APPENDIX H

STABILITY EVALUATION

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STABILITY EVALUATION

Golder conducted local and global stability analyses to evaluate the stability of the proposed tailings facility for the Piñon Ridge Project. This appendix presents the stability evaluations in detail.

DESIGN SECTIONS

For the global stability analyses, three cross-sections (see Figures 2 through 4 in Appendix H-1) were developed to represent a typical section through a tailings cell at three critical points in time:

- *End of Construction* – This phase represents the geometry after cell construction, but prior to any filling of the cells. The exposed 3H:1V interior cell slopes results in this being the critical phase in terms of stability. External embankment slopes are 5H:1V.

- *Post Tailings Deposition* – This phase represents the geometry after full tailings deposition, but prior to any cover placement. The cell geometry is the same except for the presence of the tailings. The tailings act to buttress the exposed slopes in the previous phase, increasing the overall stability.

- *Post Closure* – This phase represents the geometry after a cover has been placed over the tailings cells at closure. External embankment slopes are 10H:1V per closure requirements, and the mound geometry is assumed to extend this slope over the deposited tailings. Eight feet of loosely compacted cover fill was assumed to cap the mound.

For each case, the cell foundation was conservatively assumed to consist entirely of overburden soils even though bedrock is expected in some locations based on the geotechnical investigations.

MATERIAL PROPERTIES

The material properties used in the analyses were selected based on the results of laboratory testing. The properties of the various materials used in the stability model are discussed below:

- *Overburden Soil* - The overburden soil was modeled with a total unit weight of 107 pounds per cubic foot (pcf) based on average measurements of several in-situ soil samples. The friction angle (33.7 degrees) and cohesion (0 psf) were modeled as the lowest measured effective strength properties from two consolidated-undrained (CU) triaxial tests conducted on undisturbed samples of foundation soil.

- *Structural Fill* - Structural fill was modeled with a total unit weight of 120 pcf based on average measurements of native soil samples remolded to 95 percent of the standard Proctor maximum dry density (ASTM D698). The friction angle (30.3 degrees) and cohesion (0 psf) were modeled as the lowest measured effective strength properties from two consolidated-undrained (CU) triaxial tests conducted on remolded samples of native soil.

- *Tailings (slurry)* - Based on Golder's past experience with freshly deposited tailings, a friction angle of 20 degrees and a cohesion of 0 psf were assumed for the tailings in slurry form. These properties were used for the post deposition scenario as the tailings would have had insufficient time for complete consolidation. The total unit weight is assumed to be 120 pcf.

- *Tailings (consolidated)* - Based on Golder's past experience with consolidated tailings, a friction angle of 28 degrees and a cohesion of 0 psf were assumed for the tailings in consolidated (i.e., dewatered) form. These properties were used for the post closure scenario as the tailings would likely have had sufficient time to consolidate. The total unit weight is assumed to be 120 pcf.

- *Miscellaneous Fill* - Miscellaneous fill refers to the fill resulting from the excavation and disposal of the evaporation ponds, ore pad, and other contaminated soils requiring disposal and encapsulation at closure. The stability analyses assume the strength properties of the miscellaneous fill to be the same as those for the consolidated tailings, with a slightly lower total unit weight (110 pcf).

- *Cover Fill* - Compaction effort applied to the cover fill is expected to be light in order to enhance vegetative growth, so a reduced total unit weight of 100 pcf was used assuming approximately 80 to 85 percent of the standard Proctor maximum dry density. A friction angle of 23 degrees with zero cohesion was assumed.

- *Liner Interface* - Interface friction testing revealed the weakest interface to be that between the proposed textured geomembrane and the drainage geocomposite material (specifically, 60 mil textured HDPE geomembrane versus CETCO Texdrain 250 DS 6 Geocomposite) with a peak friction angle of 21.2 degrees and associated residual friction angle of 14.8 degrees. The global stability analyses were conducted using the peak friction angle, and checked to ensure a safety factor in excess of one using the residual friction angle, per the recommendations of Gilbert (2001). The minimum residual friction angle does not necessarily correspond to the minimum tested residual friction angle (i.e., textured geomembrane versus GCL), but instead that which corresponds to the minimum peak friction angle (Gilbert, 2001). The small amounts of apparent adhesion were conservatively ignored, using a value of zero in the stability analyses.

PHREATIC LEVELS

As the water table below the site is substantially below the zone of interest in the stability analysis (i.e., greater than 450 ft below the ground surface), the only relevant phreatic surface will be that contained with the tailings cell by the cell liner as a result of tailings deposition (during operations). At the end of construction, the cell is empty, so no phreatic surface was modeled for the first phase. Post-deposition, the phreatic surface was assumed to be at the surface of the tailings, affecting the tailings slurry material and the liner interface. Post-closure, the tailings are assumed to consolidate with the phreatic surface remaining at the tailings surface.

METHOD OF ANALYSES

For all failure mechanisms considered in the analyses, slope stability was evaluated using limit equilibrium methods based on Spencer’s method of analysis (Spencer’s method) (Spencer, 1967). Spencer’s method is a method of slices (referencing the analysis' consideration of potential failure masses as rigid bodies divided into adjacent regions or "slices," separated by vertical boundary planes). It is based on the principle of limiting equilibrium, i.e., the method calculates the shear strengths that would be required to just maintain equilibrium along the selected failure plane, and then determines a "safety factor" by dividing the available shear strength by the required shear strength. Consequently, safety factors calculated by Spencer’s, or by any other limiting equilibrium method, indicate the percentage by which the available shear strength exceeds, or falls short of, that required to maintain equilibrium. Therefore, safety factors in excess of 1.0 indicate stability and those less than 1.0 indicate instability, while the greater the mathematical difference between a safety factor and

1.0, the larger the "margin of safety" (for safety factors in excess of 1.0), or the more extreme the likelihood of failure (for safety factors less than 1.0). While there are other more rigorous methods that can be used to evaluate slope stability, Spencer's method was selected to be consistent with the current level of knowledge of the material shear strength parameters.

The seepage and stability analyses were conducted using *SLIDE 5.0*, a commercially available computer program (Rocscience, 2000), and the input parameters presented herein. For accurate modes of failure, Spencer's method was used to determine the least stable failure surface via the critical surface search routine, i.e., for each failure mode, the program iterates through a variety of failure surfaces to determine the surface with the minimum safety factor, otherwise referred to as the critical surface.

LOADING CONDITIONS

The stability analyses considered both static and earthquake-induced (i.e., pseudo-static) stress conditions. Static loading considers only the stress of the soil and tailings deposited at the designed slopes. For the tailings impoundment design, the design criteria provides for a minimum factor of safety of 1.5 under static loading conditions, per the industry standard of practice.

Earthquake (seismic) loading conditions were simulated using a pseudo-static approach. Pseudo-static-based analyses are commonly used to apply equivalent seismic loading on earthfill structures. In an actual seismic event, the peak acceleration would be sustained for only a fraction of a second. Actual seismic time histories are characterized by multiple-frequency attenuating motions. The accelerations produced by seismic events rapidly reverse motion and generally tend to build to a peak acceleration that quickly decays to lesser accelerations. Consequently, the duration that a mass is actually subjected to a unidirectional, peak seismic acceleration is finite, rather than infinite. The pseudo-static analyses conservatively model seismic events as constant acceleration and direction, i.e., an infinitely long pulse. Therefore, it is customary for geotechnical engineers to take only a fraction of the predicted peak maximum acceleration when modeling seismic events using pseudo-static analyses. Typically a factor of safety of 1.0 is considered appropriate for water retention embankments (i.e., critical structures) when the structures are modeled using one-half the peak ground acceleration generated from the maximum credible earthquake (Hynes & Franklin, 1984). A twenty (20) percent strength reduction factor is often applied to any fine-grained materials that are susceptible to strain softening resulting from a build-up in pore water pressures (Hynes &

Franklin, 1984). For these analyses, no materials were assumed to exhibit strain softening characteristics.

The pseudo-static coefficient for the stability analyses was developed by Kleinfelder (2008) for this evaluation based on the 2006 International Building Code (IBC). This seismicity analysis concluded that the peak ground acceleration (PGA) for the maximum considered earthquake (MCE) is 0.161g. The peak ground acceleration for the design earthquake is 0.107g. Hence, the pseudo-static acceleration used in the stability analyses for the pre- and post-deposition cases was 0.05g, or approximately one-half of the design earthquake PGA. For the post-closure case, a pseudo-static acceleration of 0.08g was used, or approximately one-half of the MCE PGA. For the tailings impoundment design, the design provides for a minimum factor of safety of 1.1 under pseudo-static loading conditions, per industry standard of practice.

RESULTS OF ANALYSES

The limit equilibrium stability analyses yielded the estimated minimum safety factors summarized in Table H-1 for static stability analyses and pseudo-static stability analyses for all three scenarios. As indicated, the stability analyses show that the static and pseudo-static critical failure surfaces have factors of safety greater than the minimum values set forth in the design criteria.

LINER STABILITYANALYSIS

In addition to the stability analyses discussed above, a separate simplified analysis was conducted to estimate the factor of safety of the liner system under its own weight. Interface shear testing of the liner system, presented in Appendix H-1, indicates that the textured HDPE versus the drainage geocomposite exhibits the lowest peak shear strength. Analyses of the liner system stability, presented in Appendix H-2, conservatively assumes that the liner slope is infinitely long (i.e., effects of the anchor trench, benches and buttressing were ignored) per the approach proposed by Das (1998), as well as ignores the effects of apparent adhesion along the interface. This simplified analysis results in a factor of safety against sliding of the liner system of 1.2.

REFERENCES

Das, Braja M. 1998. *Principles of Geotechnical Engineering, 4th Edition*. PWS Publishing Company, Boston.

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TABLE H-1

RESULTS OF STABILITY EVALUATION

Scenario	Minimum Static Factor of Safety [Peak (Residual)]	Minimum Pseudo-Static Factor of Safety [Peak (Residual)]
Pre-Deposition	2.0 (1.9)	1.7 (1.7)
Post-Deposition	3.0 (3.0)	2.4 (2.4)
Post-Closure	4.9 (4.4)	2.7 (2.3)

APPENDIX H-1

GLOBAL STABILITY EVALUATION

OBJECTIVES:

- Evaluate the global stability of the proposed Tailings Cells at the most critical cross section for the following three scenarios:
  - After construction of the cells, but prior to tailings deposition (pre deposition);
  - After tailings deposition to the design fill height within the cell (post deposition); and
  - After placement of closure cover and 10H:1V grading (post closure).

GIVEN:

- Topography for the original ground surface and proposed tailings cells grading plan (Figure 1).
- Underlying stratigraphy from nearby boreholes.
- Laboratory strength test results for recompacted native soils (GA-TP-07, GA-TP-09) and in-situ native soils (GA-BH-42, GA-BH-47) (Attachment 1).
- Liner interface friction properties from laboratory tests for the following interfaces, which represent the tailings cell liner configuration: (1) textured geomembrane vs. geocomposite; (2) textured geomembrane vs. GCL; (3) GCL vs. subgrade (Attachment 2).
- Peak ground acceleration (A_{peak}) for the design earthquake is 0.107g (Kleinfelder, 2008).
- Peak ground acceleration (A_{peak}) for the maximum considered earthquake (MCE) is 0.161g (Kleinfelder, 2008).

ASSUMPTIONS:

- The critical cross sections identified for the stability evaluation are shown in Figures 2 through 4 for the pre deposition, post deposition, and post closure scenarios, respectively.
- Water is assumed to be absent for the pre deposition case. For the post deposition and post closure scenarios, the water surface is assumed to be at the tailings surface and affect only the tailings and liner interface layers.
- Shallow (< 15 feet) veneer failure surfaces are ignored.
- Use pseudo-static model to evaluate the seismic stability. Check stability using a horizontal load coefficient of $\frac{1}{2}A_{peak}$, where the design earthquake applies to the pre deposition and post deposition scenarios ($\frac{1}{2}A_{peak}$ = 0.05g), and the MCE applies to the post closure scenario ($\frac{1}{2}A_{peak}$ = 0.08g) (Hynes & Franklin, 1984).
- Minimum acceptable factor of safety (FS) for static conditions is 1.5 per the design criteria.
- Minimum acceptable FS for seismic conditions is 1.1 per the design criteria.
- Minimum acceptable FS for residual strength analysis is 1.0 per Gilbert, 2001.
- The liner is assumed to be a 1-foot thick material layer with the peak and residual strength properties associated with the liner interface with the lowest peak shear strength (geomembrane-geocomposite) as per Gilbert (2001).
- The internal shear strength of the individual material components is assumed to be greater than the geomembrane-geocomposite interface strength.
- The overburden soil is sufficiently deep not to warrant the inclusion of bedrock materials in these analyses.
- Minimum thickness of closure cover soils is 8 feet.

MATERIAL PROPERTIES:

- The material parameters used in the stability analyses are summarized in Table 1.

Table 1 – Material Properties

Material	Unit Weight (pcf)	Friction Angle (deg)	Cohesion (psf)	Source
Overburden Soil	107	33.7	0	Lowest undisturbed triaxial test results (GA-BH-47)
Structural Fill	120	30.3	0	Lowest of remolded triaxial test results (GA-TP-07)
Tailings (slurry)(1)	120	20	0	Assumed based on past tailings experience
Tailings (consol)(2)	120	28	0	Assumed based on past tailings experience
Misc. Fill	110	28	0	Assumed same as consolidated tailings
Cover Fill	100	23	0	Assumed – light compaction on native soils
Liner Interface (peak)(3)	110	21.2	0	Lowest peak strength from interface shear testing (geomembrane-geocomposite)
Liner Interface (residual)(3)	110	14.8	0	Residual strength associated with geomembrane-geocomposite interface

(1) Tailings (slurry) properties used for post deposition scenario.
(2) Tailings (consol) properties used for post closure scenario.
(3) Two sets of analyses were conducted: one using the peak interface shear strength and one using the residual interface shear strength.

METHOD:

- Stability analyses were performed with RocScience's limit equilibrium program SLIDE. Minimum factors of safety were evaluated using the program's search algorithm and calculations based on the Spencer method.
- Both circular and non-circular (block) failure surfaces were analyzed for the critical cross sections.
- The three aforementioned scenarios (pre deposition, post deposition, and post closure) were evaluated for stability. Loading stages intermediate to these scenarios were not evaluated.
- Both the peak and residual strengths of the liner system are governed by the liner interface with the weakest peak strength (Gilbert, 2001). Consequently, the liner was modeled using the interface strength properties associated with the geomembrane-geocomposite interface.
- While determining the stability of the tailings cell, the critical failure surfaces were typically block failure surfaces located primarily along the liner. However, circular potential failure surfaces and other block potential failure surfaces through all materials were checked.
- Shallow veneer potential failure surfaces less than 15 feet deep were not considered critical to the stability of the structure.

CALCULATIONS:

- The SLIDE stability results are presented in Attachment 3. The global minimum factors of safety are summarized in Table 2. The stability results for each individual analysis are summarized in Tables A3-1 and A3-2 in Attachment 3.

RESULTS:

- The static and seismic analyses for all three cross sections analyzed yield factors of safety which exceed the minimum requirements as shown in Table 2.

Table 2 – Stability Analysis Summary

Scenario	Minimum Static Factor of Safety [peak (residual)]	Minimum Pseudo-Static Factor of Safety [peak (residual)]
Pre Deposition	2.0 (1.9)	1.7 (1.7)
Post Deposition	3.0 (3.0)	2.4 (2.4)
Post Closure	4.9 (4.4)	2.7 (2.3)

- The critical failure mechanism for the pre-deposition scenario (both static and pseudo-static) was found to be a circular failure surface through the upper portion of the tailings cell interior.
- The critical failure mechanism for the post-deposition scenario (both static and pseudo-static) was found to be a circular failure surface through the structural fill on the tailings cell exterior.
- The critical failure mechanism for the post-closure scenario (both static and pseudo-static) was found to be a block (wedge) failure surface with the toe of the failure surface sliding up the liner interface.

CONCLUSIONS

- Based on stability modeling, the factor of safety for the theoretical, worst-case-scenario cross section was found to meet design criteria factors of safety for all scenarios analyzed.
- The lowest factors of safety occur prior to tailings deposition.
- These analyses are considered conservative based on the strength parameters used and assumptions made.

REFERENCES:

Gilbert, R.B. (2001). "Peak Versus Residual Strength for Waste Containment Systems." In *Proceedings of GRI-15: Hot Topics in Geosynthetics II*. Geosynthetics Research Institute, Folsom, PA, 29-39.

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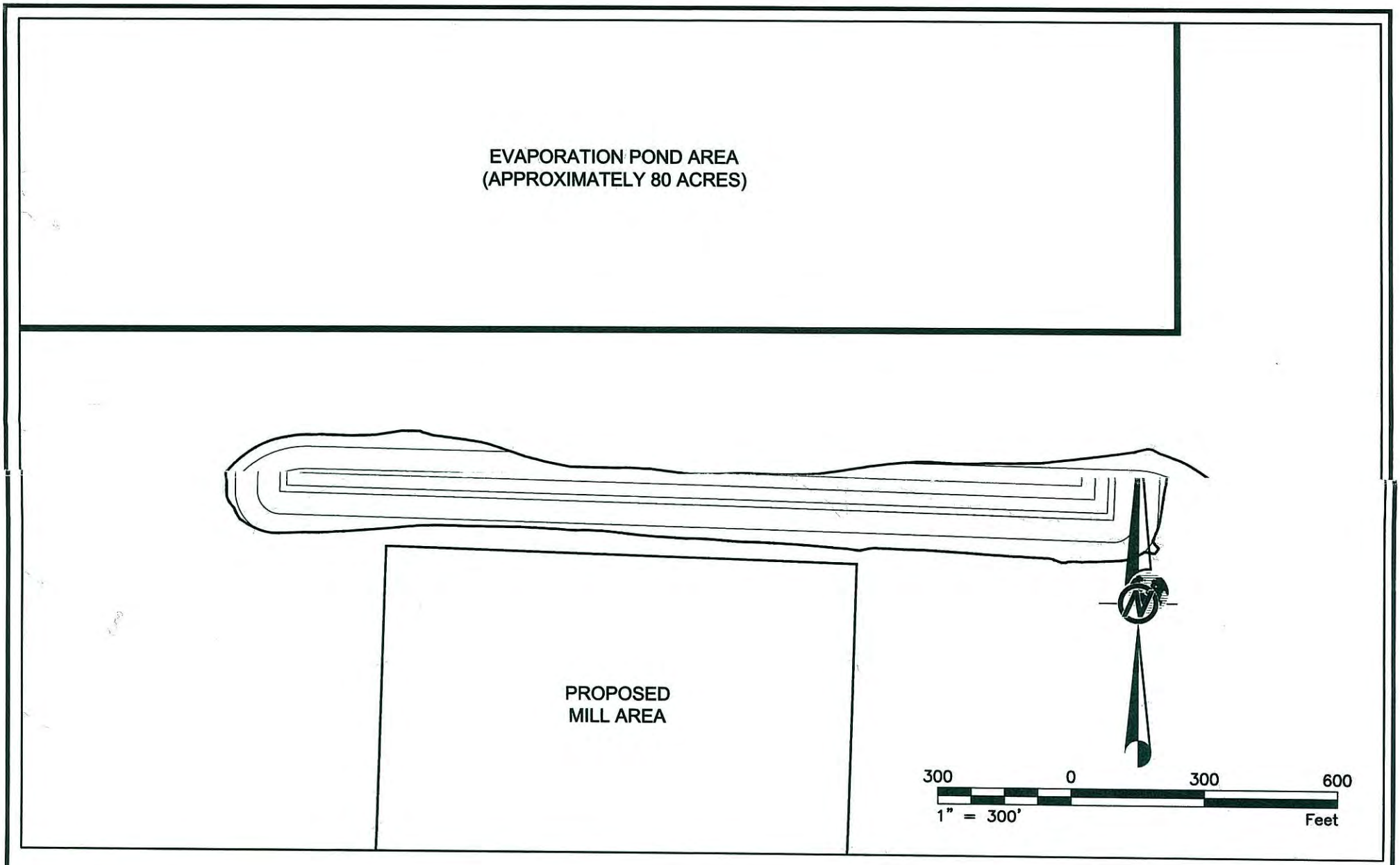
FIGURES



Golder Associates
DENVER, COLORADO

TAILINGS CELL TOPOGRAPHY

FIGURE 1

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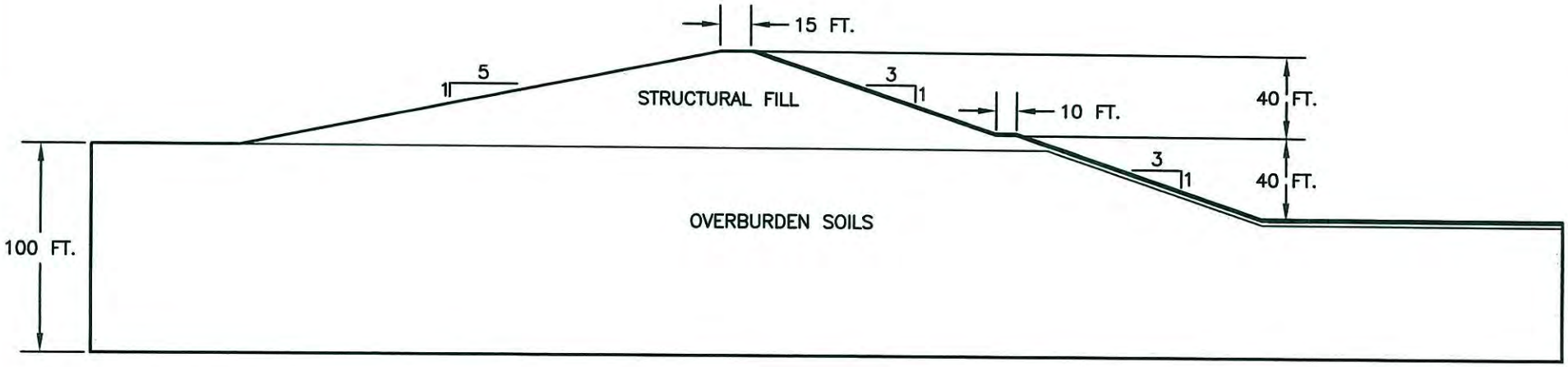

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A	02/08	JDE	STABILITY CALCULATION	JDE	KFM	JMJ

PROJECT ENERGY FUELS RESOURCES CORPORATION
PIÑON RIDGE PROJECT - TAILINGS CELL DESIGN
MONTROSE COUNTY, COLORADO

TITLE

THEORETICAL TAILINGS CELL MAXIMUM CROSS SECTION - PRE DEPOSITION

Golder Associates
DENVER, COLORADO

PROJECT No.		073-81694	FILE No.	MAX SECTION
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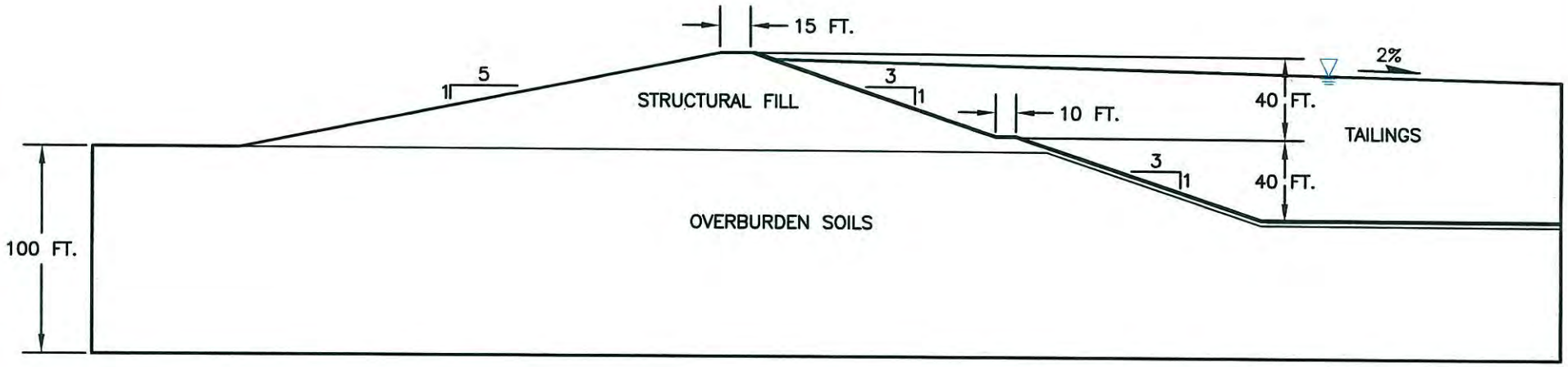

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A	02/08	JDE	STABILITY CALCULATION	JDE	KFM	JMJ

PROJECT ENERGY FUELS RESOURCES CORPORATION
PIÑON RIDGE PROJECT - TAILINGS CELL DESIGN
MONTROSE COUNTY, COLORADO

TITLE

THEORETICAL TAILINGS CELL MAXIMUM CROSS SECTION - POST DEPOSITION

Golder Associates
DENVER, COLORADO

PROJECT No.		073-81694	FILE No.	MAX SECTION
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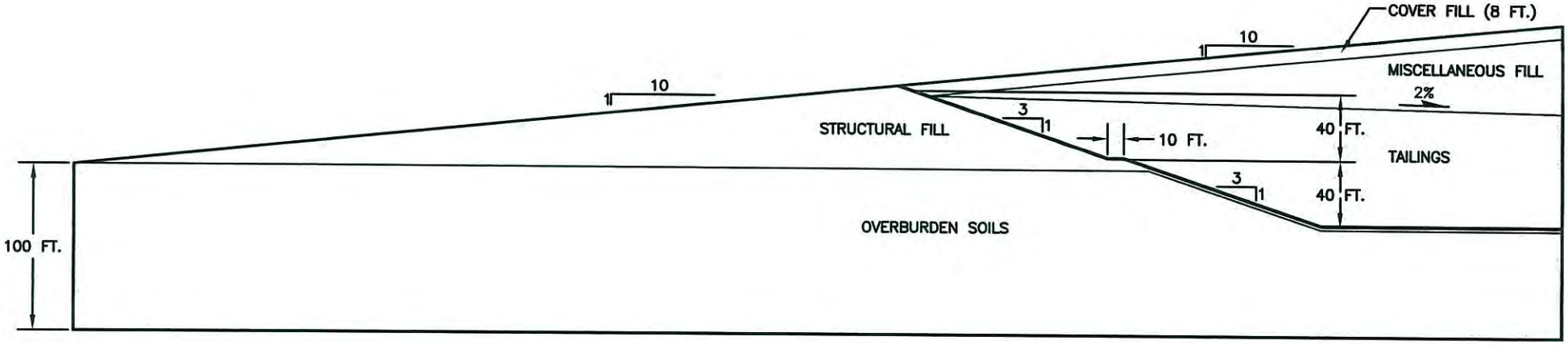

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PROJECT ENERGY FUELS RESOURCES CORPORATION
PIÑON RIDGE PROJECT - TAILINGS CELL DESIGN
MONTROSE COUNTY, COLORADO

TITLE

THEORETICAL TAILINGS CELL MAXIMUM CROSS SECTION - POST CLOSURE

Golder Associates
DENVER, COLORADO

PROJECT No.		073-81694	FILE No.	MAX SECTION
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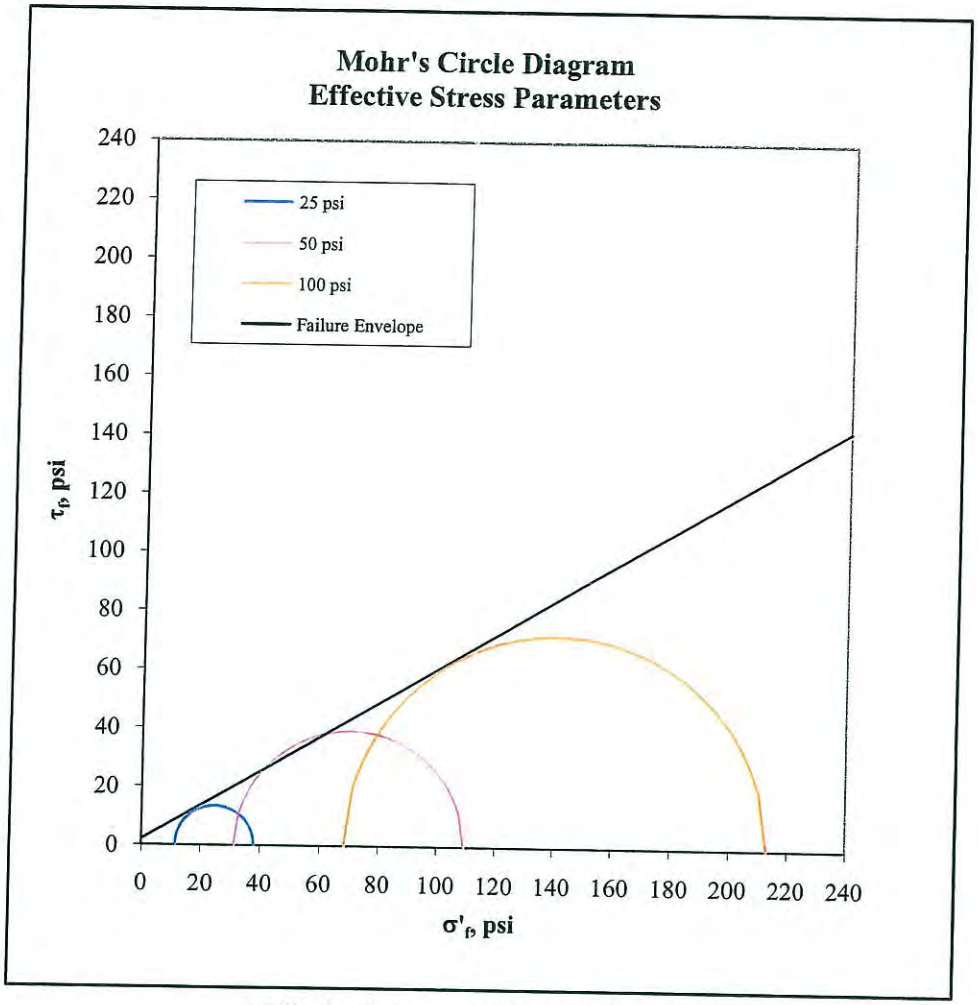
ATTACHMENT 1
LABORATORY TRIAXIAL TEST RESULTS



Effective Stress Shear Strength Parameters

ϕ' = 30.3 degrees
c' = 2.0 psi

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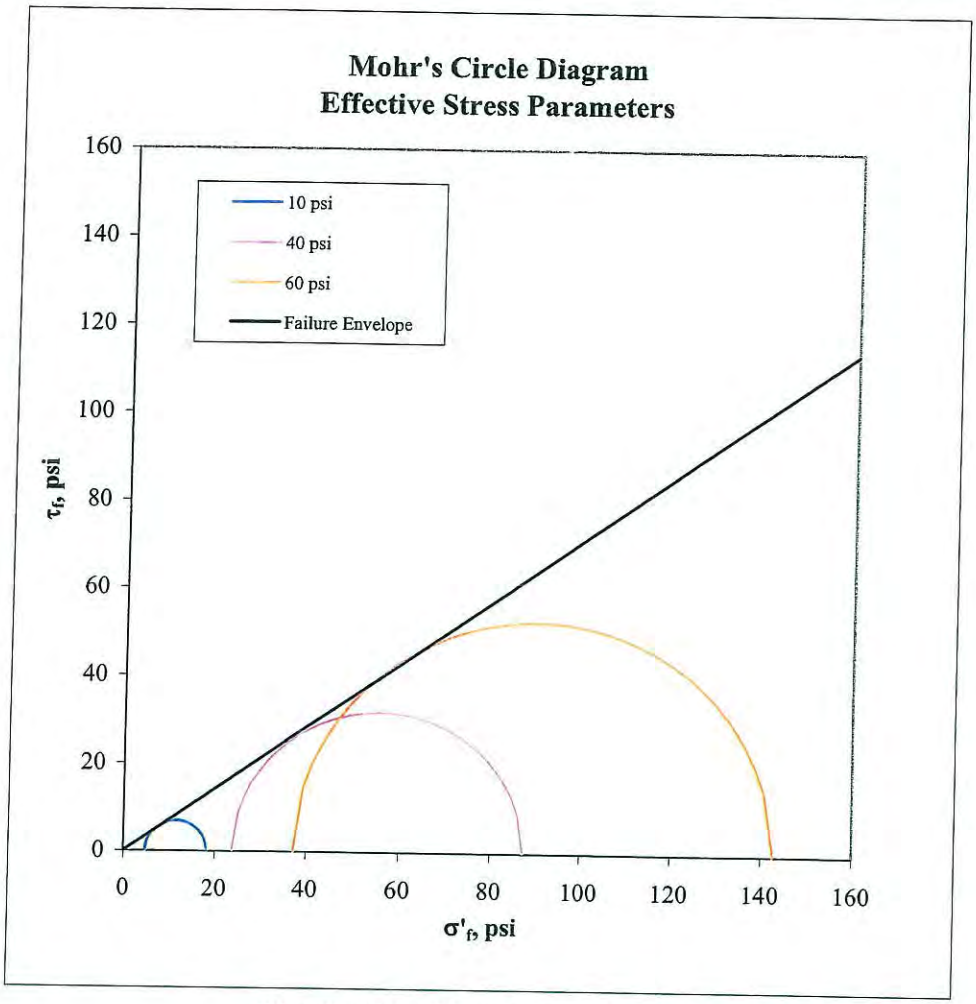
Job Short Title: EFR/Pinon Ridge					
Sample Number: GATP 7 @ 1.5-9	Reviewed: JEO	Date: 1/28/08	Job Number: 073-81694.001	Figure: 1-1	



Effective Stress Shear Strength Parameters

$\phi' =$ 35.5 degrees
$c' =$ 0.0 psi

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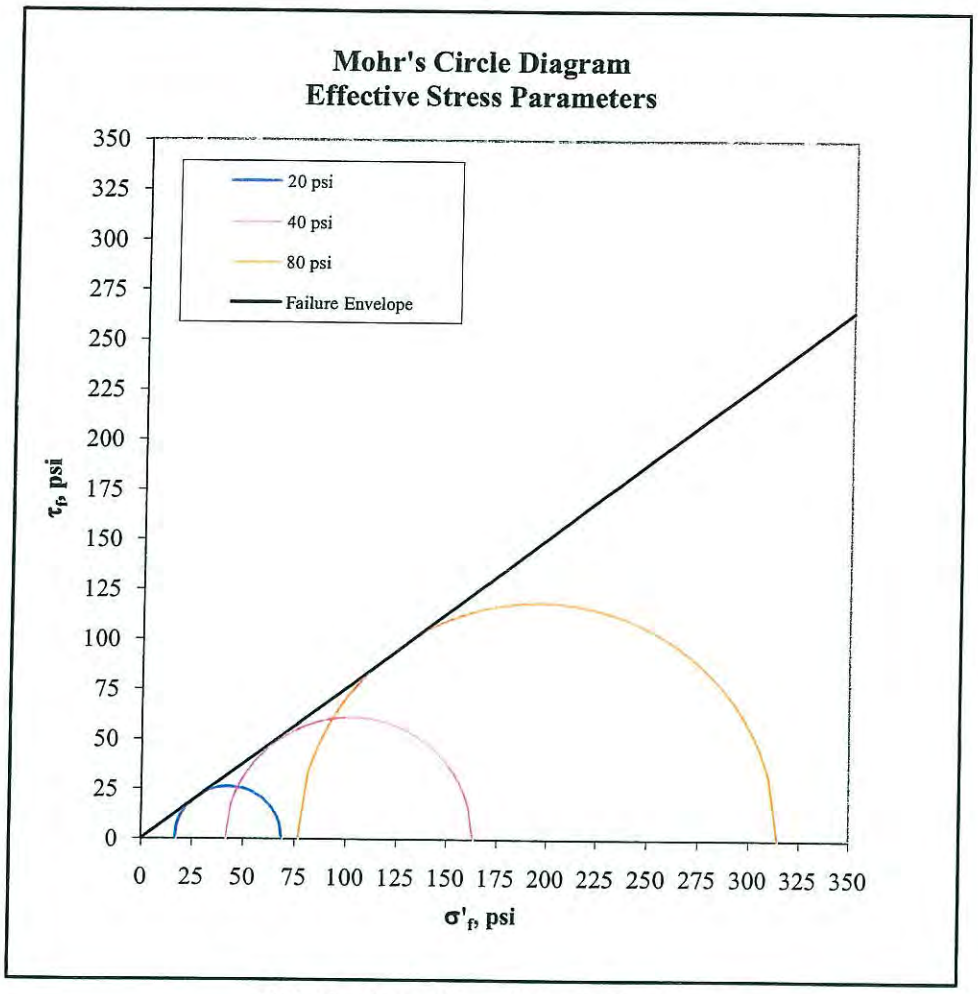
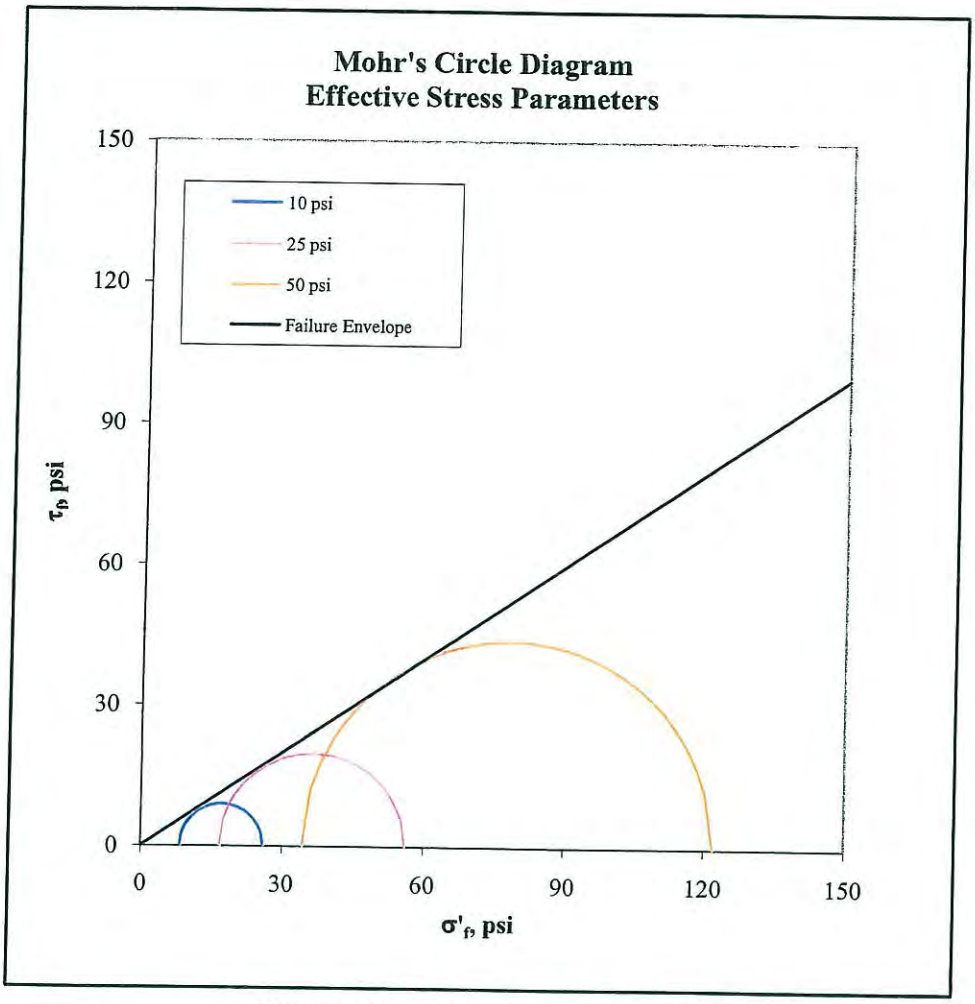
Job Short Title: EFR/Pinion Ridge				
Sample Number: GATP 9 @ 1-11	Reviewed: JEO	Date: 1/18/08	Job Number: 073-81694.001	Figure: 1-2



Effective Stress Shear Strength Parameters

ϕ' = 37.1 degrees
c' = 0.0 psi

Golder Associates, Inc. **Denver, Colorado**	**Title:** **C-U TRIAXIAL SHEAR DATA** **MOHR'S CIRCLE DIAGRAM**			
Job Short Title: Energy Fuels/Geotech Piñon Ridge				
Sample Number: GABH 42 @ 10-11'	**Reviewed:** JEO	**Date:** 2/14/08	**Job Number:** 073-81694	**Figure:** 1-3



Effective Stress Shear Strength Parameters

ϕ' = 33.7 degrees
c' = 0.0 psi

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Job Short Title: Energy Fuels/Geotech Pinon Ridge					
Sample Number: GABH 47 @ 2-3.5'	Reviewed: JEO	Date: 2/11/08	Job Number: 073-81694	Figure: 1-4	

ATTACHMENT 2
LINER INTERFACE SHEAR STRENGTH TESTING

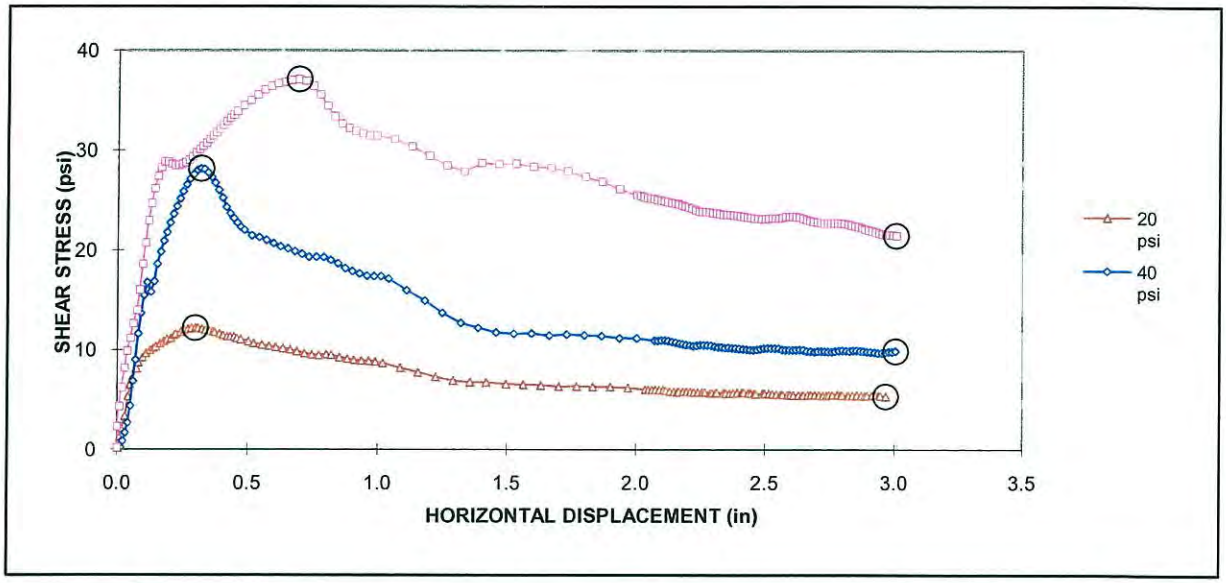
FEBRUARY 2008 073-81694

DIRECT SHEAR TEST RESULTS

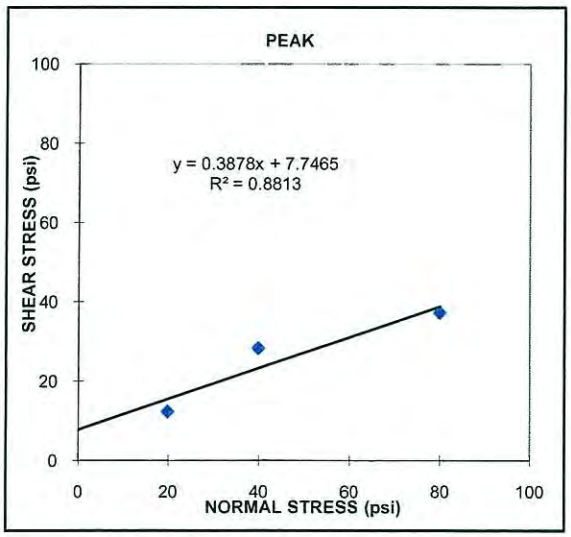
ASTM D5321

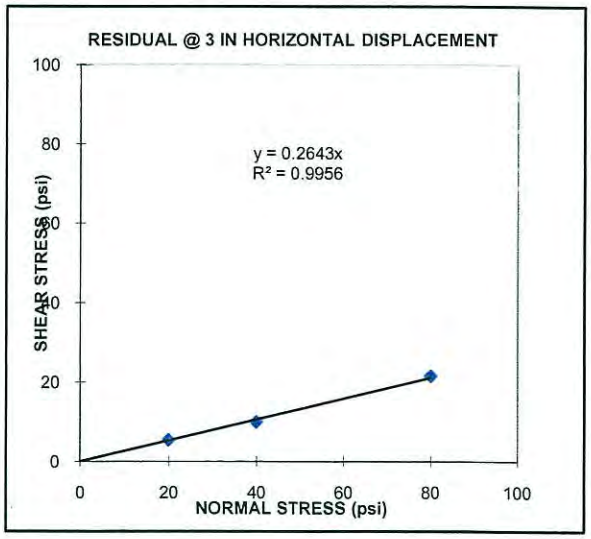
PROJECT NAME: ENERGY FUELS/GEOTECH PINON RIDGE/CO
SAMPLE NUMBER: 1 (GM vs GC)

INTERFACE TESTED: 60 mil TEXTURED HDPE GEOMEMBRANE vs TEXDRAIN 250 DS 6 GEOCOMPOSITE
TEST CONDITIONS: INTERFACES WETTED, CONSOLIDATED 15 min AT NORMAL LOAD
SHEAR RATE: 0.2 in/min
SUBSTRATE: TEXTURED RIGID PLATES



Normal Stress (psi)	Shear Stress Peak[1] (psi)	Shear Stress Residual (psi)	Peak Friction Angle	Peak Adhesion[2] (psi)	Residual Friction Angle	Residual Adhesion[2] (psi)
20	12.2	5.3				
40	28.2	9.9	21.2	7.7	14.8	0.0
80	37.1	21.5				





Observations After Test

20 psi: Shearing occurred at the interface between the Geomembrane and the Geocomposite
40 psi: Shearing occurred at the interface between the Geomembrane and the Geocomposite
80 psi: Shearing occurred at the interface between the Geomembrane and the Geocomposite

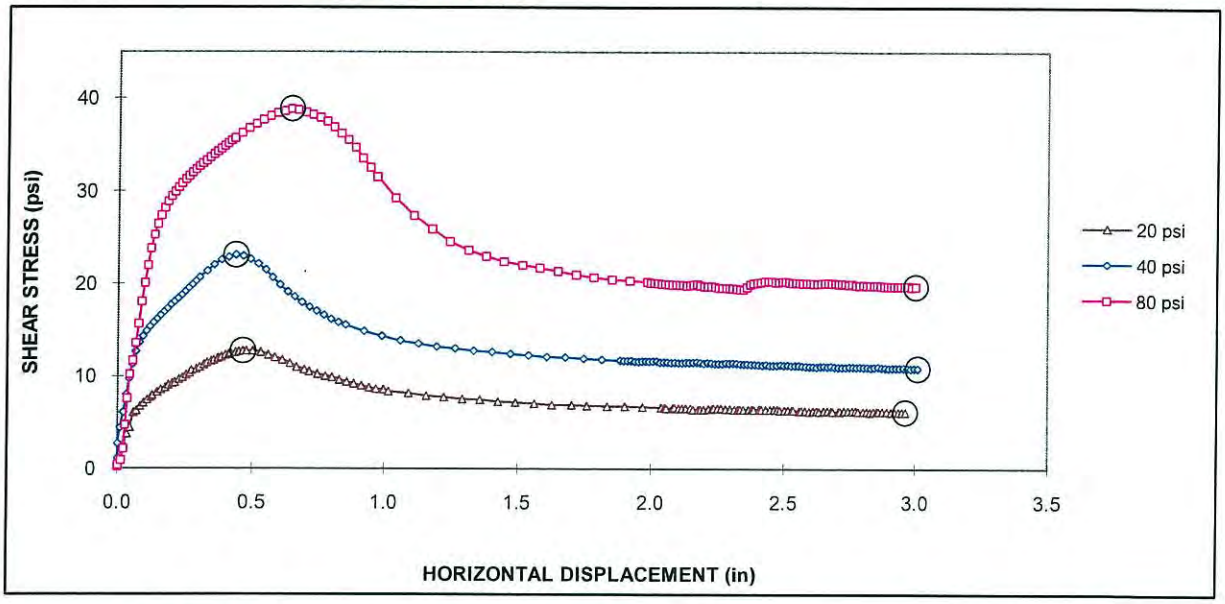
(1) The peak shear stresses for 20, 40, and 80 psi normal stresses were chosen at 0.300, 0.319, and 0.693 in horizontal displacements, respectively.
(2) The adhesion value is based on the "best-fit" line which may not show true adhesion.

DIRECT SHEAR TEST RESULTS

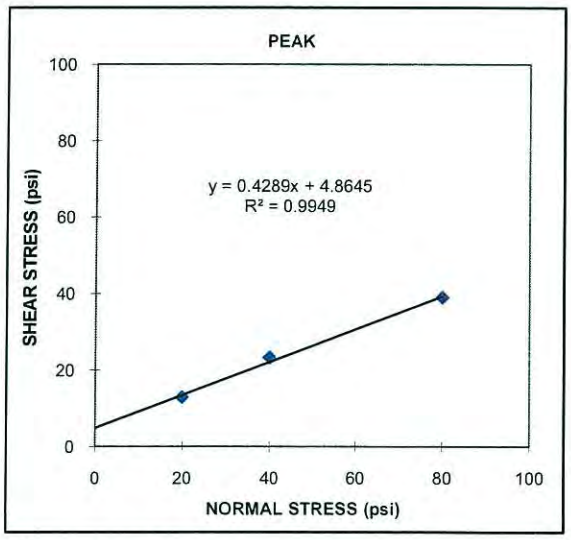
ASTM D6243

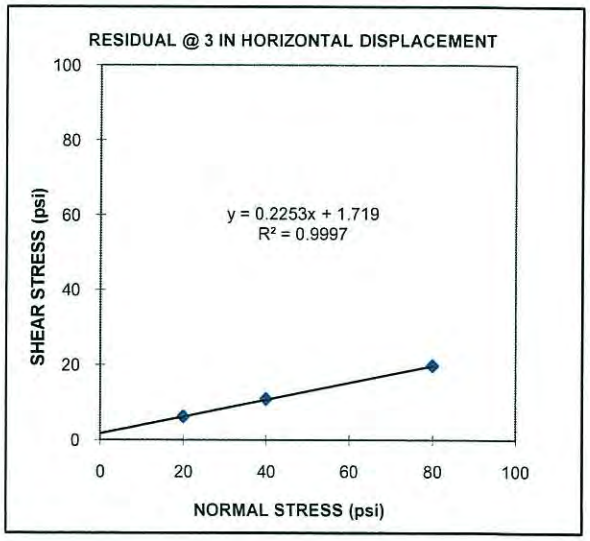
PROJECT NAME: ENERGY FUELS/GEOTECH PINON RIDGE/CO
SAMPLE NUMBER: 5 (GM vs GCL)

INTERFACE TESTED: 60 mil TEXTURED HDPE GEOMEMBRANE vs CETCO BENTOMAT ST GCL (woven side against Geomembrane)
TEST CONDITIONS: INTERFACES WETTED, CONSOLIDATED 15 min AT NORMAL LOAD
SHEAR RATE: 0.2 in/min
SUBSTRATE: TEXTURED RIGID PLATES



Normal Stress (psi)	Shear Stress Peak[1] (psi)	Shear Stress Residual (psi)	Peak Friction Angle	Peak Adhesion[2] (psi)	Residual Friction Angle	Residual Adhesion[2] (psi)
20	12.7	6.1				
40	23.1	10.9	23.2	4.9	12.7	1.7
80	38.8	19.7				





Observations After Test

20 psi: Shearing occurred at the interface between the Geomembrane and the GCL
40 psi: Shearing occurred at the interface between the Geomembrane and the GCL
80 psi: Shearing occurred at the interface between the Geomembrane and the GCL

(1) The peak shear stresses for 20, 40, and 80 psi normal stresses were chosen at 0.464, 0.436, and 0.641 in horizontal displacements, respectively.
(2) The adhesion value is based on the "best-fit" line which may not show true adhesion.

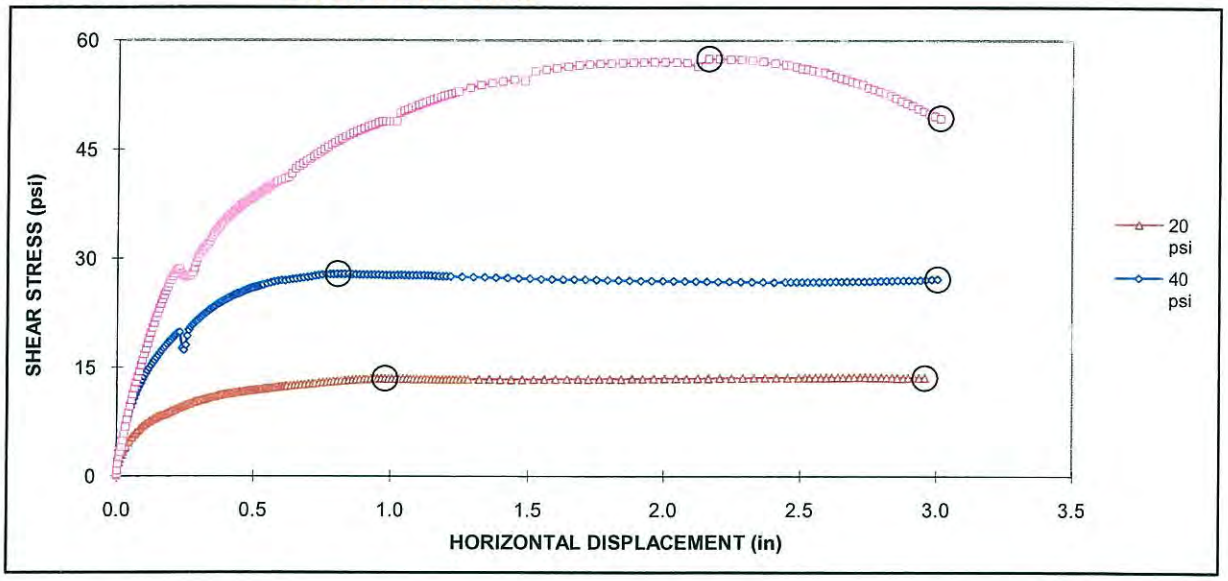
FEBRUARY 2008 073-81694

DIRECT SHEAR TEST RESULTS

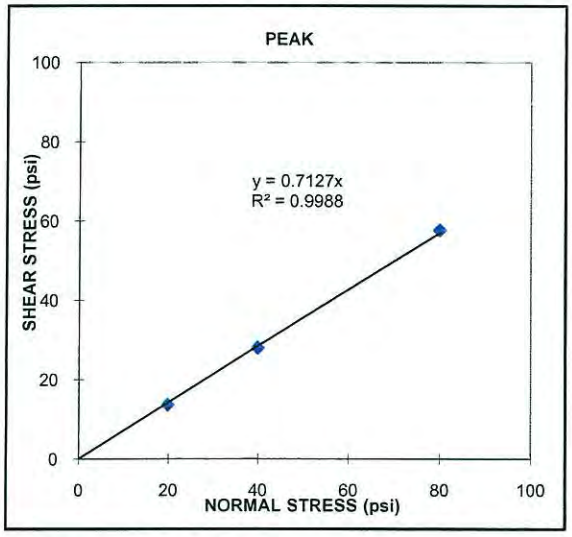
ASTM D6243

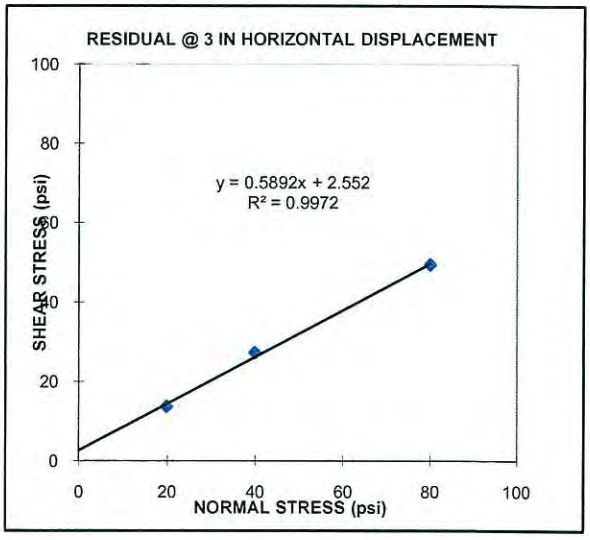
PROJECT NAME: ENERGY FUELS/GEOTECH PINON RIDGE/CO
SAMPLE NUMBER: 4 (DN GCL vs SOIL)

INTERFACE TESTED: CETCO BENTOMAT DN GCL (white nonwoven side against Soil) vs SOIL (GA-TP-7 (1.5'-9'))
SOIL CONDITIONS: REMOLDED TO 95% OF THE MAX DRY DENSITY OF 116.9 pcf AT A MOISTURE OF 12.1 +/- 0.5%
TEST CONDITIONS: INTERFACES WETTED, CONSOLIDATED 12 hours AT NORMAL LOAD
SHEAR RATE: 0.04 in/min
SUBSTRATE: TEXTURED RIGID PLATES



Normal Stress (psi)	Shear Stress Peak[1] (psi)	Shear Stress Residual (psi)	Peak Friction Angle	Peak Adhesion[2] (psi)	Residual Friction Angle	Residual Adhesion[2] (psi)
20	13.5	13.6				
40	27.9	27.2	35.5	0.0	30.5	2.6
80	57.5	49.3				





Observations After Test

20 psi: Shearing occurred at the interface between the GCL and the Soil
40 psi: Shearing occurred at the interface between the GCL and the Soil
80 psi: Shearing occurred within the Soil

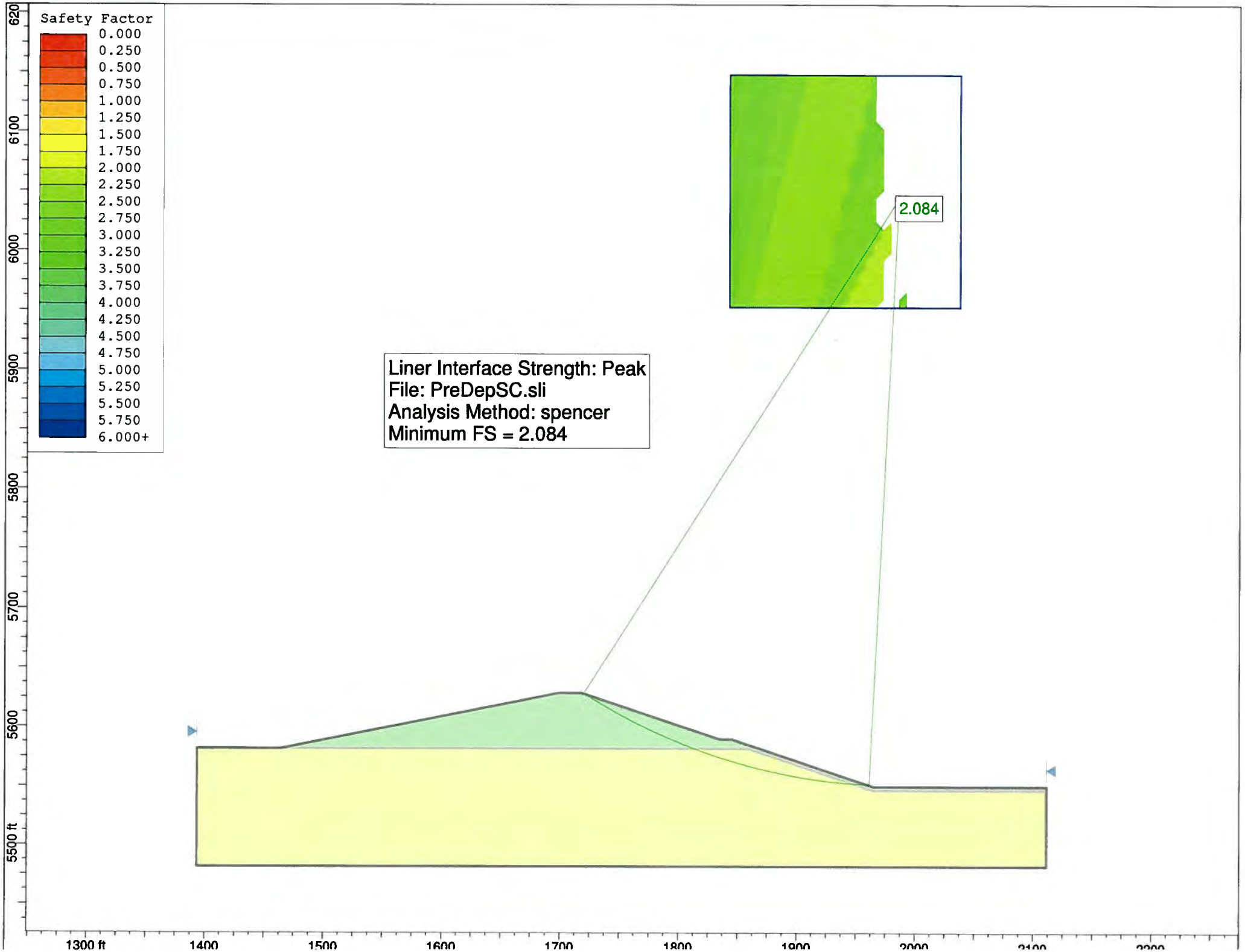
(1) The peak shear stresses for 20, 40, and 80 psi normal stresses were chosen at 0.980, 0.806, and 2.164 in horizontal displacements, respectively, which may not represent the maximum shear stresses.
(2) The adhesion value is based on the "best-fit" line which may not show true adhesion.

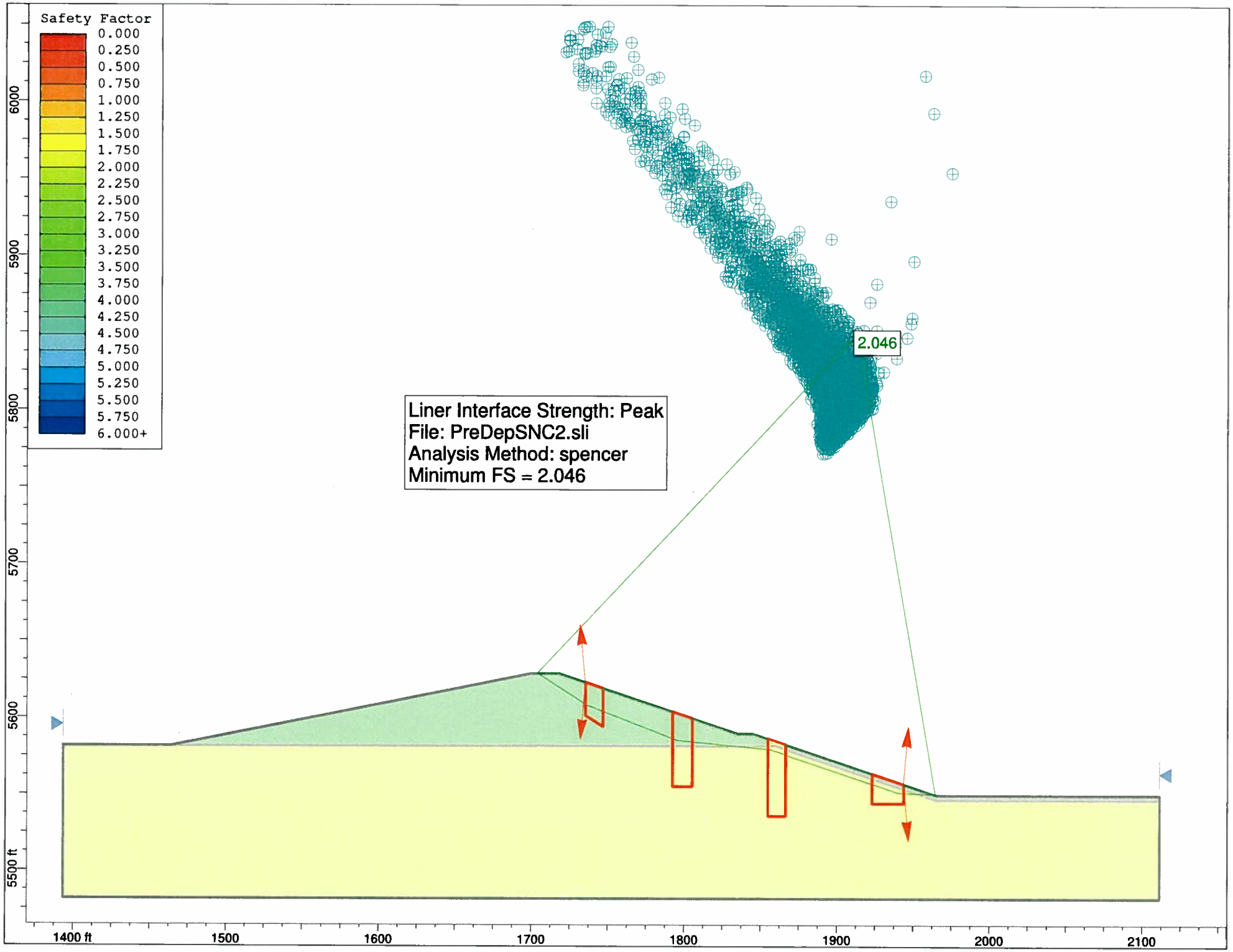
ATTACHMENT 3
SLIDE RESULTS

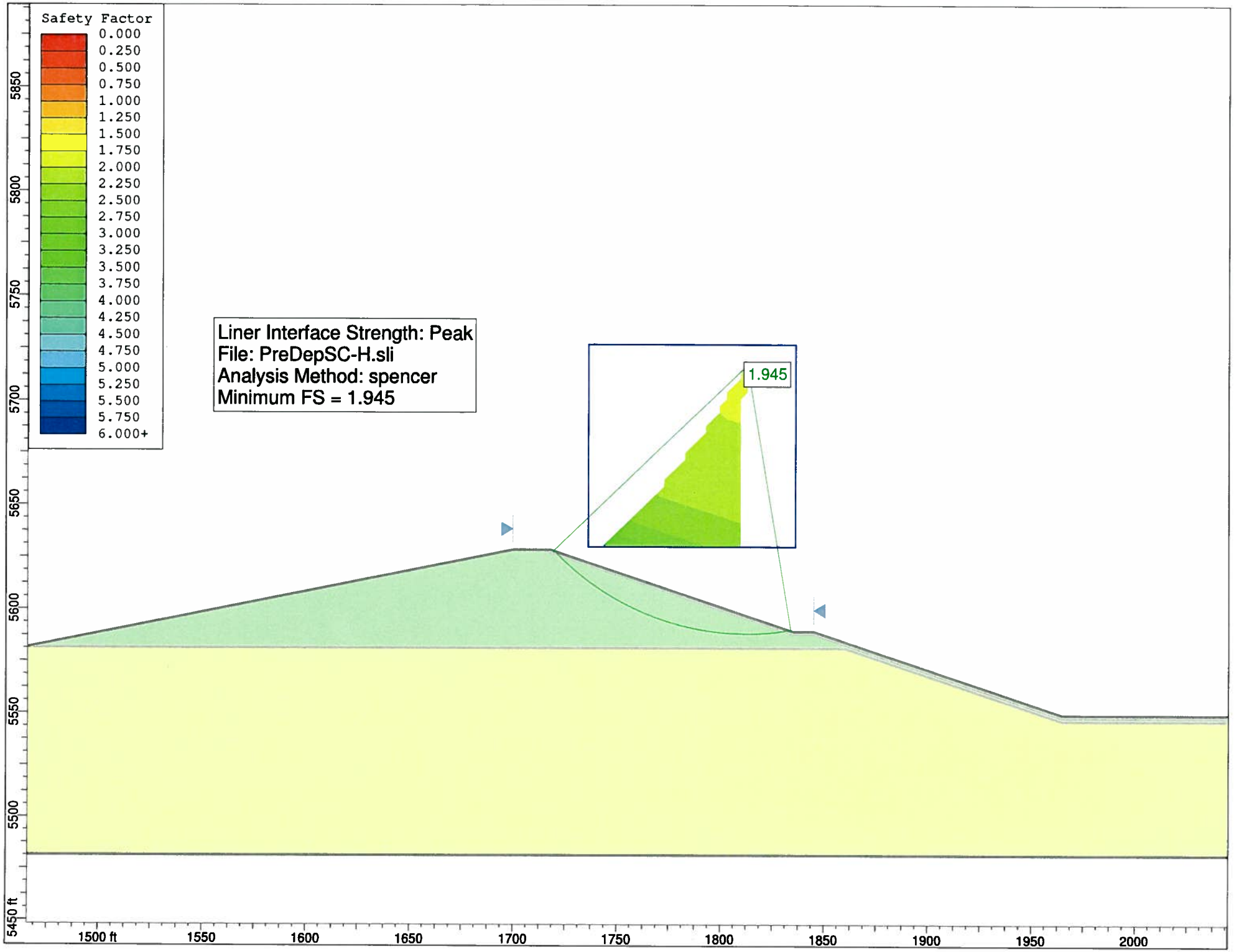
TABLE A3-1
SUMMARY OF PEAK STABILITY ANALYSES

Analyses Using Peak Liner Interface Shear Strength

Scenario	File Name	Static or Seismic	Pseudo-Static Seismic Coefficient	Surface Type	Factor of Safety
Pre Deposition	PreDepSC.sli	Static	n/a	Circular	2.08
Pre Deposition	PreDepSNC2.sli	Static	n/a	Block	2.05
Pre Deposition	PreDepSC-H.sli	Static	n/a	Circular	**1.95**
Pre Deposition	PreDepSNC-H.sli	Static	n/a	Block	1.97
Pre Deposition	PreDepEC.sli	Seismic	0.05	Circular	1.77
Pre Deposition	PreDepENC2.sli	Seismic	0.05	Block	1.74
Pre Deposition	PreDepEC-H.sli	Seismic	0.05	Circular	**1.67**
Pre Deposition	PreDepENC-H.sli	Seismic	0.05	Block	1.68
Post Deposition	PostDepSC.sli	Static	n/a	Circular	8.68
Post Deposition	PostDepSNC.sli	Static	n/a	Block	8.87
Post Deposition	PostDepEC.sli	Seismic	0.05	Circular	2.52
Post Deposition	PostDepENC.sli	Seismic	0.05	Block	2.61
Post Deposition	PostDepSC-B.sli	Static	n/a	Circular	**3.00**
Post Deposition	PostDepSNC-B.sli	Static	n/a	Block	3.08
Post Deposition	PostDepEC-B.sli	Seismic	0.05	Circular	**2.38**
Post Deposition	PostDepENC-B.sli	Seismic	0.05	Block	2.44
Post Closure	PostCloSC.sli	Static	n/a	Circular	5.23
Post Closure	PostCloSNC.sli	Static	n/a	Block	**4.89**
Post Closure	PostCloEC.sli	Seismic	0.08	Circular	2.88
Post Closure	PostCloENC.sli	Seismic	0.08	Block	**2.65**


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Peak
File: PreDepSC.sli
Analysis Method: spencer
Minimum FS = 2.084
2.084
6200
6100
6000
5900
5800
5700
5600
5500 ft
1300 ft
1400
1500
1600
1700
1800
1900
2000
2100
2200


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Peak
File: PreDepSNC2.sli
Analysis Method: spencer
Minimum FS = 2.046
2.046
6000
5900
5800
5700
5600
5500 ft
1400 ft
1500
1600
1700
1800
1900
2000
2100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0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
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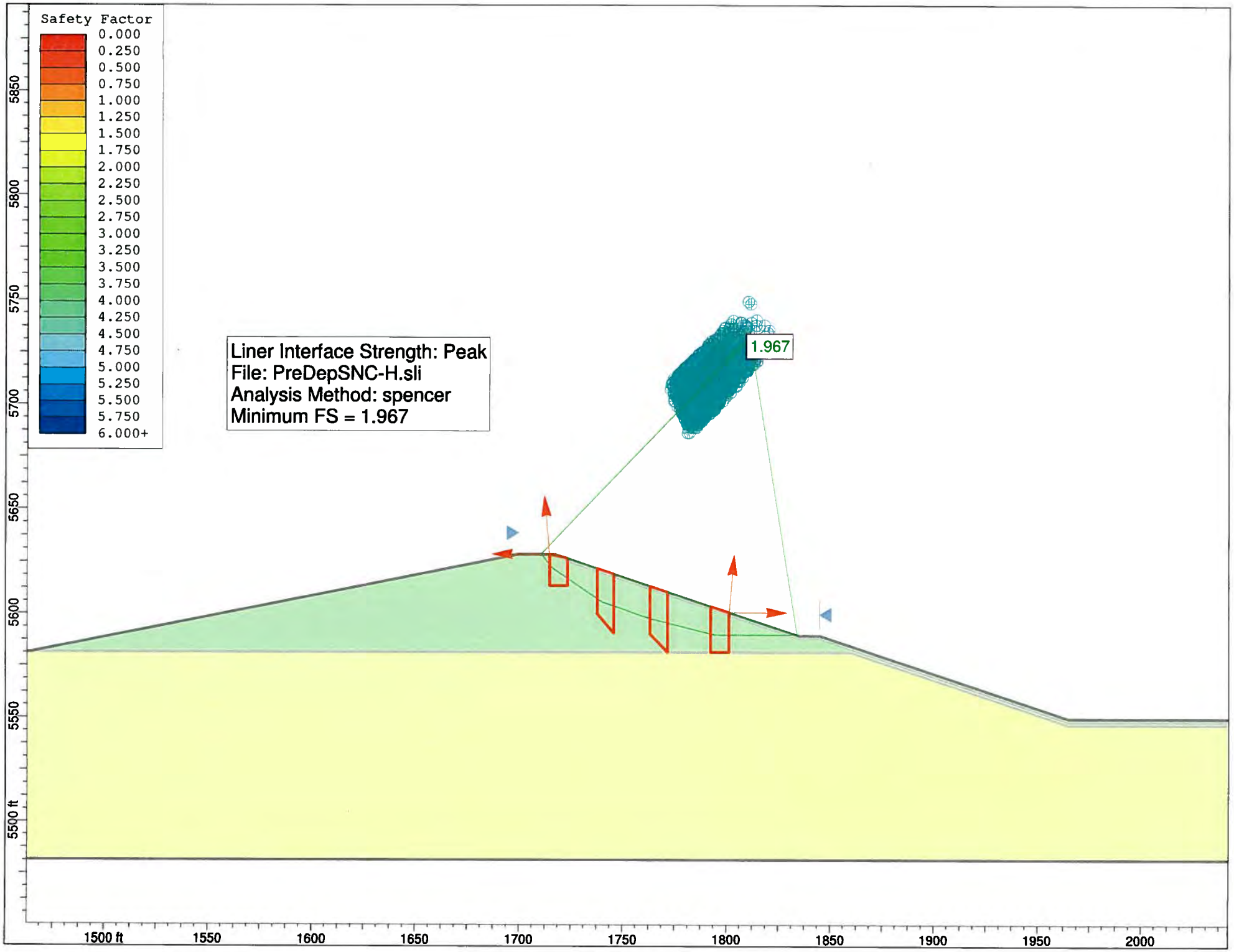
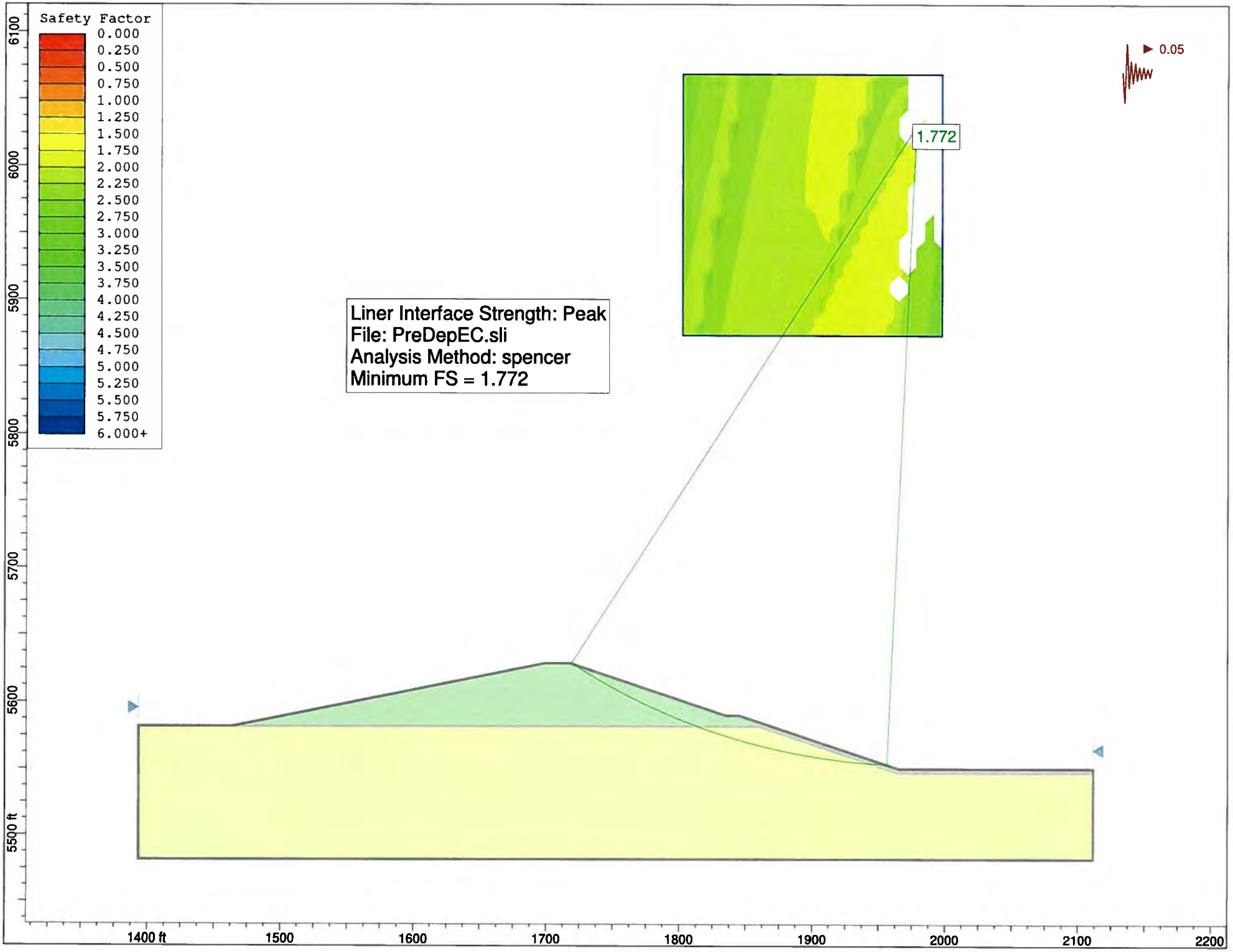
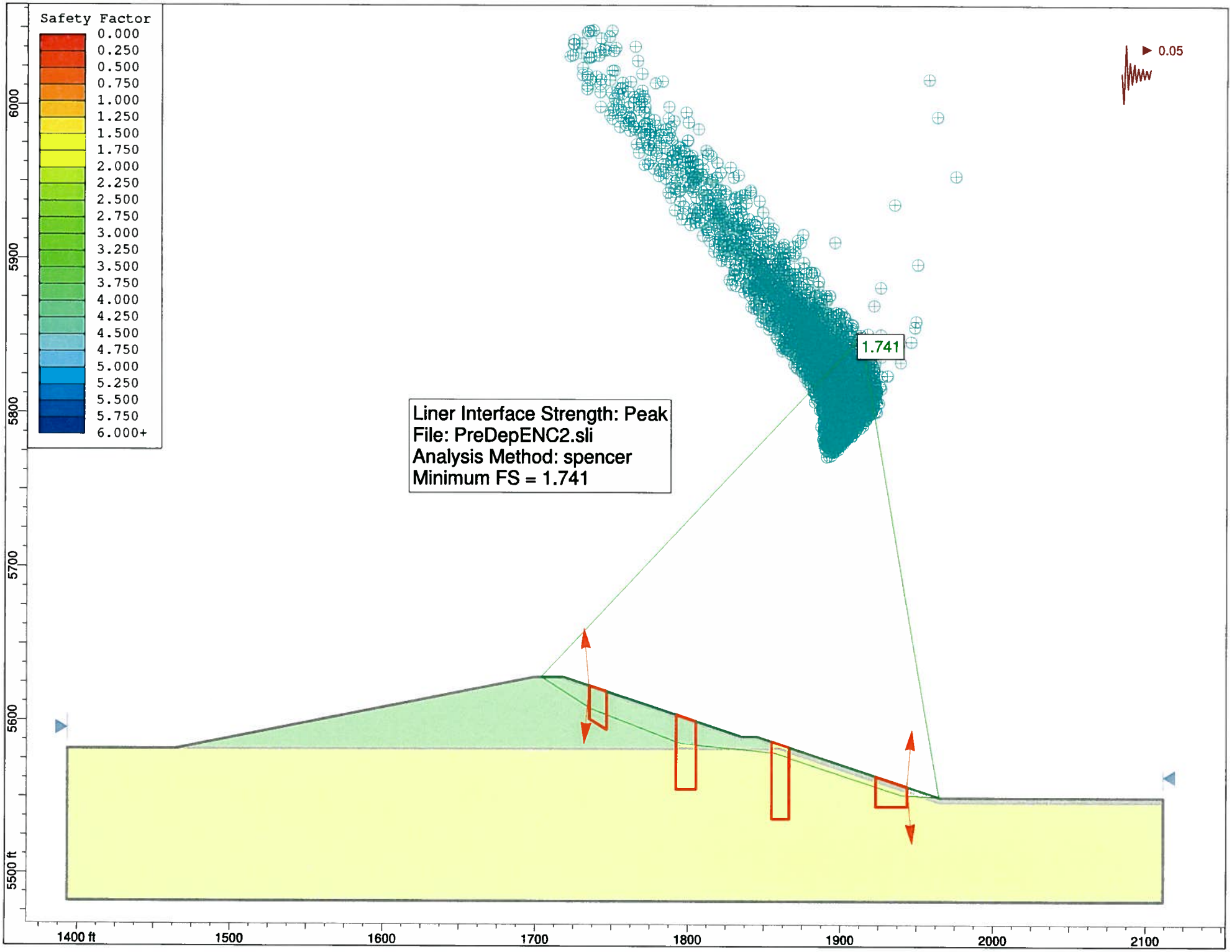
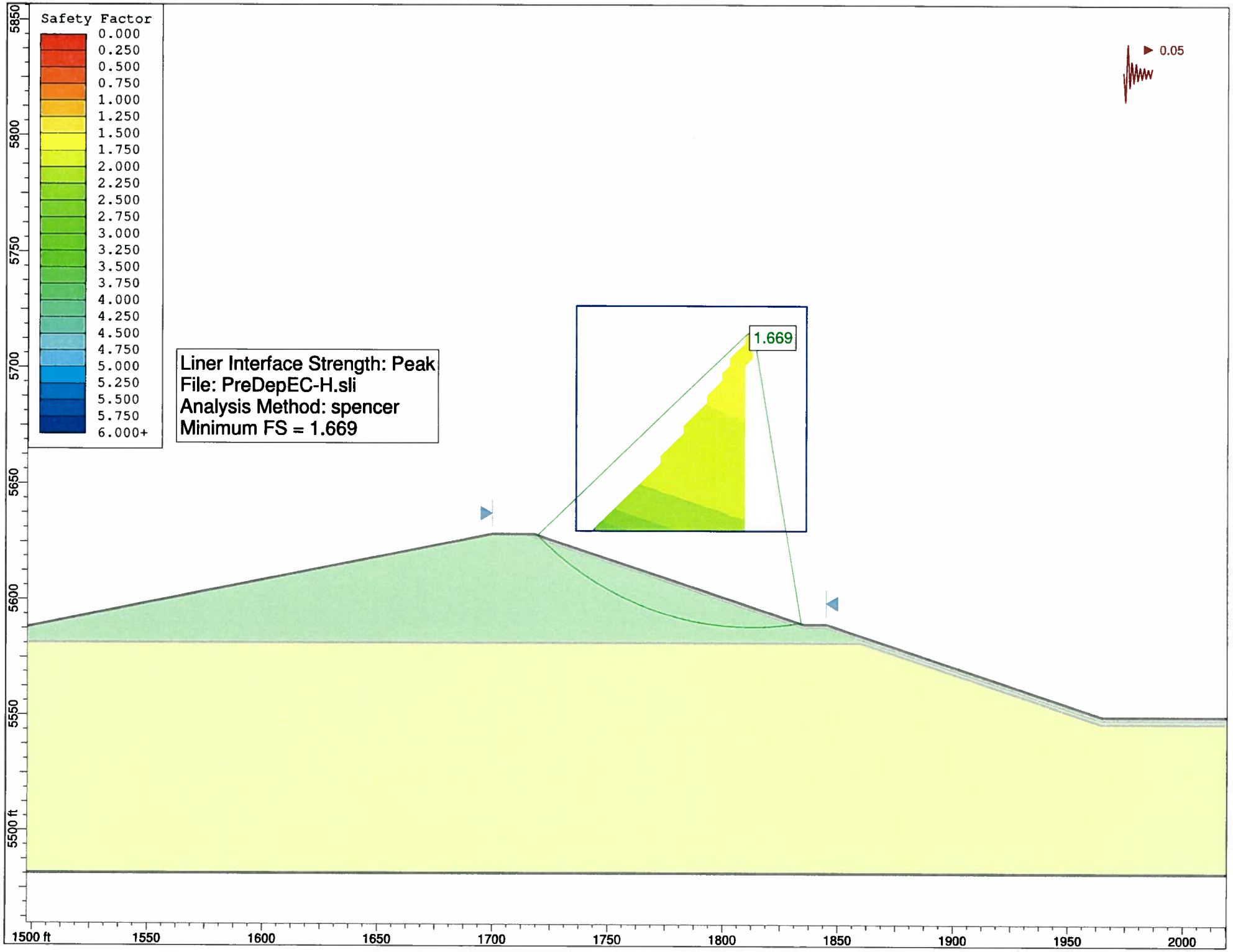
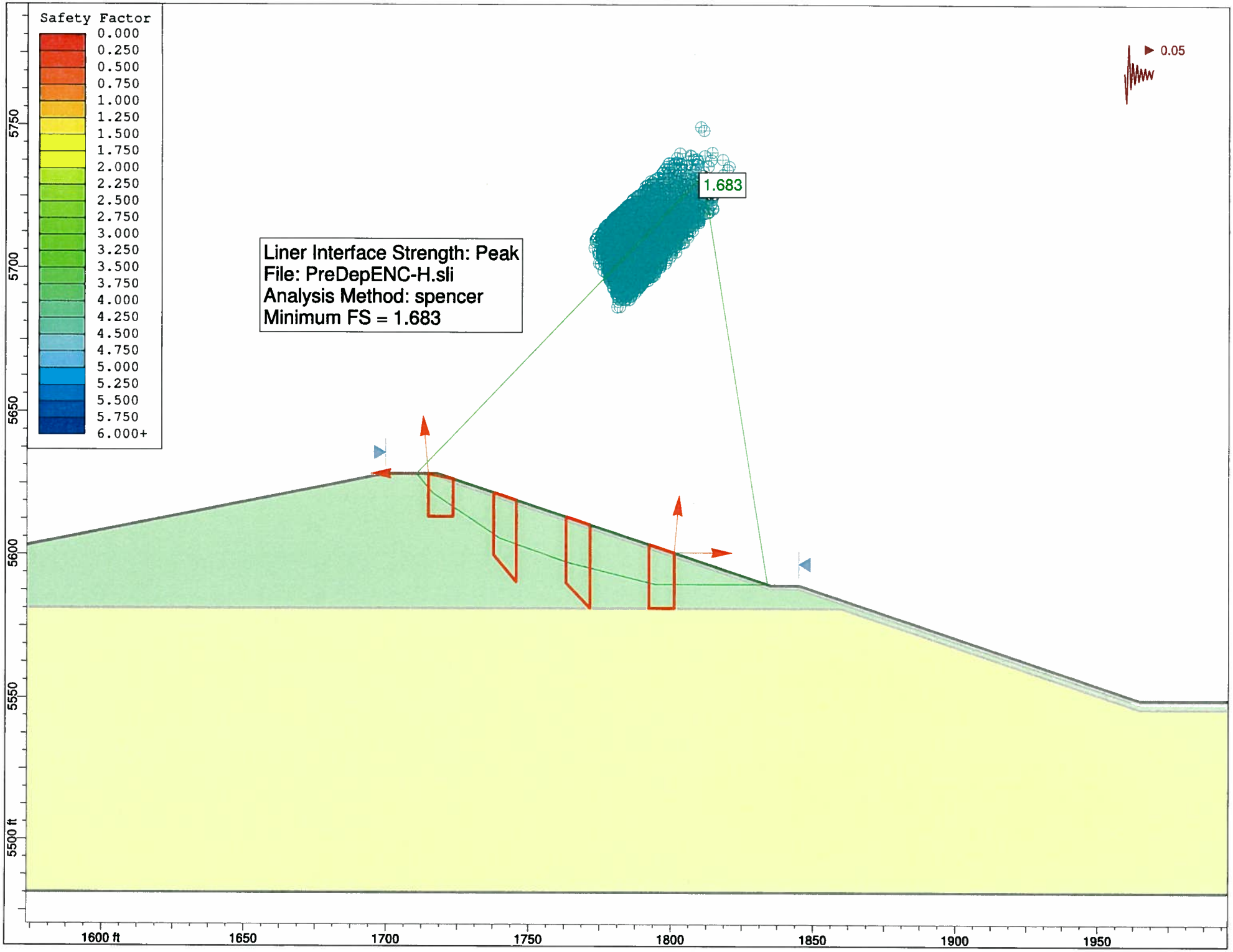
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Peak
File: PreDepSC-H.sli
Analysis Method: spencer
Minimum FS = 1.945
1.945
5850
5800
5750
5700
5650
5600
5550
5500
5450 ft
1500 ft
1550
1600
1650
1700
1750
1800
1850
1900
1950
2000

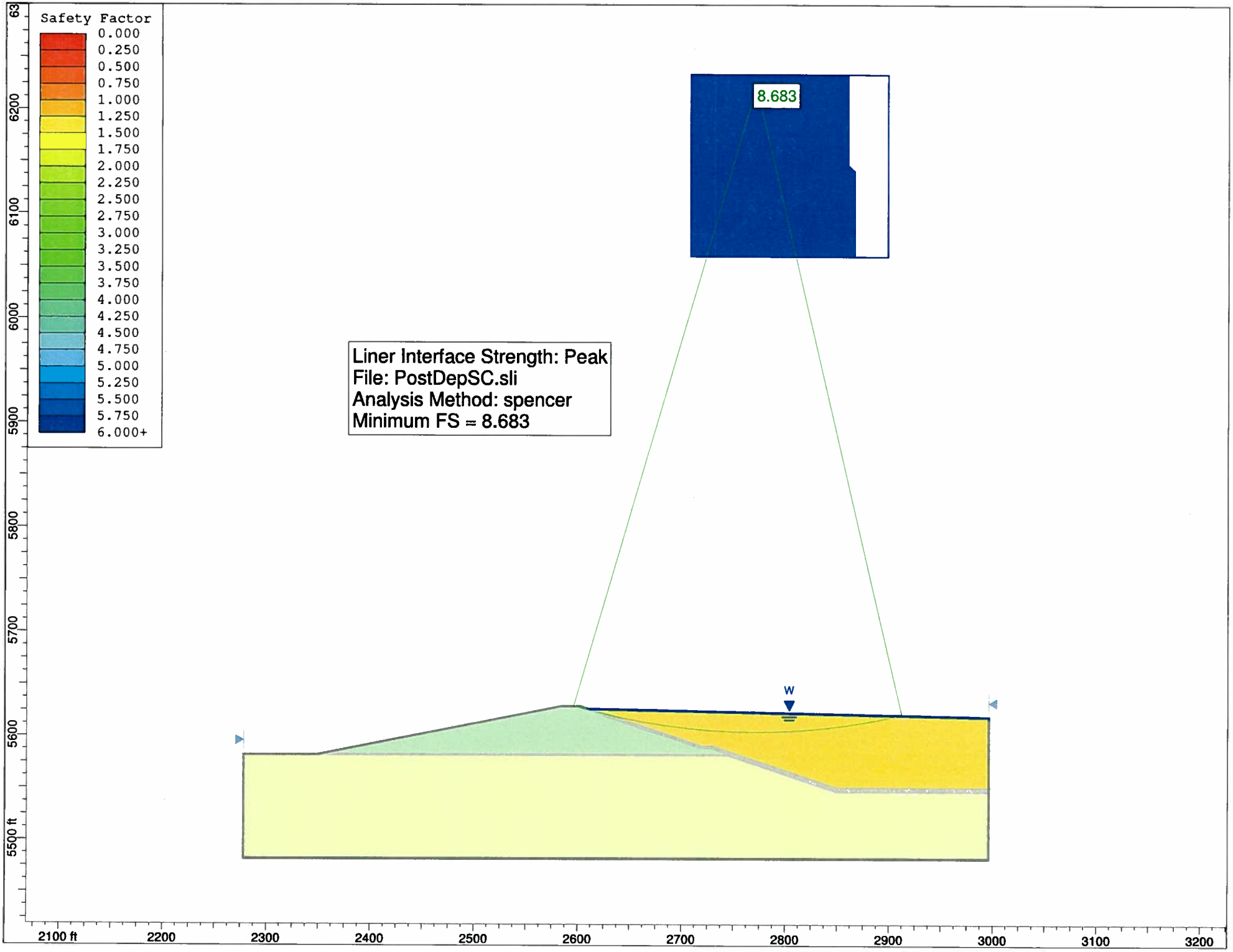

Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Peak
File: PreDepSNC-H.sli
Analysis Method: spencer
Minimum FS = 1.967
1.967
5850
5800
5750
5700
5650
5600
5550
5500 ft
1500 ft
1550
1600
1650
1700
1750
1800
1850
1900
1950
2000


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Peak
File: PreDepEC.sli
Analysis Method: spencer
Minimum FS = 1.772
1.772
0.05
6100
6000
5900
5800
5700
5600
5500 ft
1400 ft
1500
1600
1700
1800
1900
2000
2100
2200


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
0.05
1.741
Liner Interface Strength: Peak
File: PreDepENC2.sli
Analysis Method: spencer
Minimum FS = 1.741
6000
5900
5800
5700
5600
5500 ft
1400 ft
1500
1600
1700
1800
1900
2000
2100


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Peak
File: PreDepEC-H.sli
Analysis Method: spencer
Minimum FS = 1.669
1.669
0.05
5850
5800
5750
5700
5650
5600
5550
5500 ft
1500 ft
1550
1600
1650
1700
1750
1800
1850
1900
1950
2000


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Peak
File: PreDepENC-H.sli
Analysis Method: spencer
Minimum FS = 1.683
1.683
0.05
5750
5700
5650
5600
5550
5500 ft
1600 ft
1650
1700
1750
1800
1850
1900
1950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0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
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3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
8.683
Liner Interface Strength: Peak
File: PostDepSC.sli
Analysis Method: spencer
Minimum FS = 8.683
W
6300
6200
6100
6000
5900
5800
5700
5600
5500 ft
2100 ft
2200
2300
2400
2500
2600
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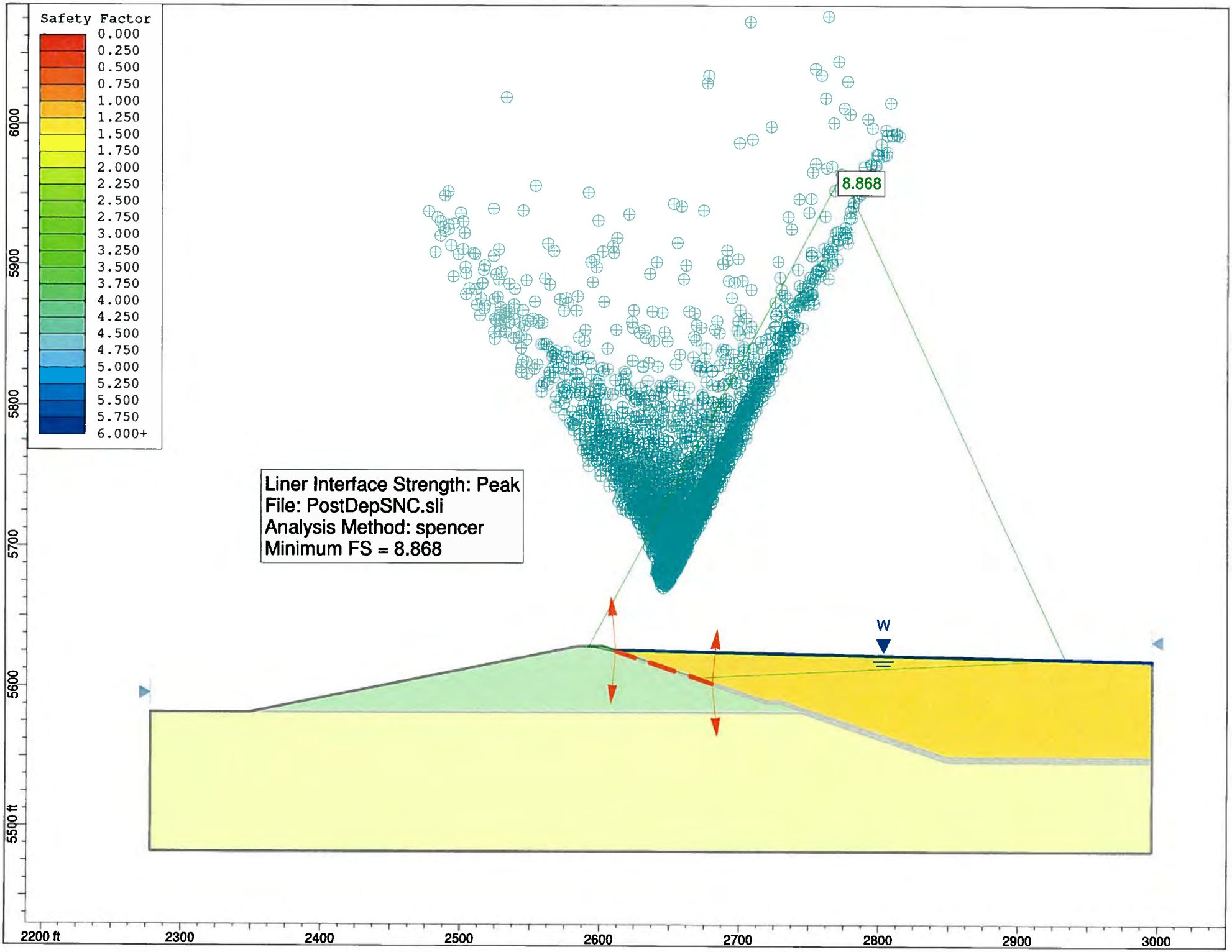
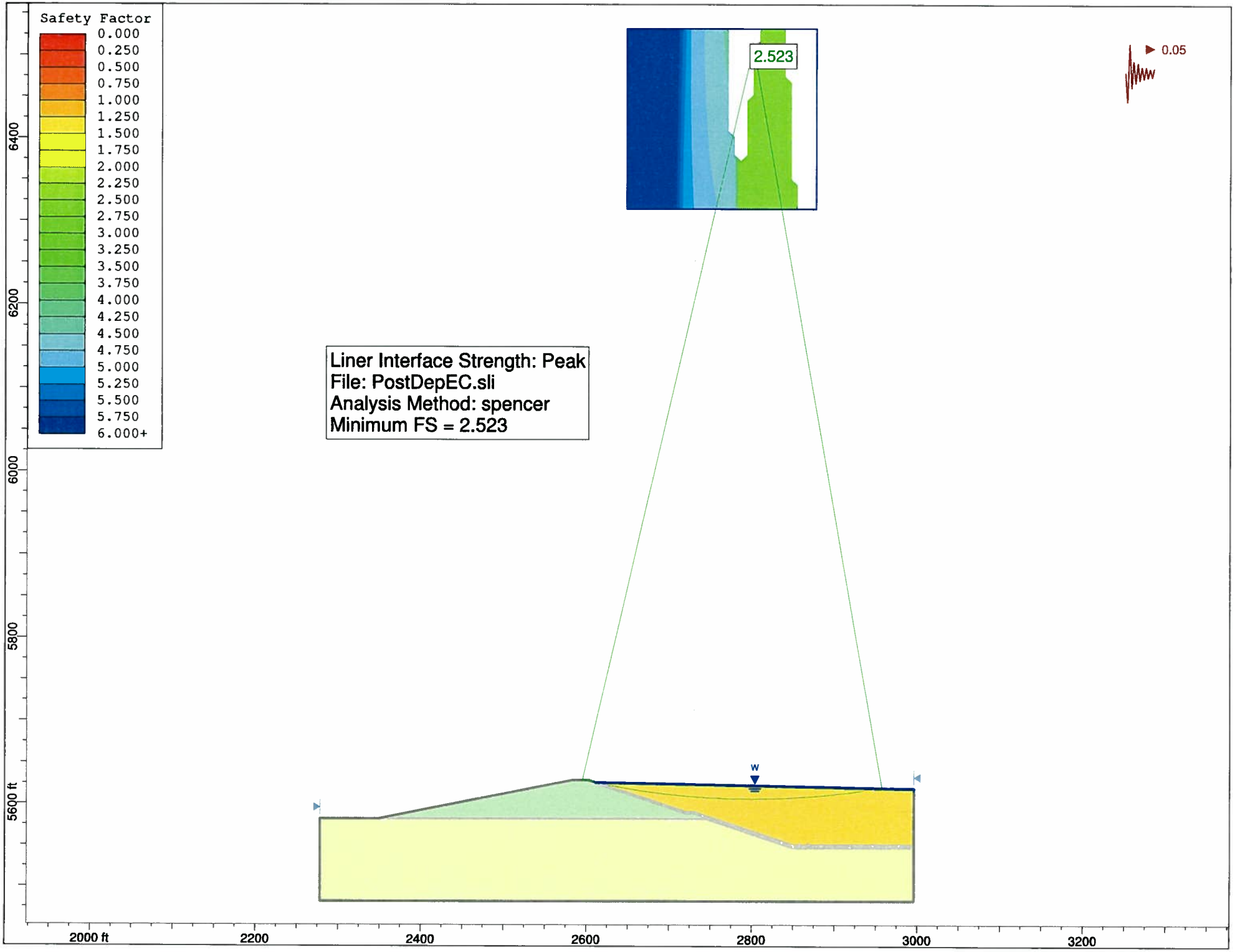
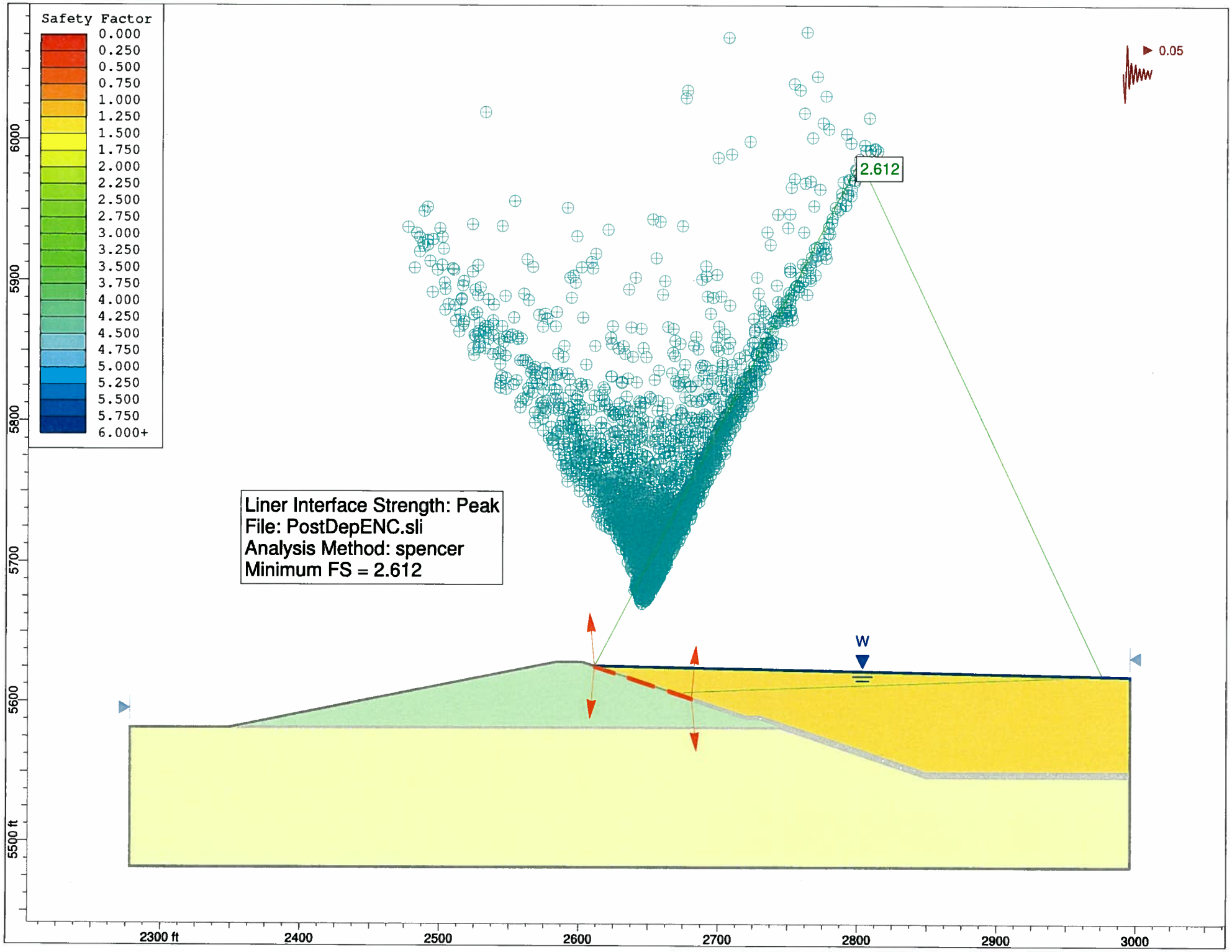
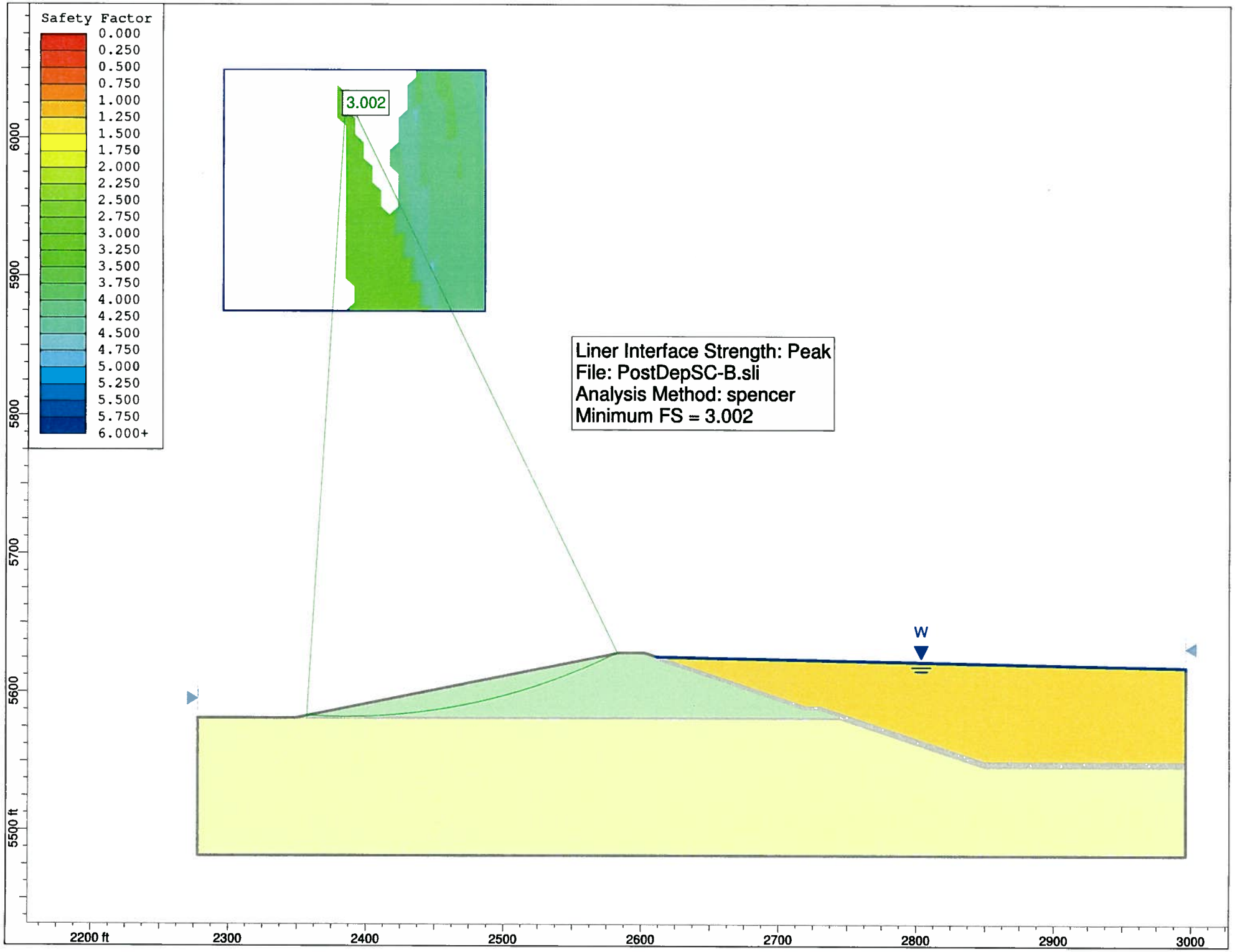
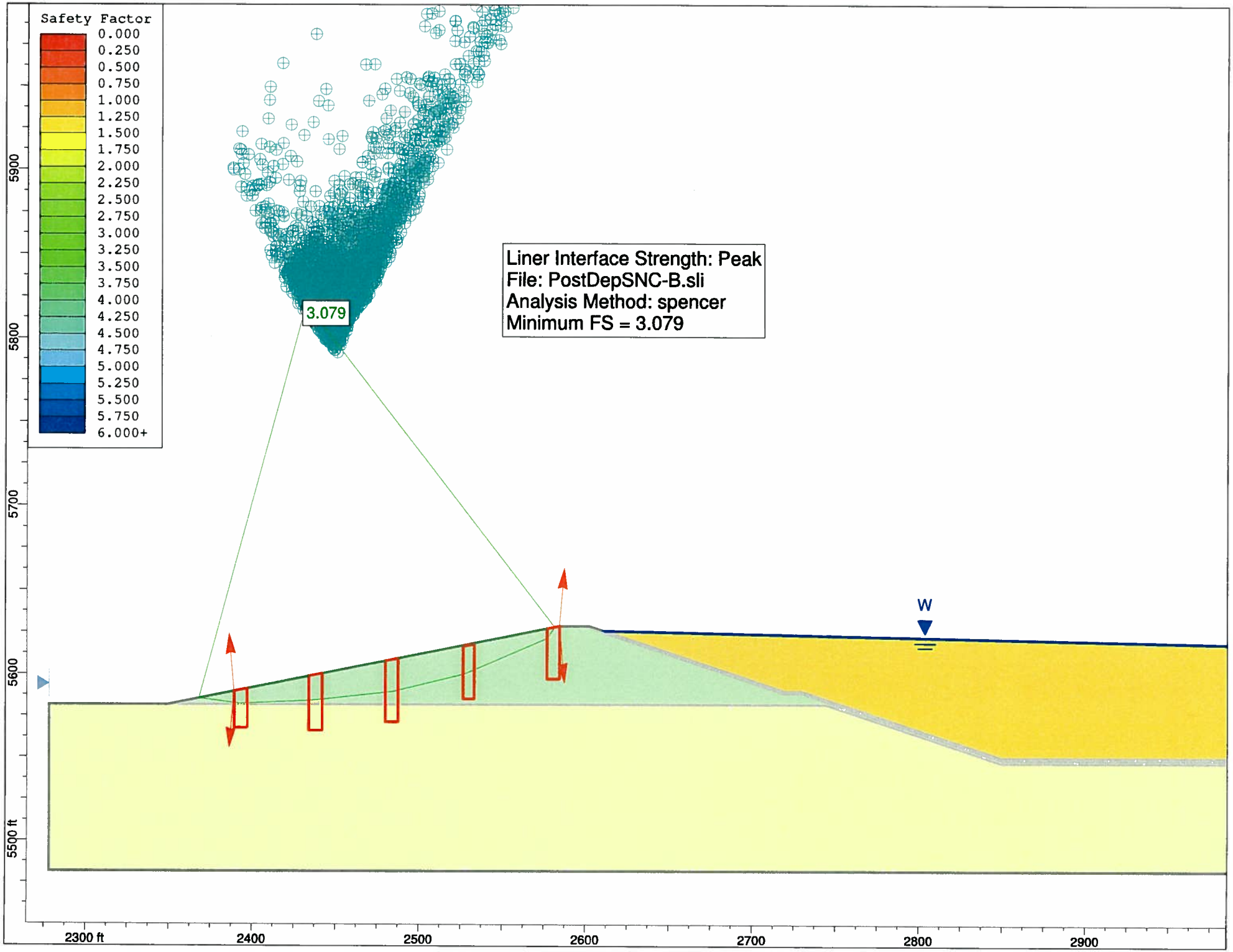
2800
2900
3000
3100
3200

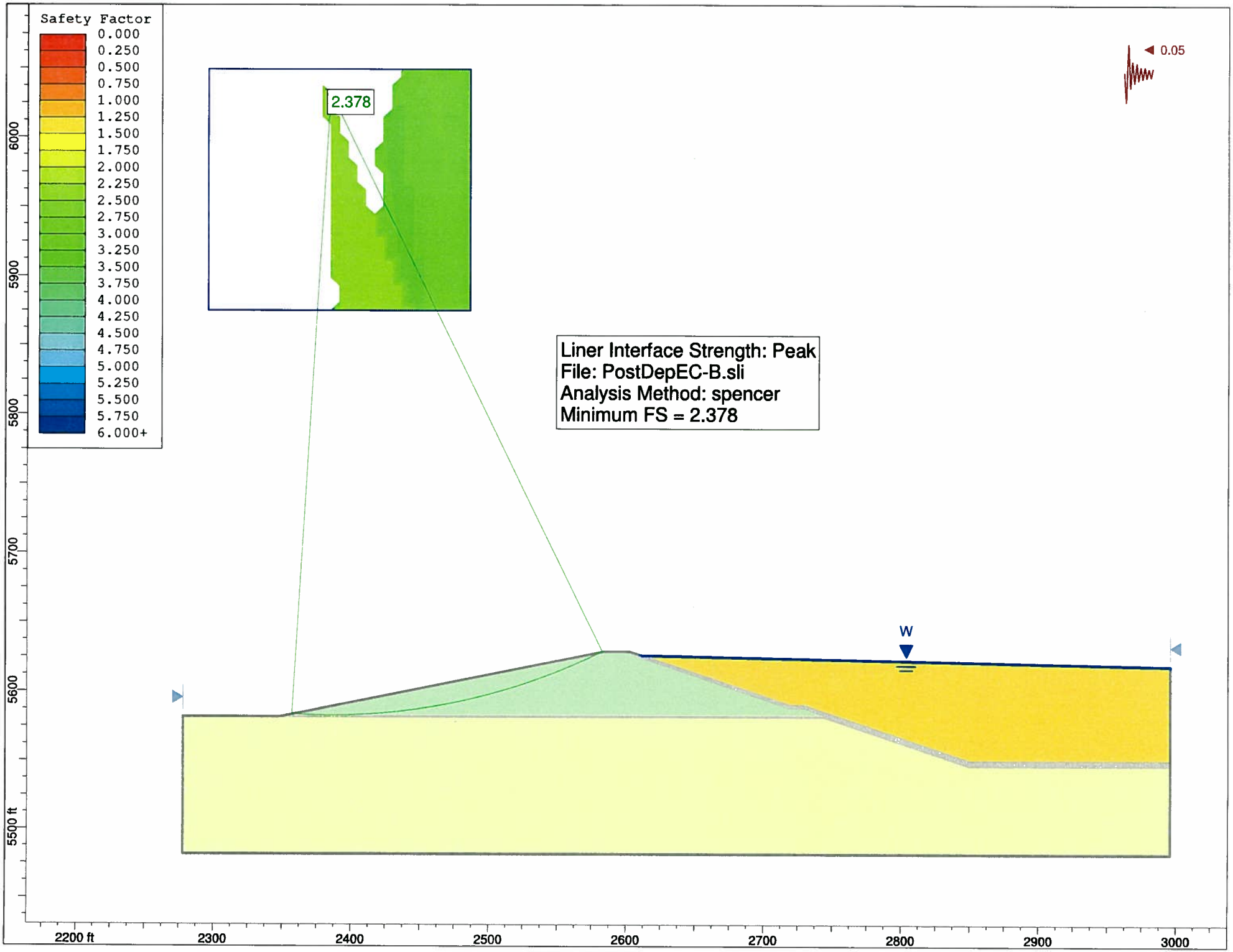

Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
8.868
Liner Interface Strength: Peak
File: PostDepSNC.sli
Analysis Method: spencer
Minimum FS = 8.868
W
6000
5900
5800
5700
5600
5500 ft
2200 ft
2300
2400
2500
2600
2700
2800
2900
3000


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Peak
File: PostDepEC.sli
Analysis Method: spencer
Minimum FS = 2.523
2.523
0.05
w
6400
6200
6000
5800
5600 ft
2000 ft
2200
2400
2600
2800
3000
3200


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
0.05
2.612
Liner Interface Strength: Peak
File: PostDepENC.sli
Analysis Method: spencer
Minimum FS = 2.612
W
6000
5900
5800
5700
5600
5500 ft
2300 ft
2400
2500
2600
2700
2800
2900
3000


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
3.002
Liner Interface Strength: Peak
File: PostDepSC-B.sli
Analysis Method: spencer
Minimum FS = 3.002
W
6000
5900
5800
5700
5600
5500 ft
2200 ft
2300
2400
2500
2600
2700
2800
2900
3000


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
3.079
Liner Interface Strength: Peak
File: PostDepSNC-B.sli
Analysis Method: spencer
Minimum FS = 3.079
W
5900
5800
5700
5600
5500 ft
2300 ft
2400
2500
2600
2700
2800
2900


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
2.378
0.05
Liner Interface Strength: Peak
File: PostDepEC-B.sli
Analysis Method: spencer
Minimum FS = 2.378
W
6000
5900
5800
5700
5600
5500 ft
2200 ft
2300
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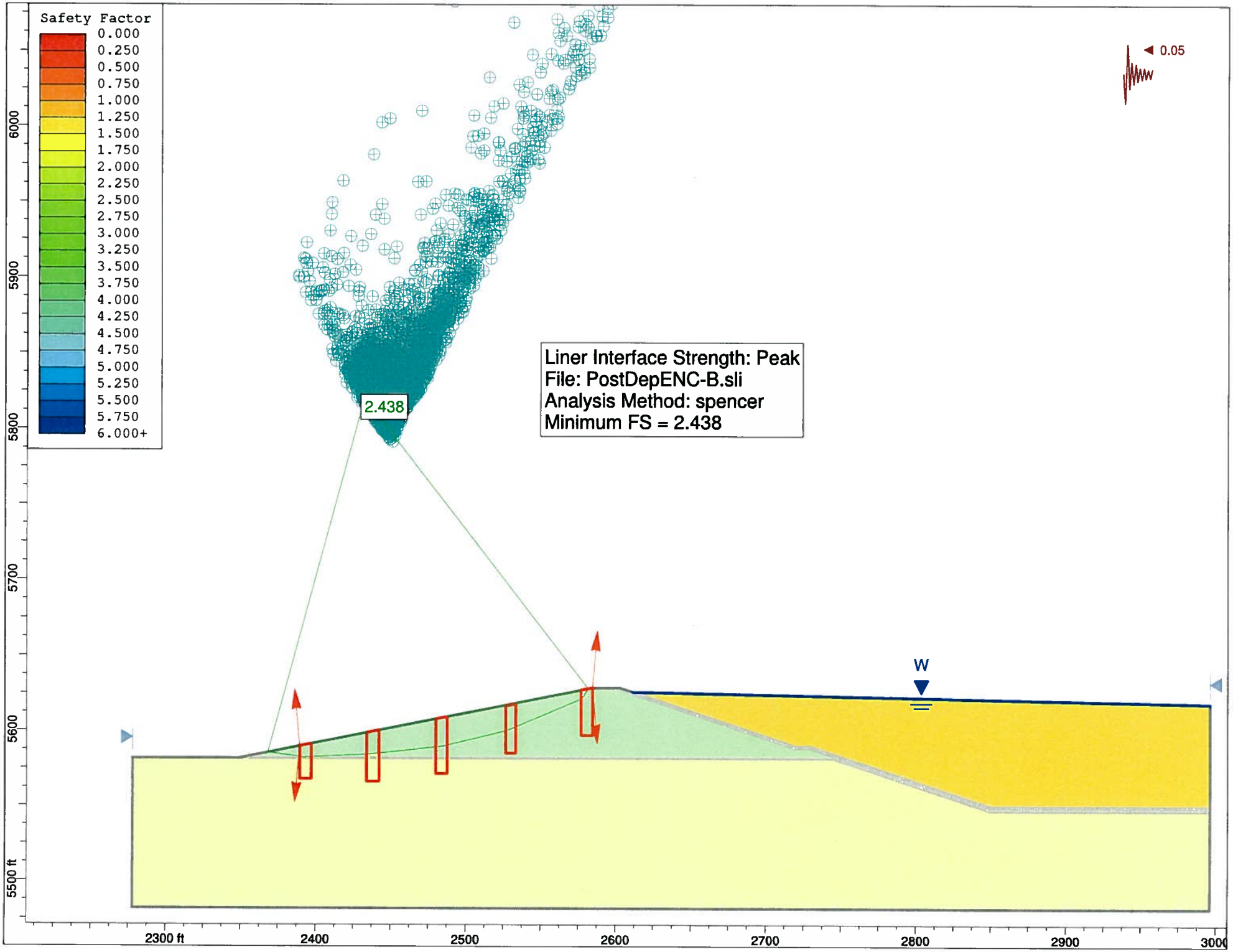
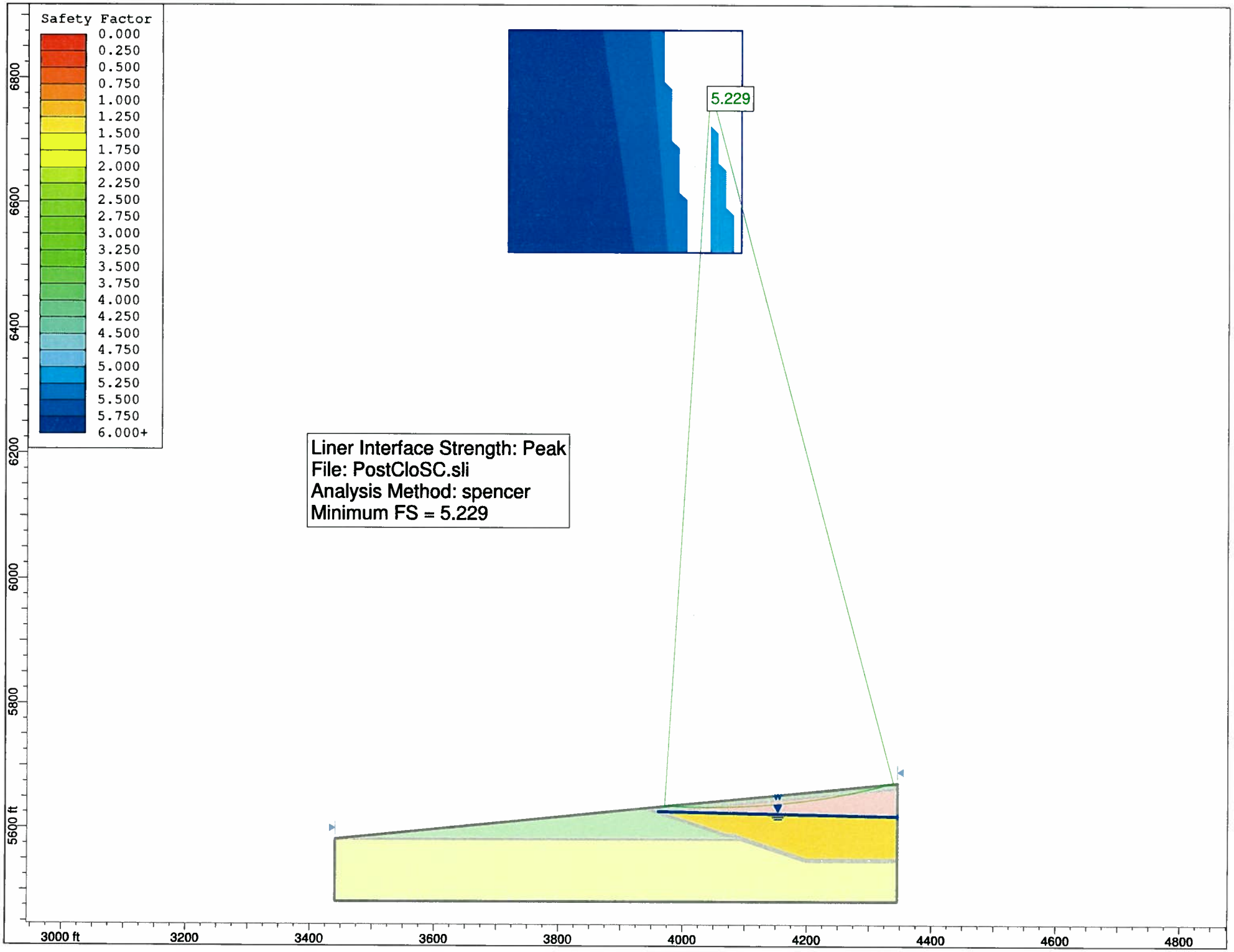
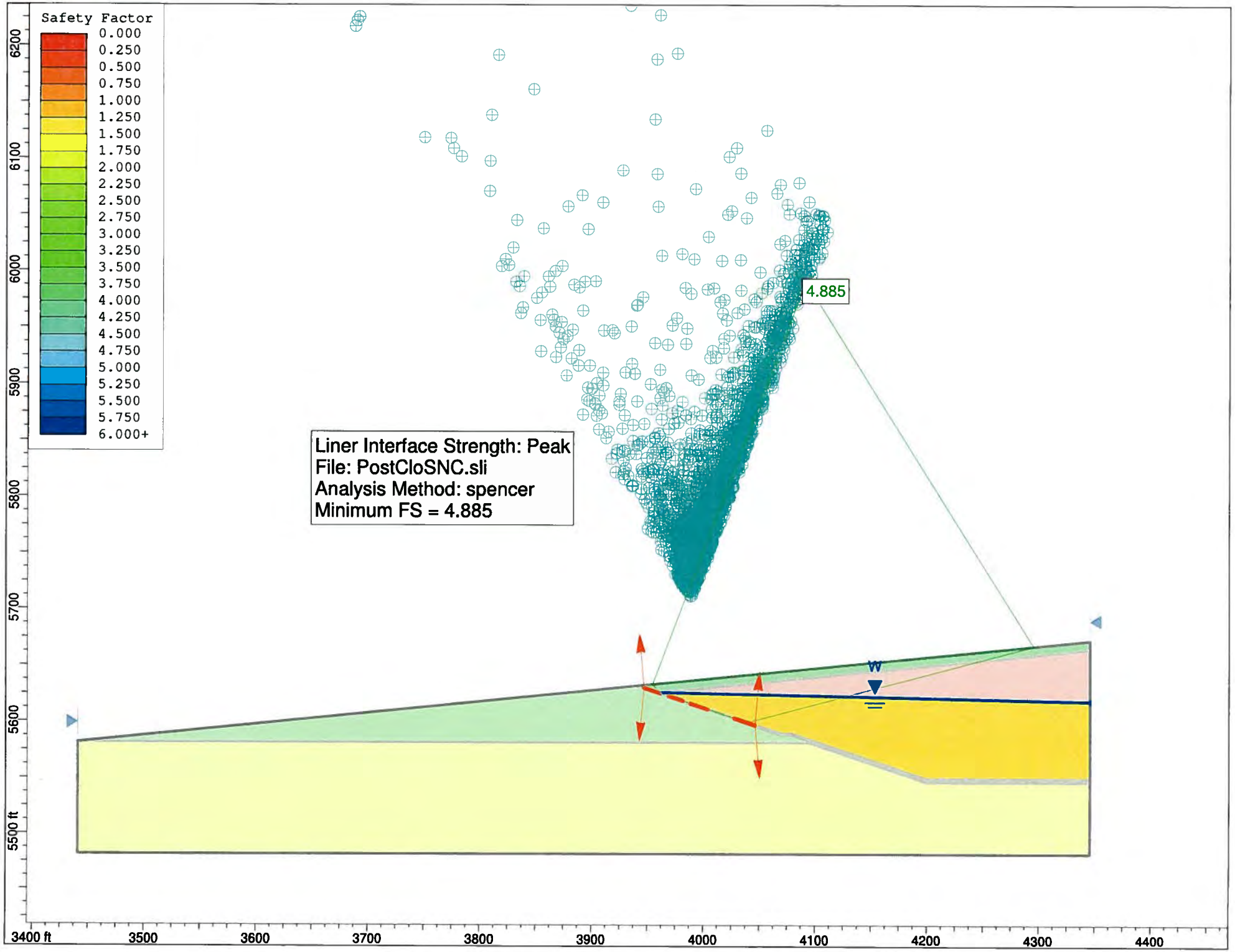
2600
2700
2800
2900
3000


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
2.438
Liner Interface Strength: Peak
File: PostDepENC-B.sli
Analysis Method: spencer
Minimum FS = 2.438
0.05
W
6000
5900
5800
5700
5600
5500 ft
2300 ft
2400
2500
2600
2700
2800
2900
3000


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
5.229
Liner Interface Strength: Peak
File: PostCloSC.sli
Analysis Method: spencer
Minimum FS = 5.229
6800
6600
6400
6200
6000
5800
5600 ft
3000 ft
3200
3400
3600
3800
4000
4200
4400
4600
4800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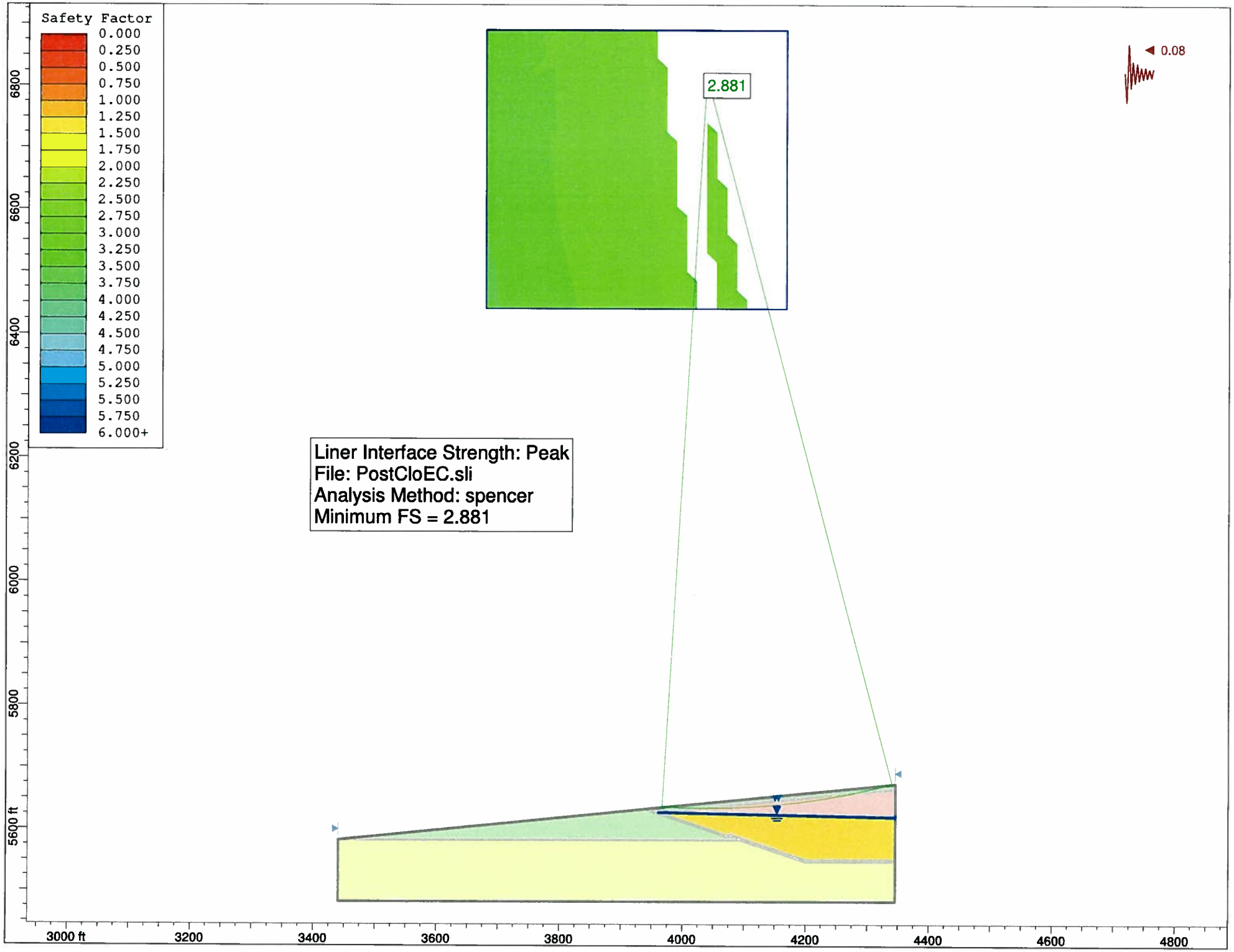
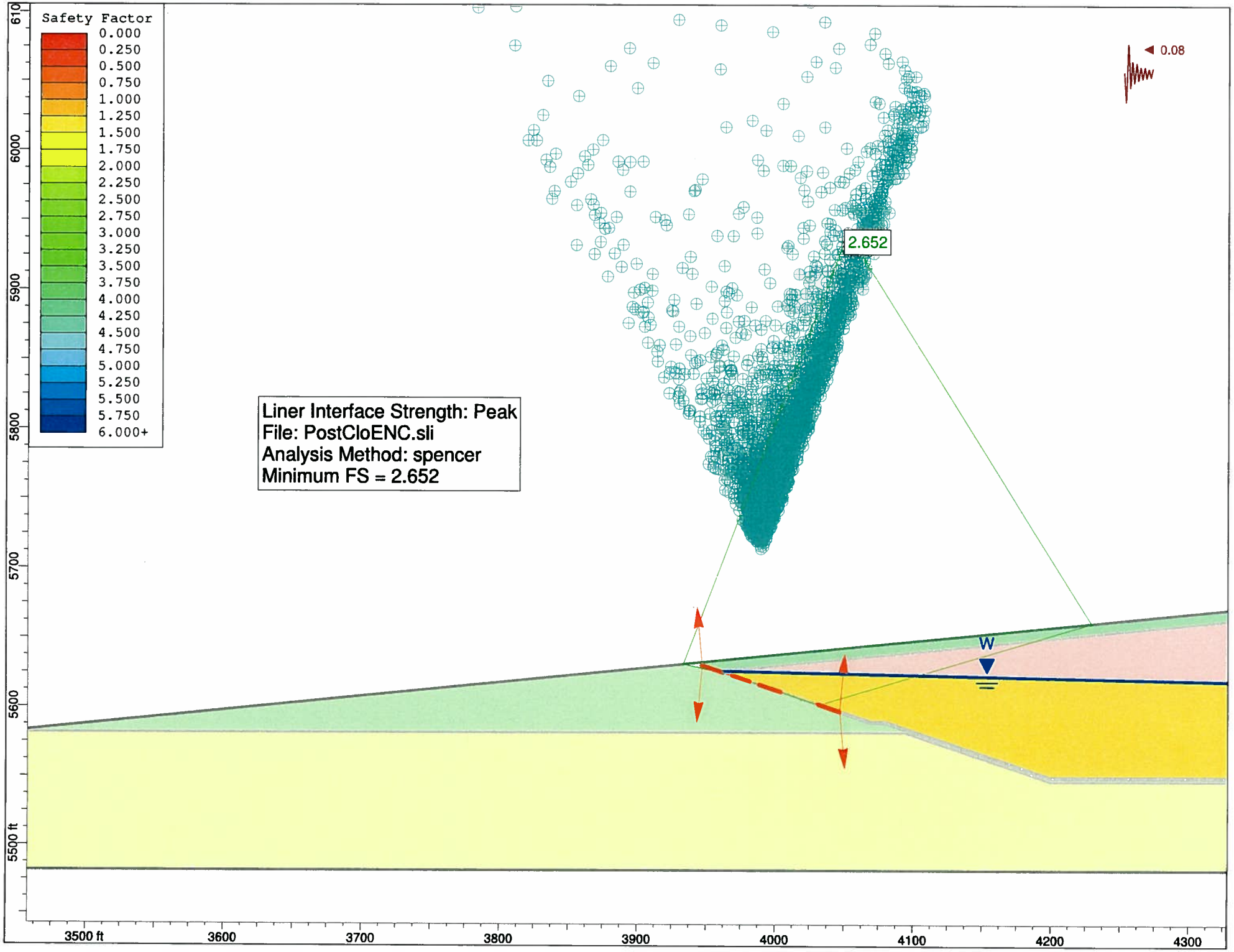
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
4.885
Liner Interface Strength: Peak
File: PostCloSNC.sli
Analysis Method: spencer
Minimum FS = 4.885
W
6200
6100
6000
5900
5800
5700
5600
5500 ft
3400 ft
3500
3600
3700
3800
3900
4000
4100
4200
4300
4400


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
2.881
0.08
Liner Interface Strength: Peak
File: PostCloEC.sli
Analysis Method: spencer
Minimum FS = 2.881
6800
6600
6400
6200
6000
5800
5600 ft
3000 ft
3200
3400
3600
3800
4000
4200
4400
4600
4800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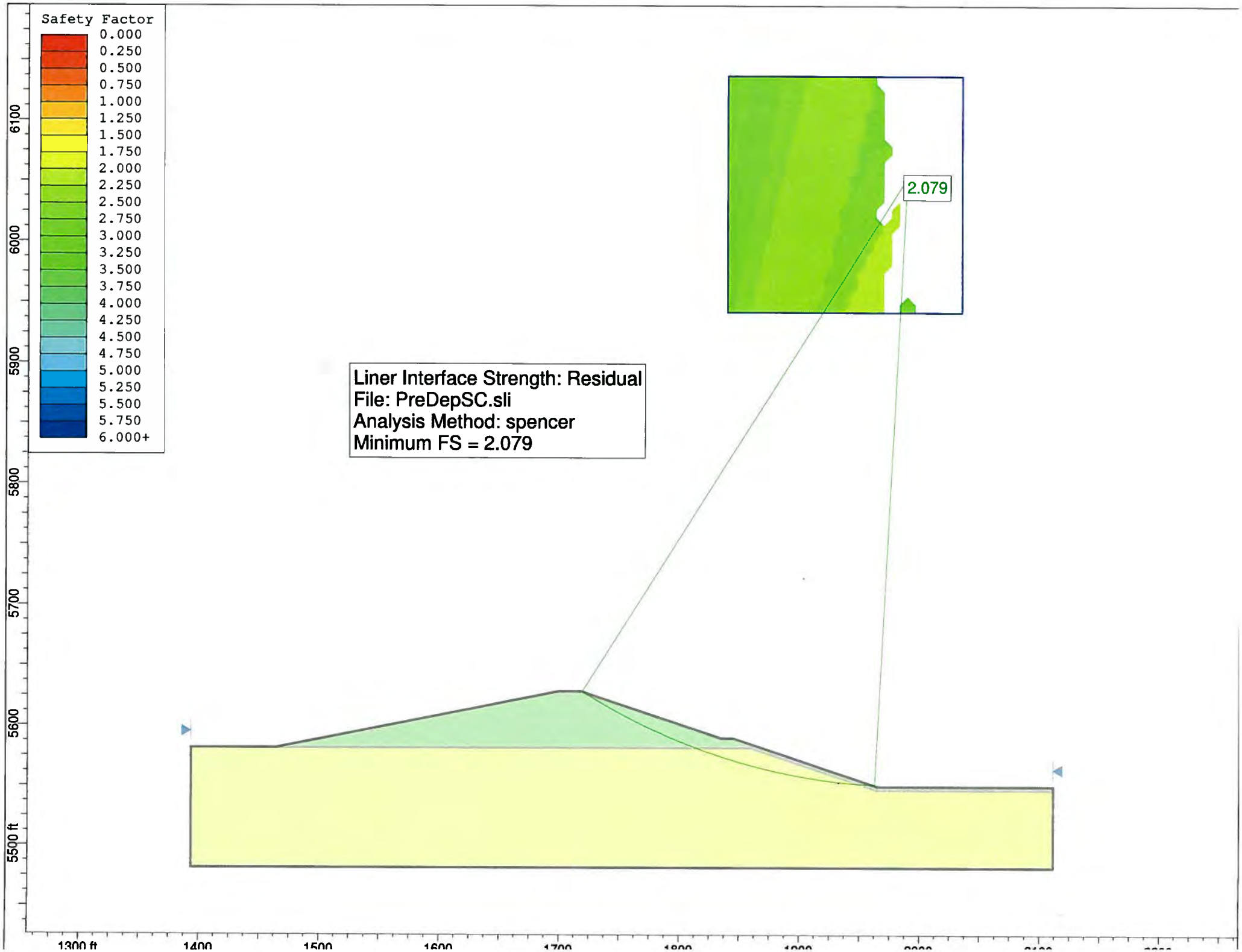
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Peak
File: PostCloENC.sli
Analysis Method: spencer
Minimum FS = 2.652
2.652
0.08
W
6100
6000
5900
5800
5700
5600
5500 ft
3500 ft
3600
3700
3800
3900
4000
4100
4200
4300

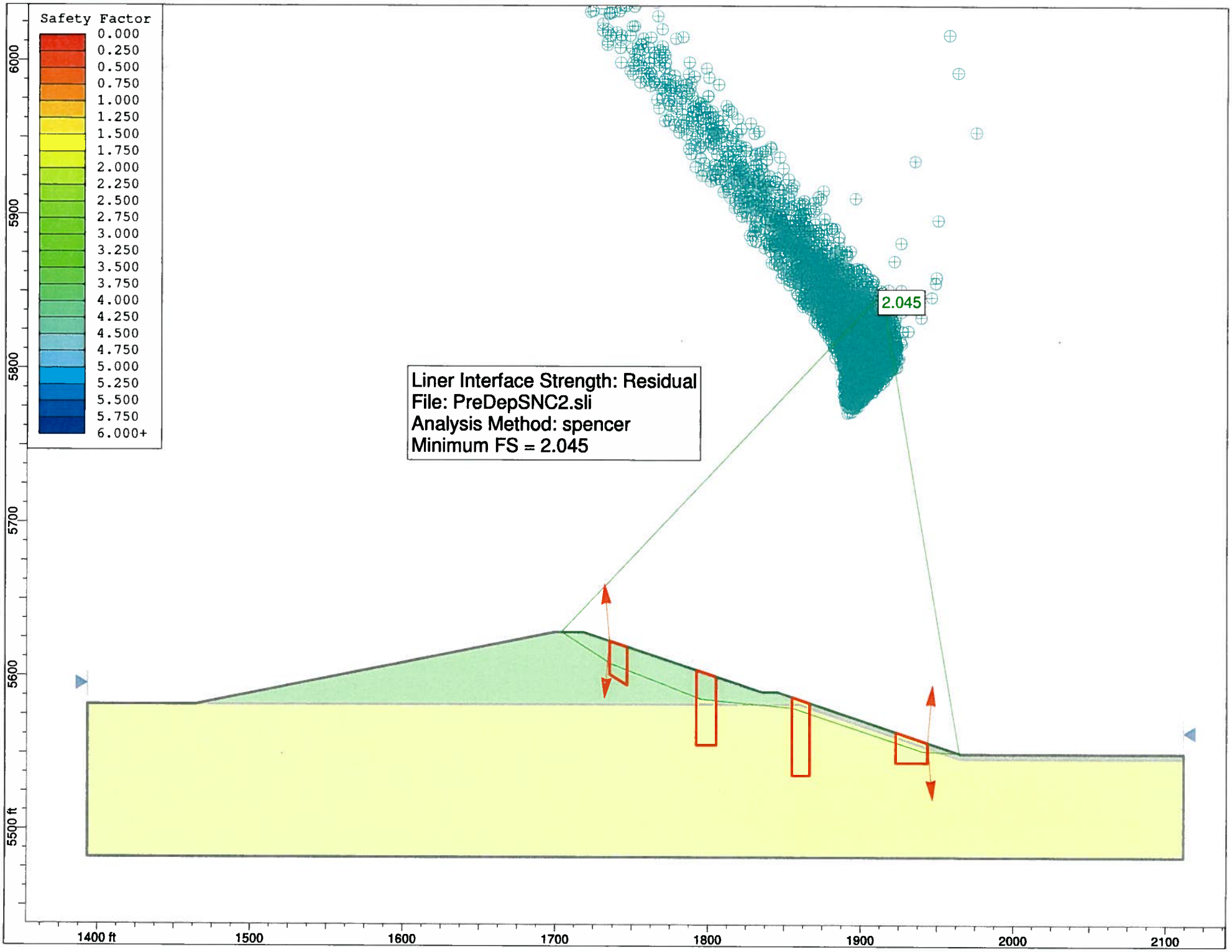
TABLE A3-2
SUMMARY OF RESIDUAL STABILITY ANALYSES

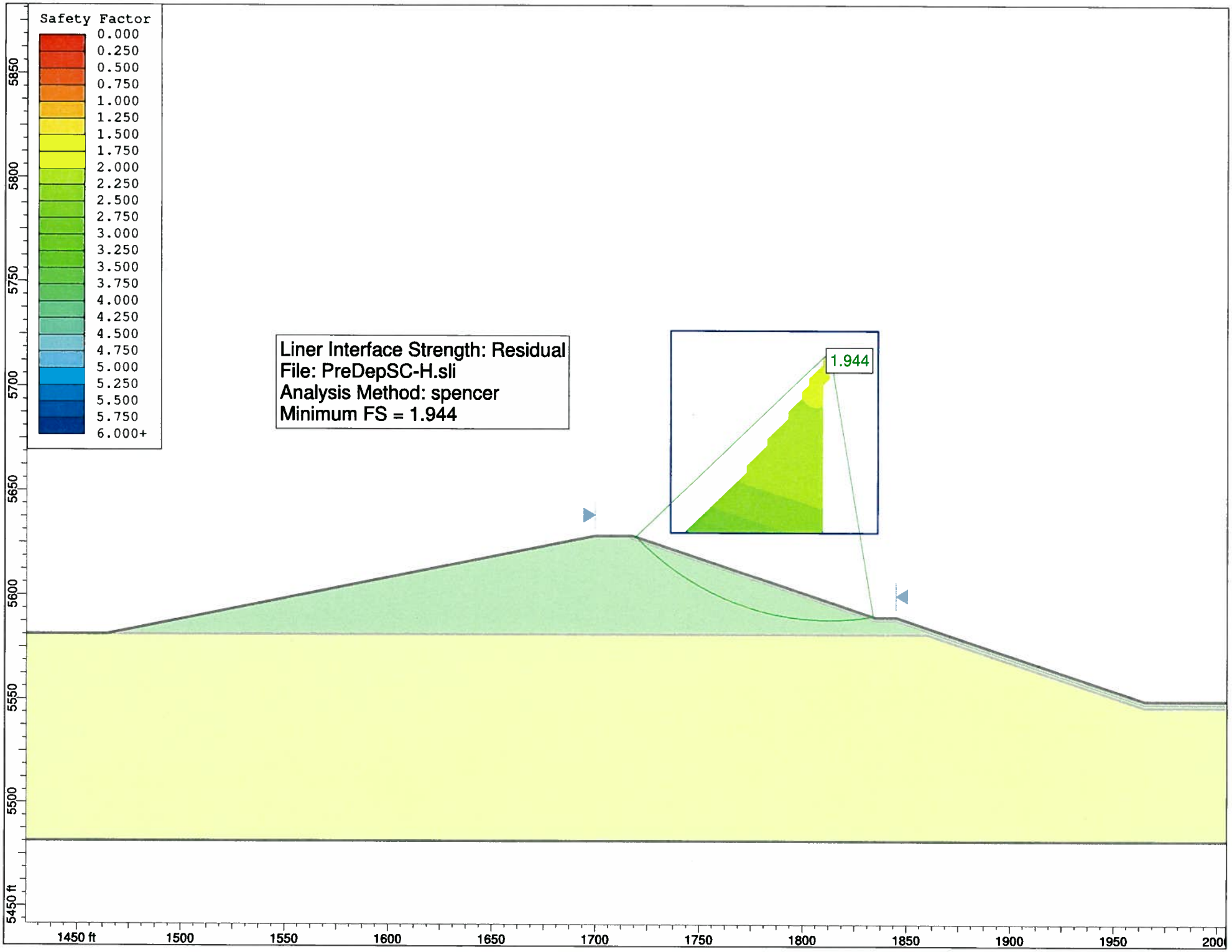
Analyses Using Residual Liner Interface Shear Strength

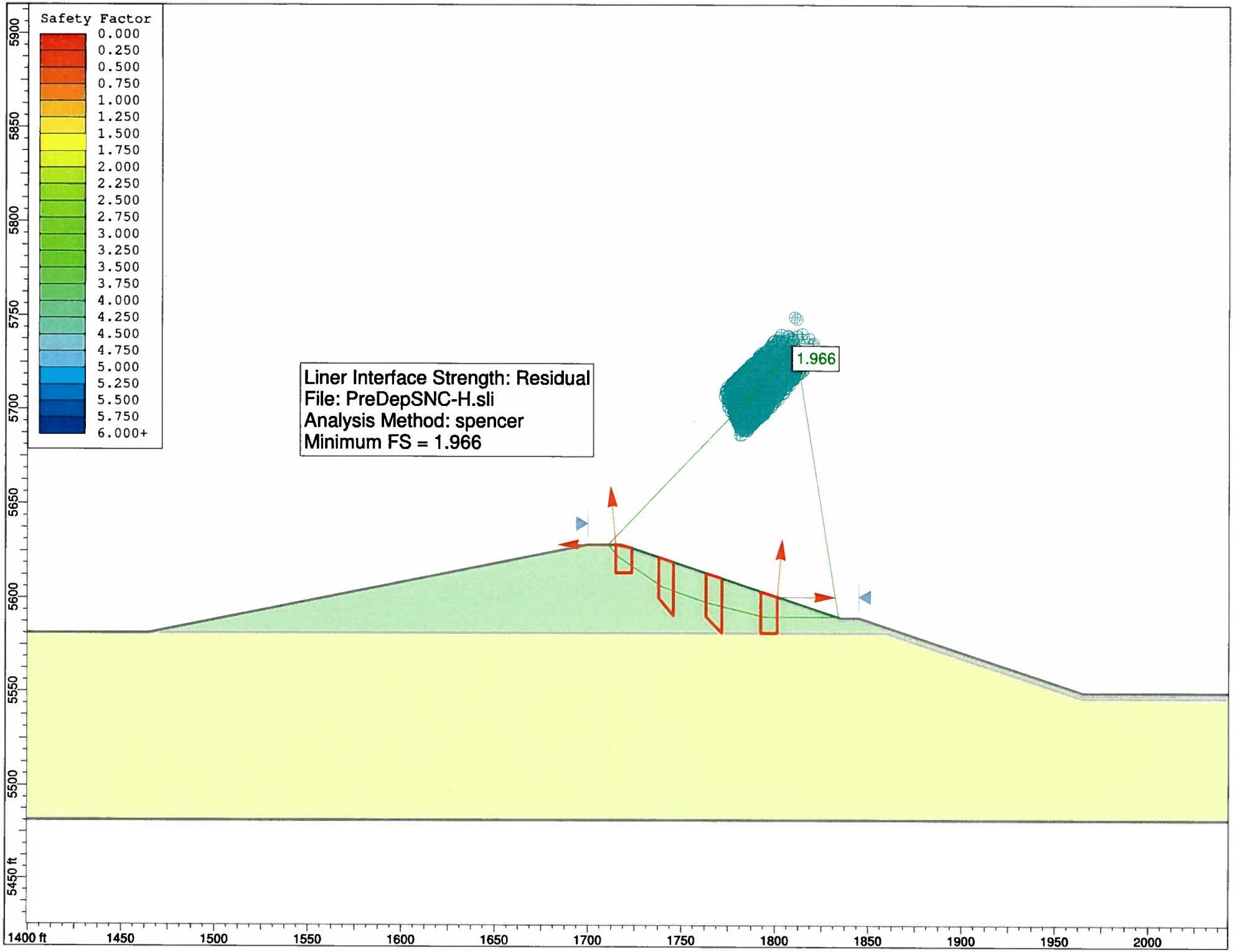
Scenario	File Name	Static or Seismic	Pseudo-Static Seismic Coefficient	Surface Type	Factor of Safety
Pre Deposition	PreDepSC.sli	Static	n/a	Circular	2.08
Pre Deposition	PreDepSNC2.sli	Static	n/a	Block	2.05
Pre Deposition	PreDepSC-H.sli	Static	n/a	Circular	**1.94**
Pre Deposition	PreDepSNC-H.sli	Static	n/a	Block	1.97
Pre Deposition	PreDepEC.sli	Seismic	0.05	Circular	1.77
Pre Deposition	PreDepENC2.sli	Seismic	0.05	Block	1.74
Pre Deposition	PreDepEC-H.sli	Seismic	0.05	Circular	**1.67**
Pre Deposition	PreDepENC-H.sli	Seismic	0.05	Block	1.68
Post Deposition	PostDepSC.sli	Static	n/a	Circular	8.61
Post Deposition	PostDepSNC.sli	Static	n/a	Block	8.05
Post Deposition	PostDepEC.sli	Seismic	0.05	Circular	2.52
Post Deposition	PostDepENC.sli	Seismic	0.05	Block	2.46
Post Deposition*	PostDepSC-B.sli	Static	n/a	Circular	**3.00**
Post Deposition*	PostDepSNC-B.sli	Static	n/a	Block	3.08
Post Deposition*	PostDepEC-B.sli	Seismic	0.05	Circular	**2.38**
Post Deposition*	PostDepENC-B.sli	Seismic	0.05	Block	2.44
Post Closure	PostCloSC.sli	Static	n/a	Circular	4.81
Post Closure	PostCloSNC.sli	Static	n/a	Block	**4.40**
Post Closure	PostCloEC.sli	Seismic	0.08	Circular	2.64
Post Closure	PostCloENC.sli	Seismic	0.08	Block	**2.34**

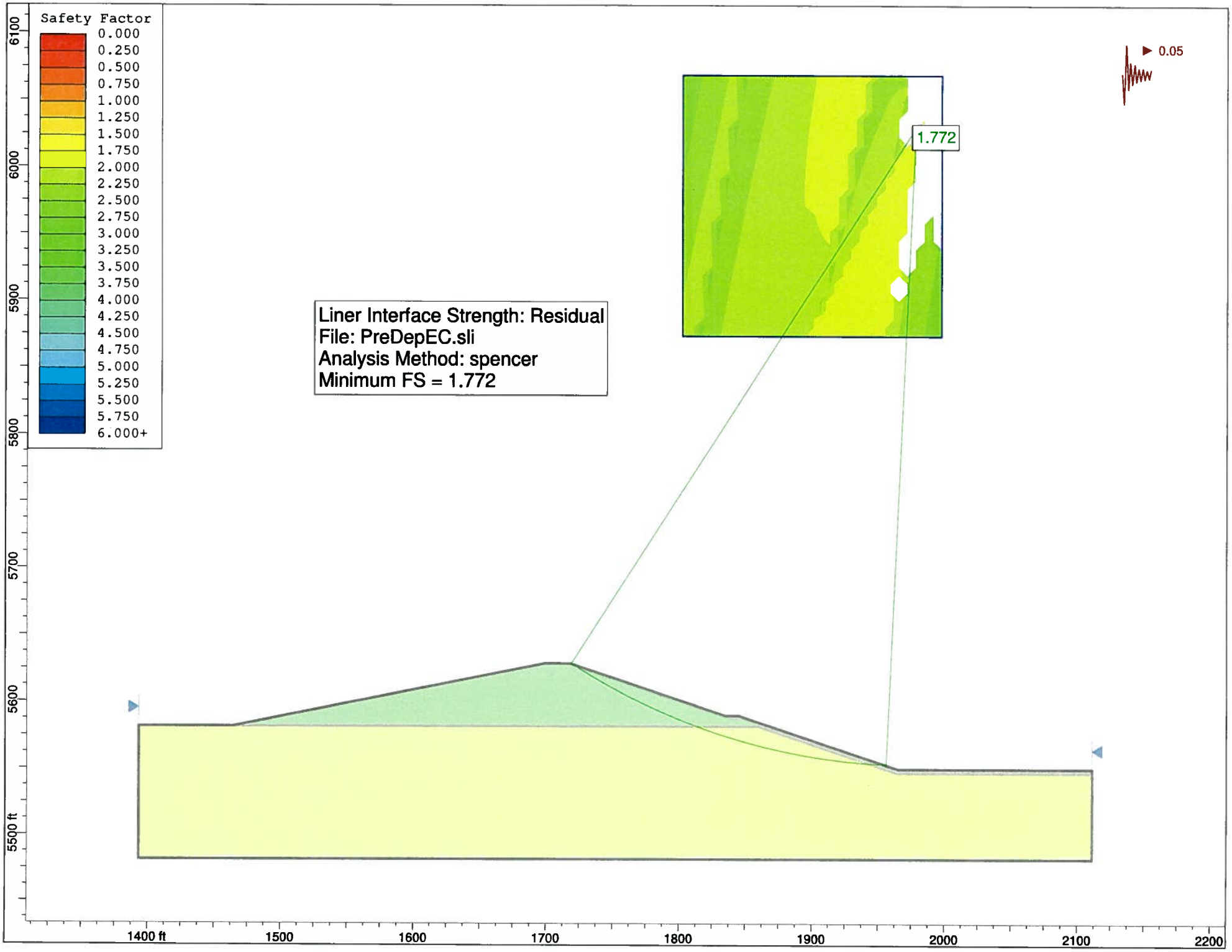
* Analysis identical to peak liner strength analysis - results not shown in Attachment 3.

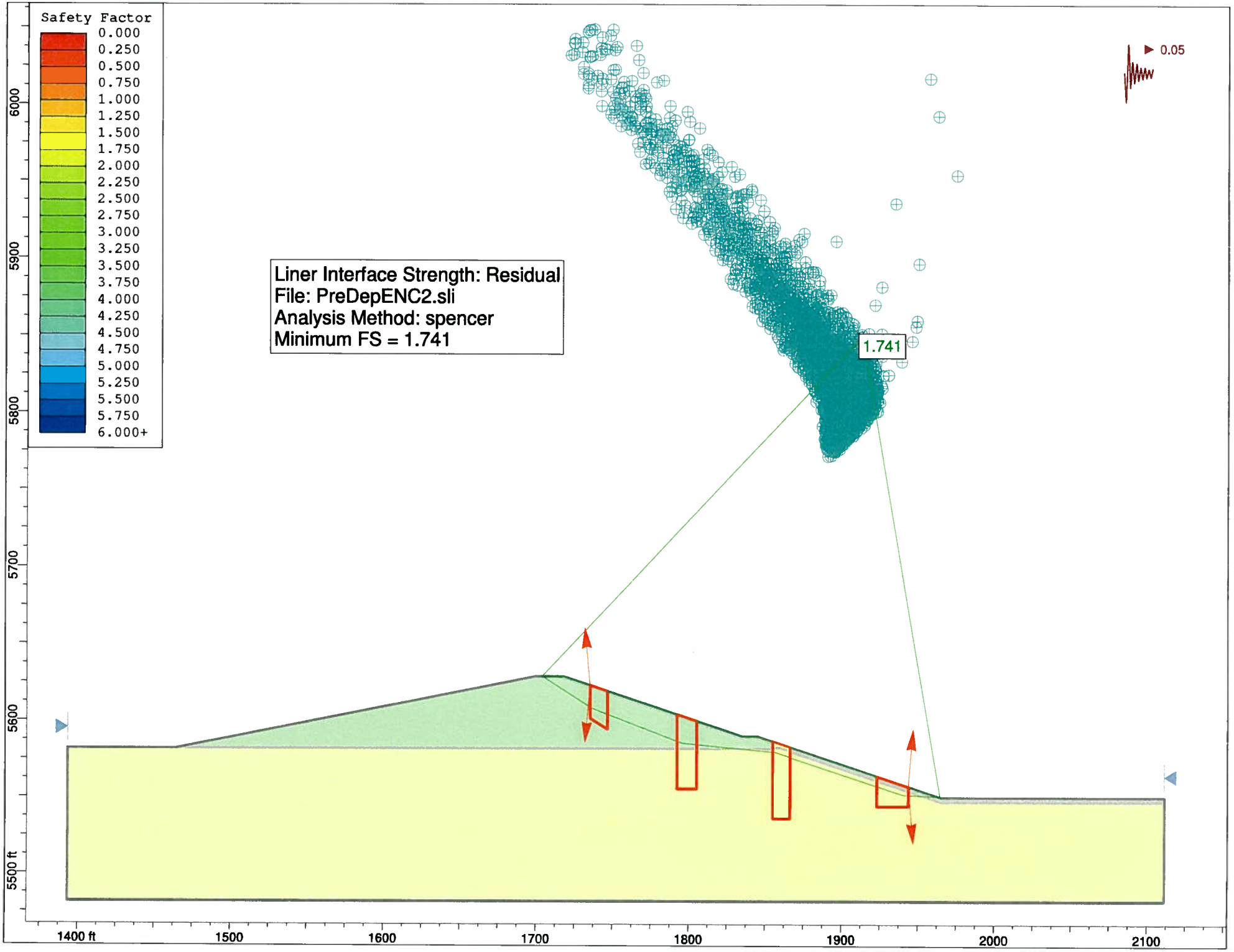

Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Residual
File: PreDepSC.sli
Analysis Method: spencer
Minimum FS = 2.079
2.079
6100
6000
5900
5800
5700
5600
5500 ft
1300 ft
1400
1500
1600

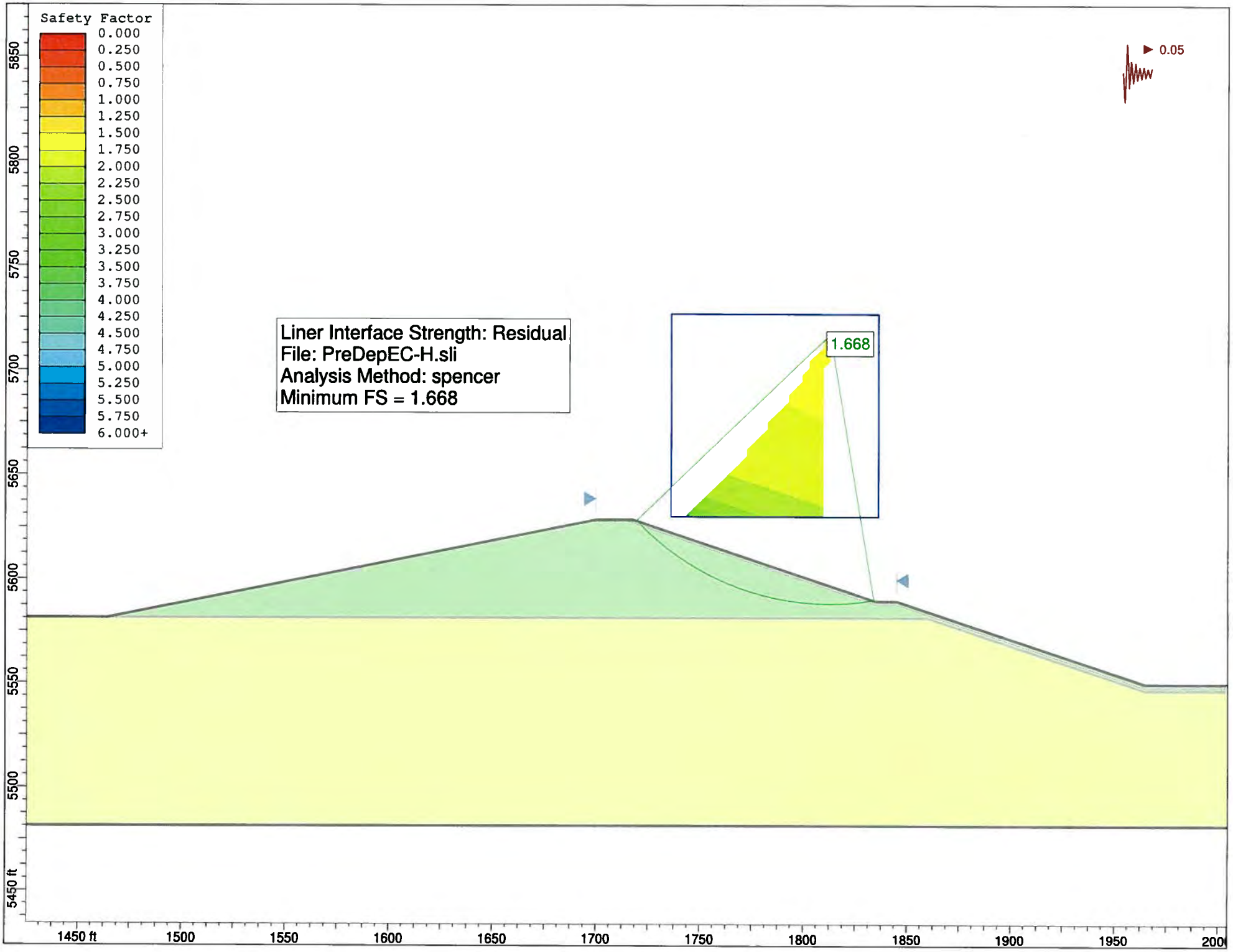

Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Residual
File: PreDepSNC2.sli
Analysis Method: spencer
Minimum FS = 2.045
2.045
6000
5900
5800
5700
5600
5500 ft
1400 ft
1500
1600
1700
1800
1900
2000
2100

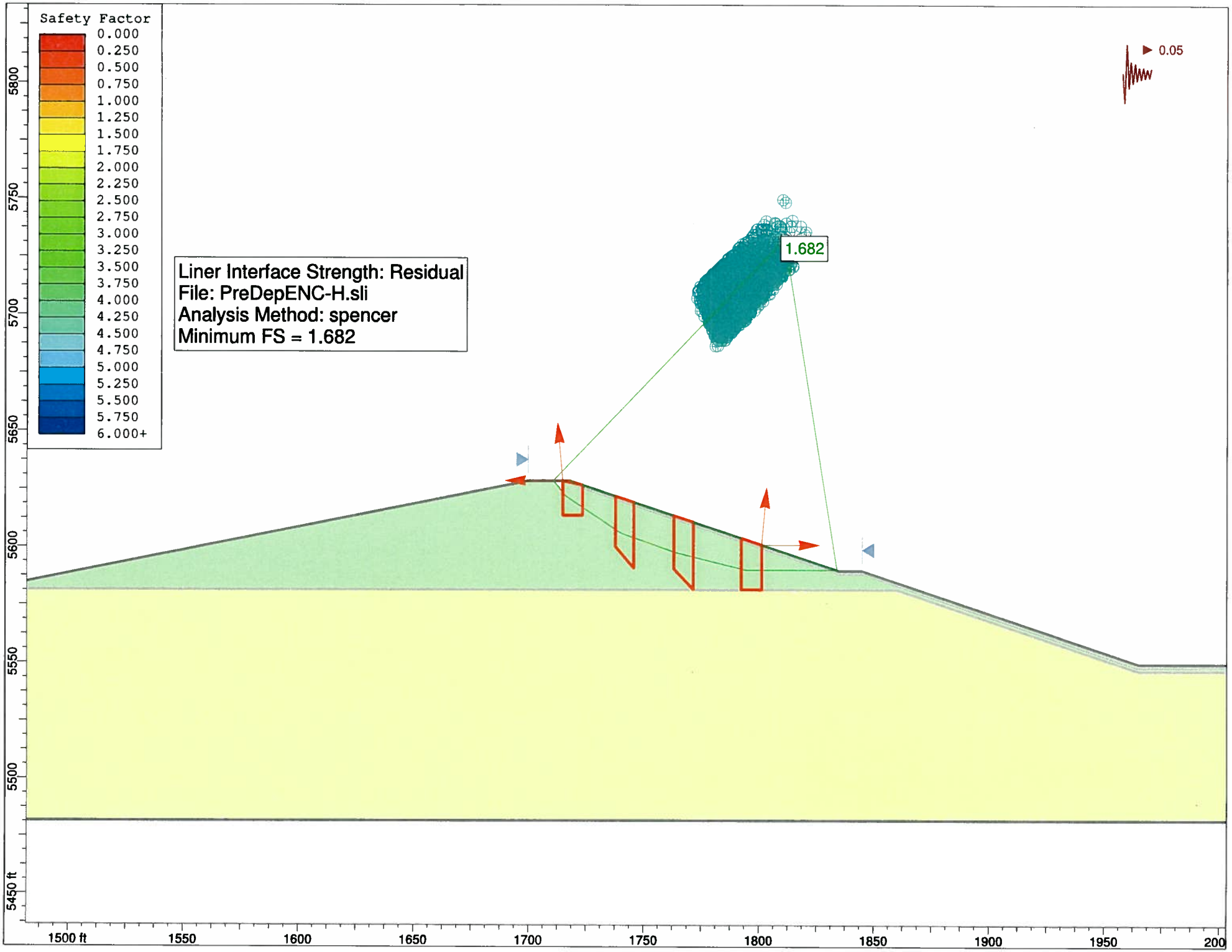

Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Residual
File: PreDepSC-H.sli
Analysis Method: spencer
Minimum FS = 1.944
1.944
5850
5800
5750
5700
5650
5600
5550
5500
5450 ft
1450 ft
1500
1550
1600
1650
1700
1750
1800
1850
1900
1950

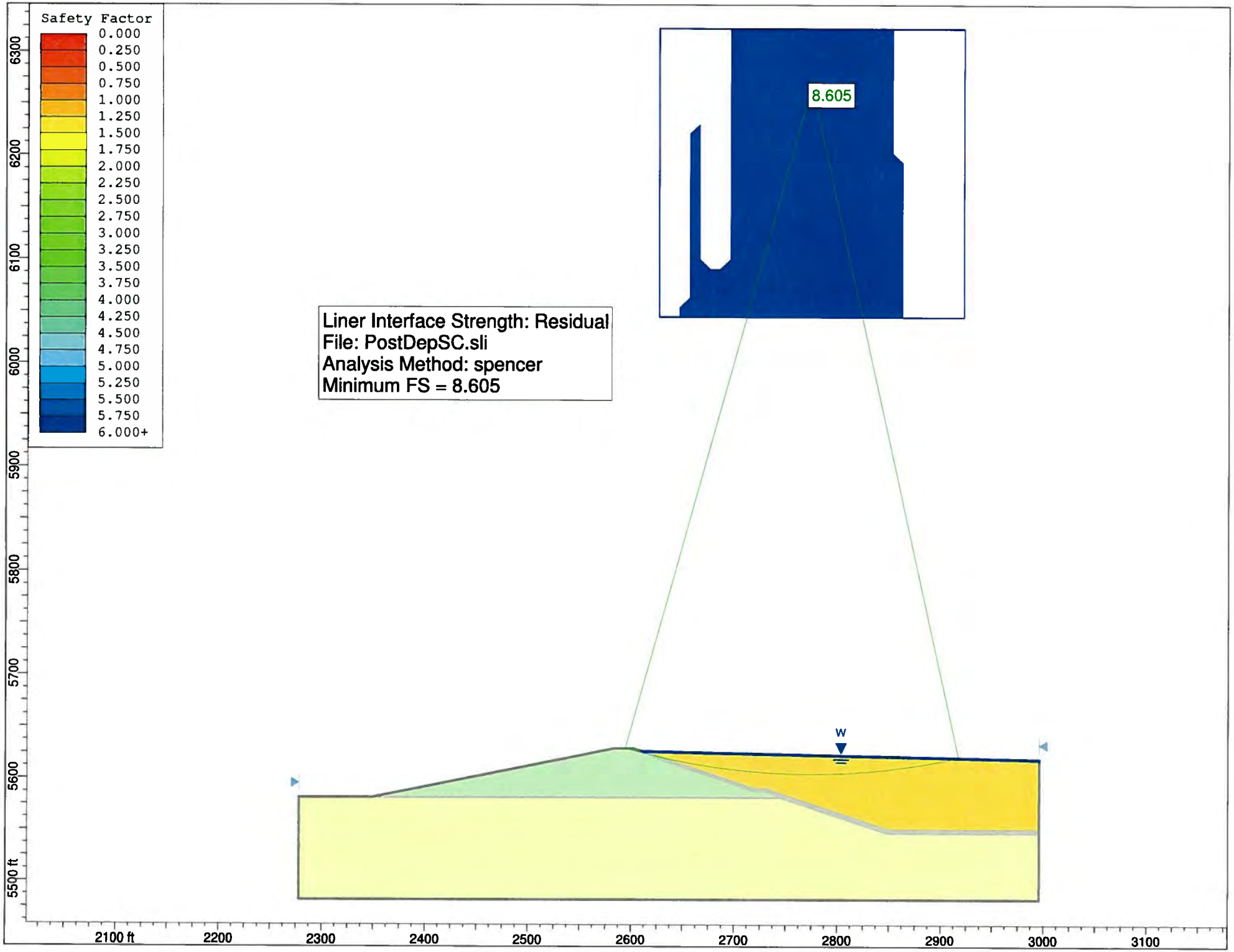

Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Residual
File: PreDepSNC-H.sli
Analysis Method: spencer
Minimum FS = 1.966
1.966
5900
5850
5800
5750
5700
5650
5600
5550
5500
5450 ft
1400 ft
1450
1500
1550
1600
1650
1700
1750
1800
1850
1900
1950
2000

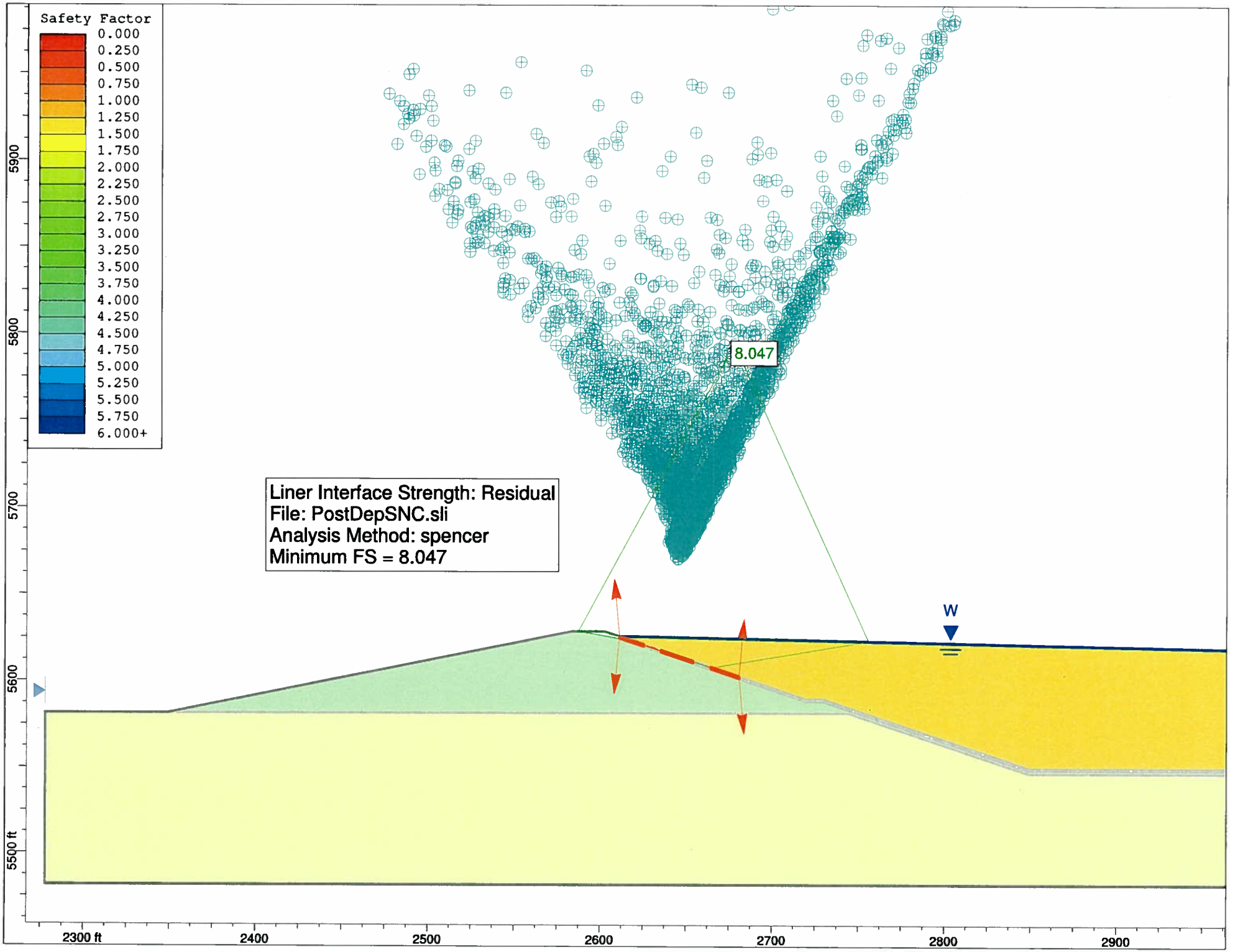

Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Residual
File: PreDepEC.sli
Analysis Method: spencer
Minimum FS = 1.772
1.772
0.05
6100
6000
5900
5800
5700
5600
5500 ft
1400 ft
1500
1600
1700
1800
1900
2000
2100
2200


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Residual
File: PreDepENC2.sli
Analysis Method: spencer
Minimum FS = 1.741
1.741
0.05
6000
5900
5800
5700
5600
5500 ft
1400 ft
1500
1600
1700
1800
1900
2000
2100


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Residual
File: PreDepEC-H.sli
Analysis Method: spencer
Minimum FS = 1.668
1.668
0.05
5850
5800
5750
5700
5650
5600
5550
5500
5450 ft
1450 ft
1500
1550
1600
1650
1700
1750
1800
1850
1900
1950


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Residual
File: PreDepENC-H.sli
Analysis Method: spencer
Minimum FS = 1.682
1.682
0.05
5800
5750
5700
5650
5600
5550
5500
5450 ft
1500 ft
1550
1600
1650
1700
1750
1800
1850
1900
1950
200


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Residual
File: PostDepSC.sli
Analysis Method: spencer
Minimum FS = 8.605
8.605
W
6300
6200
6100
6000
5900
5800
5700
5600
5500 ft
2100 ft
2200
2300
2400
2500
2600
2700
2800
2900
3000
3100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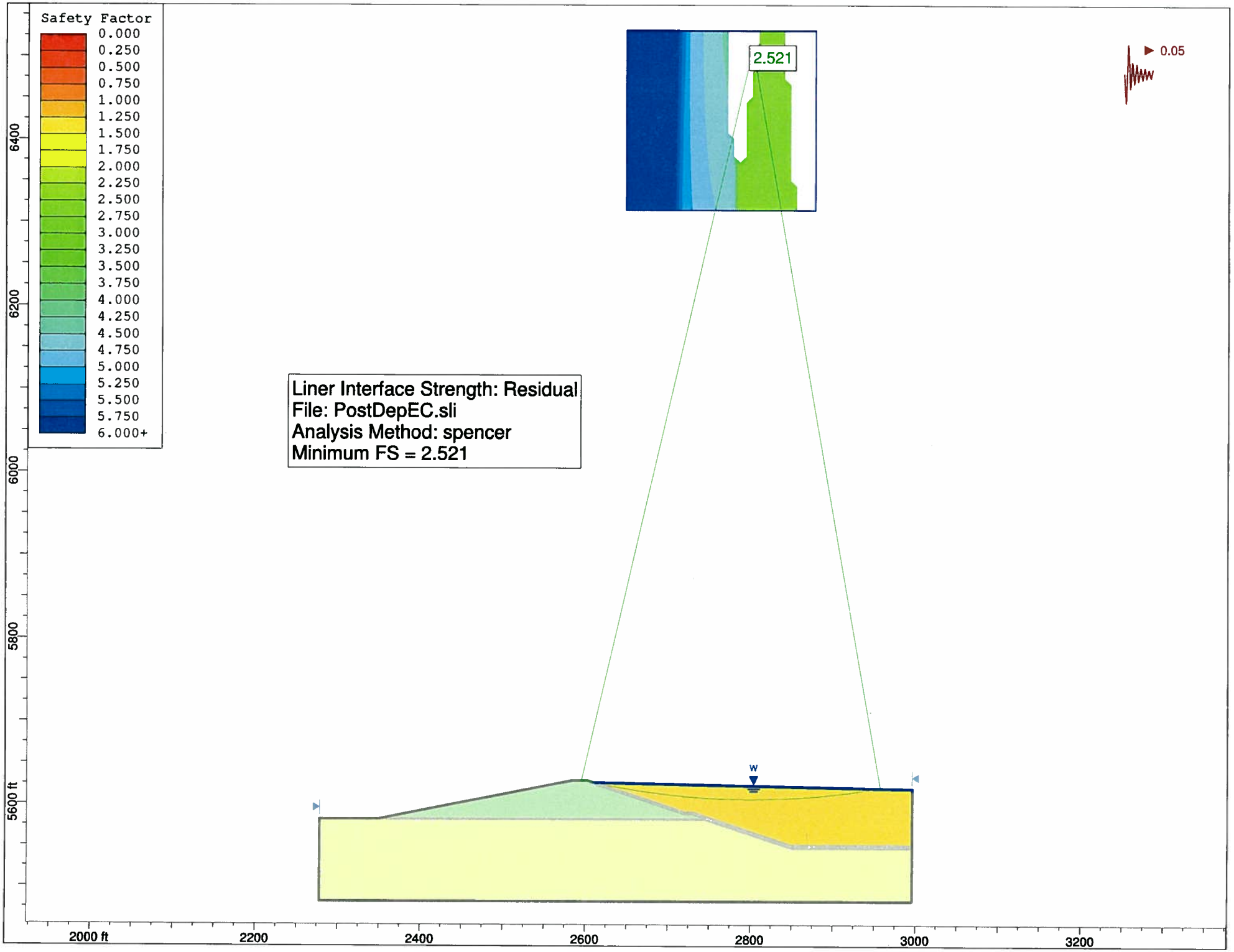
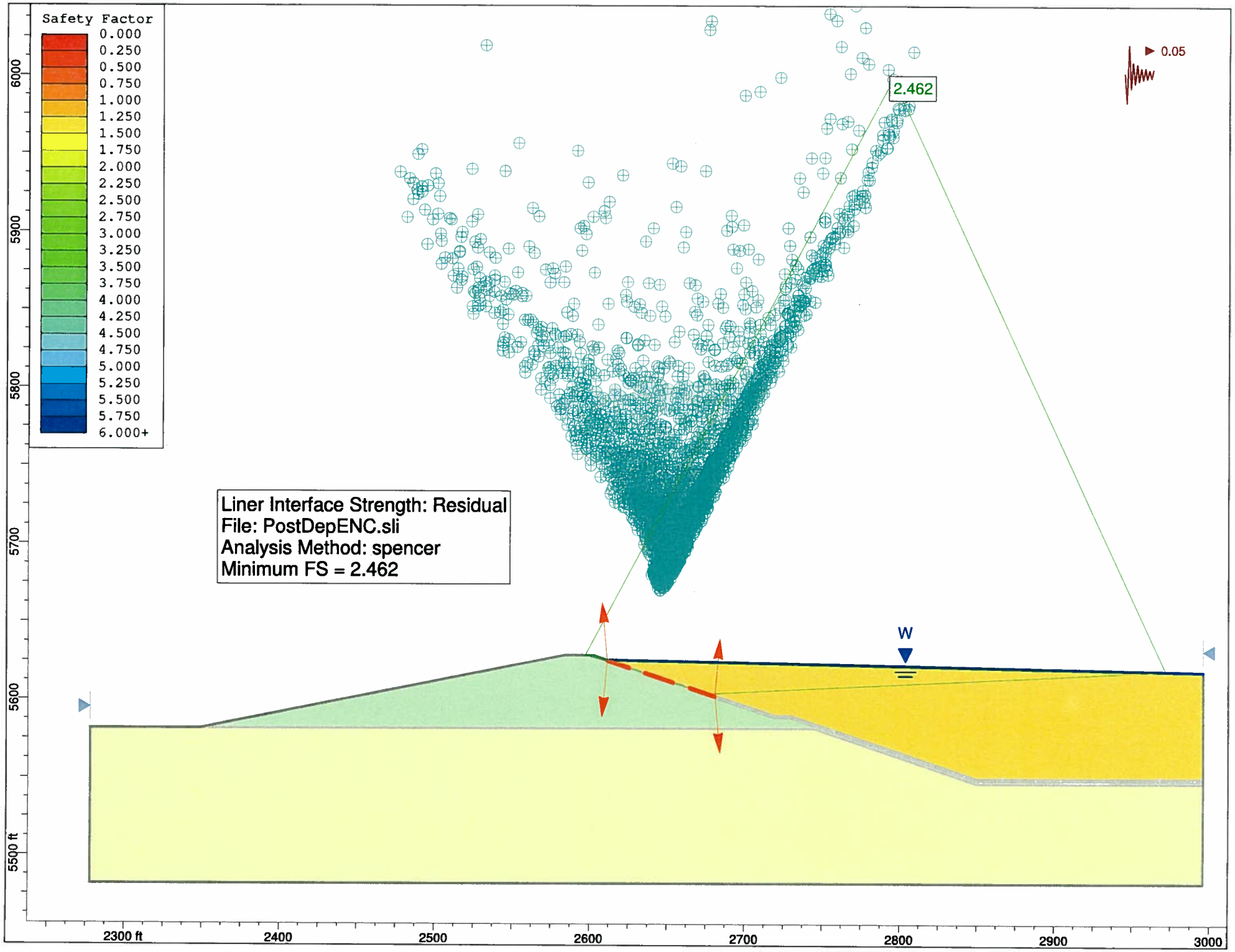
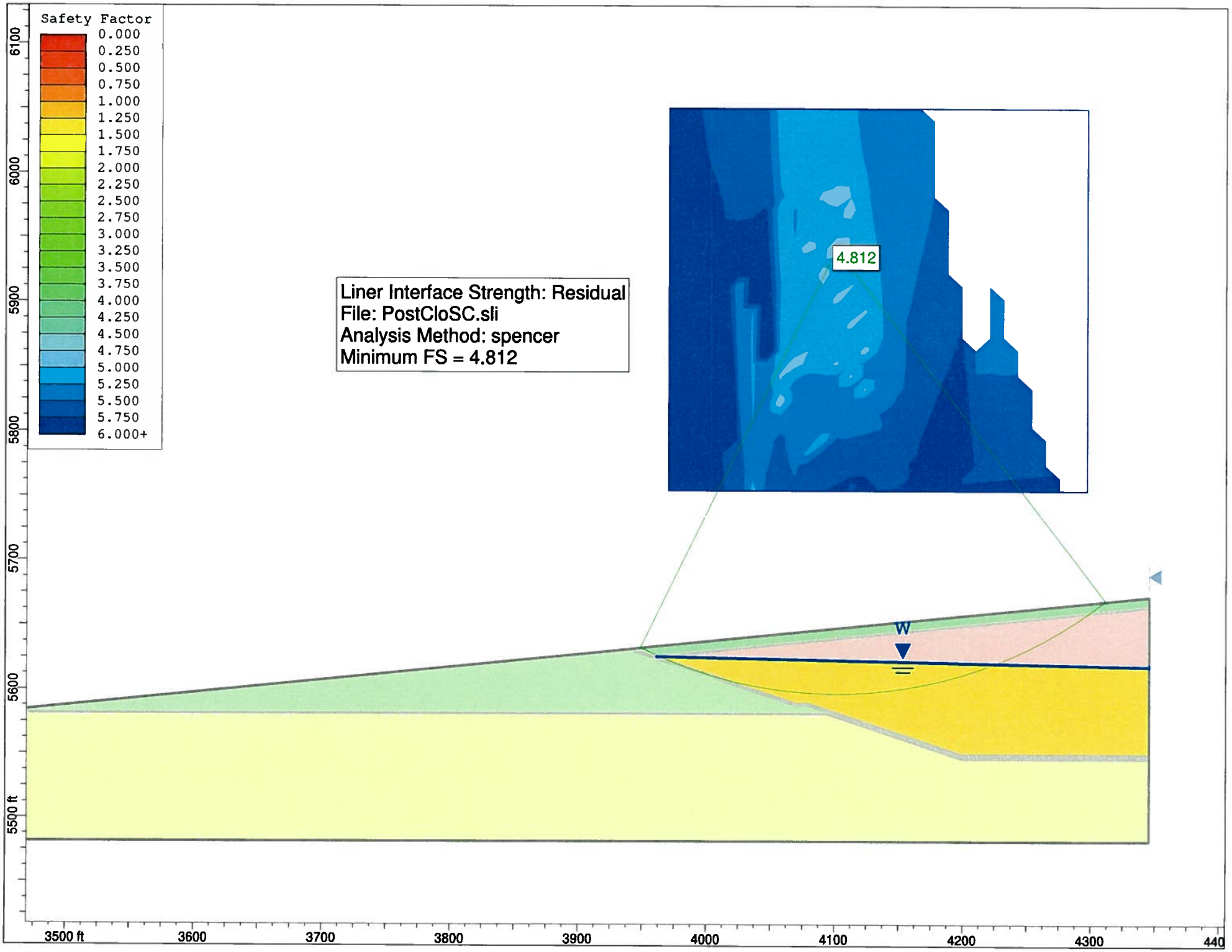
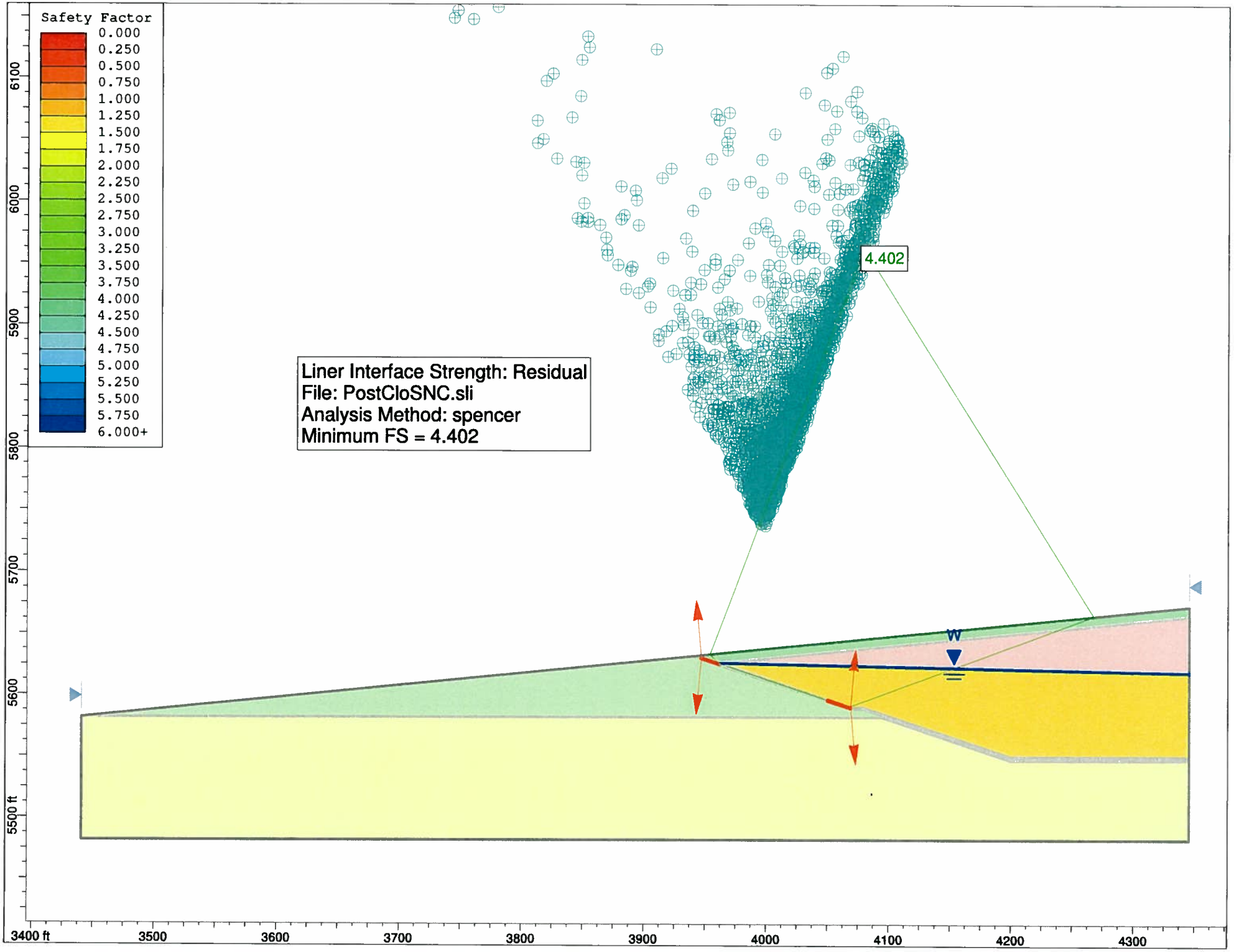
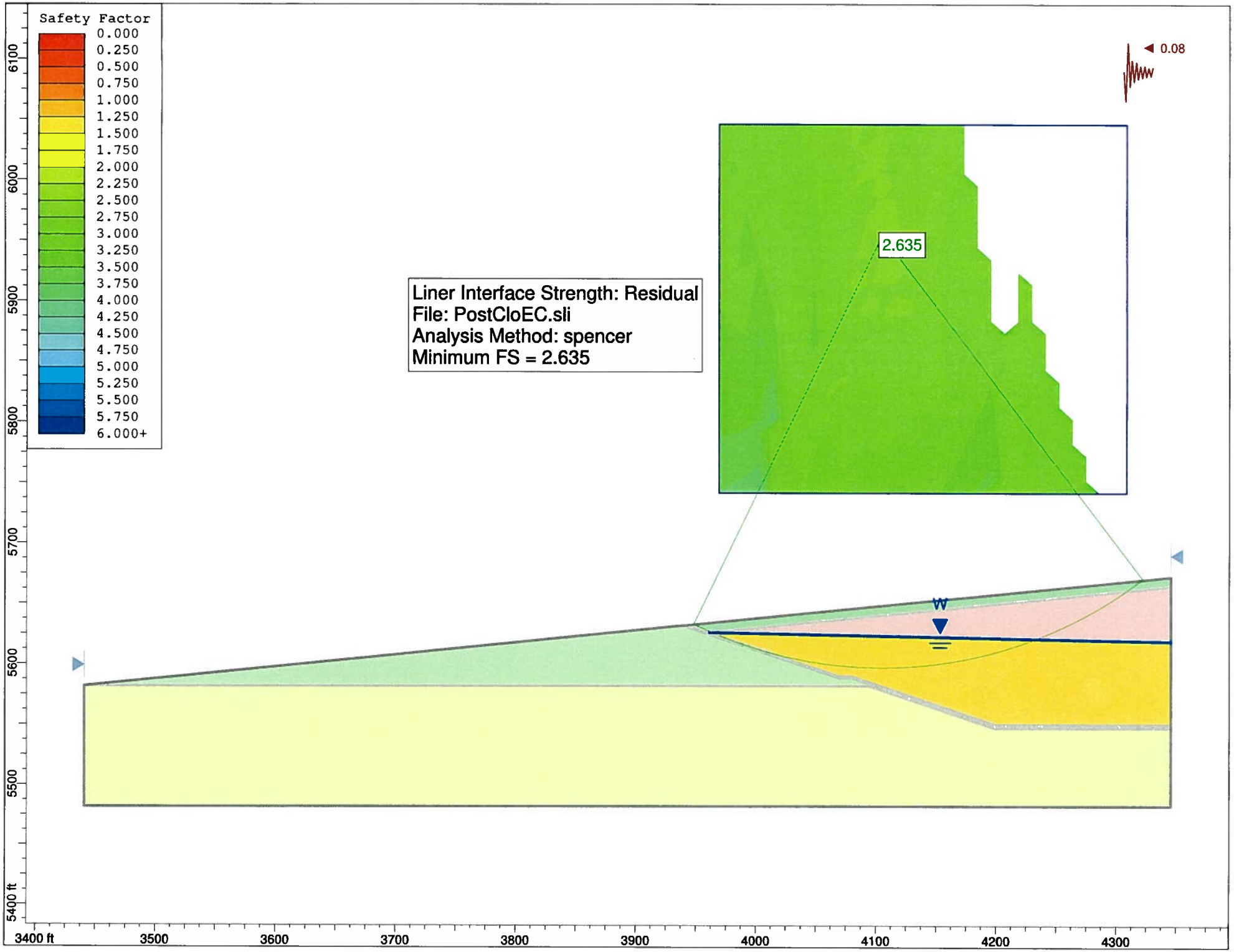
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
8.047
Liner Interface Strength: Residual
File: PostDepSNC.sli
Analysis Method: spencer
Minimum FS = 8.047
W
5900
5800
5700
5600
5500 ft
2300 ft
2400
2500
2600
2700
2800
2900

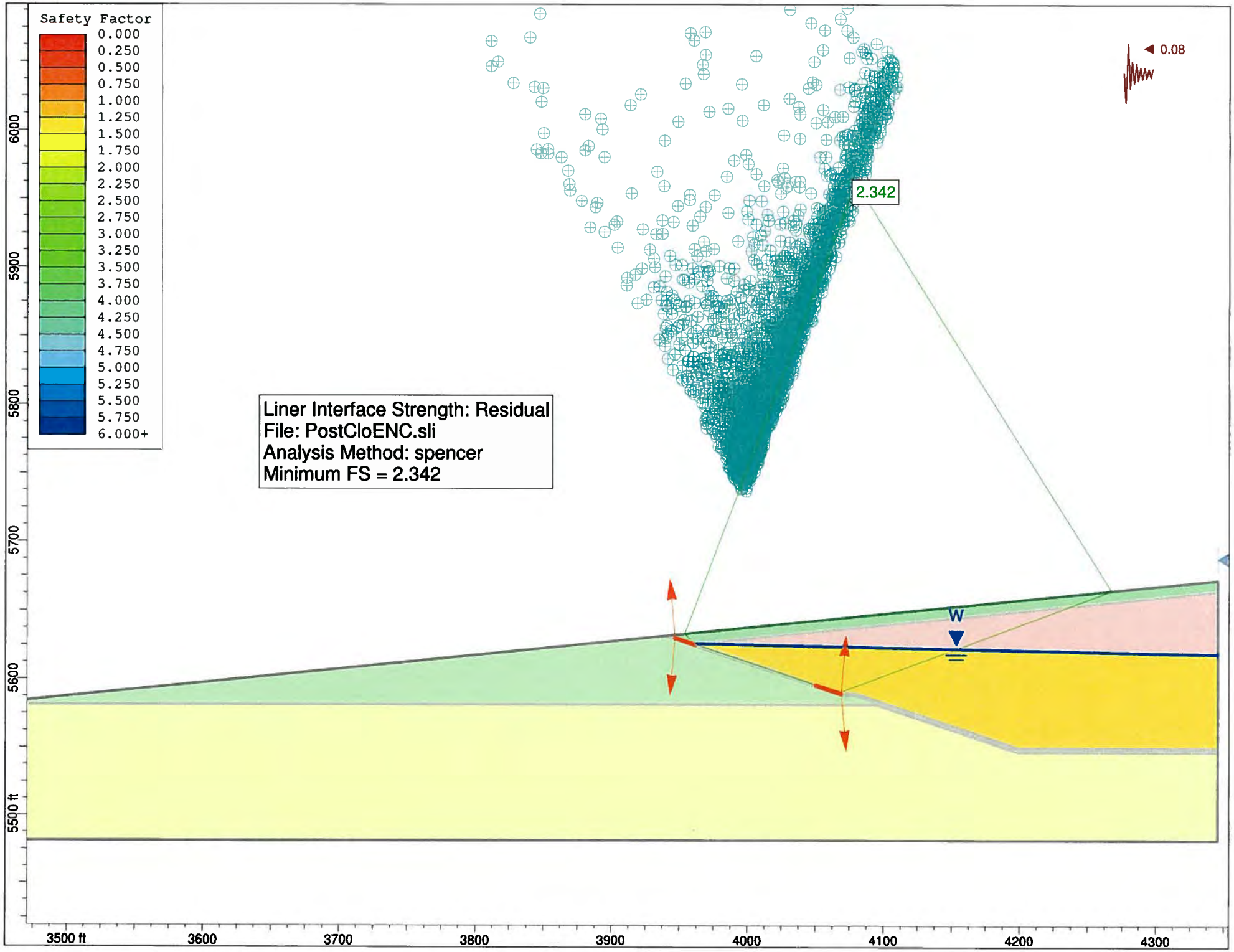

Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Residual
File: PostDepEC.sli
Analysis Method: spencer
Minimum FS = 2.521
2.521
0.05
w
6400
6200
6000
5800
5600 ft
2000 ft
2200
2400
2600
2800
3000
3200


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Residual
File: PostDepENC.sli
Analysis Method: spencer
Minimum FS = 2.462
2.462
0.05
W
6000
5900
5800
5700
5600
5500 ft
2300 ft
2400
2500
2600
2700
2800
2900
3000


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Residual
File: PostCloSC.sli
Analysis Method: spencer
Minimum FS = 4.812
4.812
W
6100
6000
5900
5800
5700
5600
5500 ft
3500 ft
3600
3700
3800
3900
4000
4100
4200
4300
440


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Residual
File: PostCloSNC.sli
Analysis Method: spencer
Minimum FS = 4.402
4.402
W
6100
6000
5900
5800
5700
5600
5500 ft
3400 ft
3500
3600
3700
3800
3900
4000
4100
4200
4300


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Residual
File: PostCloEC.sli
Analysis Method: spencer
Minimum FS = 2.635
2.635
0.08
W
6100
6000
5900
5800
5700
5600
5500
5400 ft
3400 ft
3500
3600
3700
3800
3900
4000
4100
4200
4300


Safety Factor
0.000
0.250
0.500
0.750
1.000
1.250
1.500
1.750
2.000
2.250
2.500
2.750
3.000
3.250
3.500
3.750
4.000
4.250
4.500
4.750
5.000
5.250
5.500
5.750
6.000+
Liner Interface Strength: Residual
File: PostCloENC.sli
Analysis Method: spencer
Minimum FS = 2.342
2.342
0.08
W
6000
5900
5800
5700
5600
5500 ft
3500 ft
3600
3700
3800
3900
4000
4100
4200
4300

APPENDIX H-2

LINER SYSTEM STABILITY EVALUATION

Golder Associates	Subject Piñon Ridge Project	Made by JDE	Job No 073-81694
	Tailings Cell Design	Checked by KFM	Date 5/1/08
	Liner Stability Calculation	Approved by KFM	Sheet No 1 of 2

OBJECTIVE:

Calculate the factor of safety against sliding of the tailings cell liner system assuming the interior cell slopes approximate an infinite slope situation.

ASSUMPTIONS:

- Adhesion / cohesion between liner interfaces is conservatively neglected;
- Effects of stabilizing agents (i.e. anchor trenches, buttressing pipes, etc.) are ignored; and
- Others as stated.

CALCULATIONS:

The relevant liner interfaces for the tailings cell liner system are:

- Textured Geomembrane vs. Drainage Geocomposite;
- Textured Geomembrane vs. Geosynthetic Clay Liner (GCL); and
- GCL vs. compacted native soil.

Interface shear strength testing was performed an all the above interfaces by Golder's Atlanta soils laboratory, the results of which are presented in Appendix H-1. Based on these results, the weakest interface that governs design is between the textured high density polyethylene (HDPE) geomembrane and the drainage geocomposite. Laboratory tests on this interface indicate that the peak friction angle is 21.2 degrees with apparent adhesion of 7.7 pounds per square inch (psi). This calculation conservatively ignores the adhesion component.

The factor of safety, FS, for an infinite slope problem can be expressed as follows (Das, 1998):

$$FS = \frac{c}{\gamma H \cos^2\beta \ \tan\beta} + \frac{\tan\emptyset}{\tan\beta}$$

Where c is the cohesion/adhesion, γ is the unit weight of the soil above the interface, H is the height of soil above the interface, β is the slope of the interface (in this case, 3H:1V, or 18.4 degrees), and ϕ is the friction angle of the interface. Since adhesion is conservatively being ignored, the left side of the equation goes to zero, and we are left with:

$$FS = \frac{\tan\emptyset}{\tan\beta} = \frac{\tan 21.2}{\tan 18.4} = 1.2$$

CONCLUSIONS:

The factor of safety of 1.2 calculated above indicates that the proposed liner system is stable under its own weight at the proposed tailings cell slopes. It should be noted, however, that this factor of safety excludes the additional retaining capacity provided by the apparent adhesion, as well as the resisting forces supplied via the anchor trenches and liner buttressing.

REFERENCES:

Das, Braja M. (1998). *Principles of Geotechnical Engineering, 4th Edition.* PWS Publishing Company, Boston.