2015

Geostatistical Examination of the Geotechnical Portland BES Databases with Emphasis on Silt

Alex K. Baumann
Portland State University

Geostatistical Examination of the Geotechnical Portland BES Databases with Emphasis on Silt

BY

Alex Baumann

A research project report submitted in partial fulfillment
of the requirement for the degree of

MASTER OF SCIENCE
IN
CIVIL AND ENVIRONMENTAL ENGINEERING

Project Advisor:
Dr. Trevor D. Smith

Portland State University

ACKNOWLEDGMENTS

A tremendous amount of repetitive work was required in gathering data for the results presented in this project report. Dave Demchak, a PSU CEE graduate student, participated in a substantial amount of data collection from geotechnical boring logs and reports as partial fulfillment of his degree at PSU. Additionally, Mr. Demchak contributed to the potential for future database work by building a spreadsheet that contains information from over 400 private and public sector boring logs for the Downtown, Portland area.

Dr. Trevor Smith had great interest in honoring me with being the first to ever analyze over 50 years' history of Portland geotechnical practice and statistically characterizing mechanical properties of local silts. If it were not for Dr. Smith's unique and perseverant interest in exploring such topics, the likelihood of current and future PSU students exploring these databases to this extent would be unpredictable. Dr. Smith contributed to this project on a weekly basis with his willingness to meet in person for discussions and generate new ideas for exploration and presentation of data. Elise Smith also significantly contributed to the generation of ideas for data presentation and was a source for office supplies/machines and morale boosting at times of project disarray.

Ericka Koss provided me with the databases in the form that was used by the Bureau of Environmental Services personnel. Ms. Koss gave me background information on what the databases are currently being used for and what has not been accomplished with them. Ms. Koss was enthusiastic about the databases, since nothing to the extent of what is covered in this project report has been accomplished yet. Ms. Koss has used the database extensively as a geotechnical engineer.

Natalie Ehrlich shared an office space me and frequently provided advice on potential alterations and additions to project data presentation. Ms. Ehrlich supported a positive attitude during times when work was lost from technical issues; she was always quick to boost morale with dry or cynical humor and a geotechnical, intended pun.

Amanda Hatheway and Craig Baumann were my roommates throughout the time of data collection, analysis, and report writing. They continually provided an admirable amount of support, never questioning the purpose of such academic efforts despite their primary interests in non-geotechnical aspects of life. Their well-rounded support was invaluable to me.

ABSTRACT

Willamette Valley silt deposits from historical catastrophic flood events present a difficult problem for subsurface engineers practicing in the Portland, Oregon area. Silts exhibit behavior of two very well-documented soil types, but publications containing mechanical properties for silts are scant, especially for local silts. Thus, the need for links between real Portland site investigation data and silt properties is high. To further exemplify the need for documented knowledge of local silts, this project reveals the evolving state of practice to incorporate more Pacific Northwest seismic analyses in preparation for a subduction zone earthquake. The geotechnical Portland BES databases contain thousands of private sector (PrS) and public sector (PbS) geotechnical documents from sites in the Portland area. The PrS database includes approximately 7,000 geotechnical documents for PrS projects dating primarily from the mid 1900's to 2009 for a range of project types. A statistically significant random sample of 1,500 documents from the PrS database was organized and analyzed. The approximate 1,000 documents in the PbS database containing boring logs can be linked to location through a pre-existing GIS layer. The statistically significant sample from the PrS database and the GIS layer from the PbS database were compared spatially to reveal clusters of documented geotechnical projects. An isolated cluster of 80 full geotechnical reports in the Downtown, Portland area from reputable practitioners was examined for standard penetration blow counts, equipment information, groundwater table depths, soil descriptions, unit weights, drill dates, and moisture contents to capture a range of correlated peak effective friction angles for different compositions of silt. The project types and report contents from the PrS database were analyzed in the Downtown area, and conclusions were made on the percentages of project types and apparent chronological trends in report content.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

1.1 Reasons for Database Work

The relationship between the private sector (PrS) and public sector (PbS) for public works in Oregon is different than for many other states in the United States. Oregon PbS agencies and bureaus do not house and make available a significant amount of geotechnical engineers to solve the large-scale subsurface problems in public works projects. Therefore, in Oregon, public works geotechnical site investigation and recommendations are outsourced to PrS consultants, who are in direct communication with contracting companies performing subsurface explorations, earthwork, and support installations. PrS consultants are often exclusive in the minutia of their design methodology, which can cause repetition in site investigation at the same site if past work is not accessible. However, consultants must adhere to Load and Resistance Factor Design (LRFD) approaches for their contributions to major highway project civil structures. Whether LRFD or Allowable Stress Design (ASD) methods are utilized for a particular project, published ranges of likely subsurface material mechanical properties can be extremely valuable in preliminary design or for verification of program inputs.

The behavior of silt subject to structural loading is a combination of two very well-documented soil types that geotechnical textbooks focus on: sand and clay. The teaching of elementary soil mechanics targets sand and clay separately as a means of highlighting the extreme cases in short- and long-term loading from structures. Like other soils, the moisture content, stiffness, stress history, stress path, and the rate of external structural loading on silt all have an influence on the engineer's judgment of how to predict silt behavior when loaded. Due to depositional processes, silt is often mixed with other types of soil grains, further complicating the problem. Unlike sands and clays, mechanical properties of silts are not well documented in the United States. Studies outlining typical ranges of silt mechanical properties in specific regions are rare. The Portland, Oregon area was subject to a series of catastrophic floods that deposited many layers of silt over a period of approximately 2,600 years, which are known as the Willamette Valley silt deposits. Currently, there are no publications available that capture statistically determined ranges of mechanical properties of Willamette Valley silts for a variety of compositions. This information would be valuable to local geotechnical practice, since silt of various compositions is frequently encountered in Portland site investigations. The geotechnical Portland Bureau of Environmental Services (BES) databases are a gateway to information about local silts, site investigation, and trends in geotechnical practice. This project presents the first exploration of these databases in hopes of providing a future research basis for the history of Portland geotechnical site investigation, log interpretation, and soil properties.

1.2 Scope and Objectives

This project is the commencement of a new vantage point into the vast amount of information available through documented geotechnical work in the geotechnical Portland BES databases over the past six decades. The amount of knowledge obtainable is not limited to the findings in this project report. The PrS database alone can provide several future geotechnical students with research focus, but the PbS database is likely to contain more substantial testing procedures for more significant structures (bridges, large pipelines, large retaining structures along highway cutbacks, etc.) that are managed by the PbS. The scope of this project was limited to exploring the information available through the PrS database, since the percentage of full geotechnical reports was far higher for the PrS database than for the PbS database, and site/structure background information was of great interest as supporting qualitative information for this project. However, the PbS database was utilized as part of the spatial analysis.

The objective in exploring the PrS database was to choose a cluster of full geotechnical reports for analysis from an area with a large amount of PrS development. A chronological comparison of PrS project types and report content was of interest to visualize changes in site investigation quality and frequency over the years. The quantitative analyses of Willamette Valley silt mechanical properties needed to be performed with test results widely available in the majority of site investigations. In-situ test results most often presented in geotechnical reports are from the Standard Penetration Test (SPT), which is a measurement of how many blows from a hammer are required to drive a sampler one foot into a soil layer of interest. Since soil fails in shear, parameters that determine shear strength of silt were of interest. As a soil shears, the hydraulic conductivity dictates how quickly excess pore water pressure can escape from voids that are changing in volume along shear surfaces and microcracks. A drained soil is considered to allow excess pore water pressure to quickly dissipate from these voids within the time period of shearing, providing more physical soil grain-to-grain interaction that contributes to shear strength. An undrained soil is considered to disallow this dissipation within the time period of shearing. For many applications in design, silt is considered drained upon shearing, and the concept of effective stress is applicable (whereas total stress concepts are applicable to undrained scenarios). Effective stress design approaches often require shear strength parameters that describe how soil grains interact, such as the peak effective friction angle.

The primary goal in the PrS database exploration was to bracket a range of peak effective friction angles to be referenced by local practitioners for different compositions of silt. Thus, extensive information from boring logs was required to make corrections to field SPT blow counts for use in correlating SPT results to effective friction angles. Due to the history of silt deposition and the isolation of a cluster for analysis, characterizing stratification of silt in the

Downtown area was not of interest for this project. However, general commentary on stratification is located in later sections of this report. Of particular interest was how correlations between SPT results and effective friction angles changed in accuracy between different compositions of silt, and whether the presence of clay, sand, gravel, and organics significantly affected the effective friction angle of Willamette Valley silt.

2.0 PORTLAND GEOLOGICAL HISTORY[2]

About 14 to 16 Ma, flows travelled down the ancestral Columbia River and solidified in the Portland area to form the Columbia River Basalt Group. This formation is in the shape of a large bowl, centered approximately at the Portland airport. Between about 16 Ma and present day, the center of the bowl has sunk and formation of the Tualatin and Cascade Mountain was a result of uplift around the edges of the bowl. Overlying portions of the Columbia River Basalt is the Troutdale Formation, a layer of gravels, sands, silts and clays 1,500 feet thick in some areas that was deposited from the Cascade Mountain streams and the Columbia River between about 14-2 Ma. Volcanic vents formed various basaltic buttes and small mountains (Boring lavas) in the Portland area between about 2 Ma and 260 Ka. Between about 15.3-12.7 Ka, over 90 catastrophic floods occurred from glacial dams forming and breaking in Montana. Each time a dam formed, Glacial Lake Missoula would fill. When the dams broke, the water from Lake Missoula would be released at up to an estimated 80 miles per hour and travel across parts of Idaho, Washington, and Oregon. The silt flood deposits are known as the Willamette Valley silts, which were later blown by wind over the West Hills of Portland. Figure 2-1 shows the approximate flood path from the floods that occurred from the glacial dam failures.

Figure 2-1: Approximate Path of Missoula Flood Water[7]

3.0 SILT DEPOSITION IN THE UNITED STATES[5]

Most silt deposits are commonly referred to as loess, which is often silt mixed with clay or fine sand. Most loess deposits in the United States are eolian, suspended and transported by wind from outwash-carrying, braided rivers. Eolian loess in the United States was deposited between 10 to 25 Ka, and is thickest at the deposition sources (shown as black regions in Figure 3-1). Some loess can be subject to collapsibility if clay content is low and the loess has not previously been saturated, which is more prevalent near source areas. Clay content, often being low, in loess does not typically contribute to expansion, but when subject to certain weathering processes, loess can act as expansive clay. Loess that has not been previously saturated can become saturated and cause devastating differential settlement from collapse near structure downspouts, utility line leaks, and joint leaks near pavement gutters. Figure 3-1 does not show eolian loess as covering the Portland, Oregon area, but general depositional processes of Willamette Valley silt in Portland can be referenced in the previous section of this report.

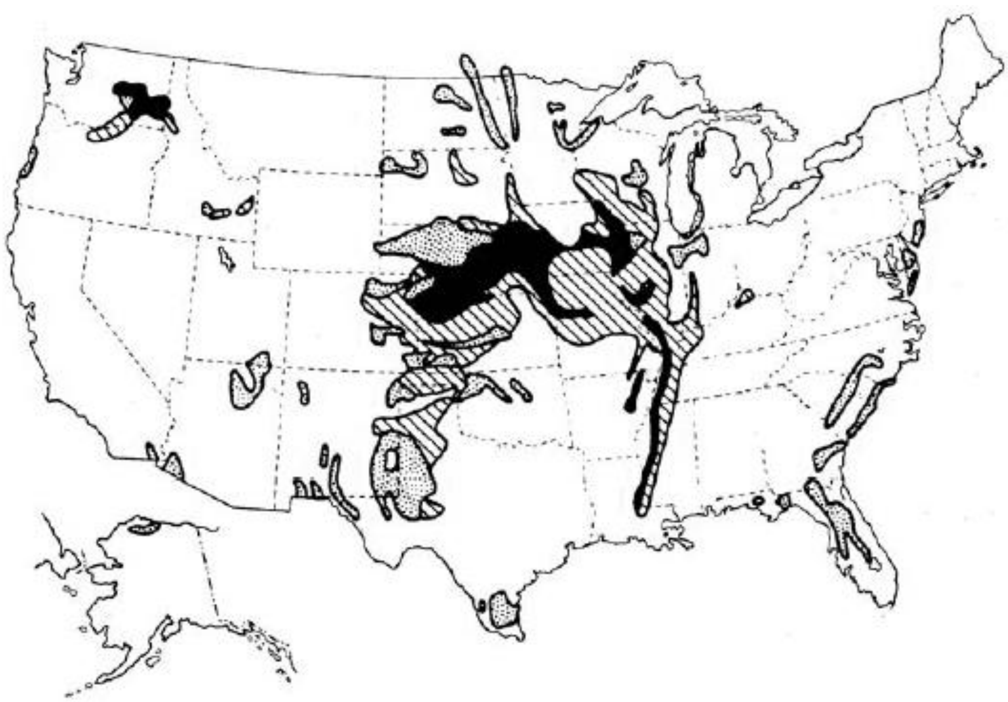

Figure 3-1: Approximate United States Eolian Surface Deposit Locations[5]

4.0 THE GEOTECHNICAL PORTLAND BES DATABASES AND THEIR CHRONOLOGY

4.1 Types of Documents in the Databases

The geotechnical Portland BES databases are split into two major categories: PrS projects and PbS projects. The PrS database contains approximately 7,000 geotechnical documents that were products of the geotechnical permitting processes. The document types included calculation pages, inter- and outer-office design memorandums, geotechnical reports on single-family dwellings, and geotechnical reports on larger structures. Actual structural and geotechnical deviations were not likely documented in these reports beyond what occurrences were considered deviations during site exploration. The types of recommendations made by consultants vary depending on the client, consultant's budget, and project. Full geotechnical reports typically include the consultant's project understanding and scope of work, geological site history, subsurface conditions, design/construction recommendations, recommendation limitations, and attached exploration and investigation documents (maps, drawings, analysis results, boring logs, and test data). PrS consultants are not required to include specific methodology for data reduction and calculating soil properties in geotechnical reports. On smaller projects, soil properties are often *not stated* in geotechnical reports, which posed as a significant challenge for this project. Since the PrS database does not contain many reports for large superstructures, it is likely that soil design parameters can be found more frequently in the full geotechnical reports of the PbS database due to higher loading from larger proposed structures and higher demand for quality testing.

The PbS database contains approximately 1,000 geotechnical documents, most of which are boring logs with little supporting information on proposed structures, geotechnical recommendations, and other site investigation. Analysis of boring logs without supporting information on the proposed structure, additional in-situ testing, lab testing, supporting analyses, and client type was not in the scope of this project. Suggestions for future PbS database work are located in later sections of this report.

4.2 Formation and Past Applications of the Databases

The PrS and PbS databases were formed by Portland BES and other city personnel as a source to reference for previous site investigations. Portland BES geotechnical engineers reference the geotechnical databases during the beginning stages of formulating a site investigation and budget. The presence of past exploration and testing can reduce the amount of investigation that is required to verify the existence of subsurface material in different locations on a site. In small projects, past work by consultants is sometimes referenced as supporting information for a sufficient site investigation. The PbS database is a far more efficient tool when verifying the presence of soil layers on a site than the PrS database due to its presence as a GIS layer of boreholes. Information can quickly be extracted from borehole locations in the GIS layer and linked to a boring log document. Similarly, but not as conveniently, the PrS database spreadsheet provided by BES can be searched for project location information, and geotechnical documents in the area of interest can be found. BES personnel(4) confirmed that no attempt has been made to organize and examine the databases beyond organization of the files provided by BES for this project. Since PSU acquired the databases, the databases have become much more than just a tool for referencing past site explorations. With the geotechnical Portland BES databases, a much-needed review and analyses in Portland geotechnical practice can now be completed: consultant work is documented, academic researchers utilize consultant documentation, and academic researchers provide processed information that is valuable to consultants in practice.

4.3 Examination and Analysis of Private Sector (PrS) Database

4.3.1 *Methods for Gathering a Statistically Significant Random Sample*

The PrS database contains approximately 7,000 geotechnical documents dating back to 1912 with the highest concentration of documents in 1990-2002. Quantitative analyses of the entire database were outside the scope of this project, so a statistically significant random sample was gathered for analyses. The RAND() function in Excel was utilized to generate a list of random numbers in a column adjacent to the document information. The entire spreadsheet was sorted by magnitude of the random number column (smallest to largest), and the first 1,500 documents were chosen as a random sample. Further analyses, similar to that shown in Figure 4-6, of the remaining database are not likely to produce much deviation from the in-situ test analyses in this project. Possible deviations from further analyses of city quarter section clusters are discussed in later sections of this report.

The statistically significant random sample of 1,500 documents was examined to find full geotechnical reports on structures that induced significant loading on underlying material. Many of the 1,500 documents were not full geotechnical reports, were memorandums, calculation pages, notes, or single-family dwellings, and were therefore discarded. Single-family dwellings were not considered to induce heavy loading to underlying material to require significant lab or in-situ testing. However, multiple-family dwellings (such as apartment complexes and multiple-storey condominiums) were included in the sample due to likelihood of higher loading than single-family dwellings and more significant soil testing. Upon discarding insignificant documents, the remaining full geotechnical reports were sorted by project type, report content, and consultant name. 50 different reputable consultant names producing full geotechnical reports on significant structures were found in the sample, some of which are no longer in business.

A way to graphically represent the statistical significance of a sample is to plot trends from the sample and from the entire database to observe the agreement in trend shapes. The sample size (20% of the full database) was assumed significant partially based on results shown in Figure 4-1. Document dates were provided in the PrS database spreadsheet, and the amount of documents corresponding to a specific year were plotted for the entire database and for the random sample of full geotechnical reports. In the PrS database spreadsheet, a total of 7,125 geotechnical documents were dated between the years 1950 and 2013, which are plotted in Figure 4-1 as the amount of documents occurring in each year. Most of the documents occurring later than 2009 were not included in the folder of geotechnical document PDF files provided by BES. From the random sample, 446 full geotechnical reports were dated between the years 1950 and 2013, which are also plotted in Figure 4-1. A gradual increase in the amount of reports generated per year can be observed between approximately 1970 and 2002, with document occurrences peaking at 2002 and plummeting between 2002 and 2013. The sharp plummet in the occurrence of geotechnical documents could be representative of the United States economic recession of the early 2000s and the period of uncertainty following attacks on the World Trade Center and Pentagon. Based on commentary by Portland BES personnel[4], it is not likely that this plummet was caused by a sudden halt in archiving geotechnical documents.

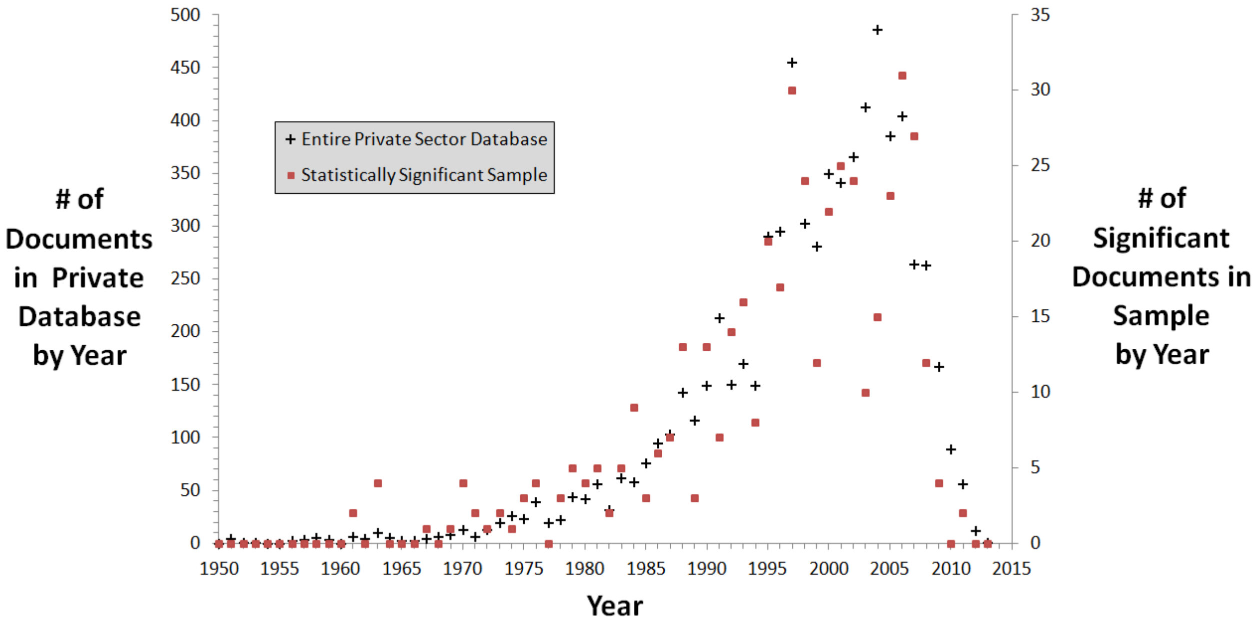

Figure 4-1: Number of Documents per Year from Entire PrS Database and Sample

4.3.2 *PrS Project Locations and Clusters*

The PrS database spreadsheet provided by Portland BES contains the city quarter section and cross streets associated with each archived geotechnical document. The integration of this information into a GIS layer, similar to what has been accomplished with the PbS database, was outside the scope of this project. However, the PrS database spreadsheet was utilized to count and plot the number of full geotechnical reports from the statistically significant random sample in each Portland city quarter section. A GIS map of Portland city quarter sections is shown in Figure 4-2. Portland city quarter section numbers are labeled 1212 to 4449, with increments of 100 in the north-south directions and increments of 1 in the west-east directions. A quarter section number can be read from Figure 4-2 by adding the north-south coordinate to the west-east coordinate. For example, the Downtown, Portland area includes approximate city quarter sections 2827, 2828, 2927, 2928, 2929, 3028, 3029, 3128, 3129, 3229, and 3329. This mapping technique does not show exact locations of projects within quarter sections, but is useful for determining clusters of project documents. Analysis of document clusters was vital for the geostatistics in this project due to the depositional processes of local silts. No geostatistical analyses have been conducted to prove that silt in Portland outside the Downtown area shows the same range of mechanical properties as silt in Downtown, Portland. Thus, a cluster of site investigations that potentially encountered silt with similar depositional history was of interest for this project. Additionally, it is intuitive that within a cluster, the project types and quality of site investigation may be similar. The Downtown, Portland area contains a significant amount of multiple-storey structures supported on deep foundations, so the depths of exploration were suspected to be larger than those in residential or industrial areas.

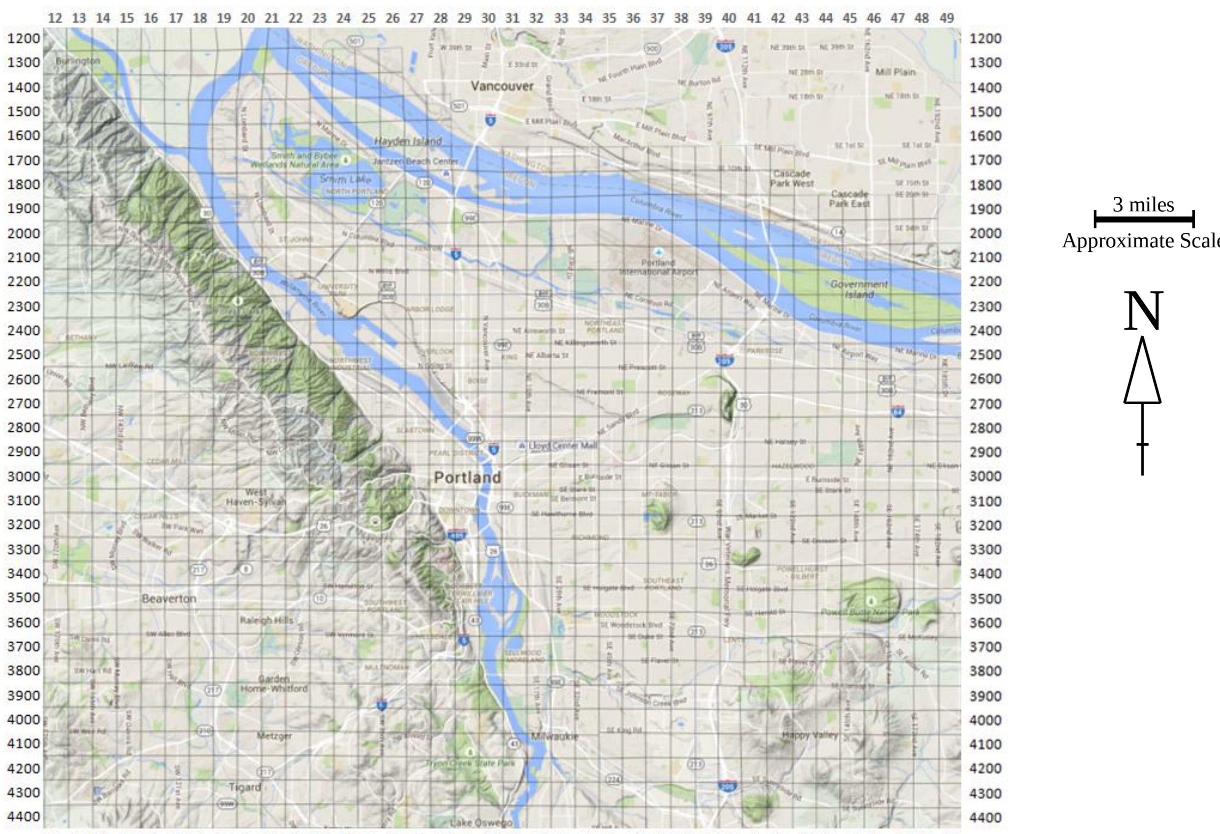

Figure 4-2: Portland City Quarter Sections GIS Layer

The amounts of full geotechnical reports per city quarter section were plotted in Figure 4-3. The shaded circles, centered at quarter sections, represent the amount of full geotechnical reports from the statistically significant random sample. The larger the circles, the more reports have been produced by consultants in that quarter section. Figure 4-3 reveals that the highest concentration of full geotechnical reports is located in the Downtown area. Of the 446 full geotechnical reports plotted throughout the Portland area in Figure 4-3, a total of 80 (18%) of these reports were from the Downtown area. Of more interest was that out of the 222 quarter sections that contained reports from the sample, 18% of these reports were contained in only 11 quarter sections covering the Downtown area.

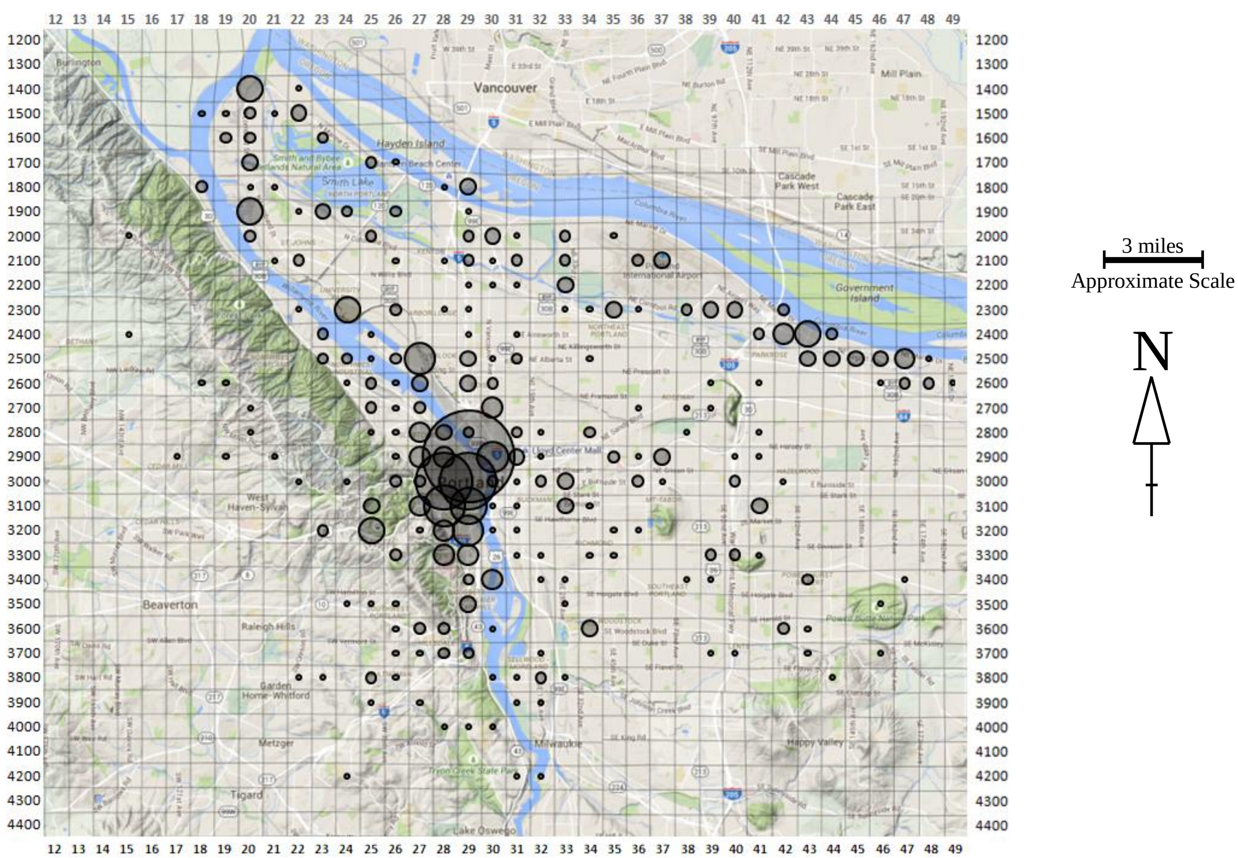

Figure 4-3: PrS Database Reports per City Quarter Section

4.3.3 *PrS Project Types and Report Contents*

From the statistically significant random sample, the full geotechnical reports in the PrS database were organized by structural project type. The project type categories of interest were multiple-storey structures, retaining structures, bridge structures, pipelines, and “other”. The “other” category encompassed mostly single-storey, non-single-family-dwelling structures or structures that did not fall into the other categories of interest. Many projects required retaining structures as a part of design recommendations, but the retaining structures category was reserved for projects focused exclusively on retaining structures. Intuitively, the Downtown area should consist primarily of multiple-storey structures, and the data from the sample supported this expectation. The PrS database was not suspected to contain many retaining structures, bridge structures, and pipelines in the Downtown area, since those project types are typically in the hands of the PbS, which was also reflected in the sample data.

To retain an updatable spreadsheet upon further organization of the geotechnical document PDF files in the PrS database, Excel macro codes were utilized. The Excel macro codes were written to extract lists of document names from specific folders within a computer drive and display the lists in a spreadsheet. Examples of these macro codes are located in the Appendix of this project report. Geotechnical report content categories of interest were seismic analyses, whether or not the contractor was the client, load testing to anchors and foundations, and slope stability analyses. Table 4-1 outlines the abbreviations for project type and report content categories that are referenced in Figure 4-4. Figure 4-4 shows various percentages for the statistically significant random sample of full geotechnical reports. The pie chart in the center of Figure 4-4 contains the percentage of the 80 full geotechnical reports from the Downtown area for each project type. Figure 4-4 reveals that multiple-storey structures were the dominant project type in the Downtown area in the PrS database. Retaining structures, bridge structures, and pipelines were a very small percentage of project types, but the majority of documentation for these projects is suspected to reside in the PbS database. Branching from each piece of the pie chart in Figure 4-4 are the percentages of report content for the project type categories. The sum of the report content percentages from each project type do not add to 100% because some reports included more than one type of report content, and some reports did not fall into any report content category. Bridge structures and pipelines were not associated with any of the report content categories. Bridge structures from the PrS database included small pedestrian bridges. The most evident trend in Figure 4-4 is that seismic analyses were far more frequent than other report content categories. When the contractor is the client for large projects, more temporary works are typically constructed. However, the sample size was not large enough to show a clear trend in client type based on project type.

Table 4-1: Project Types and Report Contents of Interest for Analysis

Project Type Categories	Report Content Categories
Multiple-Storey Structures (MS)	Seismic Analyses (SA)
Retaining Structures (RS)	Contractor as Client (CC)
Bridge Structures (BS)	Load Testing (LT)
Pipelines (PL)	Slope Stability (SS)
Other	

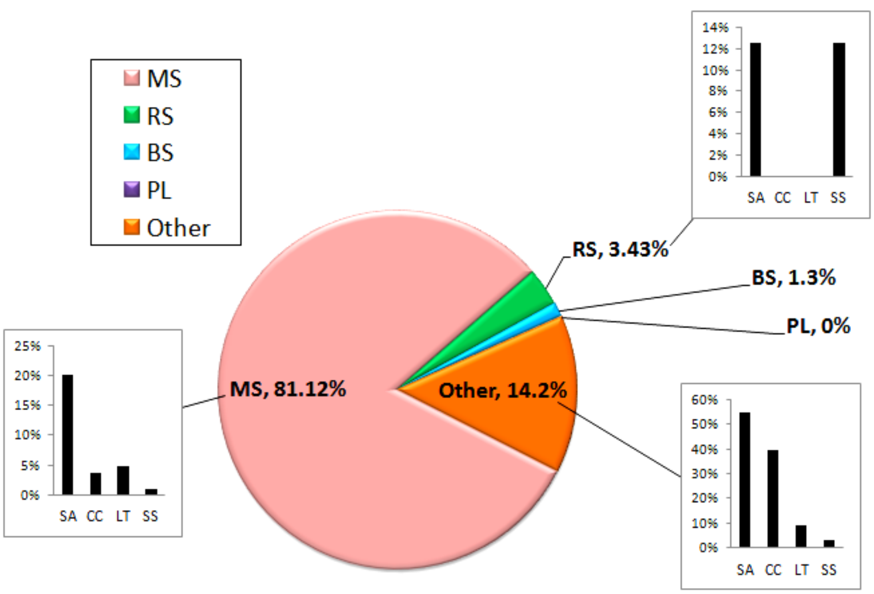

Figure 4-4: PrS Project Type and Report Content Percentages for Downtown, Portland

Figure 4-5 shows the different report content categories plotted as the number of reports containing those content categories per year. The coefficients of variation (COV) for each report content category were calculated for the years 1965-2015, since no reports with content categories of interest were observed for years prior to 1965 for the statistically significant random sample of 446 full geotechnical reports. In Figure 4-5, a higher COV meant more variation in the amount of reports containing a specific content category over the years, which indicated a potential trend in site investigation and analyses. Further discussion of these trends is located in later sections of this report.

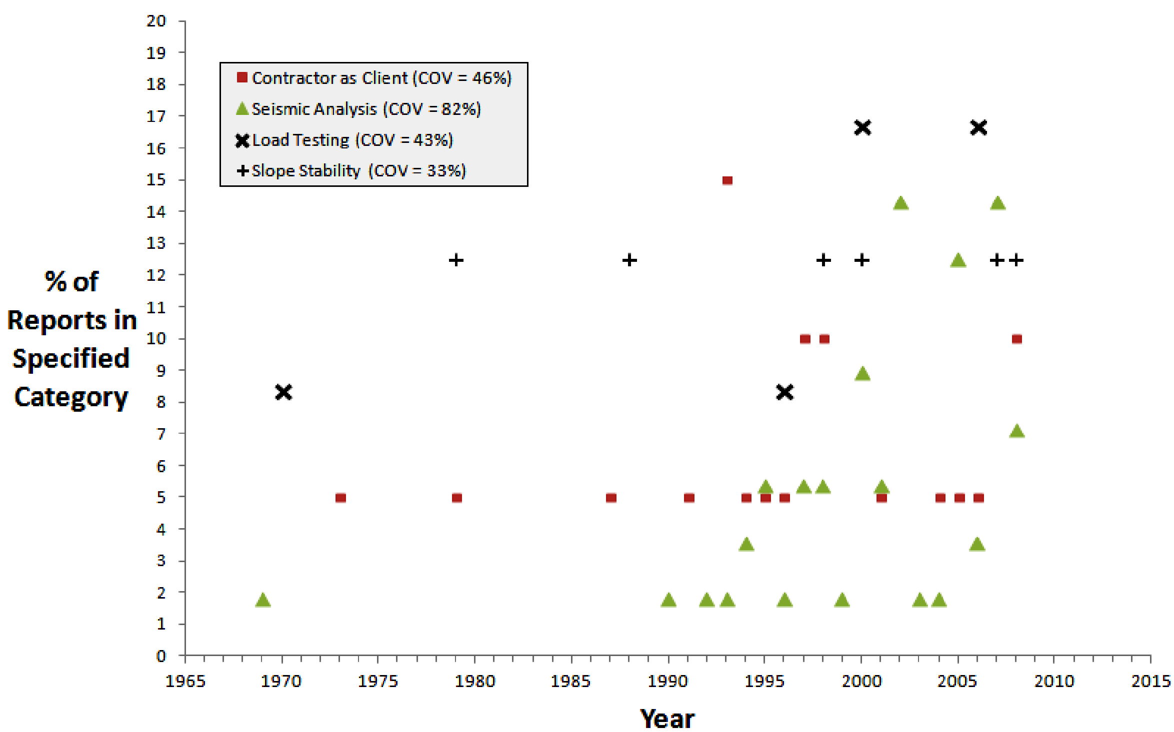

Figure 4-5: PrS Reports Containing Content Categories of Interest per Year

4.3.4 *PrS Database SPT Statistical Analysis*

A spreadsheet of boring log information from the 80 full geotechnical reports in the downtown area was constructed. Most of these reports contained multiple boring logs. From the 285 boring logs available in the 80 full geotechnical reports, 185 (65%) of these boring logs contained at least one layer of silt. The silt layer depths varied greatly. Soil descriptions in boring logs revealed that most of the material at shallow depths was fill. A source of error in the boring log analysis was the loggers' methods for visual-manual classification of soils at the times of logging. Log description styles changed from log to log, largely depending on the consultant producing the report. Therefore, some of the descriptions that obviously indicated fill material (i.e., silt with brick and wood fragments) were not actually logged as fill. Since fill materials were not of interest for this project due to high non-homogeneity in properties, layers containing silt that were considered fill were not included in field SPT blow count analyses (apart from depth and unit weight considerations). Layers that were of interest were silt with trace clay and/or sand, clayey and/or sandy silt, silt, silt with organics, silt with gravel, and any other descriptions showing predominantly non-fill silt material.

To efficiently gather and analyze information from boring logs, proper methods of field SPT blow count analyses were imperative. To drive a soil sampler into a layer at the bottom of a borehole, a hammer must strike the top of the rod that extends above the ground surface. In this process, a significant amount of energy is lost through the hammer device itself, lateral movement of the rod, and the presence of a liner in the sampler. Field blow counts are typically recorded as how many blows from a hammer are required to drive an 18-inch sampler the last 12 inches of its length into a soil layer. The first 6 inches of sampler penetration are discarded, as they often reflect resistance from slough that has dropped to the bottom of the borehole. Field blow counts must be corrected for the energy loss items listed above prior to correlation to design parameters, such as effective friction angle. Additionally, field blow counts must be normalized for effective overburden pressure at the sampler depth and for borehole diameters larger than 4 inches. A few obstacles occurred when attempting to accurately correct field blow counts for this project. The 80 geotechnical reports from the downtown area did not provide information on hammer type or efficiency (only the weight and drop height to generate a standard energy or energy that deviated from standards, which are typically 140-pound hammers dropped 30 inches), and soil dry unit weights were not often provided. To account for unknown information about hammer efficiency, a publication by William Kovacs[(6)] was utilized in conjunction with common knowledge that Oregon's site investigation practice is generally several years behind other states in adopting new equipment technologies. With these considerations, drill dates earlier than 1960 were assumed to have average hammer energies of 45% (donut hammers), dates from the 1960s through the 1990s were assumed to have average hammer energies of 60% (safety hammers), and dates proceeding 1990s were assumed to have average hammer energies of 80% (automatic hammers). Additional corrections for the presence of sample liners were applied. GRLWEAP 2010[(8)] hammer libraries show automatic hammers as having a range of 80-95% efficiency, so assigning 80% efficiency to all hammers proceeding the 1990s was a conservative approach. If dry unit weights were stated in the logs or reports, they were utilized for effective overburden pressure calculations in conjunction with ground water table depths. Since dry unit weights were infrequently stated in the reports analyzed, soil stiffness and density descriptions were interpreted and values within ranges of likely dry unit weights provided by Budhu[(1)] were assumed. Dry unit weights were adjusted to moist or saturated unit weights given the widely available values of soil moisture contents from the logs.

Multiple field blow counts and moisture contents within layers of silt were averaged for each layer, and effective overburden pressures were calculated for soil overlying silt layer midpoints.

The results for corrected field blow counts from silt layers were correlated to peak effective friction angles using two general methods, one of which included two separate types of calculations for effective overburden pressure correction. The correlation equations used in this project are shown below for peak effective friction angle[3].

$$\phi' = 27.1 + 0.3(N_1)_{60} - 0.00054[(N_1)_{60}]^2 \qquad \text{[Equation 1]}$$

$$\phi' = tan^{-1}\left[\left(\frac{N_{60}}{12.2+20.3\left(\frac{\sigma'_o}{P_a}\right)}\right)^{0.34}\right] \qquad \text{[Equation 2]}$$

$$C_N = \left(\frac{P_a}{\sigma'_o}\right)^{0.5} \qquad \text{[Equation 3]}$$

$$C_N = 0.77\log\left(\frac{20P_a}{\sigma'_o}\right) \qquad \text{[Equation 4]}$$

Equation 1 by Wolff (1989) is an approximation of the graphical correlation by Peck, Hanson, and Thornburn (1974) for SPT on granular material. Equation 2 by Kulhawy and Mayne (1990) is an approximation of work by Schmertmann (1975). C_N is a correction factor to multiply energy-corrected field blow counts (N_{60}) by to obtain blow counts corrected for effective overburden pressure. It should be noted that Equation 2 does not require effective overburden pressure corrections to N_{60}, since this correction is already incorporated in the correlation. Equations 3 and 4 are from Liao and Whitman (1986) and Peck et al. (1974), respectively.

Equation 4 is most applicable when effective overburden pressure at the depth of blow counts is greater than or equal to about 25 kPa (520 psf). Since most subsurface explorations in the Downtown area revealed existing fill, crushed concrete, and asphalt within the first few feet below ground surface, this limitation was not suspected to induce significant error in effective friction angle calculations. With Equations 1 through 4 being used in this analysis, there was a total of three different ways to calculate effective friction angle: the Wolff correlation with Liao and Whitman correction, the Wolff correlation with Peck et al. correction, and the Kulhawy and Mayne correlation.

Effective friction angle calculations were split into six general categories for silt composition: clayey silt, silt with trace clay, silt, silt with trace sand, sandy silt, silt with clay and sand, silt with gravel, and silt with organics. Before ranges of effective friction angles were calculated, it was suspected that higher amounts of clay may produce larger spread in data. SPT in clay is typically poorly correlated to effective strength properties because the sampler is being driven into material faster than pore water pressure is allowed to dissipate as the soil is sheared by the sampler. Figure 4-6 and Table 4-2 support this suspicion, and discussions of results in Figure 4-6 and Table 4-2 are located in later sections of this report.

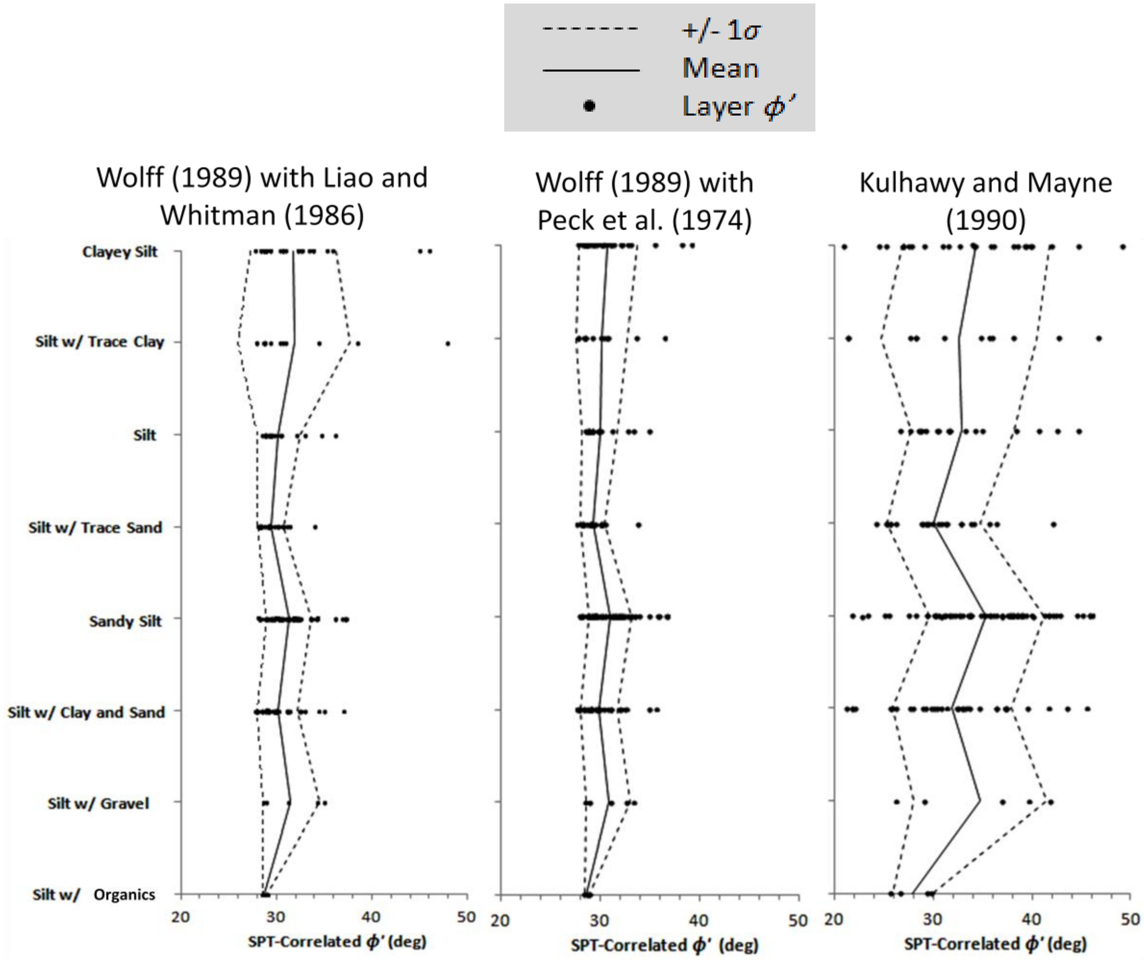

Figure 4-6: SPT Correlation Results for Peak Effective Friction Angles of Various Silt Compositions in Downtown, Portland

Table 4-2: Tabulated PrS SPT Analysis from Figure 4-6 and ASTM E-122 Results

Wolff (1989) with Liao and Whitman (1986)

Soil Description	Effective Friction Angle Range (deg)	# of Values from Sample	# of Values Required for 10% Error	# of Values Required for 5% Error
Clayey Silt	27-36	27	18 ✓	72
Silt w/ Trace Clay	26-38	12	30	121
Silt	28-32	18	5 ✓	19
Silt w/ Trace Sand	28-31	24	2 ✓	7 ✓
Sandy Silt	29-34	64	5 ✓	20 ✓
Silt w/ Clay and Sand	28-32	34	4 ✓	18 ✓
Silt w/ Gravel	29-34	5	8	32
Silt w/ Organics	29-30	4	1 ✓	1 ✓

Wolff (1989) with Peck et al. (1974)

Soil Description	Effective Friction Angle Range (deg)	# of Values from Sample	# of Values Required for 10% Error	# of Values Required for 5% Error
Clayey Silt	28-34	27	8 ✓	32
Silt w/ Trace Clay	28-33	12	7 ✓	27
Silt	28-32	18	3 ✓	14 ✓
Silt w/ Trace Sand	28-30	24	2 ✓	6 ✓
Sandy Silt	29-33	64	4 ✓	17 ✓
Silt w/ Clay and Sand	28-32	34	4 ✓	14 ✓
Silt w/ Gravel	29-33	5	5 ✓	18
Silt w/ Organics	28-29	4	1 ✓	1 ✓

Kulhawy and Mayne (1990)

Soil Description	Effective Friction Angle Range (deg)	# of Values from Sample	# of Values Required for 10% Error	# of Values Required for 5% Error
Clayey Silt	27-42	27	42	169
Silt w/ Trace Clay	25-40	12	52	207
Silt	28-38	18	23	92
Silt w/ Trace Sand	25-35	24	22 ✓	89
Sandy Silt	30-41	64	24 ✓	95
Silt w/ Clay and Sand	26-38	34	32 ✓	129
Silt w/ Gravel	28-42	5	34	135
Silt w/ Organics	26-30	4	5	18

4.3.5 *Notes on Additional Laboratory and In-Situ Testing in PrS Documents*

Additional lab and in-situ testing was present in the PrS database, but the sample size from the Downtown area was not large enough to perform a chronological or statistical analysis on test results other than SPT blow counts. Suggestions for possible future work for analysis of this content is located in later sections of this report. The 80 PrS Downtown geotechnical reports contained a range of different types of lab and in-situ testing, but triaxial and ring shear testing were not present. Direct shear testing was present, but the number of samples tested for direct shear was not large enough to sufficiently and statistically support SPT-correlated effective friction angles found in this project. Friction angle values from direct shear testing were rarely provided in reports.

4.4 Examination of Public Sector (PbS) Database GIS Layer

As discussed in previous sections of this report, the GIS layer from the PbS database contains borehole locations from approximately 1,000 boring log documents in the Portland area. By utilizing the Identify tool in recent versions of ArcGIS or QGIS, the user can click on a borehole of interest and the tool displays a borehole ID, depth to groundwater table, and maximum depth of boring if available. The folder of PDFs named by ranges of borehole IDs can easily be used to link a borehole in the GIS layer to a boring log document. Figure 4-7 shows the PbS database GIS layer and a city quarter section layer. Concentrations of boreholes can be observed primarily along the Willamette River, which is partially due to the number of bridge structures connecting the west side to the east side of the city.

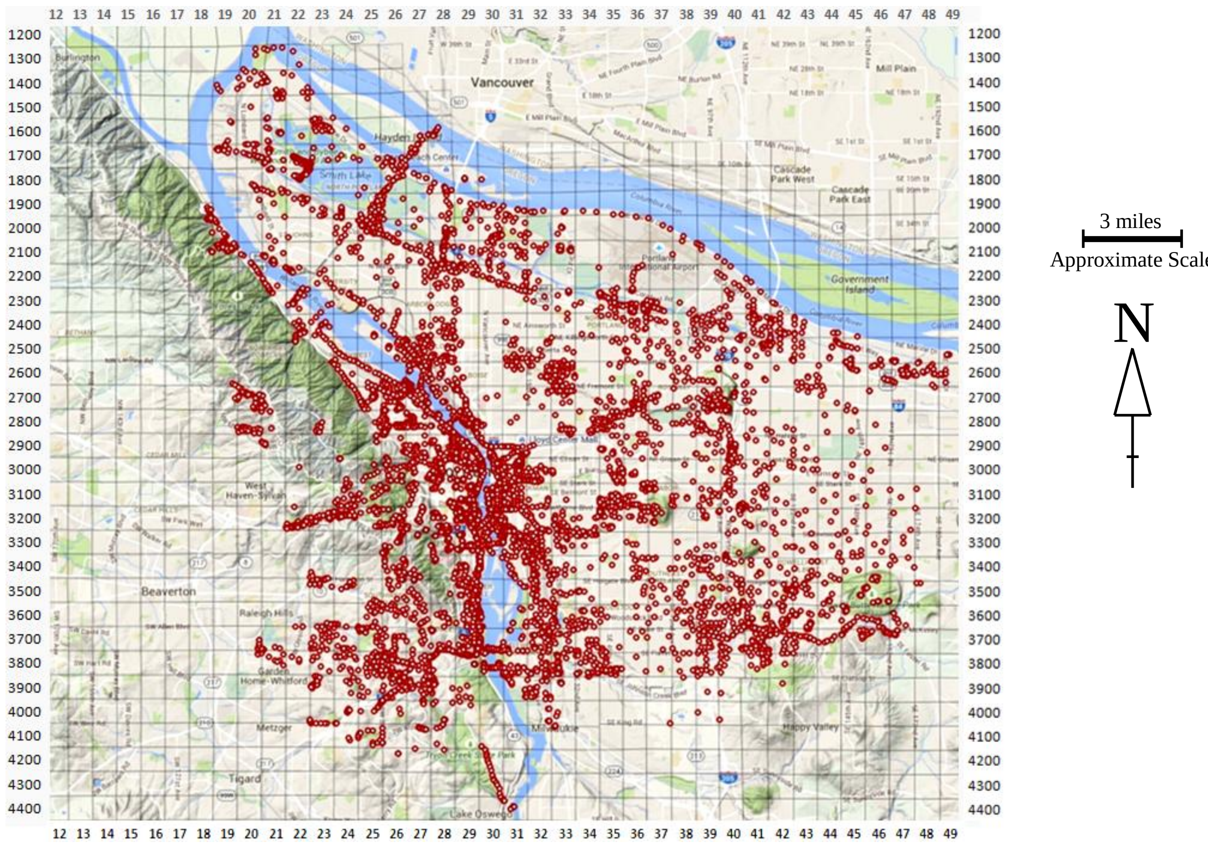

Figure 4-7: PbS Borehole and City Quarter Section GIS Layers

4.4.1 *Comparison of PrS and PbS Database Clusters*

The overlap of the PrS database and the PbS database was of interest for this project due to the fact that so few full geotechnical reports were available for analysis in the Downtown area from the PbS database. An overlap of clusters would provide evidence that analysis of the PbS database SPT blow counts may reveal similar results to those from the PrS database.

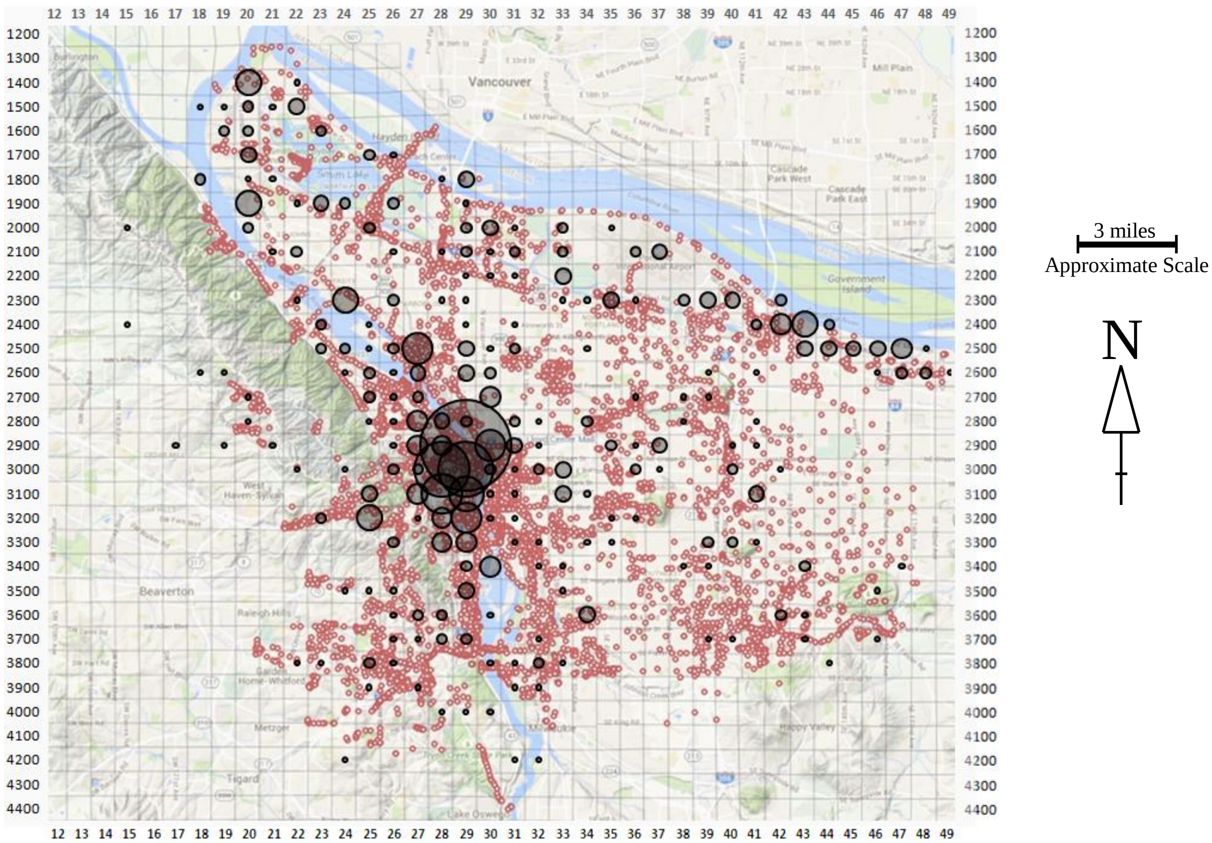

Figure 4-8: Comparison of PbS Borehole Locations to PrS Sample Project Locations

4.4.2 *Three-Dimensional Comparison of PrS and PbS Database Clusters*

With the PrS database reports per quarter section represented as bubbles in Figure 4-8, it was difficult to see the true concentration of clusters and the relative magnitudes of reports in each quarter section. Figure 4-9 shows the amount of reports in each quarter section as a percentage of the 446 full geotechnical reports (significant documents) from the statistically significant random sample. The floor of the graph in Figure 4-9 displays a two-dimensional image of the PbS GIS layer. Manipulation and rotation of this graph was made possible by methods and tools in Excel. Figure 4-9 helped to further visualize the comparison between the

PrS and PbS databases and reveal that clusters are not as prevalent as were previously suspected. Report concentrations from the PrS database exist more often along river banks and scattered throughout residential and industrial areas depending on urban planning, with the exception of the Downtown area. The Downtown area appeared to be the largest and most appropriate cluster to choose for analysis in this project. Figure 4-10 shows the magnitude of reports in each of the 11 quarter sections chosen from the Downtown area for analysis.

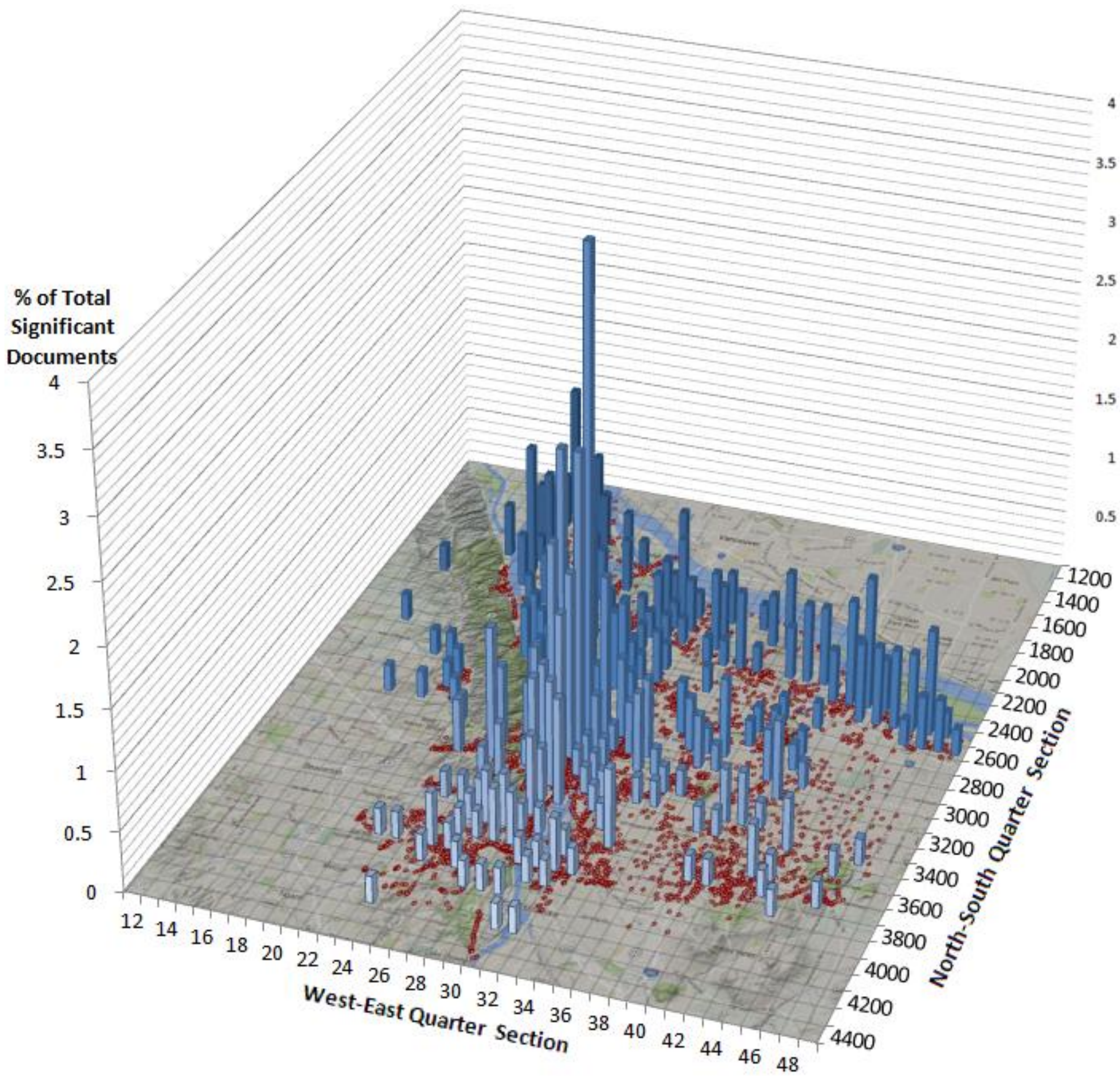

Figure 4-9: Three-Dimensional Representation of PrS Report Sample with PbS Graph Floor

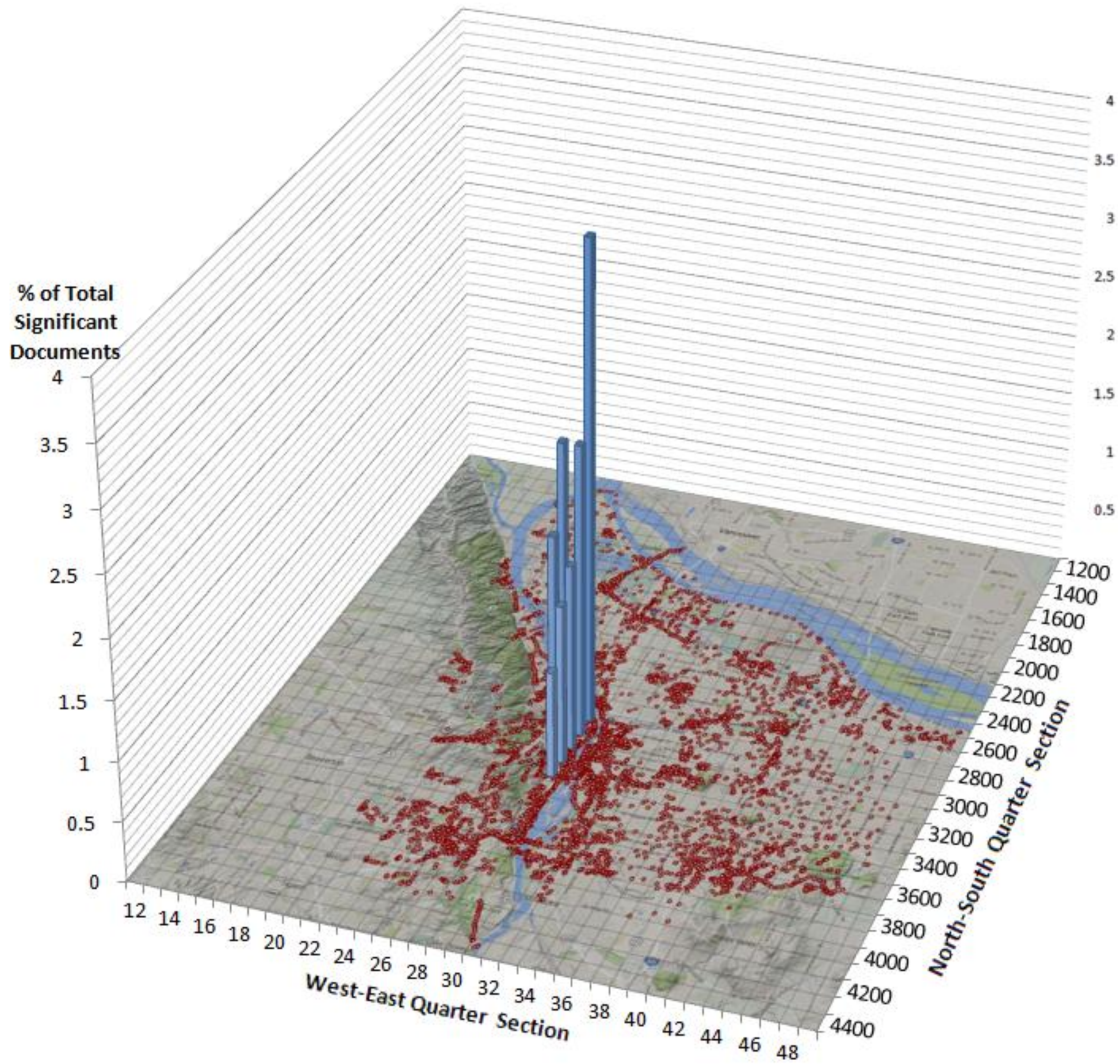

Figure 4-10: Three-Dimensional Representation of PrS Downtown Report Sample with PbS Graph Floor

5.0 DISCUSSION OF QUANTITATIVE AND QUALITATIVE FINDINGS

5.1 Discussion of Project Type and Report Content Trends

Figure 4-5 contains the percent of the statistically significant random sample of 446 full geotechnical reports in each year for specific categories of report content. A larger COV indicates a larger variation in the number of reports containing a specific report content category over the years. The highest COV was associated with seismic analyses. With the Pacific Northwest's growing concern and preparation in codes for a large subduction zone seismic event, the sudden increase of seismic analyses past 1990 makes sense. This trend might not be as prevalent in the PrS database in other areas of Portland, since less sizeable buildings generally exist outside the Downtown area. However, with the PbS database likely containing far more bridge structure, pipeline, and retaining structure projects, this trend might be more evident through PbS database analyses. Contractor as client, slope stability, and load testing categories did not show significant trends in Figures 4-4 and 4-5 due to the sample size being too small. A larger sample size combined from both the PrS and PbS databases may show more significant trends in these report content categories.

5.2 Discussion of SPT Correlations to Silt Peak Effective Friction Angles

Figure 4-6 contains the effective friction angle calculations expressed graphically from the three separate approaches in Equations 1 through 4. Solid lines indicate the trend in mean values between different compositions of silt. Dotted lines indicate the addition or subtraction of one standard deviation from the mean. The likely ranges of effective friction angle for each silt composition was represented as ranging from the mean minus one standard deviation to the mean plus one standard deviation. The larger the difference between the upper and lower end of each range in effective friction angle, the larger the spread in data. Data variations from Figure 4-6 have some limitations that should be noted by future users. The amount of effective friction angle values from each silt composition had an effect on the range. Intuitively, the range with the highest number of values and least spread would be the most accurately correlated silt composition for a specific correlation approach. Any range with a low number of values may not be representing a true spread in Portland silt properties, since the addition of more values to the data set may show a higher standard deviation for that silt composition. An example of this is for silt with organics, which only included four data points for each correlation approach, but had a low standard deviation.

The least spread in data for all correlations was for silt with trace sand. As described above, it is not valid in all cases to compare spread in data between data sets if each set contains a significantly different number of values. However, the clayey silt category contained 27 values, and the silt with trace sand category contained 24 values. The comparison between these two sets of data is not suspected to show large changes if the trace sand data set was increased to 27 values. Figure 4-6 graphically shows that silt with trace sand has a smaller standard deviation than clayey silt, which supports the concept previously discussed for samplers being driven into cohesive material. An additional reason for a larger spread in clayey silt than silt with trace sand is that correlations in Equations 1 through 4 were originally derived from data sets of testing on granular material. Correlation equations have limitations depending on material type and behavior. These limitations often originate from the type of material in the databases from which the correlations were derived. There are currently no correlations between SPT blow counts and effective friction angle for Willamette Valley silt deposits, so a comparison between correlation approaches was valuable for this project. The Kulhawy and Mayne correlation showed the largest standard deviations for all silt compositions, which was evidence that the Kulhawy and Mayne correlation might not be as appropriate for Willamette Valley silts as the Wolff correlation with Peck et al. effective overburden pressure correction. If the effective friction angle of non-fill Willamette Valley silt at ground surface in the Downtown area is of interest (for effective overburden pressures below 25 kPa), the Wolff correlation with Liao and Whitman effective overburden pressure correction may be more appropriate.

Table 4-2 shows the ranges in effective friction angle illustrated in Figure 4-6 and the number of values correlated for each silt composition and correlation approach. ASTM E-122(5) provides a calculation for the amount of values required in a data set to obtain an allowable error percentage, given a mean and standard deviation. Allowable error percentages of 5% and 10% were used to calculate the number of values needed to reach these error percentages for each silt composition, which is also shown in Table 4-2. Check marks were assigned to each error percentage met by the number of values for each silt composition. As graphically illustrated in Figure 4-6, the check marks in Table 4-2 indicate that the Wolff correlation with Peck et al. effective overburden pressure correction provided the best fit to the Willamette Valley silt deposits in the Downtown area. Although the number of values for silt with organics met allowable error in multiple correlation approaches, the data set was not large enough to consider the standard deviations to be representative of Willamette Valley silt with organics.

6.0 CONCLUSIONS, RECOMMENDATIONS, AND FUTURE DATABASE WORK

The geotechnical Portland BES databases are powerful and vast sources of information on the history of Portland geotechnical site investigation. The findings presented in this project report only scratch the surface of what can be explored by future students and practitioners. These findings focused on the occurrence of various project types and report contents from geotechnical reports in the Portland area, and effective (drained) Willamette Valley silt properties from widely available SPT results. The PrS database analyses of geotechnical report contents revealed the growing existence of seismic analyses past the year 1990. The PrS database analyses of project types in Downtown, Portland confirmed the dominance of geotechnical investigations for multiple-storey structures, and that investigations for bridge structures, pipelines, and major retaining structures were more likely to reside in the PbS database. The results of SPT data analyses from 80 full PrS geotechnical reports in the Downtown area showed that variation in data was dependent on silt composition and correlation approach.

The comprehensive and conservative correlation of extensive Downtown SPT data to Willamette Valley silt peak effective friction angles can be utilized in preliminary design or verification by practitioners with Table 4-2. It is not recommended by the author of this report that the results for silt with organics be utilized in design. This is due to the small sample size and inability for ASTM E-122 to detect the subjective need for additional data when potential changes in standard deviation are incalculable. For any sizeable geotechnical investigation, adequate field and/or lab testing of material on site should be conducted to determine design parameters unique to that site. The results presented in this project report should not be used as a sole source of information for finalized design work and analyses, specifically for those of or relating to slope stability (peak friction angles often dangerously overestimate factors of safety in slope stability analyses). Although ranges in peak effective friction angle for various silt compositions are not likely to deviate much from those presented here for the Downtown area, values in Table 4-2 should only be referenced for work in the Downtown area. Additionally, values from Table 4-2 are not applicable to silt or silty fill material.

Future possibilities for examination of the PrS and PbS databases are nearly endless. Undrained strength properties of silt are highly influenced by moisture content and density, so an investigation into the dependency of Willamette Valley silt unconfined compression strength on moisture content could be conducted for both databases. The comparison of drained and undrained properties between different sections of the Portland area could confirm that the values in Table 4-2 may be applicable to silt deposits outside Downtown. Elastic properties from lab and in-situ testing could be examined from both databases to aid in preliminary settlement calculations for site preloading. The chronological trends in site investigation quality could be expanded to include a higher number of reports for analysis, since the sample size in this project was not large enough to provide more conclusions than addressed in this section. The approximate stratification of silt deposits could be captured through additional boring log analyses. Since the majority of the spreadsheet used for boring log and geotechnical report analyses was designed to be easily updated by future users, a voiceover instructional PowerPoint presentation could be constructed on how to navigate through the spreadsheet and update cells with macros such as those shown in the Appendix of this project report. Other approaches between SPT and effective friction angle could be used to find better correlations for Willamette Valley silt. Future database explorations are not limited to those mentioned in this section, and the benefits to educators and practitioners are only in the beginning stages of growth with what has been accomplished in this project.

7.0 REFERENCES

1. Budhu, M. *Soil Mechanics and Foundations, 3rd Edition.* John Wiley & Sons, Hoboken, NJ, 2011.

2. Burns, Scott F. “Landslides in the Portland Area Resulting from the Storm of February, 1996.” Portland State University, 1998.

3. Das, Braja M. *Fundamentals of Geotechnical Engineering, 4th Edition.* Cengage Learning, Stamford, CT. 2013.

4. E. Koss, Portland BES Employee, Personal Communication, July 01, 2014.

5. Handy, R. L. and Spangler, M. G. *Geotechnical Engineering, Soil and Foundations Principles and Practice, 5th Edition.* McGraw-Hill, New York, NY, 2007

6. Kovacs, W. D. (1994). "Effects of SPT equipment and procedures on the design of shallow foundations on sand." Vertical and Horizontal Deformations of Foundations and Embankments, ASCE GSP 40, 121-131.

7. Patterson, Bruce. “The Great Missoula Floods.” < http://theava.com/archives/27649>, 2014.

8. Rausch, F. and Klesney, A. “Hammer Types, Efficiencies, and Models in GRLWEAP.” GRL Engineers, Inc., Cleveland, Ohio, United States, 2007.

APPENDIX – EXCEL MACRO EXAMPLES

```
Sub CountMS()

   Dim FolderPath As String, path As String, count As Integer
   FolderPath = "G:\PDX Database\Organized Private Reports\Organized by Report Content\(MS)
Multiple Story Structures"

   path = FolderPath & "\*.pdf"

   FileName = Dir(path)

   Do While FileName <> ""
      count = count + 1
       FileName = Dir()
   Loop

   Range("B7").Value = count
   'MsgBox count & " : files found in folder"
End Sub
```

Figure A-1: Example of Excel Macro for Counting the Number of PDF Files in a Directory

```
Sub ContentSum()
   Call CountBS
   Call CountCC
   Call CountIT
   Call CountLT
   Call CountMS
   Call CountPL
   Call CountRS
   Call CountSA
   Call CountSS
End Sub
```

Figure A-2: Example of Excel Macro for Running Multiple Written Macros

```
Function GetFileList(FileSpec As String) As Variant
'   Returns an array of filenames that match FileSpec
'   If no matching files are found, it returns False

    Dim FileArray() As Variant
    Dim FileCount As Integer
    Dim FileName As String

    On Error GoTo NoFilesFound

    FileCount = 0
    FileName = Dir(FileSpec)
    If FileName = "" Then GoTo NoFilesFound

'   Loop until no more matching files are found
    Do While FileName <> ""
        FileCount = FileCount + 1
        ReDim Preserve FileArray(1 To FileCount)
        FileArray(FileCount) = FileName
        FileName = Dir()
    Loop
    GetFileList = FileArray
    Exit Function

'   Error handler
NoFilesFound:
    GetFileList = False
End Function

Sub ShowFilesMS()
    Dim p As String, x As Variant

    p = "H:\PDX Private Database\Organized Private Reports\Organized by Report Content\(MS) Multiple
Story Structures\*.pdf"
    x = GetFileList(p)
    Select Case IsArray(x)
        Case True 'files found
            MsgBox UBound(x)
            Sheets("Content").Range("A2:A500").Clear
            For i = LBound(x) To UBound(x)
                Sheets("Content").Cells(i + 1, 1).Value = x(i)
            Next i
        Case False 'no files found
            MsgBox "No matching files"
    End Select
End Sub
```

Figure A-3: Example of Excel Macro for Displaying a List of File Names in a Directory