GEOSYNTEC CONSULTANTS

COMPUTATION COVER SHEET

Client: Honeywell **Project:** Onondaga Lake ILWD Stability **Project/Proposal #:** GJ4204 **Task #:** 14-05

TITLE OF COMPUTATIONS **SEISMIC SLOPE STABILITY ANALYSES**

COMPUTATIONS BY:

Signature Fan Zhu

1/17/2011
DATE

Printed Name and Title: Fan Zhu
Senior Staff Engineer

ASSUMPTIONS AND PROCEDURES CHECKED BY:
(Peer Reviewer)

Signature Ming Zhu R. Kulasingam

1/17/2011
DATE

Printed Name and Title: Ming Zhu/R. Kulasingam
Project Engineer/Senior Engineer

COMPUTATIONS CHECKED BY:

Signature Joseph Sura

1/17/2011
DATE

Printed Name and Title: Joseph Sura
Senior Staff Engineer

COMPUTATIONS BACKCHECKED BY:
(Originator)

Signature Fan Zhu

1/17/2011
DATE

Printed Name and Title: Fan Zhu
Senior Staff Engineer

APPROVED BY:
(PM or Designate)

Signature J. Beech

17 JAN 2011
DATE

Printed Name and Title: Jay Beech
Principal

APPROVAL NOTES: ______

REVISIONS (Number and initial all revisions)

NO.	SHEET	DATE	BY	CHECKED BY	APPROVAL

Written by:	Fan Zhu	Date:	1/14/2011	Reviewed by:	Ming Zhu/R. Kulasingam/Jay Beech	Date:	1/14/2011

Client:	Honeywell	Project:	Onondaga Lake ILWD Stability	Project/ Proposal No.:	GJ4204	Task No.:	14-05

SEISMIC SLOPE STABILITY ANALYSES

INTRODUCTION

This calculation package was prepared as part of the Remediation Area D geotechnical stability analysis for the Onondaga Lake Bottom Site. Specifically, the purpose of this package is to present seismic slope stability analyses for Remediation Area D after capping. Remediation Area D, which is also referred to as the In-Lake Waste Deposit (ILWD), is shown in Figure 1. Remediation Area D consists predominantly of Sediment Management Unit (SMU) 1 with limited portions of SMUs 2 and 7. The seismic slope stability of both (i) overall general cross sections along the ILWD slope and (ii) localized areas that have relatively steep slopes was evaluated for the condition after capping.

It should be noted that the cap configurations used in the analyses presented herein are consistent with the mean cap thickness, as documented in the main text of the *Capping, Dredging, and Habitat Design.* For the purpose of the analyses presented herein, the expected potentially critical condition with the maximum potential difference in cap thickness was assumed, as described later in this package. The liquefaction evaluation of the cap is presented in Appendix H.2 of the *Capping, Dredging, and Habitat Design* in a calculation package titled "*Liquefaction Potential Analysis*" (referred to as the Liquefaction Package).

METHODOLOGY

Seismic Slope Stability

Seismic slope stability analyses were performed using Spencer's method [Spencer, 1973], as implemented in the computer program SLIDE, version 5.0 [Rocscience, 2006]. Rotational type failure mode, i.e. circular slip surface, was considered to assess the pseudostatic slope stability factor of safety (FS) of the selected cross sections. Wedge type slip surfaces were not considered applicable for Remediation Area D because they generally only apply when known weak layers or interfaces are present. Regardless, an independent analysis was performed assuming wedge type slip surfaces. The results indicated that the FSs calculated using the wedge type slip surfaces were greater than those calculated using the circular slip surfaces. Therefore, only circular slip surfaces were evaluated. Detailed discussion regarding Spencer's method and the SLIDE program is presented in Appendix H.3 of the *Capping, Dredging, and Habitat Design* in a calculation package titled "*Static Slope Stability Analyses*" (referred to as the Static Stability Package). The procedure for the seismic slope stability analysis presented herein is summarized as follows:

- Select a pseudostatic coefficient to reduce the maximum horizontal acceleration for use in slope stability analyses. This is done in recognition that maximum acceleration exists only for a very short time [Kramer, 1996]. Based on the discussions presented in the Federal Highway Administration's seismic design guidance document [Kavazanjian et al., 1997], a pseudostatic coefficient of 0.5 was conservatively selected for this seismic slope stability evaluation.

- Calculate the horizontal seismic coefficient (k) by multiplying the maximum horizontal acceleration by the pseudostatic coefficient. A maximum horizontal acceleration of 0.09g was selected for a contingency level event (i.e., a seismic event with a 10 percent chance of exceedance in 50 years) at the site, as required in the Statement of Work of the Consent Decree for the Onondaga Lake Bottom Subsite (United States District Court, 2007) and as presented in the Liquefaction Package. Using this maximum horizontal acceleration of 0.09g and a pseudostatic coefficient of 0.5, a horizontal seismic coefficient (k) of 0.045g was calculated for the seismic analysis.

- Perform pseudostatic slope stability analyses by applying a horizontal seismic coefficient to the same procedures used for static slope stability analyses. If the calculated pseudostatic FS is greater than 1.1, the slope is considered to have an acceptable FS under the contingency level seismic event (i.e., a seismic event of 10 percent chance of exceedance in 50 years). If the calculated pseudostatic FS is less than 1.1, calculate permanent seismic displacements by performing deformation analysis and compare the calculated displacement to allowable displacements. Calculate the yield acceleration (i.e., the horizontal seismic coefficient that results in a calculated FS of 1.0) and estimate permanent displacements using the Hynes and Franklin [1984] chart (Figure 2).

SUBSURFACE STRATIGRAPHY

Detailed information regarding the subsurface stratigraphy is presented in Appendix H.1 of the *Capping, Dredging, and Habitat Design* in a calculation package titled "*Summary of Subsurface Stratigraphy and Material Properties*" (referred to as the Data

Package). In summary, the subsurface stratigraphy primarily consists of the following materials: Solvay Waste (SOLW), Marl, Silt and Clay, Silt and Sand, Sand and Gravel, Till, and Shale. In isolated areas of the ILWD, thin silt layers are present over the SOLW. The elevation of the lake water surface in the ILWD was assumed to be El. 363 feet above mean sea level (NAVD88), as presented in the Data Package.

The subsurface profile of the ILWD was developed based on the elevation of each layer from the boring logs provided by Parsons. As explained in the Data Package, the deeper surfaces (e.g., bottom of Silt and Clay, bottom of Silt and Sand) that were below the depth of shallow borings were developed based on a limited number of deeper borings in the ILWD. Since critical slip surfaces identified in the analyses are generally located within depths that were covered by the shallower borings (i.e., borings that terminated in or above the Silt and Clay layer), this is not expected to affect the seismic slope stability evaluation.

ANALYZED CROSS SECTIONS

As shown on the proposed dredging plan in Figure 1, eight cross sections were selected for the stability analyses. The dredging plan was developed by Anchor QEA and provided to Geosyntec by Parsons. Cross Sections 1 through 5 were selected to represent the overall general slope of the ILWD. Cross Sections A to C were selected to represent potentially critical localized steep slopes. As documented in the main text of the *Capping, Dredging, and Habitat Design*, the total cap thickness varies with the water depth. The minimum and mean thicknesses of each cap component correspond to several ranges in water depths.

For the overall general slopes after the entire Remediation Area D is capped, the condition where the cap in 10 to 30 ft of water has the minimum total thickness, while the caps in other areas have the mean (with overplacement) total thicknesses was found to be the potentially critical condition based on a preliminary analysis. The same cap configuration for the overall general slopes was applied to the localized steep slopes. The analyzed geometries of Cross Sections 1 through 5 and Cross Sections A through C after capping are presented in Figures 3 to 10.

MATERIAL PROPERTIES

Detailed information related to the selection of subsurface material properties was presented in the Data Package. Table 1 summarizes the material properties (i.e., unit weights and shear strengths) of each subsurface material and the cap material (i.e., the sand) used in the slope stability analyses.

Based on the material type, the appropriate undrained and drained material properties were used in the analyses. Specifically, drained shear strength properties were used for Silt and Sand, Sand and Gravel, Till, and Shale. The drained properties of Marl were used for the silt in isolated areas of the ILWD. The sand material in the proposed cap was modeled with drained strength parameters. Undrained shear strength properties were used for SOLW, Marl, and Silt and Clay, as they are fine grained materials and take a relatively long time to dissipate pore pressures generated under seismic loading conditions. As described for the after-capping condition in the Static Stability Package (see Material Properties section and Attachment 1 of that package), the undrained shear strength ratios of Marl and Silt and Clay were also manually reduced for the analyses presented herein.

RESULTS AND CONCLUSIONS

The seismic slope stability of Remediation Area D after capping was evaluated for five overall general slope cross sections (i.e., Cross Sections 1 through 5) and three localized steep slope cross sections (i.e., Cross Sections A through C). The results of seismic slope stability analyses are summarized in Table 2. As examples, the critical circular slip surfaces for Cross Sections 2, 3, and C are shown in Figures 11 through 13.

Under the after-capping condition, the calculated seismic slope stability FSs for the selected eight cross sections range from 1.4 to 1.9. The results indicate that the selected cross sections have acceptable calculated FSs after capping in case of a contingency level seismic event.

Additional analyses were performed to evaluate the sensitivity of the seismic slope stability to the undrained shear strength of SOLW. The three most critical cross sections, i.e., Cross Sections 2, 3, and C, were selected for the sensitivity analysis. In the sensitivity analysis, the SOLW shear strength value was reduced to represent the mean minus one standard deviation (i.e., 165 psf for the undrained shear strength), which was calculated based on the laboratory tests. The FSs for these three cross sections were calculated to be

1.10, 1.06, and 1.02, respectively, for the seismic condition after capping using the reduced undrained shear strength of SOLW. Because the calculated FS is less than the target FS of 1.1 for Cross Sections 3 and C, a deformation analysis was performed for these cross sections. The seismic displacements were estimated to range from 0.2 to 0.6 inches for Cross Sections 3 and C, which were considered to be acceptable. The analysis results are presented in Attachment 1.

REFERENCES

Hynes, M.E., and Franklin, A. G., "Rationalizing the Seismic Coefficient Method," Miscellaneous Paper GL-84-13, U.S Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, 1984.

Kavazanjian, E., Matasovic, N., Hadji-Hamou, T., and Sabatini, P. J., "Design Guidance: Geotechnical Earthquake Engineering for Highways – Design Priciples," Volume I, Publication No. FHWA-SA-97-076, U.S. Department of Transportation, 1997.

Kramer, S., "Geotechnical Earthquake Engineering," Prentice Hall, NY, 1996.

Rocscience, *"SLIDE – 2-D Limit Equilibrium Slope Stability for Soil and Rock Slopes,"* User's Guide, Rocscience Software, Inc., Toronto, Ontario, Canada, 2006.

Spencer, E., "The Thrust Line Criterion in Embankment Stability Analysis," *Géotechnique*, Vol. 23, No. 1, pp. 85-100, March 1973.

United States District Court, Northern District of New York. State of New York and Denise M. Sheehan against Honeywell International, Inc. Consent Decree Between the State of New York and Honeywell International, Inc. Senior Judge Scullin, Dated October 11, 2006. Filed January 4, 2007.

Written by:	Fan Zhu	Date:	1/14/2011	Reviewed by:	Ming Zhu/R. Kulasingam/Jay Beech	Date:	1/14/2011
Client:	Honeywell	Project:	Onondaga Lake ILWD Stability	Project/ Proposal No.:	GJ4204	Task No.:	14-05

Tables

Written by: **Fan Zhu** Date: **1/14/2011** Reviewed by: **Ming Zhu/R. Kulasingam/Jay Beech** Date: **1/14/2011**

Client: **Honeywell** Project: **Onondaga Lake ILWD Stability** Project/ Proposal No.: **GJ4204** Task No.: **14-05**

Table 1. Summary of Material Properties for Slope Stability Analyses

Material	Total Unit Weight (pcf)	Drained Shear Strength ϕ' (degrees)	Undrained Shear Strength
Cap – Sand[1]	120	32	N/A
Silt[2]	98	32	N/A
SOLW	81	N/A	240 psf
Marl	98	N/A	$S_u/\sigma_v' = 0.24$[3],[4]
Silt and Clay	108	N/A	$S_u/\sigma_v' = 0.26$[3],[4]
Silt and Sand	120	32	N/A
Sand and Gravel	120	32	N/A
Till	120	40	N/A
Shale	120	40	N/A

Notes:

[1]. For the purpose of the slope stability analysis, the relatively thin layer of gravel in the proposed cap was not modeled. The gravel material is expected to have a larger friction angle than the sand. Therefore, not modeling the gravel component of the cap in the slope stability analysis was considered to be conservative.

[2]. Unit weight and drained shear strength of Marl were used for Silt overlying the SOLW in certain areas of the ILWD.

[3]. The undrained shear strength ratios of Marl and Silt and Clay below the cap were manually reduced in the SLIDE program to avoid the increase of undrained shear strengths of Marl and Silt and Clay due to the additional load from cap.

[4]. The reduced undrained shear strength ratios were calculated as described in Attachment 1 of the Static Stability Package.

Written by: **Fan Zhu** Date: **1/14/2011** Reviewed by: **Ming Zhu/R. Kulasingam/Jay Beech** Date: **1/14/2011**

Client: **Honeywell** Project: **Onondaga Lake ILWD Stability** Project/ Proposal No.: **GJ4204** Task No.: **14-05**

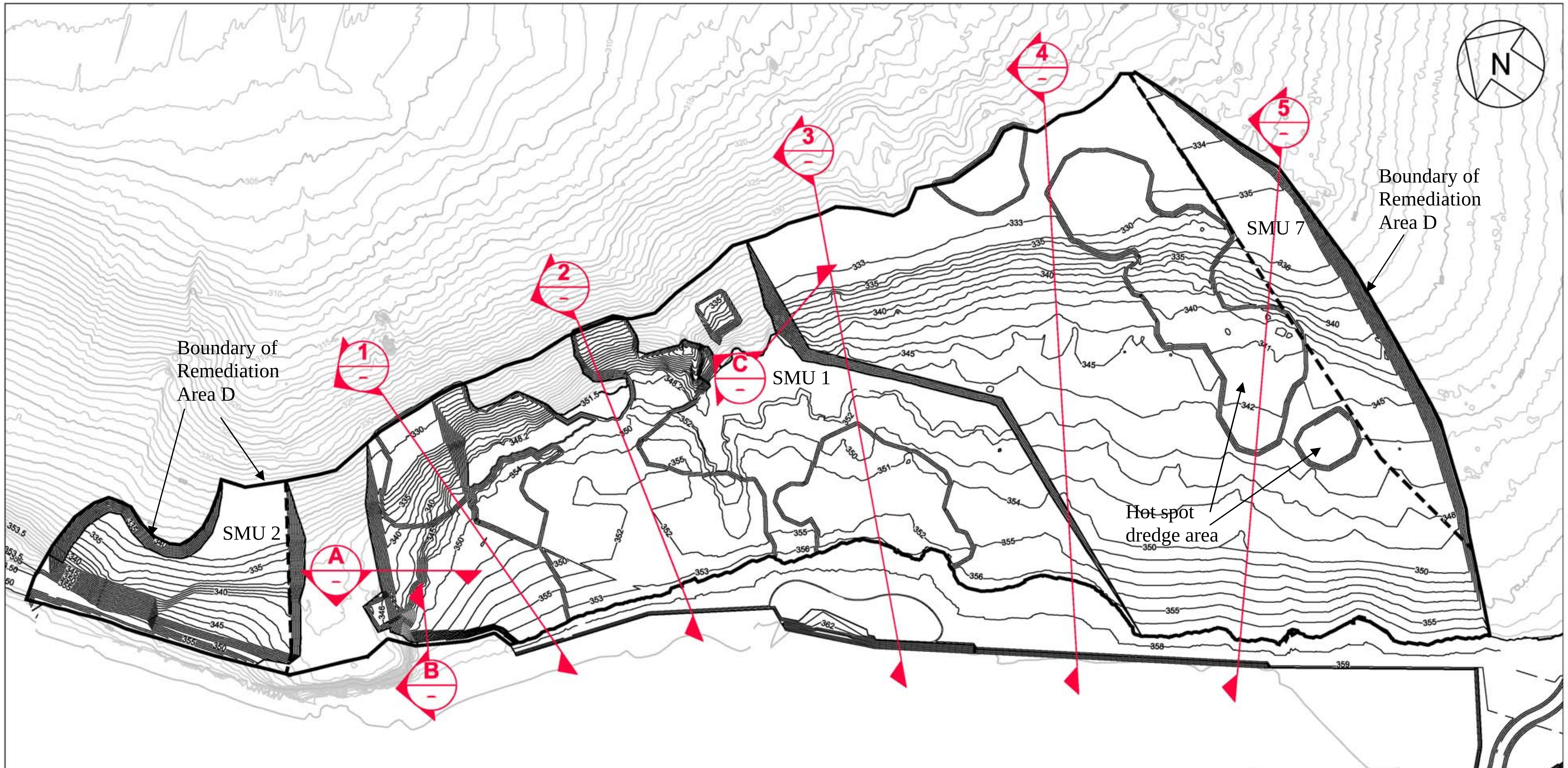
Table 2. Summary of Seismic Slope Stability Analysis Results

Cross Section	Horizontal Seismic Coefficient (K_h)	Calculated Minimum FS	Target FS	Is FS OK?	Deformation Analysis Necessary?	Note
1	0.045	1.56	1.1	Yes	No	
2	0.045	1.44	1.1	Yes	No	Results shown in Figure 11
3	0.045	1.45	1.1	Yes	No	Results shown in Figure 12
4	0.045	1.72	1.1	Yes	No	
5	0.045	1.80	1.1	Yes	No	
A	0.045	1.86	1.1	Yes	No	
B	0.045	1.69	1.1	Yes	No	
C	0.045	1.48	1.1	Yes	No	Results shown in Figure 13

Figures

Written by:	Fan Zhu	Date:	1/14/2011	Reviewed by:	Ming Zhu/R. Kulasingam/Jay Beech	Date:	1/14/2011

Client: **Honeywell** Project: **Onondaga Lake ILWD Stability** Project/ Proposal No.: **GJ4204** Task No.: **14-05**



Notes:
1. Contours of the existing ground/lake bottom were provided by Parsons.
2. Dredging plan was prepared by Anchor QEA and provided to Geosyntec by Parsons.

Figure 1. Locations of Selected Cross Sections on Dredging Plan

Written by:	Fan Zhu	Date:	1/14/2011	Reviewed by:	Ming Zhu/R. Kulasingam/Jay Beech	Date:	1/14/2011

Client:	Honeywell	Project:	Onondaga Lake ILWD Stability	Project/ Proposal No.:	GJ4204	Task No.:	14-05

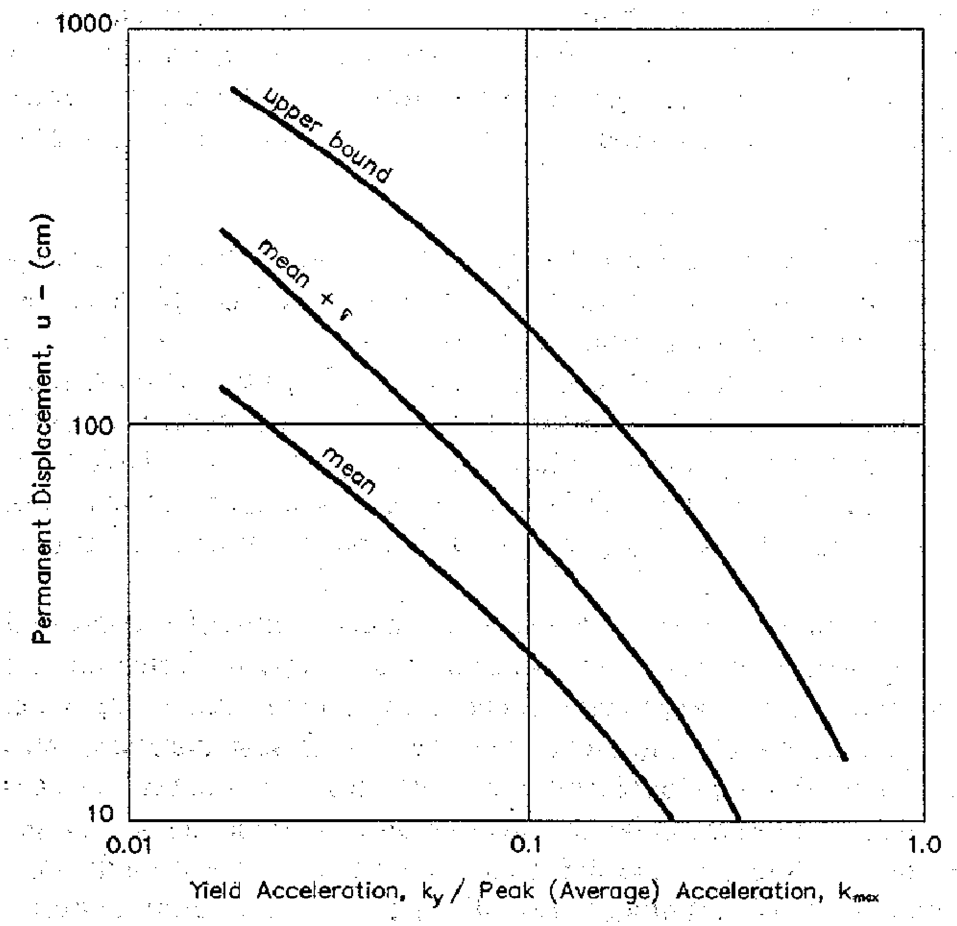


Figure 2. Permanent Seismic Deformation Chart (Hynes and Franklin, 1984)

Written by: **Fan Zhu** Date: **1/14/2011** Reviewed by: **Ming Zhu/R. Kulasingam/Jay Beech** Date: **1/14/2011**

Client: **Honeywell** Project: **Onondaga Lake ILWD Stability** Project/ Proposal No.: **GJ4204** Task No.: **14-05**

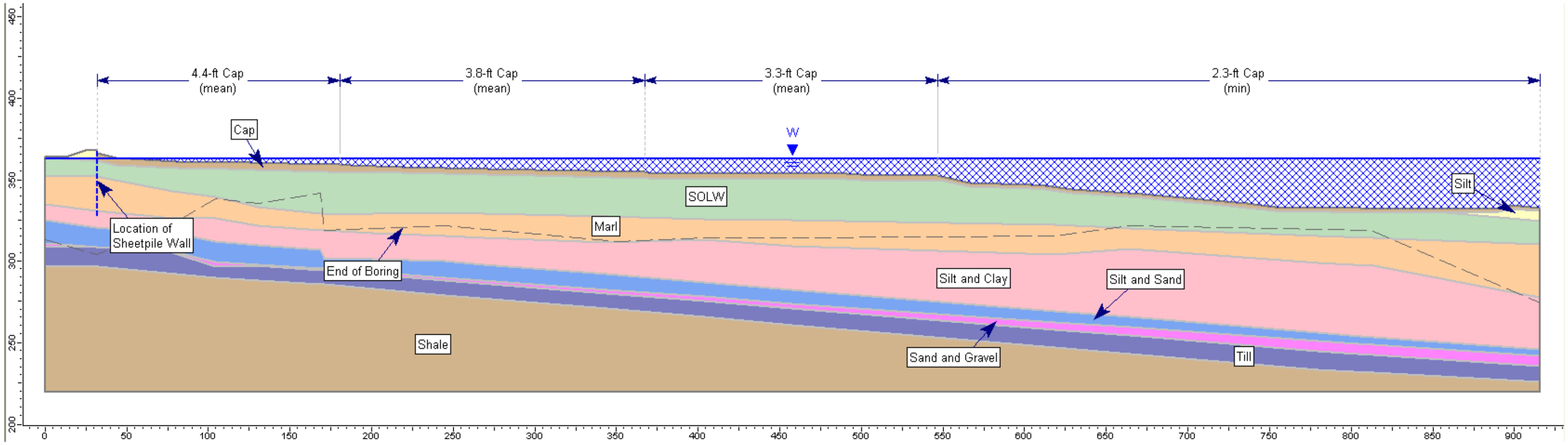


Figure 3. Geometry of Cross Section 1

Notes:

1. Axes show distances and elevations in feet.
2. Subsurface profiles below the line of end of boring were estimated based on information from deeper borings located elsewhere in Remediation Area D.
3. Above notes also apply to Figures 4 through 10.

Written by:	**Fan Zhu**	Date:	**1/14/2011**	Reviewed by:	**Ming Zhu/R. Kulasingam/Jay Beech**	Date:	**1/14/2011**

Client:	**Honeywell**	Project:	**Onondaga Lake ILWD Stability**	Project/ Proposal No.:	**GJ4204**	Task No.:	**14-05**

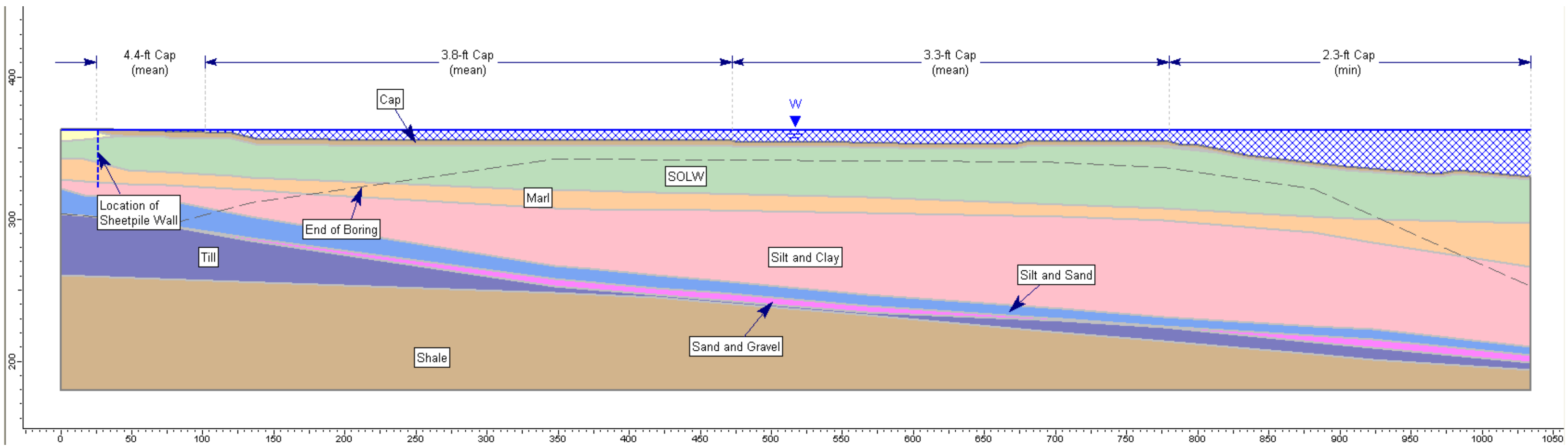


Figure 4. Geometry of Cross Section 2

Note:

1. See notes for Figure 3.

Written by:	**Fan Zhu**	Date:	**1/14/2011**	Reviewed by:	**Ming Zhu/R. Kulasingam/Jay Beech**	Date:	**1/14/2011**

Client:	**Honeywell**	Project:	**Onondaga Lake ILWD Stability**	Project/ Proposal No.:	**GJ4204**	Task No.:	**14-05**

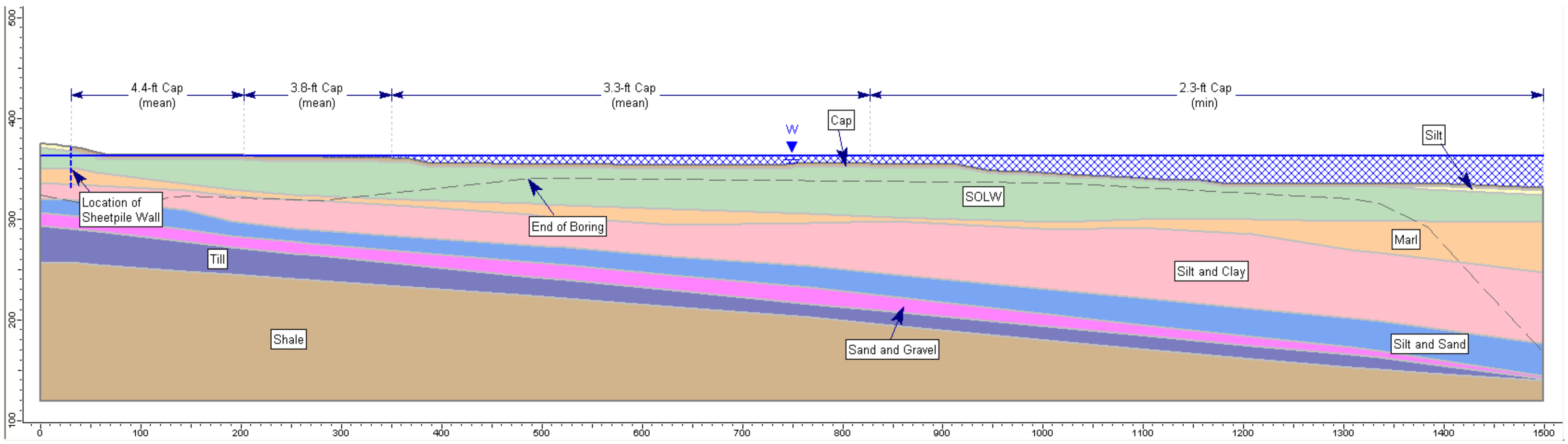


Figure 5. Geometry of Cross Section 3

Note:

1. See notes for Figure 3.

Written by: **Fan Zhu** Date: **1/14/2011** Reviewed by: **Ming Zhu/R. Kulasingam/Jay Beech** Date: **1/14/2011**

Client: **Honeywell** Project: **Onondaga Lake ILWD Stability** Project/ Proposal No.: **GJ4204** Task No.: **14-05**

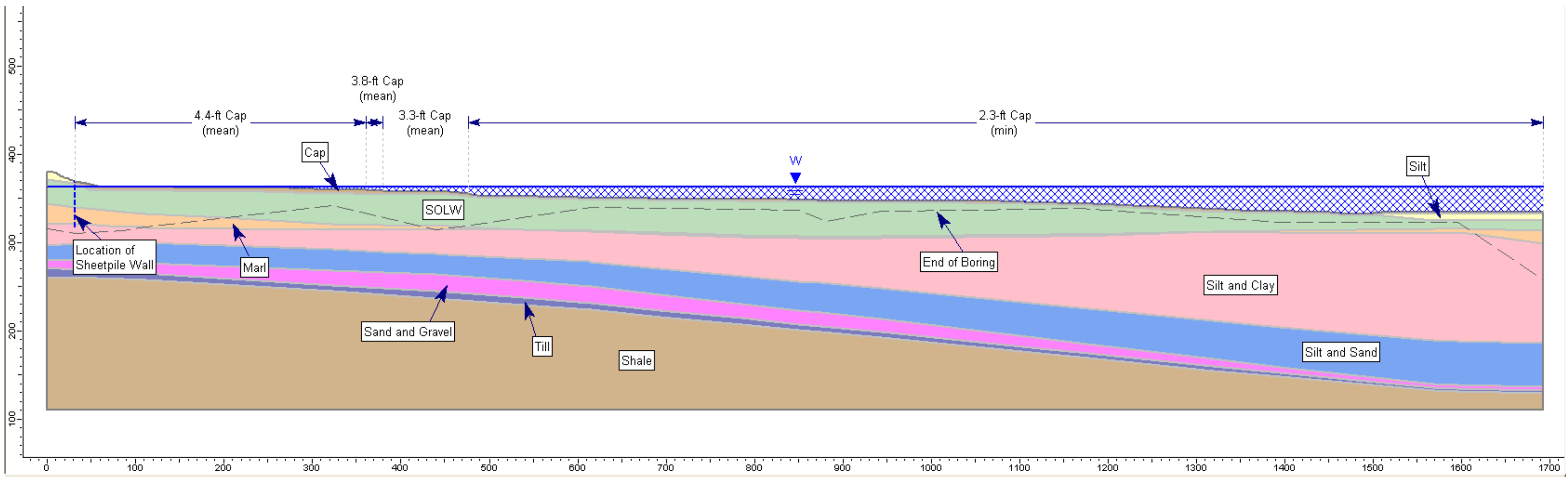


Figure 6. Geometry of Cross Section 4

Note:

1. See notes for Figure 3.

Written by:	Fan Zhu	Date:	1/14/2011	Reviewed by:	Ming Zhu/R. Kulasingam/Jay Beech	Date:	1/14/2011

Client:	Honeywell	Project:	Onondaga Lake ILWD Stability	Project/ Proposal No.:	GJ4204	Task No.:	14-05

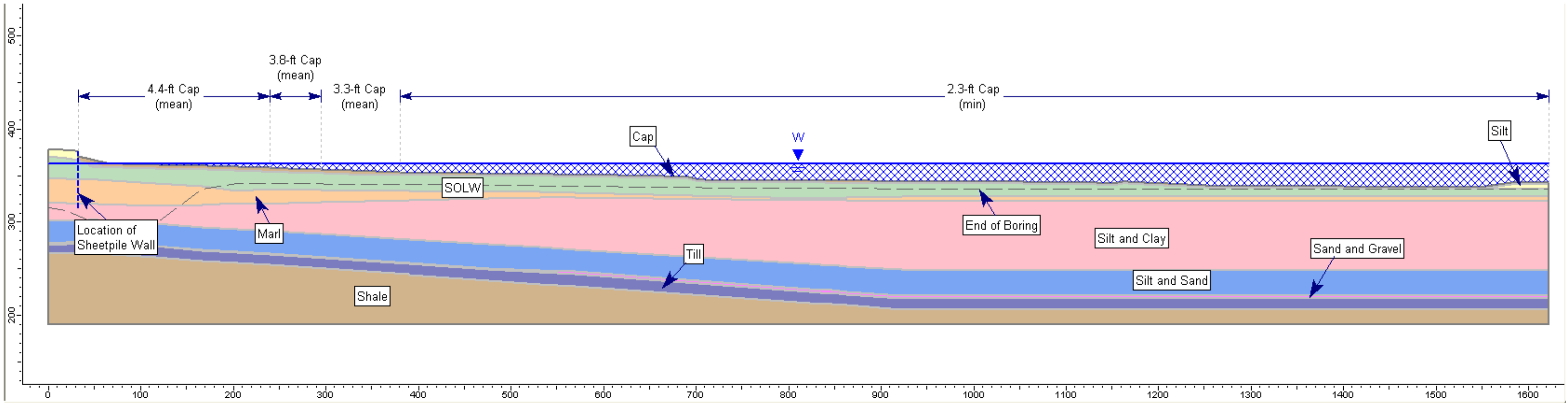


Figure 7. Geometry of Cross Section 5

Notes:

1. See notes for Figure 3.
2. The subsurface layer boundaries were extended horizontally beyond the station of 850 ft for the purpose of slope stability analysis.

Written by: **Fan Zhu** Date: **1/14/2011** Reviewed by: **Ming Zhu/R. Kulasingam/Jay Beech** Date: **1/14/2011**

Client: **Honeywell** Project: **Onondaga Lake ILWD Stability** Project/ Proposal No.: **GJ4204** Task No.: **14-05**

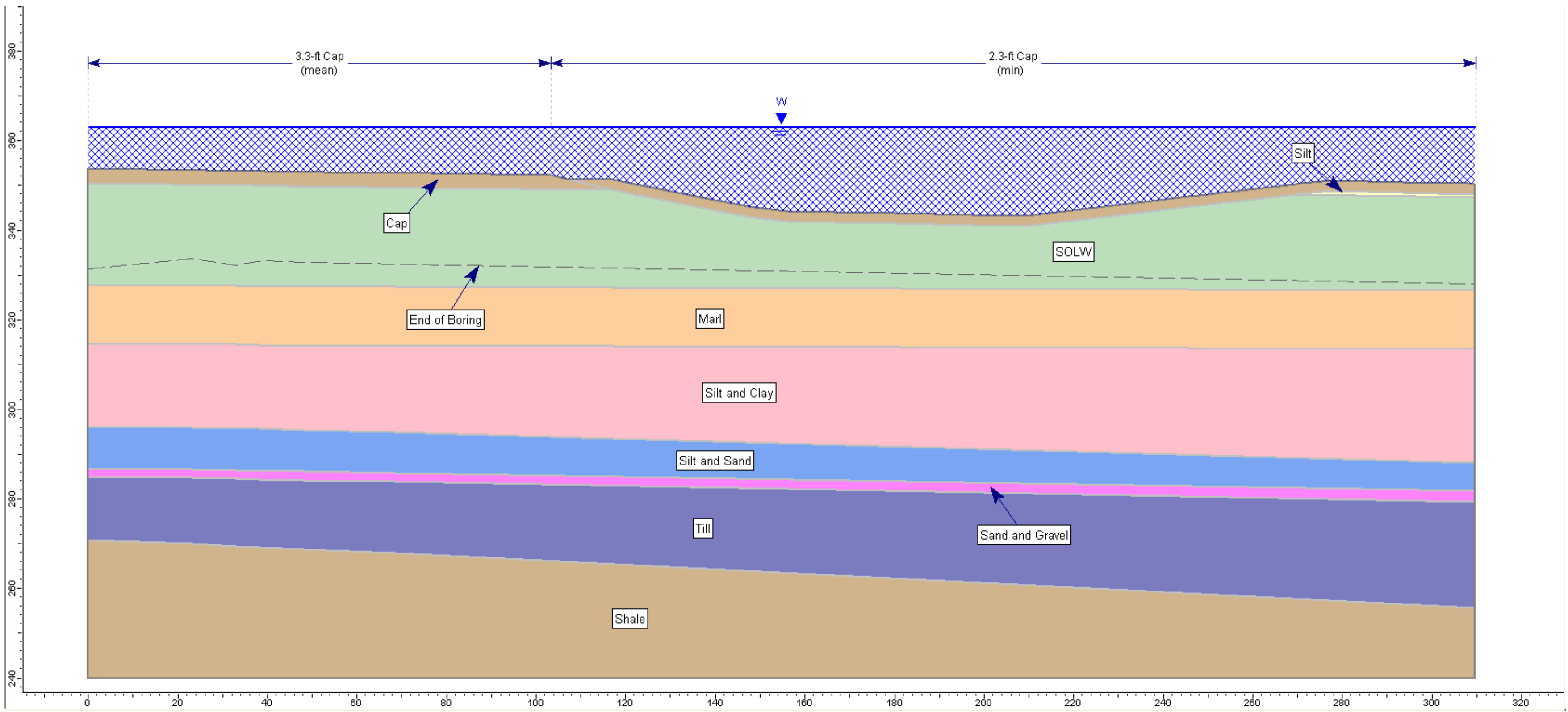


Figure 8. Geometry of Cross Section A

Note:

1. See notes for Figure 3.

Written by:	Fan Zhu	Date:	1/14/2011	Reviewed by:	Ming Zhu/R. Kulasingam/Jay Beech	Date:	1/14/2011

Client: **Honeywell** Project: **Onondaga Lake ILWD Stability** Project/ Proposal No.: **GJ4204** Task No.: **14-05**

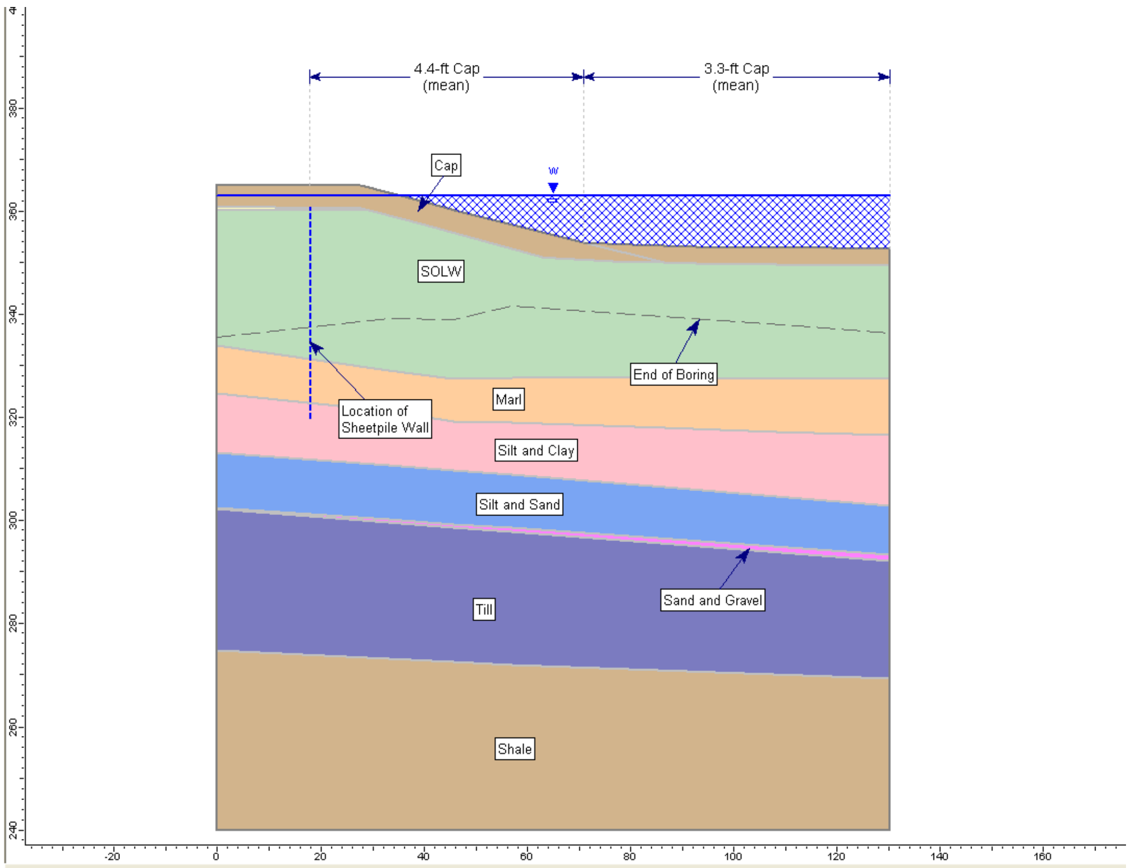


Figure 9. Geometry of Cross Section B

Note:

1. See notes for Figure 3.

Written by: **Fan Zhu** Date: **1/14/2011** Reviewed by: **Ming Zhu/R. Kulasingam/Jay Beech** Date: **1/14/2011**

Client: **Honeywell** Project: **Onondaga Lake ILWD Stability** Project/ Proposal No.: **GJ4204** Task No.: **14-05**

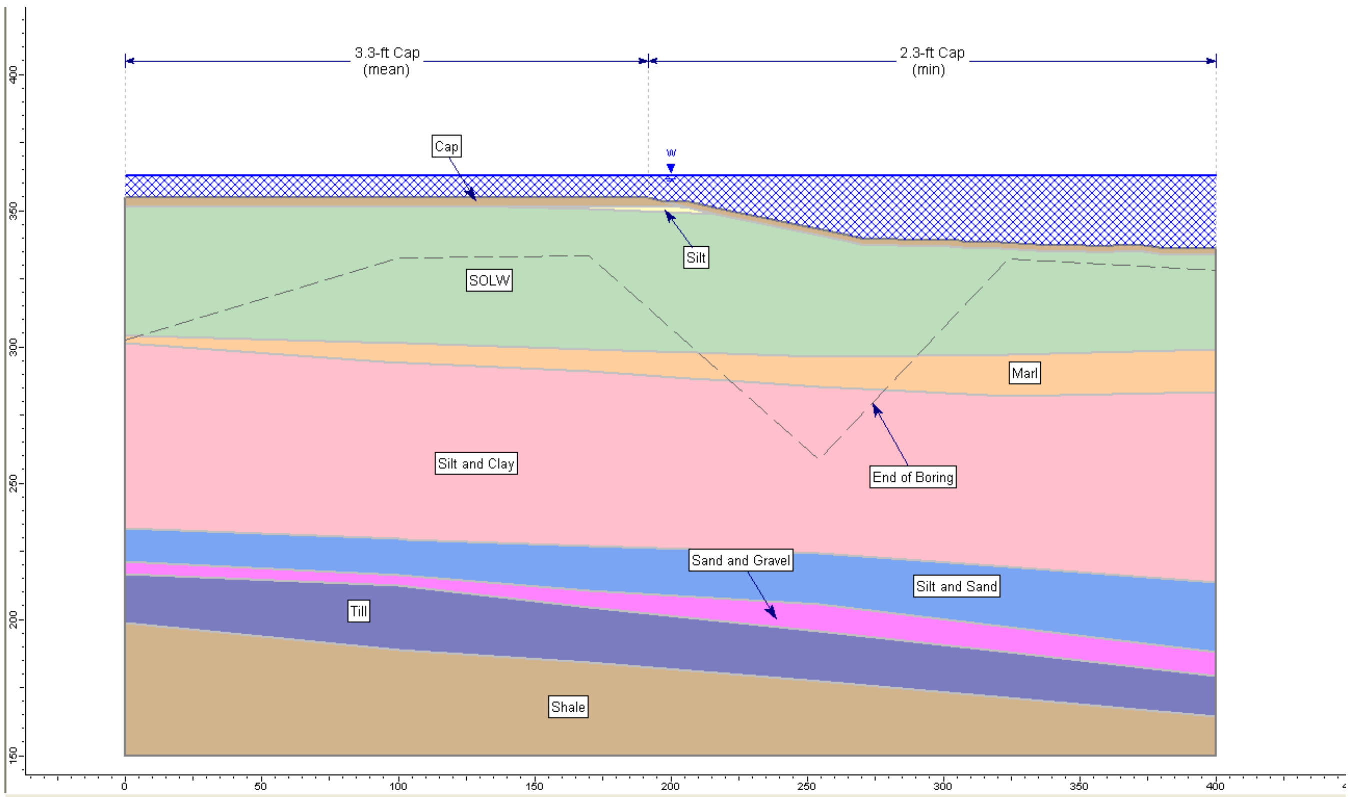


Figure 10. Geometry of Cross Section C

Note:

1. See notes for Figure 3.

Written by: **Fan Zhu** Date: **1/14/2011** Reviewed by: **Ming Zhu/R. Kulasingam/Jay Beech** Date: **1/14/2011**

Client: **Honeywell** Project: **Onondaga Lake ILWD Stability** Project/ Proposal No.: **GJ4204** Task No.: **14-05**

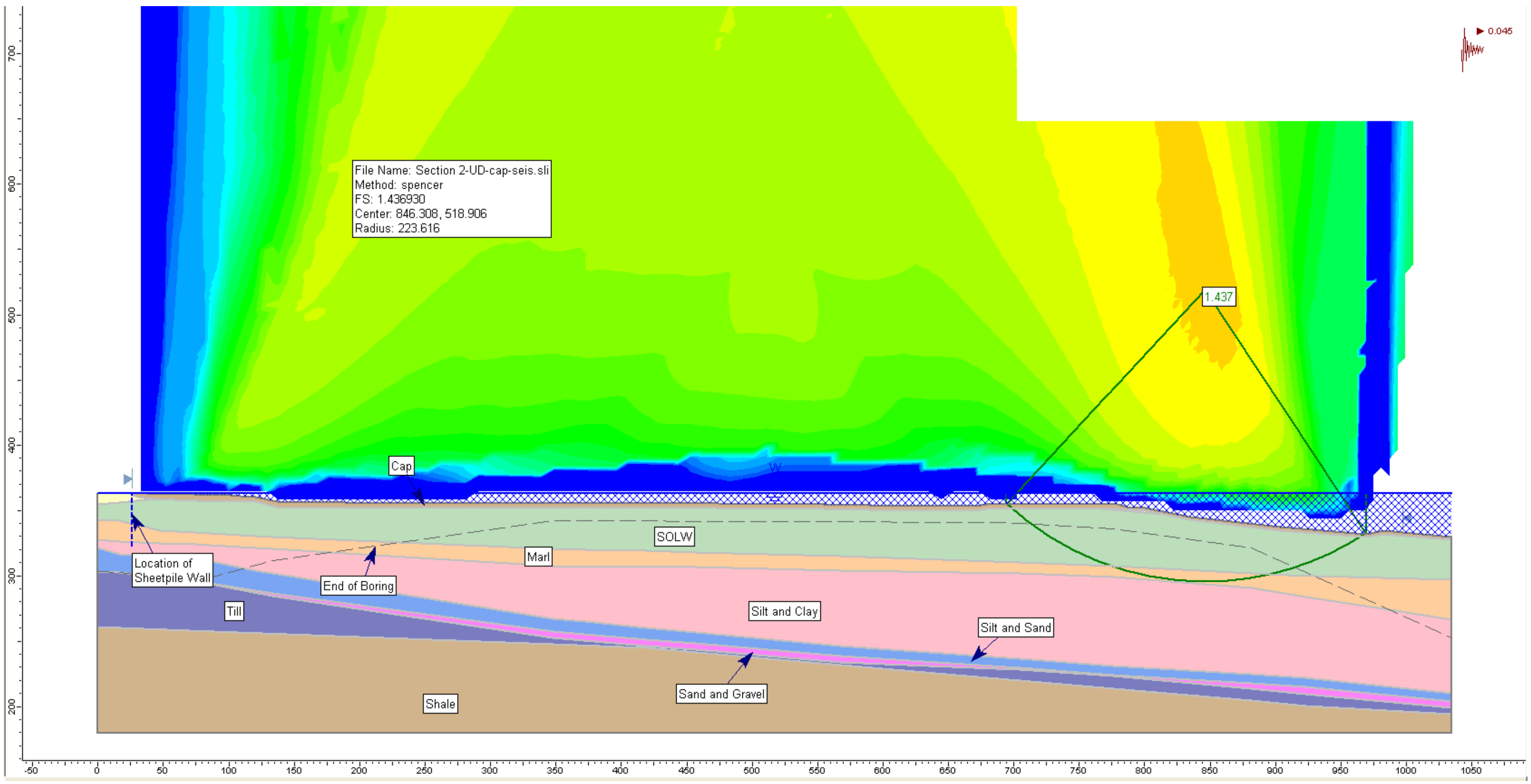


Figure 11. Slope Stability Analysis Result for Cross Section 2

Written by: **Fan Zhu** Date: **1/14/2011** Reviewed by: **Ming Zhu/R. Kulasingam/Jay Beech** Date: **1/14/2011**

Client: **Honeywell** Project: **Onondaga Lake ILWD Stability** Project/ Proposal No.: **GJ4204** Task No.: **14-05**

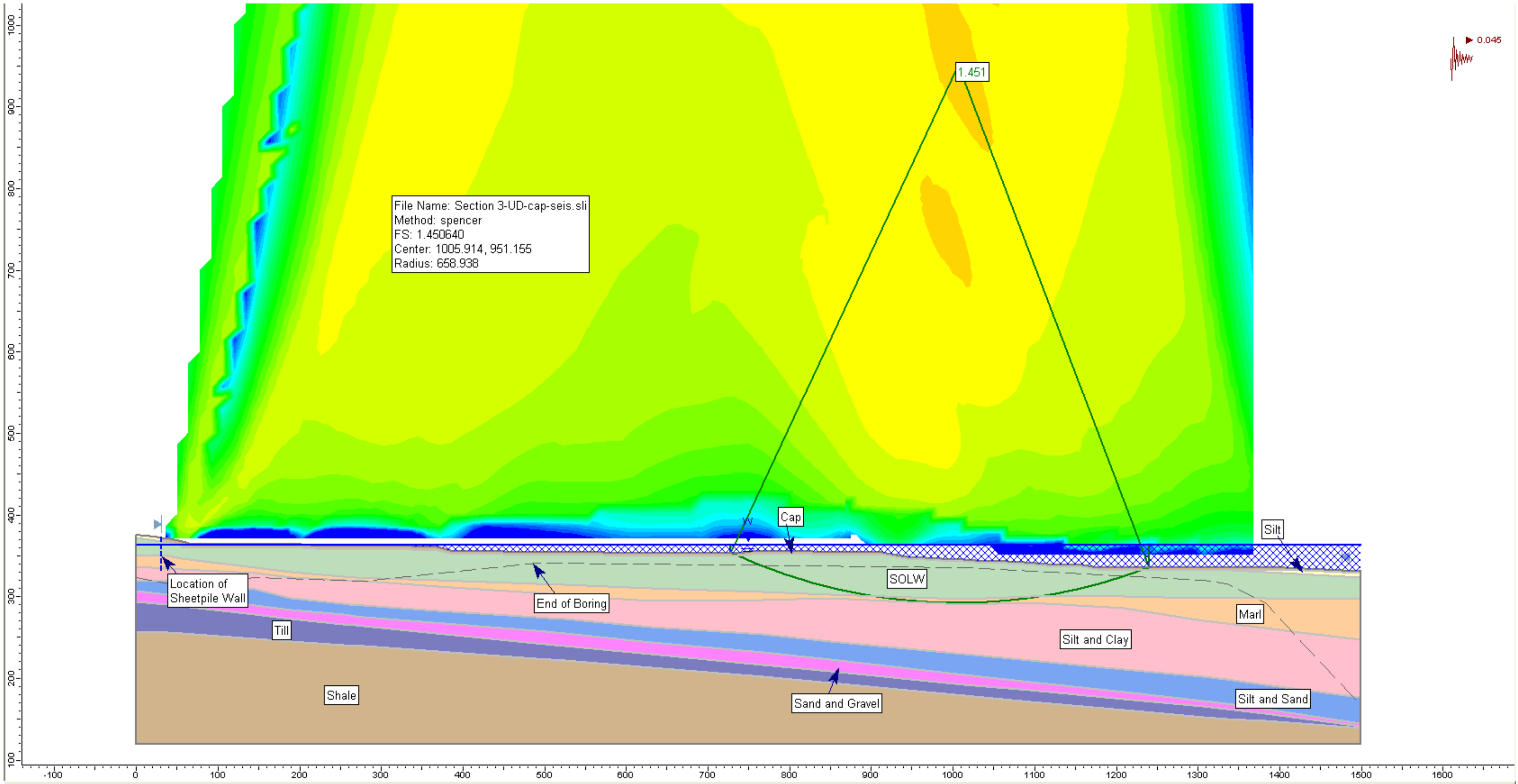


Figure 12. Slope Stability Analysis Result for Cross Section 3

Written by:	Fan Zhu	Date:	1/14/2011	Reviewed by:	Ming Zhu/R. Kulasingam/Jay Beech	Date:	1/14/2011

Client:	Honeywell	Project:	Onondaga Lake ILWD Stability	Project/ Proposal No.:	GJ4204	Task No.:	14-05

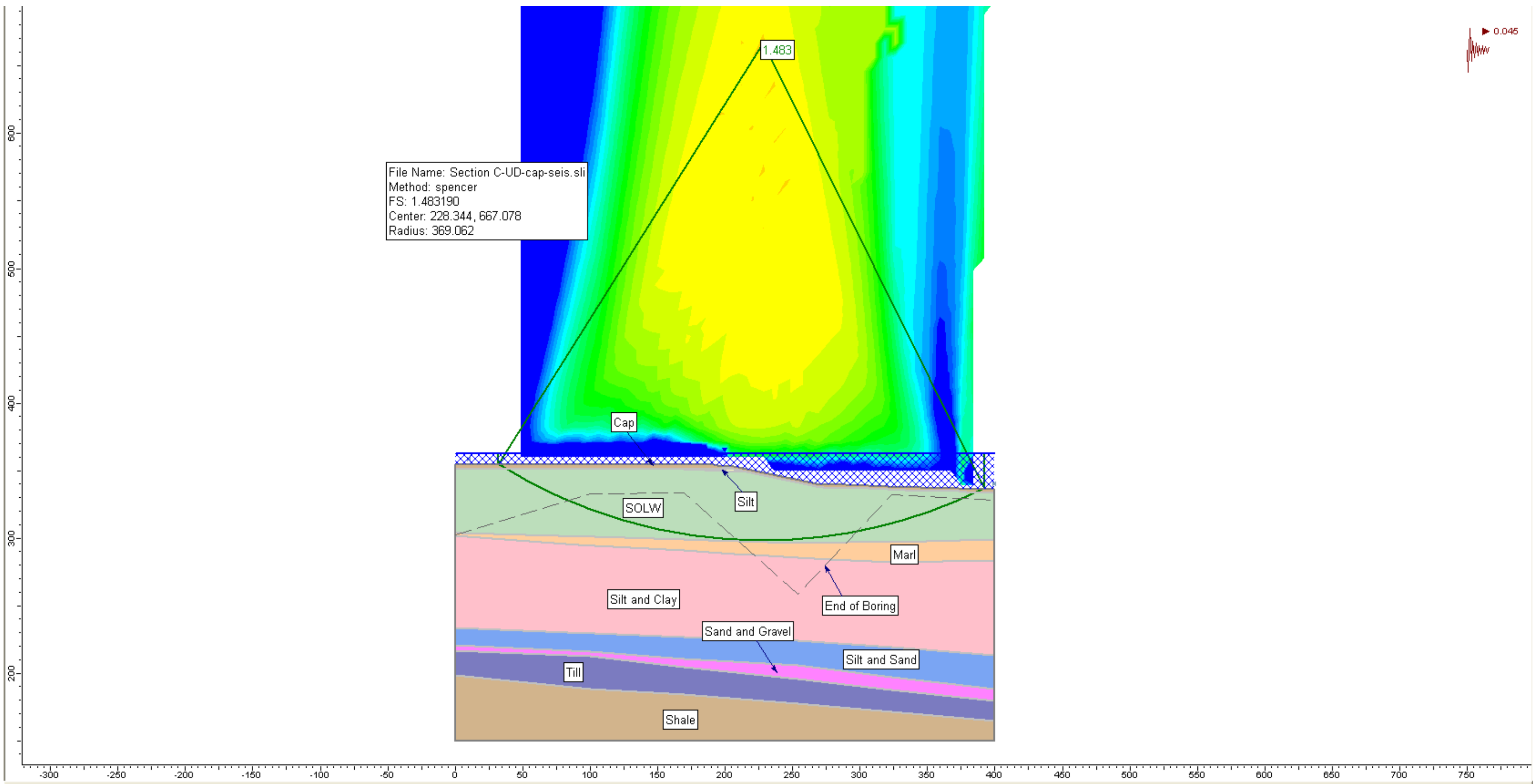


Figure 13. Slope Stability Analysis Result for Cross Section C

Attachment 1
Sensitivity Analysis

Written by:	Fan Zhu	Date:	1/14/2011	Reviewed by:	Ming Zhu/R. Kulasingam/Jay Beech	Date:	1/14/2011

Client:	Honeywell	Project:	Onondaga Lake ILWD Stability	Project/ Proposal No.:	GJ4204	Task No.:	14-05

Table 1-1. Summary of Seismic Slope Stability Sensitivity Analysis Results

Cross Section	Calculated Minimum FS using Reduced Strength of SOLW	Yield Acceleration, a_y [1] (g)	Maximum Horizontal Acceleration, a_{max} (g)	a_y/a_{max}	Interpolated Displacement Range [2] (in)
3	1.06	0.048	0.09	0.53	0.2~0.6
C	1.02	0.047	0.09	0.52	0.2~0.6

Notes:

1. The yield acceleration corresponds to the horizontal seismic coefficient that results in a calculated FS of 1.0.
2. The displacement range was interpolated using the mean and mean + standard deviation curves presented in Figure 1-1.

Written by:	Fan Zhu	Date:	1/14/2011	Reviewed by:	Ming Zhu/R. Kulasingam/Jay Beech	Date:	1/14/2011

Client:	Honeywell	Project:	Onondaga Lake ILWD Stability	Project/ Proposal No.:	GJ4204	Task No.:	14-05

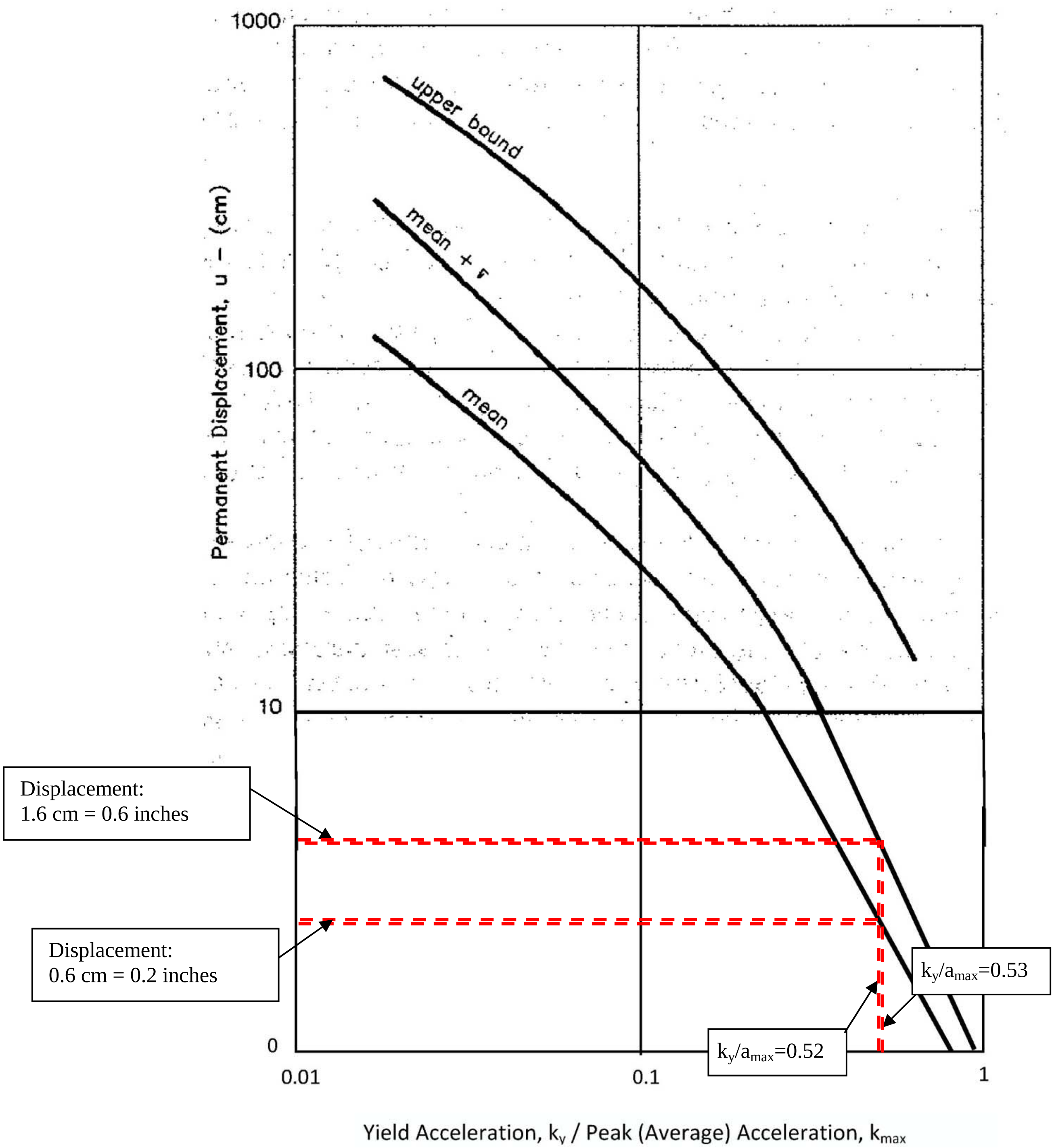


Figure 1-1. Interpolation of Displacement