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LATHAM & WATKINS LLP

October 28, 2014

Craig Melodia
Associate Regional Counsel
United States Environmental Protection Agency
Region 5
77 West Jackson Boulevard
Chicago, IL 60604-3590

Re: Ashland Lakefront Superfund Site: Dry Dredge Analysis Peer Review

Dear Mr. Melodia:

On behalf of Northern States Power Company of Wisconsin ("NSPW" or the "Company"), we are submitting the attached report by Dr. Richard J. Finno, titled "Evaluation of Geotechnical Conditions and Their Impact on Proposed Dry Dredge Removal Plan, Ashland/Northern States Power Lakefront Superfund Site."

Dr. Finno is a distinguished Professor of Civil Engineering at Northwestern University, specializing in geotechnical engineering. He has conducted substantial research in many areas directly applicable to the dry dredge remedy proposed for the Ashland Lakefront Superfund Site ("Site"), including research related to excavation support, tunnels, failure processes, soils, and ground movements. Dr. Finno's work has been widely recognized in the civil engineering community. He has received eight major awards from the American Society of Civil Engineers, including the Karl Terzaghi Award, which is considered to be the most prestigious award for a geotechnical engineer in the United States, and he has been awarded numerous National Science Foundation grants. Dr. Finno served as a member of the U.S. Environmental Protection Agency's ("EPA") Land Application Peer Review Committee. Dr. Finno has also served as Chair of the Earth Retaining Structures Committee of the American Society of Civil Engineers, as well as an editor of its Journal of Geotechnical and Geoenvironmental Engineering.

In the attached report, Dr. Finno provides an independent evaluation from a geotechnical perspective of EPA's proposed "dry dredge" option for the removal of contaminated sediments from the Site. Dr. Finno's report lists the reports and data that Dr. Finno reviewed in evaluating the proposed remedy including the data that was gathered in 2013 at the Site. Dr. Finno presents his view of the appropriate factors of safety for this site and evaluates potential failure mechanisms including bottom instability and piping. Dr. Finno also reviewed Weston's 2009

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submittal and presents his independent evaluation of Weston's approach and assumptions including a review of the sheet pile design and constructability that Weston proposed in 2009. At this time, Dr. Finno has only conducted a preliminary review of the September 23, 2014 Weston analyses and Army Corps' peer review and has concluded that these additional materials and new methodologies do not change his ultimate conclusions. Dr. Finno concludes that:

- The proposed dry dredge remedy is not safe or implementable at the Site due to the potential for bottom uplift, global instability, and numerous and insurmountable design and constructability concerns.

- The factors of safety used by Weston do not appropriately account for variability in subsurface conditions, engineering parameters, and loading conditions;

- The appropriate factor of safety to protect against the "bottom uplift" failure mechanism at this site is 1.5, not Weston's proposed factor of safety of 1.25. In addition, the factor of safety against the "piping" should meet the industry standard of 4 to 5;

- A dry dredge excavation would not be stable because bottom uplift due to artesian water pressures will likely occur at some locations after soil has been excavated. When bottom uplift occurs, the excavation area likely will be flooded by ground water from the underlying aquifer;

- The effects of the upward flow of water adjacent to the sheet pile wall for the actual subsurface conditions encountered offshore need to be considered. When these effects are considered, Dr. Finno's analysis shows that there are several locations where the factor of safety against piping is about one-half of the industry standard of 4 to 5. Thus, if piping were to occur, support provided by the soil adjacent to the sheet pile wall would be removed and the wall would collapse, flooding the excavation;

- A failure mode that encompasses the entire sheet pile wall needs to be considered but was not considered by Weston;

- The concept of using a sheet pile wall for a dry dredge is ill-founded. Weston's analyses do not adequately account for expected loading conditions, including wave loadings, development of water-filled gaps during periods of high water, or the directional effects of wave loading and here that means that bracing will be required; and

- Weston ignores a number of significant construction-related difficulties associated with the dry dredge remedy such as maintaining an impervious barrier and structural integrity and installing sheeting to required depth in hard portions of glacial tills.

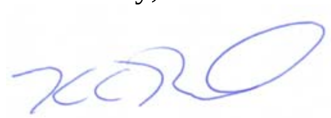
Dr. Finno further concludes that a wet dredge remedy would eliminate the risks associated with the dry dredge, and would be a far better solution to the geotechnical challenges at the Site.

We also note that Weston, in both its 2009 submittal and its September 23, 2014 report, has heavily relied on a report by Demetrious Koutsoftas, titled “State of Practice: Excavations in Soft Soils” in support of the dry dredge remedy. The Koutsoftas report cites or refers to eight of Dr. Finno’s reports, and also cites to personal communications with Dr. Finno. As described above, however, Dr. Finno, an expert upon whom Koutsoftas relies, has concluded that the dry dredge proposed for the Site is not safe or implementable.

As described above, Dr. Finno’s report is limited to his analysis ofthe existing site data and a review of Weston’s 2009 submittal and subsequent slides, with a preliminary review of the September 23, 2014 Weston Report. Because the new 2014 Weston Reports contain new analyses and substantially change the remedy set forth in the Record of Decision, we reserve the right to submit a supplemental report responding to those analyses upon our further review.

Thank you for your attention to these important matters. We look forward to discussing these issues with you further at your earliest convenience.

Sincerely,



Kelly E. Richardson
of LATHAM & WATKINS LLP

cc: Kristen Carney
Tom Benson, U.S. DOJ
Sumona Majumdar, U.S. DOJ
Lacey Cochart, WDNR
Scott Hansen, EPA
Jamie Dunn, WDNR
John Robinson, WDNR

Enclosure

ATTACHMENT 1

Richard J. Finno, P.E., Ph.D., DGE

Geotechnical Engineering **Civil Engineering**

Robert R. McCormick
School of Engineering
and Applied Science

October 27, 2014

Mr. Jerry C. Winslow
***Xcel** Energy, Inc.*
Principal Environmental Engineer
414 Nicollet Mall, MP7A
Minneapolis, MN 55401

Re: Transmittal of Report
Evaluation of Geotechnical Conditions and their Impact on Proposed Dry Dredge Removal Plan
Ashland/Northern States Power
Lakefront Superfund Site

Dear Mr. Winslow:

Attached is my report entitled "Evaluation of Geotechnical Conditions and their Impact on Proposed Dry Dredge Removal Plan." This report presents my opinions regarding the geotechnical aspects of the dry dredge option contemplated in the Record of Decision for the Ashland Lakefront Superfund Site. My opinions are based on my evaluation of the information in the Weston Solutions, Inc. technical memorandum dated November 20, 2009, as well as the data in the various reports prepared by Anchor QEA LLC and other available subsurface information as listed in my report.

I recently briefly read the 2014 Technical Submittal by Weston Solutions, Inc. and the associated peer reviews prepared by the US Army Corps of Engineers that were released by the US Environmental Protection Agency earlier this month. I saw nothing in this initial review that would cause me to alter my opinions, and I understand that the reports are based on the same set of available data that I independently reviewed to reach my conclusions. However, as I have not yet looked at the large amount of detail presented in those documents, I reserve the right to update or supplement this report following a more detailed review of those submittals.

If I can be of further assistance, please do not hesitate to contact me.

Sincerely,

Richard J. Finno, P.E., Ph.D., D.GE

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Richard J. Finno, P.E., Ph.D., DGE

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EVALUATION OF GEOTECHNICAL CONDITIONS AND THEIR IMPACT ON PROPOSED DRY DREDGE REMOVAL PLAN

ASHLAND/NORTHERN STATES POWER LAKEFRONT SUPERFUND SITE

Prepared for:

Northern States Power – Wisconsin

Prepare by:

Richard J. Finno, PE, PhD, DGE

October 27, 2014

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Executive Summary

This report summarizes my evaluation of the geotechnical conditions at the Ashland/Northern States Power Lakefront Superfund Site (the Site) and their impact on the proposed dry dredge scheme. I understand that the dry dredge scheme will entail driving a row of sheet piles across the bay and around the shore line to provide an impervious wall. Water will be pumped from this enclosure and the contaminated sediments subsequently will be excavated.

After reviewing the existing data and analyses regarding the Site, I have reached the following conclusions:

- The conceptual Weston Solutions Inc. (Weston) analyses were made before the 2013 offshore data were collected and do not reflect the current knowledge of Site conditions. Weston prepared a technical memorandum that included a conceptual geotechnical assessment of the proposed scheme based on limited subsurface data, especially offshore. They concluded that a dry excavation scheme could be a feasible means of removing contaminated sediments from the areas close to shore at the site. However, they also qualified their report by stating "It must be initially stated and understood by all relevant project participants that the analyses, conclusions and recommendations presented herein are based on limited site-specific geotechnical field and laboratory data, and therefore, must be considered preliminary and conceptual-level only." Much more site-specific data has been generated since the Weston report was released and my analyses and recommendations benefit from this additional information. Furthermore, they also stated in their conclusions and recommendations that "variability in subsurface data is likely, which may result in several different sheet piling designs along the alignment of the wall." Indeed, results of site exploration and testing completed after Weston made their recommendations, and consideration of the geologic origins of the soils at the site, did show that subsurface conditions vary significantly across the site. The one stratigraphic section that Weston considered in their report was not representative of conditions throughout the site.

- The Factors of Safety (FS) used in Weston's analyses do not appropriately account for variability in Site subsurface conditions, engineering parameters and loading condition. The FS should reflect uncertainties in subsurface conditions, engineering parameters, loading conditions and consequences of failure. The FS used by Weston did not adequately consider these factors in all cases, particularly when considering the potential for bottom heave from the artesian pressures in the Copper Falls aquifer.

- The excavation in a dry dredge scheme will not be stable because bottom heave due to artesian water pressures will likely occur at some locations after soil has been excavated. Contrary to Weston's opinion, when bottom heave occurs, the excavation likely will be flooded by ground water from the underlying Copper Falls aquifer.

- Weston's conceptual design did not consider the effects of upward flow of water adjacent to the sheet pile for the actual subsurface conditions encountered offshore as noted in the Anchor QEA December 2013 report. There are several locations defined in the offshore borings and CPT soundings, where the FS against piping is about one-half of the industry standard of 4 to 5. If piping were to occur, support provided by the soil adjacent to the sheet pile wall would be removed and the wall will collapse, flooding the excavation.

- Weston's conceptual design did not consider a failure mode that encompasses the entire sheet pile wall. The FS against this global instability was computed assuming a sliding block model when the excavation is at final depth. Results of the analysis indicate that failure will occur for the long term condition. Failure in this case implies that a mass of soil encompassing the wall sill slide into the excavation and subsequently flooding it.

- Weston's conceptual design of the sheet pile wall was superficial in that it did not adequately account for expected loading conditions. Their design did not consider wave loadings, development of water filled gaps during period of high water, or the directional effects of wave loadings. Sheet pile wall will provide resistance to bending and tensile stresses, but not compressive stresses. Therefore, when the wall has a 90 degree bend, some bracing will be required to ensure stability.

- Weston's conceptual design of the sheet pile wall results in a sheet pile wall that will not be able to be constructed such that it will perform as intended. Weston's approach is not conservative, as it assumes that the as-built sheet pile joints will be impervious, an unattainable goal for the quantities of sheet pile that comprise the proposed barrier. There also are a number of significant construction-related difficulties associated with the dry dredge option not addressed in their report. It will be very difficult to construct the sheet pile wall and maintain its function as an "impervious" barrier as well as its structural integrity. It will be difficult to install sheeting to required depth through the hard portions of the glacial tills. Till refers to any soil that is deposited from a glacier and thus includes soils deposited in many ways. Significant variations in its composition should be expected within the Site, given its size. Concentrated flows of water through the sheeting could develop as a result of losing the sheeting interlocks when driving in tills with gravel and boulders, which would lead to a collapse of the sheet pile wall and subsequent flooding of the excavation.

- A wet dredge method eliminates the problems with bottom heave, global instability and design and construction issues that are associated with the dry dredge option, and is a far better solution to the geotechnical challenges at the Site.

For these reasons, and as detailed in the body of the report, it is my opinion that the proposed dry dredge scheme is not safe or implementable at the Site, because of the potential for bottom heave, global instability and various design and/or constructability concerns discussed herein. A wet dredge approach would eliminate these risks, and is thus a far better solution to the geotechnical challenges of the project.

1. Introduction

This report provides an Independent evaluation from a geotechnical perspective of the proposed "dry dredge" option for removal of contaminated sediments. The Decision of Record contemplates the installation of a cantilevered sheet pile wall across the bay to form an "impervious" barrier. The wall will contain several 90 degree bends as it traverses the bay. Water inside the sheets will be pumped in an attempt to create a dry surface to allow contaminated sediment to be excavated with conventional earth moving equipment. Sediment will be removed to about elevation 590 ft MSL, and thus will create a cantilevered wall with an unsupported height of about 13 ft.

Weston prepared a preliminary report and concluded this approach was technically feasible based on the subsurface information available to them at the time. However, they concluded that the approach would only work if the size of the excavated area was limited to that which could be safely made without inducing an uplift failure of the soil between the bottom of the excavation and the top of the underlying Copper Formation artesian aquifer.

This report presents my evaluation of the geotechnical aspects of the Weston technical memorandum based on reports and data listed in Section 3 (most of which were not available to Weston when they prepared their report) and includes Weston's approach and assumptions regarding the site characterization, factors of safety employed in the analyses, bottom instability analyses, and sheet pile design and constructability. This report also evaluates the wet dredge option from a geotechnical prospective and presents an overall summary of my conclusions regarding the suitability of the dry excavation remedy for the Site.

2. Qualifications

I am a Professor of Civil Engineering specializing in geotechnical engineering with 35 years of experience in the field. I received a BS in Civil Engineering from the University of Illinois at Urbana-Champaign in 1975, a MSCE in Geotechnical Engineering from Stanford University in 1976 and a PhD in Civil Engineering from Stanford University in 1983. I have taught at Northwestern University since 1986. I have conducted research with competitively-secured grants of more than $8 million in the areas of full-scale performance of deep excavations and tunnels, adaptive management methods in geotechnical engineering, numerical analysis, inverse analysis techniques, failure processes in soil, small strain behavior of clays and non-destructive testing of deep foundations. These funds include a grant of more than $2 million from the National Science Foundation for research concerning predicting, monitoring and controlling ground movements caused by supported excavations. I have pioneered the use of adaptive management techniques to predict, monitor and control ground movements caused by deep excavations. I have authored or co-authored 150 reviewed technical papers and 20 technical reports.

Of the technical papers, excavation support is the subject of 54 of them. My work has resulted in recognition in the form eight major awards from the American Society of Civil Engineers (ASCE), including the Karl Terzaghi Award, considered by many as the most prestigious award for a geotechnical engineer in the US, and the Harry Schnabel Jr. Award for Career Excellence in Earth Retaining Structures. I have served as Chair of the Earth Retaining Structures Committee of ASCE and as an Editor of the Journal of Geotechnical and Geoenvironmental Engineering of ASCE. I have consulted for many organizations, including the US EPA when I provided scientific peer review for standards 40 CFR PART 503.

3. Reports/Data Reviewed

I have reviewed the following materials in connection with my evaluation:

a) Anchor QEA, LLC (2014). "Wet dredge pilot study work plan," Ashland Lakefront Superfund Site, April 2014 report
b) Anchor QEA, LLC (2013). "Shoreline and offshore geotechnical evaluation report," Ashland Lakefront Superfund Site, December 2013 report, including the following Appendices:
    - Appendix A Previously Collected Site Data
    - Appendix B Boring Logs
    - Appendix C Laboratory Data Reports
    - Appendix D Equipment Calibration and User's Manuals
    - Appendix E Field Vane Shear Testing Plots
    - Appendix F Cone Penetration Test and Pore Water Pressure Dissipation Test Results
    - Appendix G Laboratory Testing Schedule and Chain-of-Custody Forms
c) Anchor QEA, LLC (2013). "Offshore Sampling Data Report, Ashland Lakefront Superfund Site," November 2013 report
d) Anchor QEA, LLC. (2012). "Independent Evaluation of Sediment Removal Alternatives, Ashland/Northern States Power Lakefront Superfund Site," October 11, 2012 report
e) Burns and McDonnell, (2011). "Data gap investigation report for Ashland/NSPW Lakefront Site, Ashland Wisconsin, July 2011 report
f) Conetec, Inc. (2013). "Presentation of in situ testing program results," Ashland Lakefront Superfund Site, Aug 1 through Sept 13, 2013, September 17, 2013 report
g) ESEH (1996). "Sediment Investigation Report, Chequamegon Bay, Ashland, WI," July 1996 report
h) Foth (2012). Final boring logs, December 2012
i) Gradient (2012). "Critique of National contingency plan consistency of US EPA's September 2010 Record of Decision for the Ashland/Northern States Power Lakefront Site," October 2012 report
j) Northern Environmental Technologies, Inc. (1989). logs of borings 88-1 through 88-5, made in January 1989
k) URS (2007). "Remedial Investigation Report, Ashland/Northern States Power, Lakefront Superfund Site" August 31, 2007 report

l) Weston Solutions, Inc. (2009). Technical Memorandum, Conceptual Geotechnical Assessment for Sediment Removal, Ashland Northern States Power Lakefront site," Weston Solutions, Inc. Nov. 20, 2009 report

4. Evaluation of Site Characterization

4.1 Weston Approach

Weston called the stratigraphic section in their technical memorandum a "Conceptual Design Subsurface Profile." It was based on results of two, approximately 17 ft deep offshore borings, 29N 15E and 29N 20E, which bottomed out in the upper portion of the Miller Creek formation. The depth of the Copper Falls aquifer was based on logs of land borings MW-24A, MW-25A and MW-26/26A. Soil properties in their analyses were based on information collected from these 5 boreholes. Shear strength parameters were based on correlations with standard penetration blow counts (N values), correlations that, at best, provide a first order estimate of the strength parameters.

The conceptual design subsurface profile and soil parameters used in Weston's analyses are presented in Figure 1. Weston prefaced their conclusions and recommendations by stating that they are "based on limited site-specific geotechnical field and laboratory data, and therefore must be considered preliminary and conceptual-level only." They further stated that "in order for a final design of the dry excavation alternative to be properly completed, additional geotechnical data are required." Results of several detailed site investigations are now available, and the Weston profile and analyses are discussed in light of these new data in the following sections.

4.2 Site Geology

Although the geology at the Site was not discussed by Weston, the significant spatial variability in the stratigraphy and soil parameters at the Site are likely to affect the safety and implementation of the dry excavation remedy from a geotechnical perspective.

The Pleistocene geology of the Lake Superior region has been described by Clayton (1984). The site is located in the Superior Lowlands physiographic region. The soils encountered offshore are from the surface downward: post-glacial sediments, glacial tills of the Miller Creek formation and the Copper Falls aquifer. The Miller Creek formation was deposited 11,500 to 9500 years before present and consists of two separate tills: the Douglas member and the Hanson Creek member. The latter till is located below the former, and typically contains more clay that the former. This has been shown to be the case at the Ashland site, where logs of the offshore borings and CPT probes indicate that clays generally form the bottom of the aquitard. The two tills together comprise the aquitard encountered at the site. The Copper Falls formation as deposited before the Miller Creek formation and is primarily a sandy till but also contains a large amount of other material, especially sand and gravel deposited by meltwater streams.

A few comments are pertinent about the composition of a till. Till refers to any soil that is deposited from a glacier and thus includes soils deposited in many ways. For example, a lodgment till consists of material deposited from ice as a result of melting at the base of a sliding glacier. Subglacial melt-out till consists of material deposited from ice as a result of melting at the base of a non-sliding glacier. Supraglacial melt-out till consists of material that melts out from the upper surface of a glacier and is then let down and deposited when all the ice melts away. These different processes result in soil types and corresponding engineering parameters that can vary significantly over relatively short distances. Many times gravels and boulders are mixed in a matrix of other soil types when the soil has been deposited directly from the ice. Significant variations should be expected within the Site, given its size.

4.3 Stratigraphy

There has been a significant amount of subsurface exploration completed since the Weston report was written in 2009. In addition to the borings considered by Weston, I have considered both offshore and onshore borings, including those collected as part of the offshore sampling conducting by Anchor QEA LLC in 2013. The offshore borings and probes reviewed included seven AQ-SB series borings, thirteen AQ-CPT probes and twenty-three SD-series borings. The shoreline borings reviewed included thirteen SB borings. Figure 2 summarizes the variability in just the AQ series borings and CPT probes that were obtained offshore. It shows plots of cone tip resistance, q_t, water content, Atterberg limits, undrained shear strength, S_U, and overconsolidation ratio (OCR) versus elevation. Values of q_t vary at the same elevation from less than 5 tsf to as much as 400 tsf. Water contents vary significantly and large differences exist at the same elevation in plasticity indices. The same is true for S_u and OCR. Examination of the results of these probes and borings clearly showed that conditions vary significantly across the site. These variations are expected given the geologic origins of the soils at the site, and the offshore data show variations in soil types and engineering properties over relatively short distances. Given the size of the project, it would be difficult to develop one soil profile for the entire site that would be conservative for all potential modes of failure for a sheet-pile supported, dry excavation. Furthermore, one conceptual soil profile is inadequate to evaluate the technical feasibility of the proposed dry dredge scheme.

4.4 Ground Water Conditions

The waters of Lake Superior atop the Miller Creek formation can be considered a perched water table, isolated from the artesian water pressures within the Copper Fall aquifer. The piezometric level within the deeper Copper Falls aquifer is at elevation 617.1 ft MSL while the level of Lake Superior is elevation 603 ft MSL. This difference in head creates an upward flow of water through the Miller Creek formation.

With respect to the proposed dry dredge scheme, both the piezometric head within the Copper Falls aquifer and the elevation of this aquifer are important. For example, the Weston conceptual design profile indicates that the top of the Copper Falls aquifer is at elevation 558 ft and assumes a piezometric head in the aquifer of 617.1 ft. This value of piezometric head has not been disputed in the various reports I reviewed, and will be used herein as well.

While the top of the aquifer generally drops as one moves offshore, the offshore borings indicate there are local variations in the elevation where the permeable strata beneath the relatively impervious clays of the Miller Creek formation are encountered. The elevations based on the results of the AQ series borings and the CPT soundings made offshore are summarized in Table 1. Appendix A includes the stratigraphy at the location of each offshore boring and CPT probe listing in the table. Note that 4 of the CPT soundings were made close to a boring, and the results the pairs are presented together to facilitate interpretation of the results.

Table 1. Elevation of Top of Permeable Soil Beneath Aquitard

Boring and/or CPT Offshore location	Elevation of top of permeable soil (ft MSL)	Boring and/or CPT Onshore location	Elevation of top of permeable soil (ft MSL)
AQ-SB01 and CPT-03	552	SB 159	Deeper than 554[1]
AQ-SB02	563	SB 160	Deeper than 555[1]
AQ-SB03 and CPT-06	549	SB 161	Deeper than 555[1]
AQ-SB04	536	SB 162	561
AQ-SB05 and CPT-09	543	SB 163	566
AQ-SB06	549	SB 164	561
AQ-SB07 and CPT-13	Deeper than 530[1]	SB 165	Deeper than 554[1]
CPT-01	548	SB 181	560
CPT-02	541	SB 182	566
CPT-04	568	SB 183	566
CPT-05	561	SB 184	Deeper than 557[1]
CPT-07	543	SB 185	567
CPT-08	534	SB 186	Deeper than 552[1]
CPT-10	535		
CPT-11	557		
CPT-12	536		

[1] Copper Falls aquifer not encountered in boring; elevation shown corresponds to the bottom of the borehole

Shading indicates top of permeable soil is above elevation 560 ft

As one can see in the table, the top of the aquifer varies from elevation 530 ft to elevation 568 ft. The soundings that are shaded are those that show this contact to be at elevation 560 ft or above. The locations of these soundings cover a wide area both on and offshore within the western half of the Site, indicating this condition is pervasive over a significant portion of the proposed dry dredge area. As will be discussed in section 6.1, the higher elevations of aquifer result in lower FS against uplift, and in some cases, uplift failure is indicated.

4.5 Shear Strength Evaluation

The shear strengths selected for use in the analyses of undrained loading conditions presented herein are based on results of CPT test results, field vane shear tests and laboratory tests. Laboratory shear tests include unconsolidated undrained (UU) triaxial tests. Results of pocket penetrometer tests were not used to quantify shear strength of the cohesive soils; these tests provide indices of strength, at best. In keeping with the variations in stratigraphy across the site, one set of shear strength parameters is not applicable across the entire site. Rather values will be selected based on the conditions at the particular location under consideration.

No effective stress shear strength data were available that are applicable to drained shear strength of cohesive soils for use in long term analyses.

5. Evaluation of Factor of Safety

5.1 Description and Use in Geotechnical Engineering

The Factor of Safety (FS) is commonly defined as the resistance of a system divided by the applied load. An acceptable FS is a value to which a structure must conform or exceed. This term is also known as a design factor of safety or required factor of safety.[1] The FS depends on many factors, including type and importance of a structure or geostructure, the soil stratigraphy and its variability, the thoroughness of the site investigation, the expected level and method of construction inspection and quality control and the consequences of failure. These design values in geotechnical engineering also depend on the mode of failure being considered. For example, when designing a gravity retaining wall, the acceptable FS depends on the mode of failure: for potential sliding along the base of the wall and for overturning of the wall, the acceptable FS is 1.5, whereas for a bearing capacity failure, the acceptable FS is 3. These factors of safety therefore depend on both the method of analysis and the soil parameters used in the analysis. Because there always are uncertainties associated with the actual subsurface conditions (because only a minute fraction of the soil that is affected by a project is ever sampled or tested), the inherent variability of the ground should be accounted for in a rational manner.

A good example of how the interplay between uncertainties in subsurface conditions and soil parameters and consequences of failure relate to an acceptable factor of safety is shown in Table 2. This table is taken from Duncan and Buchignani (1975) and, while it is applicable strictly to slope stability analyses where shear failure of the soil is the mode of failure, it illustrates the fact that an acceptable

[1] A FS of 1 implies that a structure will fail. For example, if the results of a slope stability analysis indicates that a natural slope has a FS of 1, it means that a landslide will occur at that location. Clearly, one must design to a FS greater than 1 to ensure a safe and reliable structure.

factor of safety depends on more than just the type of analysis that is being performed. The second row of the table is appropriate for the proposed dry dredge scheme and a global stability analysis at the Site, given the variability of the subsurface conditions and the potential for loss of life to workers in an excavation if a slope failure would occur that encompasses the sheet pile wall and allows the retained Lake Superior waters to flood the excavation. There would be large economic and environmental costs associated with such a failure.

Table 2. Uncertainty and Factor of Safety

Cost and consequences of slope failure	Uncertainty of strength measurements	
	Small [1]	Large [2]
Cost of repair comparable to cost of construction. No danger to human life or other property if slope fails.	1.25	1.5
Cost of repair much greater than cost of construction, or danger to human life or other valuable property if slope fails.	1.5	2.0 or greater

[1] The uncertainty of the strength measurements is smallest when the soil conditions are uniform and high quality strength test data provide a consistent, complete and logical picture of the strength characteristics.

[2] The uncertainty of the strength measurements is greatest when the soil conditions are complex and when available strength do not data provide a consistent, complete or logical picture of the strength characteristics.

5.2 Short Term versus Long Term Conditions

An additional factor in selecting an appropriate factor of safety is the conditions for which it is applicable. The short term condition reflects the conditions at the end of construction, which for the dry dredge case refers to a situation when the sheet pile wall has been installed and the excavation has been completed. From a geotechnical viewpoint, the short-term conditions are assumed to occur under undrained loading conditions, wherein the loading has been applied rapidly causing excess pore water pressures to develop because of a lack of drainage. An undrained shear strength is commonly used for clays and silts to represent the strength for these conditions. Long term normally refers to the typical operating conditions sometime after construction has been completed and when all excess pore water pressures arising from the stress changes caused by the construction activities have dissipated. For the long term conditions, drained strength parameters, as commonly represented by the effective stress friction angle and effective cohesion, are commonly used for clays and silts to represent the strength for these conditions.

Depending on the type of loading and the stress history of the clays and silts, either of the two conditions may yield a lower FS. For example, for a compression loading, the undrained shear strength of a normally to lightly overconsolidated clay will be lower than the drained shear strength for the same effective consolidation stresses and thus yield a lower FS. Conversely, if the clay is heavily overconsolidated, the opposite is true. As such, the available resistance will change based on the condition being analyzed and the FS will depend on the assumed *type* of shear strength parameters.

Because of the size of the project, it will take more than one construction season to complete the work, and thus significant dissipation of the construction-induced excess pore water pressures will occur and both conditions will develop during the course of the project. As such, both loading conditions must analyzed and the FS for both conditions must be satisfied. This requirement is explicitly stated in the USS Steel Sheet Piling Design Manual (US Steel Corp. 1975) for sheet piles in clay.

5.3 Typical Values

This section will summarize the values I believe are appropriate for each potential failure mode and for sizing the sheet pile wall.

5.3.1 Bottom Instability Arising from Artesian Water Pressures

This potential failure mode for the dry dredge option arises from the artesian water pressures present in the Copper Falls aquifer. Once the sheet pile is in place, the water inside the sheeting is pumped, and contaminated sediment is removed. This excavation reduces the weight of the soil above the top of the aquifer. When the water pressure in the aquifer, p_{uplift}, is greater than vertical stress caused by the presence of soil above the aquifer, σ_V , then an uplift failure occurs. The FS in this case is simply the ratio of the two:

$$FS = \frac{\sigma_v}{p_{uplift}} \tag{1}$$

Industry standards regarding an acceptable FS for this failure mode have been published by the Navy in NAVFAC DM7-02 (1986). The Navy lists acceptable values of FS of 1.5 for temporary (or short term) and 2.0 for permanent (or long term) conditions. Note that these values are for a FS computed via equation 1, and do not include any resisting forces for shear developed through the soil layer(s) above the aquifer, as was done by Weston in their conceptual design. Because the acceptance of these values by industry is largely based on precedent, the FS should be computed using accepted, industry-standard formulae, equation (1) in this case.

5.3.2 Piping

When the seepage velocity of ground water is relatively large, erosion of soil can occur because of the frictional drag exerted by the flowing water on the soil particles. Erosion of soil under these conditions, known as "piping," can lead to failure of a water retaining structure. As water flows onto a free surface, it removes soil, starting from the exit point of the seepage. Erosion advances up gradient until failure occurs. This condition has led to catastrophic failures of water retention structures. Vertically upwards seepage is a source of danger on the downstream side of sheet piling and is a potential mode of failure for the dry dredge option. The large artesian water pressures create an upward flow of water concentrated adjacent to the sheet pile from the Copper Falls aquifer to the excavated surface. If piping occurs, soil will be removed from the ground adjacent to the sheet pile wall, removing lateral support for the sheeting, and will lead to a collapse of the sheet pile wall and subsequent flooding of the excavation.

The FS against piping is calculated as:

$$FS = \frac{\gamma'_{sub}}{i\,\gamma_w} \qquad (2)$$

where γ'_{sub} is the submerged unit weight of the soil, γ_W is the unit weight of water and i is the hydraulic gradient, computed at the location where the water exits the soil. Weston in their conceptual design stated that this FS should be between 4 and 5, and I agree.

5.3.3 Sheet Pile Design

A cantilever sheet pile wall is sized typically by finding the length of the sheet pile that creates moment equilibrium of active and passive lateral pressures acting against the sheeting, computing the maximum moment in the sheeting based on these equilibrated forces and selecting a sheet pile section modulus that is greater than or equal to that required to resist the moment. The final length of the sheeting is determined by increasing the embedment length by 20 to 40% to account for the fact that the passive earth pressures are not fully mobilized along parts of the sheeting. This provides a margin of safety, but is not reflected in any FS defined in the terms of resistance and load. Additional margins of safety are provided in the structural design of the sheeting.

This procedure assures that the sheet pile wall can resist the lateral loading imposed after the soil inside the walls have been excavated. Typically commercially available sheet pile sections can support a cantilever wall about 15 ft of retained soil without need of bracing such as ground anchors or internal supports.

Additionally, the entire section must be stable along possible shear failure surfaces that encompasses the entire depth of wall (US Steel Corp. 1975). If the section is not stable, a mass of soil that surrounds the sheet pile wall will slide into the excavation, thereby removing the impervious barrier retaining the waters of Lake Superior, and inundating the excavation. This global stability mode of failure can be evaluated by slope stability analyses in which the failure surface passes below the wall. In accordance with US Army Corps of Engineers requirements set out in EM-1110-2-1902, acceptable factors of safety for this mode of failure are 1.3 for short term conditions and 1.5 for long term conditions. These FS are appropriate because the sheet pile wall for the dry dredge option retains water. Note that these acceptable values also depend on adequately conservative selection of shear strength parameters and appropriate methods of analysis.

Short term conditions are applicable for the wall as soon as the excavation has been lowered to its final grade; for typical excavations, this can be as much as several months. The time frame for long term conditions depend primarily on the soil type, but if the excavation will be open for a year or more, as is the case here, then long term conditions would apply. Note that for an excavation through clayey soils that will be open at least one year, both conditions must be satisfied.

Factors related to constructability of the wall are that the as-built wall must be impervious and it must be able to be driven or vibrated to required depths without causing damage to the section or the interlocks. These constraints are not defined by a FS per se, but nonetheless must be considered when designing a retention system.

6. Evaluation of the Dry Dredge Option

This section provides an evaluation of the technical feasibility of the dry dredge option, and comments upon the approach Weston took in their analyses. Bottom stability analyses, piping and sheet pile design and constructability are discussed.

One common factor in all the analyses is the stratigraphy assumed by Weston. They developed one profile and one set of geotechnical parameters. As indicated in section 4, the subsurface conditions vary significantly across the site and different locations will be more critical for one potential failure mode. Weston's assumed stratigraphy and soil parameters are shown in Figure 1. By comparing this profile with the stratigraphy indicated in the offshore borings and CPT probes, one can see that this is not representative of the vast majority of the conditions encountered in the explorations that occurred after Weston produced their work. In each of the analyses discussed in the remainder of this section, the critical section based on the offshore explorations will be presented. Note that while there were other, shallower borings made offshore, i.e., the SD series borings, these did not extend below the Miller Creek formation and thus critical information was not available. When taking this factor into account, the number of offshore borings and CPT probes is not sufficient to define the variability of the soils encountered offshore at the Site. Consequently, to evaluate the technical feasibility of the dry dredge option, I will select the boring that represents a critical case for each of the potential modes of failure. In each case, I will use the unit weights for soil strata as summarized in the Anchor QEA, LLC December 2013 report.

6.1 Bottom Instability Analyses

There are a number of mechanisms that can result in instability of the bottom of the dry dredge excavation. These include uplift from the artesian pressures, piping and a global instability that encompasses the entire sheet pile wall. If any of these mechanisms occur, they would result in a wall collapse, and subsequent flooding of the excavation.

6.1.1 Uplift Analysis Indicates Failure of the Dry Dredge Scheme

6.1.1.1 Weston Approach

Using the soil profile and parameters in Figure 3, Weston evaluated the uplift potential from the artesian water pressures in the Copper Falls aquifer by considering the resistance to uplift solely by the weight of the soil above the aquifer using equation (1). They found that this resistance alone was not sufficient to safely excavate the entire site in the dry. Consequently, they proposed to make the excavation in a series of rectangular cells in which additional resistance was developed along the vertical planes around the periphery of cells. The results of their analyses suggested that a cell size of 150 ft by 200 ft would provide a FS of 1.25, which they deemed acceptable.

6.1.1.2 Evaluation of Approach

The soil profile used by Weston in their analyses did not address the critical conditions for uplift as revealed by borings and soundings which were unavailable to them. Table 1 listed the soundings at which the Copper Falls aquifer was found at higher elevation than Weston assumed. An example of these conditions is shown in Figure 3, a log of CPT-4. Using equation (1) with an excavated surface at elevation 590 ft MSL and the piezometric head in the aquifer at 617.1 ft, the FS for uplift in this case is 0.8. The FS for all cases where the top of the aquifer is at or above elevation 560 ft in Table 1 are shown in Table 3. Note that FS are computed using the total unit weights recommended by Anchor QEA and a uniform total unit weight for all strata of 125 pcf and 130 pcf. These latter values are included to show the relative insensitivity of the computed FS to reasonable values of total unit weight. The results on Table 3 show that all FS are less than 1.1 when the top of the Copper Falls aquifer is higher than elevation 560 ft, no matter what assumptions are made about unit weight. Even with the assumption of the highest unit weight, failure is indicated at several locations where the FS is less than or equal to 1. The calculations indicate that this would occur when the top of the aquifer is at or above elevation 566 ft. These results indicate a clearly unacceptable situation.

The use of the shearing resistance of the soil above the aquifer is not relied upon in NAVFAC in their computation of uplift FS. While some shearing resistance will be mobilized if the soil above the aquifer were to move as a rigid block, this is an unrealistic assumption for a large excavation. The soil will heave more in the middle of the excavation. Horizontal stresses will be reduced at that location, leading to development of tensile cracking in the soils at the top of the soil. A rigid body model, as implied in the Weston approach, is not applicable to these conditions, and is one reason why the shearing resistance at the edge of a block of soil should not be relied upon to provide uplift resistance.

Table 3. Computed FS against Uplift

Boring or CPT	Top of aquifer (ft MSL)	Uplift pressure (psf)	Anchor QEA total unit weights		Total unit weight 125 pcf		Total unit weight 130 pcf	
			σ_V (psf)	FS	σ_V (psf)	FS	σ_V (psf)	FS
SB-02	563	3376	3030	0.90	3375	1.0	3510	1.04
CPT-04	568	3064	2480	0.81	2750	0.90	2860	0.93
CPT-05	561	3500	3440	0.99	3625	1.04	3770	1.08
SB-162	561	3500	3210	0.92	3625	1.04	3770	1.08
SB-163	566	3189	2640	0.83	3000	0.95	3120	0.98
SB-164	561	3500	3290	0.94	3625	1.04	3770	1.08
SB-181	560	3563	3570	0.95	3750	1.05	3900	1.09
SB-182	566	3189	2640	0.83	3000	0.95	3120	0.98
SB-183	566	3189	2660	0.83	3000	0.95	3120	0.98
SB-185	567	3126	2660	0.86	2875	0.92	2990	0.96

Furthermore, the Weston model assumes the block extends to the sheet pile wall, and as such, the mobilized shearing resistance should correspond to the interface shear resistance between the sheet pile wall and the adjacent soil. The process of installing a sheet pile wall will induce high shear strains in the soil adjacent to it. This will result in a lower available strength at the interface to resist the uplift forces than was assumed by Weston. They assumed the interface strength would be the same as the shear strength of the soil, which is an unsafe assumption.

In summary, the soil conditions encountered in the offshore probes do not allow the dry dredge option to be safely constructed and operated because of the likelihood of an uplift failure caused by the artesian water pressures in the Copper Falls aquifer. If this occurs, the sheet pile wall would collapse, and subsequently flood the excavation.

6.1.2 Piping Factor of Safety is Below Industry Standards

6.1.2.1 Weston Approach

Weston estimated the upward gradient adjacent to the sheet pile wall, assuming installation of the sheet pile and excavation of the soil within a 150 ft by 200 ft cell. They did so by combining results of two separate analyses: the upward gradient caused by the artesian pressures in the Copper Falls aquifer and the gradient arising from flow around the completed excavation caused by the difference in head outside and inside the excavation. The former was made for subsurface conditions defined by their design profile shown in Figure 1. The latter was made assuming the flow around the sheet pile wall was through clean and silty sands (SP/SM according to the Unified Soil Classification System), thereby ignoring the effect of the head losses through the more impervious silt and clay of the Miller Creek formation. They computed exit gradients of 1.7×10^{-5} for the former case and 0.187 for the latter. They added these results to find the total exit gradient of 0.187.

They computed the FS against piping by equation (2) to be 5.53, which is larger than commonly accepted values of 4 to 5.

6.1.2.2 Evaluation of Approach

While the analysis for the flow around the sheet pile was conservative in that the profile was assumed to consist of granular soils, the first part of the analyses only considered the upward flow through their assumed profile (Figure 1) and thus was not representative of the conditions found during subsequent investigations. A more critical condition for the upward flow from the Copper Falls aquifer can be seen in Figure 4. In this case, the majority of the soil between the bottom of the excavation and the top of the aquifer is non-plastic sandy silt, ML. While there are only 4 Atterberg limits reported for samples of this ML soil encountered in the offshore borings, three of the four indicated that the ML is non-plastic. This type of soil is highly erodible. While the cone tip resistance indicates the material is dense to very dense, the process of installing the sheet pile wall will loosen the silt and create paths of preferential seepage. The critical location for the initiation of piping is adjacent to the sheeting at the excavated ground surface. If piping occurs there, it would lead to a catastrophic failure of the wall, a major reason why large FS are required.

The exit gradient based on the upward flow caused by the artesian pressures in the Copper Falls aquifer using a simple one-dimensional flow calculation of a uniform silt is illustrated in Figure 4. It is assumed that the hydraulic conductivity of the silt is 100 greater than that of the clay. For one-dimensional flow through soils with different hydraulic conductivities, one scales the flow length on the basis of the square root of the ratio of the hydraulic conductivities. In the example on Figure 4, this means that the actual flow length in the clay is 40 ft, rather than the actual value of 4 ft at this location. As indicated on the figure, the exit gradient is 0.4. Accepting the value of critical gradient in the Weston report of 1.034, rounded to 1 for sake of significant numbers, the FS against piping is 2.5. This value is less than the 4 to 5 range that is the industry standard, and the same one that Weston used. Consequently, the margin of safety against the possibility of piping is less than industry standards. If piping were to occur, then the sheet pile wall would collapse as a result of removal of the soil against its toe, leading to flooding of the excavation.

Note that this exit gradient does not include the effects of the flow around the sheeting, reported to be 0.187 by Weston, based on the assumption of a flow path of uniform granular soil. If this effect is included with the upward flow caused by the artesian pressures in the Copper Falls aquifer, then the exit gradient would be higher, and the FS against piping thus would be smaller making piping more likely.

6.1.3 Global Instability is Indicated based on Analysis of the Long Term Conditions

This mode of failure includes evaluation of a shear failure surface that encompasses the entire depth of the sheeting. It is a standard part of a design of any retention system (e.g., Sabatini et al 1997).

6.1.3.1 Weston Approach

Weston did not present any global stability analyses in their report.

6.1.3.2 Evaluation of Approach

Given the stiff clays and silts at the site and the relatively small excavated depth, one would not expect a deep seated failure through the clays and silts to be a problem for short term conditions of the dry dredge option. However given the artesian pressures in the Copper Falls aquifer, the effective stresses in the aquifer will be low, more so when the top of the aquifer is at a higher elevation. Because the shearing resistance of the granular soil in the aquifer is proportional to the effective stress, the shear strength of the sands near the top of the aquifer will be small and thus serve as a potential failure surface for a global failure. When the FS against uplift is 1 or less, the effective vertical stress at the top of the aquifer is zero, and the sand under these conditions has zero shear strength.

A mechanism that is appropriate for this mode of failure is a sliding block, as illustrated in Figure 5 for the conditions at CPT-04. This mechanism is appropriate when a thin, low shear strength soil is encountered. This is the case as the top of the Copper Falls aquifer when the uplift pressure equals the total vertical stress and thus the effective stress is zero at the top of the aquifer. This condition implies that there is no shearing resistance in the sand, and the shearing resistance along the central block is equal to 0.

This fact simplifies the sliding block analysis such that the FS against sliding is:

$$FS = \frac{resultant\ of\ the\ passive\ wedge}{resultant\ of\ the\ active\ wedge} \qquad (4)$$

For short term conditions, the FS will be large when using the undrained shear strengths of the silts and clays and global sliding will not a problem. However, for long-term loadings when the excess pore water pressures dissipate, and the drained shear strengths of the soils are appropriate, then the FS will be much lower. No drained laboratory tests were conducted on the silts or clays, and only UU triaxial tests wherein effective stresses were not measured were available. Therefore, assuming a friction angle of 35^o for the silt and 25^o for the clays based on relations between friction angle and plasticity index, the unit weights recommended by Anchor QEA and the conditions defined in Figure 5, the FS against sliding is 0.94. Any FS less than or equal to one indicates a sliding failure will occur. This FS is significantly less that the industry standard of 1.5 for long term analysis of global stability.

The issue then is how much time will be needed to attain this fully drained condition. This time is difficult to predict and depends on the rate of dissipation of excess pore water pressure. An estimate of this time depends on the length of the drainage path, the amount of secondary structure of the cohesive soils and their corresponding hydraulic conductivities. Excavation is an unloading process, the stress relief of which causes any joints or slickensides in the clays to open and increase the hydraulic conductivity. In stiff. overconsolidated clays, this time can be on the order of several months, as noted in the case study of an anchored bulkhead failure reported by Daniel and Olson (1982). The retained slope in stiff, overconsolidated plastic clays adjacent to a shipping channel failed 3-1/2 months after construction. As in this case, analysis using undrained conditions indicated that the retaining system was stable. However, using shear strengths appropriate for the long term, drained conditions indicated that the system as designed was unstable. From a design standpoint, the excavation at conditions defined by CPT-04 is not stable under long-term conditions. This mode of failure for the dry dredge option is a possibility and is another indication of the unsuitability of the dry dredge option.

6.2 Sheet Pile Design is Superficial

6.2.1 Weston Approach

Weston sized the sheeting using standard and appropriate methods, with the exception of no explicit analysis of global stability was made. In particular, they used the software PROSHEET, a steel sheet pile design program developed by Skyline Steel Corporation. However, they only analyzed the profile shown in Figure 2 and only did so for undrained conditions. There they did not analyze subsurface conditions as revealed by the subsequent offshore explorations, and they were not complete with their design calculations.

6.2.2 Evaluation of Approach

Both short term and long term conditions should be analyzed because excavation will be open long enough to allow significant dissipated of excavation-induced excess pore water pressures, especially considering case of one sheet pile wall extending completely across bay. Weston only considered short term conditions. Both conditions must be considered in a properly design when there is a possibility that significant excess pore water dissipation may occur. Given the scope of this proposed dry dredge option, it will likely take more than one construction season to complete the construction, thus allowing excess pore water pressures to dissipate significantly and making long term conditions applicable to the dry dredge option at the Site. Weston did not consider these conditions in their conceptual design.

Explicit consideration must be made for variations in level of Lake Superior arising from waves that develop during storms and apply a force in the direction of the wave. Because there are 90^{o} bends in the proposed sheet pile alignment across the bay, the difference in water elevations at the sheet piles in the corners caused by wave action will result in the sheet pile parallel to the wave direction to be subjected to compression. Sheet piles have very little in-plane stiffness and corner braces would need to be added to prevent buckling at corners when waves create such a direction force.

Furthermore, a water fill gap may develop at the seaward side of the sheet pile wall. This gap was a factor in the failure of the levees at the 14th Street canal in New Orleans during hurricane Katrina where water loading at the top of the sheet pile wall caused it to move away from the soil at the top of levee. It would be prudent to consider this when analyzing the sheet pile wall to resist lateral earth and water pressures, at least for the short term conditions.

In summary, Weston in their conceptual design did not considered explicitly the long term design condition, wave action, or the possibility of a water-filled gap. Exclusion of these factors in their analyses renders their conceptual design of the sheet pile section superficial.

6.3 Sheet Pile Wall will be Difficult to Construct

6.3.1 Weston Approach

Weston did not address constructability issues in their report.

6.3.2 Evaluation of Approach

It was implicitly assumed by Weston that the installed sheet pile wall would be impervious. The sheet pile wall has to be impervious enough so that water that leaks through wall can be safely pumped out of excavation to maintain a dry excavated surface. Sheet pile walls are not impervious. While hot rolled sheets are less permeable than cold rolled sheets, leakage has been observed in many excavations retaining only saturated soils, much less a wall that retains both free water and saturated soils. While the interlocks can be treated after driving to minimize this leakage, it is not clear how this can be accomplished overwater.

The assumption that the as-built sheet pile wall will be impervious and that the excavation can be made in the dry are serious flaws in the proposed dry excavation scheme because the installation process will have to be 100% reliable with respect to the impervious nature of the as-built sheet pile joints, an unattainable goal for the quantities of sheet pile that comprise the proposed barrier.

Karl Terzaghi, who is widely acknowledged as the “father of soil mechanics,” famously said, “Do not design on paper what must be wished in place.” By this, he meant that one should consider potential problems in constructing an earth work project in the design stage of the project. Driving sheet pile through very dense silts with cone tip resistances as high as 400 tsf and hard clays will present a challenge to a contractor. Furthermore, whenever gravel, cobbles and boulders are encountered, the oversized material can cause the interlocks to split, resulting in a zone of concentrated seepage, potential erosion of soil against the sheeting, and an ultimate collapse of the wall and release of Lake Superior water into the excavation.

Given the fact that the Miller Creek formation is composed of two separate tills, some of which has been deposited directly out of the ice, one should expect that gravel and boulders will be encountered when driving sheet piles through this formation. There is direct evidence in some the boring logs. For example, the Northern Technology boring log 88-5 indicates a "schist boulder" at 23 to 24 ft depth. Gravel is noted in many borings made both on and offshore. Damage to the interlocks between sheets is likely at some locations, and may will lead to concentrated flow of water from the Lake side to the excavated side of the sheet pile wall. This would lead to a collapse of the wall and subsequent flooding of the excavation.

7. Evaluation of Wet Dredge Approach from a Geotechnical Perspective

From a geotechnical perspective, use of the wet dredge approach eliminates the main obstacles to a successful dry dredge operation.

First and foremost, wet dredge will not require that a sheet pile wall be installed across the bay. This eliminates concerns regarding construction of a water tight wall, installing the wall to the required depths for both short and long term conditions and potential piping along the sheet pile. Furthermore, the costs of the installing and removing the sheet pile wall are eliminated. Even if a sheet pile wall were to be used as part of a wet dredge for wave attenuation or containment purposes, it would have water on both sides, eliminating the risk of wall collapse and catastrophic flooding.

Because the water in the bay will not be drawn down to elevation 590 ft, but remain at its current level, there will be less uplift potential because the upward gradient is not as large as for the dry dredge option because the additional water pressure when the lake water surface is maintained at its natural level serves to increase the total weight of the materials above the top of the Copper Falls aquifer. Under the worst condition shown in Table 2, i.e., subsurface conditions defined by CPT-04 and assuming the QEA Anchor unit weights for the soil, the FS increases from 0.81 to 1.07 when the soil has been wet dredged to elevation 590 ft, a substantial increase in the margin of safety. For all locations in Table 2, the FS for the dry dredge scheme varies from 0.81 to 0.99, which indicates failure conditions over a wide area of the proposed excavated area. In contrast, the FS for the wet dredge scheme at the same locations and assuming the same QEA Anchor unit weights varies from 1.07 to 1.40. At no locations does the wet dredge option cause an uplift failure. While this FS is low, there is no danger to workers and there is no possibility of a catastrophic loss of a dry excavation.

In a similar fashion, the FS against piping and global stability correspondingly increase, making a geotechnical failure of this system unlikely, and will provide a much safer geotechnical system than a dry dredge operation.

8. Summary and Conclusions

This report summarizes my evaluation of the geotechnical conditions at the Ashland Lakefront Superfund Site and associated impacts on the proposed dry dredge scheme. I reviewed the information available in the documents listed in section 3 of this report. I understand that the dry dredge scheme will entail driving a row of sheet piles across the bay and around the shore line to provide an impervious wall. Water will be pumped from this enclosure and the contaminated sediments will be excavated with conventional earth moving equipment.

After reviewing the existing data and analyses regarding the Site, I have reached the following conclusions:

- The conceptual Weston Solutions Inc. (Weston) analyses were made before the 2013 offshore data were collected and do not reflect the current knowledge of Site conditions. Weston prepared a technical memorandum that included a conceptual geotechnical assessment of the proposed scheme based on limited subsurface data, especially offshore. They concluded that a dry excavation scheme could be a feasible means of removing contaminated sediments from the areas close to shore at the site. However, they also qualified their report by stating "It must be initially stated and understood by all relevant project participants that the analyses, conclusions and recommendations presented herein are based on limited site-specific geotechnical field and laboratory data, and therefore, must be considered preliminary and conceptual-level only." Since they issued their report in 2009, much more site-specific data has been generated and my analyses and recommendations benefit from this additional information. Furthermore, they also stated in their conclusions and recommendations that "variability in subsurface data is likely, which may result in several different sheet piling designs along the alignment of the wall." Indeed, results of site exploration and testing completed after Weston made their recommendations, and consideration of the geologic origins of the soils at the site, did show that subsurface conditions vary significantly across the site. The one stratigraphic section that Weston considered in their report was not representative of conditions throughout the site.

- The Factors of Safety (FS) used in Weston's analyses do not appropriately account for variability in Site subsurface conditions, engineering parameters and loading condition. The FS should reflect uncertainties in subsurface conditions, engineering parameters, loading conditions and consequences of failure. The FS used by Weston did not adequately consider these factors in all cases, particularly when considering the potential for bottom heave from the artesian pressures in the Copper Falls aquifer.

- The excavation in a dry dredge scheme will not be stable because bottom heave due to artesian water pressures will likely occur at some locations after soil has been excavated. Contrary to

Weston's opinion, when bottom heave occurs, the excavation likely will be flooded by ground water from the underlying Copper Falls aquifer.

- Weston's conceptual design did not consider the effects of upward flow of water adjacent to the sheet pile for the actual subsurface conditions encountered offshore, as noted in the Anchor QEA December 2013 report. There are several locations defined in the offshore borings and CPT soundings, where the FS against piping is about one-half of the industry standard of 4 to 5. If piping were to occur, support provided by the soil adjacent to the sheet pile wall would be removed and the wall will collapse, flooding the excavation.

- Weston's conceptual design did not consider a failure mode that encompasses the entire sheet pile wall. The FS against this global instability was computed assuming a sliding block model when the excavation is at final depth. Results of the analysis indicate that failure will occur for the long term condition. Failure in this case implies that a mass of soil encompassing the wall sill slide into the excavation and subsequently flooding it. Standard design practice dictates that an excavation that is will be open for more than one year be designed for both short and long term conditions.

- Weston's conceptual design of the sheet pile wall was superficial in that it did not adequately account for expected loading conditions. Their design did not consider wave loadings, development of water filled gaps during period of high water, or the directional effects of wave loading. Sheet pile wall provide resistance to bending and tensile stresses, but not compressive stresses. Therefore, when the wall has a 90 degree bend, some bracing will be required to ensure stability.

- Weston's conceptual design of the sheet pile wall results in a sheet pile wall that will not be able to be constructed such that it will perform as intended. Weston's approach is not conservative, as it assumes that the as-built sheet pile joints will be impervious, an unattainable goal for the quantities of sheet pile that comprise the proposed barrier. There are a number of significant construction-related difficulties associated with the dry dredge option not addressed in their report. It will be very difficult to construct the sheet pile wall and maintain its function as an "impervious" barrier as well as its structural integrity. It will be difficult to install sheeting to required depth through the hard portions of the glacial tills. Till refers to any soil that is deposited from a glacier and thus includes soils deposited in many ways. Significant variations in its composition should be expected within the Site, given its size. Concentrated flows of water through the sheeting could develop as a result of losing the sheeting interlocks when driving in tills with gravel and boulders, which would lead to a collapse of the sheet pile wall and subsequent flooding of the excavation.

- A wet dredge method eliminates problems with bottom heave, global instability and design and construction issues associated with the dry dredge option, and is a far better solution to the geotechnical challenges at the Site.

For these reasons, and as detailed in the body of the report, it is my opinion that the proposed dry dredge scheme is not safe or implementable at the Site, because of the potential for bottom heave, global instability and various design and/or constructability concerns discussed herein. A wet dredge approach would eliminate these risks, and thus is a far better solution to the geotechnical challenges of the project.

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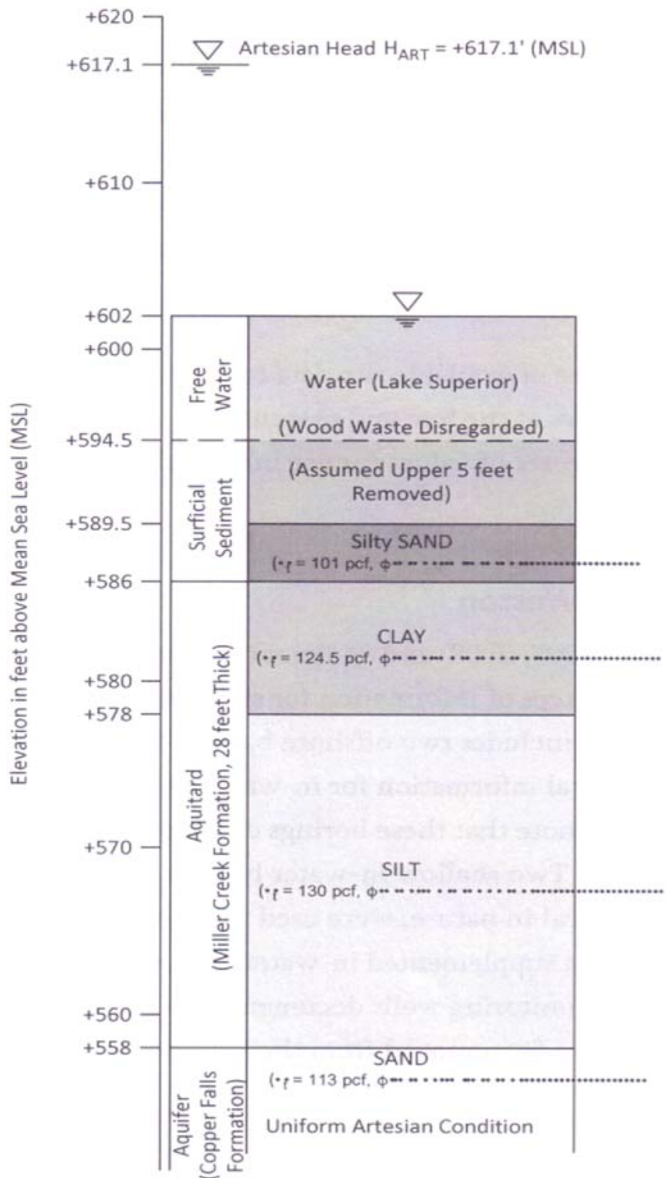
Figure 1. Soil Profile and Parameters Developed by Weston



Soil Unit	Representative Blow Count (N_{REP}; blows/ft)	Total Unit Weight (pcf)	Undrained Shear Strength (psf)	Internal Friction Angle (degrees)	Vertical Permeability (cm/sec)
Sediment	6	101	0	26	$1x10^{-2}$
Clay layer of aquitard	9	124.5	0[1]	31[1]	$1x10^{-7}$
Silt layer of aquitard	17.5	130.5	660	0	$1x10^{-5}$
Sand (aquifer)	13	113	1,250	0	$1x10^{-3}$

Figure 2. Summary of Offshore Soundings

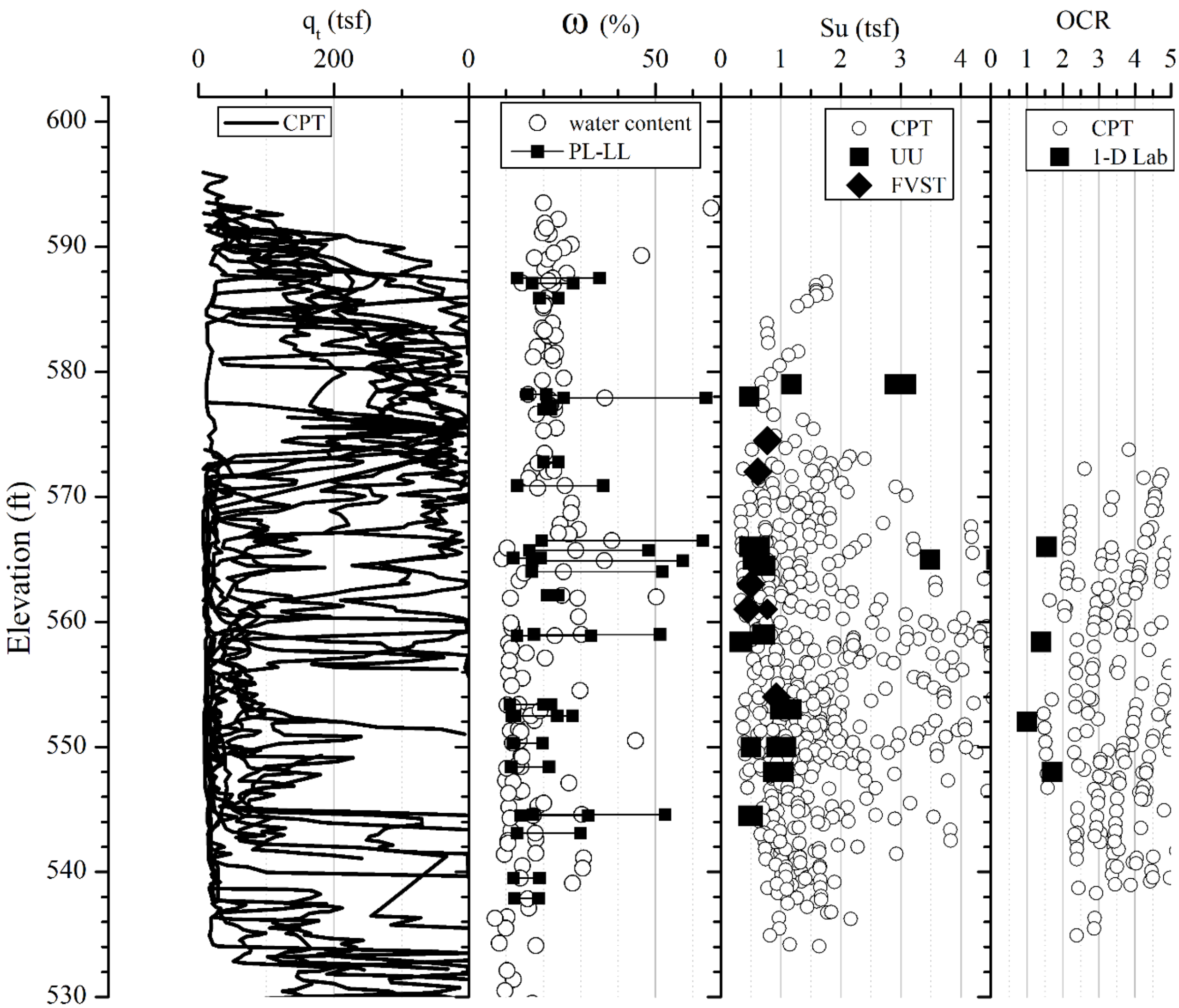
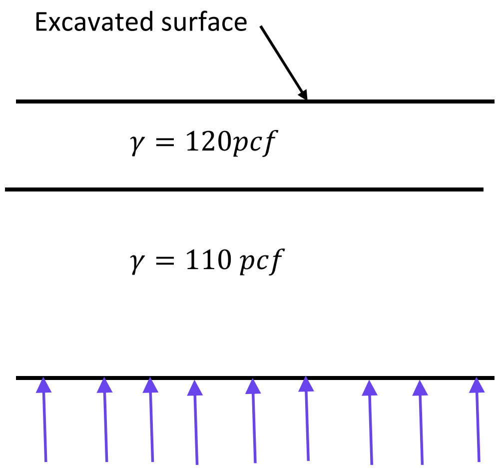


Figure 3. Subsurface Conditions and Example Uplift Calculation



P = (617.1 – 568)62.4 = 3064 *psf*

$$FS = \frac{7x120 + 15x110}{3064} = 0.8$$

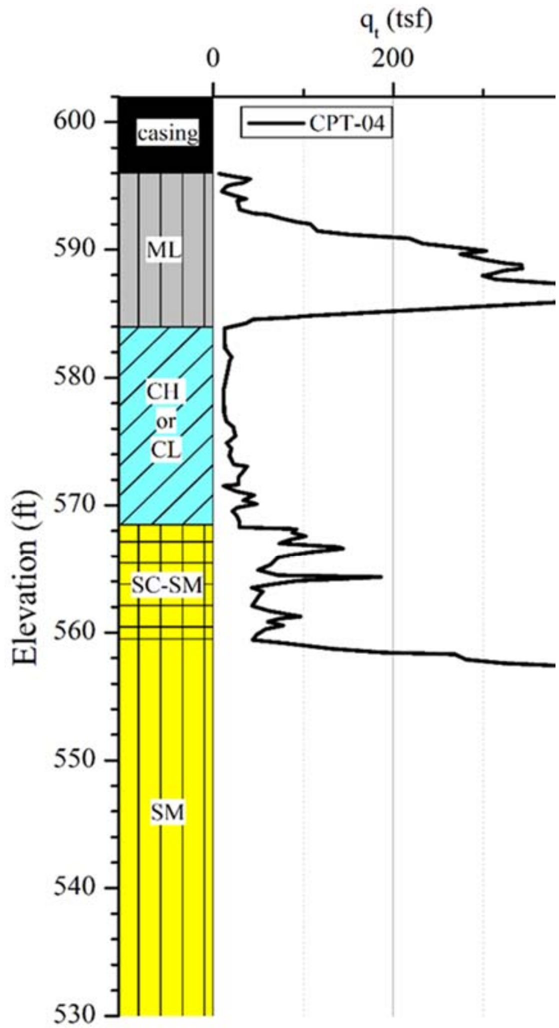
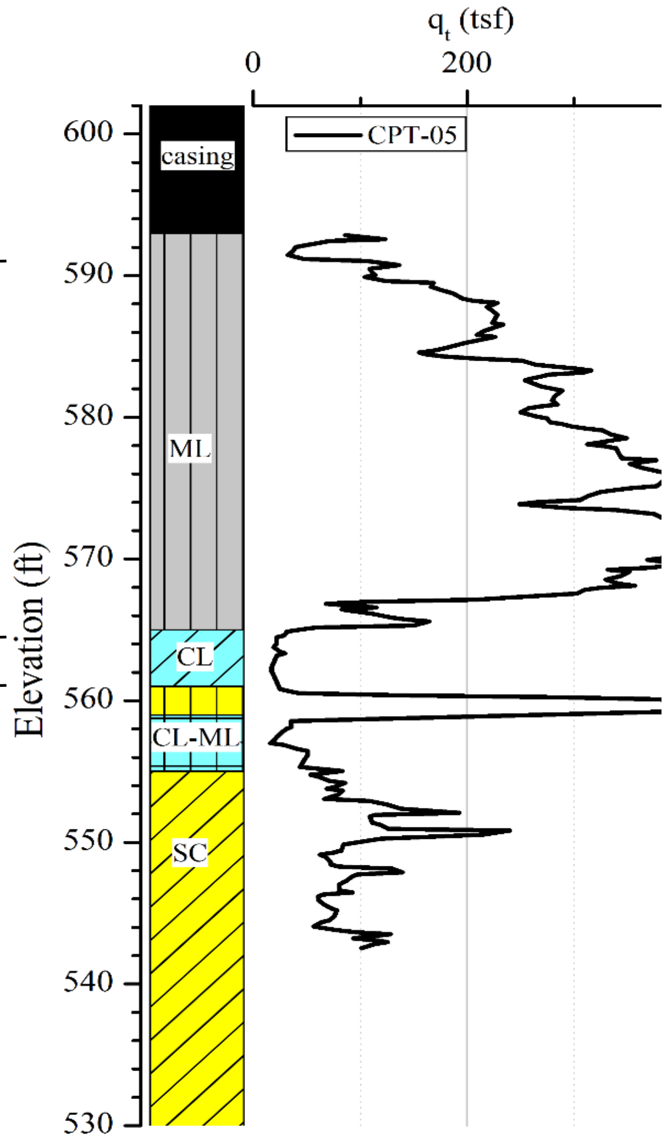


Figure 4. Subsurface Condition and Calculation of Upward Gradient



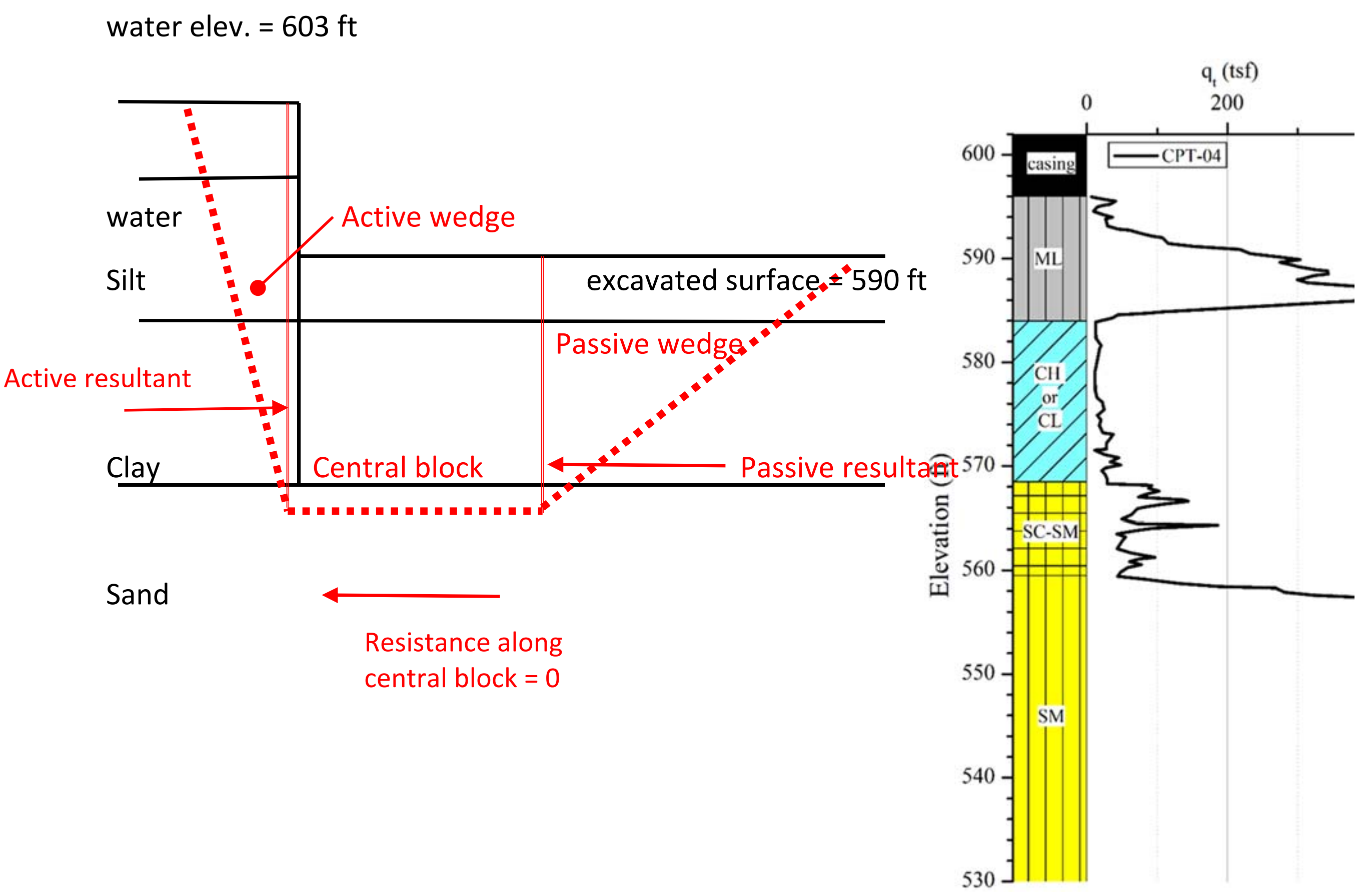
27 ft Silt, K

4 ft Clay, K/100

$$i_{exit} = \frac{617.1-590}{27+4\sqrt{100}} = 0.4$$

$$FS = \frac{i_{crit}}{i_{exit}} = \frac{1}{0.4} = 2.5$$

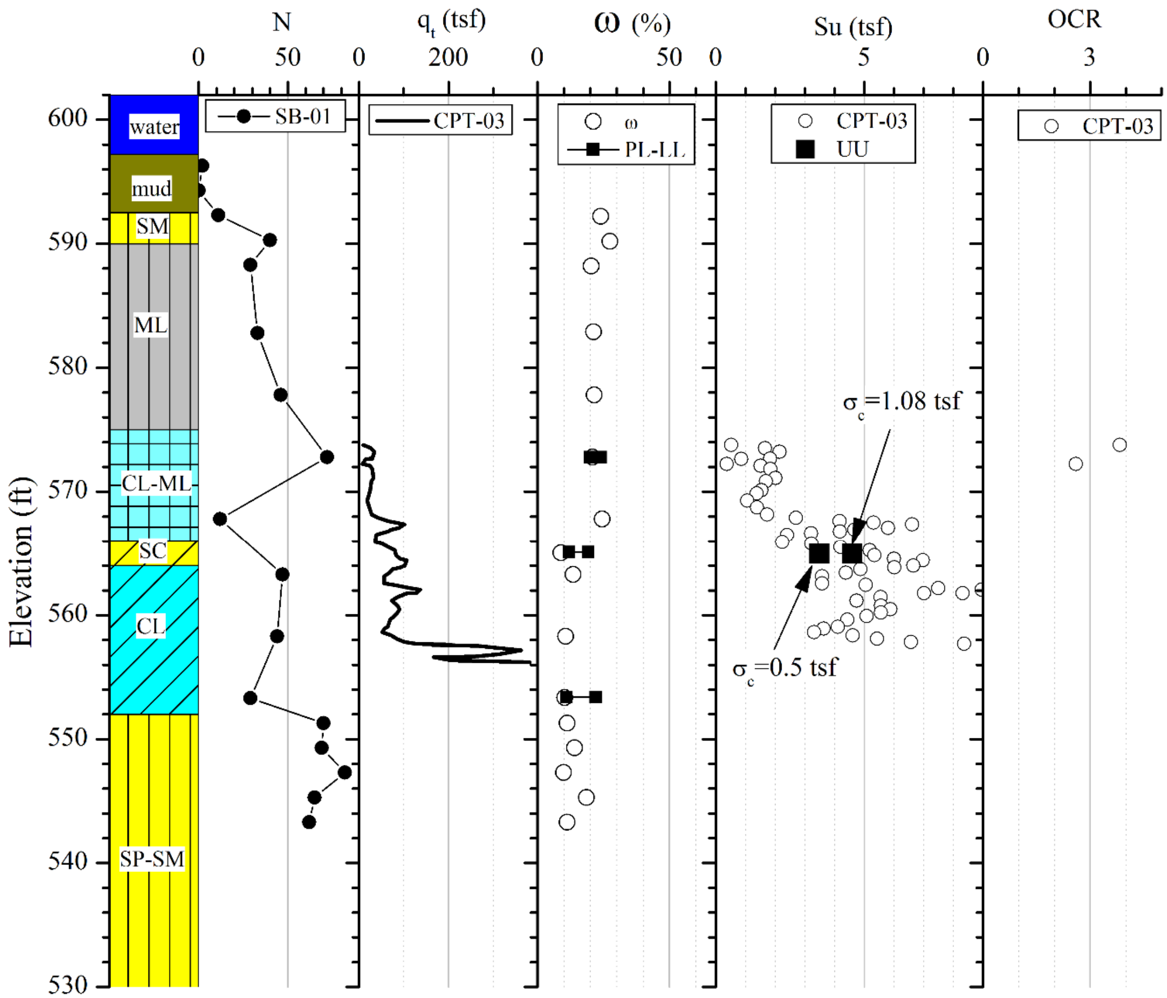
Figure 5. Sliding Block Method of Analysis



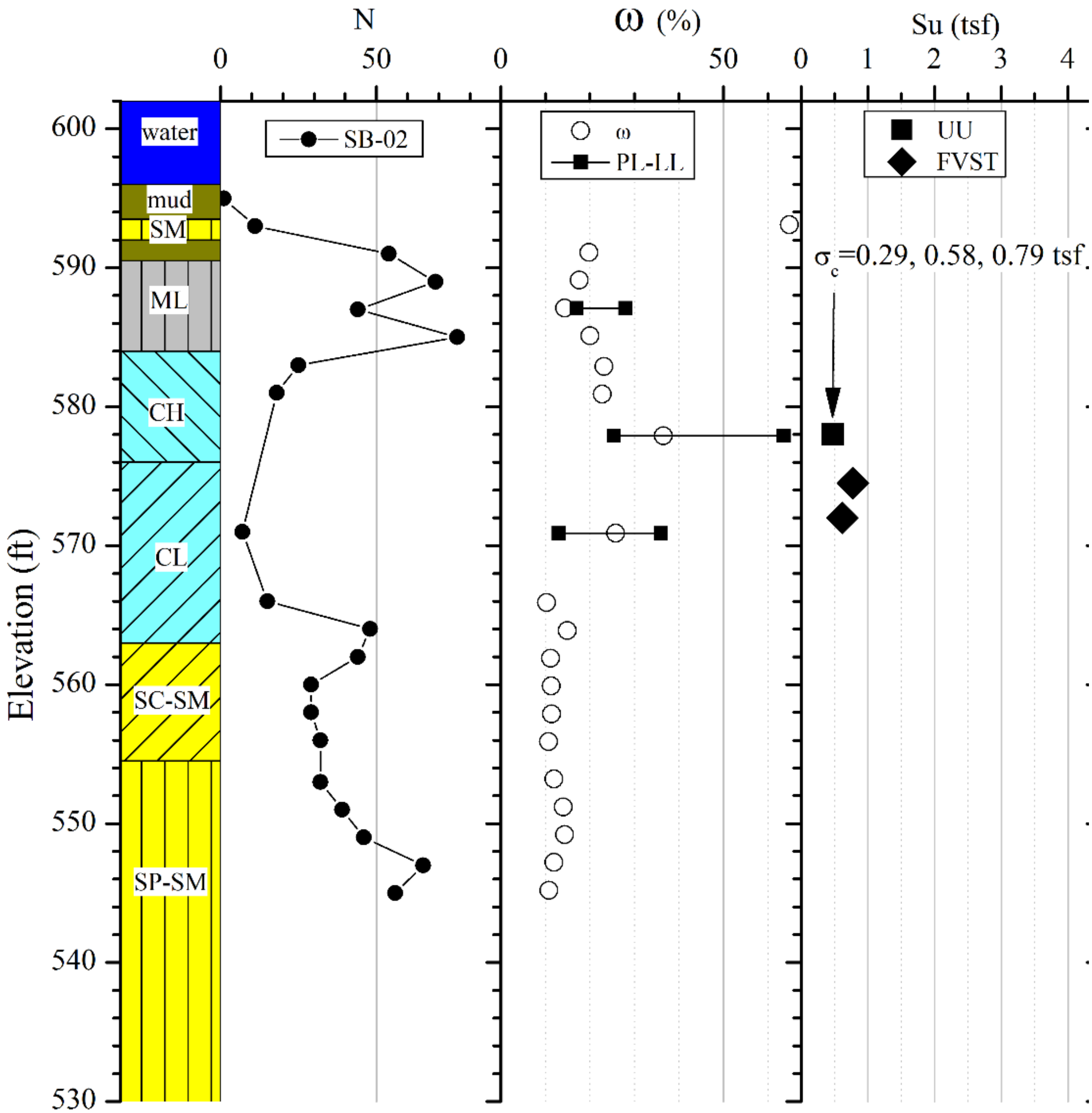
APPENDIX A

Logs of Offshore Borings and CPT Probes

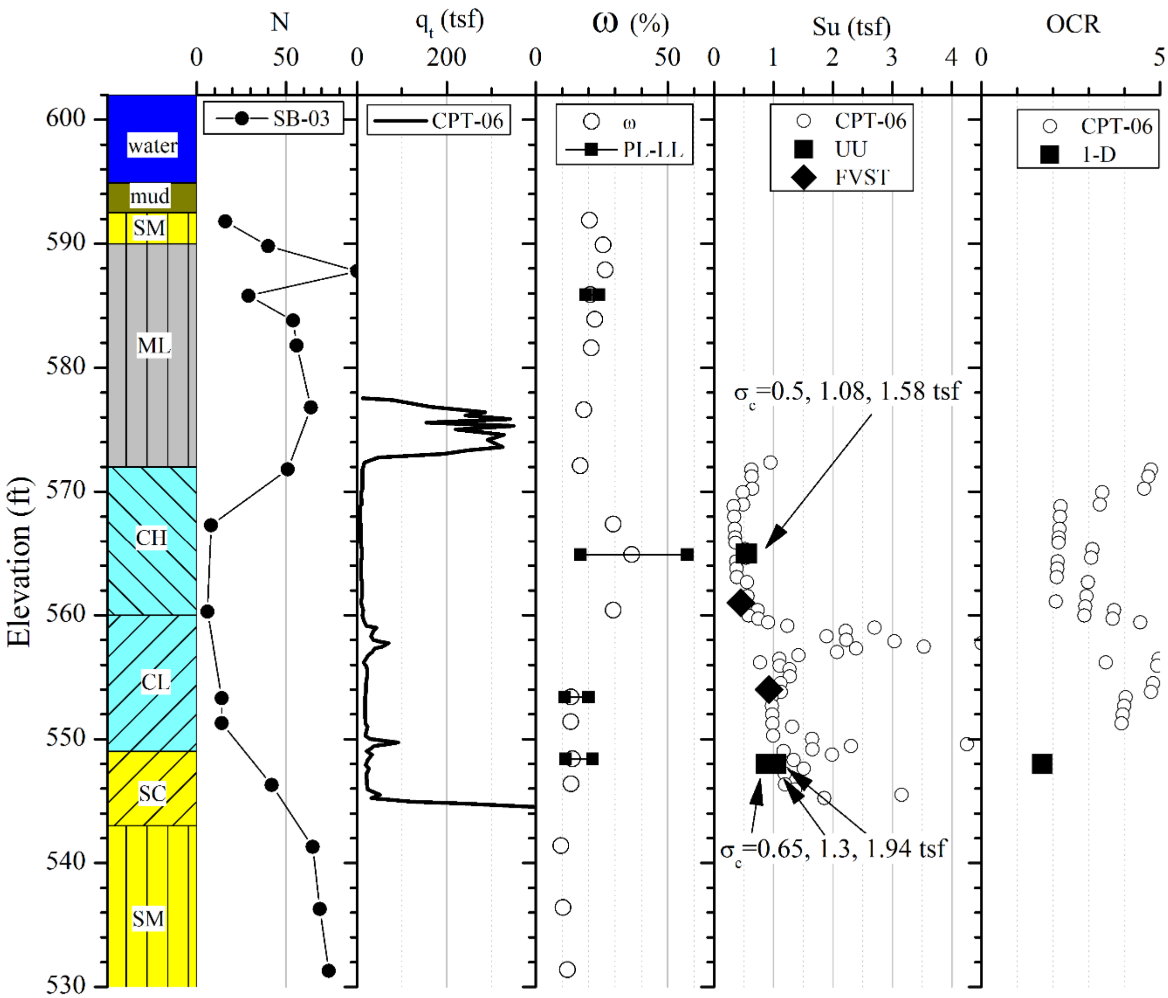
AQ SB-01 and CPT-03



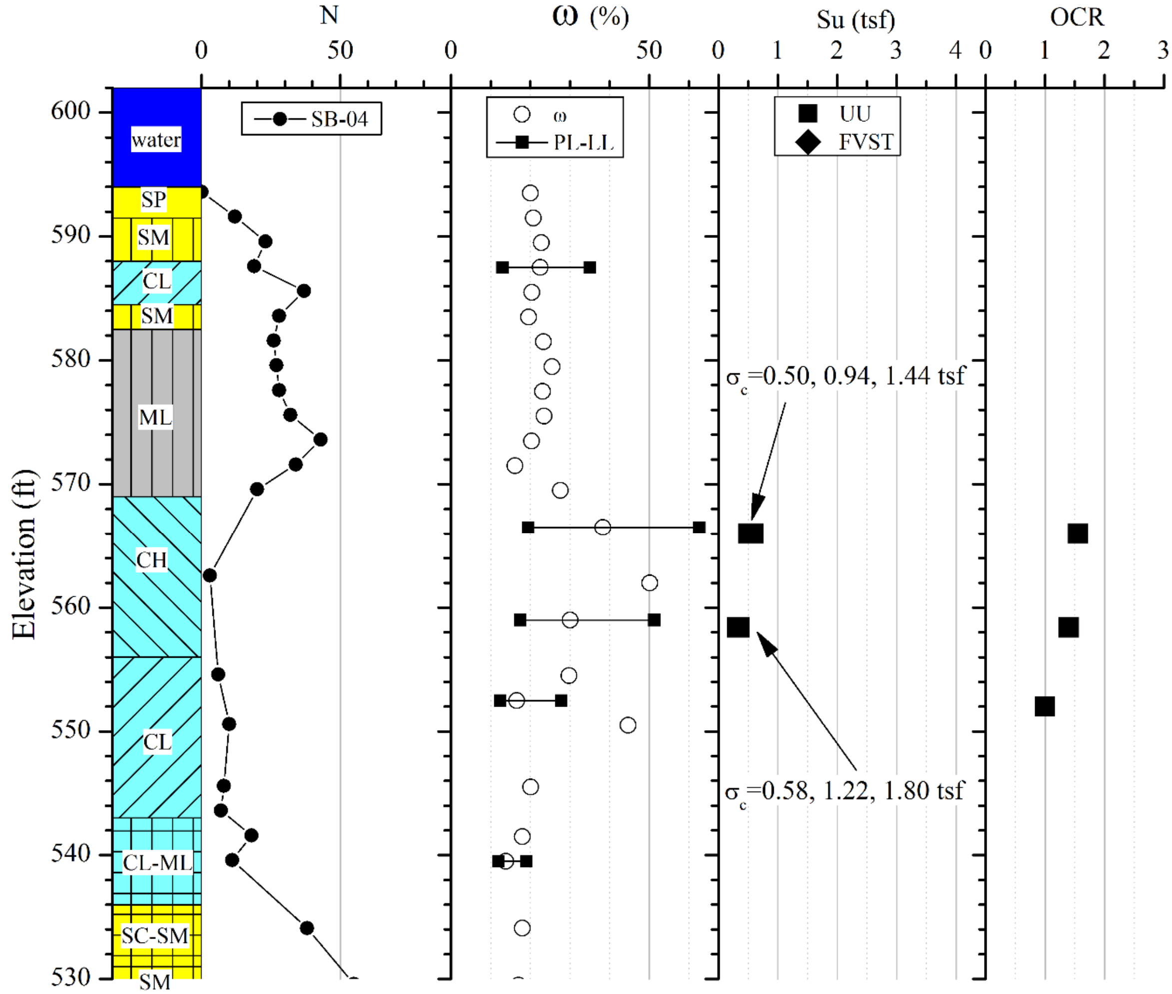
AQ SB -02


N
ω (%)
Su (tsf)
Elevation (ft)
water
mud
SM
ML
CH
CL
SC-SM
SP-SM
SB-02
ω
PL-LL
UU
FVST
σc=0.29, 0.58, 0.79 tsf

AQ SB-03 and CPT-06

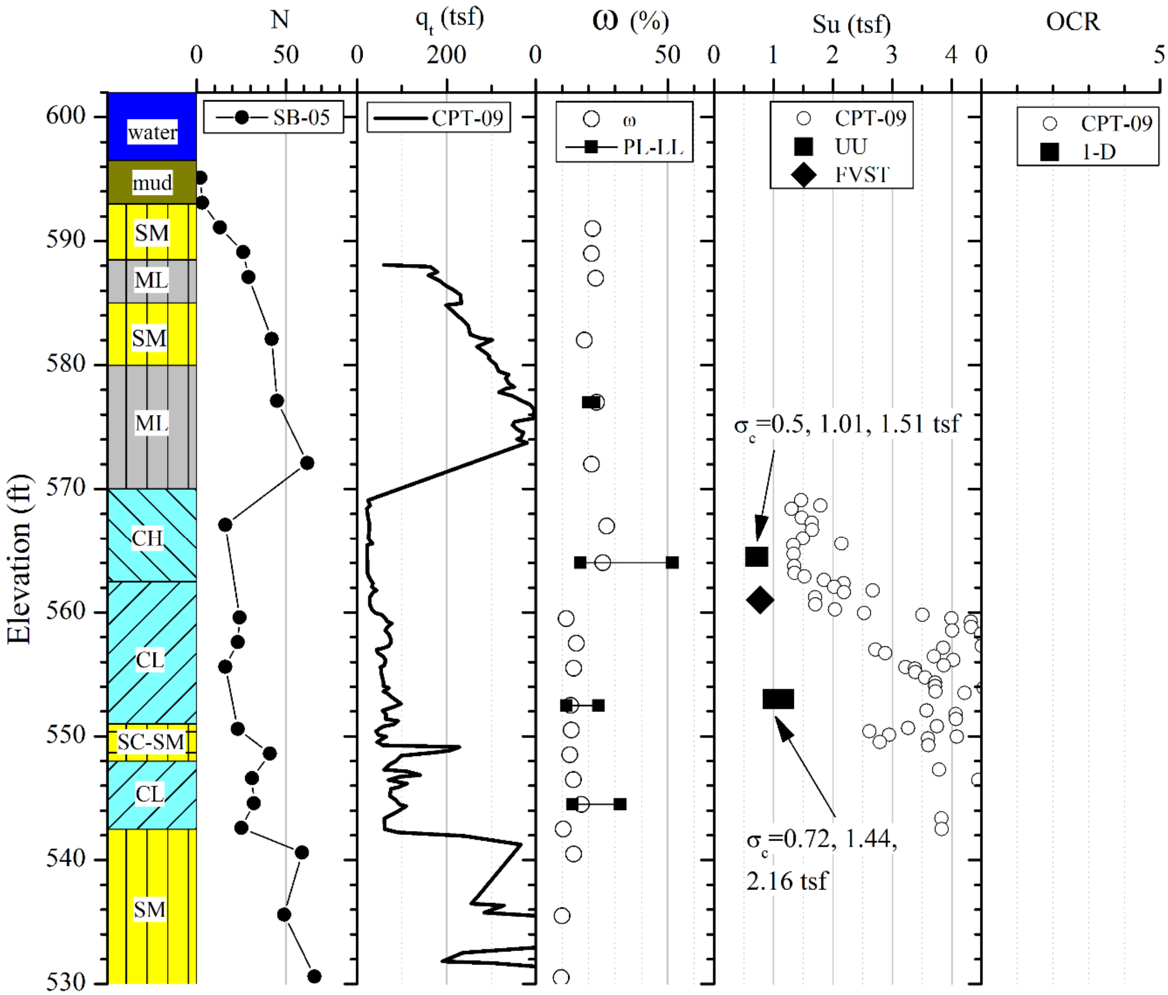


SB-04

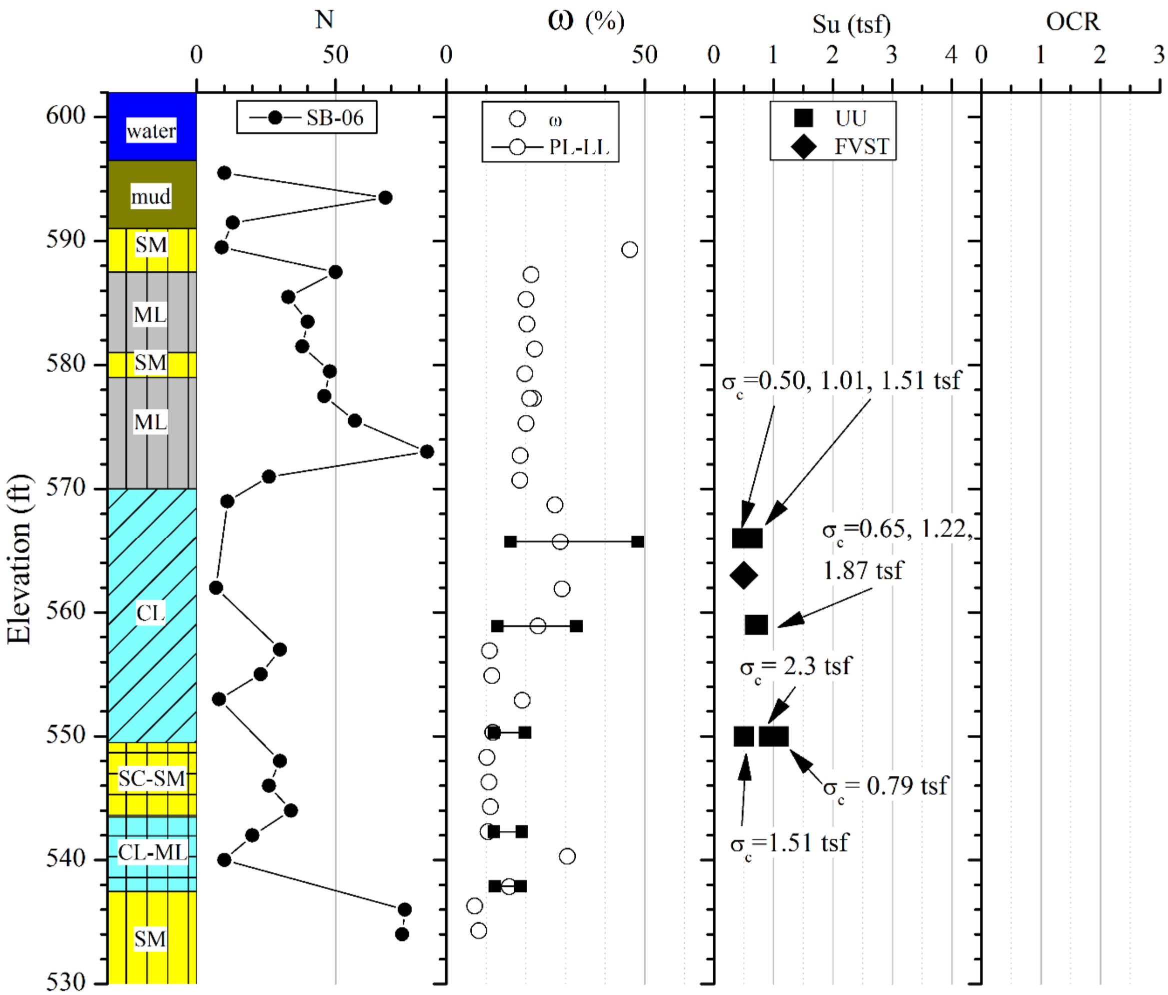


N
ω (%)
Su (tsf)
OCR
Elevation (ft)
SB-04
ω
PL-LL
UU
FVST
water
SP
SM
CL
SM
ML
CH
CL
CL-ML
SC-SM
SM
σc=0.50, 0.94, 1.44 tsf
σc=0.58, 1.22, 1.80 tsf

AQ SB-05 and CPT-09

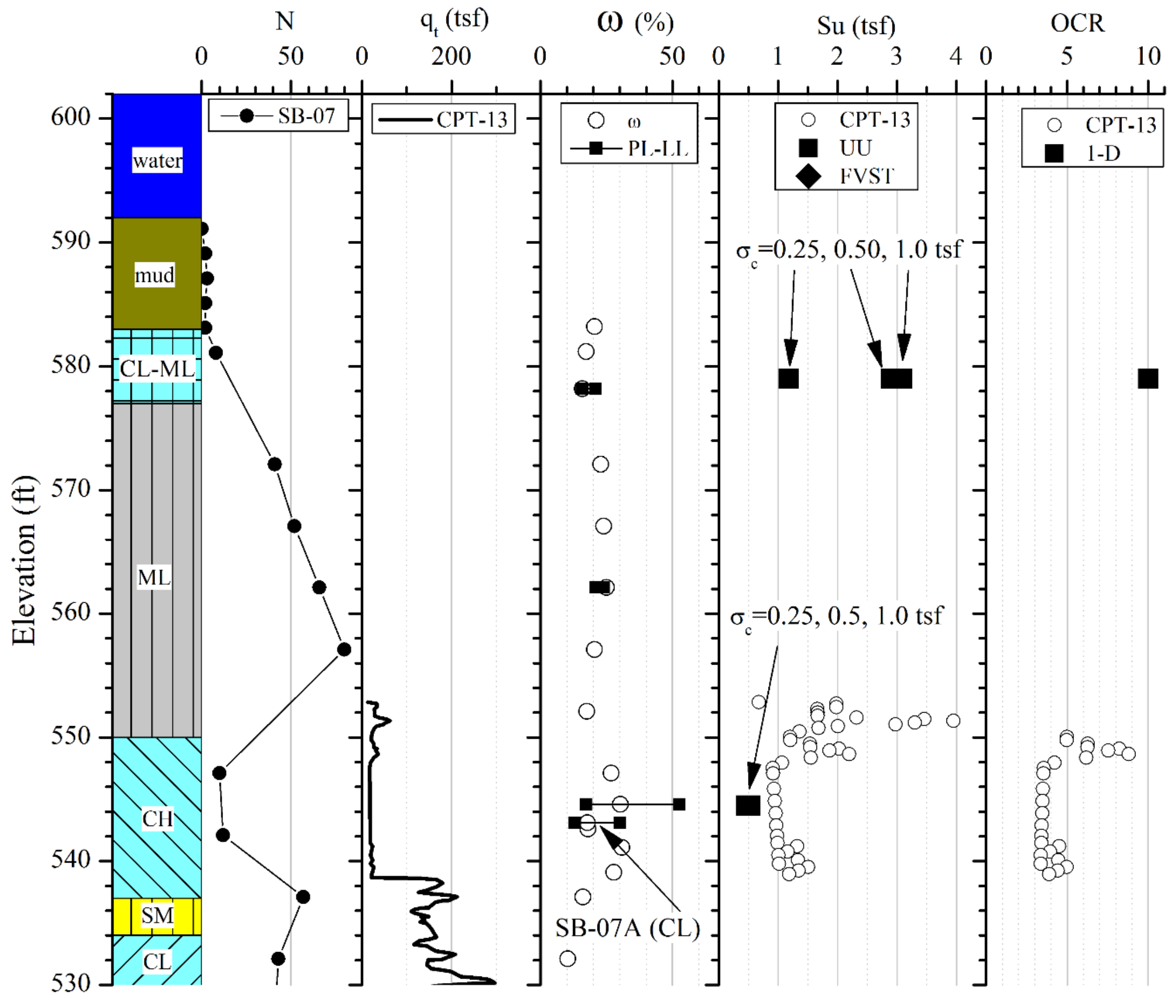


AQ SB-06

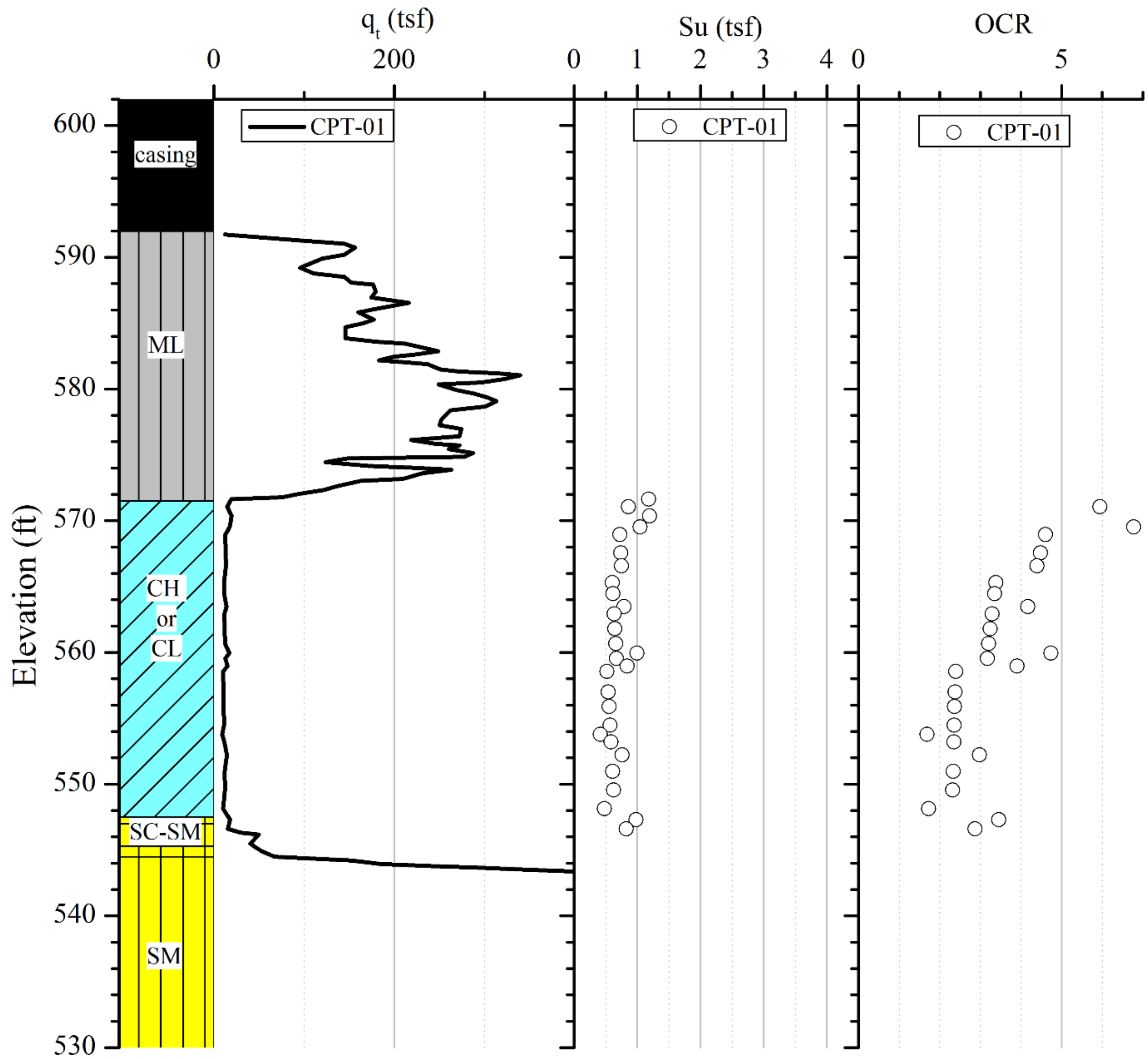


N
0
50
ω (%)
0
50
Su (tsf)
0
1
2
3
4
OCR
0
1
2
3
Elevation (ft)
600
590
580
570
560
550
540
530
water
mud
SM
ML
SM
ML
CL
SC-SM
CL-ML
SM
SB-06
ω
PL-LL
UU
FVST
σc=0.50, 1.01, 1.51 tsf
σc=0.65, 1.22, 1.87 tsf
σc= 2.3 tsf
σc= 0.79 tsf
σc=1.51 tsf

AQ SB-07 and CPT-13

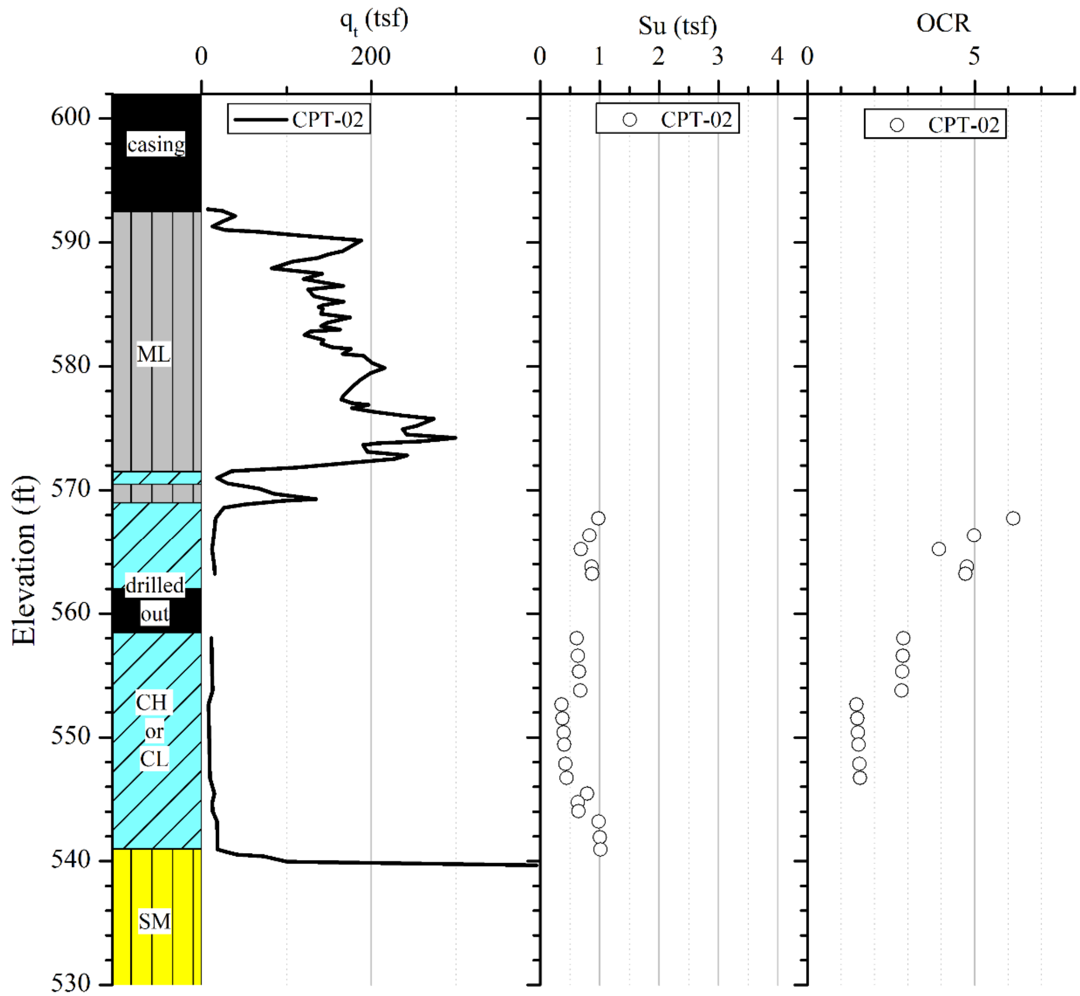


CPT-01



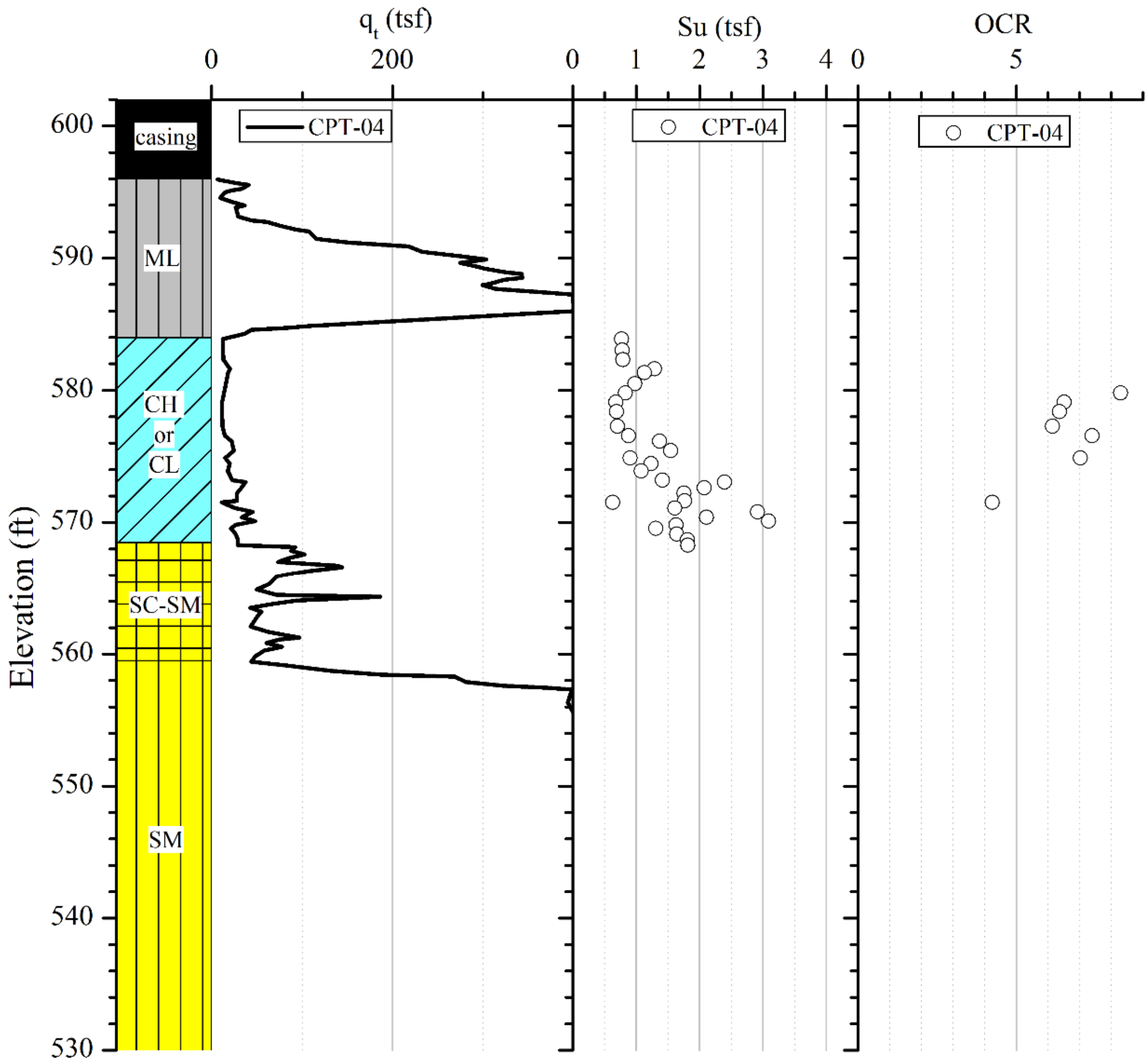
q_t (tsf)
0
200
Su (tsf)
0
1
2
3
4
OCR
0
5
CPT-01
CPT-01
CPT-01
Elevation (ft)
600
590
580
570
560
550
540
530
casing
ML
CH
or
CL
SC-SM
SM

CPT-02

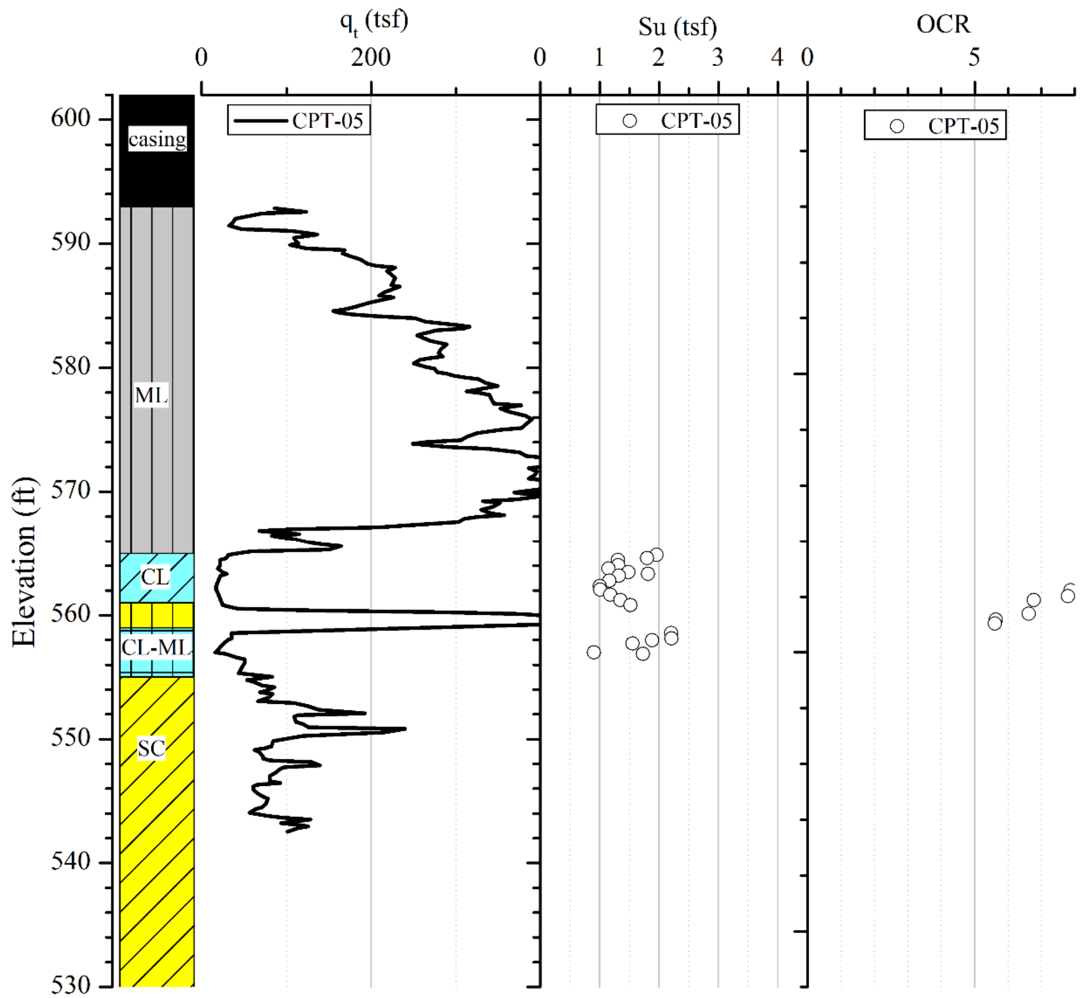


q_t (tsf)
0
200
CPT-02
Su (tsf)
0
1
2
3
4
CPT-02
OCR
0
5
CPT-02
Elevation (ft)
600
590
580
570
560
550
540
530
casing
ML
drilled
out
CH
or
CL
SM

CPT-04

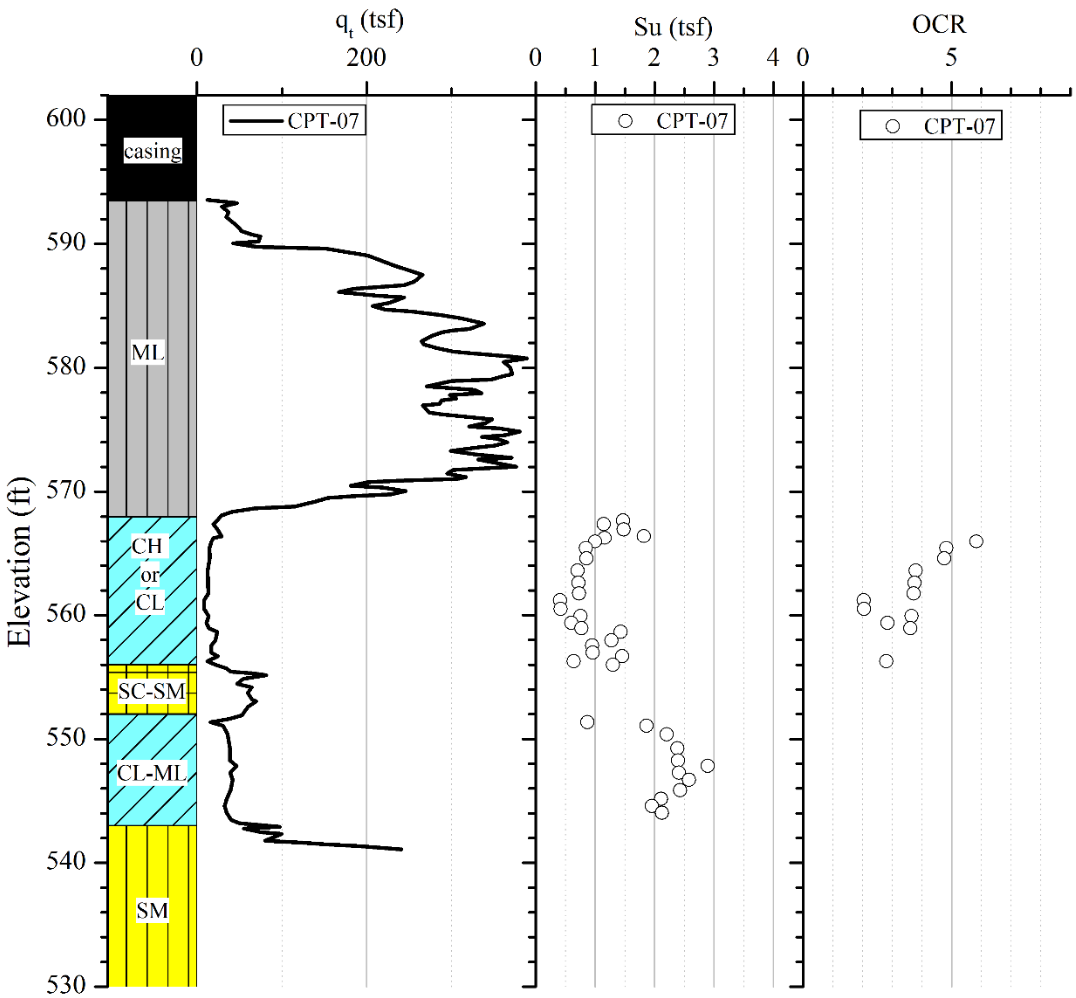


CPT-05



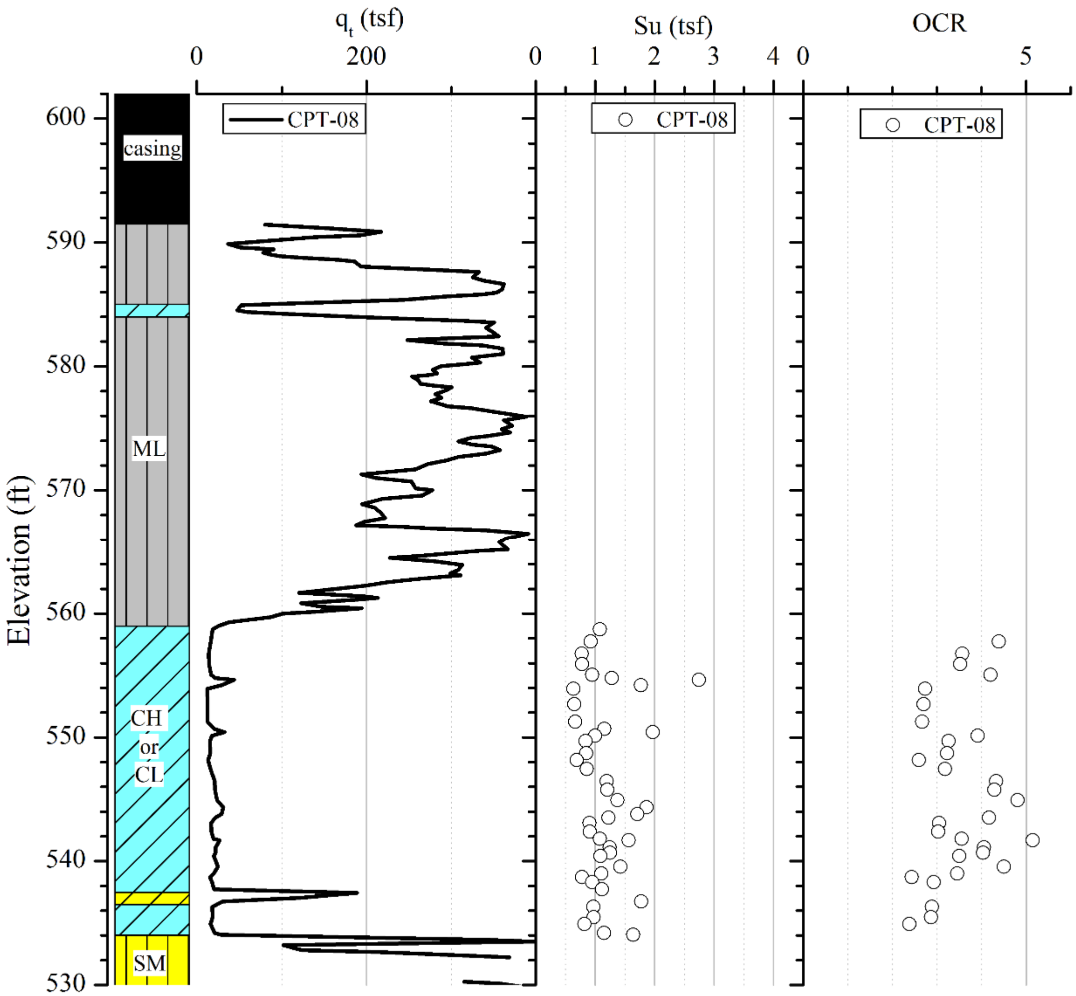
Elevation (ft)
casing
ML
CL
CL-ML
SC
q_t (tsf)
CPT-05
Su (tsf)
CPT-05
OCR
CPT-05

CPT-07



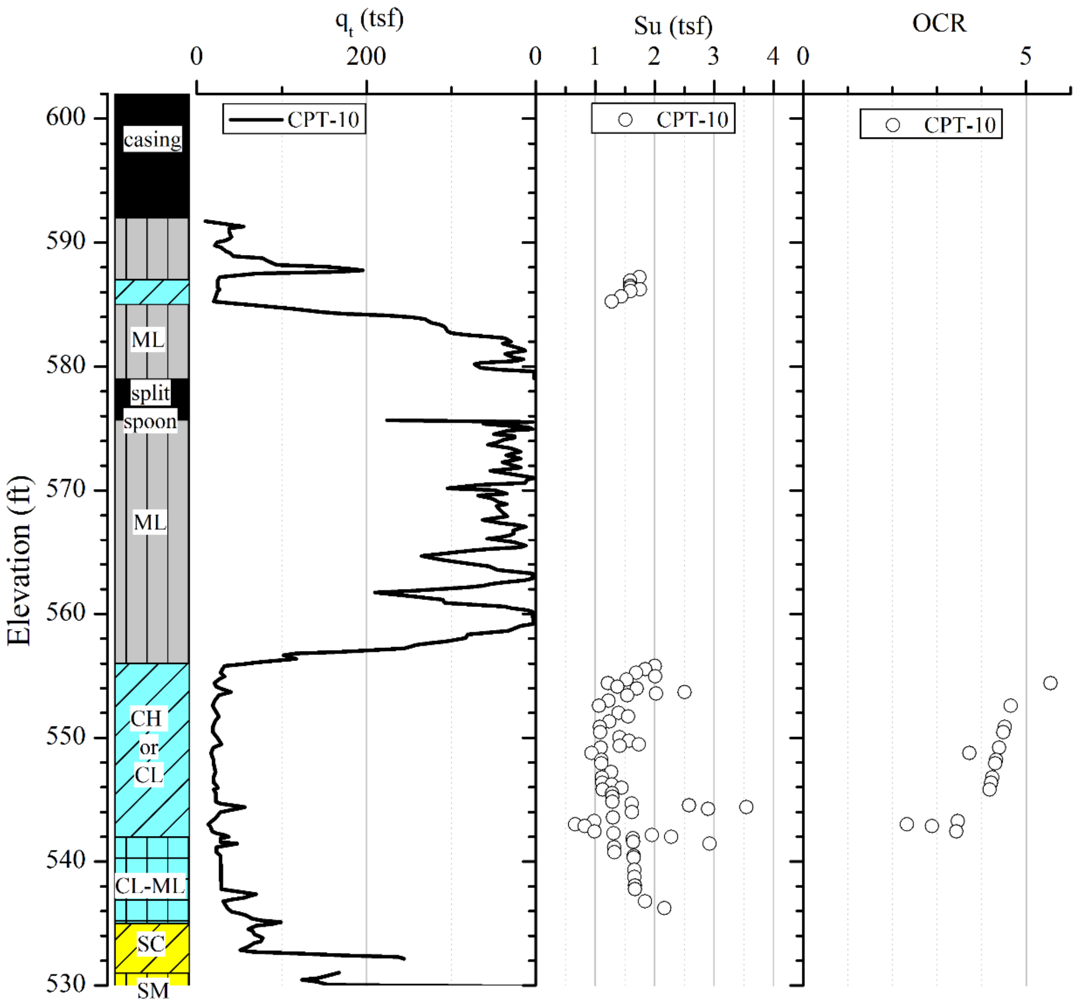
q_t (tsf)
0
200
Su (tsf)
0
1
2
3
4
OCR
0
5
CPT-07
CPT-07
CPT-07
Elevation (ft)
600
590
580
570
560
550
540
530
casing
ML
CH
or
CL
SC-SM
CL-ML
SM

CPT-08



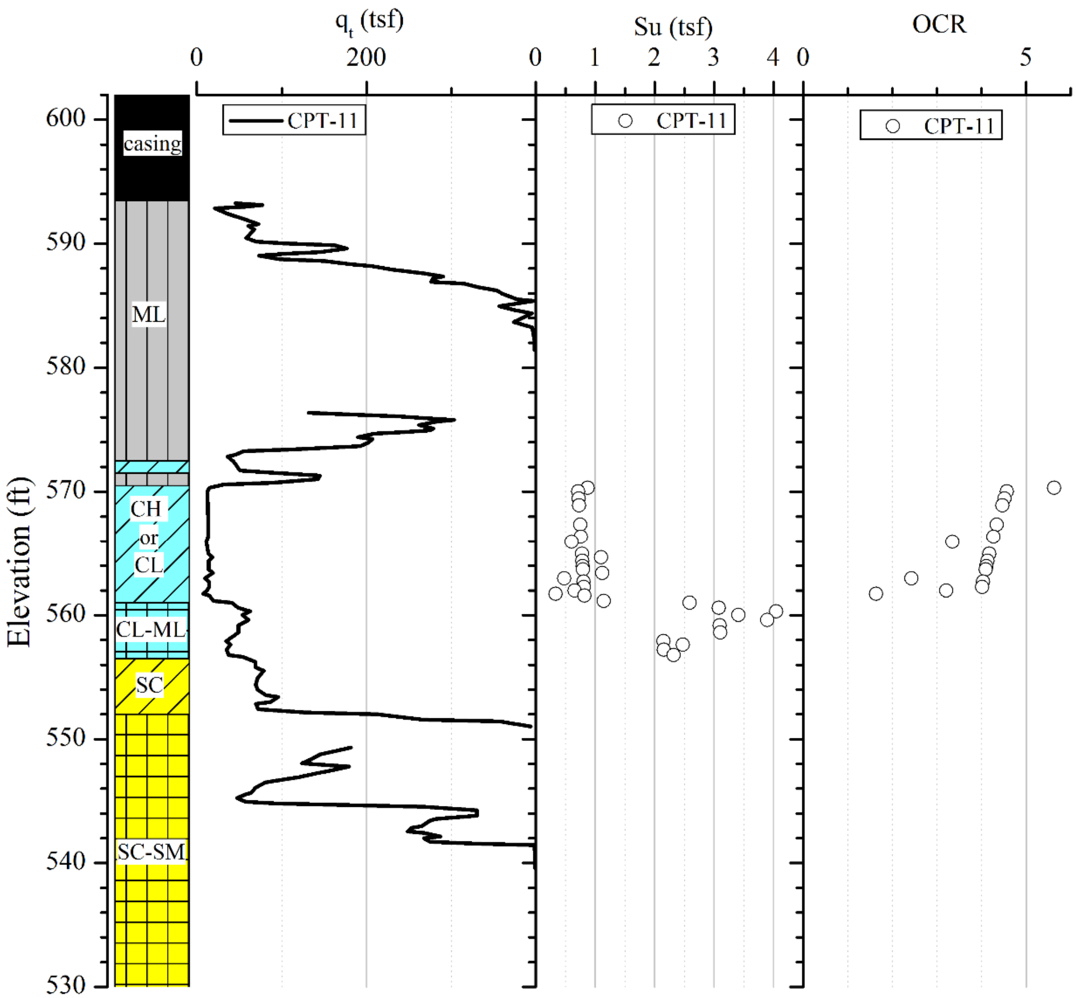
Elevation (ft)
600
590
580
570
560
550
540
530
casing
ML
CH
or
CL
SM
q_t (tsf)
0
200
CPT-08
Su (tsf)
0
1
2
3
4
CPT-08
OCR
0
5
CPT-08

CPT- 10



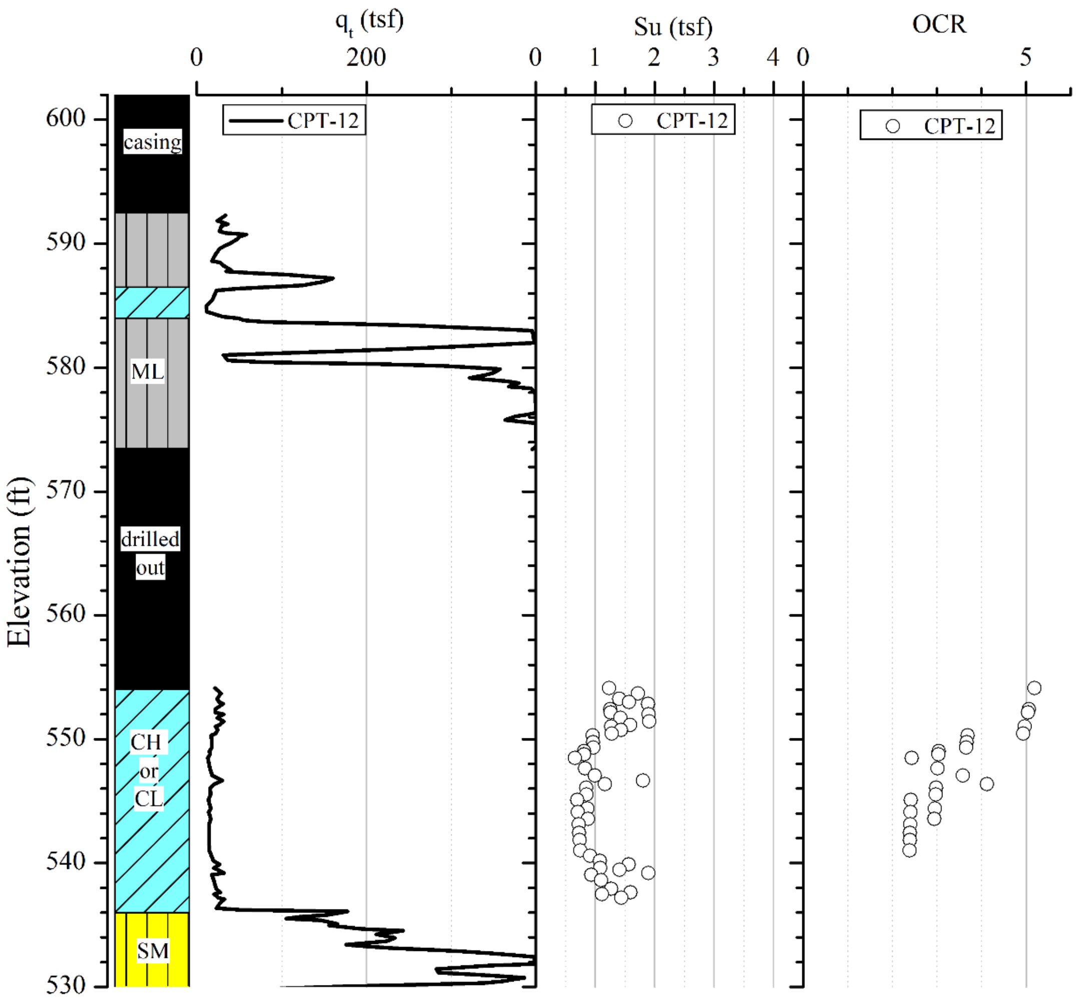
Elevation (ft)
600
590
580
570
560
550
540
530
casing
ML
split
spoon
ML
CH
or
CL
CL-ML
SC
SM
q_t (tsf)
0
200
CPT-10
Su (tsf)
0
1
2
3
4
CPT-10
OCR
0
5
CPT-10

CPT-11



q_t (tsf)
0
200
Su (tsf)
0
1
2
3
4
OCR
0
5
CPT-11
CPT-11
CPT-11
Elevation (ft)
600
590
580
570
560
550
540
530
casing
ML
CH
or
CL
CL-ML
SC
SC-SM

CPT-12



Elevation (ft)
600
590
580
570
560
550
540
530
casing
ML
drilled
out
CH
or
CL
SM
q_t (tsf)
0
200
CPT-12
Su (tsf)
0
1
2
3
4
CPT-12
OCR
0
5
CPT-12

Appendix B

Curriculum Vitae

Richard J. Finno

CURRICULUM VITA

RICHARD J. FINNO

Northwestern University
Department of Civil and Environmental Engineering
Evanston, Il 60208
(847) 491-5885

10401 S. Hamilton
Chicago, IL 60643
(773) 445-1114
r-finno@northwestern.edu

EDUCATION

August 1983	Ph.D. in Civil Engineering Stanford University, Stanford, CA.
June 1976	M.S.C.E. in Geotechnical Engineering Stanford University, Stanford, CA.
May 1975	B.S. in Civil Engineering University of Illinois, Urbana, IL.

REGISTRATION Professional Engineer, State of Illinois, 1980 (No. 062-037936)

TEACHING POSITIONS

1995-present	Professor of Civil Engineering, Northwestern University
1993-1996	James N. and Margie M. Krebs Professor, Northwestern University
1989-1995	Associate Professor of Civil Engineering, Northwestern University
1986-1989	Assistant Professor of Civil Engineering, Northwestern University
1983-1986	Assistant Professor of Civil Engineering, Illinois Institute of Technology
1982-1983	Teaching Fellow, Stanford University

INDUSTRIAL EXPERIENCE

1981	Woodward-Clyde Consultants, San Francisco, CA, Project Engineer
1979-1980	Woodward-Clyde Consultants, Chicago, IL, Assistant Project Engineer
1976-1978	Sargent & Lundy Engineers, Chicago, IL, Soil Engineer

AWARDS
Harry Schnabel Jr. Award, American Society of Civil Engineers, 2010
Karl Terzaghi Award, American Society of Civil Engineers, 2009
Civil Engineer of the Year, American Society of Civil Engineers, Illinois Section, 2007
Thomas A. Middlebrooks Award, American Society of Civil Engineers, 2004
Walter L. Huber Civil Engineering Research Prize, American Society of Civil Engineers, 1994
Thomas A. Middlebrooks Award, American Society of Civil Engineers, 1993
Arthur Casagrande Award, American Society of Civil Engineers, 1990
Environment Award, W170 Committee, US EPA, 1990
Tau Beta Pi Eminent Engineer, 1990

CONSULTANT (major projects – from more than 300 consulting assignments)

Geoengineers, Inc. (2013), provide peer review of open cell system for excavation support system for 17th St pump station in New Orleans

Toronto Transit Commission, (2012), Provide expert opinion regarding risk of tunneling under a building without compensation grouting, evaluate results of test section

Wiss, Janney, Elstner & Associates, Inc., Northbrook, IL 1989-2014 (investigations of damage to bridges, multi-story buildings, concrete pile-supported marine structures and retention systems; evaluation of construction problems and structural failure of large diameter, self-sinking caissons in Dearborn, MI)

GeoSyntec Consultants, (2008-2010) Geotechnical Assurance review of design of LNG facility, including deep soil mix treatment for foundations and retaining structures.

STS Consultants, (2007) Peer review of excavation support system for the Spire building, Chicago, IL

STV Ltd, 2004-2006, (Board of Consultants, Block 37 development in Chicago – subway tube connections)

Department of Transportation of the City of Chicago, 1999 (evaluation of design and construction of retention system)

A. Epstein & Sons International, Inc., 1999 (evaluation of MSE retaining wall failure)

Montgomery Watson, Sacramento, CA, 1998 (sunken shaft design)

Los Angeles MTA, 1994-1996, (provide peer review regarding distressed areas in subway tunnel under construction; investigate causes of tunnel collapse)

Ralph M. Parsons Co., Pasadena, CA, 1989, 1993-6, 2003-5 (investigation of excavation effects on adjacent pile-supported structure; slope instability evaluations; retaining wall studies; solute transport studies; foundation evaluation studies)

US Environmental Protection Agency, Washington, DC, 1989, member of Land Application Peer Review Committee, (scientific peer review of US EPA standards 40 CFR PART 503)

Harrison Western Corp., Denver, CO, 1986 (investigation of shaft failure)

AFFILIATIONS

Diplomate — Geotechnical Engineering, Academy of Geo-Professionals

Member: — Geo-Institute of ASCE
American Society of Civil Engineers (ASCE), Illinois Section
International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE)
US Universities Council on Geotechnical Engineering Research (USUCGER)

PROFESSIONAL COMMITTEES AND ACTIVITIES

<u>International:</u> <u>International Society of Soil Mechanics and Geotechnical Engineering</u>

Member, Technical Committee 207, Soil-Structure Interaction and Retaining Walls, ISSMGE (2010-present)
Member, Editorial Board, Acta Geotechnical, (2005-present)
Member, Technical Committee 28, Underground Construction in Soft Ground, ISSMGE (2008-2010)
Member, Advisory Board, Italian Geotechnical Journal, (1998-2009)
Co-Chairman, U.S. National Society of ISSMFE paper review for Thirteenth International Conference of Soil Mechanics and Foundation Engineering, 1994

<u>National:</u> <u>American Society of Civil Engineers</u>

At-large Trustee, Board of Directors, Academy of Geo-Professionals (2013-2016)
Member, Organizing Committee, Joint GeoInstitute–Structural Engineering Institute 2016 Congress

Technical Program Director and co-editor of proceedings, ER2010 Earth Retention Conference 3 (2010)
Editor, Journal of Geotechnical and Geoenvironmental Engineering, (2004-2007)
Chair, Awards Committee, Geo-Institute, ASCE, (2002-2005)
Member, Awards Committee, Geo-Institute, ASCE (1999-2001; 2011-present)
Member, Technical Coordinating Council, Geo-Institute, ASCE (1996-1999)
Board Member and Treasurer, USUCGER (1996-1999)
Co-Chairman, 1996 Geotechnical Engineering Congress, Madison WI
Chairman, Earth Retaining Structures Committee, Geotechnical Engineering Division (1994 -1998)
Member, Earth Retaining Structures Committee, Geotechnical Engineering Division (1989-present)
Member, Editorial Board, Journal of Geotechnical Engineering (1986-1997)
Member, Soil Properties Committee, Geotechnical Engineering Division (1984-1988)

National Science Foundation

Member of proposal review panels for Geotechnical, Geoenvironmental and Geomechanical Systems, Earthquake Hazard Mitigation and Career award Programs

Chairman, Proposed Experiments/Uses Committee, NSF Workshop on Selection and Management of National U.S. Geotechnical Test Sites, 1991

Member of peer review team of NSF-sponsored Engineering Research Center at Texas A&M University, 1991 (Offshore Technology Research Center)

Proposal reviewer

U.S. Geological Survey

Proposal reviewer

Local: American Society of Civil Engineers

Geotechnical Engineering Division, Illinois Section
Secretary/Treasurer, 1985-1986
Vice Chairman, 1986-1987
Chairman, 1987-1988
Illinois Section, Board of Directors, 1987-1988 and 1991-1993

RESEARCH ACTIVITIES

Grants Awarded:

Northwestern "GOALI: Strength loss in clays during earthquake and other cyclic loading," National Science Foundation, $451,922, (2014-2017)

"GOALI: Effects of gas in design and verification of blast densification of liquefiable sands," National Science Foundation, $478,041, (2012-2015)

"Planning Visit for Developing New International Collaborations," National Science Foundation, $23,600, (2112)

"Condition Monitoring of Urban Infrastructure," Infrastructure Technology Institute, $158,000 (2011-12)

“Advancing the Capabilities of Adaptive Management Techniques in Geotechnics,” National Science Foundation, $450,806, (2009-2012)

“Design and Verification of Blast Densification for Highway Embankments on Liquefiable Sands,” Infrastructure Technology Institute, $260,956 (2008-10)

“GOALI: Dynamic Soil Properties: Effects of Construction–induced Stress Changes,” National Science Foundation, $331,245, 2008-2011

“Condition Monitoring of Urban Infrastructure,” Infrastructure Technology Institute, $591,501 (2007-09)

“Copperative Research: A Joint NU and UIUC Project for the Development of New Integrated Tools for Predicting, Monitoring, and Controlling Ground Movements due to Excavations,” National Science Foundation, $2,066,905 (2002-2007)

“Condition Monitoring of Urban Infrastructure,” Infrastructure Technology Institute, $293,887 (2006)

“Automated Deformation Monitoring,” Infrastructure Technology Institute, $169,363 (2004-2005)

“Nondestructive Evaluation of Concrete with Flexural Waves,” Infrastructure Technology Institute, $236,290 (2004-2005)

“Performance Monitoring and Condition Assessment of the Excavation and Support System for the Lurie Research Center,” Facilities Management, Northwestern University, $37,120 (2002)

"Allowable Deformations of Gas Mains Adjacent to Deep Excavations," Infrastructure Technology Institute, $167,757 (2002-2003)

"Improved Conditioning Monitoring of Bridges: Non-destructive Evaluations of Foundations," Infrastructure Technology Institute," $140,667 (2002-2003)

"Analysis of the Performance of the Chicago-State Subway Station and its Effects on Adjacent Structures," Infrastructure Technology Institute, $187,561, (2001)

"Improved Conditioning Monitoring for Bridge Management: Non-destructive Evaluations of Existing Foundations," Infrastructure Technology Institute," $88,311 (2001)

“Objective Updating of Design Predictions for Supported Excavations using Construction Monitoring Data,” National Science Foundation, $224,585 (2001-2004)

“In situ Nondestructive Evaluation of Concrete Piles,” Naval Facilities Engineering Command, $25,564 (2001)

"Improved Conditioning Monitoring for Bridge Management: Non-destructive Evaluations of Existing Foundations," Infrastructure Technology Institute," $79,954 (2000)

"Computability of Material Instabilities – New Methods and Case Study," National Science Foundation, CMS-0085664, $142,576, Co-principal investigator with T Belytschko (2000-2001)

"Evaluation of Capacity of Micropiles Embedded in Rock," Infrastructure Technology Institute," $24,800 (2000-2001)

"Geotechnical Monitoring of Chicago-State Subway Station," Wiss, Janney, Elstner Associates, Inc., $92,500 (1999-2001)

"Analysis of the Performance of the Chicago-State Subway Station and its Effects on Adjacent Structures," Infrastructure Technology Institute, $113,904. 1999-2000

"Effects of Strain Localization on Fault Gouge Constitutive Relations," US Geological Survey, $55,000 (1998)

"Progressive Failure in Overconsolidated Soils," National Science Foundation through subcontract with University of Colorado at Denver , $44,000, (1998-1999)

"Effects of Strain Localization on Fault Gouge Constitutive Relations," US Geological Survey, 134-HQ-97-GR-03007, $60,000 (1997)

"Research Equipment Proposal: Image Analysis of Internal Deformations during Shear," National Science Foundation, CMS-9610373, $14,000 (1997)

"Support of US University Council on Geotechnical Engineering Research," National Science Foundation, CMS-9610357, $55,000 (1997-2000)

"Innovative Techniques of Foundation Rehabilitation in Restricted Access Environments," Infrastructure Technology Institute, $32,960 (1996-1997)

"Time Domain Reflectometry (TDR) Cable and Grout System to Telemetrically Monitor Soil Slope Stability," National Science Foundation Grant No. CMS-9523236, $139,996, Co-principal investigator with CH Dowding (1995-1997)

"NDE of Drilled Shafts at NGES Site," Federal Highway Administration, $24,938, (1995-1996)

"Improved Conditioning Monitoring for Bridge Management: Non-destructive Evaluations of Existing Foundations," Infrastructure Technology Institute," $499,080, (1994-1999)

"Improved Conditioning Monitoring for Bridge Management: Task 4 Foundation Problems," Infrastructure Technology Institute," $154,846, co-principal investigator with CH Dowding (1993)

"National Geotechnical Engineering Experimentation Site at Northwestern University," subcontract to University of New Hampshire as part of National Science Foundation Grant, $76,000, (1992-1996)

"Experimental Evaluation of Reservoir Bottom Remediation Material: Ludington Pumped Storage Facility," Ebasco Services Inc., $47,820, (1991-1992)

"Post Peak Behavior of Granular Soils and its Effect on Undrained Steady State Strength," National Science Foundation Grant No. BCS-9019755, $160,064, (1991-1993)

"Soil Properties Measurements Using Oscillating Electro-Kinetic Counter Pressures," National Science Foundation Grant No. MSS-9023540, $140,000, Co-principal investigator with J.R. Feldkamp (1991-93)

"Research Equipment for Geomechanics Testing," National Science Foundation, Grant No. MSM-8800796, $45,000 (1988).

"Observation and Prediction of Field Behavior of an Embankment and a Braced Cut in University Clay, Evaluating the State-of-the-Art," National Science Foundation, Grant No. MSM-8796169, $140,578, (1987-1989).

Illinois Inst. of Technology — "Evaluation of Creep-Induced Effective Stress Changes of Clay," Engineering Foundation Research Initiation Grant RI-A-84-1, $17,000, (1984).

Industry-Supported Activities:

Pile Prediction Symposium, 1989 Foundation Engineering Congress, Evanston, Il., Organized and directed detailed load test program. Three construction and six consulting firms donated construction, instrumentation, and in situ testing.

NSF-supported activities:

Organized workshop in Cambridge, UK for developing new international collaborations for research on underground infrastructure, December 2012

Participant in 2nd Japan-US Workshop on Testing, Modeling and Simulation in Geomechanics, Kyoto Japan, September 2005

Participant in Assisting and Encouraging Student Opportunities for Post-undergraduate Study (AESOPS). workshop, Washington D.C., May, 2002

Participant in U.S.-Taiwan Geotechnical Engineering Collaboration Workshop, Taipei, Taiwan, January, 1995.

Participant in U.S.-Scandinavian Workshop on Geotechnical Engineering Research Collaboration, Trondheim, Norway, June, 1994.

Reporter for working group in U.S.-France Workshop on Recent Advances in Geomechanical, Geotechnical and Geo-Environmental Engineering, Paris, France, June, 1992.

Reporter for working group on Prototype Testing and Behavior Prediction at the Workshop on Establishment of National Test Sites for Earthquake Engrg and Geotechnical Engrg. Research, 1988

Participant in France - U.S. CNRS-NSF Workshop on "Strain Localization and Size Effect Due to Cracking and Damage," Cachan, France, Sept., 1988.

Presented overview of on-going research program, "Case Histories in Geotechnical Engineering", at NSF MSME Solid and Geomechanics Program Review, Washington, D.C., March, 1988.

Laboratory Development

Secured funds and made operational servo-controlled testing devices including three triaxial, one direct simple shear and one kinematically unconstrained, heavily-instrumented plane strain compression apparati in Northwestern University Geotechnical Engineering Laboratory; developed laboratory device to rapidly measure permeability of clays using alternating current electro-kinetics; added digital image analysis capabilities for mechanical testing of soils; incorporated bender elements and local strain gages to measure very small strains in triaxial device.

PUBLICATIONS

Books (editor)

Earth Retention Conference 3, Proceedings of the 2010 Earth Retention Conference, Geo-Institute of ASCE, R.J. Finno, Y.M.A. Hashash and P. Arduino, eds., Geotechnical Specialty Publication 208, August 2010, 941 p.

Design and Construction of Earth Retaining Systems, Proceedings of sessions of Geo-Congress 98, sponsored by the Earth Retaining Structures Committee of the Geo-Institute, Boston, MA., R.J. Finno, Y. Hashash, C.L. Ho, and B.P. Sweeney, eds., Geotechnical Specialty Publication No. 83, 1998, 176 p.

Serviceability of Earth Retaining Structures, Proceedings of sessions sponsored by the Geotechnical Engineering Division in conjunction with the ASCE National Convention, Atlanta, Georgia, October, R.J. Finno, Ed., Geotechnical Special Publication No. 42, 1994, 157 p.

Predicted and Observed ‘Axial Behavior of Piles, Results of a Pile Prediction Symposium, Proceedings of the Pile Prediction Symposium, ASCE, held at the Foundation Engineering Congress, Northwestern University, Evanston, IL, R. J. Finno, Ed., Geotechnical Special Publication, 1989, 385 p.

Book Chapters

Krizek, R.J. and Finno, R.J., "Buried Conduits," Structural Engineering Handbook, Third Edition, McGraw-Hill, New York, NY, 1996, pp. 29:1-29:41.

Refereed Journal Papers

Finno, R.J, Gallant, A.P. and Sabatini, P.J., “Evaluating Ground Improvement after Blast Densification: Performance at the Oakridge Landfill,” paper submitted to the Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 2014

Arboleda-Monsalve, L.G. and Finno, R.J. “Influence of Time-dependent Effects of Concrete in Long-Term Performance of Top-down Construction,” accepted for publication in the Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 2014

Finno, R.J., Arboleda-Monsalve, L.G. and Sarabia, F., “Observed Performance of One Museum Park West Excavation,” accepted for publication, Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 2014

Vega-Posada, C.A., Finno, R.J. and Zapata-Medina, D.G., “Effect of Gas in the Mechanical Behavior of Medium Dense Sands,” accepted for publication, Journal of Geotechnical and Geoenvironmental Engineering, ASCE

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Finno, R.J., Gassman, S.L., and Osborn, P.W., "Shear and Compressive Wave Velocities at the NGES at Northwestern University, Proceedings, 5th Great Lakes Geotechnical/ Geoenvironmental Conference on Site Characterization for Geotechnical and Geoenvironmental Problems, University of Michigan, Ann Arbor, MI, May 1997.

Finno, R.J., Gassman, S.L., and Prommer, P., "Effects of Intervening Structure on Impulse Response Signals," Proceedings, Fifth International Conference on the Application of Stress-Wave Theory to Piles, Orlando, FL, Sept, 1996, pp. 708-720.

Rudnicki, J.W., Finno R.J., Viggiani, G., Alarcon, M.A., and Mooney, M.A., "Coupled Deformation-Pore Fluid Diffusion Effects on the Development of Localized Deformation in Fault Gouge," Proceedings, Prediction and Performance of ISRM International Symposium on Prediction and Performance in Rock Mechanics and Rock Engineering, EUROCK '96, Balkema Rotterdam, Torino, Italy, September, 1996, pp. 1261-1267.

Mooney, M.A., Finno, R.J., Viggiani, G., and Harris, W.W., "Issues of Uncertainties Regarding Localized Strains in Granular Soil," Proceedings, Uncertainty in the Geologic Environment, Geotechnical Specialty Conference, ASCE, Madison, WI, August, 1996, pp. 312-325.

Finno, R.J. and Gassman, S.L., "Impulse Response Evaluation of Drilled Shafts at NGES Test Section, Proceedings, Structural Materials Technology NDE Conference, P.J. Stolarski, ed., San Diego, CA, Mar. 1996.

Yin, J. Finno, R.J., and Feldkamp, J.R., "Electro-Osmotic Mobility Measurement for Kaolinite Clay," Proceedings, Geoenvironment 2000, ASCE Specialty Conference, New Orleans, LA, 1995.

Finno, R.J., Harris, W.W., and Viggiani, G., "Pore Pressures and Strain Localization in Stiff Clay," Fracture and Damage in Quasibrittle Structures, Proceedings, US-Europe Workshop on Fracture and Damage in Quasibrittle Structures, Prague, M. Jirasek ed., E & FN SPON, London, 1994 pp. 441-449.

Finno, R.J., Klein, G.J., and Sabatini, P.J., "Damage Evaluation of Building on Piers in Expansive Clays," Proceedings, Settlement 94, ASCE Specialty Conference on Geotechnical Engineering, College Station, Texas, 1994.

Finno, R.J., Riccobono, A.S., Ehasz, J., Cannon, R. Chung, C.-K., and Tandeles, N.K., "Experimental Evaluation of Reservoir Bottom Remediation Material," Proceedings, Geotechnical Practice in Dam Rehabilitation," L. Anderson, ed., ASCE, Raleigh, NC, April, 1993, pp. 740-754.

Finno, R.J. and Rhee, Y., "Kinematically Unconstrained Compression of Soft Clay," Proceedings, Stability and Performance of Slopes and Embankments - II, ASCE, University of California at Berkeley, June, 1992.

Finno, R.J., Benoit, J., and Chung, C.K., "Field and Laboratory Measured Values of K_o in Chicago Clays," Proceedings, Third International Symposium on Pressuremeters, Oxford University, 1990.

Finno, R.J., Achille, J., Chen, H-C, Cosmao, T., Park, J.B., Picard, J.-N., Smith, D.L., and Williams, G.P., "Summary of Pile Capacity Predictions and Comparison with Observed Behavior," Predicted and Observed Axial Behavior of Piles, Results of a Pile Prediction Symposium, ASCE, R.J. Finno, ed., 1989.

Finno, R.J., Cosmao, T., and Gitskin, B., "Results of Foundation Engineering Congress Pile Load Tests," Predicted and Observed Axial Behavior of Piles, Results of a Pile Prediction Symposium, ASCE, R.J. Finno, ed., 1989.

Finno, R.J., "Subsurface Conditions and Pile Installation Data: 1989 Foundation Engineering Congress Test Section," Predicted and Observed Axial Behavior of Piles, Results of a Pile Prediction Symposium, ASCE, R.J. Finno, ed., 1989.

Finno, R.J., Nerby, S.M., and Perkins, S.B., "Soil Parameters Implied by Braced Cut Behavior," Symposium on Soil Properties Evaluation from Centrifugal Models and Field Performance, ASCE, 1988, pp. 71-87.

Finno, R.J., and Krizek, R.J., "Evaluating Ground Response to Tunneling with F.E.M.," Proceedings, International Symposium on Tunneling for Water Resources and Power Projects, New Delhi, 1988.

Finno, R.J., Atmatzidis, D.K., and Nerby, S.M., "Ground Response to Sheet-pile Installation in Clay," Proceedings, Second International Conference on Case Histories in Geotechnical Engineering, St. Louis, MO, 1988.

Clough, G.W., Shirasuna, T., and Finno, R.J., "Finite Element Analysis of Advanced Shield Tunneling in Soils," 5th International Conference of Numerical Methods in Geomechanics, Nagoya, Japan, April, 1985.

Clough, G.W., Finno, R.J., and Shirasuna, T., "Observed and Predicted Ground Deformation due to Earth Pressure Balance Shield Tunneling through San Francisco Bay Mud," Proceedings, Japan Symposium on Effect of Shield Tunneling on Surrounding Ground, Nov., 1984 (in Japanese).

Schubert, W., Harrington, T., and Finno, R.J., "Glacial Clay Liners in Waste Disposal Practice," Proceedings, Specialty Conference on Environmental Engineering, ASCE, Los Angeles, CA, June, 1984, pp. 36-41.

Holloway, D.M., Moriwaki, Y., Finno, R.J., and Green, R.K., "Lateral Load Response of a Pile Group in Sand," Proceedings, 2nd International Conf. on Numerical Methods in Offshore Piling, Austin, TX, April, 1982, pp. 441-456.

Reports

Molnar, K.M., Finno, R.J., and Rossow, E.C., “Analysis of Effects of Deep Braced Excavations on Adjacent Buried Pipelines,” Final Report to the Infrastructure Technology Institute, December, 2003, Northwestern University, 158 pp.

Finno, R.J. and Voss, F., “Evaluating Damage Potential in Buildings Affected by Excavations,” Final Report to the Infrastructure Technology Institute, December, 2002, Northwestern University, 166 pp.

Finno, R.J. Calvello, M., and Bryson, S.L., “Analysis and Performance of the Excavation for the Chicago-State Subway Renovation Project and its Effects on Adjacent Structures,” Final Report to the Infrastructure Technology Institute, September, 2002, Northwestern University, 347 pp.

Finno, R.J., “Evaluation of Capacity of Micropiles Embedded in Dolomite,” Final Report to the Infrastructure Technology Institute, Northwestern University, September 2002, 79 pp.

Finno, R.J. and Bryson, S.L., “Performance of the Excavation for the Chicago-State Subway Renovation Project and Response of the Adjacent Frances Xavier Warde School,” Dep’t. of Civil Engineering Report No. CEE-2002-1, September, 2002, Northwestern University, 287 pp.

Finno, R.J., Chou, H.-C. and Lynch, J., "Non-Destructive Evaluation of *In situ* Concrete Piles at the Advanced Waterfront Technology Test Site, Port Hueneme, California," Final Report, Naval Facilities Engineering Service Center, Washington, D.C., October 2001, 52 pp.

Finno, R.J., Gassman, S.L. and Osborn, P.W., "Non-Destructive Evaluation of a Deep Foundation Test Section at the Northwestern University National Geotechncial Experimentation Site," Final Report, Federal Highway Administration, Contract DTFH61-95-P-0816, June 1997, 336 pp.

Finno, R.J., Klein G.J., and Hill, H., "Metro Red Line, Segment 2, Contract B251, Investigation of Tunnel Collapse and Sinkhole," report for the Los Angeles County Metropolitan Transportation Authority, Oct., 1995.

Klein, G.J., Finno, R.J., Fiero, E.A., Kristie, R.J., Johnson, A.P., and Shotwell, L.B., "Metro Red Line, Segment 2, Contract B251, Structural Investigation of Wood Wedge Expansion Gap System," report for the Los Angeles County Metropolitan Transportation Authority, Dec., 1994.

Finno, R.J., "Experimental Evaluation of Reservoir Bottom Remediation Materials: Ludington Pumped Storage Facility, Report to Ebasco Services Inc., Greensboro, NC, January, 1992

Finno, R.J., "Final Report: Effects of LCC Vault Construction on Main Column Pile Groups, CBI Nuclear Building, President's Island Tennessee, Report to The Ralph M. Parsons Company, Pasadena, CA, January, 1990

Finno, R.J., and Gausseres, R.F., "Measurement of Creep-Induced Effective Stress Changes of Kaolinite," Report prepared for the Engineering Foundation, Illinois Institute of Technology, Chicago, IL, June, 1986.

Finno, R.J., "Response of Cohesive Soil to Advanced Shield Tunneling," Ph.D. Dissertation, Stanford University, Stanford, CA, August, 1983.

Clough, G.W., Finno, R.J., Sweeney, P.B., and Kavazanjian, E., "Development of a Design Technology for Ground Support for Tunnels in Soil, Volume III, Observed Behavior of an Earth Pressure Balance Shield in San Francisco Bay Mud," Report prepared for the U.S. Department of Transportation, Stanford University, June, 1982.

Woodward, R.J., Finno, R.J. and Baker, G.L., "Geotechnical Evaluation of Subsurface Conditions at Conservation Services Inc., Disposal Facility," prepared for Waste Management, Inc., Oak Brook, IL, February, 1980.

Woodward, R.J., and Finno, R.J., "International Pollution Control, Inc., Site Geotechnical Evaluation," prepared for Chemical Waste Management, Inc., Houston, TX, November, 1979.

Woodward, R.J., and Finno, R.J., "Geotechnical Evaluation of Lowry Landfill," prepared for Chemical Waste Management, Inc., Long Beach, CA, October, 1979.

Woodward, R.J., and Finno, R.J., "Geotechnical Evaluation of Waste Disposal Site at Carlyss, Louisiana, Phase I Report," prepared for Waste Management Inc., Oak Brook, IL, June 1979.

Woodward, R.J., and Finno, R.J., "Slurry Trench Evaluation, Waste Disposal Site at Carlyss, Louisiana, Phase II Report, prepared for Waste Management, Inc., Oak Brook, IL, June, 1979.

INVITED LECTURES AND PAPER PRESENTATIONS

Seoul, Korea, “EPB Shield Tunneling: Capabilities of the new generation of machines,” invited lecture, Dankook University, September, 2013.

Chicago, Il. , Illinois Section ASCE, Geotechnical Group, “Tunneling with Earth Pressure Balance Shields: It’s not your father’s EPB,” February 2013.

Karlsruhe, Germany, “Factors affecting deformations caused by top-down excavation,” Invited lecture, 2nd International Workshop for 1136 Geotech, Holistic Simulation of Geotechnical Installation Processes, December 2012

Golden, Colorado, “Case studies in soft ground tunneling,” Colorado School of Mines, January 2012

Seoul, Korea, “Identification of Constitutive Parameters with Field Performance Data,” Keynote Lecture, IS Seoul 2011, International Symposium on Deformation Characteristics of Geomaterials, September, 2011

Seoul, Korea, “Performance of a Self-sinking Caisson and Implications for Design,” Seoul National University and Kyung Hee University, September 2011

Berkeley, CA. “Control of Excavation-induced Ground Movements,” SFGI - U.C. Berkeley 29th Distinguished Lecture, May, 2011.

New York, NY. “Designing Excavation Support Systems to Protect Adjacent Structures,” 2nd Annual GZA Lecture, Metropolitan Section, ASCE Geotechnical Group, March, 2011.

Chicago, IL. “Estimating Ground Movements Associated with Excavations: Capabilities of Existing Approaches,” Driven Pile: A Technical Seminar, Deep Foundations Institute, March, 2011.

St. Paul, MN. “Linking Field Data and Performance Predictions during Construction,” University of Minnesota 59th Annual Geotechnical Engineering Conference, February, 2011.

Seattle, WA. “Recent Trends in Supported Excavation Practice,” Keynote Lecture, ER2010, ASCE, August, 2010.

Shanghai, China, “Control of Excavation–induced Ground Movements,” Guanghua Lecture, Tongji University, June 2010

Taipei, Taiwan, “Failure of a Large Diameter Sunken Shaft,” and “Field Observations and Constitutive Parameters: Lessons Learned from Supported Excavation Projects,” Keynote Lectures, 2010 International Symposium on Urban Geotechnical Engineering, National Taiwan University of Science and Technology, June 2010

Houston, TX, “Evaluating Excavation Support Systems to Protect Adjacent Structures,” The 2010 Michael W. O’Neill Lecture, CIGMAT, University of Houston, April, 2010

Kansas City, MO, “Earth Pressure on Cantilever Sheet-pile Walls with Retained Slopes,” SSP Symposium, 34th Annual Conference on Deep Foundations, Oct. 2009

Incheon, Korea, “Adaptive Management of Excavation-induced Ground Movements,” keynote lecture, International Symposium on Urban Geotechnics, September, 2009.

Seoul, Korea, “Incrementally Non-linear Responses of a Freshwater Glacial Clay,” Seoul National University, September 2009

Seoul, Korea, “Self-Adapting Soil Models,” Korea Institute of Construction Technology, September 2009

Honolulu, Hawaii, “Integrated Tools for Predicting, Monitoring, and Controlling Ground Movements due to Excavations,” invited lecture, NSF Engineering Research and Innovation Conference, June 2009.

Indianapolis, IN, “Linking Field Observations and Performance Prediction Updates during Construction,” invited lecture at the 15th Great Lakes Geotechnical/Geoenvironmental Conference, Applications of geotechnical Instrumentation for the Performance Evaluation of Constructed Facilities, May, 2008.

Gainesville, FL, "Adaptive Management of Excavation-induced Ground Movements: Automating the Observational Method, " Ardaman Lecture in Geotechnical Engineering, University of Florida, April, 2008

Shanghai, China, “General Report: Analysis and Numerical Modeling of Deep Excavations,” 6th International Symposium Geotechnical Aspects of Underground Construction in Soft Ground,” April, 2008

Theme lecture, Boston, MA, “Use of Monitoring Data to Update Performance Predictions of Supported Excavations,” Field Measurements in Geomechanics, ASCE Conference, September, 2007.

Boston, MA, “Real Time Monitoring at the Olive 8 Excavations,” Field Measurements in Geomechanics, ASCE Conference, September, 2007.

Milwaukee, WI, Midwest Bridge Working Group, “Use of Non-Destructive Evaluations for Bridge Foundations,” May 2007.

Distinguished Lecture, Kentucky Geotechnical Engineering Group, Louisville, KY, “Urban Infrastructure: a Fertile Field for Geotechnical Engineering,” March 2007.

Louisville, KY, University of Louisville, “Predicting Damage to Buildings from Excavation-induced Ground Movements,” March 2007

Denver, CO, “Predicting damage to buildings from excavation-induced ground movements,” Invited lecture, GeoDenver 2007, New Peaks in Geotechnics, ASCE Geo-Institute Conference Feb. 2007.

Tempe, AZ, Arizona State University., “Adaptive Management of Excavation-induced Ground Movements: automating the observational approach,” November 2006.

Seattle, Washington, Seattle University, “Excavation Support in Urban Environments,” October 2006.

Washington, D.C., Schnabel Foundation Company, “Predicting and Measuring Responses of Supported Excavations,” September 2006.

Chicago, Il. , Illinois Section ASCE, Geotechnical Group, "Assessing the effects of excavation-induced ground movements on adjacent buildings," September 2006.

Chicago, IL, Combined Chicago Geotechnical Lectures Series and 14th Annual Great Lakes Geotechnical and Geoenvironmental Conference, "Inverse Analysis to Update Deformation Predictions for Braced Excavations," May 2006.

Keynote Lecture, Bochum, Germany, International conference of Construction Processes in Geotechnical Engineering for Urban Environment, "Selected Topics in Numerical Simulation of Supported Excavations," March, 2006.

Bochum, Germany, International conference of Construction Processes in Geotechnical Engineering for Urban Environment, "Lessons learned from case studies of excavation support systems through Chicago glacial clays," March, 2006

Atlanta GA, GeoCongress 2006, Geotechnical Engineering in the Information Technology Age, ASCE "Representing internal bracing systems in 3-D models of deep excavations," Feb 2006

Atlanta GA, GeoCongress 2006, Geotechnical Engineering in the Information Technology Age. "Use of lateral movements and strut loads in inverse analysis of supported excavations," Feb 2006

31st Martin l. Kapp Lecture, New York, NY, ASCE Metropolitan Section, "Developments in the Observational Approach for Controlling Excavation-induced Ground Movements, December 2005.

Rensselaer Polytechnic Institute, Rensselaer, NY, "Automating the Observational Approach for Controlling Excavation-induced Ground Movements," October 2005.

Kyoto, Japan, US-Japan Workshop on Testing, Modeling and Simulation in Geomechanics, "Small Strain Responses of a Freshwater Glacial Clay," September, 2005.

Osaka, Japan, 16th International Conference on Soil Mechanics and Geotechnical Engineering, "Maximum shear modulus and incrementally nonlinear soils," September, 2005.

Osaka, Japan, 16th International Conference on Soil Mechanics and Geotechnical Engineering, "Observed bracing responses at the Ford Design Center excavation," September, 2005.

Colorado School of Mines, Golden, CO, "Predicting, Monitoring and Controlling Ground Movements caused by Deep Excavations," May 2005

Great Lakes Geotechnical and Geoenvironmental Conference, Milwaukee, WI, "Automated Monitoring of Supported Excavations," May 2005

Association of Engineering Geologists, Chicago, IL., "Lessons learned from performance monitoring of supported excavations in Chicago," May 2005

Midwest Bridge Working Group, Chicago, Il., "Ground Movements Associated with Deep Excavations," May 2004.

Seattle, Washington, ASCE Seattle Geotechnical Group, "Lessons Learned from Performance of Excavation Support Systems in Soft Clays," January 2004.

University of Washington, "Updating Predictions of Performance of Supported Excavations," January 2004.

Delft, Netherlands, "Development of new integrated tools for predicting, monitoring and controlling ground movements due to excavations," April 2003

Johns Hopkins University, “Prediction and Performance of the Excavation for the Chicago-State Subway Renovation,” March 2003

Purdue University, “Prediction and Performance of Deep Excavations,” October 2002

Seoul, Korea, Seoul National University, “Prediction and Performance of the Excavation for the Chicago-State Subway Station Renovation,” July 2002

Seoul, Korea, Yonsei University, “Performance of a Stiff Support System in Soft Clay,” July 2002

Seoul, Korea, Hanyang University, “Guided Wave Interpretation of Surface Reflection Techniques for Deep Foundations,” July 2002

Atlanta, GA, Invited lecture at the Sowers Symposium, “Prediction and Performance of the Excavation for the Chicago-State Subway Station Renovation,” May 2002

Chicago, Il, Illinois Section of ASCE, "Ground Movements Associated with Supported Excavations: Prediction and Update Based on Field Performance Data" April, 2002

Minneapolis, MN, University of Minnesota, “Effects of Excavation-Induced Ground Movements on Adjacent Structures,” June 2001

Chicago, IL, TCDI- Hayward Baker Ground Modification Seminar, “Performance of the Chicago Avenue – State Street Subway Renovation Excavation,” May 2001

St. Paul, MN, TCDI- Hayward Baker Ground, Modification Seminar, “Performance of the Chicago Avenue – State Street Subway Renovation Excavation,” May 2001

Chicago, Il, Illinois Section of ASCE, "Performance of the Excavation for the Chicago-State Subway Renovation," February 2001

Chicago, IL., University of Illinois, “Evaluating Movements associated with Supported Excavations,” February 2001

Amherst, MA, Performance Confirmation of Constructed Geotechnical Facilities, Geo-Institute Specialty Conference, ASCE, “The National Geotechnical Experimentation Site at Northwestern University,” April 2000

Madison, WI, Nondestructive Evaluation of Bridge Conditions Short Course, "Nondestructive Evaluation of Existing Deep Foundations," December 1999

Urbana, IL, Third National Conference of the GeoInstitute, ASCE, "Summary of Current Research, " Workshop on Research Needs and Opportunities for Urban Underground Facilities, June 1999.

Green Bay, WI, ITI Bridge NDE Users Group Meeting, "Non-destructive Evaluation of Deep Foundations," April 1999.

Newport, RI, US University Council on Geotechnical Engineering Research Workshop, "The National Geotechnical Experimentation Site at Northwestern University," November 1998.

Naples, Italy, Second International Symposium on Hard Soils - Soft Rocks, "Design Parameters for Drilled Shafts in Intermediate Geomaterials," October 1998

Indianapolis, IN., Sixth Great Lakes Geotechnical/Geoenvironmental Conference, "Limitations of Impulse Response Tests of Drilled Shafts," May 1998

Madison, WI, Nondestructive Evaluation of Bridge Conditions Short course, "Nondestructive Evaluation of Existing Deep Foundations," December 1997

Chicago, Il, Illinois Section of ASCE, "Forensic Evaluation and Repair of Damaged Columns in Building Constructed in Expansive Clays," November 1997

Chicago, Il, Fifth Great Lakes Geotechnical/Geoenvironmental Conference, "Shear and Compression Wave Velocities at the NGES at Northwestern University," May 1997

Washington DC, ASCE Annual Convention, "Lateral Earth Pressures for Supported Excavations," October, 1996

Absecon, N.J., Fourth ITI Bridge NDE Users Group Conference, "Nondestructive Evaluation of Existing Foundations" November, 1995

San Diego, CA, Structural Materials Technology NDE Conference, "Impulse Response Evaluation of Drilled Shafts", March, 1995

Northbrook, IL, Wiss, Janney, Elstner Associates, Inc. Technical Symposium, "Effects of Tunneling Procedures on Ground Movements and Liner Loads," February, 1995

Chicago, IL., Illinois Section ASCE Geotechnical Group, "Effects of Hydrocompression at Twin Tunnels," February 1995

Washington, D.C., Transportation Research Board Annual Meeting, "National Geotechnical Experimentation Site at Northwestern University," January 1995

SIMECSOL, Le Plessis Robinson, France, "Ground Movements During Construction of a Braced Excavation in Clay," June 1994

Texas Tech University, Lubbock, Texas, "Finite Elements in Geotechnics: Elegance versus Practicality, an Overview of Three Case Studies," April 1994

University of Rome "La Sapienza", Rome, Italy, "Evaluation of the State of the Art of Braced Excavations in Soft Clay," November, 1993

Minneapolis, MN, Fortieth Annual Geotechnical Engineering Conference, "Limitations of the Accuracy of Deformation Predictions in Soft Clay," 1992

Purdue University, West Lafayette, IN., "Limitations of Predicting Deformations during Excavation in Soft Clay," 1992

Chicago, IL, Deep Foundations Institute Annual Meeting, "Limitations of Predicting Deformations during Excavations in Soft Clay," 1991

Foundation Engineering Congress, Evanston, "Overview of Pile Capacity Prediction Event," 1989

Foundation Engineering Congress, Evanston, " Results of Axial Load Tests and Evaluation of Predictions," 1989

Nashville, Tennessee, ASCE National Convention, "Soil Parameters Implied by Braced Cut Observations," 1988

Paris, France, NSF Workshop on Strain Localization and Damage, "Field Observations of Strain Localization in Soft Clay," 1988

University of California, Berkeley, "Finite Element Analyses of EPB Shield Tunneling," 1985

University of Illinois, Urbana, "Analyses of Deformations Associated with Advanced Shield Tunneling," 1983

Johns Hopkins University, "Controlling Deformations with Earth Pressure Balance Shield Tunneling," 1982

GRADUATE STUDENT SUPERVISION

Ph.D.

R.F. Gausseres, "Generalized Time-Dependent Behavior of Clays Consolidated Under Different Stress Ratios," May 1988 (Illinois Institute of Technology)

I.S. Harahap, "Numerical Evaluation of the Performance of the HDR-4 Excavation," August, 1990

C.K. Chung, "Laboratory Investigation of Stress-Strain-Strength Behavior of Compressible Chicago Glacial Clay Tills" June, 1991

Y.H. Rhee, "Laboratory Investigation of Strain Localization in Soft Clay" December, 1991

M. Mahmoud, "Evaluation of Dilatometer Penetration in Saturated Clays," December, 1991

Nirmala Gnanapragasm, "Degradation of Bentonite by Selected Organic Solvents" (co-advisor with BA Lewis) December 1993

K.Y. Chung, "Coefficients of Consolidation and Permeability by Alternating Current Electro-osmosis Tests" December 1993

J. Yin, "Theoretical Evaluation of Coefficient of Permeablity from Alternating Current Electro-Osmosis Experiments" December 1993

W.W. Harris, "Localization of Loose Granular Soils and its Effect on Undrained Steady State Strength Soils," June 1994

P.J. Sabatini, "Finite Element Analysis of Localized Deformation for a Normally Consolidated Clay," December 1994

M. A. Mooney, "An Experimental Study of Strain Localization and the Mechanical Behavior of Sand," June 1996

S. L. Gassman, "Nondestructive Evaluation of Deep Foundations," June 1997

A. Hanifah , "A Theoretical Evaluation of Guided Waves in Deep Foundations," June 1999

M.A. Alarcon, "Constitutive Modeling of Direct Measures of Strain in Simulated Fault Gouge," June 2000 (co-advise with John Rudnicki)

A.L. Rechenmacher, "Effects of Consolidation History and Shear Rate on the Critical State of Two Sands," December 2000.

L.S. Bryson, "Performance of Stiff Excavation Support Systems in Soft Clays and the Response of Adjacent Buildings," September 2002

M. Calvello, "Inverse Analysis of a Supported Excavation through Chicago Glacial Clays," September 2002

Hsiao-Chou Chao, "An Experimental Model for Pile Integrity Evaluation using a Guided Wave Approach," December 2002

Jill F. Roboski, "Three-dimensional Performance and Analyses of Deep Excavations," December 2004

Helsin Wang, "Theoretical Evaluations of Embedded Plate-like and Solid Cylindrical Concrete Structures with Guided Waves," 2004

Terence P. Holman, "Small strain behavior of compressible Chicago glacial clay," 2005

J. Tanner Blackburn, "Automated remote sensing and three-dimensional analysis of internally braced excavations," 2005.

Cecilia Rechea Bernal, "Inverse analysis of excavations in urban environments," 2006.

Xuxin Tu, "An incrementally non-linear model for clays with directional stiffness and a small strain emphasis," 2006.

Wanjei Cho, "Recent Stress History Effects on Compressible Chicago Glacial Clay," 2007

James Lynch, "Experimental Evaluation of Concrete Piles subjected to Flexural Guided Waves," 2008

Taesik Kim, "Incrementally Nonlinear Responses of Soft Chicago Glacial Clays," 2011

Fernando Sarabia, "Hypoplastic Constitutive Law Adapted to Simulate Excavations in Chicago Glacial Clays," 2012

David Zapata-Medina, "Evaluation of Dynamic Soil Parameter Changes due to Construction-induced Stresses," 2012

Carlos Vega Posada, "Evaluation of Liquefaction Susceptibility of Clean Sands after Blast Densification," 2012

Kristi Sue Kern, "Behavior of Chicago Desiccated Clay Crust and its Effect on Excavation-induced Ground Movements," 2014

Luis G. Arboleda-Monsalve, "Performance, Instrumentation and numerical Simulation of One Museum Park West Excavation," 2014

Aaron P. Gallant, "A Field and Numerical Evaluation of Blast Densification," 2014

Post-Doctoral Fellows

C.-K. Chung (1991-1992)
Y.H. Rhee (1991-1992)
G. Viggiani (1994-1995)
A. Alarcon (2000-2001)
H.C-Chou (2002-2003)
Y. H. Jung (2005-2007)
W. Cho (2007-2008)
T, Kim (2011-2012)
F.-C. Teng (2013-2014)

M.S.

W.R. Shubert, "Chemical Compatibility of Clay Liners in Waste Disposal Practice," May, 1985 (Illinois Institute of Technology)

M-A Kamel, "Evaluation of Design Pressures for Shaft Construction Through Sands," June, 1988

S.B. Perkins, "Observed Performance of a Deep Braced Cut in Clay," June 1988

S.M. Nerby, "Analysis of Field Observations of a Braced Excavation Through Clay," June 1988

L. Smith, "Performance of an Automated Research Engineering Direct Simple Shear Device," Dec. 1989

T. Cosmao, "Analyses of Axial Load Tests of Four Piles," December, 1989

B. Gitskin, "Axial Load Tests of Four Piles: Procedures and Results," June, 1990

J. Merl, "Development of Experimental Setup and Procedures for Constant Head Hydraulic Conductivity Testing with Hazardous Permeants," December, 1990

C. Bonczkiewicz, "Evaluation of Soil-Reinforcement Parameters by Large Scale Pullout Test," June 1991

W.W. Harris, "Evaluation of Time-Dependent Behavior of Clays Under K_o conditions" December, 1991

P.A. Sabatini, "Effects of Sheet-pile Installation on Computed Response of Braced Excavations in Soft to Medium Clay," December, 1991

N. Tandeles, "Experimental Evaluation of Silts as Filter Protected Soils Based on Permeability and Piping Potential," December 1992

W.M. Sabra, "Non-Destructive Evaluation of Foundations and Soil Parameters," Dec., 1992

N.A. Stiber, "Undrained Steady State Strength of Fine Sands under Axisymmetric Conditions," December 1992

M. Berrebi, "Review of Failure Mechanisms in Stiff Overconsolidated Clays" December 1993

C. Pierce, "Evaluation of Flow Rules for Chicago Glacial Clays in Compression" December 1993

S. Gassman, "Undrained Steady State Shear Strength and Instabilities of Fine Sands," June 1994

P. Prommer, "Non-destructive Evaluations of Existing Deep Foundations," December 1994

M. Bauer, "Measurement of the Coefficient of Permeability of Clay Soils using Alternating Current Electroosmosis," December 1995

A. Shaer, " Strain behavior of sand specimens in the presence of shear bands," December 1996

R. Austin, "Earth pressures from clayey backfills," June 1997

P. Osborne, "Parallel Seismic Evaluation of the NDE test section at the NU NGES," December 1997

C. Orozco, "Evaluation of Compaction Grouted Minipiles at the NU NGES," December 1997

P. Champy, "Cross Hole Sonic Logging Evaluation of Drilled Shafts at the NGES," December 1997

E. Budyn, "The Design of Drilled Shafts in Intermediate Geomaterials: A Review," December 1997

K. Kawamura, "Hardening Soil Parameters for Compressible Chicago Glacial Clays," December 1999

Y.-H. Hu, "Interpretation of Impulse Response Test using a Guided Wave Approach," December 1999

D.J. Priest, "Analysis of Mechanically Stabilized Earth Retailing Wall with Clay Backfill," December 2000

B. Paineau, "Evaluation of Capacity of Micropiles in Rock," December 2000

J. Roboski, "Development of Soil Parameters for Constitutive Modeling of Compressible Chicago Glacial Clays, June 2001

F. Voss, "Evaluating Damage Potential in Buildings Affected by Excavations," June 2003

K.M. Molnar, "Analysis of effects of Deep Braced excavations on Adjacent Buried Pipelines," June 2003

X. Tu, "Observations and Calculation of Creep Movements of Supported excavations in Chicago Clays," December 2003

G.E. Andrianis, "Excavation-induced Strains and Cantilever Deflections in Compressible Clays," June 2006

L.B. Erickson, "Plane Strain Responses of Compressible Chicago Clay," June 2006

A. Morgan, "A Parametric Study of a Supported Excavation and Tunnel Connection through Chciago Glacial Clays," June 2006

M. Langousis, "Automated Monitoring and Inverse Analysis of a Deep Excavation in Seattle," June 2007

S.M. Henning, Reinforcing Effects of Caisson Use in Top-down Construction," June 2007

Katkhuda, I. "Automated Monitoring and Performance Evaluation of the MFA Excavation in Boston, MA." December, 2008

H.B. Knai, "Measuring the Effect of Occluded Gas Bubbles on Stress-strain Response of Loose to Medium Dense Sand," June 2011

A Gallant, "A Parametric Study of Open Cell Cofferdam Construction at the Port of Anchorage Marine Terminal Redevelopment Project," June 2011

K. Kern, "Analysis of Top-down Construction at the Block 37 Project in Chicago, Il," June 2011

W. Geng, "Finite Element Analysis of the Jones College Preparatory School Excavation in Chicago, IL.," June 2014

J. Lizarraga Barrera, "Performance and Analyses of the Mather South Excavation," June 2014

Current — Advising 3 Ph.D. students, 2 MS students

UNIVERSITY COMMITTEES AND ACTIVITIES:

ILLINOIS INSTITUTE OF TECHNOLOGY: (1983-1986)

University: Graduate Study Committee

Civil Engineering: Department Coordinator, responsible for scheduling all department classes, advising graduate students and coordinating groups' activities
Secretary, Faculty Meetings
Arranged Geotechnical Graduate Seminars

Semester Courses Taught:

Graduate:
- Mechanical Behavior of Soils
- Advanced Soil Mechanics
- Rock Mechanics
- Numerical Methods in Geotechnical Engineering
- Design of Embankments and Earth Structures
- Tunnels and Underground Structures

Undergraduate:
- Engineering Geology
- Introduction to Geotechnical Engineering

NORTHWESTERN UNIVERSITY: (1986-present)

University: Limited Submissions Advisory Committee (2013-2014)

	Committee on Athletics and Recreation member (1993-1999) GFC Subcommittee on Research Affairs member (1993-1996) Selection committee member for McCormick Professors and University Distinguished Lectureship (1994)
McCormick School:	Freshman Advisor (1987-1997) Committee on our Future member (1993-1994, 1997-1998, 2011-2012) Promotion and Tenure committee (1997-1999; 2011-2013)
Civil Engineering Department:	Secretary, Department Faculty Meetings (1986-1992) Geotechnical Admissions Correspondent Undergraduate Advisor (1998-present) Research Committee member (1990-2000) Executive Committee (1995-1997) Chair, Curriculum Committee (2006-2008) Chair, Search Committee for Department Chair (2008-2009) Chair, Faculty Advisor Committee (2009-2010) Faculty Advisory Committee member (2010-2011) Chair, Search Committee for Geotechnical Faculty member (2010-2011) Geotechnical Group Coordinator (2010-present)

Courses Taught:

Undergraduate:	Foundation Engineering Introductory Soil Mechanics Engineering Properties of Soils
Graduate:	Soil Mechanics I – Mechanical Properties of Soils Soil Mechanics II – Foundation Engineering Soil Mechanics III – Earth Structures and Slope Stability Case Studies in Geotechnical Engineering Soil Rheology – Constitutive Properties of Soils Underground Construction Soil Dynamics Environmental Geotechnics Engineering Properties of Soils