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TREE ROOT INFLUENCE ON BUILDING FOUNDATIONS IN EXPANSIVE CLAY SOILS IN NORTH TEXAS

by

ROCIO VEGAMARTINEZ

Presented to the Faculty of the Honors College of

The University of Texas at Arlington in Partial Fulfillment

of the Requirements

for the Degree of

HONORS BACHELOR OF SCIENCE IN ARCHITECTURAL ENGINEERING

THE UNIVERSITY OF TEXAS AT ARLINGTON

May 2023

ACKNOWLEDGMENTS

I would like to thank my mentor Dr. Hossain for being such an inspirational instructor and piquing my interest in geotechnical engineering. It is with his encouragement and support that I will be pursuing graduate school for a PhD.

Thank you to the research graduate students of the Solid Waste Institute for Sustainability for taking the time to help me with my project. I truly appreciate Zobair Ahmed for his help with the resistivity and analyzing the results.

A special acknowledgment to the University of Texas at Arlington McNair Scholars program for allowing me the opportunity to explore academia. Thank you to the UTA Library services and Writing Center for assisting in my preparation as a scholar.

Furthermore, I would like to thank all my friends for their support. Thank you to my friend Joanna Aguilar for providing the case study house. Their encouragement throughout the Summer has made this project possible.

I would finally like to thank my family members for all their support in all my endeavors. Their support over the Summer during this project and my academic career have led to all my achievements.

November 18, 2022

ABSTRACT

TREE ROOT INFLUENCE ON BUILDING FOUNDATIONS IN EXPANSIVE CLAY SOILS IN NORTH TEXAS

Rocio VegaMartinez, B.S. Architectural Engineering

The University of Texas at Arlington, 2023

Faculty Mentor: Sahadat Hossain

Coupled with the expansive soil profile and climatic nature of Texas, trees repeatedly damage pavements and building foundations. The drying of tree roots places residential foundations at risk for soil desiccation and displacement. This research seeks to grasp a better understanding of the relationship between Texas expansive soils, tree root growth, and residential foundations in the North Texas area. This paper presents a case study of a residential house in Arlington, Texas, experiencing foundation cracking and settlement with two large trees on the property. Electrical Resistivity Imaging was done to monitor the relationship between the soil and the tree roots. Two imaging sessions in May and August were conducted, and the preliminary results indicate root volume is gravitating

toward the slab during periods of drought due to moisture changes in the soil. The study revealed that the damage currently experienced can be attributed to the tree roots drying.

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CHAPTER 1

INTRODUCTION

The influence of trees on foundations in clay soils has presented a major concern requiring an engineering solution. The expansive soils most commonly found in Texas are sensitive to moisture changes and the moisture demands of vegetation near foundations can lead to significant settlement. There is limited information documented on tree influence on residential foundation in expansive soils in urban areas.

Foundation failure due to expansive soils cost Texans $2 billion annually in repairs (HD Foundations, Inc., 2019). Expansive soils, as given by their name, contract and expand or shrink and swell due to variation in water content. Moreover, Texas endures alternating periods of rainfall and drought creating the perfect environment for foundation failure in expansive soils. Couple this with water-seeking root growth caused by large trees constantly affecting the moisture of the soil, and residential and light-weight commercial building foundations are further at risk.

In the Dallas-Fort Worth Metropolitan area, there is a growing concern among homeowners about the state of their foundations. The beautiful trees and vegetation surrounding homes are extracting water, causing localized settlement and structural damage. To better understand the impact of trees on residential foundations in the Arlington area, this report presents a case study of a residential house damaged by expansive soil movement due to tree root growth.

CHAPTER 2

LITERATURE REVIEW

2.1 Brief Introduction

Structures constructed on expansive clay soils present a significant engineering problem. Damages and structural failures of buildings, pavements, and highways can be attributed to the shrinkage and swelling characteristics of expansive soils. Moisture fluctuations due to climatic regions lead to soil volume changes that weaken the subgrade, induce cracking, and damage the overlying structure (Nelson and Miller, 1992).

Texas experiences cyclic periods of rainfall and drought, which contribute to moisture fluctuations throughout the year, resulting in expansive/shrinkage movements during prolonged dry periods that follow months of wet weather. Significant changes in moisture levels typically occur from poor drainage or from substantial vegetation, causing heave and shrinkage, respectively.

Many Texas homeowners like their home gardens with shrubs, trees, and other large vegetation, improving property value and providing shade and aesthetics. Street trees are provided by local government authorities to improve the landscape, enhance the environment, and increase land values. The influence of trees near foundations in clay is a major concern because moisture demand on the clay can result in significant settlement. Traditionally, residential foundations here in Texas are slab-on-grade, which have elevated moisture conditions below. Neighboring trees migrate toward these conditions for sustenance during extended dry periods.

2.2 Texas Expansive Clay Soil

Damage to buildings and pavements due to expansive soils is more common than damages from natural disasters. But what is expansive soil in Texas? Expansive soil is a term used for soils that exhibit moderate to high plasticity, low to moderate strength, and high swell and shrinkage characteristics (Holtz & Gibbs, 1956). Soils here in DFW primarily comprise of montmorillonite and illite minerals that contribute to low strength and high swell/shrinkage. These minerals are found throughout the state, where the majority of damage from expansive clays occurs in the areas highlighted in Figure 2.1 (HD Foundations, Inc., 2019; Wise et al., 1971). Thick layers of montmorillonite and illite clay soils are nearly always present when swelling of the foundation is extensive enough to cause damage to building structures (Wise et al., 1971).

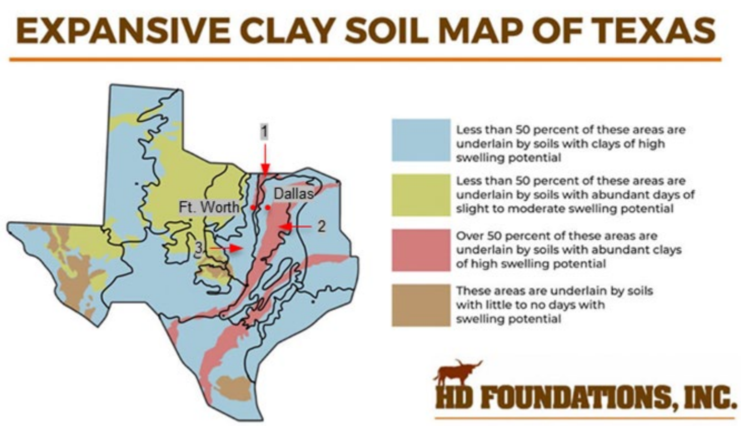

Figure 2.1: Soil Map of Texas. Note: HD Foundations. (2019, March 15). *Expansive Clay Soil Map of Texas*. [Map]. HDFoundationRepair.com. https://hdfoundationrepair.com/how-to-stabilize-expansive-clay-soil-in-texas/

Soils with higher plasticity, like those composed of montmorillonite minerals, are prone to severe movements and interactions, meaning expansive clay soils in unsaturated states are the most susceptible to soil drying and subsidence due to moisture changes

(Biddle, 2001; Bryant et al., 2001). Low strength and volumetric movements deteriorate the subgrade and, in due course, influence pavement weakness by developing cracks caused by differential heave settlements, seen in Figure 2.2.

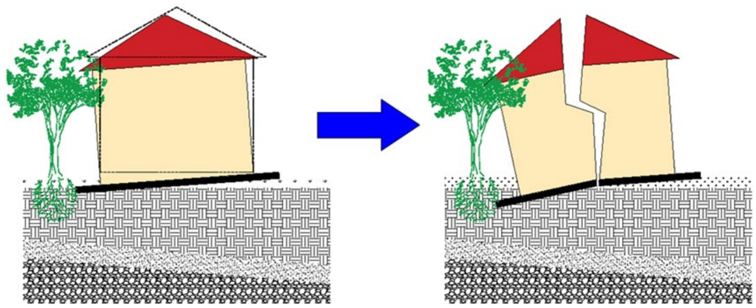

Figure 2.2: Differential Settlement and Cracking. Note: VegaMartinez, R. (n.d.). [Diagram of the process of differential settlement and cracking].

Cyclic heave and shrinkage commonly affect the perimeter of the foundation, causing uplift or shrinking at the edge of the structure (the constant cycles of up and down movement) leading to cracking and damage to the foundation. The amount of cyclic heave and shrinkage depends on the change in moisture content of the clays below the structure's perimeter. The moisture change, in turn, depends on the severity of the drought and rainy seasons, the influence of drainage and irrigation, and the presence of live tree roots, which can extract moisture and cause clays to shrink.

2.3 Texas Climate

Texas endures cyclic droughts and precipitation that affects water level availability for landscape and soil. The geographical location of Texas guarantees a constant change from temperate to extreme weather. The National Climatic Data Center classifies Texas into 10 climate regions as precipitation and temperature vary across the state. The Dallas-Fort Worth metroplex is region 3: sub-tropical subhumid mixed savanna and woodlands. In the DFW area, the driest months are during summer in July and August, with an average rainfall of 2.08 and 2.18 inches and an average high of 95.6 °F and 95.8 °F, respectively. There are two rainy seasons throughout Texas in the spring and fall, with the most precipitation occurring in May and October for the DFW area at 4.78 and 4.37 inches, respectively. The coldest months are during winter in January and December, with an average low of 36.1 °F and 38.3 °F, respectively (National Weather Service et al., 2020). Considering the temperature throughout the seasons and varying precipitation levels, soil shrinkage and swelling are likely to occur around the aforementioned months, affecting residential foundations.

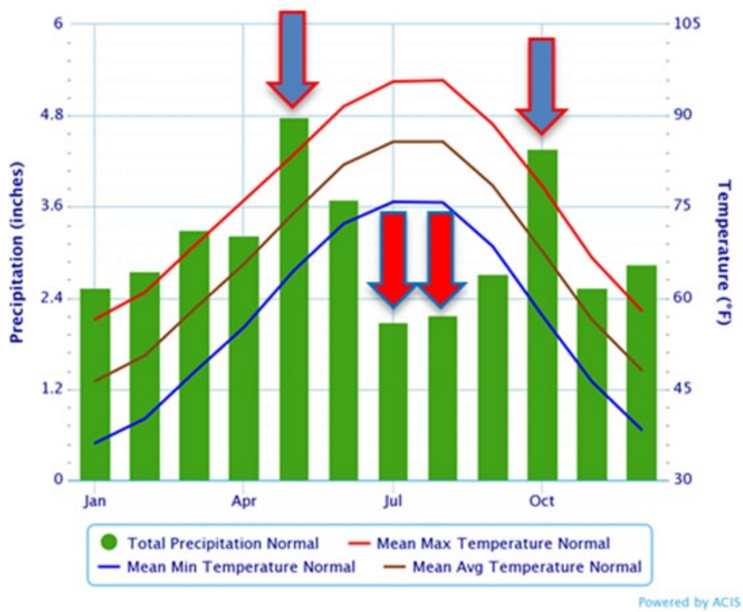

Figure 2.3: Dallas-Fort Worth Normals. Note: National Weather Service, Regional Climate Centers, National Centers for Environmental Information, & Applied Climate Information System. (2020*). Monthly Climate Normals (1991–2020) - Dallas-Fort Worth Area, TX* [Dataset]. National Weather Service.

2.4 Trees

Vegetation in the modern landscape is always welcome. Bountiful gardens filled with various plants, trees, and shrubs provide great benefits to the home and its occupants.

Vegetation surrounding properties improve real estate value, provide shade, are energy efficient, boost overall health, and are aesthetically pleasing. Furthermore, trees supplied by local government ordinances improve community landscape, enhance the surrounding environment, and increase land values. However, trees can also cause problems to the surrounding architecture.

2.4.1 The Root System

Tree root systems are complex structures. Tree roots are responsible for providing nourishment to the whole tree structure through mineral and water uptake and energy storage, as well as providing support and stability by anchoring itself to the ground. The first thing to understand is root growth. The most common analogy for a tree system is a wine glass as seen in Figure 2.4. The cup representing the crown, leaves and branches, the stem as the trunk, and the base as the root system (Biddle, 2001). This helps to understand that only a small portion of the root system extends to further depths. The root system can be broadly classified into two groups, woody roots and fine roots.

Woody roots are more rigid and play the structural role of supporting and anchoring the tree. They are typically located in the rapid taper zone within six feet of the stem (Wilson, 1964). Past the rapid taper zone is a framework of structural woody roots that collect water and nutrients from long distances to the trunk (Alani & Lantini, 2019).

Fine roots, as their name suggests, are small with a diameter less than eight inches and are responsible for the water and nutrient uptake (Alani & Lantini, 2019). The lifespan of fine roots can range from days to week, as they depend on the ever-changing soil conditions and climate. During the dry seasons, the tree's fine roots search for moisture and gravitate toward building foundations with higher moisture content. This change in moisture leads to the removal of interstitial water and a decrease in soil volume. This removal occurs only where the roots are "generating differential subsidence" of the foundation (Satriani et al., 2010).

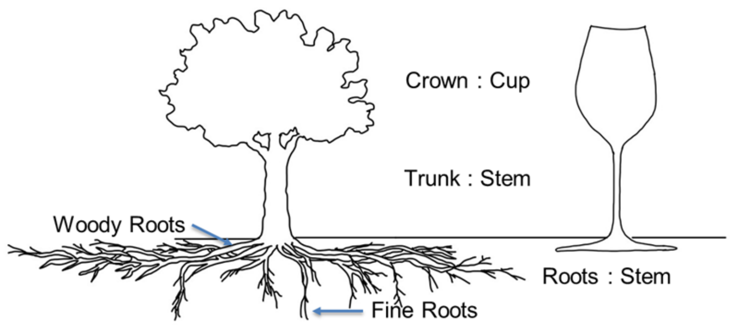

Figure 2.4: Tree Root System and Wine Glass Analogy.
Note: VegaMartinez, R. (n.d.). [Sketch of root and glass analogy].

2.4.2 Transpiration

It is understood that trees need water to undergo photosynthesis, which is how plants produce energy. Over 99% of water is lost during this process. This water loss is known as transpiration. Water loss begins at the leaves, which have a surface area six times greater than the ground surface they cover. Water loss at the leaf establishes a cycle of suction within the vessel cells. These cells extend to the roots through the branches and trunk to the fine veins of the leaf, allowing water to flow throughout the tree system (Biddle, 2001). Transpiration occurs through the stomata of leaves, where the stomata releases oxygen, water vapor, and other gases into the atmosphere. More specifically, transpiration is the rate of water loss and can determine how quickly vegetation cycles through moisture, though it depends on climatic and environmental conditions.

2.5 Destructive and Non-Destructive Testing Methods

Usually, tree root systems affecting foundations are identified through destructive excavation. This type of investigation is time-consuming and expensive and does little to find preventive solutions for the structure (Alani & Lantini, 2019). It also puts the structure at risk. Thus, there is an increasing interest in using non-invasive and non-destructive techniques that assess the development of the tree root systems in the soil and around building and monument foundations. The advancing technology has led to high-resolution imaging and geophysical techniques that offer spatial accuracy and clarity while minimizing impacts.

2.5.1 Destructive Testing Methods

The three most common methods are: Ingrowth Coring, Auger Method, and the Monolithic Method.

Ingrowth Coring is done by replacing site soil with root-free soil encased in a mesh bag. This sample is then reexamined after a determined period. The results from this method illustrate the root-growth rate and quantify root production within a particular soil (Alani & Lantini, 2019). However, the sampling technique—removal of soil and introducing mesh—disturbs the soil structure, altering root production and growth rate. Furthermore, the ingrowth coring may cause damage to the existing root structure leading to unnatural regrowth.

The Auger Method involves taking soil samples from the site using a drilling auger and then washing the sample to separate the roots from the soil. The results from this method estimate the root density of the soil but require an increased number of samples to grant reliable results (Böhm, 2012). This continued drilling and sampling damage the root system and is overall time-consuming. There is also the possibility that the type of soil, like stone or dry clay, cannot be sampled by drilling.

The Monolithic Method is similar to the Auger Method. Samples are taken and washed to separate the soil and roots without displacing the roots from their original positions. This is achieved by driving in pinboards (boards covered with spikes) to hold the roots in place while the soil is washed. The results of this technique estimate the root volume and delineate the architectural system of the roots. But this type of sampling requires great skill, has limiting sample size constraints, and cannot be repeated (Böhm, 2012). Furthermore, the washing process can lead to significant loss of fine roots, affecting root density results.

2.5.2 Non-Destructive Testing Methods

The development and improvement of technology and imaging techniques has allowed the investigation of materials to be more effective, non-destructive, and repeatable for long term study and monitoring. The main methods used for non-destructive testing are: Rhizotrons and Minirhizotrons, Acoustic Detection, Ground Penetrating Radar, and Electrical Resistivity Tomography.

Rhizotrons and Minirhizotrons involve using transparent panels to observe the root system while still in the soil. Rhizotrons are underground walkways with windows viewing the natural soil profile surrounding the passageway. This method allows for successive measurements on individual roots or the entire visible system and quick estimation of root growth. Sensors and cameras may be installed to measure temperature, oxygen or carbon dioxide concentration, water content, or pH of the soil and capture root development over time (Taylor et al., 1990). However, rhizotrons are costly and ineffective at capturing the relationship between soil and vegetation in an urban or populated setting. Rhizotrons are best used when constructed and vegetation planted over the walkway. A minirhizotron is a clear tube that is installed in soil and used to lower a camera to observe root production. This method determines root length and dimeter, lifespan, and information on branching and root architecture. However, this method has some limitations: difficult installation in certain soil types, static imaging, and limiting observational depth (Taylor et al., 1990).

Acoustic detection measures the velocity of the acoustic sound to identify roots. A transmitter is installed near the base of the trunk and sends short signals to the receiver, which is placed into the ground at a minimum distance of 1 foot. The presence of roots decreases the response time to the receiver, making it possible to identify root volumes. This technique can identify roots with a minimum 1.5-inch diameter and a maximum depth of 20 feet (Alani & Lantini, 2019). This method has limiting identification constraints and cannot detect small or deep roots. It is also sensitive to moisture and can be impaired by high water content or the presence of buried objects.

Ground Penetrating Radar, GPR, is used for shallow subsurface exploration and monitoring (Zenone et al., 2008). GPR operates through an impulse radar system that transmits pulse frequencies through a transducer. When these waves hit a target with a differing electrical potential, refractions are sent and recorded by the receiving antenna. The remaining energy continues to transmit through the transducer (Butnor et al., 2001). The recorded waveforms are stored for imaging through a control unit. GPR can characterize soil profiles, accurately determine root lengths and diameters, and provide mapping of the root system. The most significant shortfall of this method is the inability to distinguish individual roots when clustered. GPR does not directly indicate changes in water content or soil distribution in all directions (Alani & Lantini, 2019).

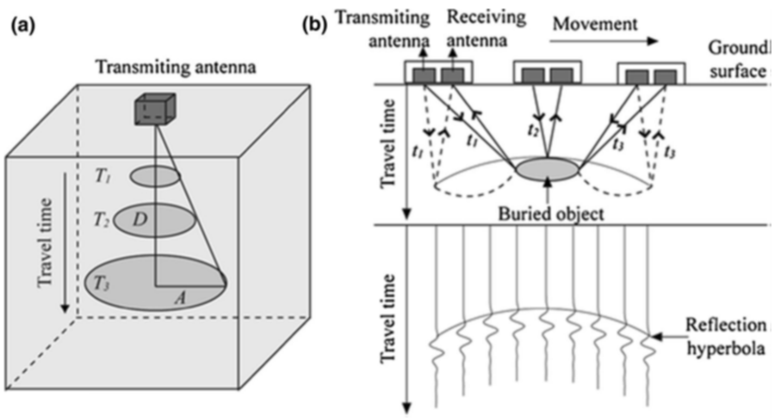

Figure 2.5: Ground Penetrating Radar. Note: Alani, A. M., & Lantini, L. (2019). [Schematic of the Ground Penetrating Radar transmission process].

hyperbola

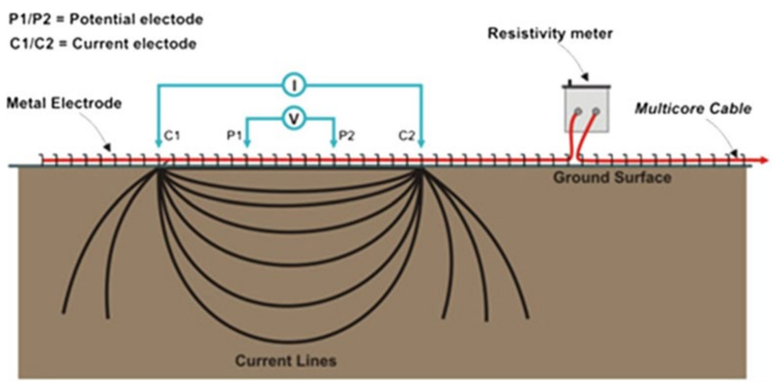

Figure 2.6: Electrical Resistivity Tomography. Note: Alani, A. M., & Lantini, L. (2019). [Schematic of the Electrical Resistivity Tomography process].

Electrical resistivity tomography, ERT, is a geophysical testing method that calculates the subsurface electrical resistivity distribution of the soil (Zenone et al., 2008). Electrical resistivity measures a material's ability to limit electrical current through a uniform body. Soil resistivity is measured by applying electric currents through at least two conductors and calculating the differences in electric potential (Alani & Lantini, 2019).

The depth of investigation is based on ERT layout and spacing. This method is used to characterize soil heterogeneity through the contrast between resistivity. Electrical Resistivity Tomography results describe soil compaction, water content, and water flow within soils and vegetation. Root zones can be identified through differing electrical potential and can be accurately mapped. However, in cases of low root volume, the electrical response can be indistinguishable from background noise and too weak to be detected.

CHAPTER 3

METHODOLOGY

For this research, electrical resistivity tomography will be used to determine the soil distribution and detect temporal changes in moisture and root volumes. Because the electrical resistivity of wood, soil, and water are different, a correlation between the dry and wet soil conditions in relation to root volumes is expected.

Figure 3.1: ERT Components and Set-Up. Note: VegaMartinez, R. (n.d.). [Photo of Electrical Resistivity Tomography equipment and layout].

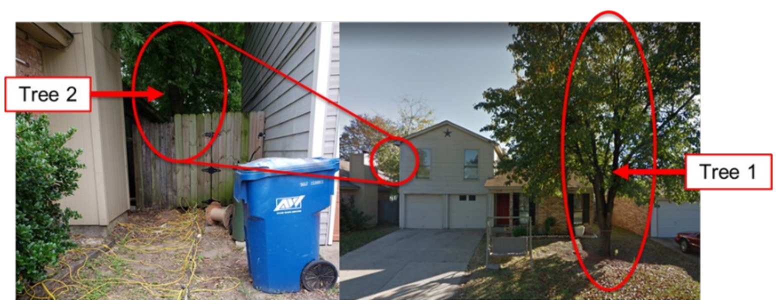

Figure 3.2: Case Study House, Site, Located in Arlington, TX. Note: VegaMartinez, R. (n.d.). [Photo of offending tree location and house].

This case study focuses on the North Texas area. The case study house is located in Arlington, Texas. It is a two-story residential home that is experiencing foundation cracking. This research focuses on two trees, as noted in Figure 3.2. There were two imaging sessions conducted, one in May and another in August. These time periods were chosen based on the Climatic Normals data. The soil would be wetter and have an increased volume in May, while in the dryer summer months, like August, the soil would be dryer and decrease in volume. From these ERT imaging sessions, the results gathered should show a discrepancy in moisture causing the trees to react. Presumably, this comparison in data will exhibit a change in root mass gravitating toward the wetter soil beneath the house foundation, drawing water. Over time this pattern of wet and dry will cause cracking and settlement to occur under the house.

Two 2-D resistivity imaging lines, Line A-A and Line B-B were conducted around the building to capture the two offending trees. The resistivity layout and site plan are shown in Figure 3.3.

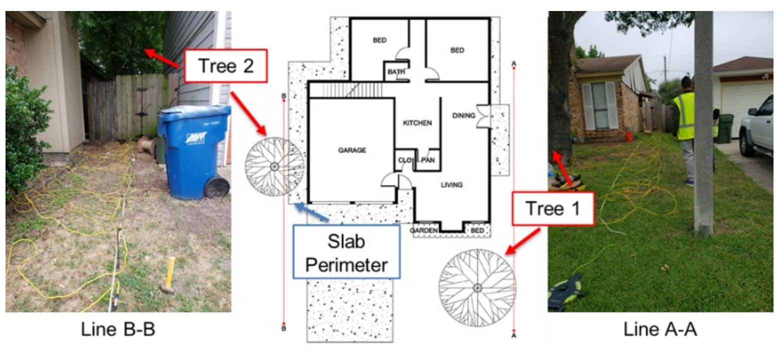

Figure 3.3: ERT Resistivity Layout and Site Plan. Note: VegaMartinez, R. (n.d.). [Photo and sketch of house floor plan and tree location].

CHAPTER 4

RESULTS

The results from Line A-A for the May and August sessions are shown in Figure 4.1 below. A lower resistivity is indicative of moisture. The results from Line A-A however are inconclusive as far as determining the soil and root relationship. It is difficult to determine the interaction between the soil and the tree roots. Overall, a drying in the soil from a wetter to drier month is seen, but it cannot conclusive be said that this discrepancy is a result of extended root growth. This is in due part because of the location of the resistivity line. It is located approximately 8 feet from the end of Tree 1, which is not close enough to get an accurate reading of the interaction. Unfortunately, due to the 5 feet extension of the slab from the structure and later site changes, proximity to Tree 1 was limited.

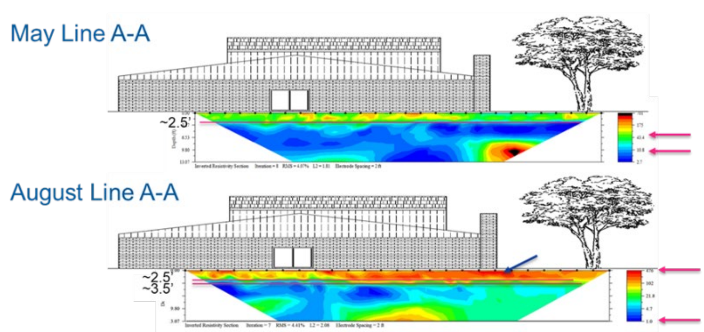

Figure 4.1: Results for Tree 1 Line A-A. Note: VegaMartinez, R. (n.d.). [Data from imagining sessions for Tree 1].

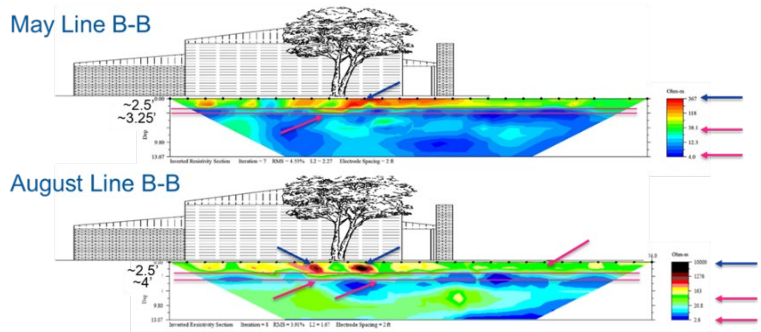

Figure 4.2: Results for Tree 2 Line B-B. Note: VegaMartinez, R. (n.d.). [Data from imagining sessions for Tree 2].

The results from Line B-B for both sessions are shown in Figure 4.2 above. From the May session, the initial soil conditions and relationship to the tree are shown. The blue designates the moist soil at varying saturation levels, where the water table can be implied to be at about 2.5 feet. Above the water table, varying levels of moisture exist at the topsoil. Focusing on the area beneath Tree 2, there is a dip shown in green. Green delineates a drier soil content that declines slightly below the water table. This describes the initial position of Tree 2's roots, already seeking moisture below.

Comparing the results of May to August for Tree 2 Line B-B, there is general drying of the soil. This is to be expected due to the change in temperature and precipitation. Looking at the initial position of the water table at 2.5 feet, there is a change in moisture. The soil is slightly drier as indicated by the lighter blue shade. Looking beneath Tree 2, there are now two indentions located at approximately 4 feet in depth and about 6 feet apart. The position of the tree roots has extended themselves about 3 feet laterally and 9 inches in depth. The black colorization indicates a resistivity of 1000 ohmmeters, which is extremely dry and slightly mirror the dry areas shown in May's session. Furthermore, when compared to the area of the soil undisturbed by tree root interaction, there is slight drying noticed due to climate but overall, the topsoil remains undisturbed.

CHAPTER 5

CONCLUSION

Unfortunately, the results from Tree 1 Line A-A were inconclusive. All that can be definitively stated is that there has been a change in moisture content within the soil profile. Somethings to note about the results, because of the proximity of the line to the tree being farther than ideal, an accurate relationship between the soil and the roots could not be depicted. This is due to the extended slab, to remedy this, I would consider drilling holes into the slab to better capture the tree. And perhaps imaging horizontally across the house rather than vertically. Also, there were changes to the site upon the August visit. The right side of the house had undergone some home improvements with the grassy area replaced with turf and a French irrigation system. This led to a change in the resistivity line by two feet, skewing the results of the imaging.

Figure 5.1: Tree 1 Line A-A Problems. Note: VegaMartinez, R. (n.d.). [Photo of Tree 1 proximity and changes to site].

Tree 2 Line B-B provided clearer results with demonstrative conclusions. The difference in images exhibit a change in root mass gravitating toward the wetter soil beneath the slab. The roots grew laterally 3 feet and 9 inches in depth in search of water during this drought. The extreme resistivity results shown in black in Figure 4.2 are an anomaly and most likely depicts the concrete slab. From the first imaging in May for Line B-B, the same area is dry but indistinguishable from surrounding composition. Now from the August imaging, the area is made clearer.

Overall, there is a change in root volume in line with the change in water content impacting the nearby foundation. More imaging is needed to further develop the relation between the soil, root growth, and foundation. To further understand the interaction between these roots and the site, I'd like to continue imaging throughout the various seasons, with an imaging session in the Fall, around October, in the Winter, around January, and finally another in the Spring, May, for a whole year.

REFERENCES

Alani, A. M., & Lantini, L. (2019). Recent Advances in Tree Root Mapping and Assessment Using Non-destructive Testing Methods: A Focus on Ground Penetrating Radar. *Surveys in Geophysics*, *41*(3), 605–646. https://doi.org/10.1007/s10712-019-09548-6

Alani, A. M., & Lantini, L. (2019). [Schematic of the Electrical Resistivity Tomography process].

Alani, A. M., & Lantini, L. (2019). [Schematic of the Ground Penetrating Radar transmission process].

Biddle, G. (2001). Tree Root Damage to Buildings. *Expansive Clay Soils and Vegetative Influence on Shallow Foundations*. https://doi.org/10.1061/40592(270)1

Böhm, W. (2012). Methods of Studying Root Systems. Springer Publishing.

Bryant, J. T., Morris, D. V., Sweeney, S. P., Gehrig, M. D., & Mathis, J. D. (2001). Tree Root Influence on Soil-Structure Interaction in Expansive Clay Soils. *Expansive Clay Soils and Vegetative Influence on Shallow Foundations*. https://doi.org/10.1061/40592(270)7

Butnor, J. R., Doolittle, J. A., Kress, L., Cohen, S., & Johnsen, K. H. (2001). Use of Ground-Penetrating Radar to Study Tree Roots in the Southeastern United States. Tree Physiology, 21(17), 1269–1278. https://doi.org/10.1093/treephys/21.17.1269

HD Foundations. (2019, August 26). *Expansive Clay Soils in Texas and Foundation Repair*. https://hdfoundationrepair.com/expansive-clay-soil-texas-foundation-repair/#:%7E:text=This%20type%20of%20soil%20is,That%20leads%20to%20foundation%20cracks.

HD Foundations. (2019, March 15). *Expansive Clay Soil Map of Texas*. [Map]. HDFoundationRepair.com. https://hdfoundationrepair.com/how-to-stabilize-expansive-clay-soil-in-texas/

Holtz, W. G., & Gibbs, H. J. (1956). Engineering Properties of Expansive Clays. *Transactions of the American Society of Civil Engineers*, *121*(1), 641–663. https://doi.org/10.1061/taceat.0007325

Li, J., & Guo, L. (2017). Field Investigation and Numerical Analysis of Residential Building Damaged by Expansive Soil Movement Caused by Tree Root Drying. *Journal of Performance of Constructed Facilities*, *31*(1). https://doi.org/10.1061/(asce)cf.1943-5509.0000908

National Weather Service, Regional Climate Centers, National Centers for Environmental Information, & Applied Climate Information System. (2020). *Monthly Climate Normals (1991–2020) - Dallas-Fort Worth Area, TX* [Dataset]. National Weather Service.

Nelson, D. J. & Miller, J. D. (1992). Expansive Soils: Problems and Practice in Foundation and Pavement Engineering*, John Wiley and Sons*.

Satriani, A., Loperte, A., Proto, M., & Bavusi, M. (2010). Building Damage Caused by Tree Roots: Laboratory Experiments of GPR and ERT Surveys. *Advances in Geosciences*, *24*, 133–137. https://doi.org/10.5194/adgeo-24-133-2010

Taylor, H. M., Upchurch, D. R., & McMichael, B. L. (1990). Applications and Limitations of Rhizotrons and Minirhizotrons for Root Studies. Plant and Soil, 129(1), 29–35. https://doi.org/10.1007/bf00011688

Wilson, B. F. (1964). Structure and Growth of Woody Roots of Acer Rubrum L. *Harvard Forest Paper*, *11*.

Wise, J. R., Hudson, W. R., & Center for Highway Research the University of Texas at Austin. (1971, July). *An Examination of Expansive Clay Problems in Texas* (No. 118–5). U. S. Department of Transportation Federal Highway Administration.

Zenone, T., Morelli, G., Teobaldelli, M., Fischanger, F., Matteucci, M., Sordini, M., Armani, A., Ferrè, C., Chiti, T., & Seufert, G. (2008). Preliminary Use of Ground-Penetrating Radar and Electrical Resistivity Tomography to Study Tree Roots in Pine Forests and Poplar Plantations. *Functional Plant Biology*, *35*(10), 1047–1058. https://doi.org/10.1071/fp08062

BIOGRAPHICAL INFORMATION

Rocio VegaMartinez is in her senior year at the University of Texas at Arlington (UTA) pursing an Honors Bachelor of Science in Architectural Engineering with a minor in Sustainable Engineering. She previously attended Richland Community College, where she earned an Associate of Science in Spring 2020. She transferred to UTA in Fall 2020 and began working as a research assistant for Dr. Nur Yazdani of the Civil Engineering Department. Her work with Dr. Yazdani primarily consisted of research in permeable pavements and assisting his graduate students with their projects.

Rocio VegaMartinez is a 2022 McNair Scholar and completed her research with Dr. Sahadat Hossain in Summer 2022. Her research concerning tree root growth and residential foundations was awarded The Friends of the UTA Library Scholarship for McNair Scholars and published in the McNair Scholars Journal.

She currently intends to pursue a Master of Science and Ph.D. in either Structural Engineering or Geotechnical Engineering.