section G, the OLE load case accelerations were lower, CLE were similar, and MCE were higher. Because of the trend, the factor of safety was only significantly reduced for the MCE load case in Section G. The factor of safety for other load cases increased or was similar to the previous analysis. Table N9 shows the results for the updated pseudo-static global stability analysis in Sections F and G.

Table N9. Summary of SLOPE/W Analysis—Sections F and G

Section F North Replacement / Extension	
Load Case	**Factor Safety**
OLE (Pseudo-static Acceleration = 0.05g)	1.6
CLE (Pseudo-static Acceleration = 0.09g)	1.3
MCE (Pseudo-static Acceleration = 0.13g)	1.2
Section G North Extension	
Load Case	**Factor Safety**
OLE (Pseudo-static Acceleration = 0.06g)	1.9
CLE (Pseudo-static Acceleration = 0.14g)	1.5
MCE (Pseudo-static Acceleration = 0.25g)	1.1

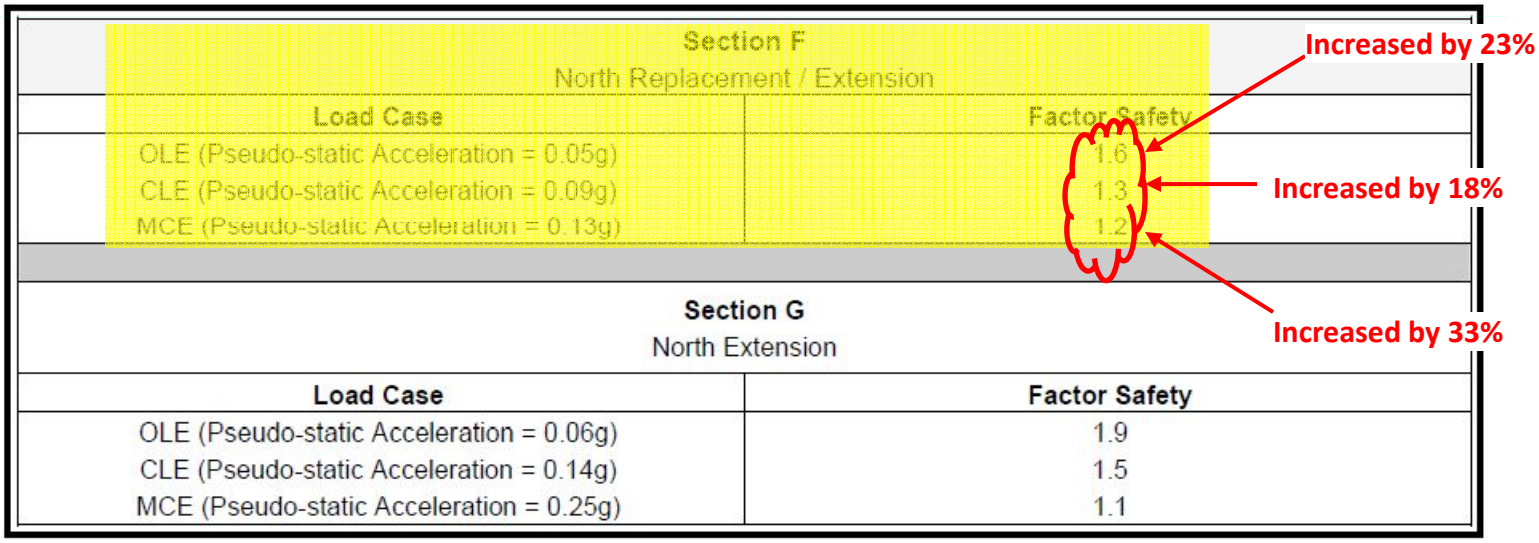


Figure E10. FS values obtained from the revised pseudo-static stability analyses (PND, 2008 – Appendix N).

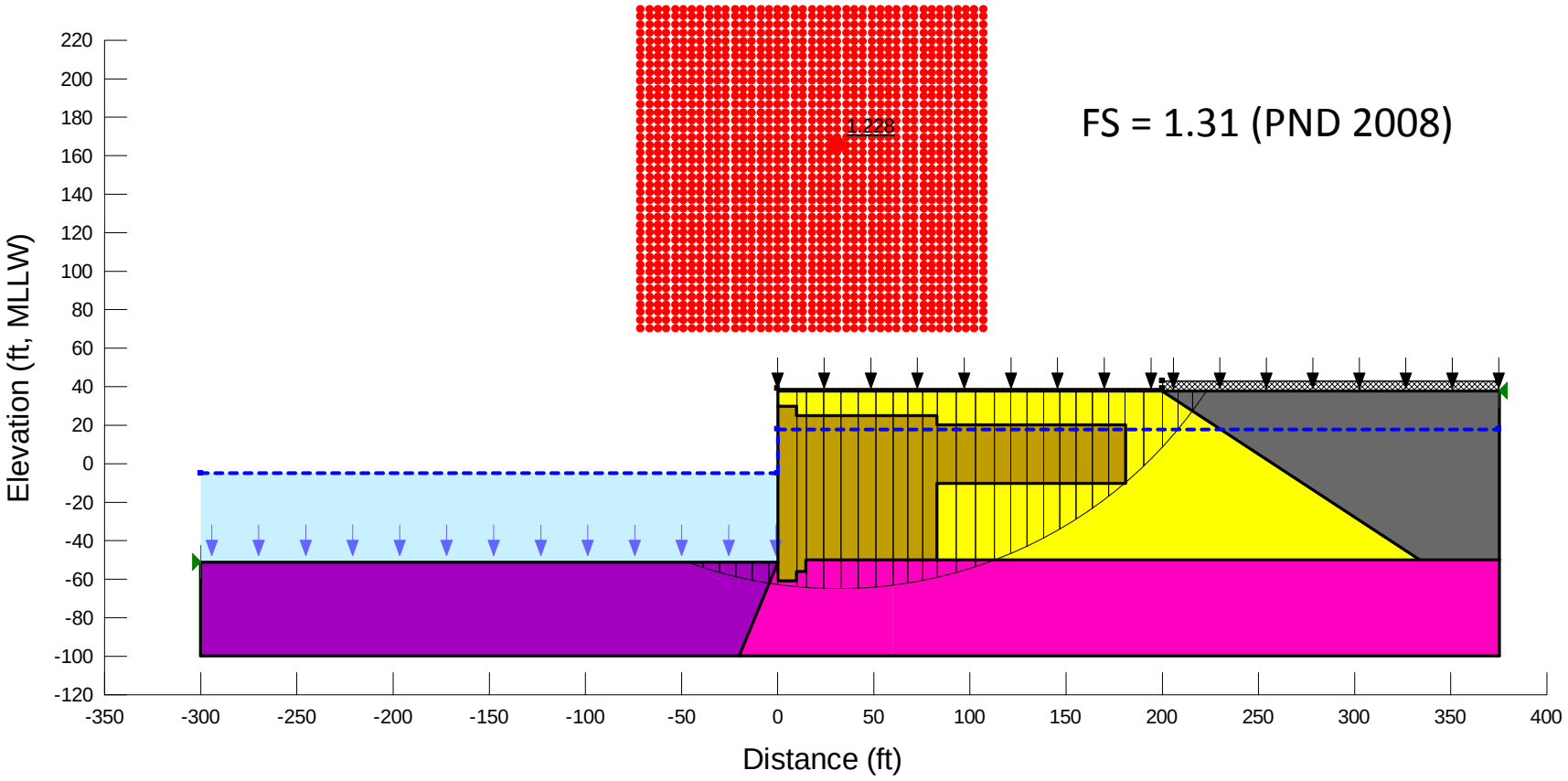


Figure E11. Re-analyzing the short-term static (EOC) case for Section F using SLOPE/W (2-clay, circular surface).

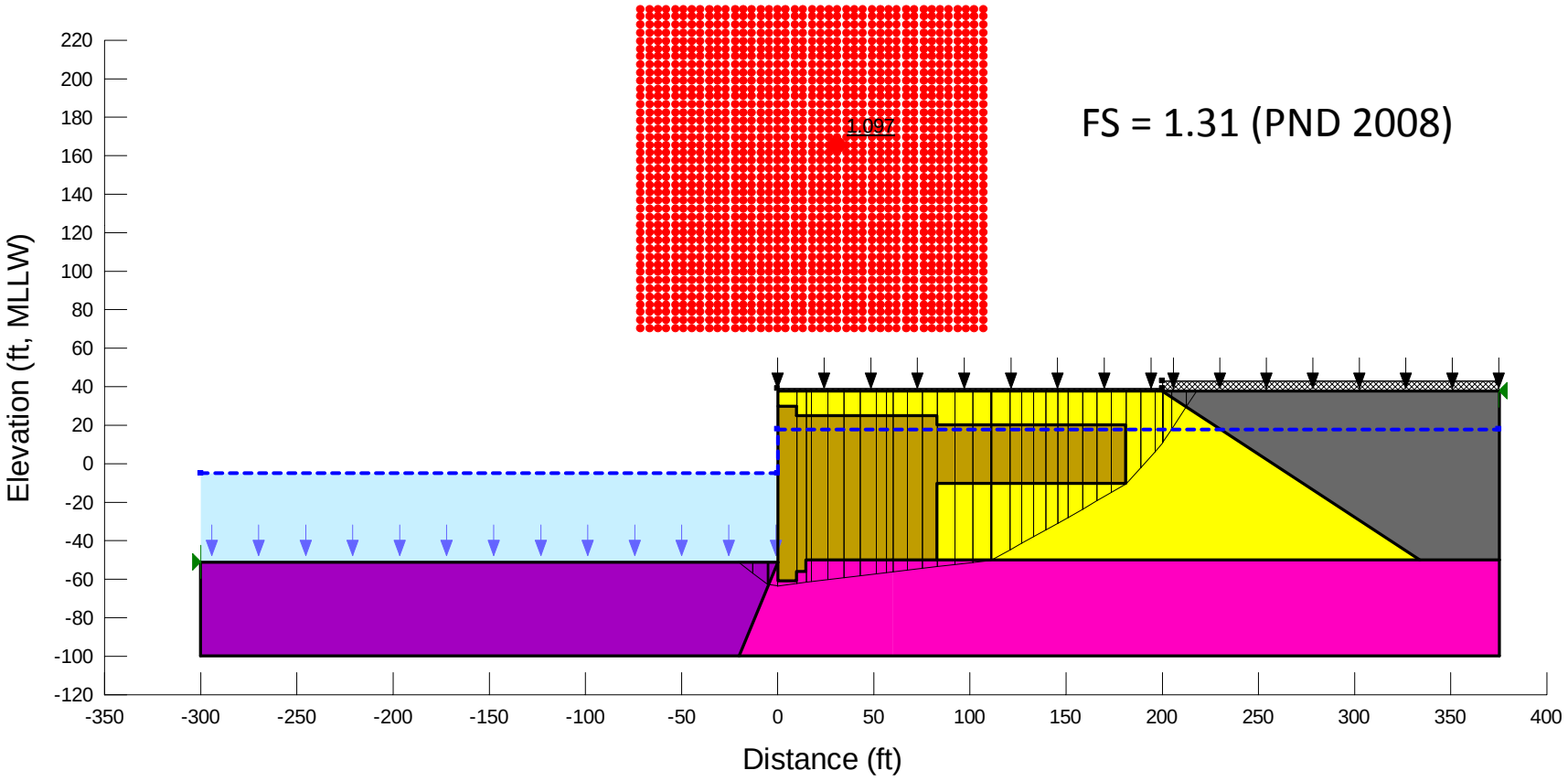


Figure E12. Re-analyzing the short-term static (EOC) case for Section F using SLOPE/W (2-clay, optimized surface).

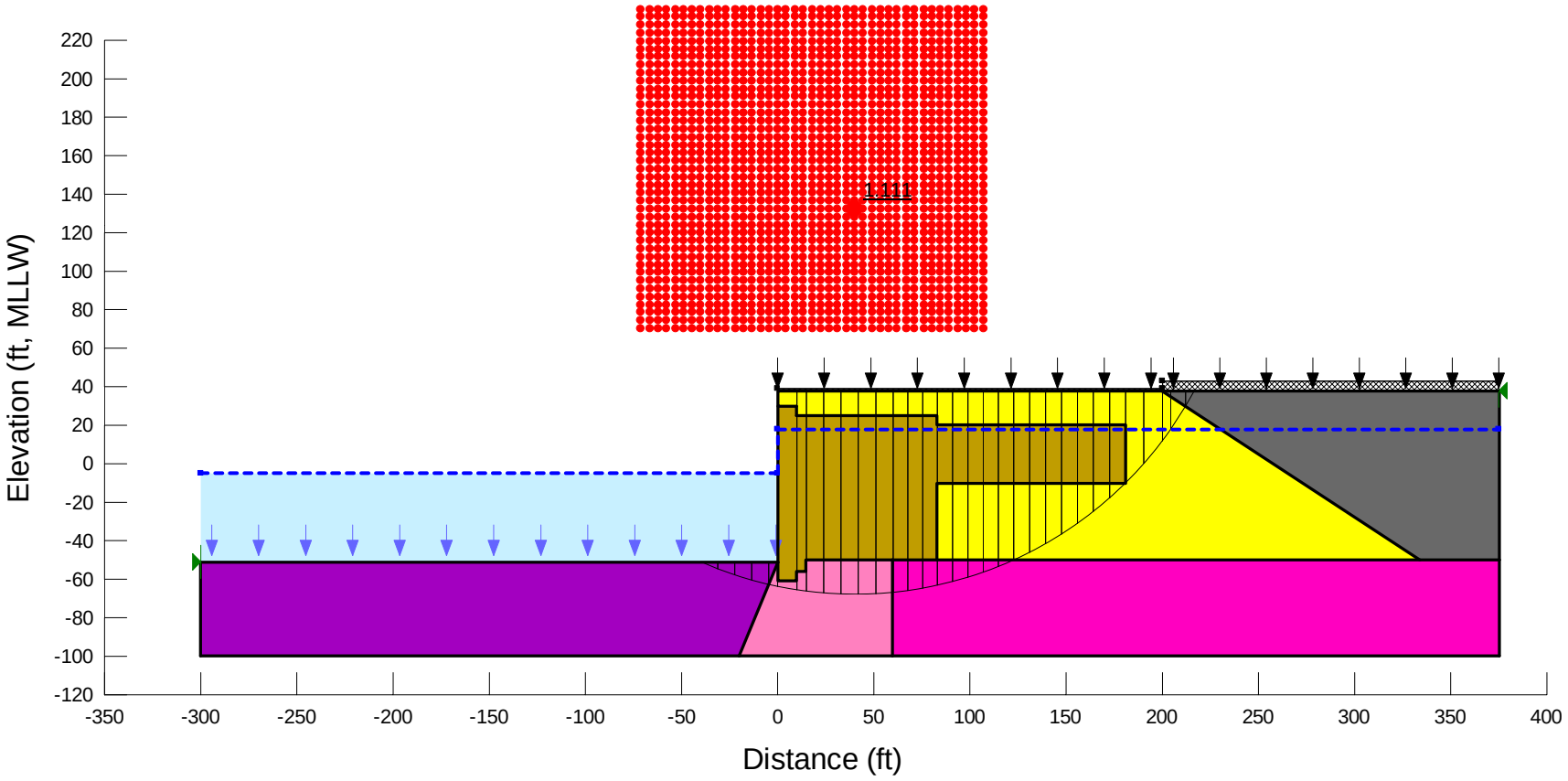


Figure E13. Re-analyzing the short-term static (EOC) case for Section F using SLOPE/W (3-clay, circular surface).

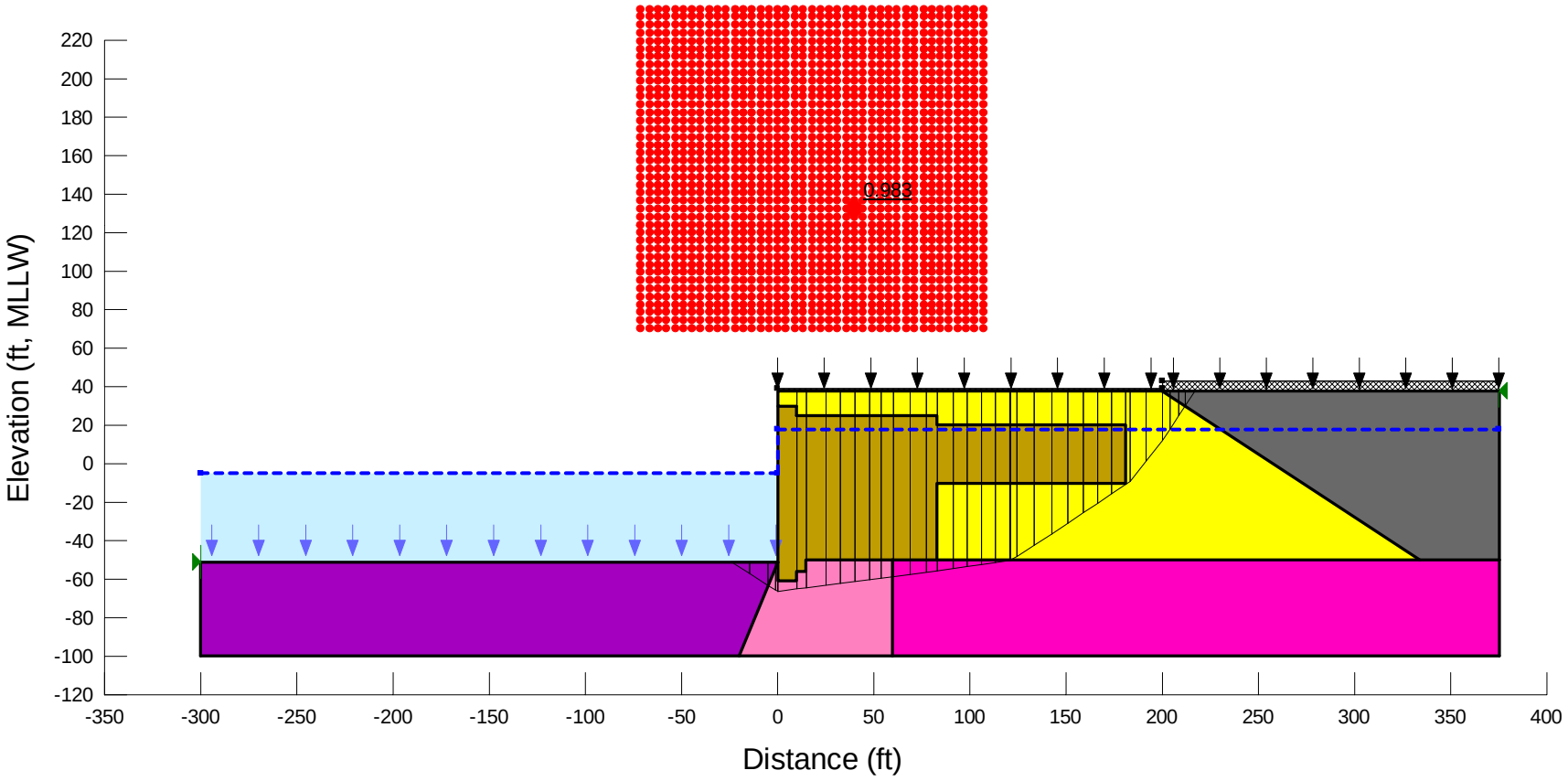


Figure E14. Re-analyzing the short-term static (EOC) case for Section F using SLOPE/W (3-clay, optimized surface).

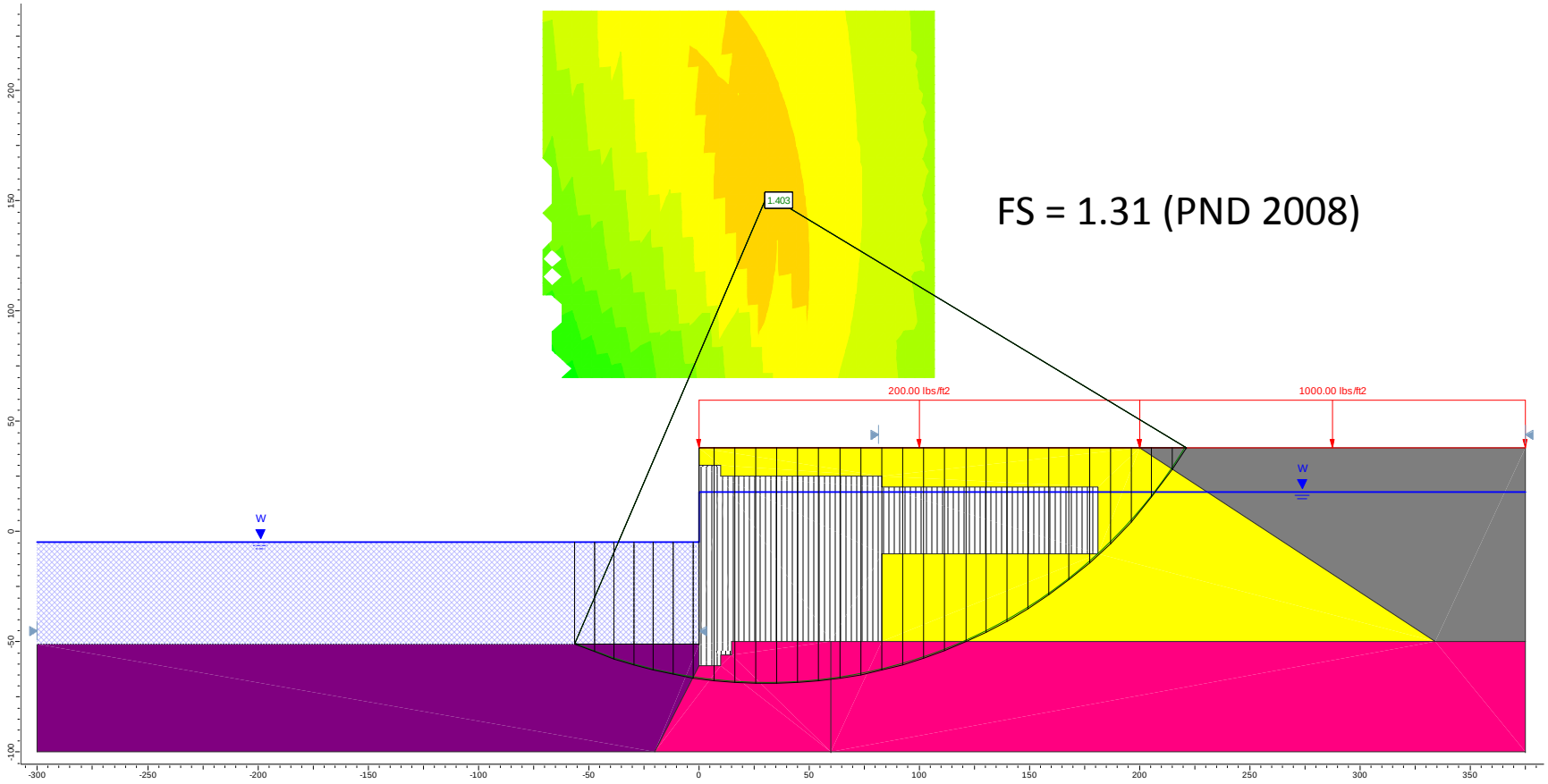


Figure E15. Re-analyzing the short-term static (EOC) case for Section F using Slide (2-clay, circular surface).

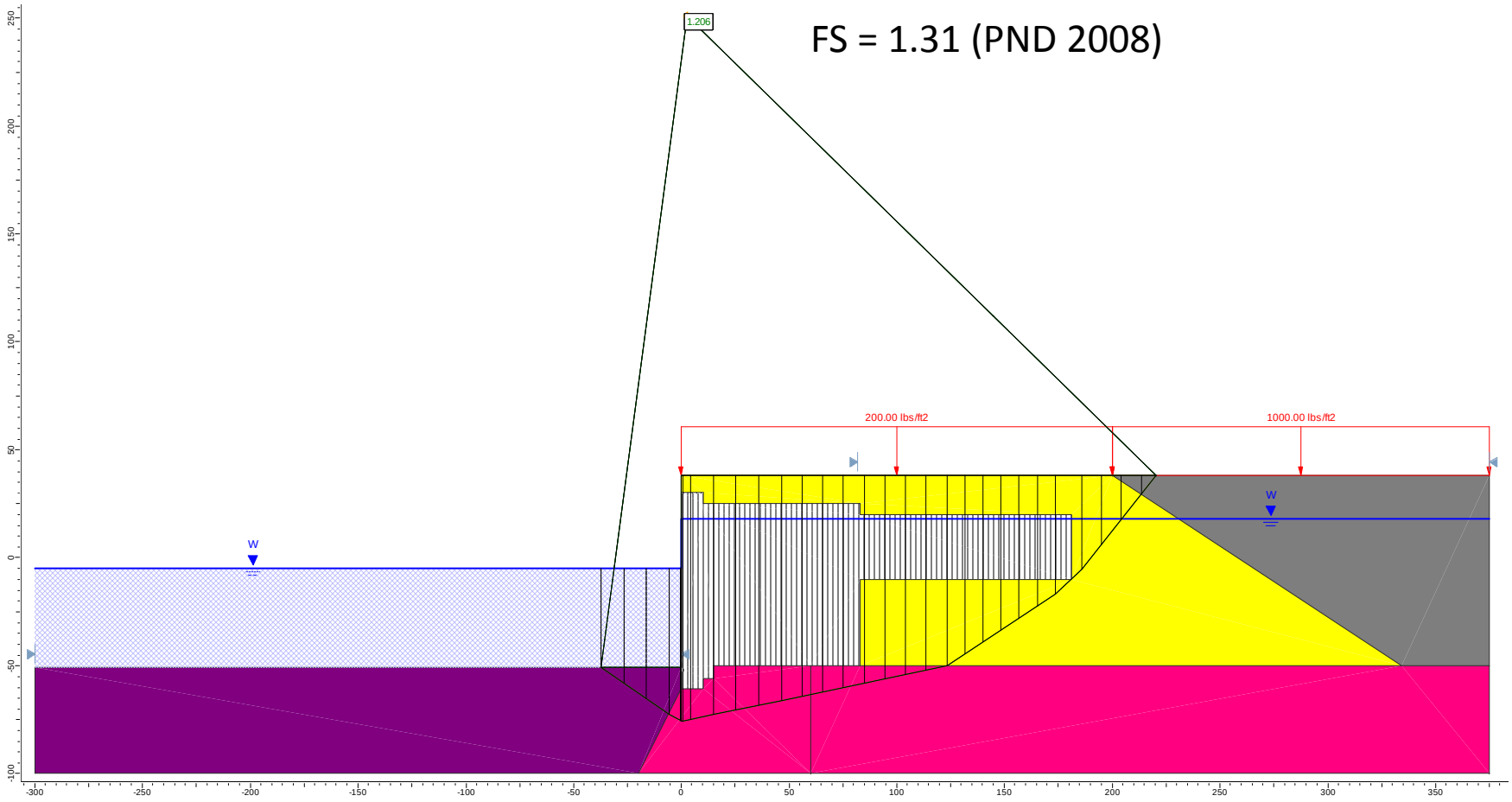


Figure E16. Re-analyzing the short-term static (EOC) case for Section F using Slide (2-clay, optimized surface).

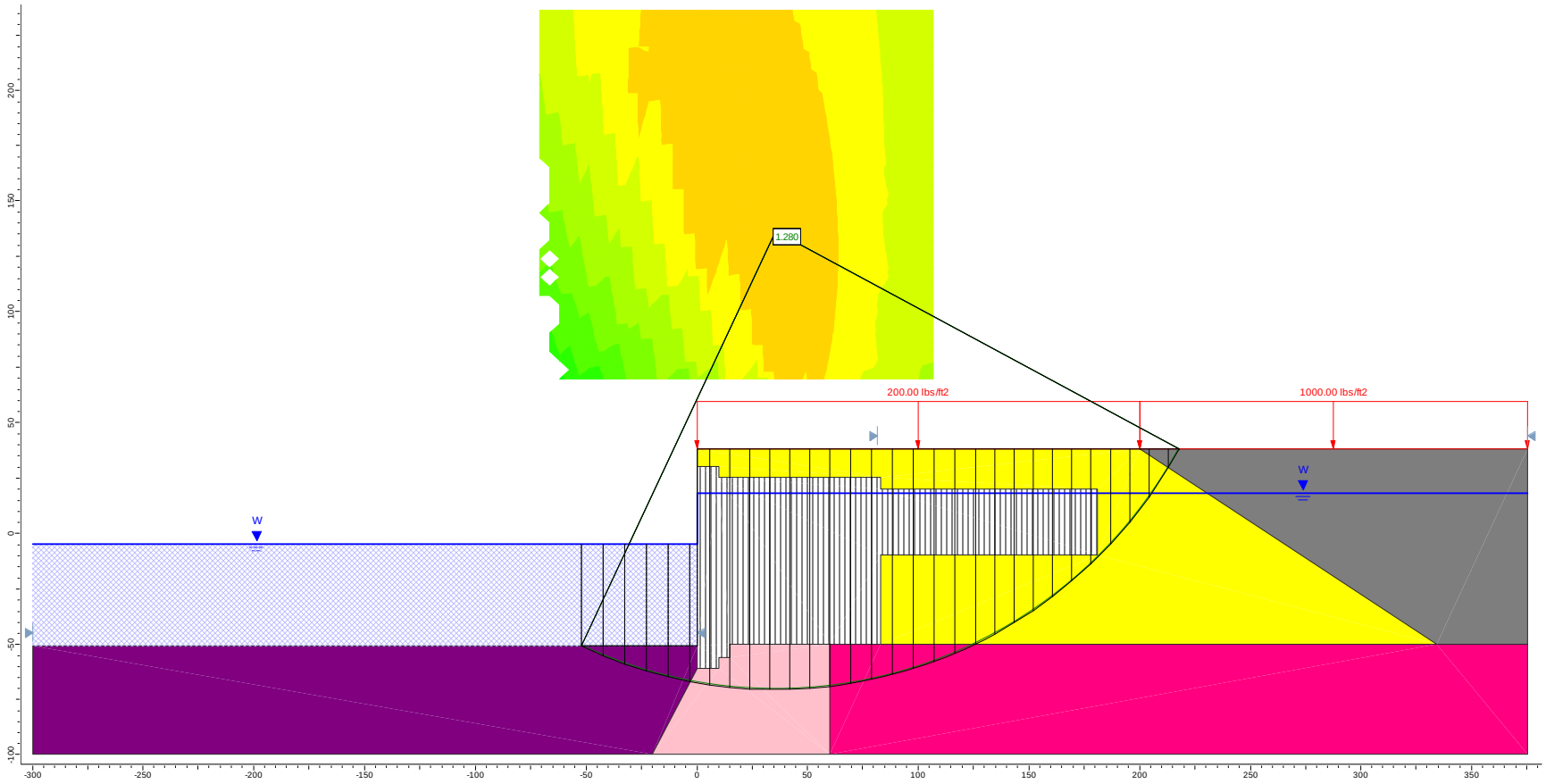


Figure E17. Re-analyzing the short-term static (EOC) case for Section F using Slide (3-clay, circular surface).

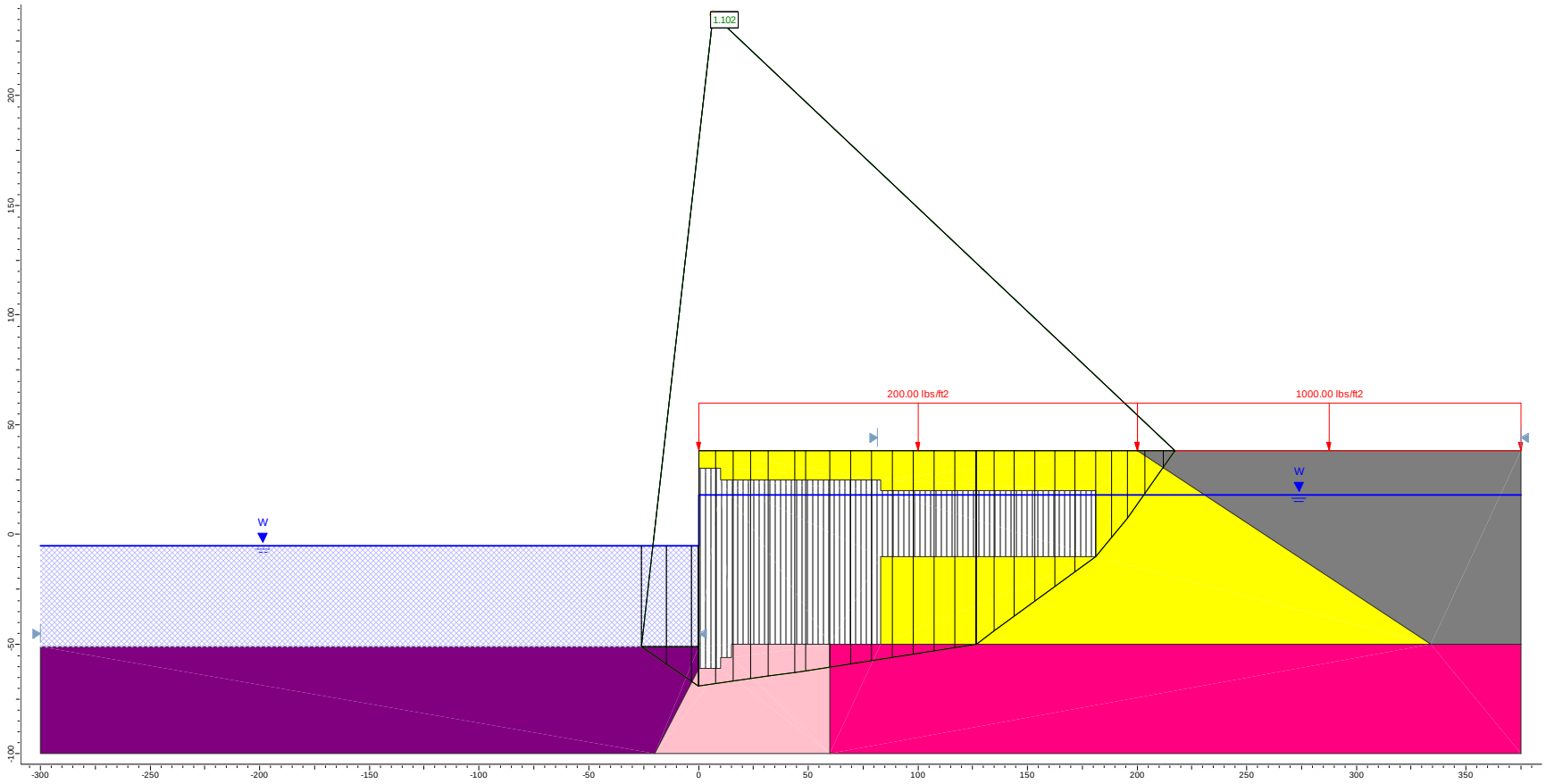


Figure E18. Re-analyzing the short-term static (EOC) case for Section F using Slide (3-clay, optimized surface).

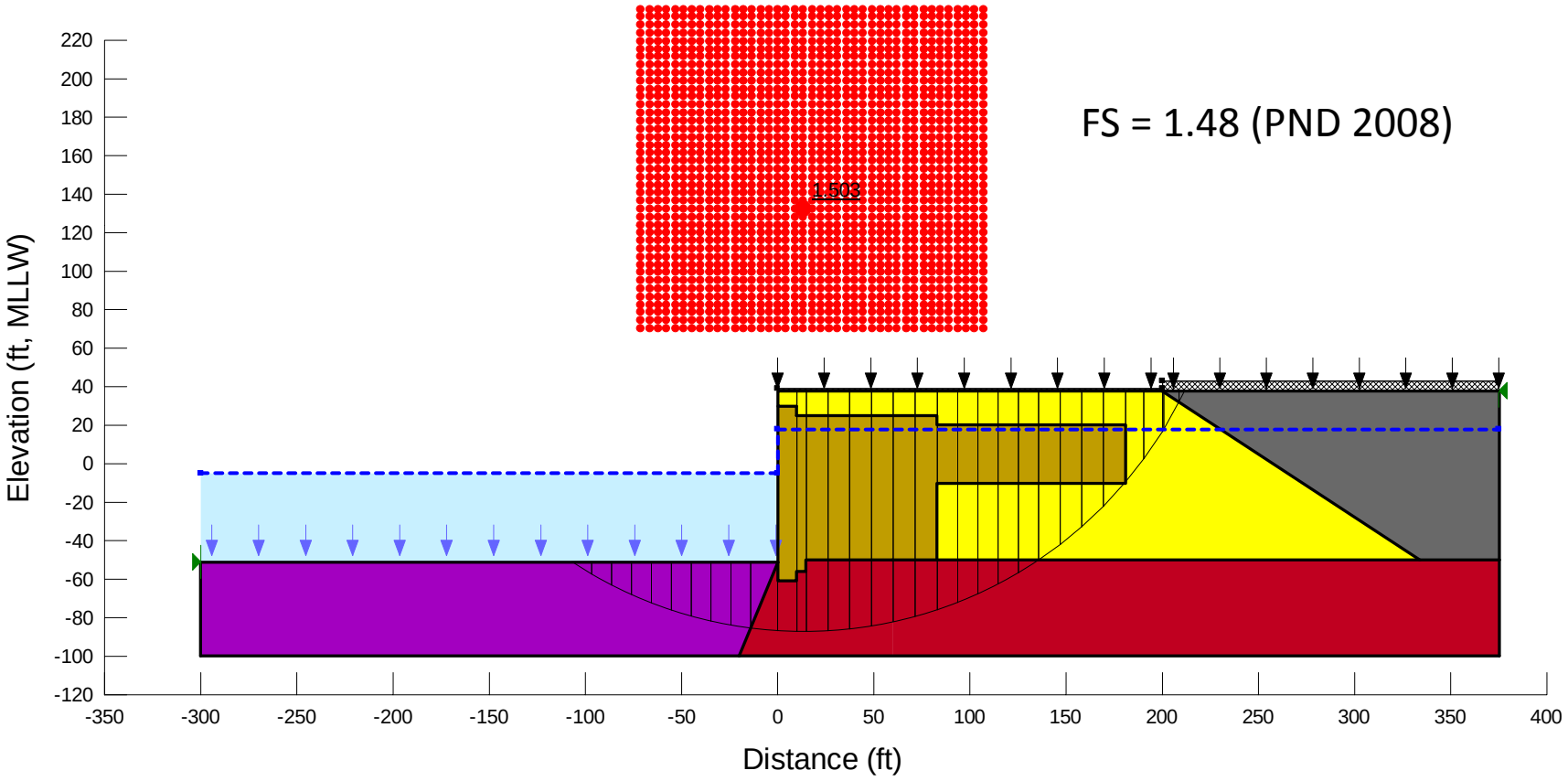


Figure E19. Re-analyzing the long-term static-undrained case for Section F using SLOPE/W (2-clay, circular surface).

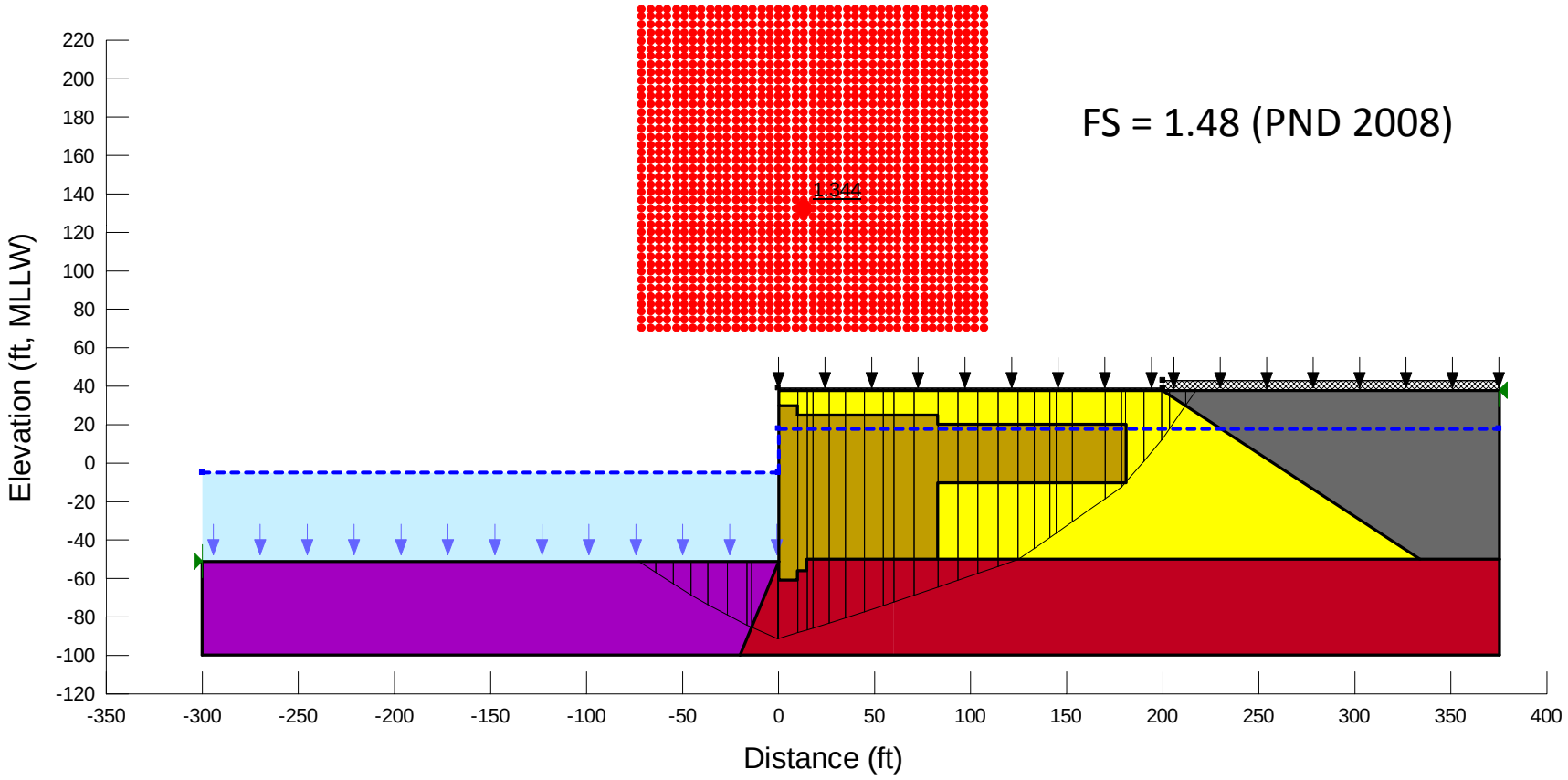


Figure E20. Re-analyzing the long-term static-undrained case for Section F using SLOPE/W (2-clay, optimized surface).

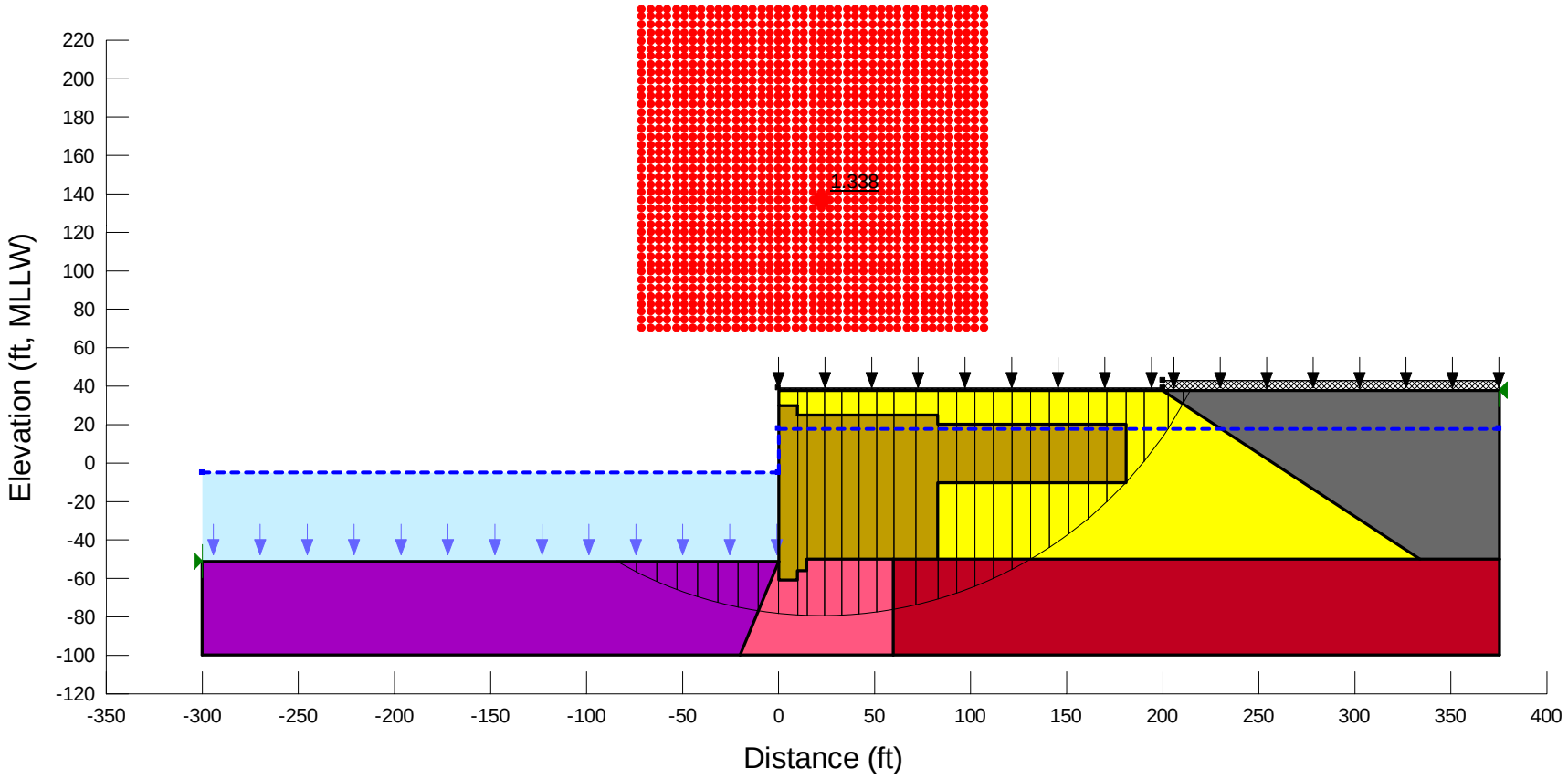


Figure E21. Re-analyzing the long-term static-undrained case for Section F using SLOPE/W (3-clay, circular surface).

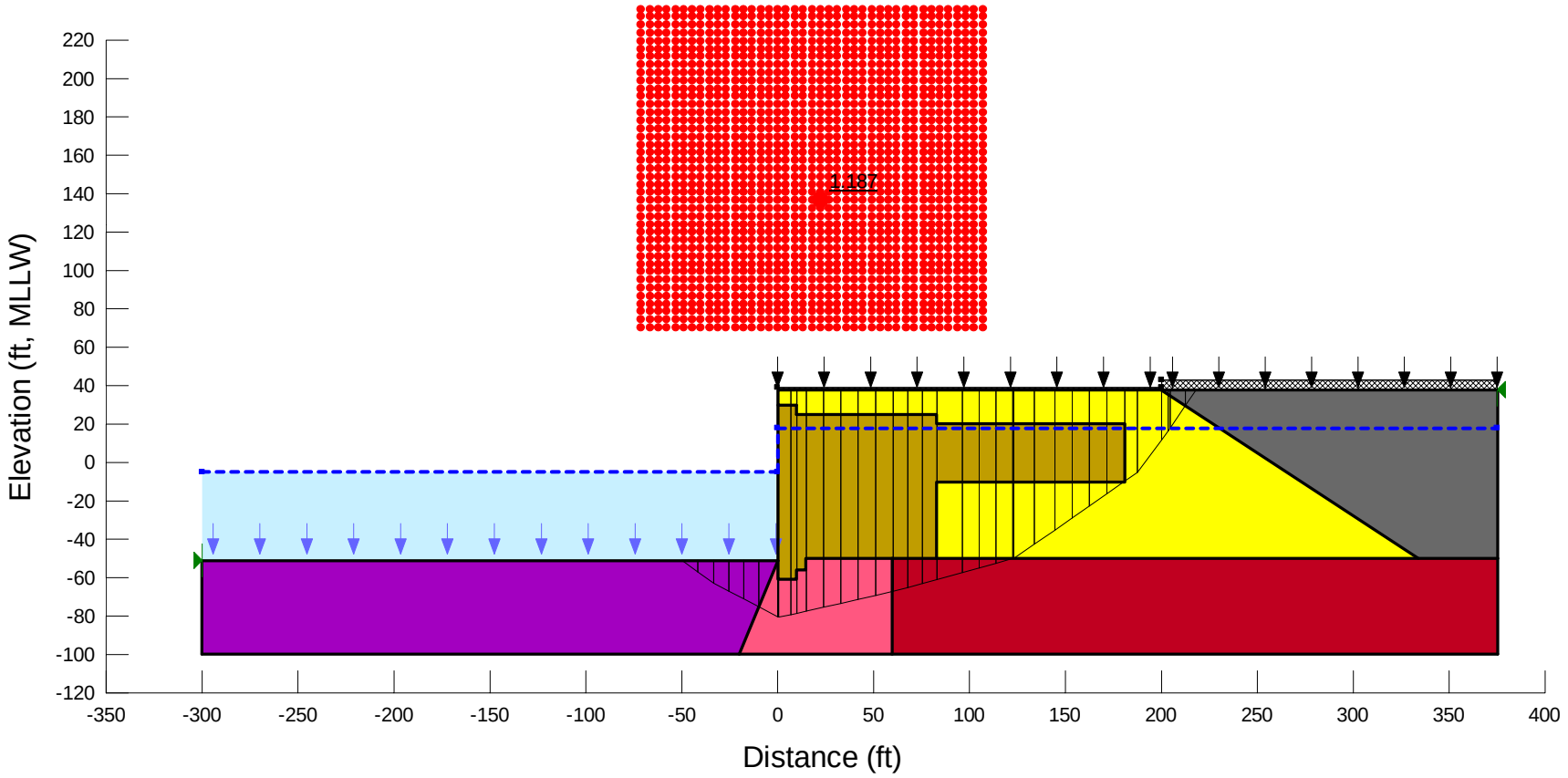


Figure E22. Re-analyzing the long-term static-undrained case for Section F using SLOPE/W (3-clay, optimized surface).

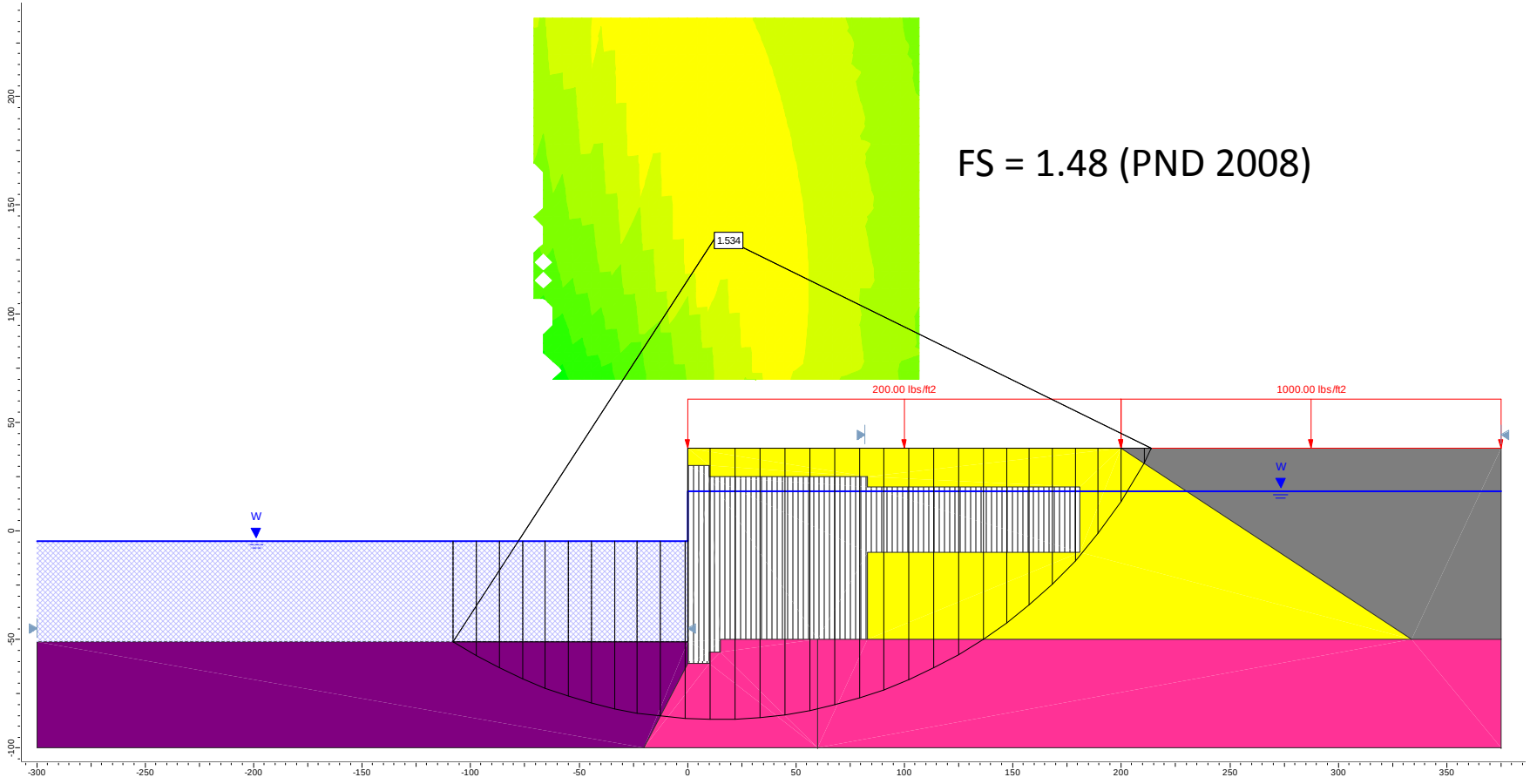


Figure E23. Re-analyzing the long-term static-undrained case for Section F using Slide (2-clay, circular surface).

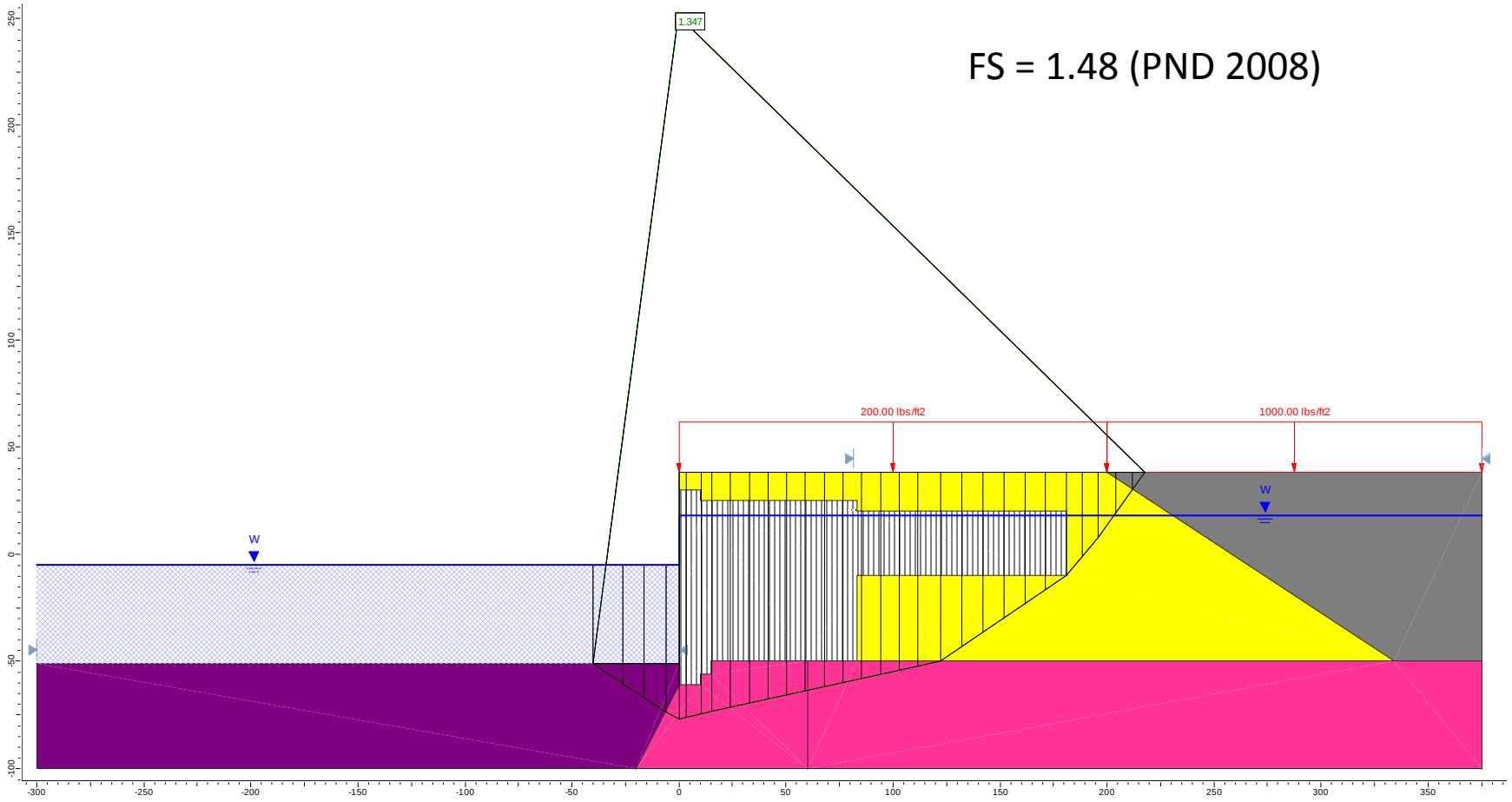


Figure E24. Re-analyzing the long-term static-undrained case for Section F using Slide (2-clay, optimized surface).

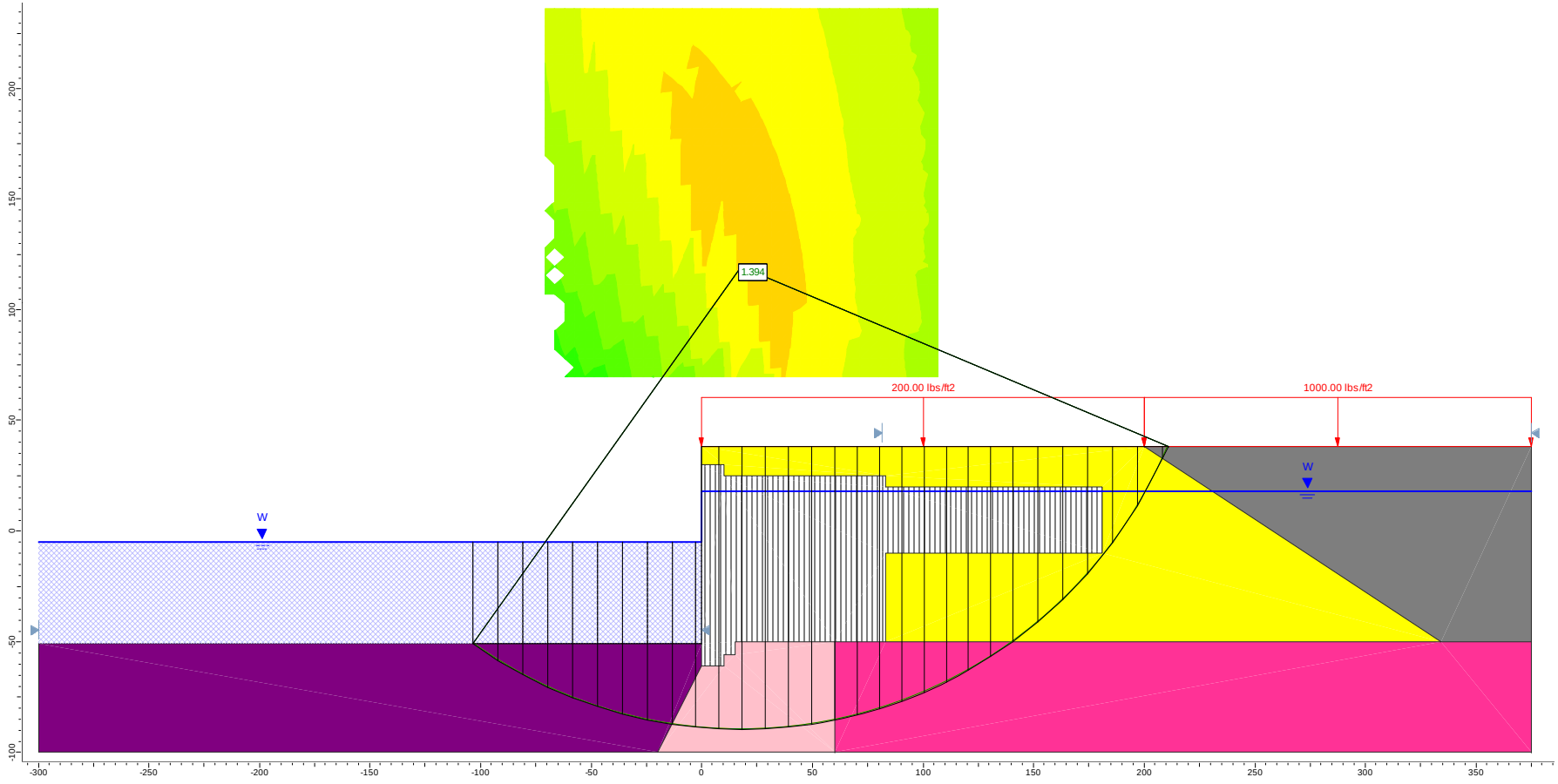


Figure E25. Re-analyzing the long-term static-undrained case for Section F using Slide (3-clay, circular surface).

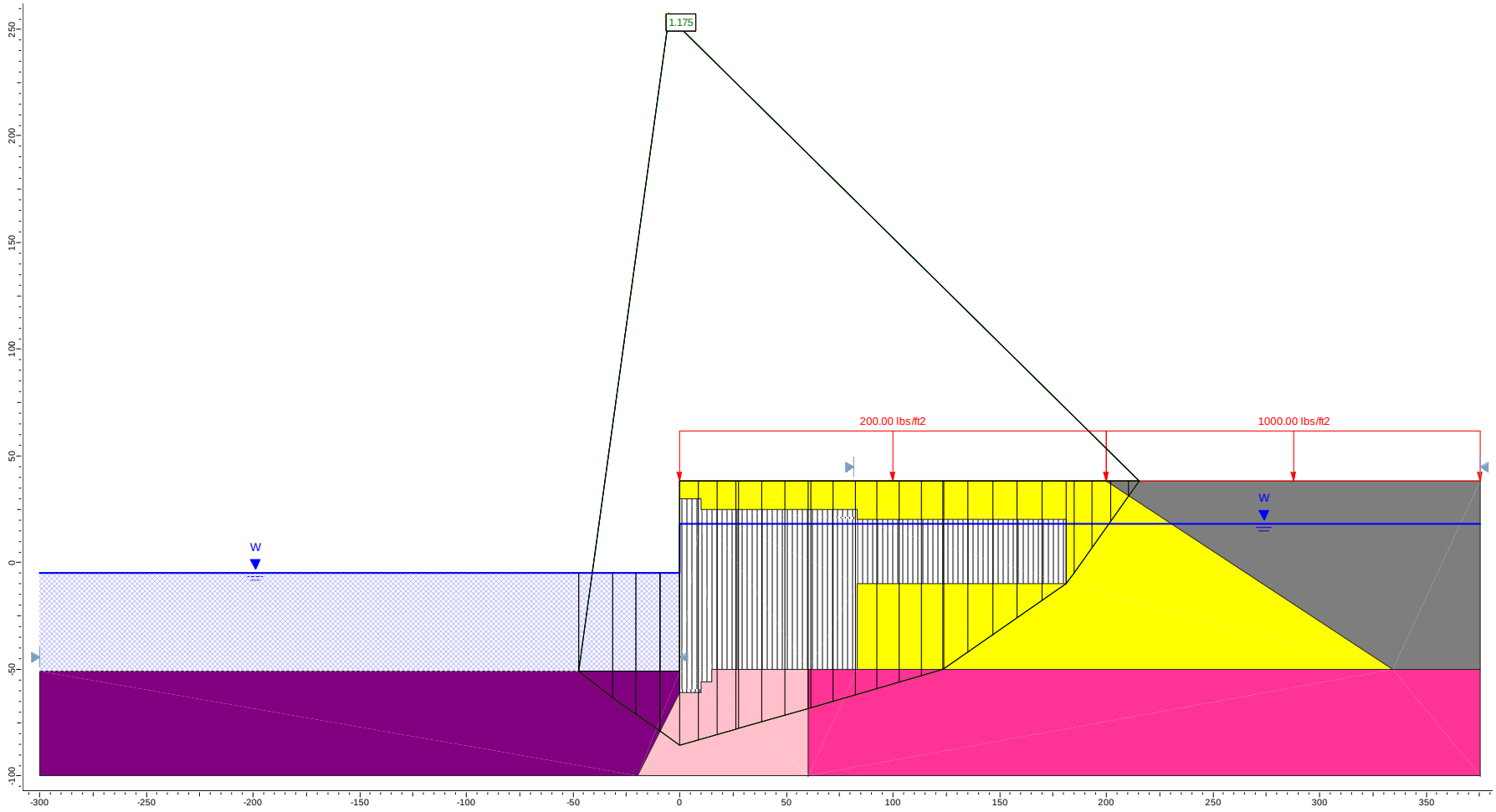


Figure E26. Re-analyzing the long-term static-undrained case for Section F using Slide (3-clay, optimized surface).

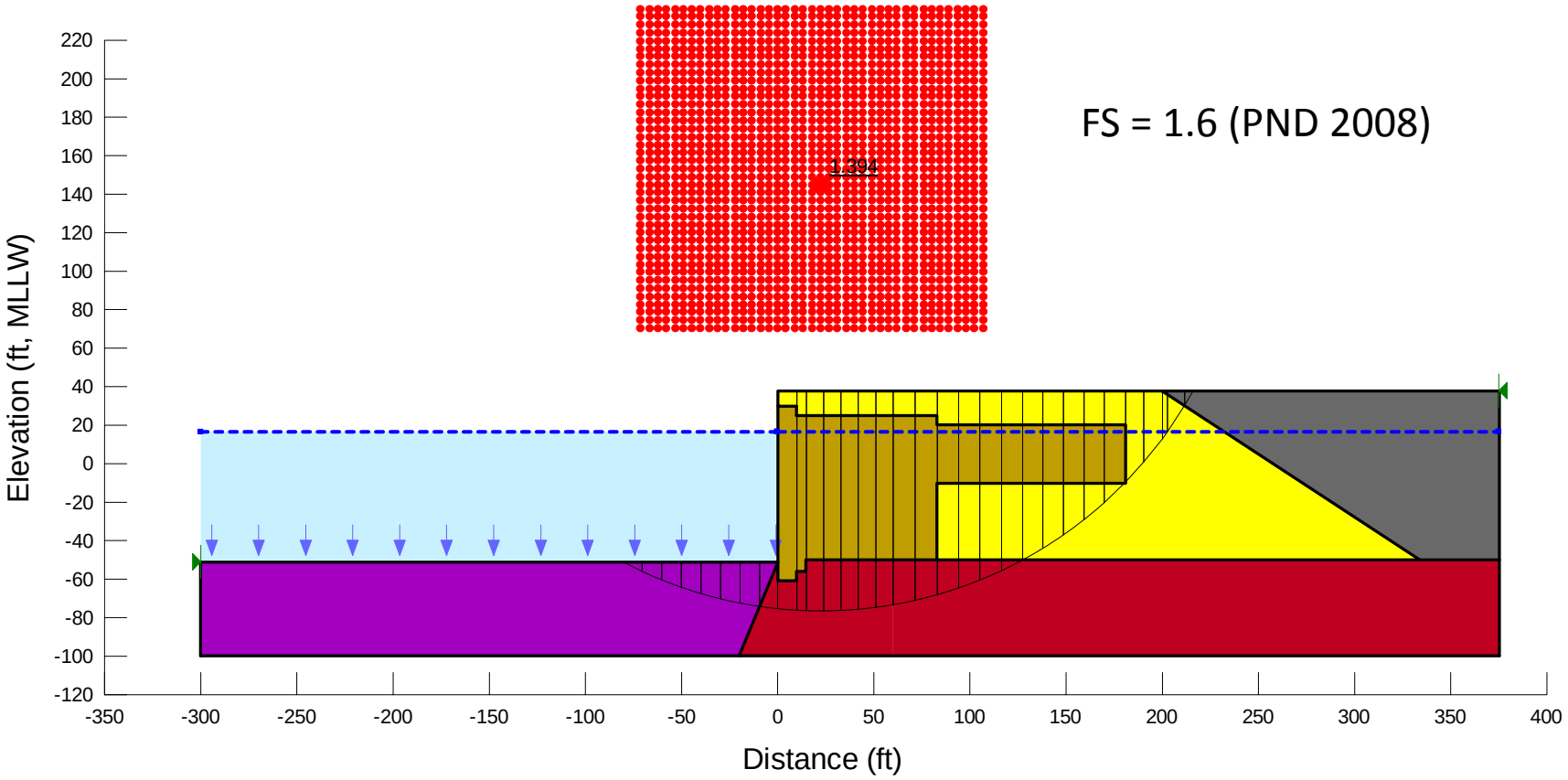


Figure E27. Re-analyzing the OLE case for Section F using SLOPE/W (2-clay, circular surface).

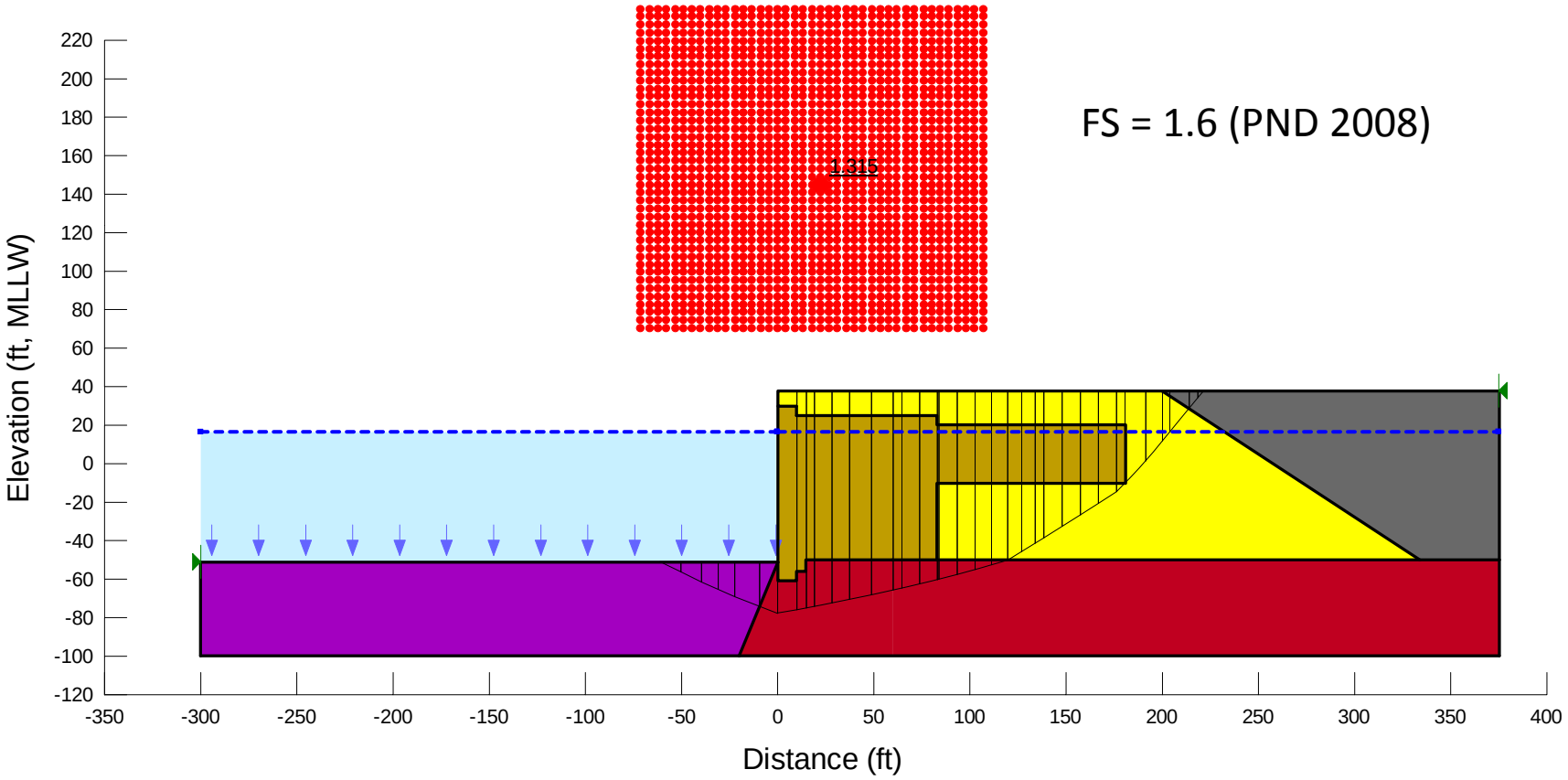


Figure E28. Re-analyzing the OLE case for Section F using SLOPE/W (2-clay, optimized surface).

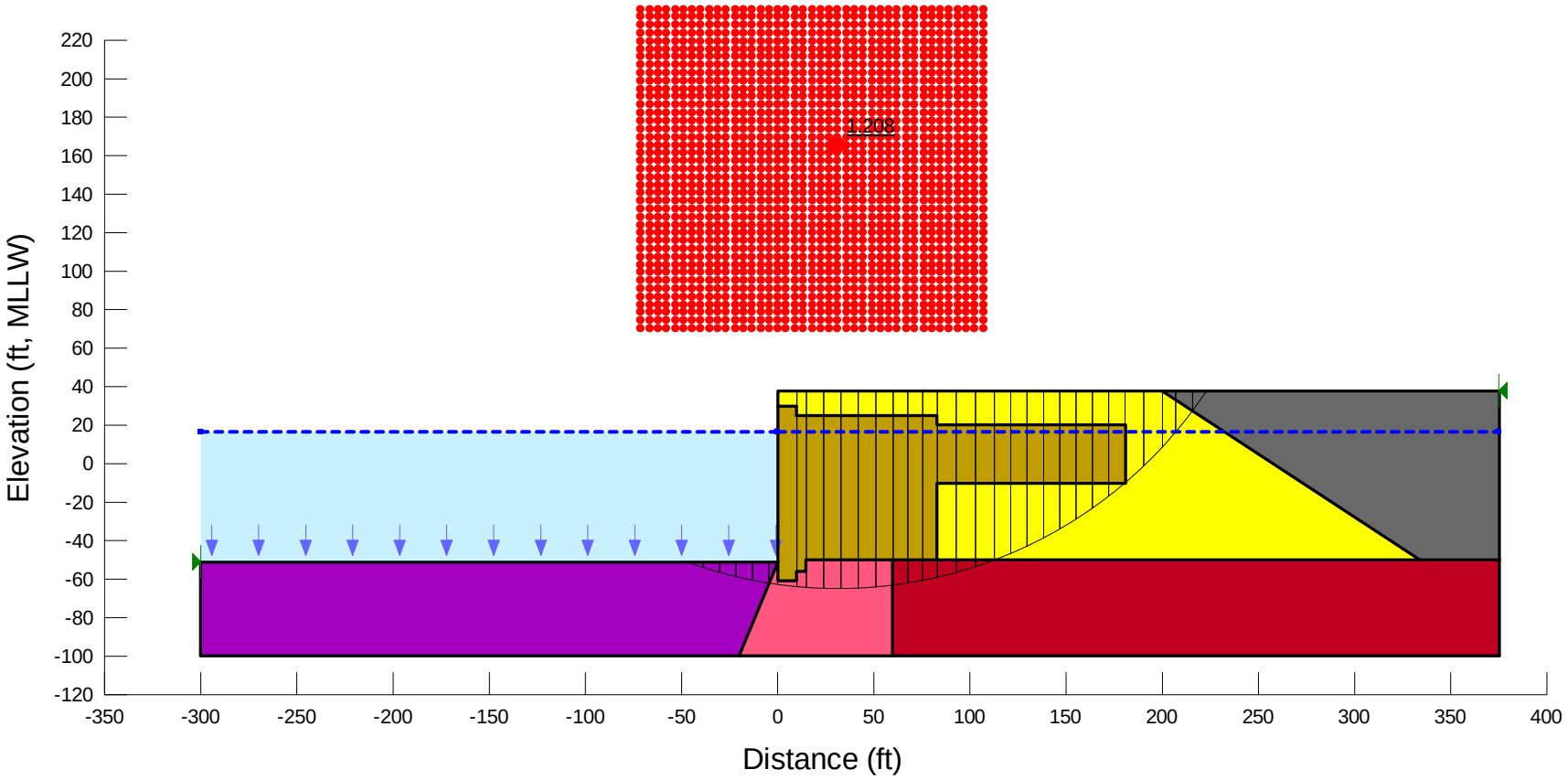


Figure E29. Re-analyzing the OLE case for Section F using SLOPE/W (3-clay, circular surface).

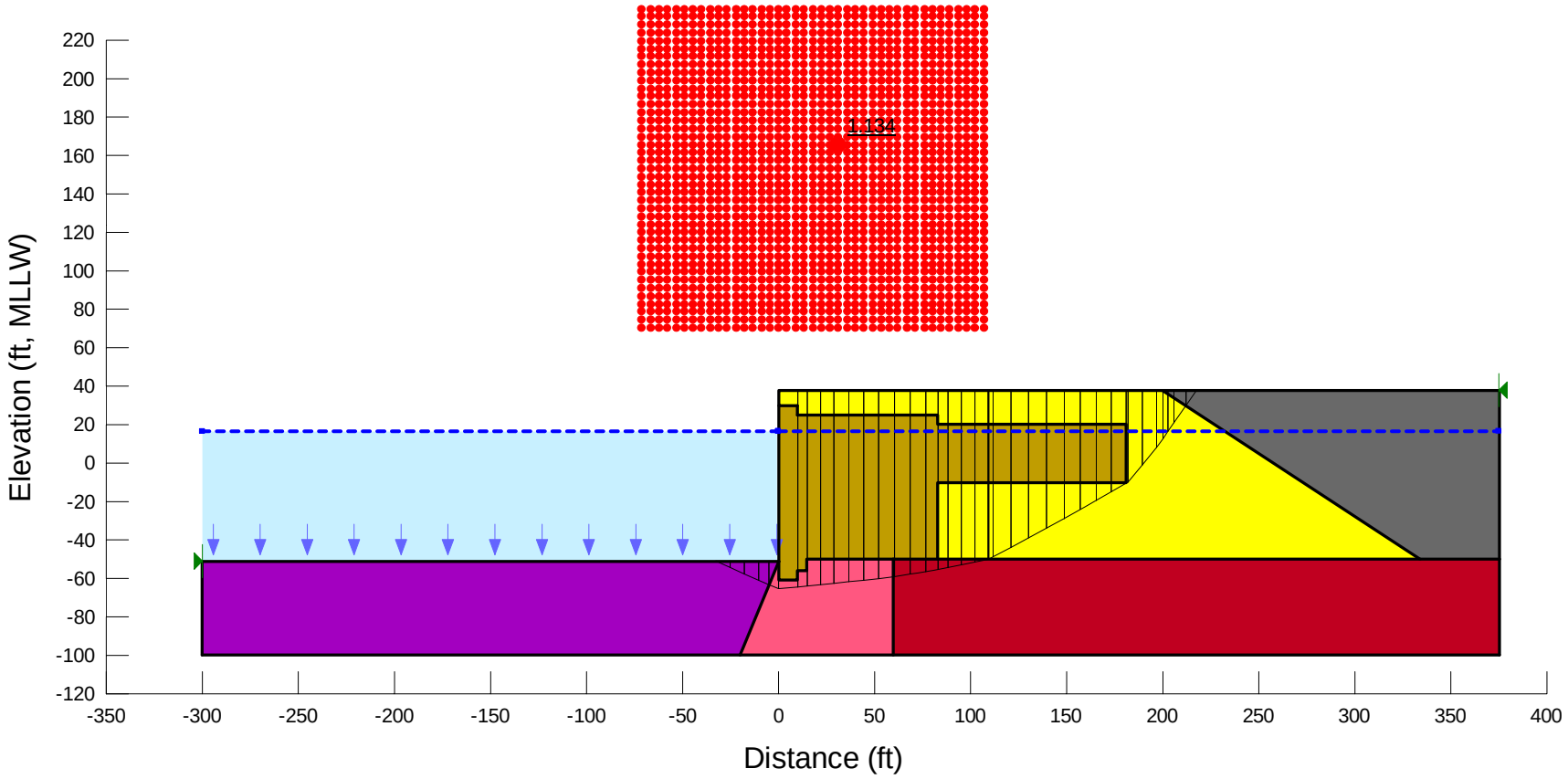


Figure E30. Re-analyzing the OLE case for Section F using SLOPE/W (3-clay, optimized surface).

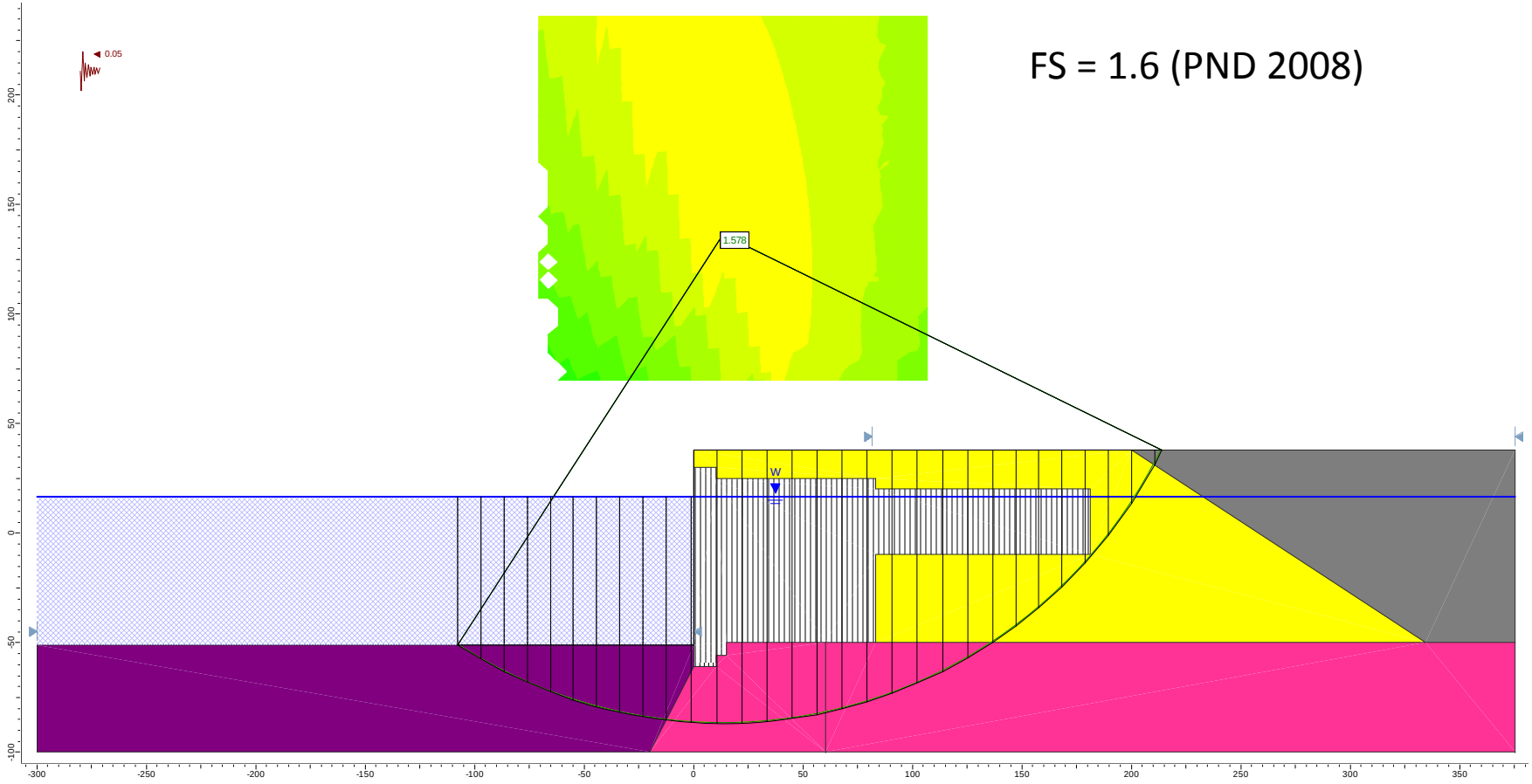


Figure E31. Re-analyzing the OLE case for Section F using Slide (2-clay, circular surface).

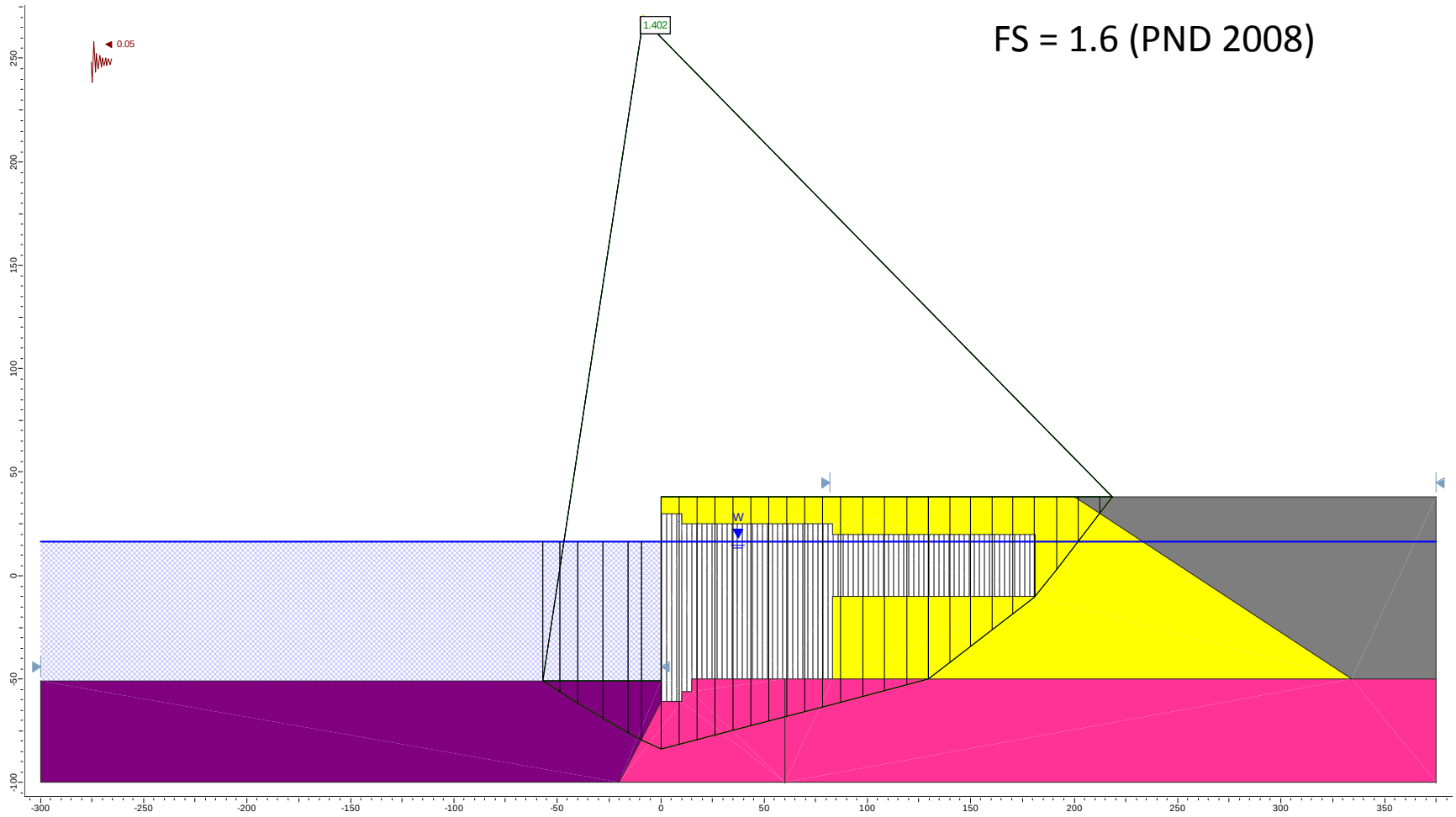


Figure E32. Re-analyzing the OLE case for Section F using Slide (2-clay, optimized surface).

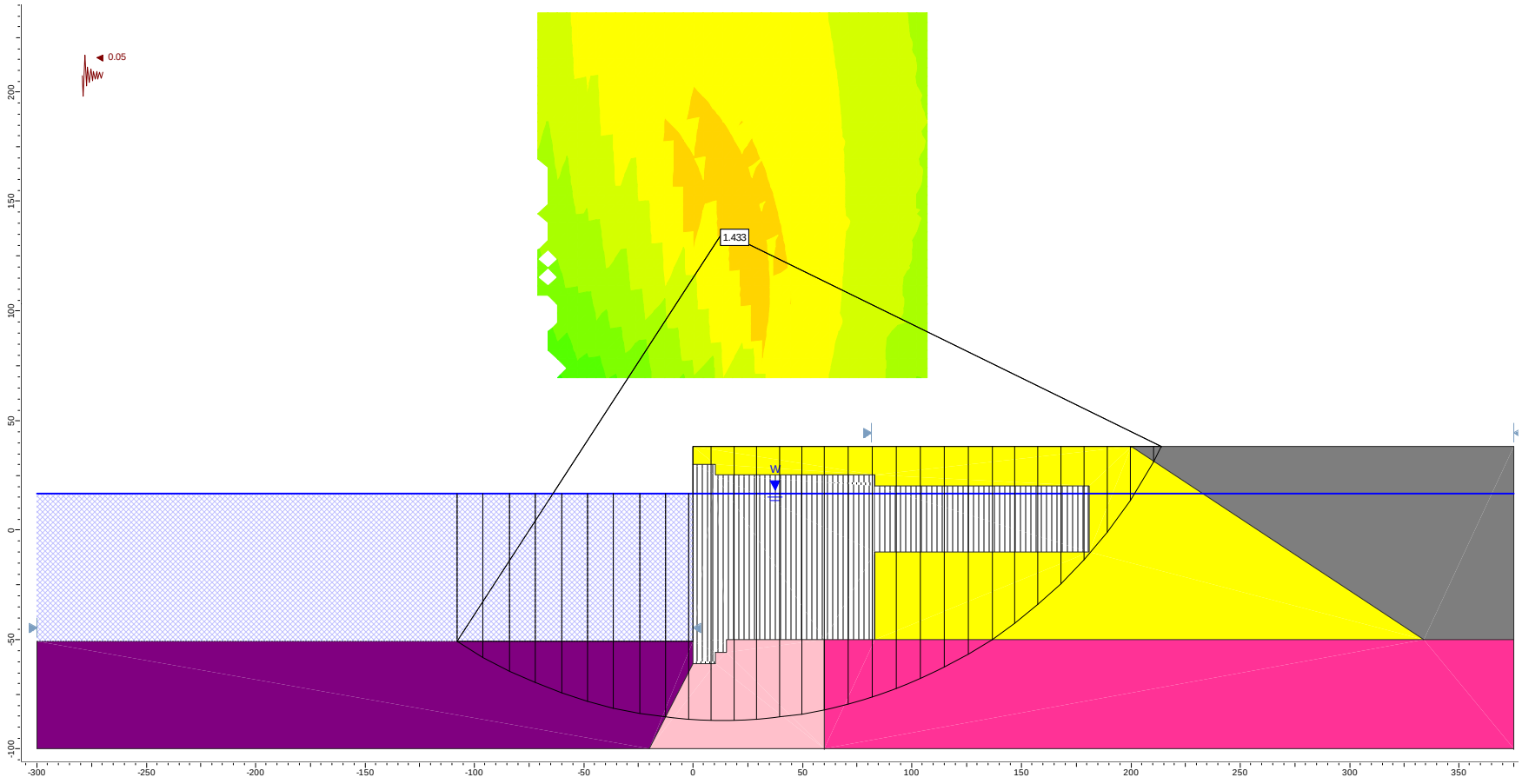


Figure E33. Re-analyzing the OLE case for Section F using Slide (3-clay, circular surface).

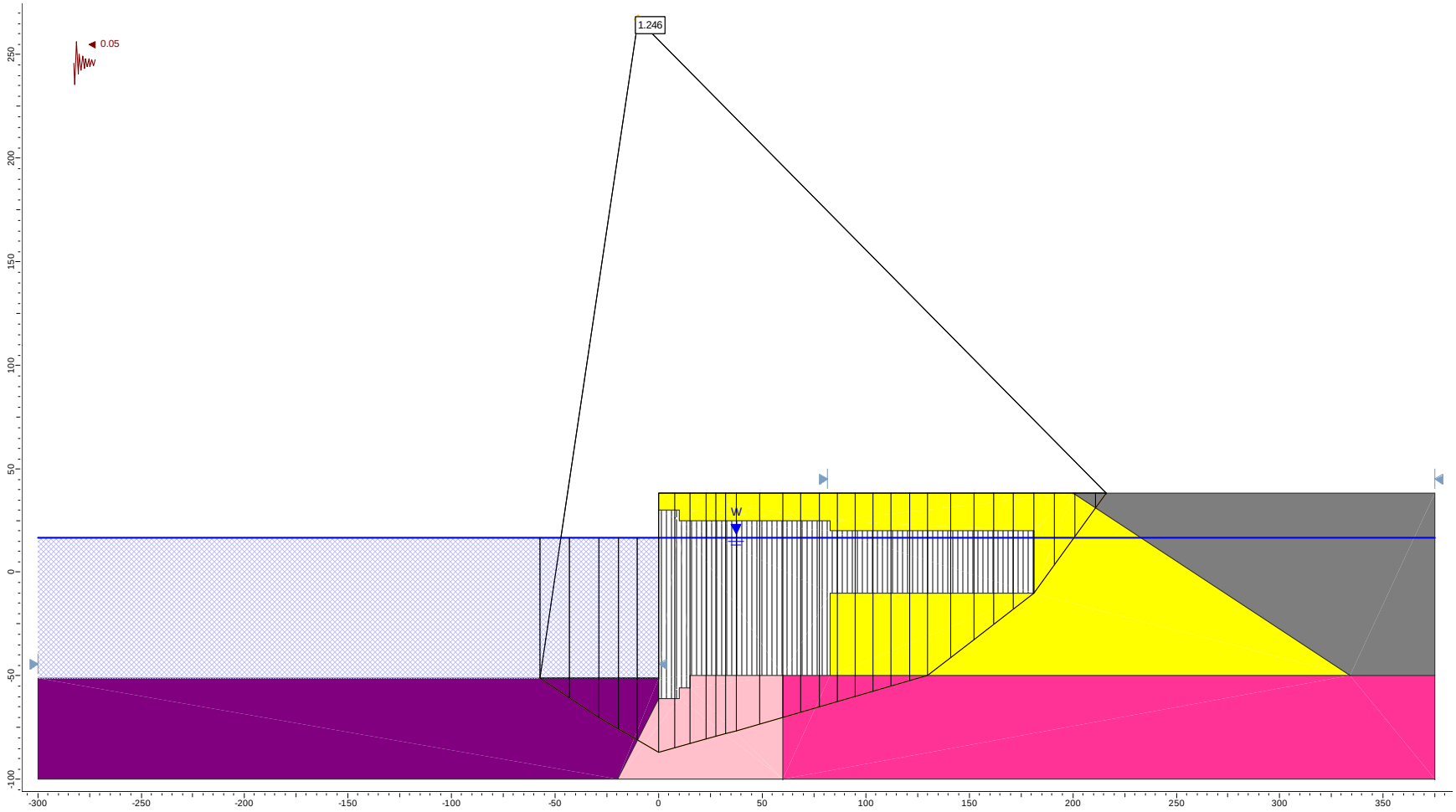


Figure E34. Re-analyzing the OLE case for Section F using Slide (3-clay, optimized surface).

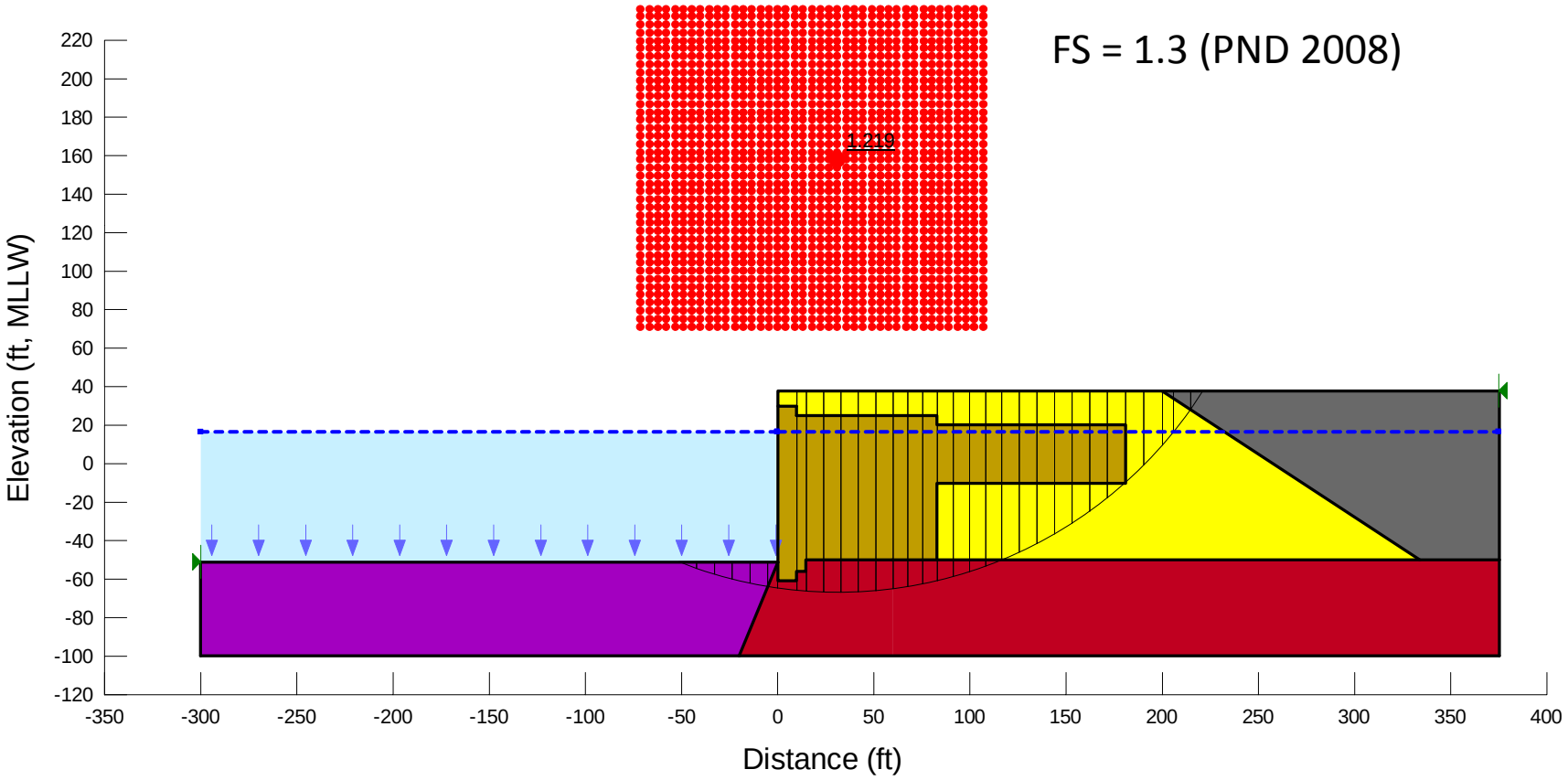


Figure E35. Re-analyzing the CLE case for Section F using SLOPE/W (2-clay, circular surface).

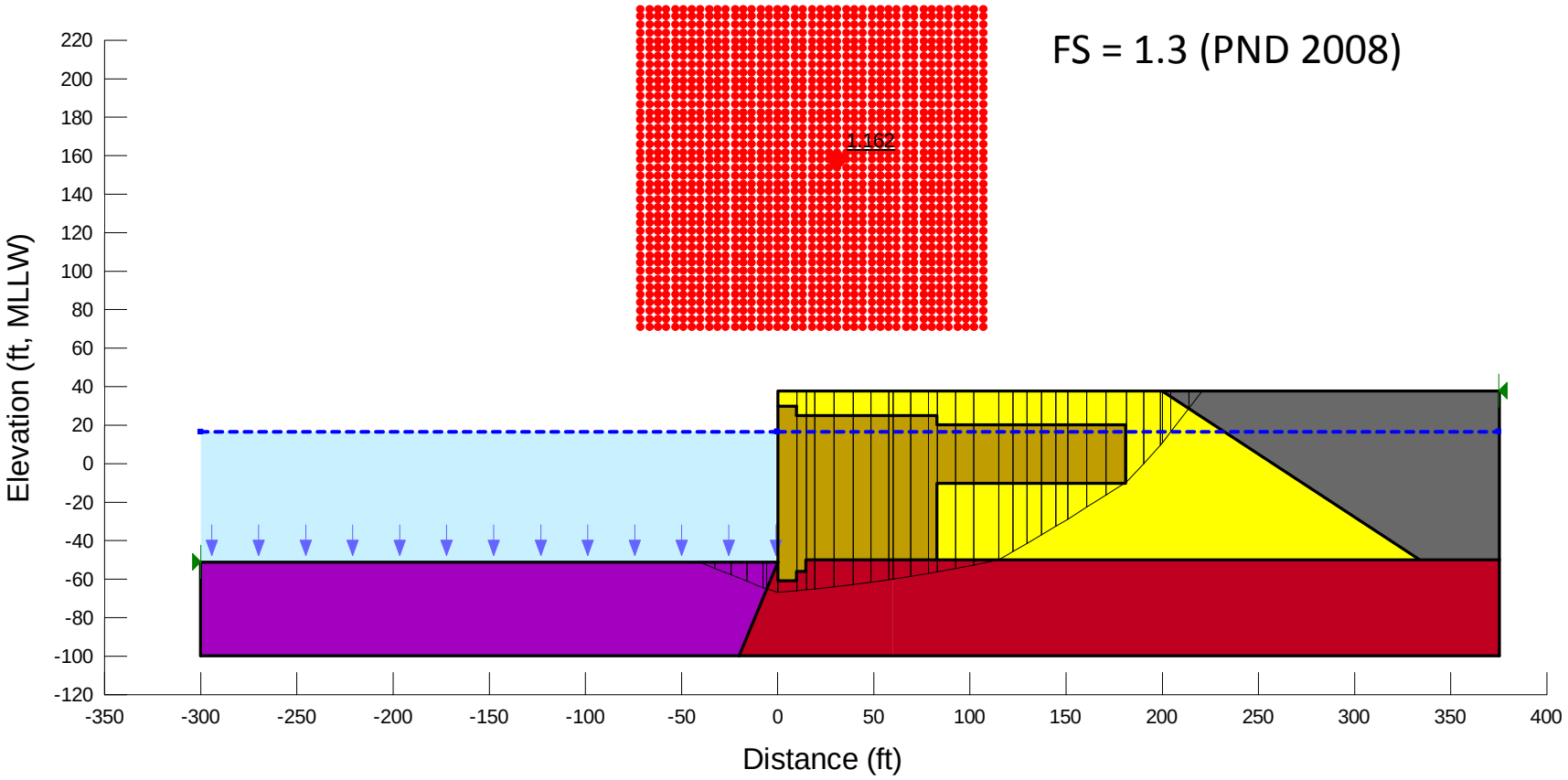


Figure E36. Re-analyzing the CLE case for Section F using SLOPE/W (2-clay, optimized surface).

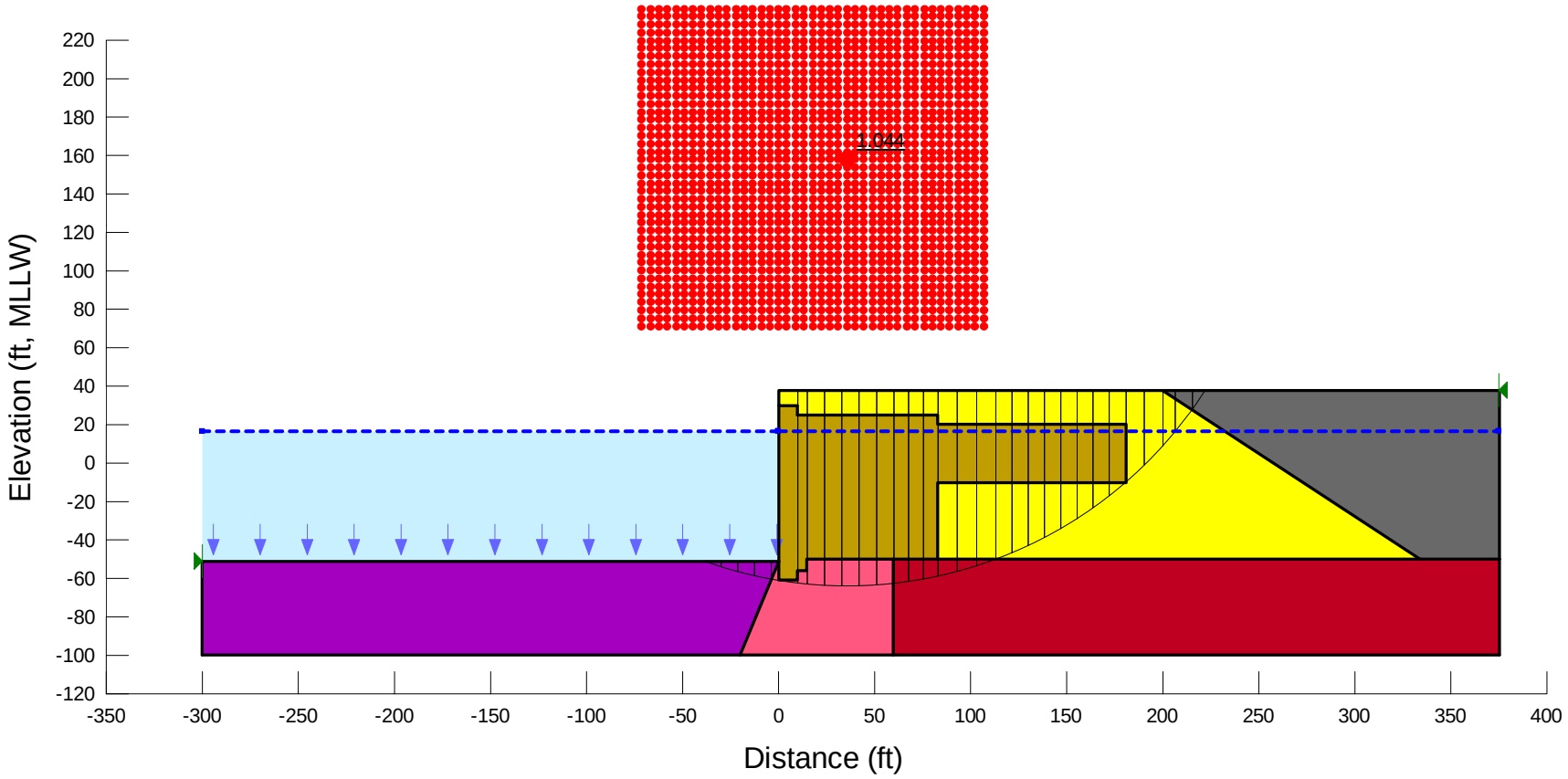


Figure E37. Re-analyzing the CLE case for Section F using SLOPE/W (3-clay, circular surface).

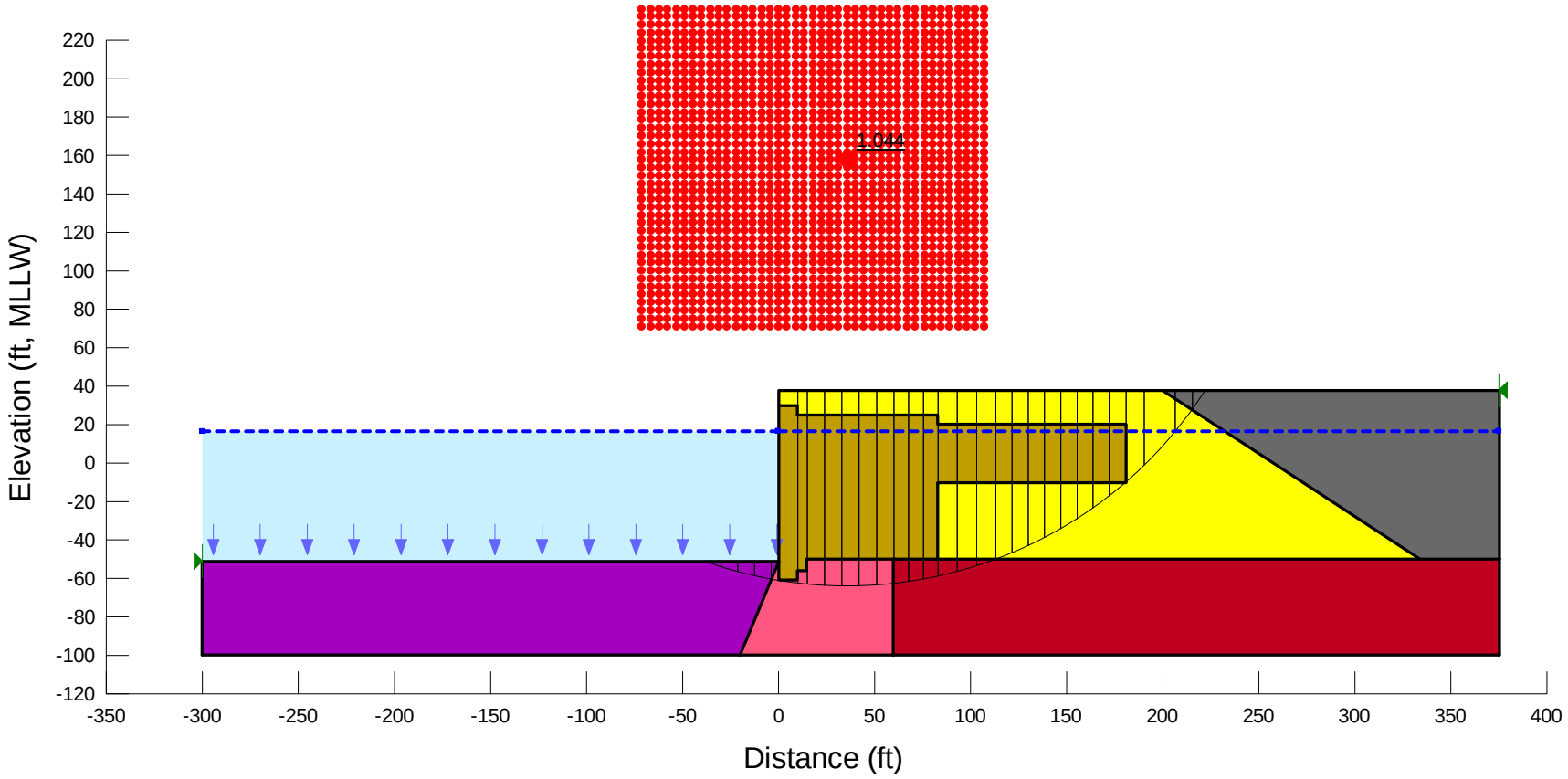


Figure E38. Re-analyzing the CLE case for Section F using SLOPE/W (3-clay, optimized surface).

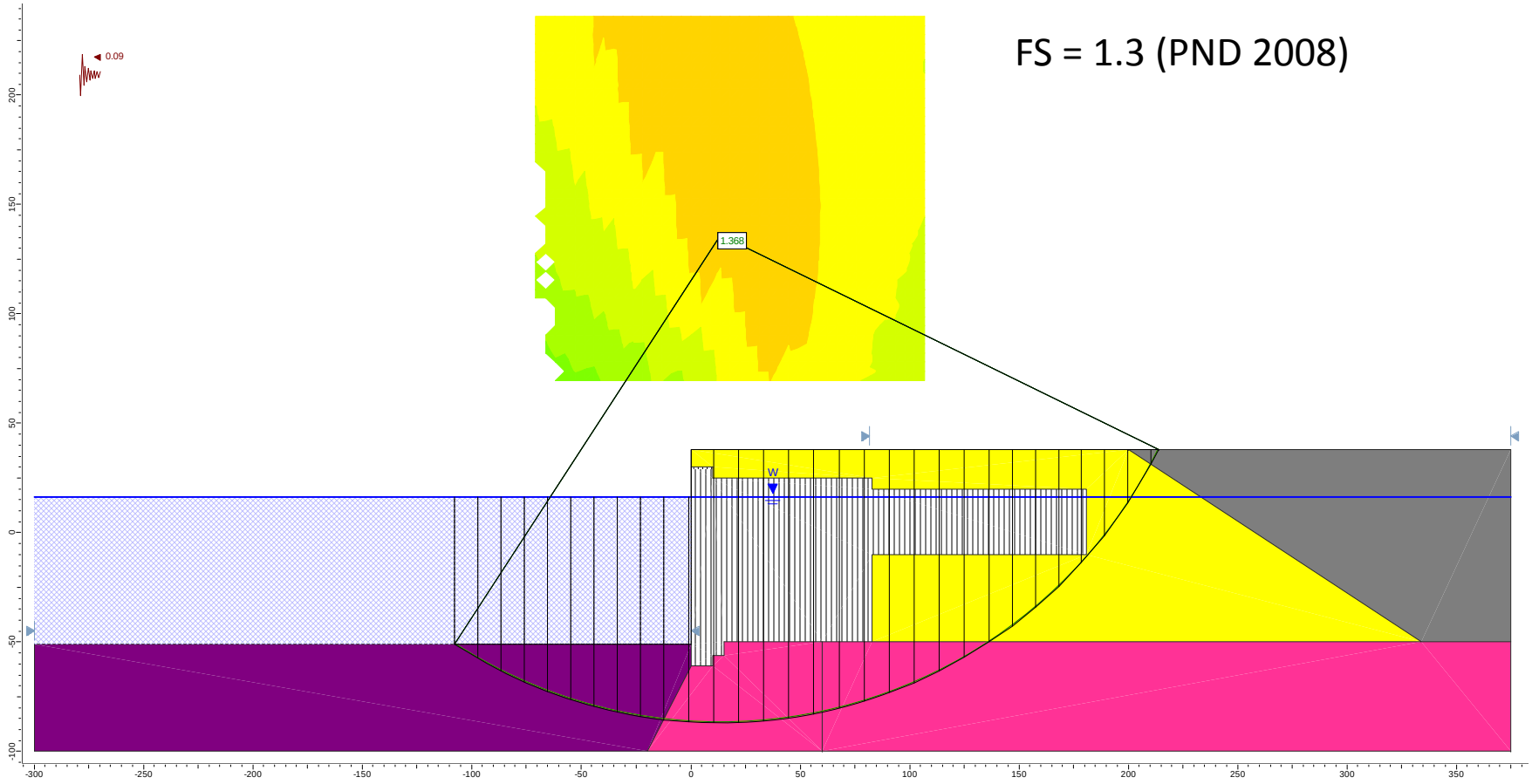


Figure E39. Re-analyzing the CLE case for Section F using Slide (2-clay, circular surface).

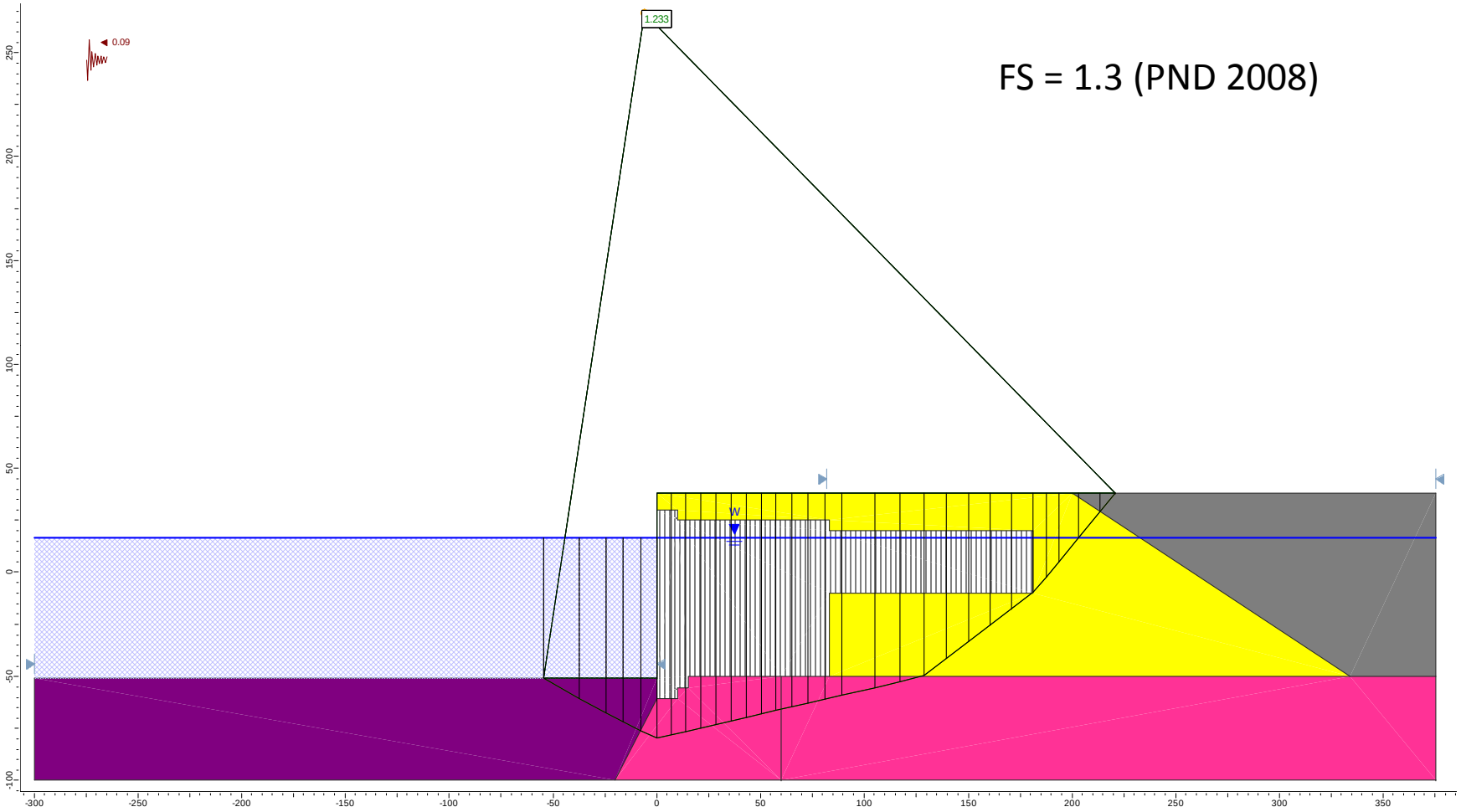


Figure E40. Re-analyzing the CLE case for Section F using Slide (2-clay, optimized surface).

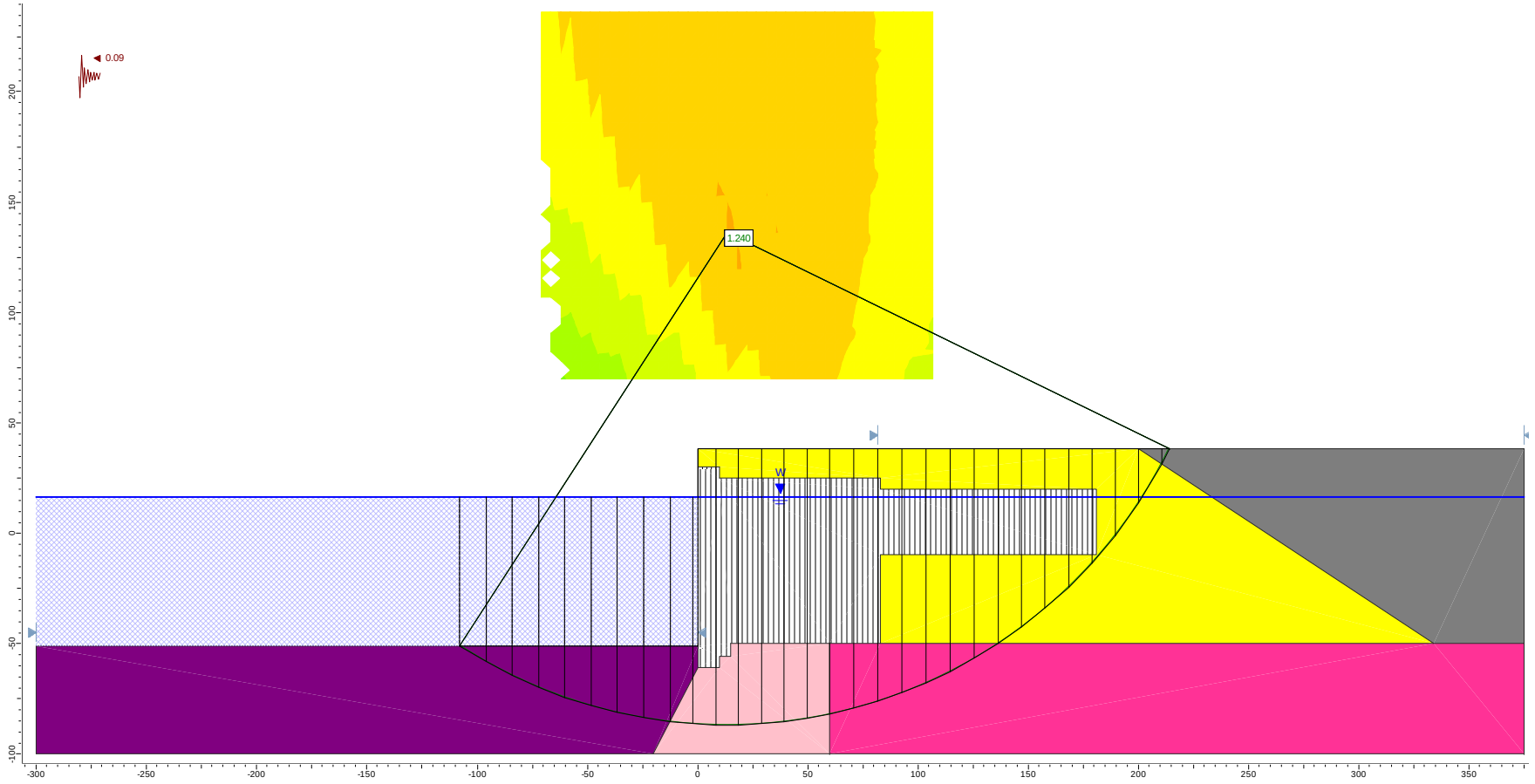


Figure E41. Re-analyzing the CLE case for Section F using Slide (3-clay, circular surface).

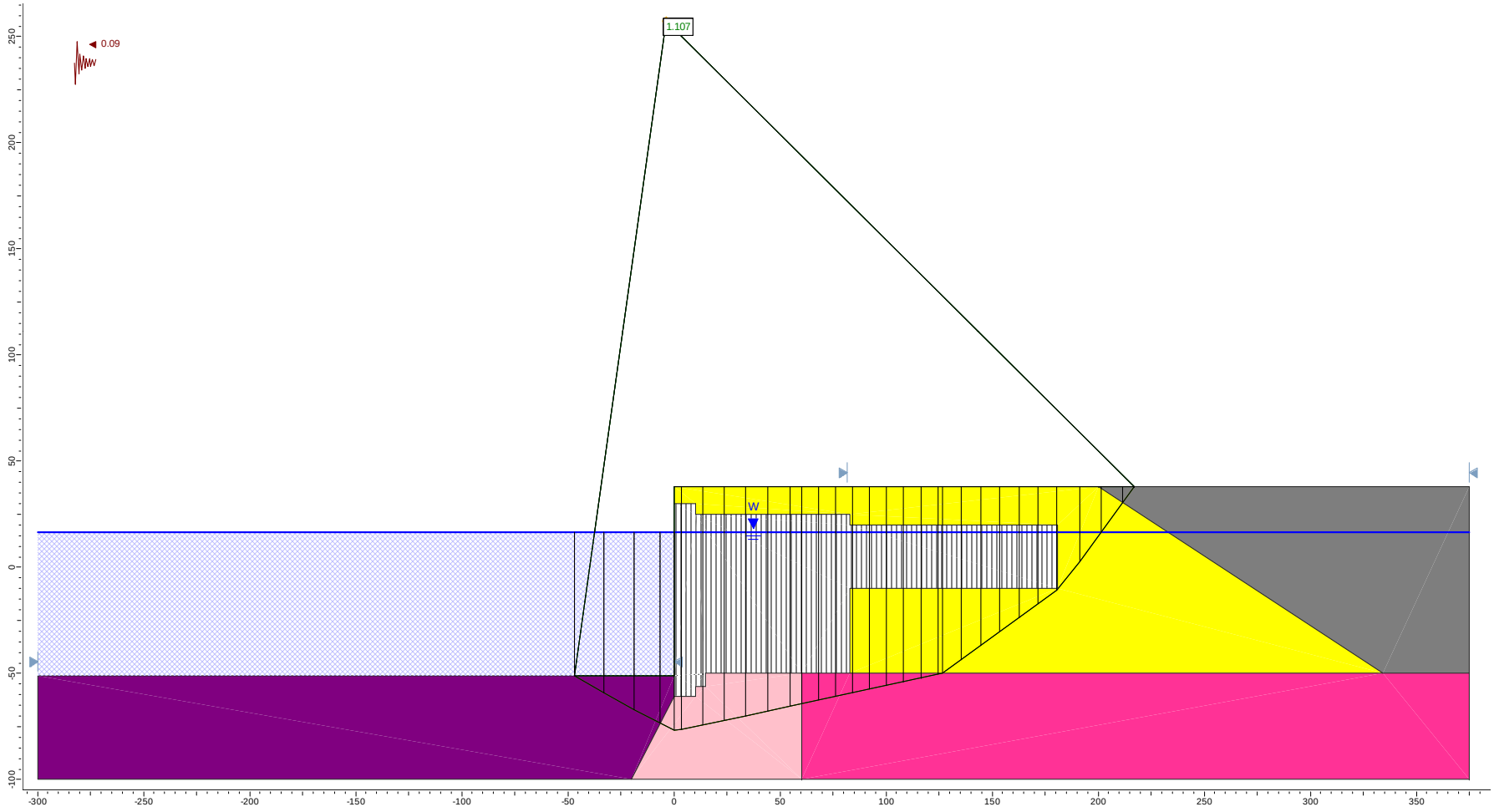


Figure E42. Re-analyzing the CLE case for Section F using Slide (3-clay, optimized surface).

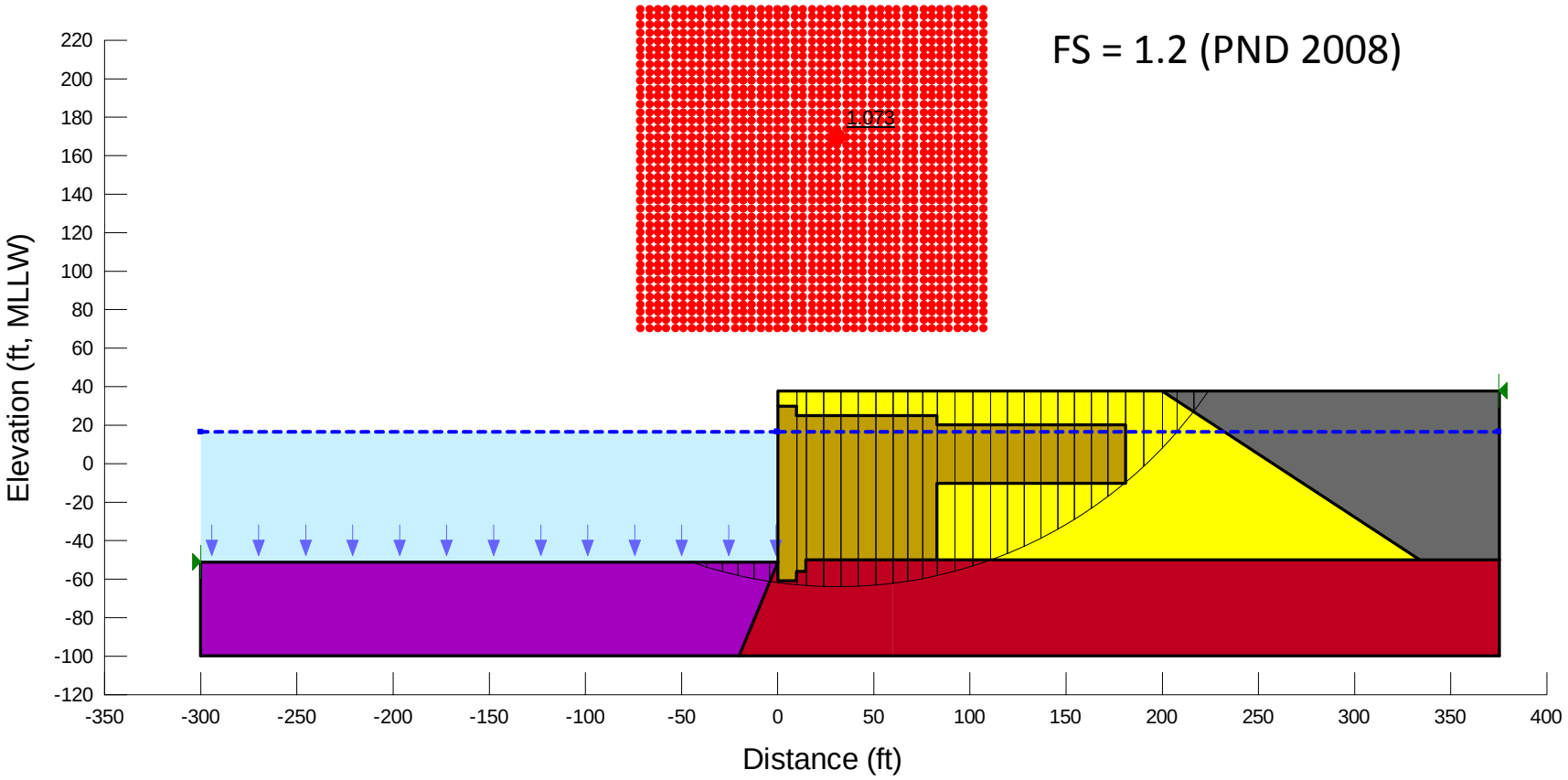


Figure E43. Re-analyzing the MCE case for Section F using SLOPE/W (2-clay, circular surface).

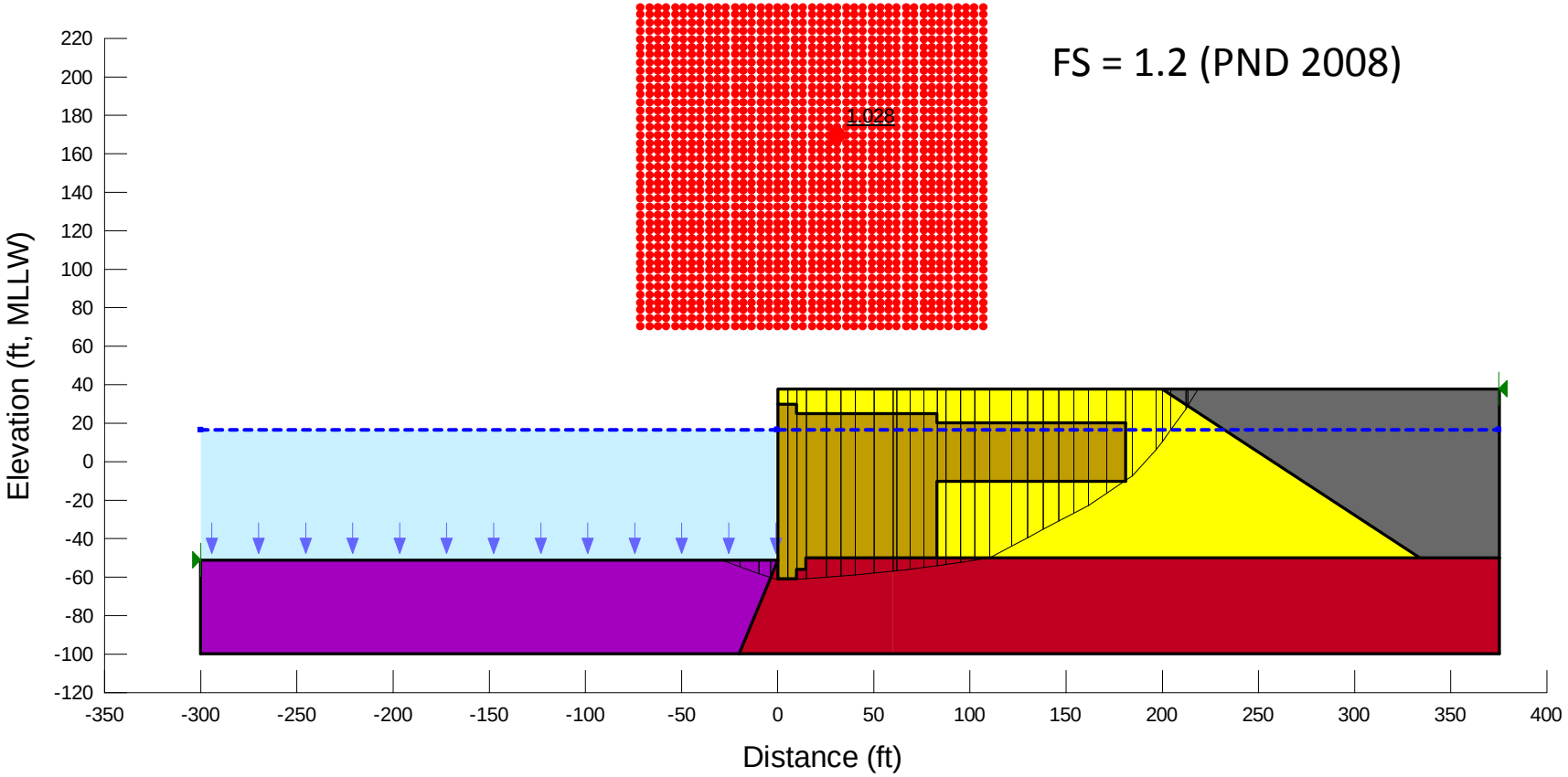


Figure E44. Re-analyzing the MCE case for Section F using SLOPE/W (2-clay, optimized surface).

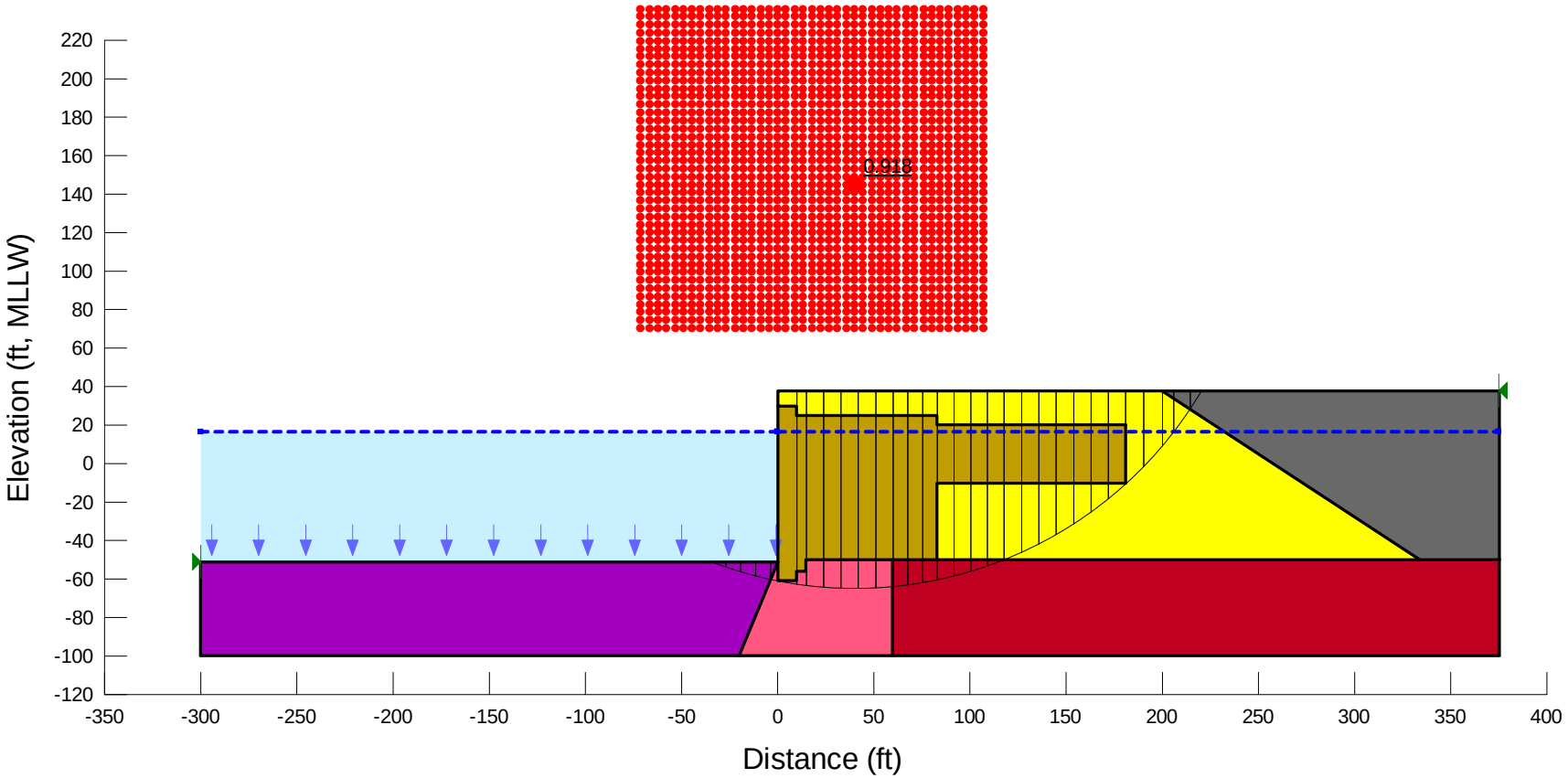


Figure E45. Re-analyzing the MCE case for Section F using SLOPE/W (3-clay, circular surface).

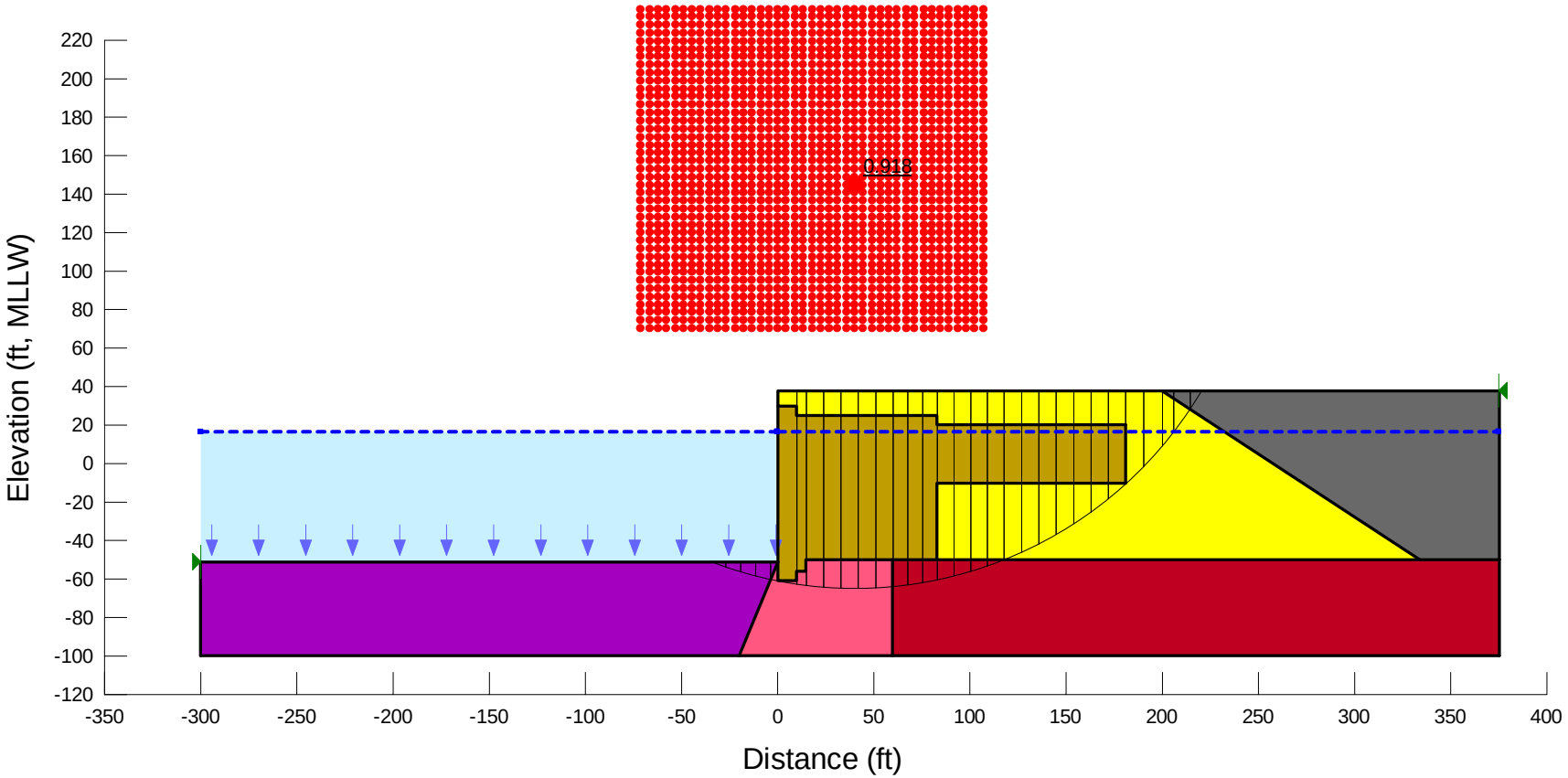


Figure E46. Re-analyzing the MCE case for Section F using SLOPE/W (3-clay, optimized surface).

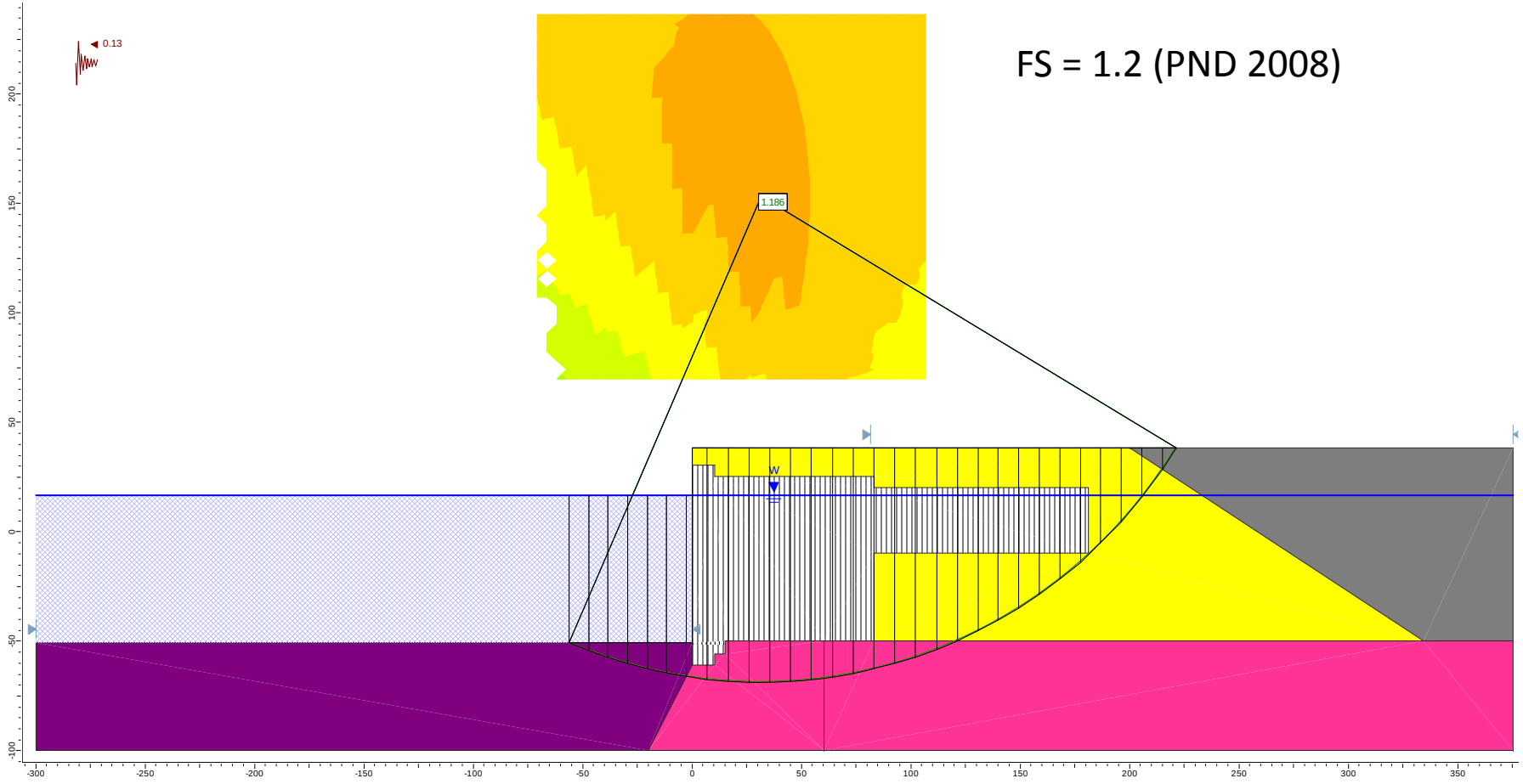


Figure E47. Re-analyzing the MCE case for Section F using Slide (2-clay, circular surface).

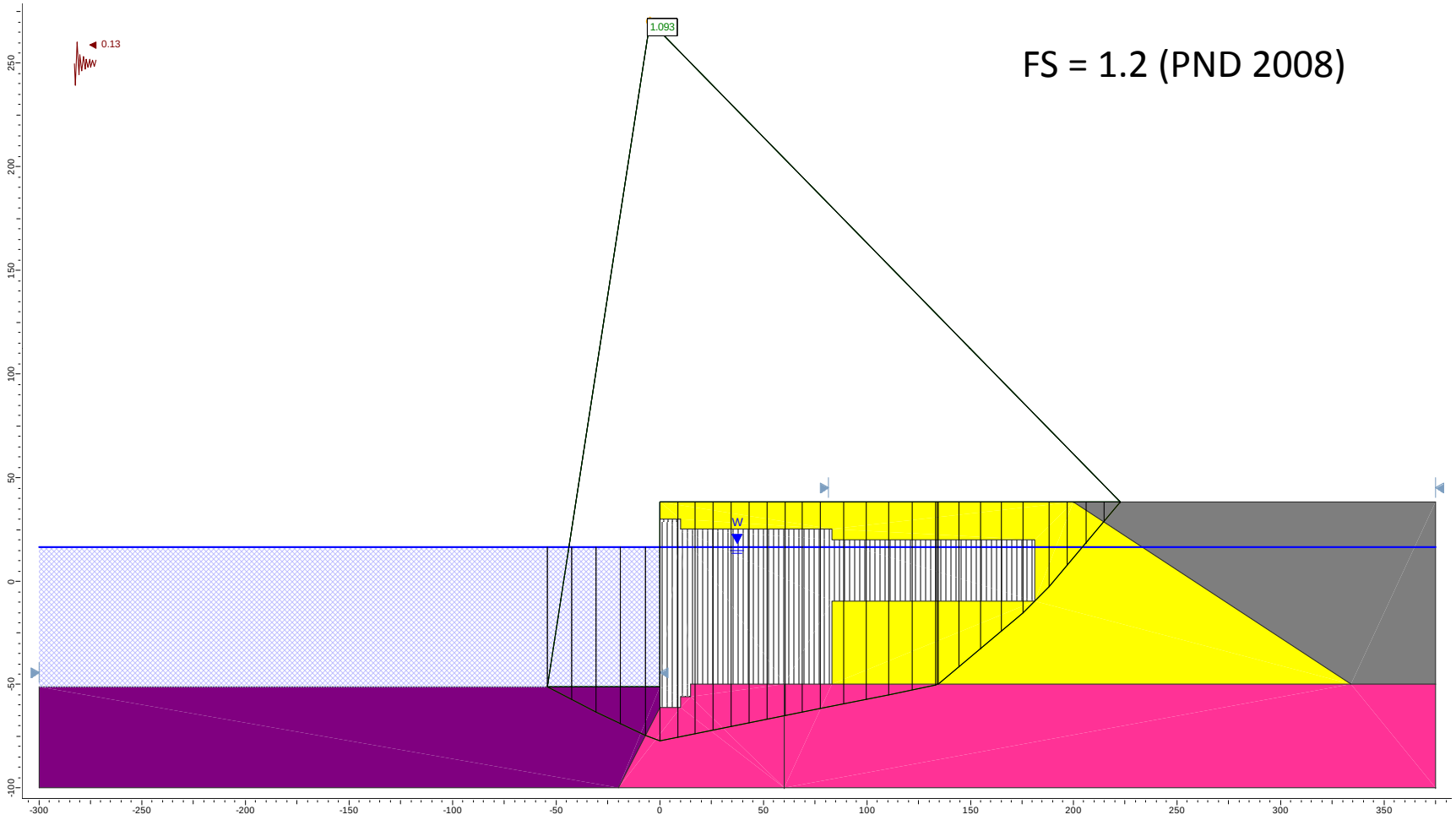


Figure E48. Re-analyzing the MCE case for Section F using Slide (2-clay, optimized surface).

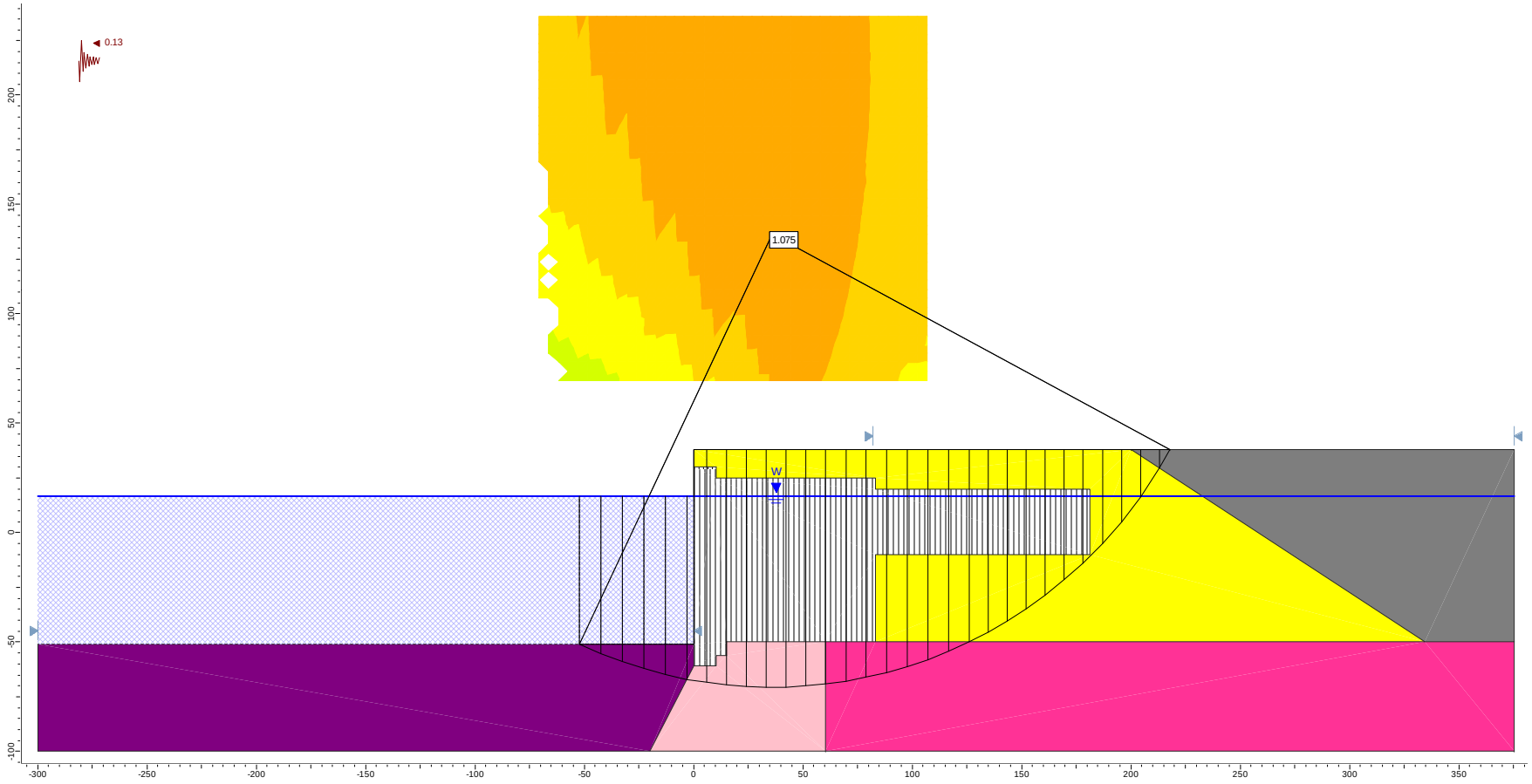


Figure E49. Re-analyzing the MCE case for Section F using Slide (3-clay, circular surface).

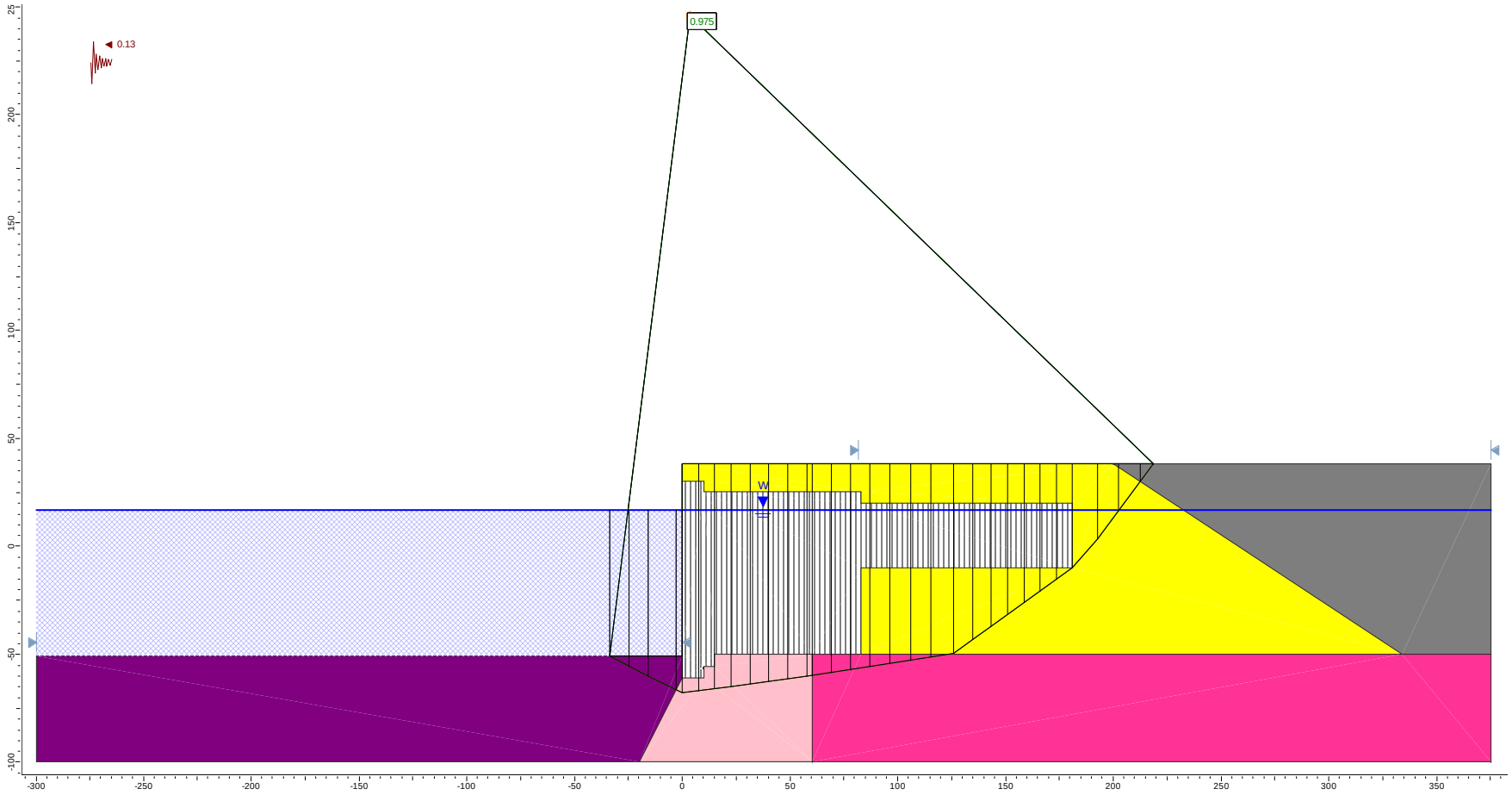


Figure E50. Re-analyzing the MCE case for Section F using Slide (3-clay, optimized surface).

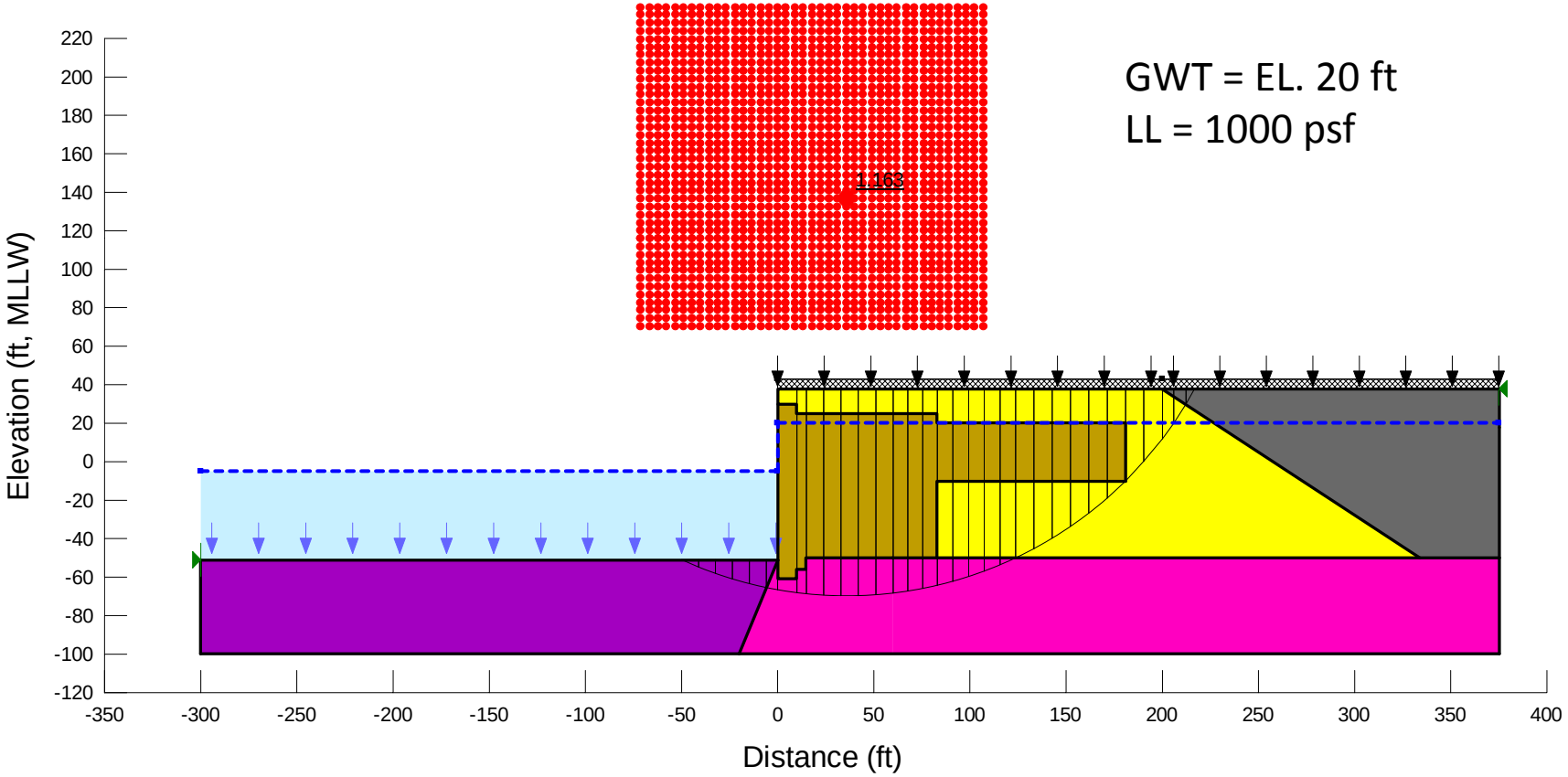


Figure E51. Re-analyzing the short-term static (EOC) case for Section F using SLOPE/W (2-clay, circular surface).

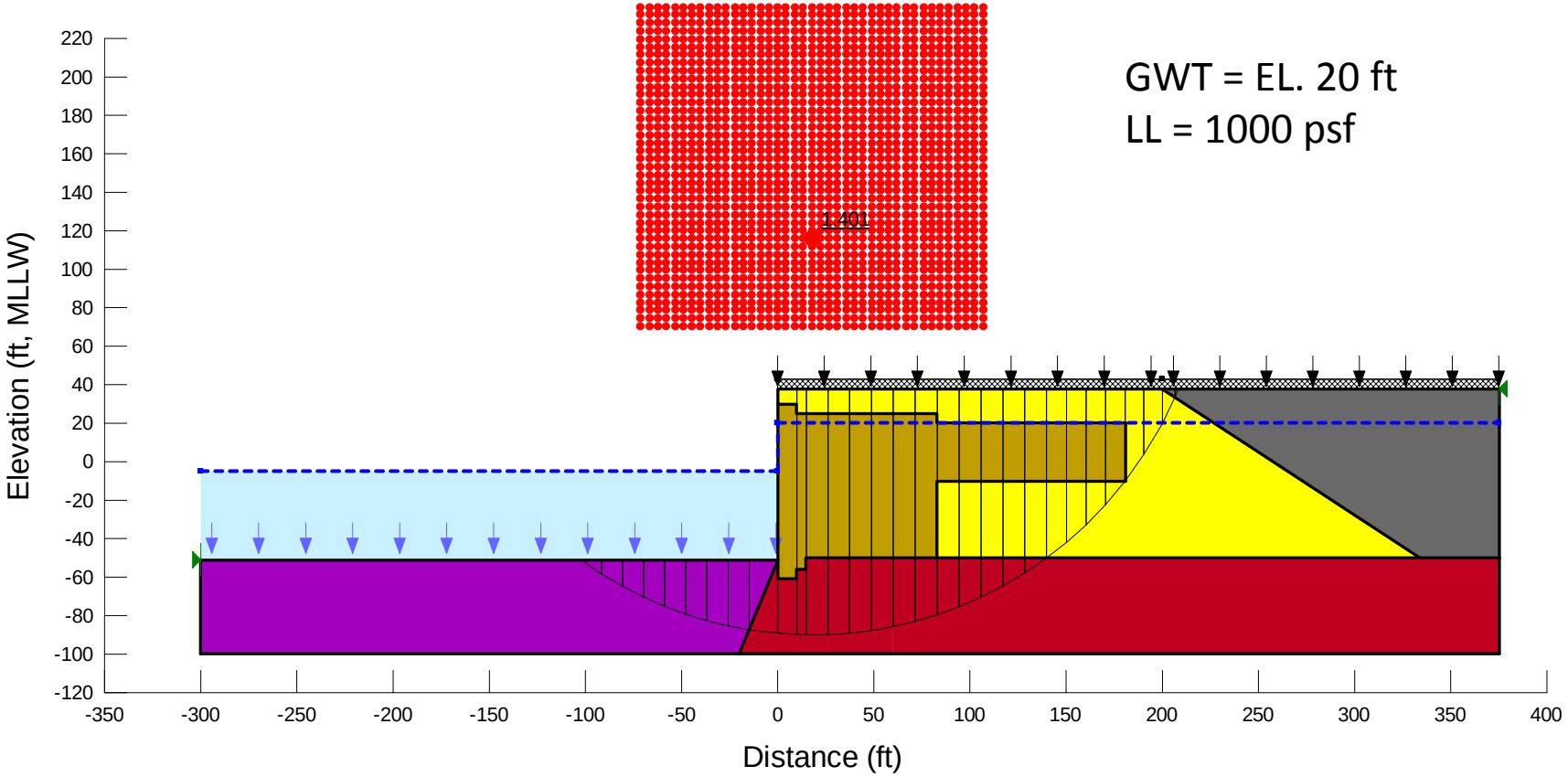


Figure E52. Re-analyzing the long-term static case for Section F using SLOPE/W (2-clay, circular surface).

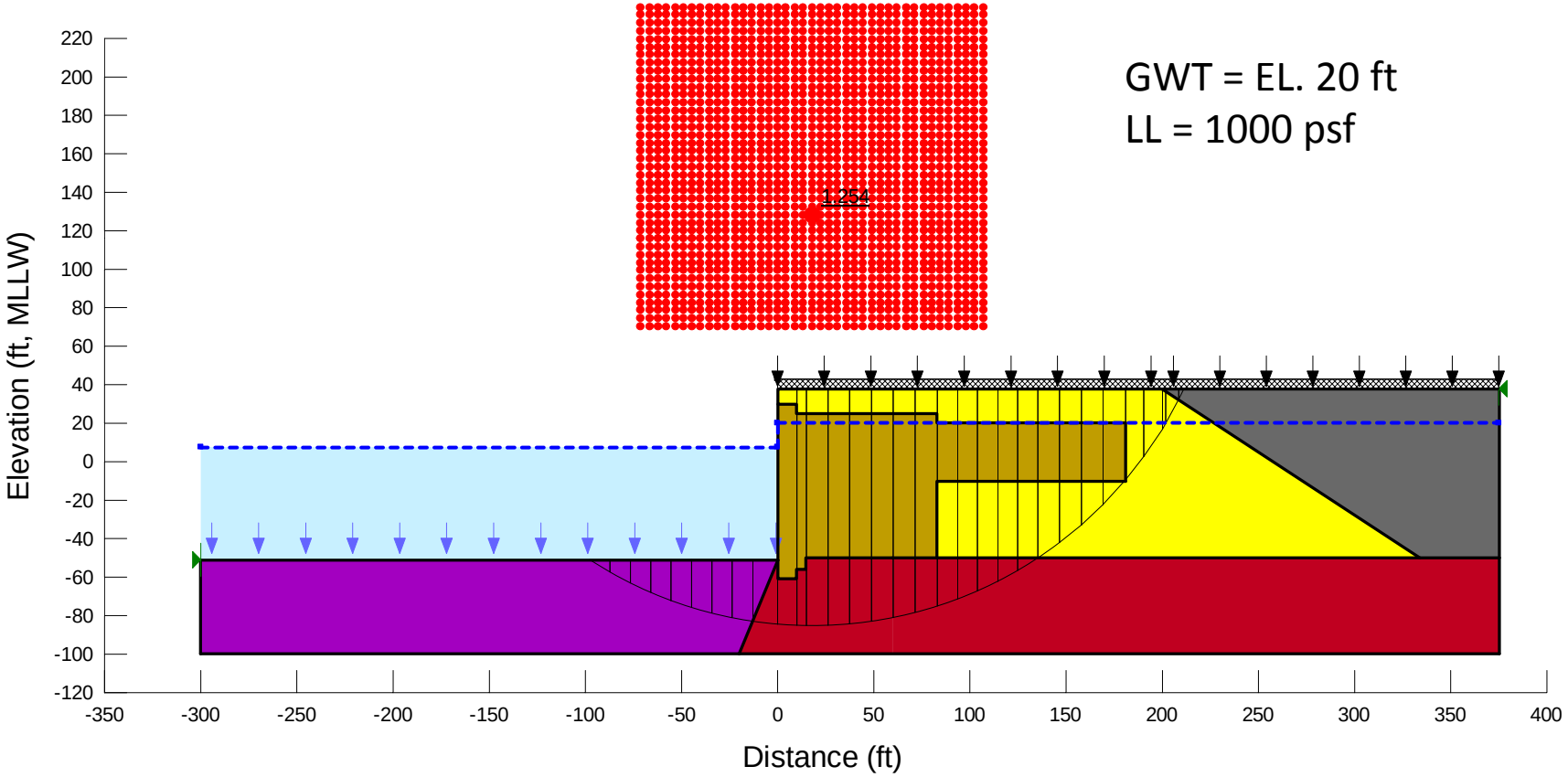


Figure E53. Re-analyzing the OLE case for Section F using SLOPE/W (2-clay, circular surface).

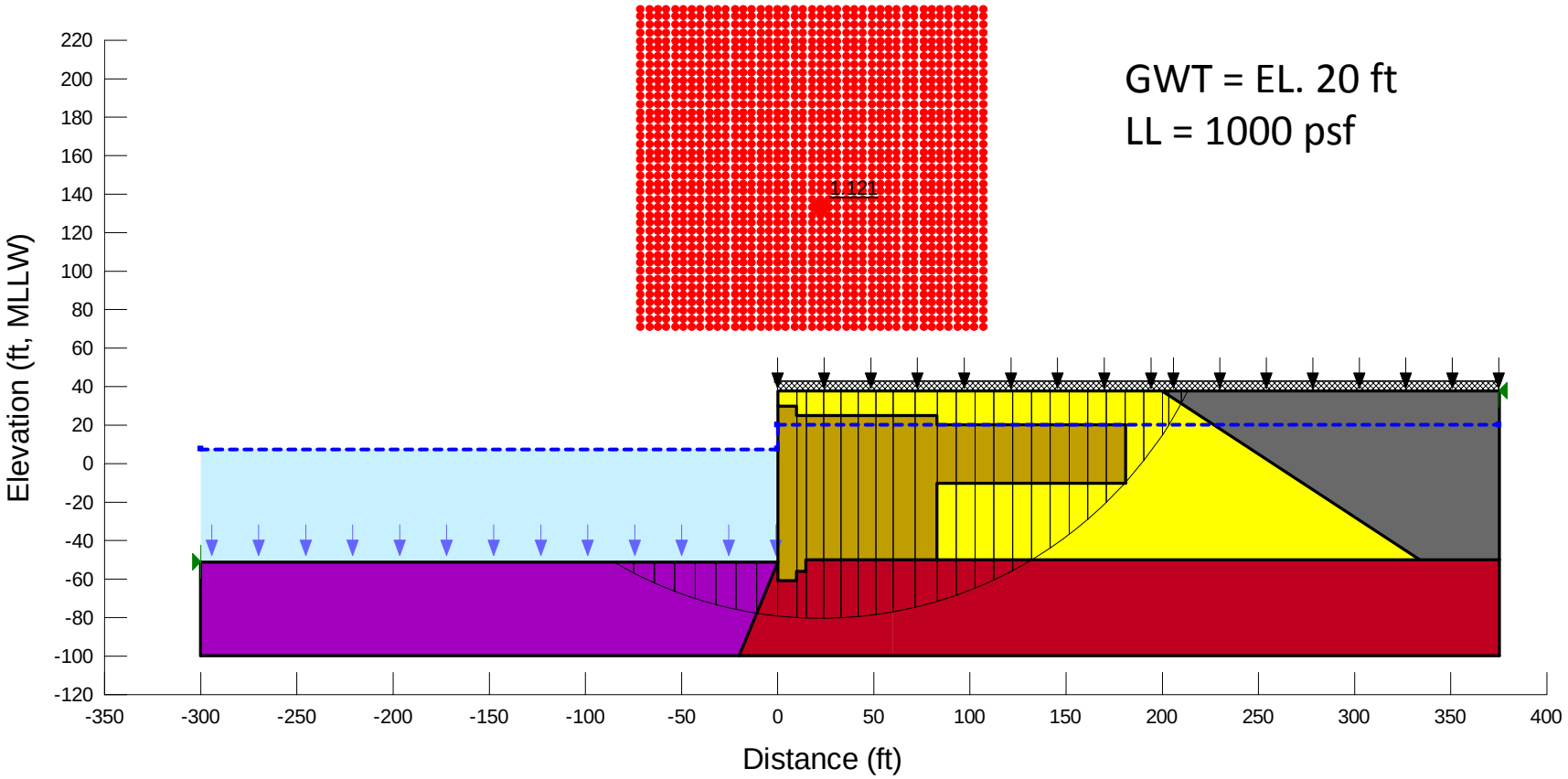


Figure E54. Re-analyzing the CLE case for Section F using SLOPE/W (2-clay, circular surface).

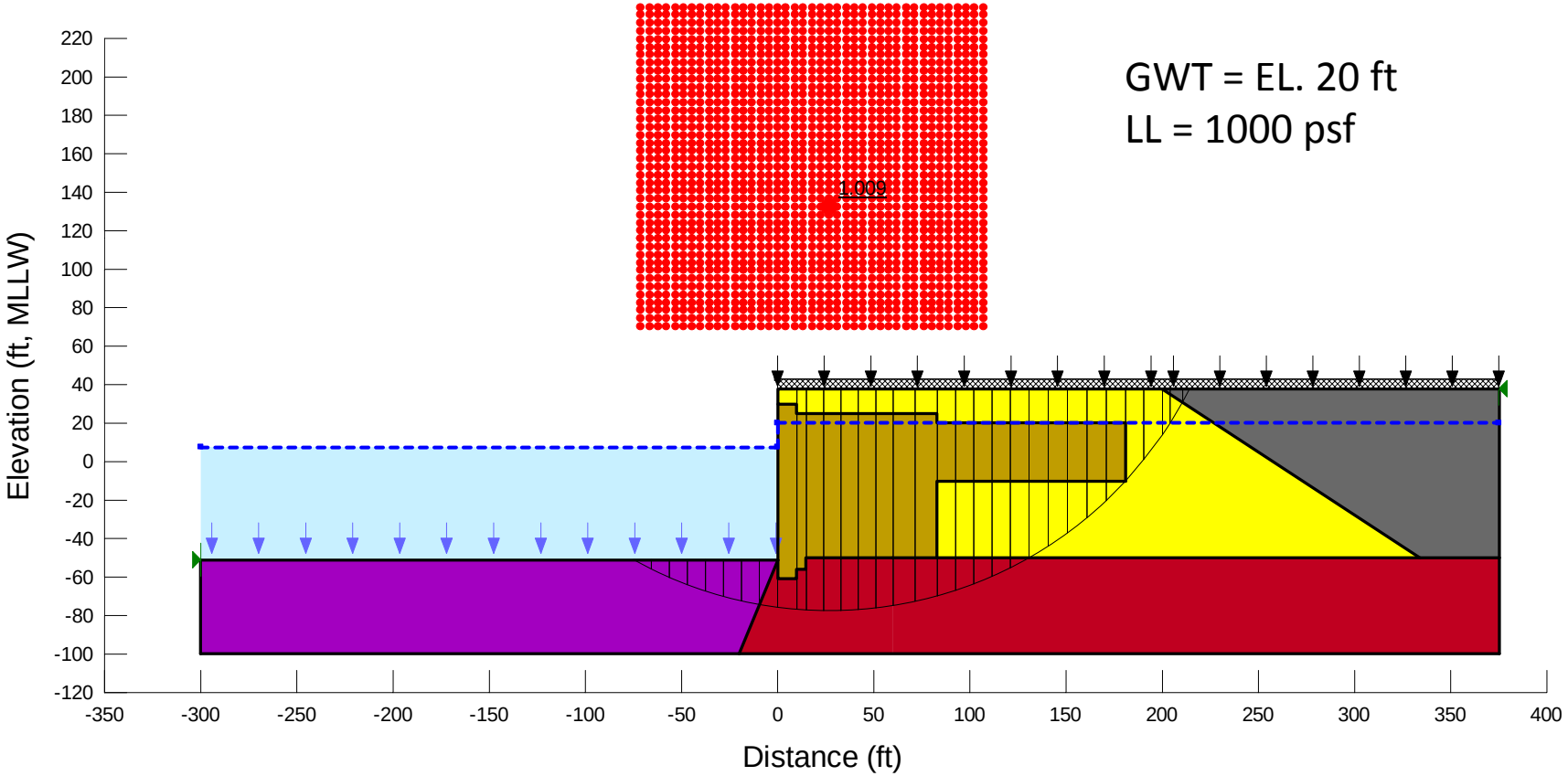


Figure E55. Re-analyzing the MCE case for Section F using SLOPE/W (2-clay, circular surface).

Load Case	Factor of Safety (FS)				
	As Reported by PND (2008)	Circular Slip Surface		Non-Circular Slip Surface	
		SLOPE/W	Slide	SLOPE/W	Slide
End-of-construction	1.31	1.23	1.40	1.10	1.21
Long-term Static-Undrained	1.48	1.50	1.53	1.34	1.35
OLE	1.60	1.39	1.58	1.32	1.40
CLE	1.30	1.22	1.37	1.16	1.23
MCE	1.20	1.07	1.19	1.03	1.09

Figure E56. Summary of results for Section F obtained from the 2-zone model (TXE and TXC).

Load Case	Factor of Safety (FS)				
	As Reported by PND (2008)	Circular Slip Surface		Non-Circular Slip Surface	
		SLOPE/W	Slide	SLOPE/W	Slide
End-of-construction	1.31	1.11	1.28	0.98	1.10
Long-term Static-Undrained	1.48	1.34	1.39	1.19	1.18
OLE	1.60	1.21	1.43	1.13	1.25
CLE	1.30	1.04	1.24	1.04	1.11
MCE	1.20	0.92	1.08	0.92	0.98

Figure E57. Summary of results for Section F obtained from the 3-zone model (TXE, DSS and TXC).

Load Case	Percent Decrease in Factor of Safety When Using Non-Circular Slip Surface (%)			
	2-zone Model		3-zone Model	
	SLOPE/W	Slide	SLOPE/W	Slide
End-of-construction	12	16	13	16
Long-term Static-Undrained	12	13	13	18
OLE	5	13	7	14
CLE	5	11	0	12
MCE	4	9	0	10

Figure E58. Effect of the shape of the slip surface on FS values.

Load Case	Percent Decrease in Factor of Safety When Using 3-zone Model for the BCF Clay (%)			
	Circular Slip Surface		Non-Circular Slip Surface	
	SLOPE/W	Slide	SLOPE/W	Slide
End-of-construction	11	9	12	10
Long-term Static-Undrained	12	10	13	14
OLE	15	10	17	12
CLE	17	10	12	11
MCE	16	10	12	11

Figure E59. Effect of the shear strength of the BCF clay on FS values.

Load Case	Percent Decrease in Factor of Safety When Combining Non-Circular Slip Surface and 3-zone Model for the BCF Clay (%)	
	SLOPE/W	Slide
End-of-construction	26	27
Long-term Static-Undrained	26	30
OLE	23	26
CLE	17	23
MCE	16	21

Figure E60. Combined effect of slip surface shape and the shear strength of the BCF clay on FS values.

Load Case	Factor of Safety (FS)		
	PND (2008)	CH2M HILL (2012)	Decrease (%)
OLE	1.60	1.39	15
CLE	1.30	1.22	7
MCE	1.20	1.07	12

Figure E61. Effect of water levels on FS values.

Conclusions:

1) **Using the same assumptions by PND (i.e., circular slip surface and 2-zone model), the FS values calculated by CH2M HILL for Section F using SLOPE/W were either equal or lower than those reported by PND (2008).**
2) **The FS values decreased from zero to 18% when the a non-circular slip surface was assumed.**
3) **The FS values decreased from 9% to 17% when a 3-zone model that considers TXC-, DSS-, and TXE-based shear strengths was used for the BCF clay.**
4) **When combining both non-circular slip surface assumption with the 3-zone model, the FS values decreased from 16% to 30%.**
5) **When using the CH2M HILL's assumption regarding the water levels during seismic events, the FS values decreased from 7% to 15%.**