Development of Implementation Guidelines to Assess the Strength of Soil Cement Base in Alabama

by

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Abstract

Soil cement is a mixture of soil, portland cement, and water that forms a strong, durable, frost-resistant pavement base once compacted and cured. Variation among construction practices and concerns of current quality assurance testing of soil cement base have led to research for more reliable strength testing methods. The primary objective of this research is to develop guidelines for the Alabama Department of Transportation to cost-effectively and reliably assess the strength of soil cement base. The secondary objective of this research is to develop software to conduct all calculations necessary to relate the field results from the dynamic cone penetrometer to a comparable unconfined compressive strength of the soil cement. This effort is an incentive for using the dynamic cone penetrometer for on-site testing in place of the current method and is meant to streamline the quality assurance process with a more reliable test method.

Based on the research, the plastic-mold method should be used to produce molded cylinders on-site for quality assurance testing of the soil cement mixture. Should the compressive testing results from the plastic-mold cylinders give indications that the strength is not acceptable for full payment, then the dynamic cone penetrometer must be used to determine the in-place compressive strength of the soil cement base. To help with the last step, the Microsoft Excel program, DCPAL, was developed to assist the Alabama Department of Transportation to implement the above recommendations.

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Chapter 1

Introduction

1.1 Background

Soil cement, when used as a base for roadways, is a mixture of local soils and/or manufactured aggregates, portland cement, and water (Halsted, Luhr and Adaska 2006). This mixture is compacted and allowed to cure to produce an economical, strong, durable, frost resistant paving material (Halsted, Luhr and Adaska 2006). The functionality of this material has been proven throughout the industry as a pavement base for highways, roads, streets, parking areas, airports, industrial facilities, and materials handling and storage areas (Halsted, Luhr and Adaska 2006).

The first documented use of soil cement base was in 1935 in South Carolina to improve a state highway roadbed (Halsted, Luhr and Adaska 2006). Prior to the first use of soil cement for roadway base construction, the use of unbound aggregates was a standard practice to achieve desired results. The major mechanism for achieving durability when using unbound aggregate was the ability for aggregate particles to interlock. If the particles could all interlock, then no movement from traffic loads over time would affect the base’s ability to support the asphalt surface course. Unfortunately, the interlocking mechanism is highly variable and has led to many failures over time. An illustration of this concept can be seen in Figure 0.1.

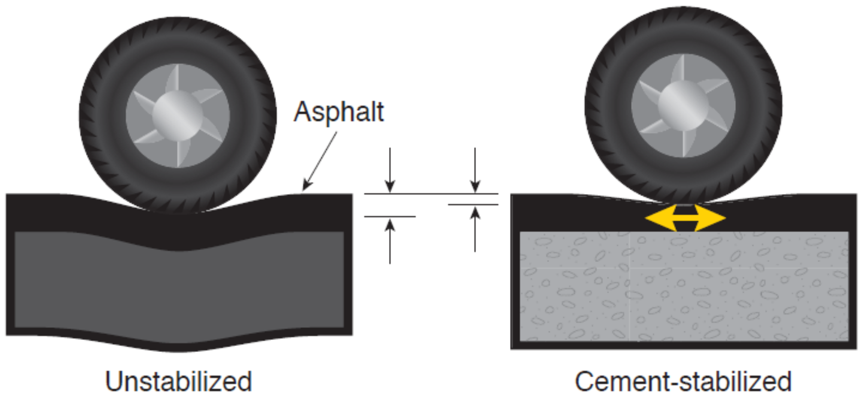

Figure 0.1**:** Unstabilized bases versus cement-stabilized bases (Halsted, Luhr and Adaska 2006)

When portland cement is mixed with the native soils, it creates a tightly bound cement-stabilized base. The formation of this base efficiently disperses loads over large areas of the subgrade while being minimally affected by moisture (Halsted, Luhr and Adaska 2006). The typical unbound granular base is not able to disperse such loads without complete interlocking and tends to distribute the loads directly to the subgrade in a small concentrated area. Higher loads applied to one location on the subgrade will lead to a higher chance of subgrade failure, as can be seen from the illustration in Figure 0.2.

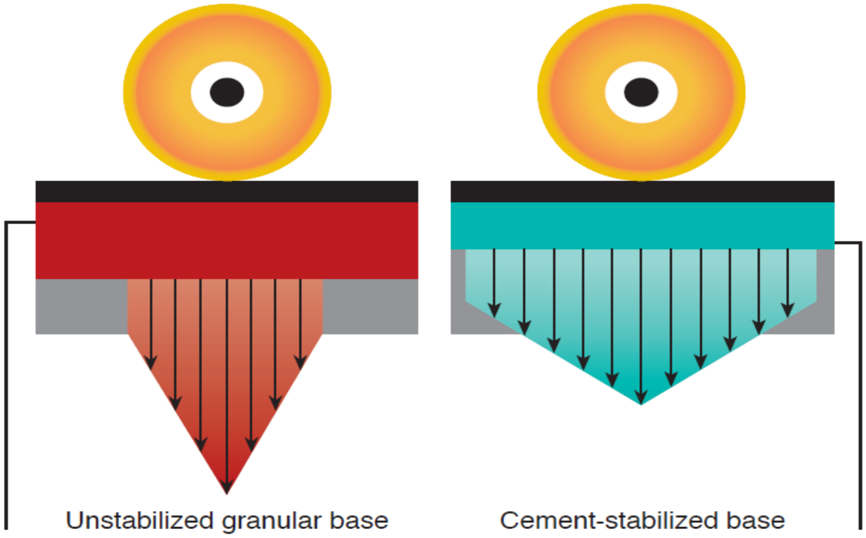

Figure 0.2: Soil in cement-stabilized bases harden into a slab to distribute loads (Halsted, Luhr and Adaska 2006)

In certain areas of Alabama, crushed stone is unavailable or has become too costly to transport to the project site. When soil cement is properly mixed, compacted, and cured, there are multiple benefits that follow when compared to a granular base. These benefits include, but are not limited to (Halsted, Luhr and Adaska 2006):

- It provides a stiffer and stronger base, reducing deflections from traffic loads, which delays the onset of surface distress and extends pavement life.
- The thickness of a soil cement base is less than the required thickness for granular bases. Due to the shear strength of the soil cement base, traffic loads can be distributed across sections of the base, reducing the stress applied to the subgrade. This results in less subgrade failures, potholes, and road roughness.
- Local, in-situ soils of many varieties can be used for this alternative base, negating the need to transport expensive crushed stone.
- The construction process has less impact on the travelling public due to less hauling trucks needed for the projects.
- Soil cement does not displace as easily as unbound aggregates would under traffic loads, which will reduce the potential for rutting.
- Pumping is not as much of an issue for soil cement bases because the cement binds the base together, decreasing the potential for water intrusion.
- Soil-cement is similar to concrete in the fact that it will continue to gain strength over time. The slow strength gain over long periods of time slightly improves the pavement service life.

With any roadway construction, the goal is to maximize the service life of the pavement as economically as possible, all while staying in budget. A major issue that pavements face over time are cracks from distress. In previous research, it was found that the strength of the soil cement base made an impact on the number of cracks observed (George 2002). To increase the service life of soil cement base pavements, an upper and lower bound has been recommended for the strength. If the base is too weak, rutting and deflection mitigation is no longer an advantage in comparison to the unbound granular base (George 2002). If the base is too strong, the excessive cement content leads to shrinkage cracking, and may cause the asphalt surface to crack via reflexive cracking (George 2002).

To ensure the soil cement base is properly constructed, the Alabama Department of Transportation (ALDOT) has specified strength values to meet upper and lower bound requirements for compressive strength (ALDOT 304 2014). ALDOT has specified the compressive strength lower and upper limits to be 250 psi and 600 psi, respectively (ALDOT 304 2014). If the compressive strength is found to be more than 600 psi or less than 250 psi, ALDOT prescribes Equation 1.1 and Equation 1.2, respectively, to determine the pay reduction for the tested soil cement base section (ALDOT 304 2014). Any section of soil cement base where compressive strengths equal to or less than 200 psi or equal to or greater than 650 psi are found must be removed and replaced by the contractor without compensation (ALDOT 304 2014).

$$Price\ Reduction = (0.4\%\ per\ psi)\ x\ (250\ psi - f_c) \qquad \text{(Equation 0.1)}$$

$$Price\ Reduction = 20\% - (0.4\%\ per\ psi)\ x\ (650\ psi - f_c) \qquad \text{(Equation 0.2)}$$

Where,

$Price\ Reduction$ = reduction in pay (%), and

f_c = compressive strength (psi).

The current practice is to use cores tested at seven days to test for compressive strength compliance, which is similar to the method used for regular concrete. A core is cut from the soil cement base six days after placement and cured overnight to be tested on the seventh day (ALDOT 304 2014). The issue with testing soil cement this way is that its matrix is not as strong as concrete at this age. Therefore, damage to the cores typically occurs during core cutting and extraction. Additionally, high variability of core strengths has led engineers to question if coring to test for in place strength for soil cement is a valid and fair test method. Compressive strength results from cores taken in close proximity at ALDOT projects in Houston County and Geneva County have proven to be extremely variable (Nemiroff 2016). The contractor was forced to remove and replace some sections of the soil-cement base and to take a pay reduction in some other places.

In an effort to mitigate the possibility of highly variable test methods being a main contributor to variable compressive strengths, another in-place strength test method has been researched and developed: the dynamic cone penetrometer (DCP) (Nemiroff 2016). ASTM D6951, *Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications*, is the procedure followed to test for in-place strength with the DCP (Nemiroff 2016).

Molded cylinder testing is another method that is used to test the strength of conventional concrete that has been modified to be used for soil cement applications. There are two types of methods to produce molded cylinders for soil cement base applications: steel-mold (SM) method and plastic-mold (PM) method. Wilson (2013) created the SM method by modifying ASTM D1632, *Standard Practice for Making and Curing Soil Cement Compressive and Flexure Test Specimens in the Laboratory* (ASTM D1632 2017). This specification was modified for soil cement cylinders to better mimic how conventional concrete cylinders would be made at the project site for strength quality assurance. Due to the laborious nature of the SM method, the PM method was created as an alternative to the SM method (Sullivan, Howard and Anderson 2014).

1.2 Research Objectives

The primary objective of this research was to develop and recommend guidelines for the Alabama Department of Transportation to cost-effectively and reliably assess the strength of soil cement base. A secondary objective was to develop a software package that would be used to automatically analyze the data collected from the DCP. The goal is to use the developed relationship between the DCP and soil cement compressive strength to generate an output in a user-friendly format to streamline quality assurance testing for ALDOT.

1.3 Research Approach

All research discussed in this report was conducted in the laboratory. The soils used varied in classifications set by the American Association of State Highway and Transportation Officials (AASHTO) and experiments were conducted on soils with ranging levels of cement content. The SM method modified by Wilson (2013) and the PM method modified by McLaughlin (2017) and Scales (2020) were used to created molded cylinders from the same batch of soil cement.

Based on the results from this new research project, the plastic-mold method should be used to produce molded cylinders on-site for quality assurance testing of the soil cement mixture. If the compressive testing results from the plastic-mold cylinders give indications that the strength is not acceptable for full payment, then the dynamic cone penetrometer must be used to determine the in-place compressive strength of the soil cement base. To help with the last step, the Microsoft Excel program, DCPAL, was developed to assist the Alabama Department of Transportation in implementation of the above recommendation.

1.4 Thesis Outline

A review of relevant previous literature and research is summarized in Chapter 2. This chapter details the materials used, the relevant engineering properties (density, compressive strength, etc.), and different strength evaluations used during this research (DCP, PM, and SM). A section in this chapter is specifically devoted to comparing different state departments of transportation methods for using soil cement as a base for pavement construction. Also, guidance on the usage of Excel Visual Basic to create an automated program to analyze the DCP output is discussed in this chapter.

The experimental plan developed for the laboratory phase of this project is discussed in Chapter 3. This chapter details the laboratory procedures followed, test methods used, and materials tested to evaluate the compressive strength results from the PM and SM cylinders.

All results obtained from the comparison of the PM versus SM methods are discussed in Chapter 4. The properties used to compare the SM and PM methods are density, moisture, and compressive strength.

Chapter 5 discusses the development of DCPAL. The DCPAL development plan includes screenshots from the software for each step in the process. Additionally, decisions made, and the consequences of each choice, while using the software are explained throughout. Next, a few examples of the software in use are given. The examples reflect the three potential outcomes in accordance with ALDOT 304 acceptance and payment criteria.

Chapter 6 details the implementation recommendation for soil cement base quality assurance testing for ALDOT. The recommendation includes the use of the PM method and the DCP with DCPAL.

A brief summary of the research performed and conclusions drawn are presented in Chapter 7. In addition, recommendations for future research in this field of study are noted at the end.

Appendices A through G follow the references. Appendix A contains the main code used in development of DCPAL. Appendices B and C contain supplemental code used by the main code of DCPAL. Appendix D lists the strength, density, and moisture content results, organized based on soil type and cement content used. Appendices E, F, and G display the input file data and output results of the three potential outcomes of DCPAL based on the acceptance and payment criteria set by ALDOT 304 (2014).

Chapter 2

Literature Review

1.5 Introduction

In this chapter, a literature review of previous research related to the topic of soil cement base and Excel visual basic calculation automation is presented. The review first includes a summary of the materials required to produce soil cement and the specifications that limit the permitted materials. Next, the various methods of soil cement base production and the current quality control measures are presented. The literature review then covers key engineering properties determined during assembly and testing. The soil cement portion of the literature review concludes with a discussion of the numerous test methods used to evaluate the strength of soil cement base. The methods to determine strength vary among state departments of transportation (DOT), and thus, each variance found will be discussed. Relevant literature on the automation of Excel using Visual Basic for calculations is also discussed.

1.6 Soil Cement

1.6.1 Materials

1.6.1.1 Soil

Soil is defined as the relatively loose agglomerate of minerals, organic minerals, and sediments found above the bedrock (Holtz and Kovacs 1981). Many types of soil are permitted for use in soil cement production. The only soils prohibited are organic soils, highly plastic clays, and poorly reacting sandy soils (ACI 230 2009). Research has shown that sandy soils with more than two percent of organic matter or a pH lower than 5.3 can have an adverse effect on the performance of soil cement base due to an “abnormal reaction” (Robbins and Mueller 1960).

Additionally, it was discovered that any acidic organic material would often inhibit the strength development of the final soil cement product.

In general, even though all soil types can be used, granular soils are ideal because they pulverize and mix more easily than fine-grained soils (ACI 230 2009). The most common soils used in the production of soil cement are silty sand, processed crushed or uncrushed sand and gravel, and crushed stone (ACI 230 2009).

1.6.1.1.1 Particle Size

For this research, AASHTO terminology was used to specify the boundary between coarse-grained and fine-grained soils. The boundary is indicated by the percentage retained or passing the No. 200 sieve (McCarthy 2007). If more than 35 percent of the soil is retained on or above the No. 200 sieve, the soil is considered a coarse-grained soil. Otherwise, if more than 35 percent of the soil sample passes through the No. 200 sieve, the soil is considered fine-grained soil (Halstad, Adaska and McConnell 2008).

Portland cement stability is gained from the hydration of the cement particles; therefore, it does not rely on the cohesion or internal structure of the soil to bond (PCA 1995). More specifically, well graded coarse-grained soils having between 10 and 35 percent of non-plastic fines are believed to produce the most economical soil-cement base in terms of cement content and favorable characteristics (ACI 230 2009). Gap-graded soil mixtures that are dominated by two or three aggregate sizes are not desirable for soil-cement applications (Halsted, Luhr and Adaska 2006). Fine-grained soils require more cement for adequate strength and are harder to pulverize, making them less economical than their coarse-grained counterparts (ACI 230 2009).

Coarse-grained soils have larger particles than fine-grained soils, and therefore, will have a lower total particle surface area. The amount of binder needed to cover all particles is similar in theory to that which is used for concrete design. Therefore, to minimize the cement content, an ideal range of particle sizes must be used that still meets strength requirements for the soil cement base (Halsted, Luhr and Adaska 2006).

Figure 0.1 shows the aggregate gradation band recommended by PCA to optimize cement economy with the strength and density requirements (Halsted, Luhr and Adaska 2006). Gradations that fall outside the recommended band are susceptible to lower strengths due to improper structural interlocking for strength or interference with compaction, requiring more cement to compensate (Halsted, Luhr and Adaska 2006).

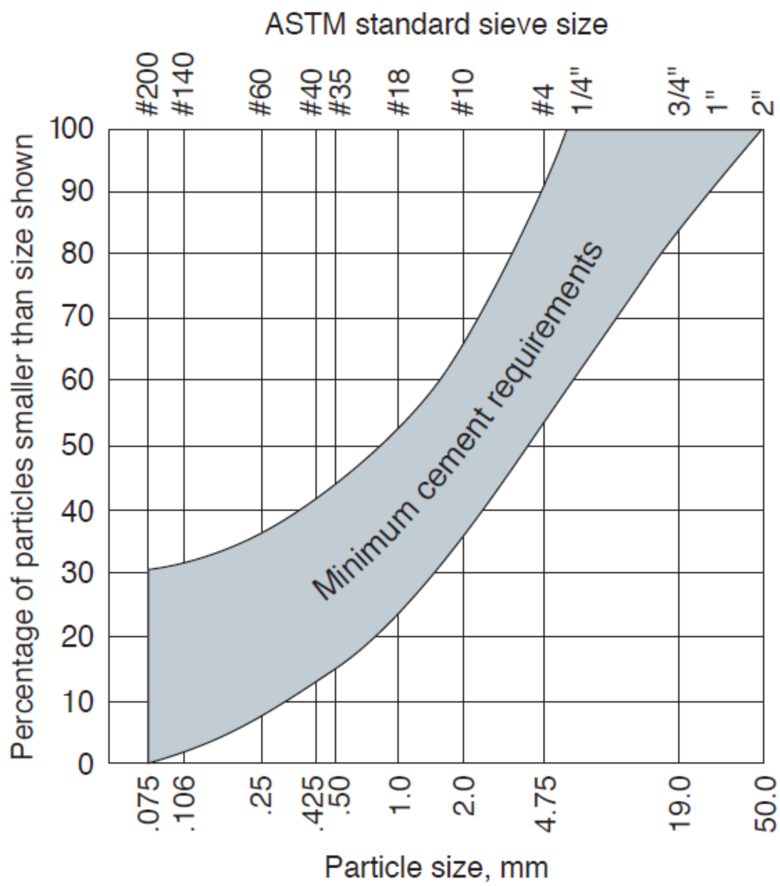

Figure 0.1: Aggregate gradation band for minimum cement requirements (Halsted, Luhr and Adaska 2006)

1.6.1.2 Portland Cement

Type I or Type II portland cement conforming to the requirements prescribed in ASTM C150 are the typical cement types used for soil-cement applications (ASTM C150 2016). The required cement content ranges from 2 to 16 percent by dry weight of soil depending on the desired properties and soil type used (ACI 230 2009). A table to assist in estimates for mixture proportioning is provided by ACI 230 (2009) and is shown in Table 0.1. It is critical to understand that this table is simply intended to provide an estimate and that the actual cement content is dependent upon the desired properties and soil type of a specific application (ACI 230 2009).

Table 0.1: Typical cement requirements for various soil types (ACI 230 2009)

AASHTO Soil Classification	ASTM Soil Classification	Typical Cement Range, * percent by weight	Typical Cement for moisture-density test (ASTM D558), percent by weight	Typical Cement for durability tests (ASTM D559 & D560), percent by weight
A-1-a	GW, GP, GM, SW, SP, SM	3 to 5	5	3-5-7
A-1-b	GM, GP, SM, SP	5 to 8	6	4-6-8
A-2	GM, GC, SM, SC	5 to 9	7	5-7-9
A-3	SP	7 to 11	9	7-9-11
A-4	CL, ML	7 to 12	10	8-10-12
A-5	ML, MH, CH	8 to 13	10	8-10-12
A-6	CL, CH	9 to 15	12	10-12-14
A-7	MH, CH	10 to 16	13	11-13-15
* Does not include organic or poorly reacting soils. Also, additional cement may be required for severe exposure conditions such as slope protection.				

Similar to conventional concrete applications, supplementary cementitious materials such as fly ash, slag cement, and additives such as hydrated lime have been successfully used in soil-cement base operations. Slag cement should meet the requirements of ASTM C989 and when blended with portland cement should meet the requirements of ASTM C595 or C 1157 (ACI 230

2009). Class F fly ash that complies with ASTM C618 is the most predominant class of fly ash used for soil cement applications when employed as a filler or as cementitious material components (ACI 230 2009). Hydrated lime has been successful in reducing the plasticity of highly plastic clay soils as well as easing the pulverization of the material before mixing with cement (ACI 230 2009).

1.6.1.3 Water

In the production of soil cement, water is an essential component in achieving maximum compaction as well as activating the portland cement through hydration (PCA 1995). Considerations have been made as to what type of water can be used for soil cement base applications without adverse effects on its strength or durability. ACI 230 (2009) noted that the water used must be either potable water from the city or water that is free from harmful amounts of alkalis, acids, or organic matter. ASTM D1632 (2017) suggested the water should be free of acids, alkalis, and oils and should be suitable for drinking. ALDOT (2012) offers a table prescribing the type of water that can be used, limiting oil and impurities as shown in Table 0.2.

Table 0.2: Maximum limit for impurities in water used for soil cement applications (Alabama Department of Transportation 2012)

Item	Limit
Acidity or alkalinity	500 mg/L AASHTO T26
Total organic solids	500 mg/L AASHTO T26
Total inorganic solids	500 mg/L AASHTO T26
Chloride ion concentration	250 mg/L AASHTO T26
Sulfate ion concentration	250 mg/L AASHTO T26
pH	6.0 to 8.0 ASTM D1293

1.6.2 Engineering Properties

The structural properties of soil cement base depend on the soil material, quantity of cement, curing conditions, and age (Halsted, Luhr and Adaska 2006). From conception to service of soil cement base, specific properties are used to determine if the mixture meets the requirements put in place by industry professionals and researchers. Among some of the important characteristics to test for in soil cement construction are its moisture-density relationship, unconfined compressive strength, and durability, each of which will be discussed in the following sections.

1.6.2.1 Density and Moisture Content

Density of soil is typically measured in terms of dry density (ACI 230 2009). The amount of water in the mixture is known as moisture content and is represented as a percentage by weight of oven-dry soil cement (cement and soil particles. The typical range of moisture contents in soil cement base applications can range from as low as five percent to as high as 15 percent (ACI 230 2009). The Proctor Compaction Test is a laboratory test used to determine the optimum moisture content and the maximum dry density of a soil. A typical moisture density curve, as shown in Figure 0.2, is used to determine the optimum moisture content and maximum dry density.

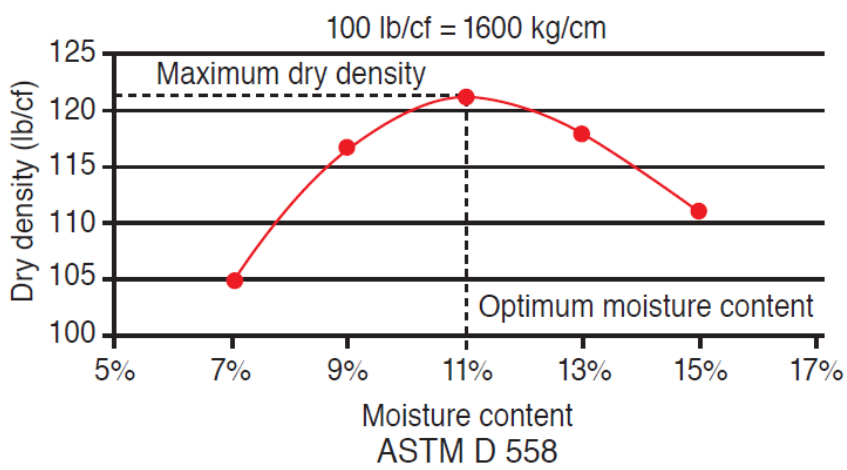

Figure 0.2: Maximum dry density and optimum moisture content (ASTM D558 2019)

Although the Proctor Curve is fairly predictable for soils, the compactive effort required increases once cement is added to the mixture. It is known that cement alters the moisture content and the maximum dry density to some extent (ACI 230 2009). The alteration is due to the method by which the cement reacts with the soil and moisture in the mixture. A desirable trait of the interaction is a higher density because it leads to higher compressive strengths of the cohesionless soil cement mixture (Yoon and Abu-Farsakh 2008). An increase in optimum moisture content can occur due to the flocculating action of cement, which decreases the maximum dry density (ACI 230 2009). An increase in dry density can occur due to the relatively high specific gravity of portland cement (ACI 230 2009).

The relationship between dry density and moisture content with cement added was investigated by Yoon and Abu-Farsakh (2008) to determine the correlation of the amount of decrease or increase of each property in relation to another. Figure 0.3 illustrates compaction curves obtained for nonstabilized sand and cement-sands prepared at varying cement contents. The compaction curves prove that when the cement content increases, it leads to an increase in dry density with similar optimum moisture content (Yoon and Abu-Farsakh 2008).

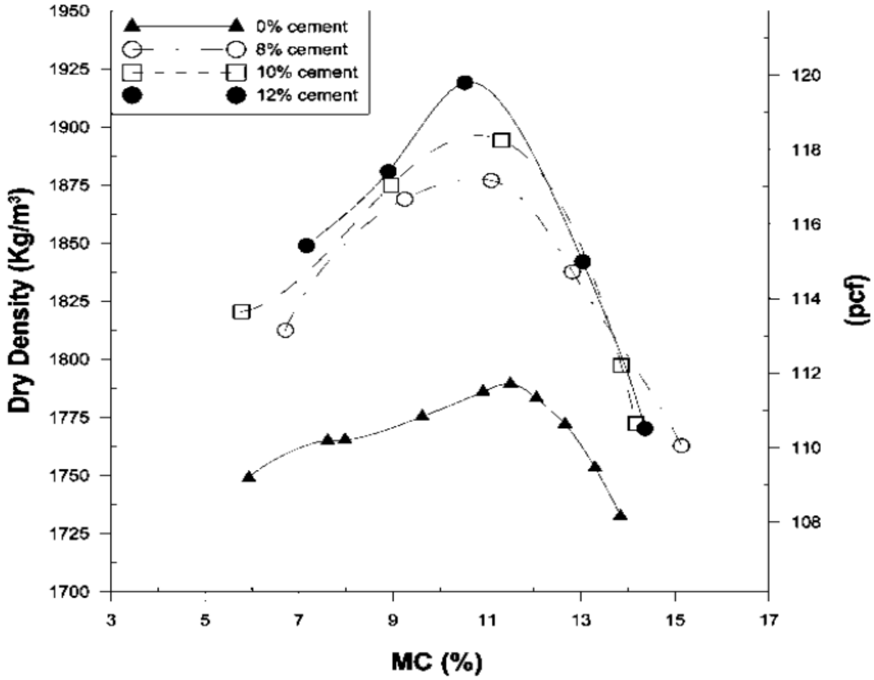

Figure 0.3: Relationship between dry density and moisture content with added cement (Yoon and Abu-Farsakh 2008)

Further research into the relationship of moisture-density with added cement was conducted while adding a water-reducing admixture (WR). During hydration, water typically acts as a lubricant between the soil particles to aid in compaction and achieve maximum dry density when at optimum moisture content (Jin, Song and Huang 2018). Without the addition of a WR, water can get trapped between sand or cement particles that flocculated during the hydration process, therefore wasting some of the water that was intended for hydration of the cement.

All water-reducing admixtures are surfactants that lower the surface tension at the cement-water interface to mitigate the chances for cement grains to flocculate around the water particles (Mehta and Monteiro 2014). Jin, Song, and Huang (2018) studied the effects of water reducers in cement treated soils. They found that WR decrease the optimum moisture content, increase the maximum dry density, reduce weight loss in wet-dry cycles, and reduce permeability (Jin, Song and Huang 2018). The research was conducted on different soils types, discovering that the composition of the soil plays a major role in the effectiveness of the WR. An example of the effects of the WR on silty gravel with and without cement can be seen in Figure 0.4.

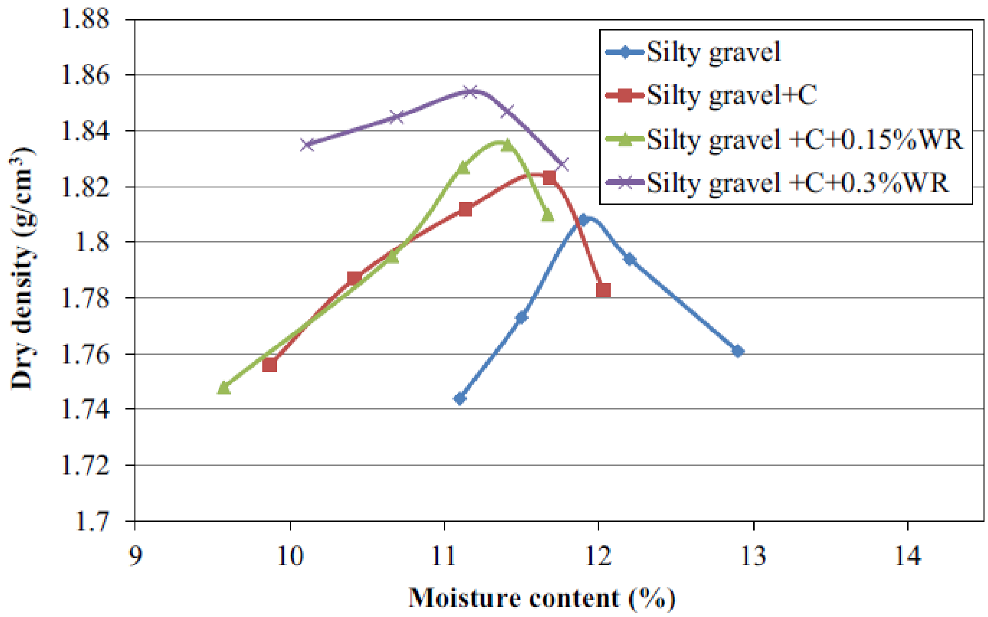

Figure 0.4: Effect of WR on compaction curves of silty gravel soil (Jin, Song and Huang 2018)

The hydration process between water and cement happens quickly, and thus requires swift placement to achieve the best results possible for compaction and strength. Soil cement that has sat idle for over two hours before being compacted could result in significant decrease in density (West 1959). A decrease in density has been directly correlated to a decrease in compressive strength (Shen and Mitchell 1966). If the mixture remains idle due to unforeseen circumstances, Felt (1955) determined that the adverse effects of noncompaction in the early stages of the mixture could be mitigated by remixing the soil cement several times in an hour. This delay technique is only a viable option if the moisture content is maintained at or slightly above optimum moisture content once the material is eventually compacted. (Felt 1955)

1.6.2.2 Unconfined Compressive Strength

The unconfined compressive strength (f_c) is the most widely referenced property of soil cement (ACI 230 2009). The unconfined compressive strength serves as an indication of how much the cement reacted with the mixture (ACI 230 2009). Compressive strength is typically measured by following ASTM D1633 (2017) for soil cement mixtures. ACI 230 (2009) summarizes 28-day unconfined compressive strengths for soaked soil cement specimens, ranging from as low as 250 psi for clayey soils to as high as 1000 psi for sandy and gravelly soils.

Strength is directly related to density and, as such, is similarly affected by the degree of compaction and water content (ACI 230 2009). As discussed in Section 1.6.2.1, an increase in cement content will lead to an increase in dry density. This is true to a point, but considerations must be given to the water-to-cement ratio to achieve proper hydration of the mixture (Yoon and Abu-Farsakh 2008). The research showed a relationship between the dry density and unconfined compressive strength as shown in Figure 0.5.

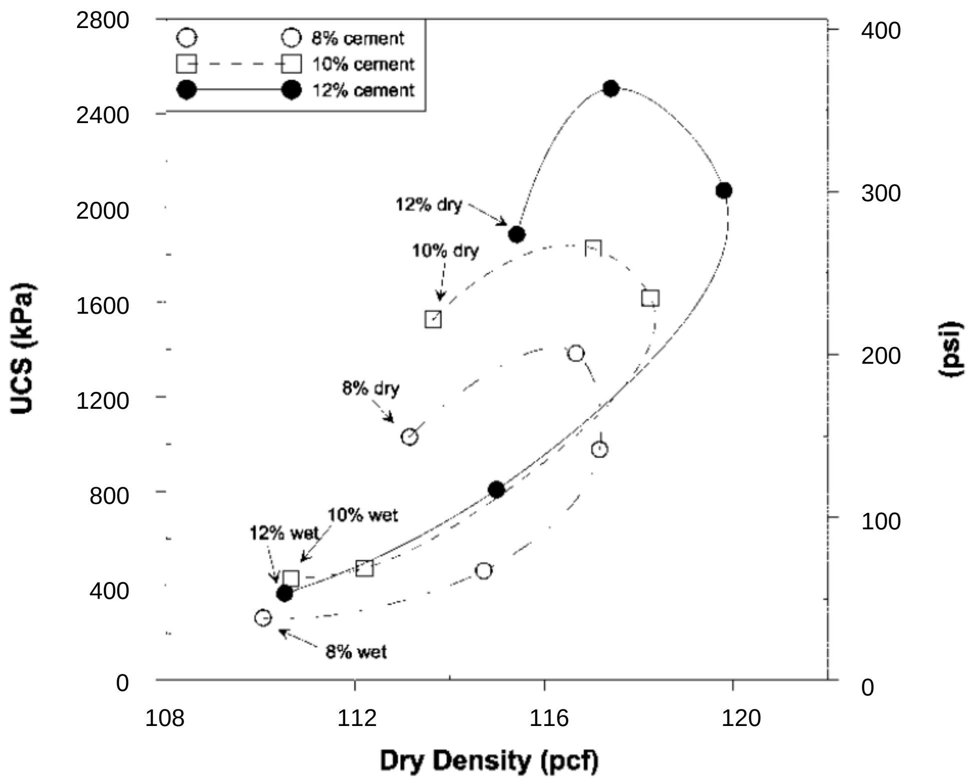

Figure 0.5: Relationship between dry density and unconfined compressive strength (Yoon and Abu-Farsakh 2008)

Another factor that significantly affects the compressive strength of soil cement is the time allowed for proper curing (FHWA 1979). Research was conducted on different soil types to determine the effect that curing time had on soil cement strength. It was found that the unconfined compressive strength of fine-grained soil mixtures was lower than that of coarse-grained soil mixture at the same curing time (FHWA 1979). Additionally, it was concluded that both soil types gained strength over the curing period as shown in Figure 0.6.

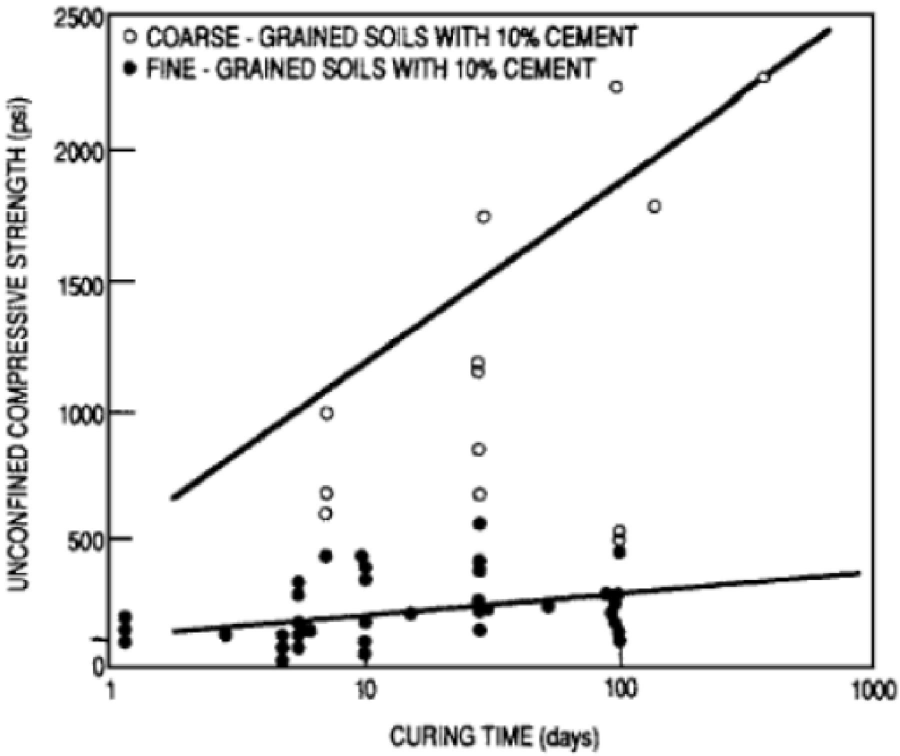

Figure 0.6: Effects of curing time and different soils on unconfined compressive strength (FHWA 1979)

1.6.2.3 Durability

Durability of soil cement structures is an important characteristic to consider for a longer service life. Similar to concrete, soil cement may undergo cracking due to shrinkage via moisture loss, wet-dry cycles, or freeze-thaw cycles (ACI 230 2009). Cracks in the soil cement base layer of a pavement tend to propagate upward via stress concentration points to form cracks in the upper asphalt layer called reflexive cracks (Kuhlman 1994). Cracks like these are an issue because they allow for foreign particles and moisture to intrude into the layers of the pavement, decreasing the performance of the structure over time. The other major durability consideration for soil cement applications is weight loss (ACI 230 2009). Loss of the soil cement mass depends on the cement content and can occur during natural cycles of freeze-thaw and wet-dry periods (ACI 230 2009).

1.6.2.3.1 Shrinkage Cracking

The orientation, size, and spacing of cracks can determine the outcome of pavement durability. For example, alligator cracking in the wheel paths of the pavement could indicate an inadequate design and structural failure (Kuhlman 1994). ACI 230 (2009) notes that large cracks will cause raveling, loss of subgrade material, pavement faulting, surface deterioration, and poor ride quality. Alternatively, cracks that are closely spaced and narrow are more desirable because load transfer is still possible and minimal water can intrude into the opening (ACI 230 2009). It is essential to maintain sound construction and quality control procedures to minimize overall cracking (George 2002). An example of transverse and longitudinal cracking can be seen on U.S. Highway 84 as shown in Figure 0.7.

Figure 0.7: Transverse and longitudinal cracking on U.S. Highway 84 (McLaughlin 2017)

Aside from good construction practices, there are other factors that play a role in the magnitude and scale of cracks that form. George (2002) correlated soil cement cracking to characteristics such as volume change due to drying and/or temperature differentials, tensile strength, stiffness and creep, and subgrade restraint. Soon after construction of the soil cement base, volume shrinkage of the structure will commence, generating tensile stresses (Kuhlman 1994). Similarly to conventional concrete, soil cement is not nearly as strong under tensile stress as it is for compressive stress (ACI 230 2009). Once the tensile strength limit is reached, cracks form to relieve pressure (ACI 230 2009). The number of cracks is dependent upon the amount of shrinkage that the structure undergoes, which is primarily dependent upon cement content, soil type, water content, degree of compaction, and curing conditions (ACI 230 2009).

In conventional concrete, cement content is a major contributor to drying shrinkage due to the complex microstructure of hydrated cement paste (Mehta and Monteiro 2014). Therefore, research conducted on supplementing a portion of the portland cement with fly ash has shown some benefit to reduce drying shrinkage (George 2002). Alternatively, the use of expansive cements or a thicker base layer with less cement content has been recommended as a potential mitigation measure for drying shrinkage (ACI 230 2009).

Research was conducted in Australia at five different test locations with differing soil types, each producing a different crack pattern (ACI 230 2009). It was noted that soils containing clay experienced more total shrinkage but maintained smaller crack widths at closer intervals of spacing than other types of soils (ACI 230 2009). On the contrary, granular soils experienced less shrinkage but produced larger cracks spaced further apart. A method to mitigate crack widths in soil cement would be to limit the number of fines allowed in the mixture (ACI 230 2009).

Kuhlman (1994) studied the effects of moisture on soil cement cracking. It was determined that the least cracking will occur in soil cement mixtures having the lowest moisture content at the time of compaction (Kuhlman 1994). Soils containing clays and silts will therefore have the greatest tendency for drying shrinkage in comparison to granular soils that require lower moisture contents. Additionally, ACI 230 (2009) suggests that compacting at a slightly less than optimum moisture content may be effective in mitigating cracking based on the idea that more moisture means more shrinkage on drying.

Curing is an important part of strength development but can also play a major role in mitigation of undesirable cracks in the soil cement base layer. By prolonging the curing period to 14 to 28 days, the initial cracks can form freely (ACI 230 2009). The prolongation of curing can be achieved via water application or placement of a bituminous curing compound (ACI 230 2009). The asphalt layer tends to bridge the gaps made by the initial cracks, reducing the reflectivity and size of the cracks (ACI 230 2009).

A separate study investigated the effects of intentionally inducing microcracks in accord with proper curing before the asphalt was placed. Scullion (2002) discusses an experiment conducted on three high-traffic streets that used soil cement as the base layer and a delay in the final hot mix asphalt (HMA) surface was adhered to (Scullion 2002). Once the base was placed, it was allowed to cure undisturbed for 24 hours (Scullion 2002). Following that cure period, a vibratory roller was used to create a microcracked structure in the stabilized layer (Scullion 2002). After cracking, the layer was allowed to cure for another 48 hours before the surface layer was added. By allowing for the additional 48 hours of curing, the asphalt, once placed, could fill the cracks. Scullion (2002) asserts that the results of the mitigation technique in reducing the instance of large cracks were astounding for the local areas of Texas that experienced large cracks over soil cement bases.

1.6.2.3.2 Mass Loss

Soil cement may have many challenges to face with reflective cracking, but mass loss can be just as fatal for pavement life duration. Mass loss is usually a result of wetting and drying or freezing and thawing cycles due to the wear and tear they induce on the permeable soil cement base. This phenomenon can be closely related to that of conventional concrete. When water particles that have become trapped in the microstructure of concrete freeze, they expand (Mehta and Monteiro 2014). Expansion causes stresses on the cavity that holds the water molecule, which could eventually rupture the cavity and cause deterioration of the microstructure. Alternatively, drying periods will further the amount of dehydrating beyond what the concrete had already experienced during hydration. Drying further than the natural ambient humidity at which a cement-bound structure was cured has proven to be a driving force for major shrinkage (Mehta and Monteiro 2014). A consecutive wetting period would then wash away the material that was fractured from the microstructure, causing further mass loss.

In order to secure the mass structure cohesion and maintain stability during natural weather cycles, the amount of cement needed for each mixture can be determined by ASTM D559 (2015) or ASTM D560 (2016). The Portland Cement Association (PCA 1971) provides guidance for wet-dry and freeze-thaw durability. It is noted that cement contents sufficient to prevent weight loss greater than the values indicated in Table 0.3 after 12 cycles of wetting, drying, freezing, or thawing are considered adequate to produce durable soil cement bases.

Table 0.3: Criteria for soil cement as indicated by wetting-and-drying and freezing-and-thawing durability tests (PCA 1971)

AASHTO soil group	Unified soil group	Maximum allowable weight loss, %
A-1-a	GW, GP, GM, SW, SP, SM	14
A-1-b	GM, GP, SM, SP	14
A-2	GM, GC, SM, SC	14*
A-3	SP	14
A-4	CL, ML	10
A-5	ML, MH, CH	10
A-6	CL, CH	7
A-7	OH, MH, CH	7

* Ten percent is maximum allowable weight loss for A-2-6 and A-2-7 soils.
Additional Criteria:

1. Maximum volume changes during durability test should be less than 2% of initial volume.
2. Maximum water content during test should be less than quantity required to saturate sample at time of molding.
3. Compressive strength should increase with age of specimen.
4. Cement content determined as adequate for pavement, using the aforementioned PCA criteria, will be adequate for soil cement slope protection that is 5 ft (1.5 m) or more below the minimum water elevation. For soil cement that is higher than that elevation, cement content should be increased two percentage points.

Aside from the listed standard testing, it has been common practice to use the compressive strength to approximate the minimum cement content required to achieve a satisfactory service life (ACI 230 2009). The relationship between strength and durability for soil cement suggests that a strength of 800 psi would be adequate for all soils, but may not be the most economical design for every application (ACI 230 2009). The relationship is illustrated by a curve that can be seen in Figure 0.8.

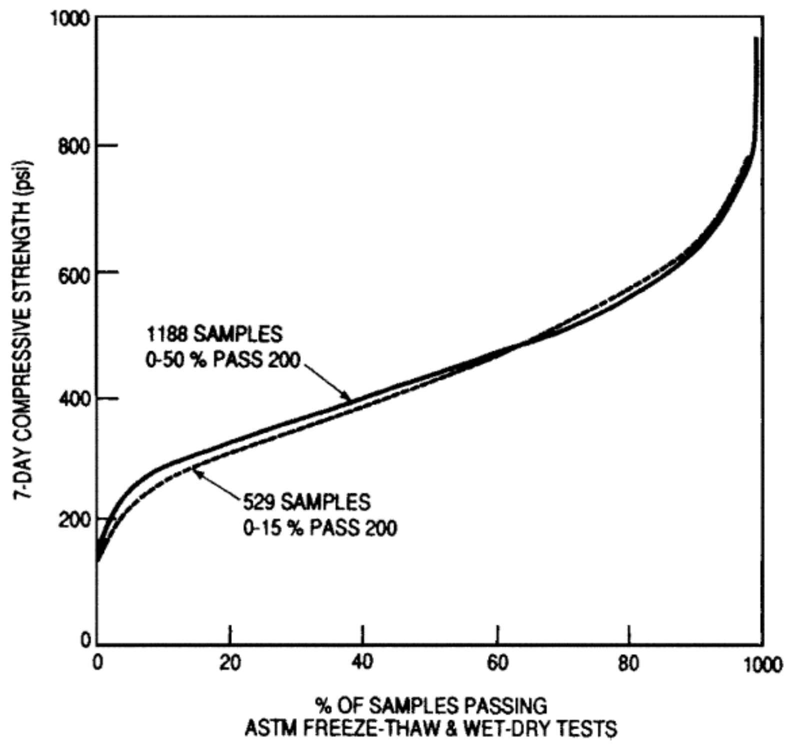

Figure 0.8: Relationship between compressive strength and durability of soil cement based on PCA durability criteria (ACI 230 2009)

1.6.3 Soil Cement Base Construction

The objective when constructing soil cement is to obtain a thoroughly mixed, adequately compacted, and cured material with sufficient strength (ACI 230 2009). Restrictions on weather events have been imposed in order to achieve this objective. ACI 230 (2009) states that soil cement shall not be mixed or placed when the soil or subgrade is frozen or when the air temperature is below 45 degrees Fahrenheit. ALDOT 304 (2014) states that soil cement should not be mixed or placed when the air temperature is below 40°F in the shade, when the temperature of the soil is below 50°F, when rain is imminent, or during a rain event. Soil cement shall be protected from freezing for at least seven days if freezing temperatures are expected (ACI 230 2009). If there is heavy rainfall during placement, it can be detrimental, especially if the optimum moisture had already been achieved in the mixture or if the cement is still being spread (ACI 230 2009). Rain will not normally harm the soil cement mixture if it has been compacted (ACI 230 2009). It is recommended that soil cement shall not be placed unless mixing, placement, and compaction can be completed within two hours without interruption (ALDOT 304 2014).

To create a soil cement base, a sequence of events must take place from beginning to end of construction. First the material is mixed either by way of mix-in-place or using a central mixing plant. Then the mixture is compacted, finished, and cured before the asphalt is placed. The construction sequence is discussed in the following sections.

1.6.3.1 Mixed In-Place Method

Mixing operations can be performed with transverse single-shaft-type mixers (ACI 230 2009). An example of a transverse single-shaft mixer can be seen in Figure 0.9. During construction, some soils may require multiple passes of the mixer to achieve adequate pulverization and uniformity (ACI 230 2009). Almost all types of soil, from granular to fine-grained, can be pulverized and mixed to produce soil cement in the field (ACI 230 2009). These soils can consist of material already in-place or obtained from a borrow pit.

Figure 0.9: Transverse single-shaft mixer (Scales 2020)

This mixing method begins with preparation of the subgrade. All soft or wet subgrade areas are located and corrected. All deleterious materials such as stumps, roots, organic soils, and aggregates greater than three inches should be removed (ACI 230 2009). Once all unwanted materials are removed, the soil is then shaped to approximate final lines and grades before mixing using a single-shaft mixer (ACI 230 2009).

After the soil is prepared, the cement is distributed in bulk over the soil using a mechanical spreader or in a slurry form by using a distributor truck equipped with an agitation system (Halstad, Adaska and McConnell 2008). An example of a mechanical spreader used to spread cement on a highway is shown in Figure 0.10.

Figure 0.10: Mechanical spreader (Scales 2020)

The primary objective of the cement-spreading operation is to achieve uniform distribution of the cement in the proper proportions across the width of the roadway (ACI 230 2009). To obtain a uniform spread, the mechanical spreader should be operated at a uniform speed with a constant level of cement in the hopper (ACI 230 2009). Cement is moved pneumatically from the truck through an air-separator cyclone, which removes the air pressure, before the cement falls into the hopper of the spreader (ACI 230 2009). If there is a concern of major dusting of the cement into the air, cement can be applied as a slurry (ACI 230 2009). Dusting of the cement can be seen in Figure 0.11 where the slurry method was not used.

Figure 0.11: Cement dusting without use of slurry (Scales 2020)

For slurry applications, a 50/50 by weight of water and cement is mixed in a slurry pump thoroughly that is then pumped into a liquid tanker truck (ACI 230 2009). This truck is equipped with internal agitation devices or recirculation pumps to keep the cement in suspension (ACI 230 2009). The amount of cement required is specified as a percentage by weight of oven-dry soil or in pounds of cement per cubic foot of compacted soil (ACI 230 2009).

Once all the cement has been evenly applied to the roadbed, a single-shaft mixer is used to pulverize and mix the cement with the soil. Another example of a single-shaft mixer used to mix the soil cement is shown in Figure 0.12. The soil and cement must be sufficiently blended before water contacts the mixture to prevent the formation of cement balls (Halsted, Luhr and Adaska 2006). Agricultural-type equipment is not recommended due to the relatively poor mixing uniformity (ACI 230 2009). Soils with higher fines contents are generally more difficult to pulverize and mix (ACI 230 2009). In-place mixing efficiency, as measured by the strength of the soil cement, is usually less than that found in the laboratory (ACI 230 2009). This deficiency can be compensated for by adding one or two percent cement content more than what was determined in the laboratory testing (ACI 230 2009).

Figure 0.12: Single-shaft mixer used in mixed-in-place construction (McLaughlin 2017)

Once the cement has been mixed into the soil, a water truck is then used to apply the amount of water needed to obtain the desired moisture content onto the surface. The water truck may be required to make multiple passes to apply all water necessary. For coarse-grained soils, mixing at less than optimum moisture content minimizes the chances for cement balls to form, while for fine-grained soils, keeping the moisture content near optimum may be necessary for effective pulverization (ACI 230 2009). A water truck spraying water onto the surface can be seen in Figure 0.13. The single shaft mixer then passes over the material again to ensure a properly mixed material.

Figure 0.13: Water truck applying water to soil cement (Scales 2020)

1.6.3.2 Central-Mixing Plant Method

Central mixing plants tend to be used for projects that need borrow materials. Most soil borrow sites are located near the construction site or roadway. Natural soil deposits usually do not consist of homogenous and uniform materials. If the material in the borrow area varies with depth, full-face cuts should be made with excavation equipment to ensure that some material from each layer is obtained (ACI 230 2009). If the material varies laterally across the borrow pit, loads from different locations in the borrow area should be mixed (ACI 230 2009). Mixing for gradation uniformity can be done at the plant location with the help of a bulldozer and front-end loader. Excavated material dumped at the base of the stockpile can be pushed up the stockpile using a bulldozer and a front-end loader can be used to load the soil feed (ACI 230 2009).

An adequate check for unsuitable materials, such as clay lenses, cobbles, or cemented conglomerates should be performed routinely to ensure that large particles and clay balls are removed. Most plants will have a 1.0- to 1.5-inch mesh to screen the material before mixing. Granular borrow materials are generally used because of their ease in handling and mixing and lower cement requirements, while clayey soils should be avoided because they are difficult to pulverize (ACI 230 2009).

The two types of central plant mixers are rotary-drum mixers and pug mill mixers. Typically, pug mill mixers consist of two types: continuous flow and batch. The most common mixer used is the continuous-flow pug mill mixer with production rates varying between 200 and 800 tons per hour (ACI 230 2009).

Just like any soil cement mixing operation, the objective of the central plant mixers is to produce a thorough and intimate mixture of the soil, cement, and water with the correct proportions (ACI 230 2009). Central plant mixers typically consist of at least one soil bin or stockpile, a cement silo with surge hopper, a conveyor belt to deliver the soil and cement to the mixing chamber, a mixing chamber, a water-storage tank for adding water during mixing, and a holding or gob hopper to temporarily store the mixed soil cement prior to loading (ACI 230 2009). An schematic of a continuous-flow pug mill plant can be seen in Figure 0.14.

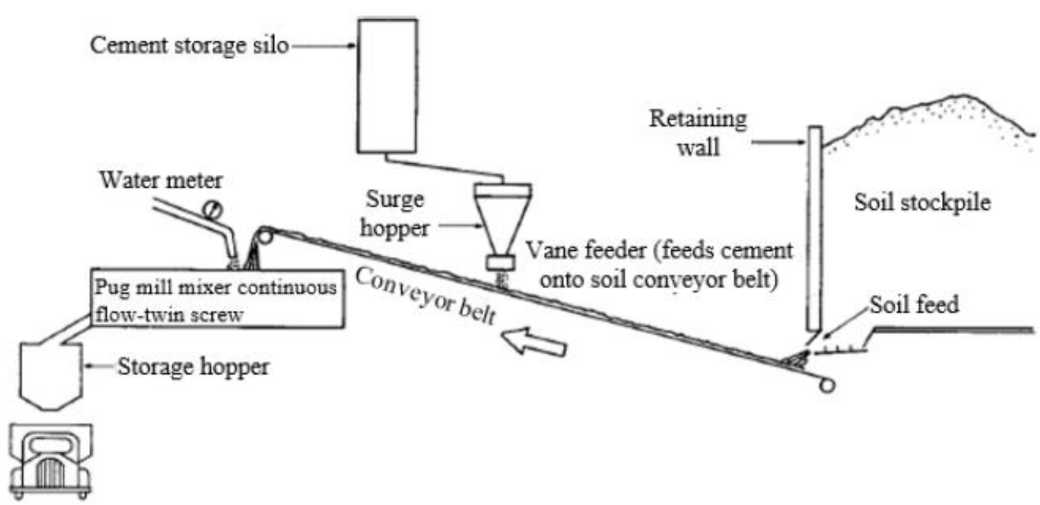

Figure 0.14: Continuous-flow pug mill plant (ACI 230 2009)

The mixing chamber consists of two parallel shafts equipped with paddles along each shaft that rotate in opposite directions (ACI 230 2009). The soil cement is moved through the mixer by the pitch of the paddles (ACI 230 2009) as shown in Figure 0.15. Thorough mixing is very important and is specified to last about 15 to 30 seconds depending on the efficiency of the mixer (ACI 230 2009).

Figure 0.15: Twin-shaft pug mill mixing chamber (Halsted, Luhr and Adaska 2006)

Once the soil cement has finished mixing and is being held in the storage hopper, it must be transported to the site and start being compacted within 60 minutes (ACI 230 2009). To reduce evaporation losses during hot, windy conditions and to protect from sudden showers, rear and bottom dump trucks are equipped with protective covers (ACI 230 2009). Haul time in these trucks is usually limited to 30 minutes as that would leave 30 minutes to place and spread the soil cement before starting compaction (ACI 230 2009). ALDOT (2012) states that cement treated bases shall be delivered and spread within 45 minutes after mixing, and if a mixture has not been compacted within two hours of placement is to be rejected and removed at the contractor’s expense.

Before placing the mixed soil cement, all adjacent surfaces and the subgrade should be moistened (ACI 230 2009). The most common way to spread the soil cement is by using a motor grader or spreader box attached to a dozer or by using asphalt-type pavers (ACI 230 2009). An example of motor grader spreading soil cement in preparation for compaction can be seen in Figure 0.16. Asphalt-type pavers sometimes place one or more tamping bars on the back to initiate the compaction process (ACI 230 2009). Soil cement is typically placed in a layer about 10 to 30 percent thicker than the desired final compacted thickness (ACI 230 2009). This percentage is determined by trial-and-error methods or by contractor experience.

Figure 0.16: Motor grader spreading soil cement (Scales 2020)

1.6.3.3 Compaction of the Soil Cement Base

West (1959) and ACI 230 (2009) state that compaction should begin as soon as possible and should be completed within two hours of initial mixing. Sections should not be left unworked for longer than 30 minutes during compaction (ACI 230 2009). In order to obtain maximum density, the soil cement mixture should be at or near optimum moisture content (ASTM D558 2019). Standard practice requires that the soil cement base be compacted to a minimum of 95 to 98 percent depending on the state’s requirements. North Carolina, Georgia, and Alabama’s requirements for percent compaction are covered in Section 1.6.5.

Once all soil cement has been placed or mixed along the section, the compaction process should begin. The main types of rollers used for soil cement compaction are sheepsfoot rollers, pad foot rollers, multiple-wheel rubber-tired rollers, vibratory steel-wheeled rollers, and heavy rubber-tired rollers (ACI 230 2009). An example of a pad foot roller and a steel-wheeled roller can be seen in Figure 0.17 and Figure 0.18, respectively. Initial compaction may be combined with the placement of the soil cement using a tamping bar as previously mentioned. If the tamping bar is not used, a pad foot roller is then used to initiate compaction. A vibratory steel-wheeled roller then follows the initial compaction.

Figure 0.17: Pad foot roller compacting soil cement (Scales 2020)

Figure 0.18: Vibratory steel-wheeled roller compacting soil cement (Scales 2020)

1.6.3.4 Finishing of the Soil Cement Base

When finishing the soil cement base layer, a multiple-wheel, rubber-tired roller is used for fine-grained soils (ACI 230 2009). An example of a multiple-wheel rubber-tired roller is shown in Figure 0.19. A vibratory steel-wheeled roller, without vibration, or a heavy rubber-tired roller is used for more granular soils (ACI 230 2009). To obtain adequate compaction, it is sometimes necessary to operate the rollers with ballast to produce greater contact pressure (ACI 230 2009). The general rule is to use the greatest contact pressure that will not exceed the bearing capacity of the soil cement mixture (ACI 230 2009). A finished compacted layer tends to range from six to nine inches in depth (ACI 230 2009).

Figure 0.19: Multiple-wheel rubber-tire roller used to finish soil cement base (McLaughlin 2017)

1.6.3.5 Curing of the Soil Cement Base

Once the required density is achieved, grade requirements and cross sections are finalized. Curing commences once compaction and finishing have concluded. Proper curing of soil cement is critical because strength gain is dependent upon time, temperature, and the presence of water (ACI 230 2009). Therefore, strength gain due to the hydration of the cement requires a moist environment. During hydration, strong bonds form between the cement and soil particles. The curing process generally takes three to seven days, during which heavy equipment is not allowed on the soil cement section (ACI 230 2009). Lighter traffic is allowed on the completed soil cement after construction provided that the method of curing is not negatively impacted (ACI 230 2009).

The two most popular methods of curing soil cement are water-sprinkling and sealing with a bituminous coating (ACI 230 2009). Sprinkling the surface with water until a bituminous cure coat is applied, or the 3- to 7-day curing period is complete has proven successful (ACI 230 2009). Soil cement is commonly sealed with emulsified asphalt coating where the rate of application is dependent upon the emulsion (ACI 230 2009). The rate typically varies from 0.15 to 0.30 gallons per square yard (ACI 230 2009). If traffic is allowed on the soil cement during the curing period, it is desirable to apply sand over the bituminous coating to minimize the tracking of the bituminous material (ACI 230 2009). Before this bituminous coating can be applied, the soil cement should be moist and free of dry, loose material (ACI 230 2009). An example of a bituminous coating applied to the compacted soil cement for curing can be seen in Figure 0.20.

Figure 0.20: Asphalt emulsion placed on the soil cement base (McLaughlin 2017)

Concrete curing compounds can be used to cure soil cement as well but should be applied at a rate of 1.5 times its normal application rate for concrete (ACI 230 2009). Soil cement curing can also be accomplished by covering it with wet burlap, plastic tarps, or moist earth (ACI 230 2009). If the temperature drops below freezing during the curing period, insulation blankets, straw, or soil cover should be used to protect the soil cement from the elements (ACI 230 2009).

1.6.4 Quality Control and Assurance Testing

Quality control is conducted by testing the soil cement base as it is being produced to make sure the base is meeting the proper requirements and specifications. Quality assurance is conducted by testing a final product that the contractor has constructed to establish if it is adequate for its intended use and in accordance with the plans and specifications. Field inspection and testing of soil cement construction involves controlling the cement content, mixing uniformity, moisture content, compaction, compressive strength, and lift thickness and surface tolerance. The quality assurance of soil cement base as it pertains to compressive strength is covered in Section 1.6.5. Each of the other field testing and inspection methods are discussed in the rest of this section.

1.6.4.1 Cement Content

For mixing soil cement in-place where cement is spread by bulk cement spreaders, a check on the accuracy of the cement spread is necessary to ensure that the proper quantity is being applied (ACI 230 2009). This check is made in two ways: spot check and overall check. A spot check is done by placing a sheet of canvas or tarp that is one square yard in area ahead of the cement spreader. An example of the sheet of canvas being utilized for cement content checks can be seen in Figure 0.21. Once the spreader has passed, this sheet is carefully picked up and weighed. The cement application rate is then calculated. If necessary, the spreader is adjusted, and the procedure is repeated until the correct coverage per square yard is obtained (ACI 230 2009). For slurry applications, the sheet is replaced with a metal pan that would capture the liquid and then be weighed, as the cement content can be determined by knowing the water-to-cement ratio of the slurry (ACI 230 2009). The overall check takes the known weight of cement in the truckload and compares it to the area in which the truckload placed the cement and then compares that area to the theoretical area that the truckload should have covered (ACI 230 2009). It is important to keep a continuous check on cement-spreading operations as continuous adjustments may need to be made throughout construction (ACI 230 2009).

Figure 0.21: Cement content being checked via canvas sheet (ACI 230 2009)

For a central mixing plant operation, proper proportions of cement and soil need to be checked before entering the mixing chamber (ACI 230 2009). Proper quantities of soil, cement, and water for each batch in a batch-type pug mill or rotary-drum mixing plant are weighed on scales prior to being transferred to the mixer (ACI 230 2009). These plants are calibrated simply by checking the accuracy of the scales (ACI 230 2009). For a continuous-flow mixing plant, there are two methods of calibration that can be used. The first method of calibration is accomplished while the plant is operating. Soil passing through the plant during a specific time period is collected in a truck and the same is done for the cement directly from the cement feeder. Both the soil and the cement are then weighed. The cement feeder is adjusted as necessary until the correct amount of cement is discharged (ACI 230 2009). The second method of calibration occurs when the plant is operated with only soil feeding onto the main conveyor belt. Soil is collected along a selected length of the conveyor belt and its dry weight is determined. The same procedure is then repeated with only cement being feed onto the main conveyor belt until the correct amount of cement is discharged onto the belt (ACI 230 2009). Plants are typically calibrated daily at the project's beginning and then periodically thereafter to assure no changes have occurred in the operation (ACI 230 2009).

Determining the cement content of freshly mixed soil cement can be done in the field using ASTM D5982 (2015) and can provide accurate results in about 15 minutes to within one percent of the actual cement. Some limitations of using this method are that the mixture must contain 3 to 15 percent cement content, the maximum particle size of the mixture can only be three inches, and at least 50 percent of the soil material must pass through the No. 4 sieve size (ASTM D5982 2015). The cement content of a hardened soil cement mixture can also be determined using ASTM D806 (2019) based on the determination by chemical analysis of the calcium oxide content of the sample. A limitation of using this test method is that it should not be used on soil cement material that contain soil or aggregate that yield significant amounts of dissolved calcium oxide as it would affect the results of this test (ASTM D806 2019).

1.6.4.2 Mixing Uniformity

A thorough mixture of pulverized soil, cement, and water is necessary to make high-quality soil cement (ACI 230 2009). For quality control purposes, mixing uniformity can be determined by observation of the soil cement after mixing has been completed for the mixed in-place method. A series of holes at regular intervals for the full depth of the treatment can be dug to inspect the uniformity of the color and texture (ACI 230 2009). If the mixture has uniform color from top to bottom, the mixture is satisfactory but if there are streaks, then more mixing needs to be done (ACI 230 2009).

For central mixing plant operations, the uniformity is normally checked visually at the mixing plant (ACI 230 2009). Once the soil cement mixture has been transported and placed on-site, the same method as the mixed in-place method can be used to check the uniformity, although corrections may not be easily made at this point. The mixing time necessary to achieve a uniform mixture will depend on the soil gradation and the plant used (ACI 230 2009). With this method, the average mixing time varies between 20 to 30 seconds (ACI 230 2009).

1.6.4.3 Moisture Content

Optimum moisture is necessary to reach adequate compaction and for proper hydration of the portland cement to occur. The optimum moisture content is determined through the moisture-density test (ASTM D558 2019). Additional moisture may be added to account for evaporation that normally occurs during construction (ACI 230 2009). For quality control, an estimate of the moisture content of a soil cement mixture can be made by feel or by observation (ACI 230 2009). A mixture near or at optimum moisture content is just moist enough to dampen the hands when it is squeezed in a tight ball (ACI 230 2009). Mixtures that are above optimum moisture content will leave excess water on the hands, while mixtures below optimum will tend to easily crumble (ACI 230 2009). If the surface of the soil cement mixture becomes dry during the compaction and finishing process, a very light spray of water can bring the moisture content back to optimum (ACI 230 2009). Proper moisture content of the compacted soil cement is evidenced by a smooth, moist, tightly knit, compacted surface that is free of cracks and surface dusting (ACI 230 2009).

1.6.4.4 Compaction

The density requirement ranges from 95 to 100 percent of the maximum density as determined by the moisture-density test (ASTM D558 2019). To determine the in-place density, the most common methods include the nuclear gauge method (ASTM D6938 2005), the Sand-Cone method (ASTM D1556 2015), and the balloon method (ASTM D2167 2015). The densities are determined daily at frequencies that vary per each state's Department of Transportation regulations and on the application of the soil cement (ACI 230 2009). Density tests are taken immediately after rolling to determine if adjustments need to be made when compared to the results from the moisture-density test to ensure compliance with job specifications (ACI 230 2009). ALDOT (2012) specifies that measurements of in-place density be taken using the nuclear gauge method. Most states prefer to use the nuclear gauge method because of how quickly results can be obtained on-site, even though the equipment may be relatively expensive. An example of a nuclear gauge measuring the in-place density on a small portion of soil is shown in Figure 0.22.

Figure 0.22: Nuclear density gauge for field density measurements (McLaughlin 2017)

1.6.4.5 Lift Thickness and Surface Tolerance

Lift thickness is more critical for pavements than for embankment applications (ACI 230 2009). The lift thickness of soil cement is checked when performing field density tests if using the sand-cone or balloon method (ACI 230 2009). If using the nuclear gauge method, small holes must be dug in the fresh soil cement to determine the thickness prior to density testing on the compacted soil cement. To visually determine the base layer, a two percent solution of phenolphthalein can be squirted down the side of a freshly cut face of compacted soil cement. The soil cement will turn a pinkish-red, while the subgrade will remain its natural color, unless it is calcium-rich soil (ACI 230 2009). ALDOT (2012) requires coring to check for the strength of soil cement, so the lift thickness is normally checked during the coring process. Regardless of the method, the compacted lift thickness of the layer shall not be more than half an inch less than or one inch more than the specified thickness (ALDOT 304 2014).

Surface tolerances are usually specified for soil cement pavement applications and measured in smoothness (ACI 230 2009). Smoothness is usually measured with a 10-foot or 12-foot straightedge, or with surveying equipment. The U.S. Army Corps of Engineers (USACE) and most states typically require that deviations from the plane of a soil cement base cannot exceed 3/8 inch over 12 feet, although deviations from design grade of up to 5/8 inch are usually allowed (ACI 230 2009). ALDOT (2012) requires that the finished surface shall not vary more than half of an inch in any 25-foot section.

1.6.5 Strength Evaluation

The compressive strength is often considered the most valued property by designers and engineers for assessing conventional concrete (Mehta and Monteiro 2014). This statement can be similarly applied to soil cement for any state DOT that considers strength as a pay factor. Strength can be assessed in the lab by creating soil cement cylinders or in-place by coring or using the dynamic cone penetrometer (DCP). Each state DOT considers different factors and uses different methods for determining if the soil cement base is of acceptable quality once constructed. The following sections will discuss the strength test methods most commonly used as well as give insight into the variations among state DOTs that use cement stabilized bases in a similar fashion to ALDOT's soil cement base construction as prescribed by ALDOT 304 (2014).

1.6.5.1 Overview of ALDOT Practice from ALDOT Section 304

The Alabama Department of Transportation (ALDOT) specifications for the construction of soil cement follow Section 304 of the ALDOT Standard Specifications for Highway Construction (2012). ALDOT 304 (2014) provides the specifications to construct soil cement for a base, subbase, shoulder, or other structures. ALDOT specifies that soil cement shall be produced using either the Mixed-In-Place method or the Central-Plant-Mixed method. The time allowed from the initial mixing of the soil cement until compaction is completed is two hours. Soil cement construction shall not take place if the air temperature is below 40°F in the shade, when the soil temperature is below 50°F, during rain, or if rain is imminent. Once compaction is completed and the surface is finished, a prime coat of "Bituminous Treatment, Type A, MC 30 or MC 70" shall be applied to the completed soil cement structure.

The type of soil that must be used in the construction of soil cement according to ALDOT must meet a certain gradation. The gradation and chemical properties of the soil must meet all of the following requirements as prescribed by ALDOT 304:

- 100% passing the 1.5-inch sieve
- At least 80% passing the No. 4 sieve
- Between 15% and 65% passing the No. 50 sieve
- 0% to 25% passing the No. 200 sieve
- Must contain 4% to 25% clay
- 0% to 25% liquid limit
- 0% to 10% plasticity index

- Dry density must be 95 pounds per cubic foot or more
- pH of the soil must be 4 or more
- Sulfate content must be no more than 4,000 parts per million

During compaction, the moisture content must be 100 percent of the optimum moisture content and not exceed 120 percent of the optimum moisture content. The required density shall be at least 98 percent of the theoretical maximum dry density. ALDOT checks these values using a nuclear gauge over each section that can be no more than 528 feet.

ALDOT 304 (2014) states that the soil cement compressive strength needs to meet the specifications for full pay or potentially be subject to a pay reduction. At least two cores shall be taken to evaluate the in-place compressive strength of the soil cement per each 528 ft section. For a soil cement base at least seven inches in depth, the core must be six inches in diameter. For a soil cement base less than seven inches in depth, the core must be four inches in diameter. Dependent upon the core strengths determined, ALDOT (2014) gives guidance on how to take appropriate action for contractor pay, as shown in Table 0.4.

Table 0.4: ALDOT Compressive Strength Pay Requirements

7-Day Compressive Strength ($\boldsymbol{f_c}$)	**Specification Action**
$\boldsymbol{f_c}$ < 200 psi	Remove and Replace
200 psi ≤ $\boldsymbol{f_c}$ < 250 psi	Price Reduction
250 psi ≤ $\boldsymbol{f_c}$ ≤ 600 psi	No Price Reduction
600 psi < $\boldsymbol{f_c}$ ≤ 650 psi	Price Reduction
$\boldsymbol{f_c}$ > 650 psi	Remove and Replace

The thickness is checked where the cores are taken. The compacted layer shall not be more than one half of an inch less or one inch more than the required thickness. When all quality assurance checks of density, strength, and thickness meet ALDOT requirements, the contractor may then by paid for the work completed, as necessary.

1.6.5.2 Molded Cylinder Strength Test Methods

1.6.5.2.1 Strength Correction Factor for Length-to-Diameter Ratios

For concrete cylinders, ASTM C39 (2020) states that if a specimen's length-to-diameter ratio (L/D) is 1.75 or less, the compressive strength must be multiplied by the appropriate strength correction factor. ASTM D1632 (2017) suggests that the use of the same strength correction factors be used for soil cement specimens. However, Wilson (2013) performed a study on L/D strength correction factors for correcting unconfined compressive strength of soil cement cylinders and found evidence suggesting that this was not a wise practice. It was shown that the ASTM C39 L/D strength correction factors were not applicable to soil cement cylinders when made using ASTM D1632 (2017). The unbiased estimate of the standard deviation for the error when using ASTM C39 correction factors was six times greater than that of using no correction factors (Wilson 2013). It was recommended that no L/D strength correction factor be applied for L/D ratios of soil cement that ranged between 1.0 and 2.0 (Wilson 2013).

1.6.5.2.2 Proctor Molded Specimens

In accordance with ASTM D559 (2015), soil cement compressive strength testing is conducted using a specimen size of 4.0 inches in diameter and 4.58 inches in height with a L/D ratio of 1.15. ASTM D1633 (2017) states that using a specimen of this size gives a "relative measure of the strength rather than a rigorous determination of compressive strength". As most soil testing laboratories have this equipment on hand, it is often used because of its availability.

ASTM D1633 (2017) states that in order to use this method, at least 70 percent of the material must be able to pass the 19.0 millimeter (¾ inch) sieve. To produce a soil cement specimen, ASTM D698 (2012) outlines a specific technique and procedure. The method utilizes a Proctor mold and a 5.5-pound hammer. A soil cement mixture is placed in the mold in three equal lifts and the hammer is dropped 25 times per lift around the specimen. Once three lifts are completed, the top portion of the mold is removed, and the surface is trimmed to the top edge of the bottom mold. An example of the equipment used can be seen in Figure 0.23.

Figure 0.23: Standard Proctor mold and hammer used to make soil-cement specimens (McLaughlin 2017)

ASTM D1632 (2017) specifies how the specimen should be cured. The molded specimen shall remain in the Proctor mold in a moist room for 12 hours or longer, and once it is removed, the specimen shall be extruded from the mold (ASTM D1632 2017). The soil cement specimen should then be placed back into the continuous moist-curing room (ASTM D1632 2017). Before the unconfined compression strength testing, the specimen shall be immersed in water for four hours and then immediately tested (ASTM D1632 2017).

1.6.5.2.3 Steel-Mold Method

The Steel-Mold (SM) method pertains to the procedures of ASTM D1632 (2017). Wilson (2013) studied the previous version of the specification to determine how best to produce and cure soil cement specimens. ASTM D1632 (2017) procedures produce a soil cement cylinder that has a diameter of 2.8 inches and a height of 5.6 inches that results in a L/D of 2.0. The specimen size gives a better measure of the compressive strength than the Proctor specimen since it reduces the complex stresses that may occur during the shearing of the smaller L/D ratio specimens (ASTM D1633 2017). The cylindrical steel molds used have an inside diameter of 2.8 ± 0.01 inches and a height of nine inches. All equipment used in the SM method is shown in Figure 0.24, with detailing shown in Figure 0.25, which includes (ASTM D1632 2017):

- Machined steel top and bottom pistons with diameter 2.795 inches, only 0.005 inches less than the mold inside diameter
- 6-inch long mold extension
- Spacer clips
- Two aluminum separating disks 1/16 inches thick by 2.78 inches in diameter
- Two ultra-high molecular weight (UHMW) polyethylene plugs with diameter 2.795 inches, only 0.005 inches less than the mold inside diameter
- Smooth steel tamping rod

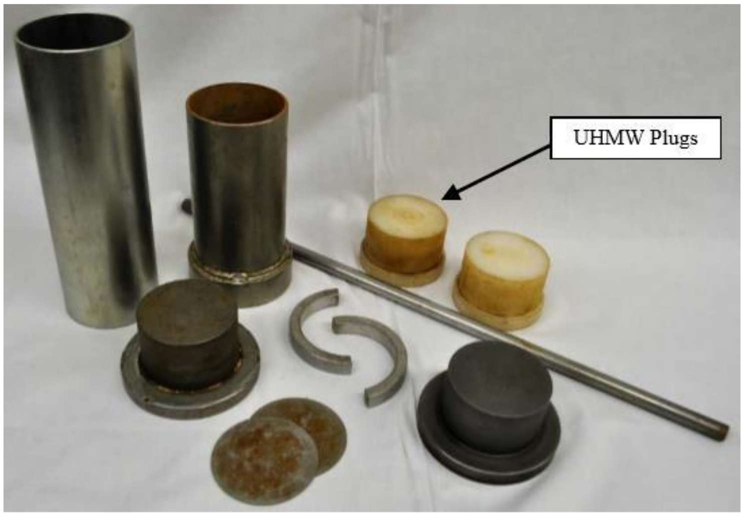

Figure 0.24: Soil cement SM method equipment (McLaughlin 2017)

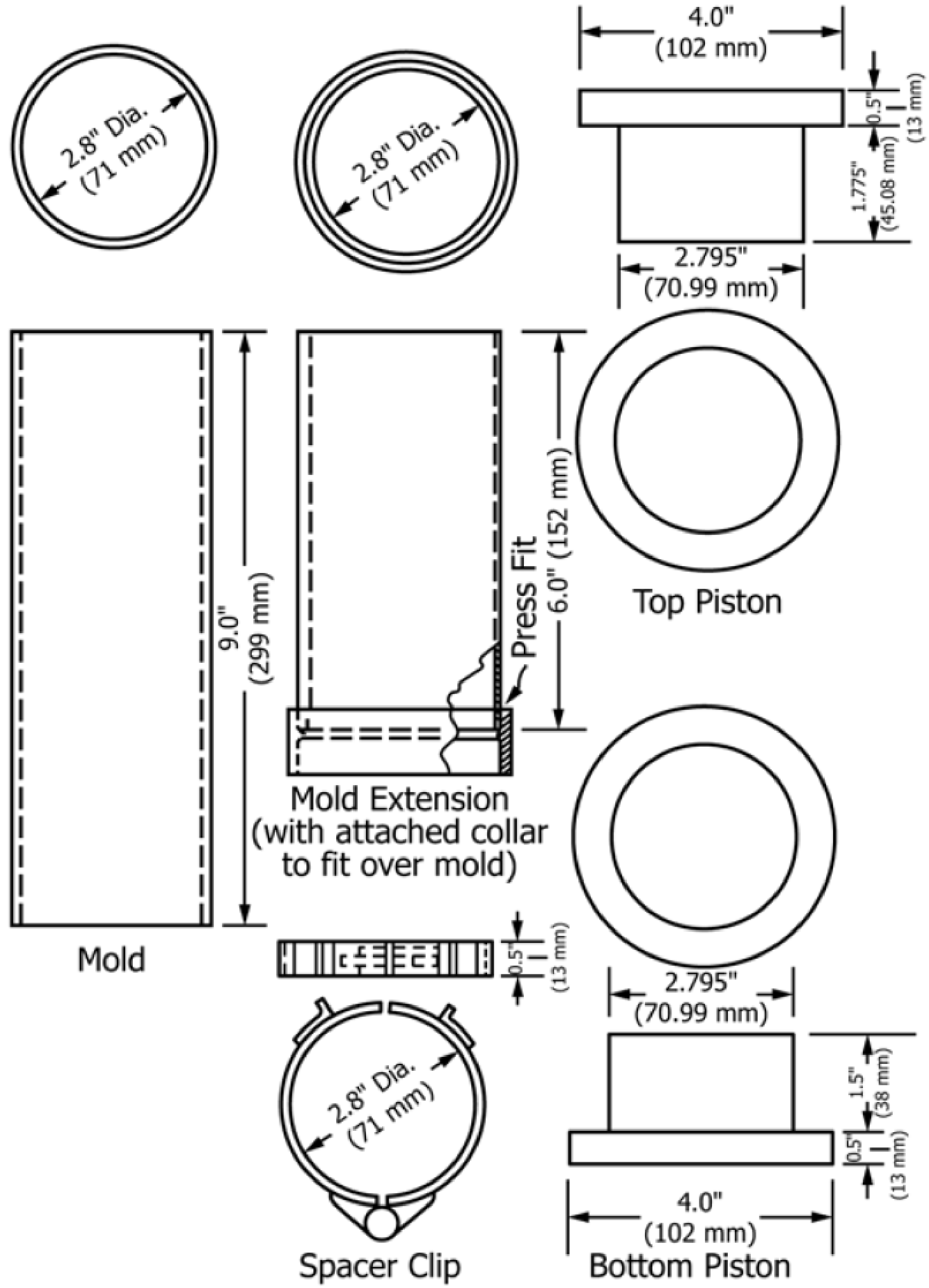

Figure 0.25: Soil cement SM method equipment details (ASTM D1632 2017)

To produce a specimen, a freshly mixed soil cement sample is tested to determine its moisture content. Based on the moisture content and the moisture-density curve of the mixture, a target mass is determined to create a specimen with a density of at least 98 percent, as shown in

Equation 2.1. The coefficient of 9.056 incorporates the volume of the cylinder and converts the weight from pounds to grams for lab scale usage (Wilson 2013).

$$M_{SC} = 9.056\ x\ \gamma_{dry} \qquad \text{(Equation 0.1)}$$

Where,

M_{SC} = Target mass of soil cement required (grams), and

γ_{dry} = Dry unit weight corresponding to sample optimum moisture content $\left(\frac{lb}{ft^3}\right)$.

After the mass required is determined, the mold is then assembled on the scale. First the bottom piston is placed, head down, and the spacer clips are situated around the shaft. Then, the mold and separating disks are lightly coated with a low-viscosity oil and placed on the spacer clips. Once assembled, the extension is placed on top of the mold and the scale is tared to read zero grams. With the assembly complete, soil cement can now be added to the apparatus.

Soil cement is transferred into the mold until approximately half of the required mass has been added, then the tamping rod is used to tamp the soil cement lightly. The rest of the soil cement is added, and the tamping rod is then used again. This time, tamping is done to ensure that all material is below the bottom of the extension. This requires the ability to see into the top of the extension where the seam between the mold and the extension is. Once all soil cement is below the mold-extension seam, the weight is confirmed to have been unchanged and the extension sleeve is removed. A separating disk and the top piston are then placed on top of the mold. The spacer clips are removed, and the specimen is then ready for compaction.

The specimen is compacted until the top and bottom pistons touch the mold, causing refusal of further compaction due to intended equipment limits. Compaction is conducted using a compacting drop-weight machine. Depending on the cement content and moisture of the mixture, compaction could take anywhere from 10 to 50 hammer drops. Once refusal is reached, the pistons are replaced with the UHMW plugs and wrapped with aluminum tape to limit moisture loss during the initial stages of in-lab curing. An example of a specimen in the compaction apparatus can be seen in Figure 0.26. An example of these lab specimens once initial curing has begun can be seen in Figure 0.27.

Figure 0.26: SM cylinder compacted in a drop-weight machine (Wilson 2013)

Figure 0.27: SM cylinders during the initial curing period in the lab. (Scales 2020)

The steel-molds are then transferred out of the sun or to a location in the laboratory where they have limited exposure to the elements to eliminate chances of rapid evaporation. After 12 hours, the specimens are then transported to the laboratory where the specimens are extruded from the mold using a vertical specimen extruder. Nemiroff (2016) adjusted the curing method by immediately placing the SM specimens into sealed plastic bags and then placing the bagged specimens inside a moist-curing room. It was found that specimens placed without bags in the moist-curing room became soft and did not gain strength from three to seven days (Nemiroff 2016). An example of the sealed specimen in the bag can be seen in Figure 0.28.

Figure 0.28: Soil cement specimen wrapped in a plastic bag to moist-cure

1.6.5.2.4 Plastic-Mold Method

Both Alabama and Mississippi have been conducting research into using the plastic mold method as a way to ensure quality assurance of the soil cement base. Sullivan, Howard, and Anderson (2014) developed a method using a plastic mold (PM) similar to that used to make concrete cylinders to produce and cure soil cement specimens in the laboratory and in the field. The details of this method can be seen in Section 1.6.6.1. McLaughlin (2017) used the newly developed PM method for research on Alabama soil cement projects. The methods have the same principle in determining the unconfined compressive strength of a soil cement mixture in the laboratory and field settings. Both studies found that using the PM method was much easier and took less time and effort to create specimens than using the SM method.

Most of the PM method equipment used to create a test specimen is the same as that used with steel molds. A steel mold was designed to allow a 3-inch diameter by 5.9-inch tall specimen to be compacted while preventing the mold from distorting. The mold is mounted to an 11.4- by 9.5- by 0.5-inch steel plate via compression from a split mold. The split-mold inner diameter is the same as the outer diameter of the plastic mold to better facilitate alignment and to prevent the plastic mold from distorting from pressure during compaction. The opening of the split mold is held together with locking pliers. The collar helps to temporarily contain soil during the compaction process. Compaction is accomplished using a modified Proctor hammer; the hammer is 10 pounds in weight and is dropped from a height of 18 inches. The equipment used by McLaughlin (2017) and Scales (2020) is shown in Figure 0.29.

Figure 0.29: Plastic-mold method equipment (Scales 2020)

ALDOT and McLaughlin (2017) collaborated to alter the method developed by Sullivan, Howard, and Anderson (2014) due to the fact that specimens were damaged during extrusion. The damage only occurred in some samples and consisted of horizontal cracks developed around the specimen as shown in Figure 0.30.

Figure 0.30: Plastic-mold specimen damaged by extrusion process (McLaughlin 2017)

The collaboration gave way to the idea of avoiding the extrusion shearing stresses by instead making a vertical cut down the side of the plastic mold with a box blade (McLaughlin 2017). This way, the specimen would be able to slide out of the mold with minimal surface shear stress because the mold would deform to a larger diameter. During the compaction process, even though the mold would be held together by the Proctor mold and locking pliers, the mold was sealed together with aluminum tape to imitate an uncut mold. The modification process used to cut the plastic mold and the final product developed by McLaughlin (2017) can be seen in Figure 0.31.

Figure 0.31: PM Method modification process and result (McLaughlin 2017)

Scales (2020) conducted research following the modification of the PM method made by McLaughlin (2017). It was found that the tape on some of the PM molds was splitting along the direction of the mold cut. This issue was corrected by simply adding two strips of tape at the top that wrap around one third of the circumference of the mold, centered on the cut (Scales 2020). It was reported that the chance of the tape splitting while being compacted was greatly reduced (Scales 2020). An example of this modification can be seen in Figure 0.32.

Figure 0.32: Modification to PM method mold to reduce tape splitting (Scales 2020)

When preparing the specimen using the PM method, compaction consists of three equal lifts. The PM method is not dependent upon water content and thus does not require pre-weighing of the material once mixing is complete. With research conducted by McLaughlin (2017) and confirmed by Scales (2020), seven blows with the hammer is adequate for creating enough energy for this size of cylinder to compact the soil cement to at least 98 percent density. Following the final lift, the collar is removed, and the material trimmed flush with the top of the mold using a straightedge. An example of a straight edge used can be observed in Figure 0.29. Finally, a plastic cap is used to cover the exposed top of the specimen and a piece of tape is applied to help prevent further moisture loss during initial curing.

The PM cylinders are them transported back to the lab and demolded after 24 hours. To demold, the tape along the side is removed and the mold is pulled slightly open at the split. The cylinder would then simply slide out once the mold is pulled open enough. The specimens are then weighed, and the height and diameter measurements are taken. Curing for the PM cylinders followed the method Nemiroff (2016) used for the SM cylinders where the specimens are placed in sealed plastic bags and put in the cure room until the time of testing.

Testing followed ASTM D1633 (2017) on the seventh day of curing with a few changes recommended by Wilson (2013). The modifications are as follows:

- The specimens were not soaked for four hours prior to compression testing
- The loading rate was changed to 10 ± 5 psi/second.
- The specimens were also not capped.

1.6.5.3 In-Place Strength Test Methods

1.6.5.3.1 Core Testing

Coring is a destructive test method used to extract a sample of material for strength tests to determine the in-place strength of the base. Coring is currently ALDOT's quality assurance method of determining the in-place strength of soil cement as mentioned in section 2.2.5.1. Figure 0.33 shows an example of a core being removed from an ALDOT project.

Figure 0.33: Core removal (Scales 2020)

There are several methods used to cut cores from the soil cement and to condition them until the time of testing. For the state of Alabama, ALDOT 304 (2014) states that the locations of cores taken are to be randomly selected by the project engineer. ALDOT 419 (2008) specifies the requirements for the coring operation and states that the coring equipment shall follow the specifications in AASTHO T24. ALDOT 304 (2014) states that cores shall be six inches in diameter for soil cement layers greater than seven inches in thickness. If the core is not greater than six inches in height, then the cut core must be discarded, and another core must be retrieved that meets the length requirements. Coring should be done dry but can be performed with a minimum amount of water at a low flow. Figure 0.34 shows a discarded core that deteriorated during extraction and was too short to meet minimum length requirements.

Figure 0.34: Soil cement core that failed to meet minimum length requirements (Scales 2020)

All cores taken from the in-place soil cement base shall be placed in a plastic bag to minimize moisture loss on site and during transportation to the lab (ALDOT 419 2008). If water was used during the operation, the core shall be allowed to air dry in the shade for 30 minutes before being placed in the plastic bag (ALDOT 419 2008). Once bagged, the cores are to be placed horizontally with at least half of their diameter embedded in a pre-dampened bed of sand in a covered wooden box or cooler that is provided by the contractor, then transported to the testing location as soon as all cores have been removed (ALDOT 419 2008). The sample is removed from the plastic bag and dry-sawn down to remove any irregularities to the surfaces upon arrival at the testing location. ALDOT 419 (2008) states that both ends of the cores should be capped per AASHTO T231 specifications using sulfur mortar only. Cores should only be tested when the sulfur mortar has hardened (ALDOT 419 2008). Testing equipment shall meet AASTHO T22 guidelines and the person performing the test shall be an ACI certified Concrete Strength Testing Technician (ALDOT 419 2008). Since the length-to-diameter ratio is less than 2, a correction factor specified in AASHTO T22 shall be applied to the unconfined compressive strength results (ALDOT 419 2008). Once the cores have been extracted, the contractor shall fill the holes with either the same mixture of soil cement or by other repair methods approved by the State Materials and Tests Engineer (ALDOT 419 2008). If repaired with the soil cement mixture, it shall be placed in increments of 3-inch thick layers at a time and consolidated by tamping (ALDOT 419 2008).

Core strength results from past ALDOT projects have been found to be highly variable. The unconfined compressive strength results taken from ALDOT project STPAA-0052 (504) over the length of the roadway were plotted. These results indicate that core strengths are highly variable due to a large amount of data points falling outside of the Upper Limit or the Lower Limit bounds. The plotted compressive strength results from this project are shown in Figure 0.35.

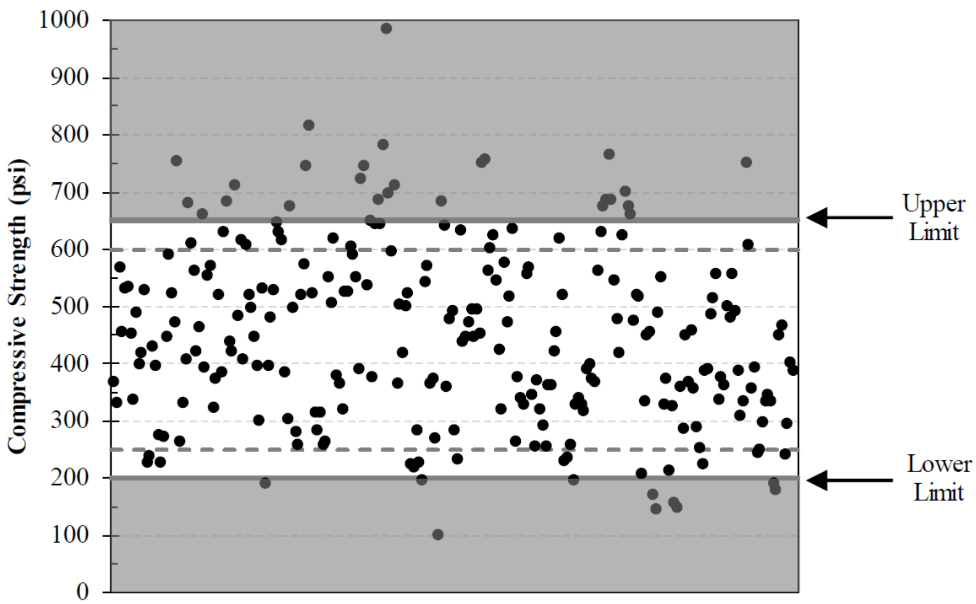

Figure 0.35: Compressive strengths of cores from ALDOT project STPAA-0052 (504) (Nemiroff 2016)

1.6.5.3.2 Dynamic Cone Penetrometer

The dynamic cone penetrometer (DCP) is an in-situ testing device used in field exploration, and for quality control and quality assurance of compacted soils during construction. It is easy to operate while being relatively inexpensive and produces repeatable results (Nemiroff 2016). The DCP was originally developed in South Africa for in-situ evaluation of pavement layer strength (Scala 1956). Ahsan (2014) states that the DCP has been used in South Africa, the United Kingdom, Australia, New Zealand, and in a few states in the United States. The DCP has been correlated to engineering properties such as the California Bearing Ratio (Mohammadi, et al. 2008), soil classification (Huntley 1990), and unconfined compressive strength (Nemiroff 2016).

By changing the weight and or the drop height, a dynamic cone penetrometer can be configured for its intended use. ASTM D6951 (2018) is for DCP used in shallow pavement applications. This DCP configuration consists of a 17.6 pound (8 kg) or a 10.1 pound (4.6 kg) hammer with a drop height of 22.6 inches (575 mm) (ASTM D6951 2018). A schematic of this ASTM-standard DCP is shown in Figure 0.36.

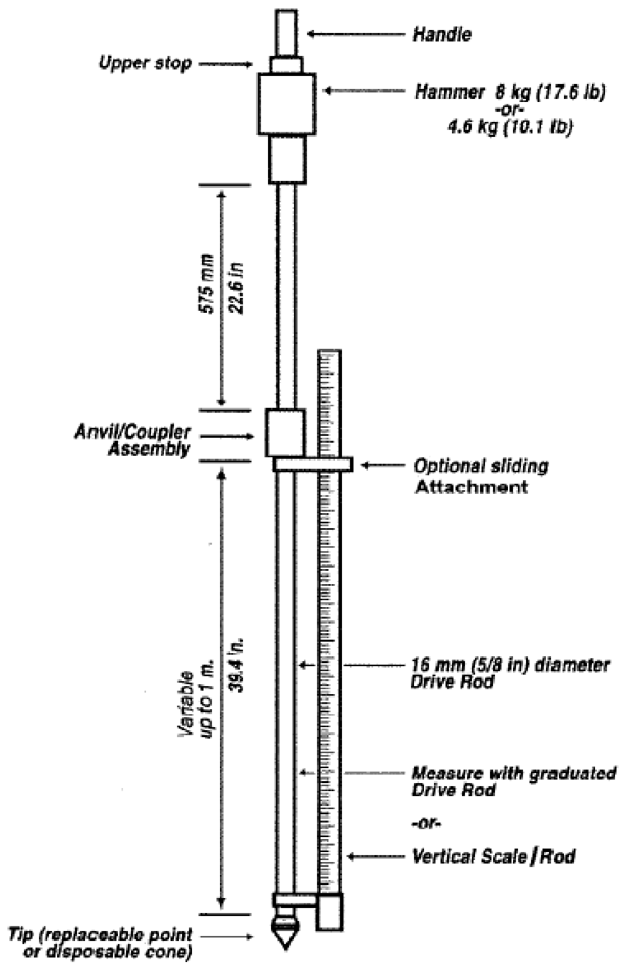

Figure 0.36: ASTM-Standard DCP schematic (ASTM D6951 2018)

The ASTM-Standard DCP consists of a 5/8-inch (16 mm) diameter steel drive rod with a replaceable point or disposable cone tip, a coupler, a handle, and a vertical scale (ASTM D6951 2018). The tip has an included angle of 60 degrees and a diameter at the base of 20 mm (ASTM D6951 2018). Schematic drawings of a replaceable point tip and a disposable cone tip are shown in Figure 0.37.

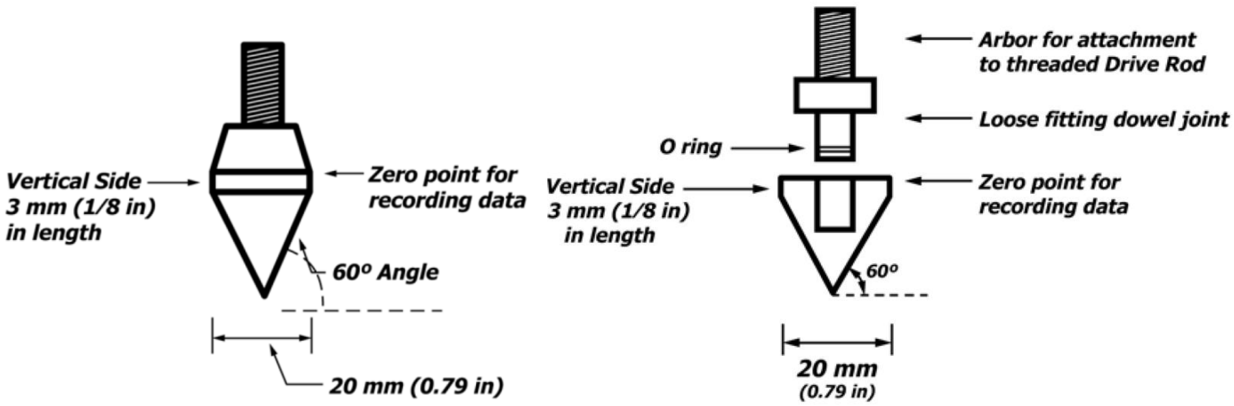

Figure 0.37: Schematic of DCP replaceable point tip (left) and disposable cone tip (right) (ASTM D6951 2018)

To use the DCP, the device is to be held plumb and the hammer raised to the maximum height and then dropped. The penetration distance is read on the scale and recorded. There are two methods to recording the distance after it has been dropped, using a magnetic ruler or manually on a millimeter scale. A magnetic ruler will read it automatically after every drop, while in accordance with ASTM D6951 (2018) a reading is manually recorded after every five drops on a millimeter scale. An example of the DCP outfitted with a magnetic ruler can be seen in Figure 0.38.

Figure 0.38: DCP equipped with a magnetic ruler (McLaughlin 2017)

The readings obtained are then used to calculate various parameters depending on the intended purpose. One important parameter calculated is the dynamic cone penetration index (DCPI). The DCPI, known formerly as dynamic penetration index (DPI), is defined as "the amount of cone penetration due to one drop of the hammer and hence the unit for DPI is mm per one blow or inches per one blow" (Enayatpour, Puppala and Vasudevan 2006). The DCPI is determined using Equation 2.2.

$$DCPI = \frac{PR_2 - PR_1}{BC_2 - BC_1} \qquad \text{(Equation 0.2)}$$

Where,

PR = Penetration (mm),

BC = Blow count,

$PR_2 - PR_1$ = Difference between two consecutive depth readings, and

$BC_2 - BC_1$ = Difference between two consecutive blow counts.

The DCPI can be calculated after every five drops or can be calculated based on the total penetration depth and blow count. The unconventional use of millimeters as units for penetration was chosen as it is more accurate and easier to record penetration data in millimeters than in inches. This unit convention has also been used previously by Ahsan (2014), Nemiroff (2016), McLaughlin (2017), and Scales (2020) during their investigations into using the DCP to determine strength of stabilized soils.

Extensive research has been performed on soils for factors that can affect the DCP tests. Plasticity, density, moisture content, and gradation affect the measurements of the DCP (Kleyn and Savage 1982). Hassan (1996) concluded that moisture content, AASHTO soil classification, confining pressures, and dry density of fine-grained soils affect the DCP measurements. George and Uddin (2000) concluded that the maximum aggregate size and the coefficient of uniformity could affect the DCP results.

Also, researchers have found that the DCP penetration slope, in penetration depth per blow, is inversely related to the strength of the specimen being tested (McElvaney and Bunadi Djatnika 1991; Patel and Patel 2012; Nemiroff 2016; Scales 2020). Therefore, a specimen that has a high strength will take many more blows to reach a certain penetration depth compared to a low strength specimen reaching the same depth.

1.6.5.3.2.1 Configuration of DCP Strength Evaluation in Laboratory

Research pertaining to methods for evaluating DCP strength results has been conducted in the laboratory and in the field. Nemiroff (2016) evaluated the use of the DCP to estimate cylinder strengths in the laboratory. NCDOT (2015) has a field manual that covers how the DCP should be used and evaluated on field projects. McLaughlin (2017) used the DCP to assess the in-place strength of soil cement base. Scales (2020) continued the work of Nemiroff (2016) and McLaughlin (2017) by further lab and field evaluation of the DCP.

Nemiroff (2016) designed a concrete block that confines a cylindrical, plastic five-gallon bucket. The bucket was 12-inches in diameter and 14-inches in height and was chosen based on research performed by Enayatpour, Puppala, and Vasudevan (2006) as the bucket allowed for a 10-inch tall specimen to be produced and a large enough diameter for the DCP to collect representative data (Nemiroff 2016). The confinement block was necessary to replicate the confinement present in field conditions when testing an in-situ base (Nemiroff 2016). A schematic of the confinement block is shown in Figure 0.39. An example of the reinforced concrete confinement block with and without a specimen inserted can be seen in Figure 0.40.

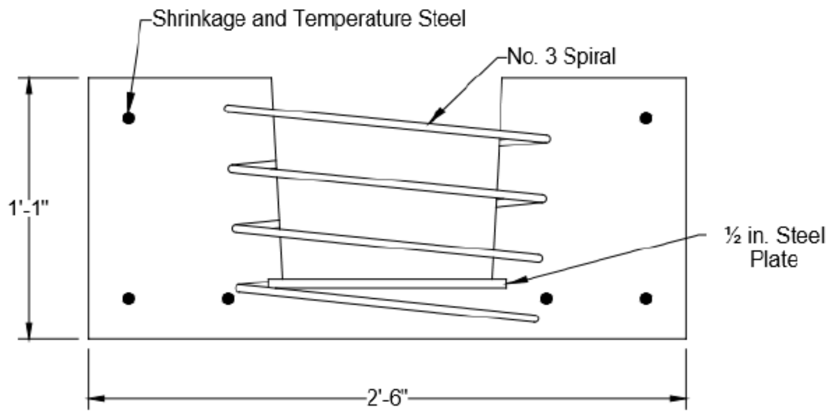

Figure 0.39: Designed reinforced concrete confinement block schematic (Nemiroff 2016)

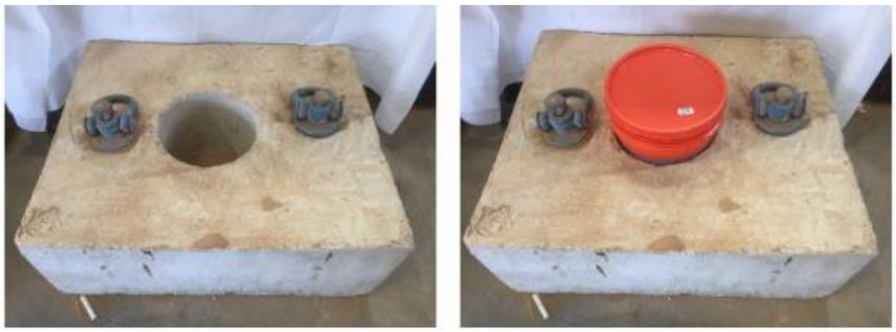

Figure 0.40: Reinforced concrete confinement block with and without a DCP Specimen (Nemiroff 2016)

Nemiroff (2016) compacted the soil cement in the mold using a Kango 900B ¾ in. Hex Demolition Hammer based on recommendations from ASTM C1435 (2014). A circular steel tamping plate welded to a steel shaft was attached to the compaction hammer to simulate the vibrating roller used to compact soil cement in field construction (Nemiroff 2016). An example of the vibrating compaction hammer and mounted plate can be seen in Figure 0.41.

Figure 0.41: Vibrating compaction hammer with circular steel plate (Nemiroff 2016)

The production of the specimens started immediately after the soil cement mixing was completed (Nemiroff 2016). An empty five-gallon bucket was placed inside the concrete block with marks at 4.5 inches, 7.5 inches, and 11.5 inches from the bottom to indicate the depths at which the soil cement would be compacted into three equal lifts to ensure the entire specimen would be compacted equally, similar to the compaction method used in ASTM D1557 (2012) (Nemiroff 2016). The DCP compaction pattern followed ASTM D1557 (2012) for each compaction layer. For positions 1 through 4, the vibrating hammer was run for three seconds each. The hammer then moved in a circular pattern making one revolution every 14 seconds. Three complete revolutions were made before stopping the vibratory compactor and the next layer was filled. This was done until three DCP specimens were made using the same soil cement mixture. An illustration of the compaction pattern can be seen in Figure 0.42.

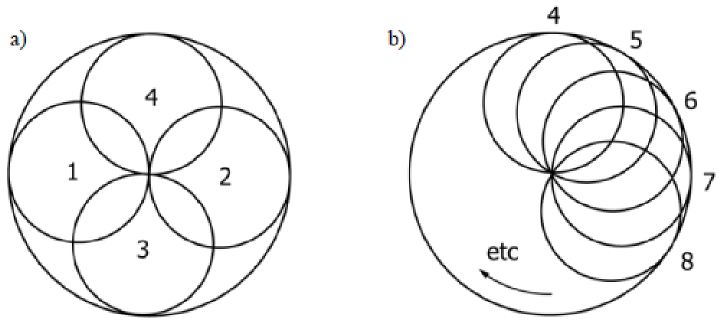

Figure 0.42: DCP compaction pattern (ASTM D1557 2012)

Curing of these laboratory DCP specimens began as soon as the compaction process was completed. The buckets were covered with a lid and moved to a moist-curing room. Once in the moist-curing room, the lids were removed for a few minutes to allow moist air to enter the bucket and the lid was then placed back on the bucket (Nemiroff 2016). After 12 to 48 hours, the lid was removed and replaced with a plastic sheet attached using plastic clips to prevent water from entering the specimen (Nemiroff 2016).

Scales (2020) tested the effect that using only the plastic sheet and clips had on the slope results. It was concluded that the difference of using plastic sheets or the lids was small and therefore negligible for the purposes of the research (Scales 2020). This conclusion has allowed for all DCP specimens produced using either method to be combined into one database for analysis (Scales 2020).

After the specified amount of time was spent in the curing room, DCP tests were performed at three and seven days. The DCP specimens were moved back to the concrete confinement block where the DCP was seated in the center of the specimen and run to a depth of eight inches (Nemiroff 2016). The three DCP specimens tested were then combined for a single DCP penetration slope result (Nemiroff 2016).

1.6.5.3.2.2 Configuration of DCP Strength Evaluation in Field Construction

The details of the NCDOT field manual as it pertains to DCP methodology will be discussed further in Section 1.6.6.3. Although NCDOT (2015) prescribed five tests per location, McLaughlin (2017) reduced the number of DCP tests to three in an effort to reduce the number of DCP blows and technician effort while still achieving accurate results. The pattern used was triangular in shape and each test was conducted two feet apart to avoid impacting the other tests while remaining close enough to collectively characterize the in-place strength at the testing location (McLaughlin 2017). An illustration of the triangular testing pattern used by McLaughlin (2017) can be seen in Figure 0.43.

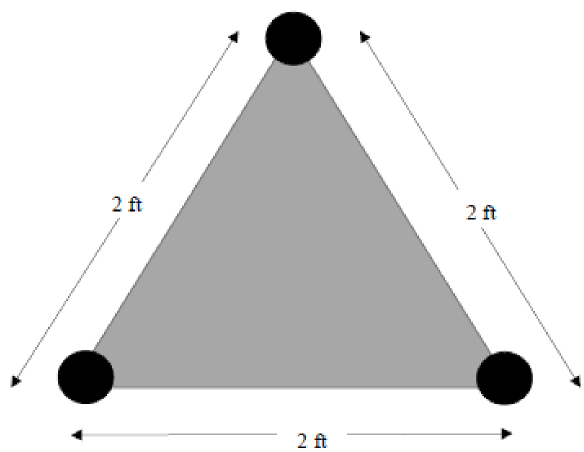

Figure 0.43: DCP testing pattern (McLaughlin 2017)

The average DCP result would be inserted into the Nemiroff (2016) equation that is discussed in detail in Section 1.6.5.3. The DCP was conducted using the triangular pattern to a depth of eight inches at each of the three location, one for core testing and two for material collection to make molded cylinders. Figure 0.44 illustrates the location of a core indicated by the circle with a crosshair at location 3 and the location of material sampling to be used to make cylinders by the hollow ring at locations 1 and 2 that was used by McLaughlin (2017) .

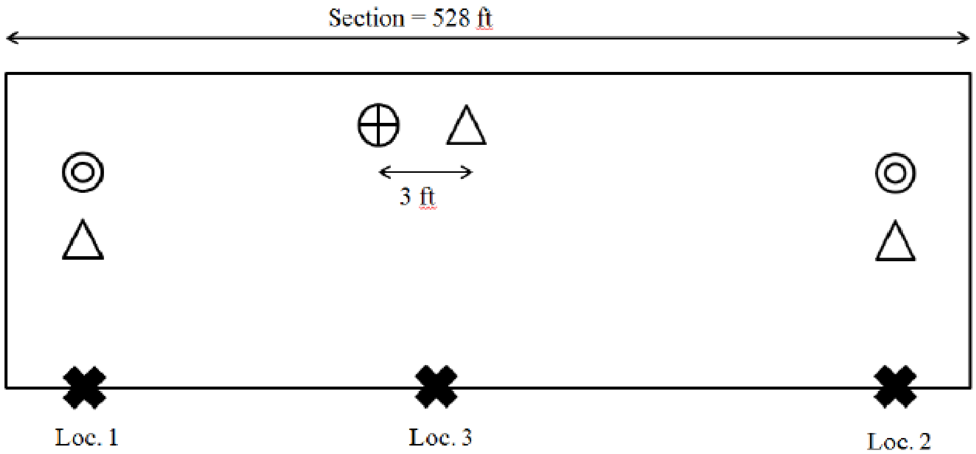

Figure 0.44: Field testing plan conducted by McLaughlin (2017)

Scales (2020) continued DCP field research, following the investigation conducted by McLaughlin (2017), on an ALDOT project using soil cement base. The research compared the compressive strength results from core testing (ALDOT 419 2008), cylinders made using the PM method (Scales 2020), and DCP testing (ASTM D6951 2018). The DCP slope results were converted to strength. The variation made by Scales (2020) was to follow the NCDOT guideline for DCP testing using five tests at each location of coring or material sampled to make molded cylinders as opposed to three tests done by McLaughlin (2017). The field-testing plan followed by Scales (2020) can be seen in Figure 0.45 which uses markers for cores as the hollow ring at locations 1, 2, and 3 and markers for cylinder material sampling as the circle with an “X” at locations A, B, C, and D. An example of the DCP testing conducted by Scales (2020) at the ALDOT project can be seen in Figure 0.46.

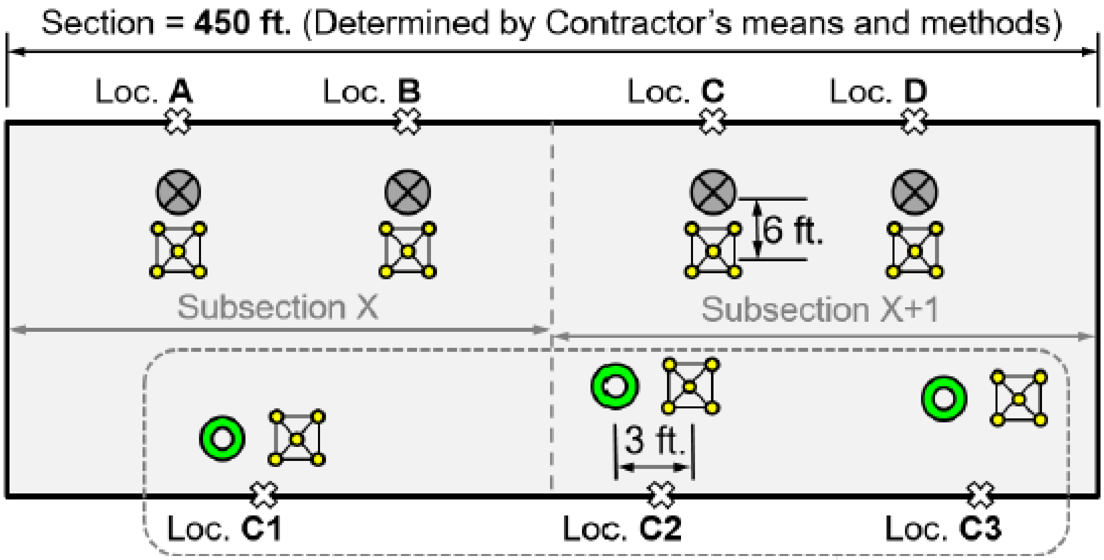

Figure 0.45: Field testing plan conducted by Scales (2020)

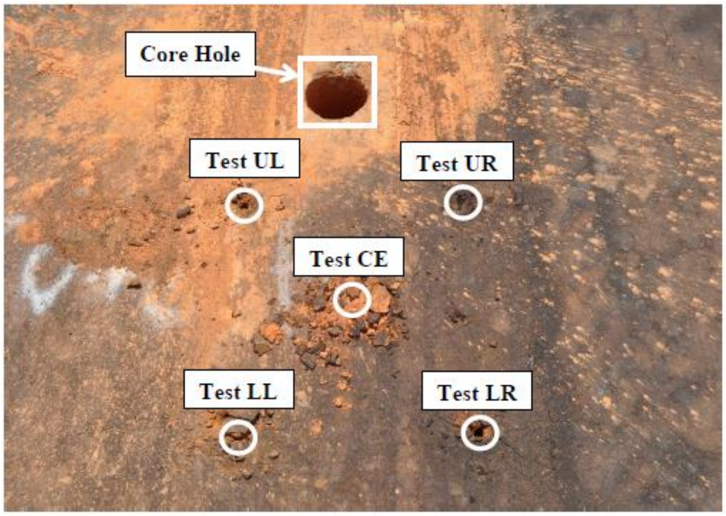

Figure 0.46: Testing pattern for each DCP testing location conducted by Scales (2020)

The field research conducted by Scales (2020) compared the number of DCP tests to determine a balance between operator effort and reliable results. The options were three, four, or five tests at one location. The benefit of using five tests is to collect more data to better characterize the soil strength at each location, but the benefit of using three tests is that the operator effort significantly decreases per location. Scales (2020) focused on confirming whether a series of three tests was able to give reliable enough results, and checking a series of four tests for the same reasoning. Scales (2020) created a chart to display the variation between the number of tests for each depth analyzed which can be seen in Figure 0.47. It was concluded that three tests was an adequate collection of data at one location to give reasonable results.

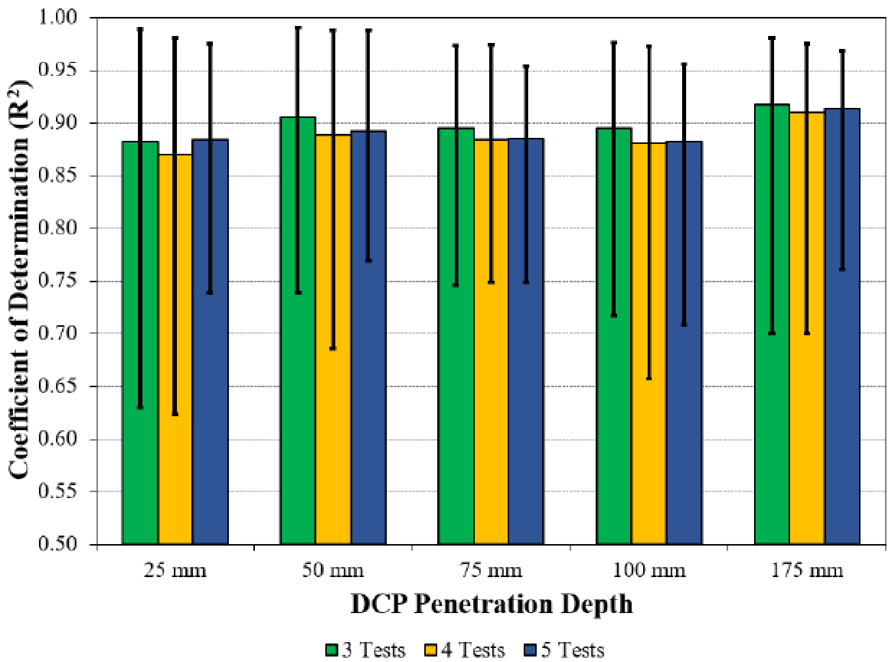

Figure 0.47: Coefficient of determination for all DCP test results collected (Scales 2020)

Additionally, a method to determine whether outliers were present at each location was discussed to determine the variability of the field results for the DCP (Scales 2020). It was found that, in some instances, some of the test locations were highly variable in the 2-foot distance between the DCP tests, skewing the data inappropriately (Scales 2020). By using the acceptable error range of 50 percent recommended by McLaughlin (2017), a detailed method to identify whether or not outliers are present was discussed. These calculations will be discussed in further detail in Section 1.9.10.

1.6.5.3.2.3 Correlation between DCP and Unconfined Compressive Strength

Research has been completed on various soil types to determine the relationship between the dynamic cone penetration index and the unconfined compressive strength. The first efforts were laboratory studies performed by McElvaney and Djatnika (1991) on silty clay, clay, and sandy clay with and without the addition of lime. McElvaney and Djatnika (1991) performed DCP tests using an ASTM-standard DCP hammer of 17.6 pounds on specimens that were 5.98 inches (152 mm) in diameter and 4.57 inches (152 mm) tall. The test specimens were penetrated a total of 50 millimeters (McElvaney and Djatnika 1991). The unconfined compressive strength tests were conducted using British Standard (BS) 1924 (BSI 1975) on specimens with a L/D ratio of 2.0 (McElvaney and Djatnika 1991). McElvaney and Djatnika (1991) concluded that the DCP can be used to provide an estimate of the unconfined compressive strength of lime-stabilized soil mixtures. It was also concluded that since the inclusion of data for material with zero lime content had negligible effects, the correlation is a function of strength and not the method by which the strength is obtained (McElvaney and Djatnika 1991). McElvaney and Djatnika (1991) developed three correlations shown in Equations 2.3 to 2.5 but cautioned these might only apply to lower strength values. The results were then plotted on a graph to determine the relationship between the unconfined compressive strength and the DCP results considering both stabilized and unstabilized material (McElvaney and Djatnika 1991). The resulting graph can be seen in Figure 0.48.

50 percent probability of underestimation:

$$\log(UCS) = 3.56\text{-}0.807\log(DN) \qquad \text{(Equation 0.3)}$$

95 percent confident that probability of underestimate will not exceed 15 percent:

$$\log(UCS) = 3.29\text{-}0.809\log(DN) \qquad \text{(Equation 0.4)}$$

99 percent confident that probability of underestimation will not exceed 15 percent:

$$\log(UCS) = 3.21\text{-}0.809\log(DN) \qquad \text{(Equation 0.5)}$$

Where,

UCS = Unconfined compressive strength (kPa), and

DN = DCP reading (mm/blow).

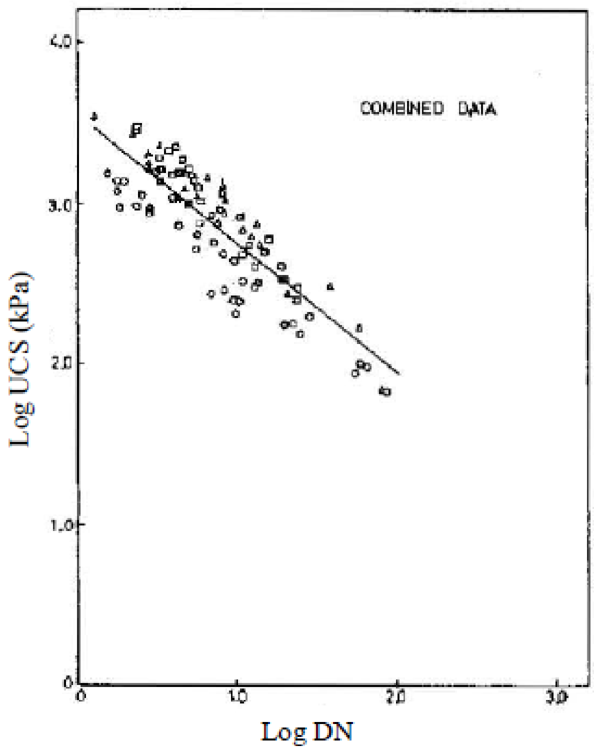

Figure 0.48: Correlation between UCS and DCP results (McElvaney and Djatnika 1991)

Patel and Patel (2012) conducted tests on in-situ conditions simulated in the laboratory on ASTM classified soils of CH, CI, CL, CL-ML, MI, SC, and SM-SC. These soils were also tested while being stabilized with cement, lime, and fly ash. The DCP tests were performed using an ASTM-standard, 17.6-pound hammer on soaked and unsoaked specimens using an automated DCP device (Patel and Patel 2012). The penetration was recorded up to 300 millimeters. Unconfined compressive strength was tested in accordance with Indian Standard (IS) 2720 (1973), using a L/D ratio of 2.0. Patel and Patel (2012) obtained an equation for stabilized and non-stabilized soils that can be seen in Equation 2.6.

$$UCS = 3.1237 \times DCPI^{-0.865} \quad \text{(Equation 0.6)}$$

Where,

UCS = Unconfined compressive strength (N/mm^2), and

DCPI = DCP Index (mm/blow).

Patel and Patel (2012) concluded that the correlation between the unconfined compressive strength and DCPI were independent of soil type and the use of cement, lime, or fly ash. The correlation Patel and Patel (2012) found between the unconfined compressive strength and the dynamic cone penetrometer index for a wide variety of soils that were stabilized using cement, lime, and fly ash and non-stabilized soils can be seen in Figure 0.49.

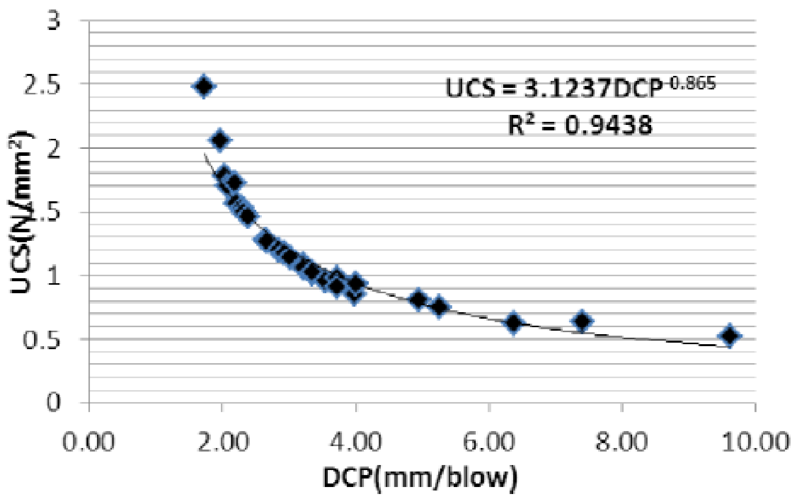

Figure 0.49: Correlation between UCS and DCP results (Patel and Patel 2012)

Enayatpour, Puppala, and Vasudevan (2006) performed a series of laboratory tests on cement and lime stabilized soils to correlate the unconfined compressive strength with the DCP. The percent content of cement and lime were related to the DCP index to estimate the unconfined compressive strength (Enayatpour, Puppala and Vasudevan 2006). The equations for cement and lime are shown in Equations 2.7 and 2.8, respectively (Enayatpour, Puppala and Vasudevan 2006). The coefficient of determination for cement is 0.97 and for lime is 0.91. The results of the predicted strengths of the specimens using the equations versus the measured strength of the specimens can be seen in Figure 0.50.

$$q_c = 470.0+104.3 \times CC+201.0 \times t-4052.7 \times DPI \qquad \text{(Equation 0.7)}$$

$$q_c = 241.2-26.2 \times LC+21.6 \times t+335.7 \times DPI \qquad \text{(Equation 0.8)}$$

Where,

q_c = Unconfined compressive strength (kPa),

CC = Cement content (%),

LC = Lime content (%),

t = Curing time (days), and

DPI = DCP Index (mm/blow).

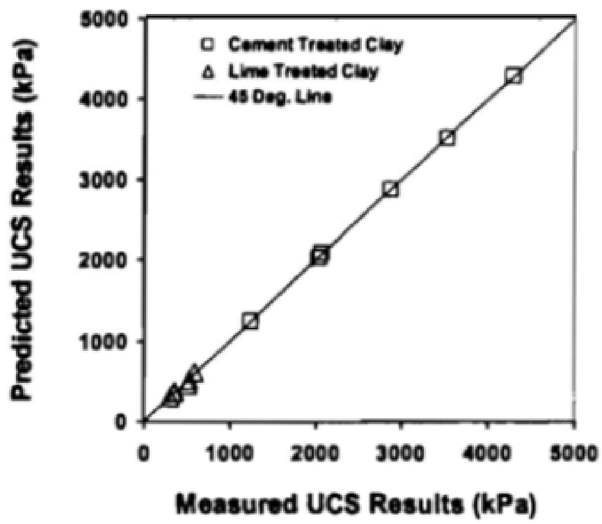

Figure 0.50: Comparison between predicted and experimental results (Enayatpour, Puppala and Vasudevan 2006)

Nemiroff (2016) conducted tests on in-situ conditions simulated in the laboratory on ASTM classified soils of SC, SP, and SP-SC stabilized with cement. The tests were performed with an ASTM-standard DCP hammer of 17.6 pounds on 3- and 7-day cured soil cement specimens (Nemiroff 2016). The specimens were made in five-gallon buckets and confined by a reinforced concrete block to simulate the 8-inch lift thickness of constructed soil cement. The first inch (25 mm) of penetration was discarded as per ASTM D6951 (2018) to allow the DCP to be seated and the next seven inches (160 mm) were recorded. Nemiroff (2016) determined that a 75-millimeter (3-inch) penetration depth was the ideal penetration depth because it produced the best results with the least amount of technician effort. This depth of penetration was also recommended by McLaughlin (2017) and Scales (2020). McLaughlin (2017) concluded that the 75 millimeter depth produces the most efficient results in the field which matches the laboratory results of Nemiroff (2016). Unconfined compressive strengths were determined following the modified ASTM D1632 (2017) method that Wilson (2013) created using a L/D of 2.0 (Nemiroff 2016). Nemiroff (2016) recommended Equation 2.9 for soil cement applications. Nemiroff (2016) used a total of 185 cylinders and 57 DCP specimens to determine the relationship. The equation is valid for a strength range between 100 and 800 psi (Nemiroff 2016).

$$MCS = 926e^{-0.615DCP} \qquad \text{(Equation 0.9)}$$

Where,

MCS = Molded cylinder strength (psi), and

DCP = Dynamic cone penetrometer slope (mm/blow).

Nemiroff (2016) determined that a logarithmic relationship was best suited to correlate the unconfined compressive strength and the DCP slope for typical soils used for soil-cement applications. It was concluded that the correlation between unconfined compressive strength and the DCP was independent of soil type and the amount of cement that was used to stabilize the material (Nemiroff 2016). The MCS to DCP relationship was plotted as shown in Figure 0.51.

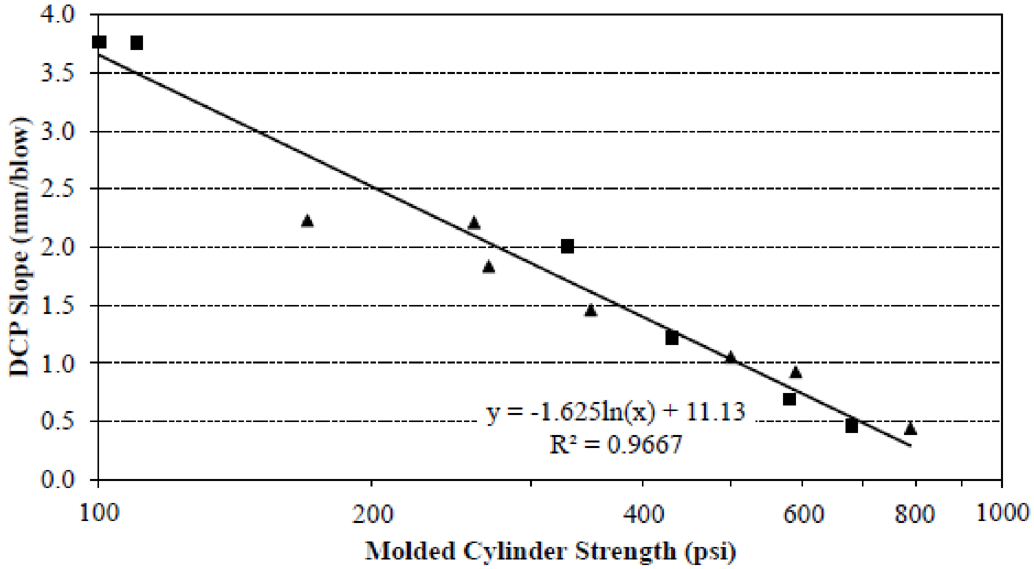

Figure 0.51: Logarithmic correlation of DCP slope and MCS (Nemiroff 2016)

The study conducted by Nemiroff (2016) was continued by Scales (2020) to investigate the suitability of the DCP for strength assessment of soil cement base. Scales (2020) also investigated the strength range for which the DCP would no longer be suitable for compressive strength assessment. This was done similarly to Nemiroff (2016) in that the point of refusal was used as indication of the upper bound strength limit. It was determined that a compressive strength of 965 psi was the general point at which the DCP was no longer able to penetrate (Scales 2020). Therefore, the DCP was considered viable for ALDOT projects because the specified upper strength limit is 650 psi. During the study, Scales summarized the amount of blows it would take for specific strength ranges based on depth and soil cement strength. The blow count summary can be seen in Table 0.5.

Table 0.5: Summary of blow counts needed to reach each penetration depth (Scales 2020)

Penetration Depth	Blow Count		
	250 psi	425 psi	600 psi
25 mm	9	13	20
50 mm	18	26	39
75 mm	26	40	59
100 mm	35	53	79

Scales (2020) combined the results found with those collected by Nemiroff (2016) to create a database of 435 cylinders and 207 DCP specimens. Scales correlated the compressive strength to DCP with a new equation to better represent all data collected. This equation can be seen in Equation 2.10. With all data, a more representative plot of soil cement data was created as shown in Figure 0.52. The validity of converging the databases is the primary purpose of this research and the findings are discussed in Chapter 4.

$$MCS = 1220e^{-0.559DCP} \quad \text{(Equation 0.10)}$$

Where,

MCS = Molded cylinder strength (psi), and

DCP = Dynamic cone penetrometer slope (mm/blow).

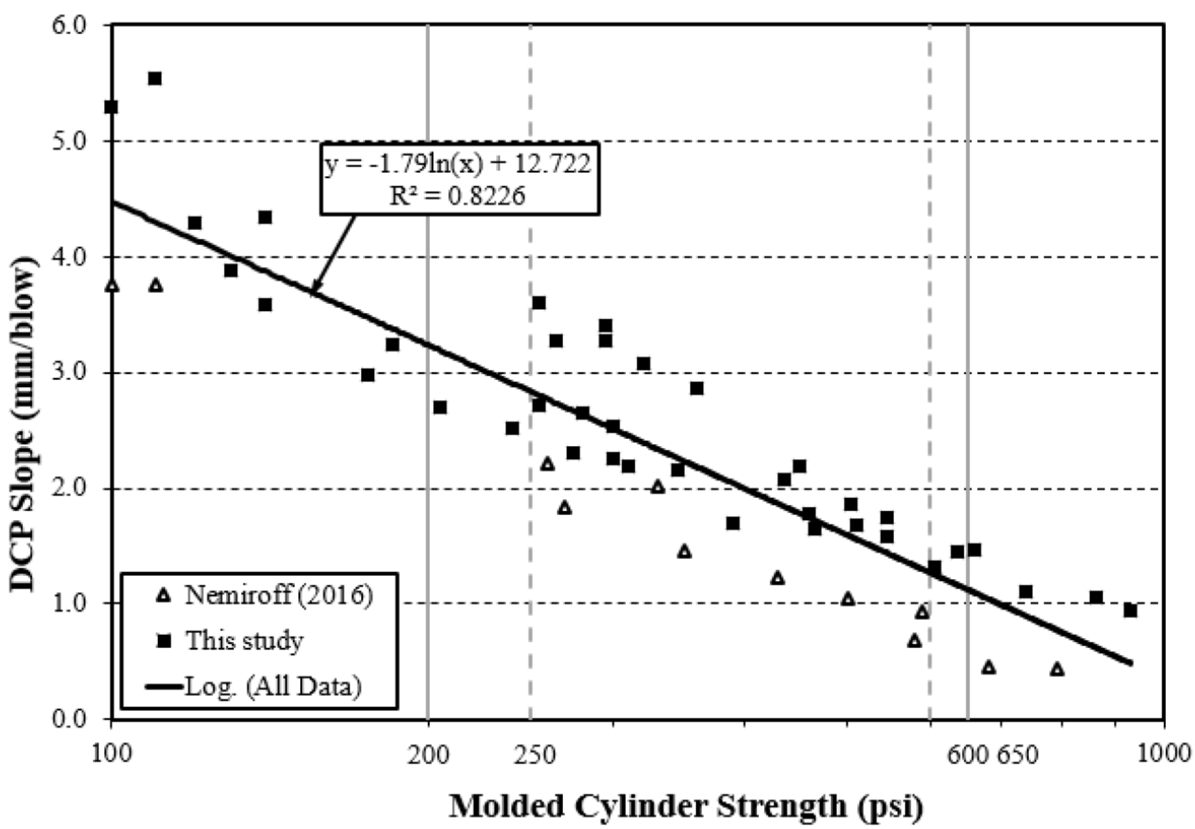

Figure 0.52: Best-fit logarithmic equation for all data collected (Scales 2020)

1.6.6 Testing Methods Used by Other State Departments of Transportation

Every state department of transportation requires some criteria to be met on a project, but each department has their own procedures to follow. Therefore, some of the states surrounding Alabama were investigated to reveal any related literature for soil cement quality evaluation practices. The only surrounding states that currently use or have considered strength assessment of soil cement and/or use the DCP to relate to strength are Mississippi, Georgia, and North Carolina. The practices of these states will be discussed first, followed by other states with relatable information on their practices for pavement bases stabilized by cement.

1.6.6.1 Mississippi Department of Transportation

The Mississippi Department of Transportation (MDOT) uses soil cement extensively as quality base aggregates are in short supply (Sullivan and Howard 2017). Sullivan, Howard, and Anderson (2014) developed the PM method as a way to produce a feasible device that would produce reasonable soil cement specimens that were not as variable as core testing. MDOT uses the same method that was developed by Sullivan et al. (2014). This method uses a standard 3-inch by 6-inch mold, which meets the single use concrete mold requirements based on ASTM C470 (2015). However, the mold has been modified to sand down the bottom plastic ridge to provide a flush surface during compaction (Sullivan, Howard and Anderson 2014). Additionally, a drill-press is used to create a 1.4-inch diameter hole through the center of the mold's bottom. This hole is created to allow for the specimen to be extruded without any damage. An aluminum plate that is three inches in diameter and 0.06 inches thick is inserted into the bottom of the mold to cover the hole and provide a rigid surface for extrusion. The plastic cut-outs from the drilling process are placed back over the bottom of the mold and held in place with tape to provide a solid compaction surface. The modification process is shown in Figure 0.53.

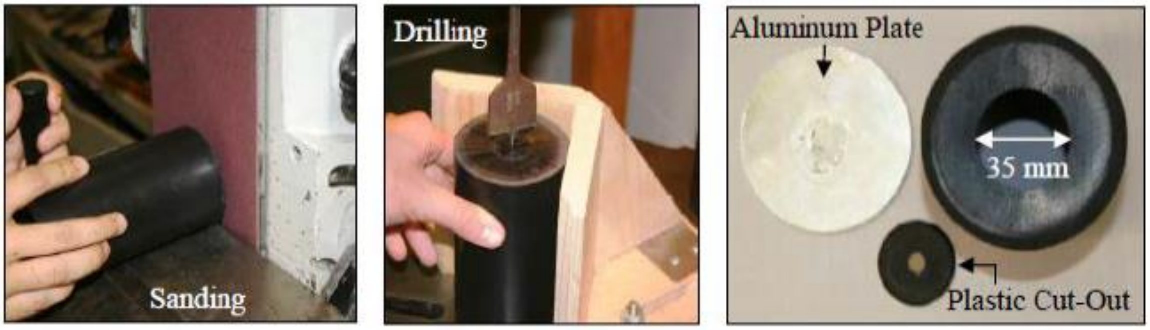

Figure 0.53: Plastic mold modification process (Sullivan, Howard and Anderson 2014)

Sullivan, Howard, and Anderson (2014) produce the soil cement specimens using three pre-weighed lifts. Each lift is compacted using five blows with the modified-Proctor hammer and each lift is scarified before adding more material. After the last lift, the collar is removed, and the material is trimmed flush with the top of the mold with a straightedge. It was found that this method produced between 92 to 100 percent of the target maximum dry density with the mold capped (Sullivan, Howard and Anderson 2014). The weight of each lift was determined using Equation 2.11.

$$W_{S\text{-}C} = 3.8 \text{ x } \gamma_d \text{ x } \left(\frac{100+OMC}{100}\right) \qquad \text{(Equation 0.11)}$$

Where,

$W_{S\text{-}C}$ = Weight of soil cement material per lift (grams),

γ_d = Maximum dry density of soil cement mixture $\left(\frac{lb}{ft^3}\right)$, and

OMC = Optimum moisture content of soil cement mixture (%).

The specimens were demolded using a vertical extruder after 24 hours (Sullivan, Howard and Anderson 2014). Measurements for diameter and height are to be collected before placement inside of the moist-curing room. Curing of the specimens followed the procedures of ASTM D1633 (2017) until strength testing was done on the seventh day. The specimens are not soaked prior to compressive testing (Sullivan, Howard and Anderson 2014).

1.6.6.2 Georgia Department of Transportation

The Georgia Department of Transportation (GDOT) specifications for the construction of soil cement follow Section 301 of the GDOT General Specifications for Base and Subbase Courses (GDOT 301 2013). GDOT uses Section 301 (2013) to construct soil cement as a base, subbase, and shoulders. Section 301 (2013) specifies that soil cement must be constructed using the Mixed-In-Place or Central-Plant-Mix methods. Soil cement should not be constructed if the air temperature is below 40°F and if the soil temperature is below 50°F. If construction of the soil cement is interrupted for more than two hours after cement has been added, or if rain increases the moisture content outside of the limits, the section must be removed and replaced (GDOT 301 2013).

GDOT 301 (2013) specifies that the soil used in soil cement construction shall all pass through the 1.5-inch sieve and at least 80 percent of the soil pass through the No. 4 sieve. This soil type limitation applies for both methods of soil cement construction. All organics and rocks that exceed three inches must also be removed and the maximum thickness allowed to compact is eight inches (GDOT 301 2013). Compaction of the soil cement mixture must begin within 45 minutes of water being added to the mixture and must be done in two hours (GDOT 301 2013).

GDOT 301 (2013) requirements for quality control and assurance include compaction, finishing, thickness, and strength. For compaction, a density of at least 98 percent of the maximum dry density must be achieved. For finishing, the variation of slope and grade from the plans must not exceed a quarter of an inch. Thickness shall not exceed more than half an inch absolute difference from the specified plan thickness. And for strength, GDOT uses cores to test the unconfined compressive strength. If the compressive strength falls below 300 psi and the density is less than 98 percent, then more cores are taken and retested from the area. If the compressive strength still falls below 300 psi then 135 pounds per square yard of asphaltic concrete must be added to the area. If the compressive strength is less than 200 psi then the area must be reconstructed. GDOT 301 (2013) does not specify what to do if the compressive strengths are too strong or if stronger bases are acceptable to some extent.

GDOT 301 (2013) and ALDOT 304 (2014) have similar requirements for the soil cement. Both states allow for either mixing method to be used. The time allowed to mix and the quality control and assurance tests are the same except for the compressive strength requirement. GDOT 301 (2013) does not specify an upper bound strength that is unacceptable while ALDOT 304 (2014) limits base strength to a maximum of 650 psi.

1.6.6.3 North Carolina Department of Transportation

North Carolina Department of Transportation (NCDOT) follows the *NCDOT Standard Specifications for Roads and Structures (Standard Specifications)* when constructing soil cement as a subgrade or base. For quality assurance testing of soil cement, NCDOT uses the *Chemical Stabilization Subgrade/Base QA Field Manual* (2015). The field manual (2015) states that NCDOT can use two types of chemical stabilization, cement or lime. Lime is generally used when the soil contains a high clay content and cement typically reacts well with sandy or silty soils (NCDOT 2015).

The soil requirements are the same for both the lime and cement stabilization operations. Before beginning to mix, each soil must be pulverized and mixed until all the material will pass a one-half inch sieve and at least 80 percent passes the No. 4 sieve (NCDOT 2015). For the addition of cement, the moisture content of the mixture must stay in the range of plus or minus two percent of the optimum moisture content. Any soil that has been treated with cement has a maximum amount of time to be compacted and finished of 30 minutes (NCDOT 2015). For both lime and cement operations, the density that must be achieved is at least 97 percent along with maintaining their specific moisture content ranges (NCDOT 2015).

The quality assurance procedures for NCDOT are to accept the density and the strength performance. Density is measured using a nuclear gauge and shall be compared immediately to the laboratory tested optimum moisture content and maximum dry density (NCDOT 2015). The NCDOT Field Manual (2015) states that if this test is failed, the contractor may continue to compact until the allotted 30 minutes has finished to try and reach the 97 percent compaction. If the density is not achieved, more lime or cement shall be added, and density shall be tested again 24 hours later (NCDOT 2015). Failure again may lead to the removal and replacement of the material after the engineer inspects the section (NCDOT 2015).

For strength, the NCDOT Field Manual (2015) states that one soil sample shall be collected every 440 feet and compacted in a “split” Proctor Mold in accordance to ASTM D698. The cylinder must then cure for a seven-day period in a humidity room without being directly in contact with water (NCDOT 2015). An unconfined compression test following ASTM D1633 procedures is then performed to make sure lime treated soils reach an average strength of 60 psi and cement treated soils reach an average strength of 200 psi (NCDOT 2015). The NCDOT Field Manual (2015) also states that cement treated specimens may not exceed 600 psi as soils this strong can create problems for flexible pavement structures.

If the contractor prefers not to do the compression tests, the NCDOT Field Manual (2015) requires DCP tests to be conducted. NCDOT Field Manual (2015) suggests that the DCP is normally only used for lime-treated subgrades, although it can also be used on soil cement subgrades as well if only minimal curing time has elapsed. The NCDOT Field Manual (2015) requires the DCP depth penetrated to be read in centimeters and plugged into the CBR equation as shown in Equation 2.12. The calculated CBR can then be converted to pounds per square inch using Equation 2.13.

$$CBR = 10^{[1.53-(\mathrm{Log}X) \times 1.066]} \qquad \text{(Equation 0.12)}$$

Where,

CBR = California Bearing Ratio, and

X = Penetration (cm).

$$psi = \left(\frac{CBR}{0.70}\right)^{0.658} \times 1.171 \qquad \text{(Equation 0.13)}$$

Where,

psi = Compressive strength (psi), and

CBR = California Bearing Ratio.

The NCDOT Field Manual (2015) randomizes the test locations but the number of locations depends on the length of the soil cement section divided by 440 feet. The resulting number is rounded up to give a total number of DCP test locations (NCDOT 2015). Each test location requires five DCP tests to be performed (NCDOT 2015). The pattern in which the tests should be conducted are shown in Figure 0.54.

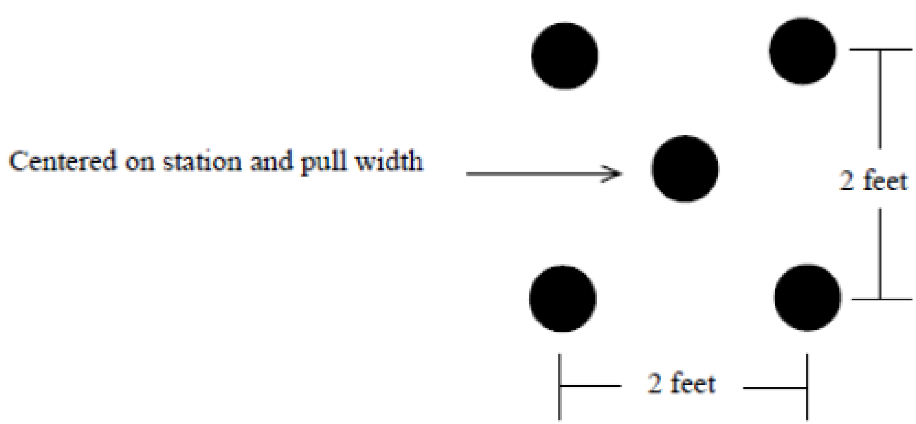

Figure 0.54: NCDOT dynamic cone penetrometer testing pattern (NCDOT 2015)

The five tests are averaged together to gain a single CBR value used to determine the strength of the chemically treated subgrade (NCDOT 2015). The NCDOT Field Manual (2015) states that if the strength is not reached, it needs to be reevaluated in order to determine if removal and replacement is necessary.

1.6.6.4 Texas Department of Transportation

Texas Department of Transportation (TxDOT) follows the *TxDOT Pavement Manual* (2019), which references *TxDOT Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges* (2014) for cement treated base construction and DCP usage. Although the standard does not require testing for strength as the pay item, there are still many similarities between TxDOT practice and ALDOT practice that are worth noting. TxDOT (2019) includes a statement on concerns and mitigation for durability issues. A major concern of the state is the extended time necessary for the cement-treated base construction before traffic on the roadway can resume. Additional concerns are stated to point out contractor error in cement content distribution and depth of mixing. Should too much cement be added, further drying shrinkage will be the consequence. As discussed in Section 1.6.2.3, shrinkage cracking can cause major durability issues for the pavement surface layer and much higher costs for maintenance. TxDOT recommend that a method of microcracking be done within 24 to 48 hours of the start of curing as recommended by Scullion (2002). Design, quality control, and quality assurance statements that are either similar or contrasting to ALDOT specifications are summarized below (TxDOT 2014):

- Existing base material may be used instead of new base material.

- Borrow source materials will be tested for a sulfate content of more than 3000 parts per million and an organic content greater than one percent to require further instruction from an engineer to proceed with the material.
- All pulverized base material must separately pass through a 2.5-inch sieve.
- Air temperature must be above 40°F and the soil temperature must be above 50°F.
- Compaction must be completed within two hours of the application of water to the mixture of material and cement.
- The moisture content must be within two percent of the optimum moisture content.
- The thickness of an engineer-selected area must not be deficient by more than half of an inch or the cement content deficient by more than ½ percent target cement content.
- At least 95 percent of the maximum density must be achieved.
- Curing of the base is required for three days by sprinkling and applying an asphalt sealing layer. For microcracking, the cure period is specified as two days after completing the microcracking.
- Pay is based on layer thickness and it is noted that no payment will be made for thickness or width exceeding that shown on the plans.

TxDOT Section 3 (2014) discusses the usage of the DCP for in-situ soil stiffness determination. The soil stiffness gives an indication of the effective depth of a granular base. The test indicates to the user if there are soft pockets of material within the base mixture depth. This method of using the DCP does not correlate to the research discussed here, but its usage is worth noting for future considerations.

1.6.6.5 Florida Department of Transportation

Florida Department of Transportation (FDOT) follows the *Standard Specifications for Road and Bridge Construction* (2000). The most current version was adopted in 2019, but the 2000 version will be discussed in this section due to its association with soil cement base construction and evaluation found in section 270. Although the practice is not in accordance with testing for strength as the pay item, there are still many similarities between FDOT practice and ALDOT practice that are worth discussing in this section. Design and quality control and assurance statements that are either similar or contrasting to ALDOT specifications are summarized as follows (FDOT 2000):

- Maximum organic material of five percent
- Maximum total clay and silt content of 25 percent
- All materials must pass through the 2-inch sieve, at least 55 percent of material must pass through the No. 4 sieve, and at least 37 percent of materials must pass through the No. 10 sieve
- Cement content must not be less than five percent by weight if mixed-in-place. Central mixed may be exempt from this limitation.
- Air temperature must be above 40°F in the shade and rising.
- All moistened pulverized soil must pass through the 2-in sieve, at least 95 percent pass the 1-inch sieve, and a minimum of 80 percent passes a No. 4 sieve.
- Do not allow more than 30 minutes to elapse between the last pass of moist mixing and the start of compaction.
- Curing is conducted over seven days.

- Acceptance requirements include a minimum density of 97 percent of maximum density, surface finish irregularities less than three inches, thickness deviations less than one inch, and strength of at least 60 percent of the specified 28-day strength for seven days.
- Payment is based on density and layer thickness criteria.

1.6.6.6 South Carolina Department of Transportation

South Carolina Department of Transportation (SCDOT) follows the *Standard Specifications for Highway Construction* (2007). For specificity to cement stabilized bases, SCDOT follows *Division 300 Bases and Subbases* (2004). Although the practice is not in accordance with testing for strength as the pay item, there are still many similarities between SCDOT practice and ALDOT practice that are worth mentioning. Design and quality control and assurance statements that are either similar or contrasting to ALDOT specifications are summarized as follows (SCDOT Division 300 2004):

- Work shall not be performed in excessively wet or frozen subgrade or subbase.
- Primarily uses central mixed operations but may approve mix-in-place as required
- Sampling and testing must follow appropriate AASHTO and ASTM guidelines as prescribed by the engineer specific to each project.
- Percent cement must be maintained within ±0.5 percent of target cement content during mixing.
- Moisture content to remain within two percent above optimum moisture content and shall not be below optimum moisture content
- Sample test molds are made often and use the Standard Proctor Test split mold.
- All sample material for core molds must pass through a No. 4 sieve.

- Compaction must commence within 30 minutes of moist mixing and must be completed within two hours of initial rolling.
- Compaction must be at least 95 percent of the maximum density.
- Phenolphthalein solution is used in test holes to check for adequate layer thickness.
- Thickness deficiencies greater than half of an inch will require correction by contractor.
- Pay reduction is considered if the checked average thickness is more than a quarter of an inch deficient from thickness shown on plans.
- Surface smoothness tolerance with a 10-foot straight edge is ±0.375 inches parallel to centerline and ±0.5 inches parallel to cross section.
- Curing asphalt membrane shall be allowed to set for seven days uninterrupted.

1.7 Excel Visual Basic Calculation Automation

Microsoft Excel is a commonly used tool for data analysis due to its flexible environment and the ability to be altered in an intuitive interface for many analysis needs (Brandelik 2009). Excel is also commonly used for its built-in macro function in order to repeat a simple specified process as necessary for the operator. Macros are event-based and require manual input on a spreadsheet from the operator. Furthermore, a powerful programming language and interface is embedded in the Developer tool of Excel that is called Visual Basic for Applications (VBA) (Brandelik 2009). VBA is used to create a customized macro of sorts to fulfill many calculation routines as designated by the user in a coding format (Brandelik 2009). Therefore, an input-based calculation or database input that a user would have to complete multiple times a day could be achieved via VBA with the click of a button in a user-friendly environment.

VBA has been used for many reasons throughout its development for anything from chemical analysis of minerals (Brandelik 2009) to geochemical discrimination plotting (Wang, et al. 2008). The program is structured in an event-based and dialogue-based interface for the user to be able to redefine the limitations of the Excel program. Some users have recreated the source files for Excel to be able to make the customized application interface the start-up screen rather than Excel default screen (Wang, et al. 2008). An extensive knowledge is required of code source file management to take advantage of this method of manipulation. Others simply use the default spreadsheets as the start-up, then include interactive buttons or icons for the operator to use to begin the created VBA software (Brandelik 2009). Regardless of the experience, Excel VBA is a powerful tool that is effective for automation of repetitive calculations.

Chapter 3

Experimental Plan

1.8 Introduction

The goal of this research project was divided into two sections. The first section focused on comparing the PM cylinder results to the SM cylinder results to confirm if the data are comparable and combinable into a single database. The testing plan includes an outline of the soil cement mixtures from various pit locations, equipment used, detailed testing procedures, and curing conditions.

1.9 Molded Cylinder Laboratory Testing Plan

The purpose of the molded cylinder testing is to verify the approach used by Scales (2020) in regards to combining the plastic-mold method and the steel-mold method results as if from the same testing method. McLaughlin (2017) left SM cylinders made on a jobsite out of the testing comparisons due to the lower strength results found in the field data. Therefore, the questions of using lab SM results with PM results remained open until this research project. The two molded cylinder methods used were the modified SM method developed by Wilson (2013) and the PM method as used by Scales (2020). All cylinders were tested for their unconfined compressive strengths at three days and seven days of age. Upon testing, an outlier analysis was conducted to determine the existence of any data points that needed to be removed from the dataset. After the outlier analysis had been completed, the SM results were compared to the PM results. A summary of the testing plan that was developed can be seen in Figure 0.1.

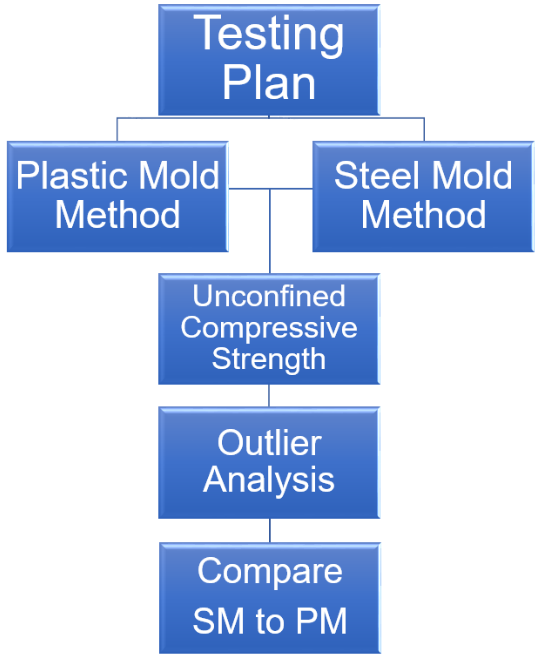

Figure 0.1: Summary of testing plan

The goal of the testing plan was to obtain a range of compressive strengths that were within and just outside of the ALDOT compressive strength requirements for soil cement pavement bases. The testing plan was iterated for multiple soil types, each at varying cement contents. Different soil types with varying amounts of fines were not expected to result in largely different compressive strengths at the same cement content (Scales 2020). During testing, Scales (2020) was conducting an experiment on the impact of soil types, determining that soil type has little effect on the results.

The soils used are denoted as Elba, Waugh, and Coarse for the remainder of this thesis. The Elba soil is classified by AASHTO standards as A-2-4 and was tested at cement contents of 5, 6.5, and 8 percent by weight of dry soil. The Waugh soil is classified by AASHTO standards as A-2-6, but due to the unavailability of remaining Waugh soil in the lab at the time of testing, the Waugh material was only tested at 5 percent cement content by weight of dry soil. The Coarse soil is classified by AASHTO standards as A-1b and was tested at cement contents of 4, 6, 8, 9, and 10 percent by weight of dry soil. The selected cement contents were chosen based on a series of estimated strength ranges: the low range (100 to 250 psi), the moderate range (250 to 600 psi), and the high range (600 to 800 psi). The moderate range corresponds to the acceptable values specified by ALDOT 304 (2014). A summary of the variables that were altered for each iteration of the testing plan can be seen in Figure 0.2.

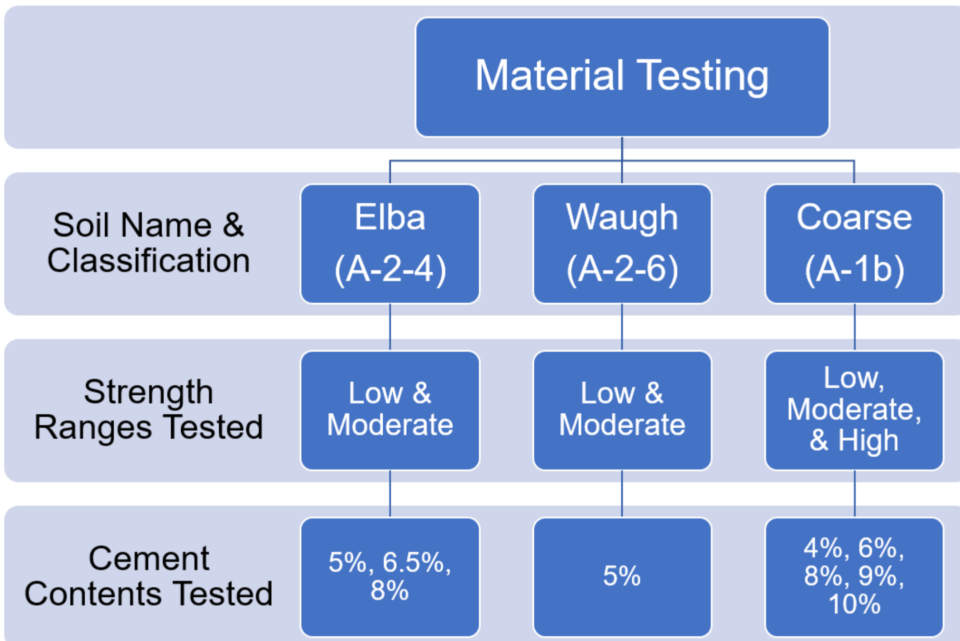

Figure 0.2: Summary of testing variables

The names of each soil type tested indicates the location of the borrow pits from which they were collected. Each borrow pit selected has been used for soil cement base projects or collected from an ongoing soil cement base project during the time of this research study. Selecting materials that have been used on soil cement base projects ensures that the research gives a fair and realistic representation for comparison of soil cement testing methods.

Once the soils were collected, each soil type was tested to determine the Unified Soil Classification System (USCS) and AASHTO soil classifications. The optimum moisture content and maximum dry unit weight corresponding to a specific cement content was determined using a proctor test. Curing methods used followed the methods described by Scales (2020). Each sample was placed into a plastic bag and sealed before curing in a moist-curing room. Once tested and outliers removed from the data, a comparison of the strengths was conducted to determine how the results from the two molded cylinder methods compare to each other.

1.9.1 Soil Cement Mixtures Evaluated

The soils were sampled from Central and South Alabama locations. Each soil type was either used as is from the borrow location or was mixed to meet strength and gradation requirements (ALDOT 304 2014). The Elba soil was used as is, the Waugh soil consisted of a mixture of the Waugh clay and Waugh sand, and the Coarse soil consisted of a mixture of Coarse sand and Waugh clay. All soils used are similar to the soils used by Scales (2020). An image of the soils used for this project can be seen in Figure 0.3.

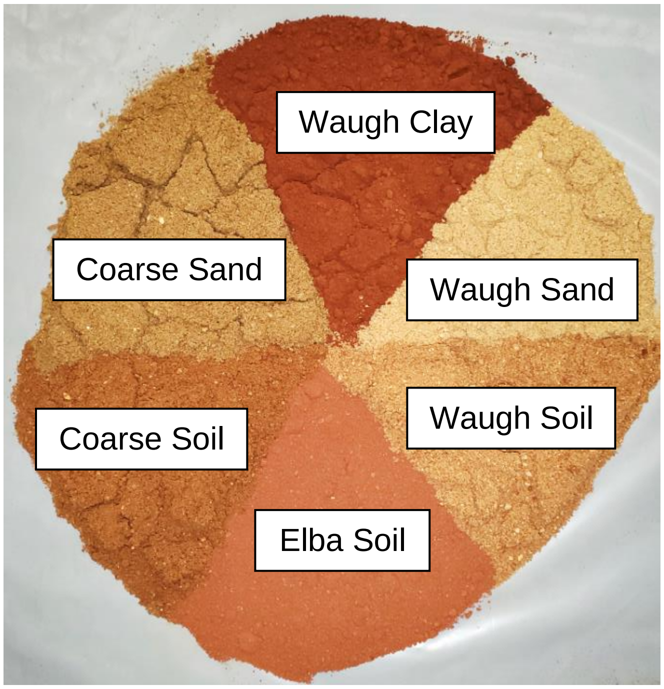

Figure 0.3: Soils used during testing (Scales 2020)

1.9.1.1 Waugh Soil

According to ALDOT 304 (2014), a soil cement mixture must have a fines content ranging from 5 to 35 percent. Therefore, the Waugh clay and Waugh sand were mixed at a ratio of 20:80 respectively to achieve the fines content required. The mixture of the Waugh clay and Waugh sand is hereafter referred to as Waugh soil. Samples of the Waugh clay and Waugh sand were collected from a pit owned by Newell Construction in Waugh, Alabama. The location of the borrow pit resides at coordinates N 32.366983, W -86.042014, as shown in Figure 0.4.

Figure 0.4: Location of the Waugh borrow pit (Google Maps 2020)

1.9.1.2 Elba Soil

The Elba soil was collected from a soil cement project that was ongoing during the time of testing. This soil met the fines percent range requirements set by ALDOT 304 (2014), and therefore did not need additional mixing with a sand or clay material. The contractor on the project site was S.A. Graham. The project location was along the Eastbound U.S. Highway 84 to the East of Elba. The location at which the soil was sampled from the project was at coordinates N 31.400602, W -86.006807, as shown in Figure 0.5.

Figure 0.5: Location of the Elba project collection location (Google Maps 2020)

1.9.1.3 Coarse Soil

The Coarse sand collected was typically used as a fine aggregate for mixing concrete, thus having a larger fineness modulus than the other soils. To meet the fines percent range requirements set by ALDOT 304 (2014), the Coarse sand was mixed with Waugh clay at a ratio of 80:20 respectively. The mixture of the Waugh clay and Coarse sand is hereafter referred to as Coarse soil. The Coarse sand was collected from a borrow pit located in Emerald Mountain, Alabama, which is owned by Foley Materials. The location of the borrow pit is at coordinates N 32.415318, W -86.179164, as shown in Figure 0.6

Figure 0.6: Location of the Coarse borrow pit (Google Maps 2020)

1.9.2 Material Classification

The geotechnical properties of each soil were determined in order for the soil classification to be determined. First, ASTM D422 (2007) was be used to determine the soil's grain size distribution. The soils were then classified using both the AASHTO method and the USCS method. ASTM D698 (2012) was then used to run proctor tests to determine the optimum moisture content and maximum dry density of the soil cement mixture.

1.9.3 Moisture-Density Curve

Before producing soil cement, a proctor test was performed to obtain a moisture-density curve. A detailed discussion of this can be found in Section 1.6.2.1. The proctor test was performed for each mixture at different cement contents. The optimum moisture content and maximum dry density were determined using ASTM D698 (2012). This information is critical to properly weigh out all the material before production. Method A from ASTM D698 (2012) was followed, using a four-inch diameter mold. For this method, the specimen is compacted in three equal lifts using 25 blows per lift. The weight of the mold and soil cement was weighed once compaction was completed. A sample from the soil cement was taken to determine the moisture content. The results from each sample were then plotted to create the moisture-density curve. A curve was oriented through the plotted points and the optimum moisture content and maximum dry density was determined by scaling off at the peak of the curve.

1.9.4 Batching

The material that was used for batching was first spread out on a plastic sheet and thoroughly mixed. An image of the spreading and mixing method can be seen in Figure 0.7. This spreading and mixing method was used to ensure the moisture content was uniform throughout the soil before batching. If the material was placed back into a barrel before batching, the moisture content may be lower at the surface and higher at the bottom of the container. The moisture content of the soil was then tested using ASTM D2216 (2019). Based on the optimum moisture content and maximum dry density determined from the moisture-density curve, the weight of the soil, cement, and water was proportioned to achieve 100 percent density. The components were weighed out in five-gallon buckets to the nearest one hundredth of a pound and sealed with lids to minimize moisture loss until mixing commenced.

Figure 0.7: Spreading and mixing of soil before batching (Scales 2020)

Two batches of soil cement were produced during each testing day. The first batch included all materials being tested at three days of age. The second batch included all materials being tested at seven days of age. Due to inherent operator measurement errors and imperfections of the mixing apparatus, the type and amount of materials varied slightly, ultimately affecting the compressive strength of the cylinders to some extent; however, all SM and PM cylinders compared to each other were made from the same batch, so this issue would not affect the comparisons made for this project. An outlier analysis was conducted after testing to ensure any batching and mixing error was considered before proceeding to compare the SM and PM cylinder results collected for the research project.

1.9.5 Mixing

The soils collected from the borrow pits were stored in 55-gallon drums with a plastic liner until preparation for testing and mixing. The portland cement used in the mixtures was Type I/II. The water used in the mixtures was collected from the City of Auburn’s public water supply as sourced from a tap in the laboratory. Each batch was produced together with Scales’ (2020) batches, requiring a 2.5 cubic foot batch to produce enough material to create five PM cylinders and five SM cylinders as well as the additional testing conducted for another phase of this research. A mortar mixer with a capacity of 12 cubic feet was powerful enough to uniformly mix the full batch of material. The mixing was performed by a Multiquip/Whiteman WM120PHD mortar mixer as shown in Figure 0.8. Once mixing was completed, samples were collected to determine the moisture content of the material.

Figure 0.8: 12 cu. ft. mortar mixer used for soil cement mixing (Nemiroff 2016)

1.9.6 Molded Cylinder Production

1.9.6.1 Plastic-Mold Method Cylinder Production

The 3-inch by 6-inch PM cylinder production followed the method documented by Scales (2020), who changed the method slightly from the method that McLaughlin (2017) created. The mold was cut down the side with a box blade. After cutting, the mold was taped together with aluminum foil tape to keep the cut closed during production of the specimen. The way the mold was taped is changed from the McLaughlin (2017) method. McLaughlin (2017) used a single, vertical strip of aluminum tape to seal the side. Scales (2020) modified this method by adding two strips of tape from the top edge that wrap around one third of the circumference of the mold, centered on the cut. The tape modification was discussed in further detail in Section 1.6.5. This method greatly reduced the chance of the taped mold splitting while being compacted. An image of the tape configuration before and after the modification can be seen in Figure 0.9.

Figure 0.9: PM tape arrangements before (left) and after (right) the modification (Scales 2020)

The PM cylinders were compacted using seven blows per lift in accordance with McLaughlin (2017). The number of blows was chosen to obtain the 98 percent compaction required by ALDOT while minimizing the effort by the operator. Once compaction was completed, the mold was removed from the testing apparatus and the soil cement was trimmed level with the top of the plastic-mold. A plastic cap was then secured on the top to prevent moisture loss during initial curing. An image of the specimen being trimmed to the height of the mold can be seen in Figure 0.10.

Figure 0.10: Straightedge used to trim the soil cement specimen (Scales 2020)

1.9.6.2 Steel Mold Method Cylinder Production

The SM cylinders were produced following the modified ASTM D1632 method created by Wilson (2013). The procedure for SM cylinder production was previously discussed in Section 1.6.5. After forming, the specimens were placed in the upright position in the laboratory for the initial curing period. An image of the specimens during the initial curing phase can be seen in Figure 0.11.

Figure 0.11: SM cylinders during initial curing

1.9.7 Initial Curing

Sullivan, Howard, and Anderson (2014) suggested PM cylinders be stored on site for one day before moving to laboratory. This procedure was used in the laboratory as well. The specimens shall be stored exposed to laboratory air conditions in the mold for initial curing overnight. Research performed by Wilson (2013) showed that the specimens were too weak to be removed from their cylindrical steel mold immediately after production. Therefore, the soil cement must remain in the mold until initial curing was complete. The initial curing period was kept constant between the two methods and typically lasted 24 hours under laboratory conditions.

The next day, the soil cement cylinders were removed from their molds following the methods detailed in Section 1.6.5. Once extracted, the weight, diameter, and height of the cylinders were measured to calculate the density of the specimen, described in Section 1.9.9. This was done to make sure the specimens achieved the requirement of 98 percent of maximum dry density (ALDOT 304 2014).

1.9.8 Final Curing

Final curing began as soon as the specimens were removed from the mold and sealed in a sealable zipper plastic bag. All air was removed prior to sealing the bag and a rubber band was wrapped around the circumference to assist in keeping the bag fitting tightly around the specimen. The cylinders were then placed on their sides in the moist-curing room which was kept at a temperature of 73 °F ± 3 °F. The specimens remained there until it was time for compression testing at three days and seven days of age. An image of the cylinders sealed in bags for final curing is shown in Figure 0.28.

1.9.9 Testing

1.9.9.1 Moisture Content and Density

When the soil cement cylinder was removed from the plastic mold, measurements of its diameter, length, and weight were taken. A caliper was used to read the values of the diameter and length of the soil cement cylinder. A measurement was taken at the top, middle, and bottom of the cylinder with the caliper to obtain an average diameter of the soil cement cylinder along the length. Two readings are taken of the length of the cylinder to determine an average length best representative of the actual length. An image showing measurements of the diameter and length using a caliper can be seen in Figure 0.12.

Figure 0.12: Demonstration of taking cylinder measurements (Scales 2020)

The weights of the samples and equipment used were determined in accordance with ASTM D2216 (2019). Following the completion of the unconfined compressive strength test, as described in Section 1.9.9.2 , a representative sample of the soil cement was placed into an oven-safe tin, weighed, then left in an oven overnight. The sample tins were then removed and weighed again to determine the moisture content of each specimen. This moisture content was then used to determine the dry density of the specimen. The dry density was calculated using Equation 3.1. Once the dry density was computed, it was compared to the maximum dry density to ensure a percent compaction of at least 98 percent per ALDOT 304 (2014) requirements.

$$\gamma_{dry} = \frac{W_{sample}}{V\,(1 + w)} \qquad \text{(Equation 0.1)}$$

Where,

γ_{dry} = Dry density of soil cement mixture $\left(\frac{lb}{ft^3}\right)$,

W_{sample} = Weight of soil cement material (lb),

V = Volume of sample (ft^3), and

w = Water content of soil cement mixture (%).

1.9.9.2 Cylinder Compressive Strength

Compression testing of the plastic-mold cylinders followed the changes that Wilson (2013) made to ASTM D1633 (2007). For precise control of the loading rate, a 100-kip compression testing machine from Forney was used as shown in Figure 0.13. The specimens were removed from the moist-curing room and taken out of the plastic bags one at a time and tested to determine their compressive strength. The vertical axis of the specimen was aligned with the center of thrust from the upper plate to avoid any load eccentricity that may negatively impact the measured strength.

Figure 0.13: 100-kip compression testing machine (McLaughlin 2017)

The load applied to the specimens was kept at a constant rate of 10 ± 5 psi/s until failure. The failure load was recorded to the nearest five pounds for each specimen tested. The compressive strength was then calculated by dividing the total failure load by the cross-sectional area of the specimen. The average compressive strength of the five specimens was rounded to the nearest five psi.

1.9.10 Outlier Analysis Approach

To determine if any outliers existed in the datasets, the outlier analysis was conducted in accordance with research done by McLaughlin (2017). The coefficient of variation for molded cylinder compressive strength found by Wilson (2013) of 7.1 percent for no capping of the specimen was used. Based on the number of test results, the multiplier of the coefficient of variation from ASTM C670 (2015) was used to obtain an acceptable error range for the results. The range is determined by taking the difference between the maximum and minimum compressive strengths and dividing that by the average compressive strength of the cylinders (ASTM C670 2015). Five cylinders were made for each method each testing day. Therefore, the multiplier used was 3.9, which yielded an acceptable range of 27.7 percent. If an outlier was found, it was removed from the data set. The outlier analysis was then again performed, but the multiplier corresponding to the remaining number of test specimens was used instead of 3.9 to determine a new acceptable error range for the remaining specimens. A table of the multipliers prescribed by ASTM C670 is shown in Table 0.1. This method of identifying outliers is consistent with the methods by which Wilson (2013), McLaughlin (2017), and Scales (2020) identified outliers.

Table 0.1: Standard deviation or coefficient of variation multipliers (ASTM C670 2015)

TABLE 1 Maximum Acceptable Range of Test Results[A]

Number of Test Results	Multiplier of Standard Deviation or Coefficient of Varitation[B]
2	2.8
3	3.3
4	3.6
5	3.9
6	4.0
7	4.2
8	4.3
9	4.4
10	4.5

[A] A test result can be a single determination or the average of two or more determinations as defined in the test method.
[B] Values were obtained from Table A7 of "Order Statistics and Their Use in Testing and Estimation," Vol 1, by Leon Harter, Aerospace Research Laboratories, United States Air Force.

Chapter 4

Presentation and Analysis of Molded Cylinder Method Results

1.10 Introduction

In this chapter, results of the soil cement testing plan described in Chapter 3 are presented and discussed. An analysis of the comparison of the PM method and SM method for quality assurance testing is presented. The analysis consists of the direct comparison of the density, moisture content, and strength that resulted from all laboratory tests.

1.11 Comparison of Molded Cylinder Methods

1.11.1 Material Classification

The methods used to determine the AASHTO and USCS classification of the different soils used for this research project were described in Section 1.9.2. Table 0.1 summarizes the classification for each soil used.

Table 0.1: Summary of Soil Properties and Classifications (Scales 2020)

Soil Name	Percent Passing #200 Sieve	Liquid Limit (LL)	Plasticity Index (PI)	USCS	AASHTO
Waugh Clay	38.9%	21*	18*	SC	A-6b
Waugh Sand	1.2%	N/A	N/A	SP	A-1b
Waugh Mix	8.3%	14*	12*	SP-SC	A-2-6
Elba	0.9%	N/A	N/A	SM	A-2-4
Coarse	8.2%	N/A	N/A	SW-SC	A-1b

* Nemiroff 2016

1.11.2 Mixture Properties

The laboratory tests performed to collect the mixture properties of each soil were described in Section 1.9.3. Table 0.2 includes the optimum density and moisture content at each cement content used for each soil type. These soils are the same material used by Scales (2020) at the same time of testing. Therefore, the gradation for these soils are the same as used by Scales (2020).

Table 0.2: Mixture Properties of Laboratory Materials (Scales 2020)

Mixture Type	Cement Content (%)	Optimum Moisture Content (%)	Maximum Dry Density (lb/ft^3)
Elba	8	12.2	116.9
	6.5	13.8	115.1
	5	12.4	115.0
Waugh	5	10.7	120.0
Coarse	10	10.2	126.2
	9	11.0	125.3
	8	10.8	125.2
	6	11.2	123.8
	4	11.7	120.5

1.11.3 Direct Comparisons of Testing Methods

In order to properly compare the two datasets from the SM and PM methods, an Identity Line graph was used. This type of graph is able to efficiently compare two datasets visually by comparing all data to a line on the graph with a slope of one, 1:1, or x. This line is referred to as the Line of Equality. Any data comparison that falls on the Line of Equality is mathematically identical. If two datasets are exactly the same, then comparing their datapoints on an Identity Line graph will result in all datapoints falling on the line of equality.

Realistically, no two datasets for soil cement comparisons will be exactly the same due to the vast number of variables involved and the variability of the test methods. Therefore, an acceptable error range of ± 40 percent error for compressive strength was used as the deciding limit between similar or dissimilar datasets (Wilson 2013; McLaughlin 2017; Scales 2020). Additionally, error margins for density and moisture content were determined in accordance with ASTM C670 (2015) to determine if any inconsistencies existed between compaction efficiency and moisture loss effects.

During testing of the PM and SM methods, results for molded cylinder strength, density, and moisture content were recorded for each specimen. The average of the five specimens produced for each test were determined for the PM and SM methods separately, then compared on Identity Line graphs. Any outliers found in accordance with ASTM C670 (2015) were discarded and are not considered in this analysis. All data for the following comparisons can be found in Appendix D.

1.11.3.1 Comparison of Density from PM and SM methods

The density comparison was conducted to determine the coefficient of determination and the equation of the trend line and to produce an Identity Line graph to visually compare the laboratory-determined cylinder densities obtained when using these two methods. This analysis was important because the results showed major variations in the compaction efficiency of the cylinders between the two test methods if any such disparity existed. The relationship of the PM method to SM method laboratory-determined cylinder density results is shown in Figure 0.1. Due to the low dispersion of the data points and the format of this type of graph, a zoomed view of the same graph is shown in Figure 0.2.

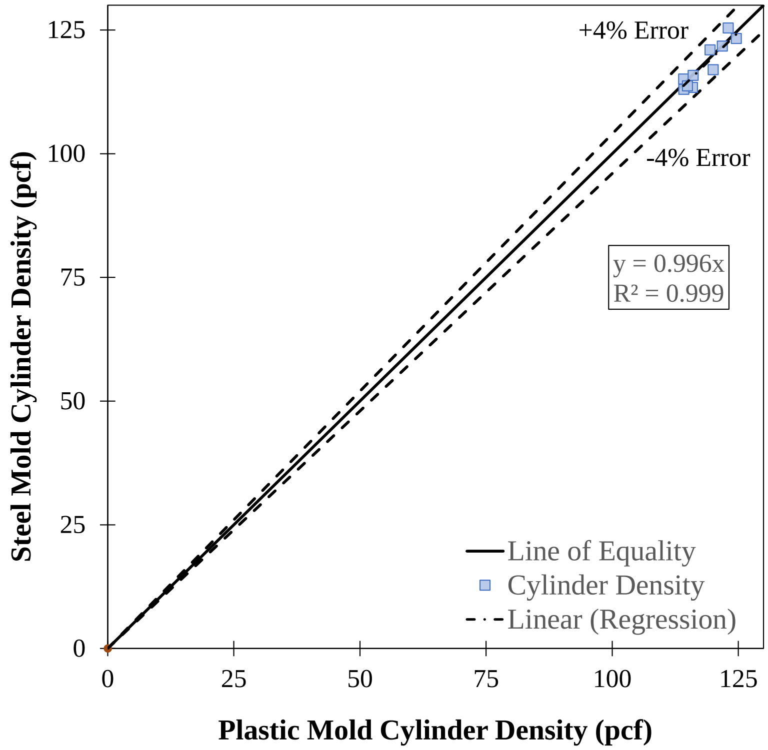

Figure 0.1: PM versus SM cylinder density comparison

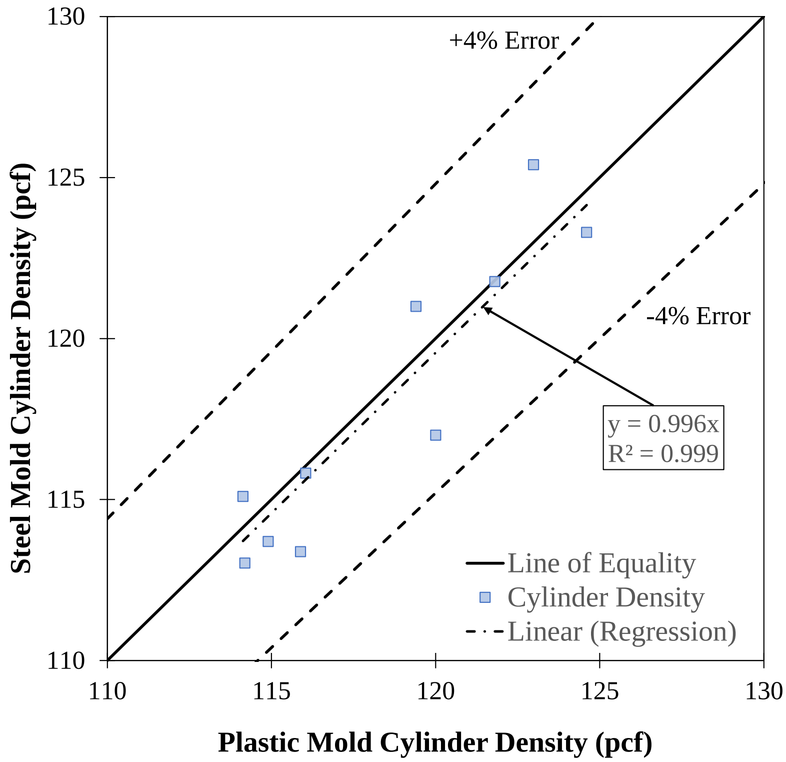

Figure 0.2: PM versus SM cylinder density comparison (Zoomed)

The graph in Figure 0.2 that the best fit line, Linear (Regression), is very close to the Line of Equality. The equation of the line from the laboratory-determined cylinder density results was determined as y = 0.996x. The fact that the line lies below the Line of Equality indicates that the SM method on average produces only slightly less compacted (approximately one percent) specimens than the PM method. This equation is very similar to the equation describing the Line of Equality, which is y = x, though, and considering the expected small variability of the density measurements, it is the opinion of the author that the slight discrepancy may be disregarded. The coefficient of determination (R^2) of the data when the line is set to intersect the origin was determined as 99.9 percent. This means that the data are extremely well characterized by this linear function. All data points fell within the ± 4 percent error margins. Therefore, it can be concluded that the cylinder density results determined in the laboratory show no statistically significant difference in the compaction efficiency between the PM method and SM method.

1.11.3.2 Comparison of Moisture Content from PM and SM methods

The moisture content comparison was conducted to determine the coefficient of determination and the equation of the trend line and to produce an Identity Line graph to visually compare the laboratory-determined cylinder moisture contents obtained when using these two methods. This analysis is important because the results would show major variations in the moisture loss during curing of the cylinders between the two test methods if any such disparity existed. The relationship of the PM method to SM method laboratory-determined cylinder moisture content results is shown in Figure 0.3. Due to the low dispersion of the data points and the format of this type of graph, a zoomed view of the same graph is shown in Figure 0.4.

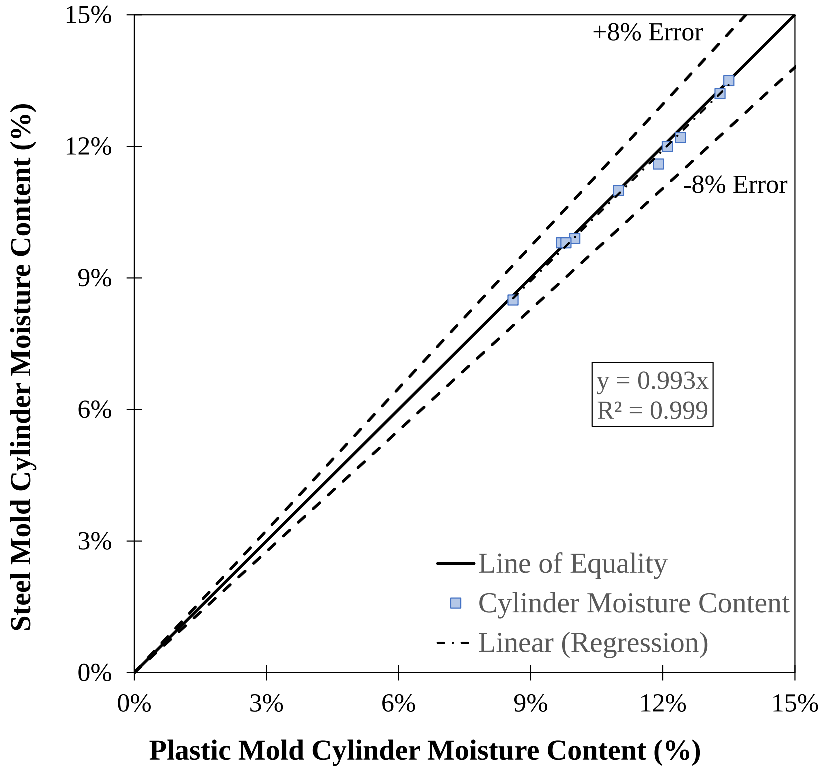

Figure 0.3: PM versus SM cylinder moisture content comparison

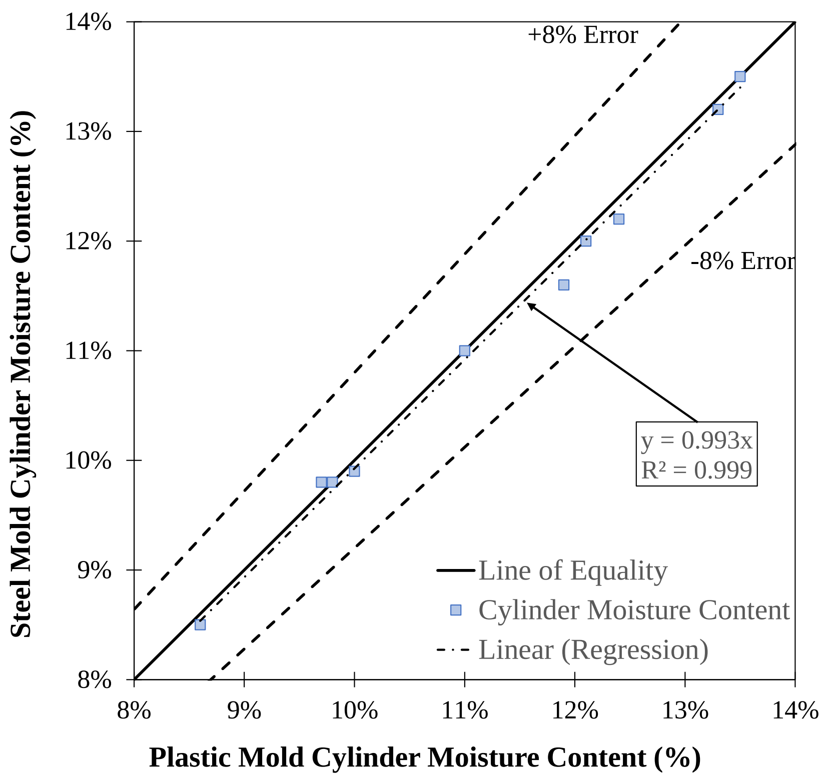

Figure 0.4: PM versus SM cylinder moisture content comparison (Zoomed)

It can be seen on the graph in Figure 0.4 that the best fit line, Linear (Cylinder Moisture Content), is very close to the Line of Equality. The equation of the line from the laboratory-determined cylinder density results was determined as y = 0.993x. The fact that the line corresponding to this equation lies below the Line of Equality indicates that the SM method retains only slightly less moisture during curing than the PM method. This equation is very similar to the equation for the Line of Equality, though, so it is the opinion of the author that this very slight discrepancy may be disregarded. The coefficient of determination (R^2) of the data when the line is set to intersect the origin was determined as 99.9 percent. This means that the data are almost exactly identical, with negligible variation. All data points fell within the ± 8 percent error margins. Therefore, it can be presumed that the cylinder moisture content results show no statistically significant difference in the moisture retention between the PM method and SM method.

1.11.3.3 Comparison of Strength from PM and SM methods

The compressive strength comparison was conducted to determine the coefficient of determination and the equation of the trend line and to produce an Identity Line graph to visually compare the compressive strengths between the two methods. The plot of the PM method to SM method compressive strength results is shown in Figure 0.5.

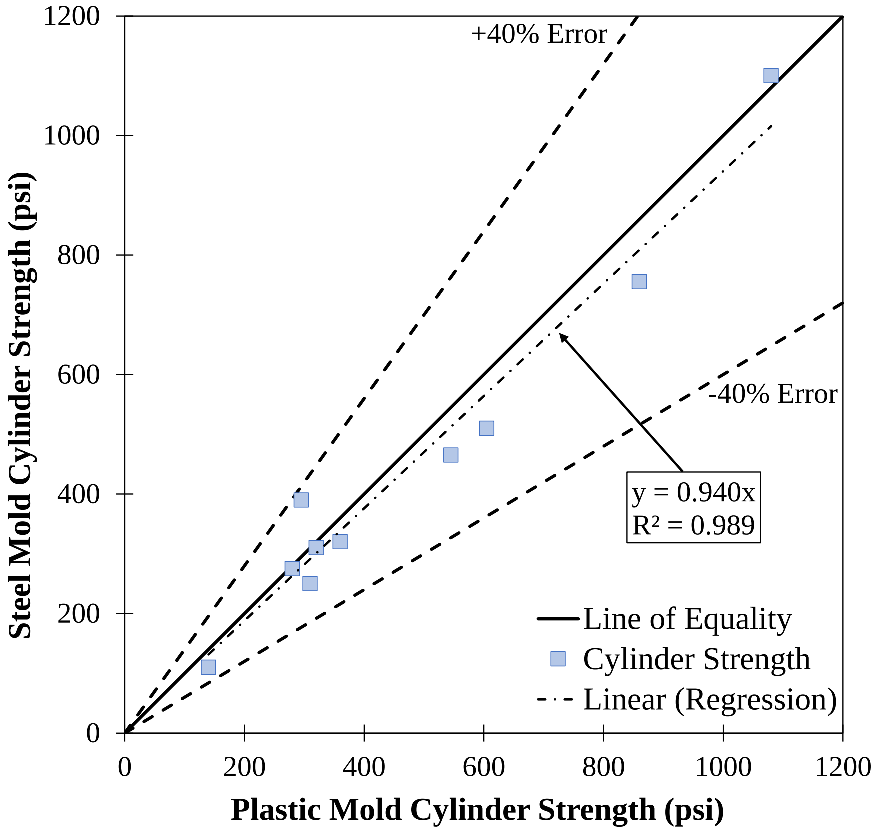

Figure 0.5: PM versus SM cylinder strength comparison

It can be seen on the graph in Figure 0.5 that the best-fit line, Linear (Regression), is very close to the Line of Equality. The equation of the Line of Equality is y = x, and the best-fit line was determined to be y = 0.940x. The fact that the plot of this line falls below the Line of Equality indicates that the SM method on average produces only slightly weaker (six percent) specimens than the PM method. This equation is very similar to the equation for the Line of Equality, though, and considering the expected small variability of the test, it is the opinion of the author that the slight discrepancy may be disregarded. The coefficient of determination of the data when the line is set to intersect the origin was determined as 98.9 percent. This means that the data are well characterized by this linear function. With this fact and considering that all data points fell within the ± 40 percent error margins, it can be concluded that the compressive strength results determined in the laboratory between the PM method and SM method are statistically similar and, furthermore, that the two DCP versus cylinder strength datasets from previous research may be merged.

A total of 200 cylinders were created for the strength, density, and moisture content comparisons. Of these cylinders, only 11 were discarded. Only one PM cylinder was discarded due to the cylinder breaking apart before it could be tested. The other discarded cylinders were considered outliers in accordance with ASTM C670 (2015) and all cylinders that were discarded as outliers were made using the SM method.

As mentioned from previous work by Nemiroff (2016) and McLaughlin (2017), the reliability of the SM method results was questioned if the mass of the cylinder is even slightly different from the calculated mass required to reach 98 percent compaction. Further evidence of susceptibility to errors was shown in the comparison of outliers for the two methods. While the PM method had no calculated outliers, the SM method had 10. Out of the total number of cylinders made with the SM method, 10 percent of them were discarded. From this study, it is concluded that the SM method produces results that were more susceptible to variability than results determined from the PM method. Therefore, of these two methods, the PM method was recommended to be used on ALDOT projects.

Chapter 5

Development of DCPAL

1.12 Introduction

In this chapter, a description of DCPAL is given. First, an overview of the user interfaces is discussed, then the worksheets in the workbook file are described and major aspects of the coding process are presented. Following the description of the software, a few examples are shown to illustrate what the software would look like in potential outcomes. The three outcomes are based on ALDOT 304 (2014) compressive strength pay requirements as shown in Table 0.4.

1.13 DCPAL – DCP Analysis Tool for ALDOT

The purpose of developing DCPAL was to simplify the calculations process to transform the raw DCP data into an equivalent compressive strength result for ALDOT. DCPAL was created using Excel's Developer Application: Visual Basic Application (VBA). The VBA open platform for creating personalized macros was incorporated with calculations across several spreadsheets. The logo that was designed to accompany DCPAL is shown in Figure 0.1.

Figure 0.1: Logo for DCPAL

The design goal of the software was to be as user-friendly as possible while still allowing for any changes, as necessary. This was accomplished by avoiding hard-coded values and integrating user interfaces to specify all input data. The completed macro-enabled Excel workbook was then converted into an executable application using a third-party program called XLS Padlock to add security measures to the file. The executable program limits the editable qualities of an Excel workbook, therefore only allowing the user to interact with the prompted items as intended. The transition from an Excel workbook to an executable application is the step that converts the set of automated calculations into a user-friendly program.

The following sections detail the operations of DCPAL. The user interfaces are described first to show how each decision affects the logic flow of DCPAL from the user's perspective. Each worksheet is then briefly described in the order which they are listed in the workbook version of DCPAL. Some of the coding techniques are then discussed to give a concise overview of the coding process.

1.13.1 User Interfaces

The user interfaces allow the user to interact with DCPAL. The choices a user makes dynamically change how the software responds. In Excel VBA, user interfaces are created by formatting userforms. Formatting the userforms consists of adding editable fields via textboxes, inserting labels to provide information, or simply changing the color of the userform window. Some userforms require user action while others only provide information to the user throughout the analysis process. The decisions made by the user in DCPAL follow a successive order of choices prompted by userforms. An illustration of the overall decision-making process is in the flow chart shown in Figure 0.2.

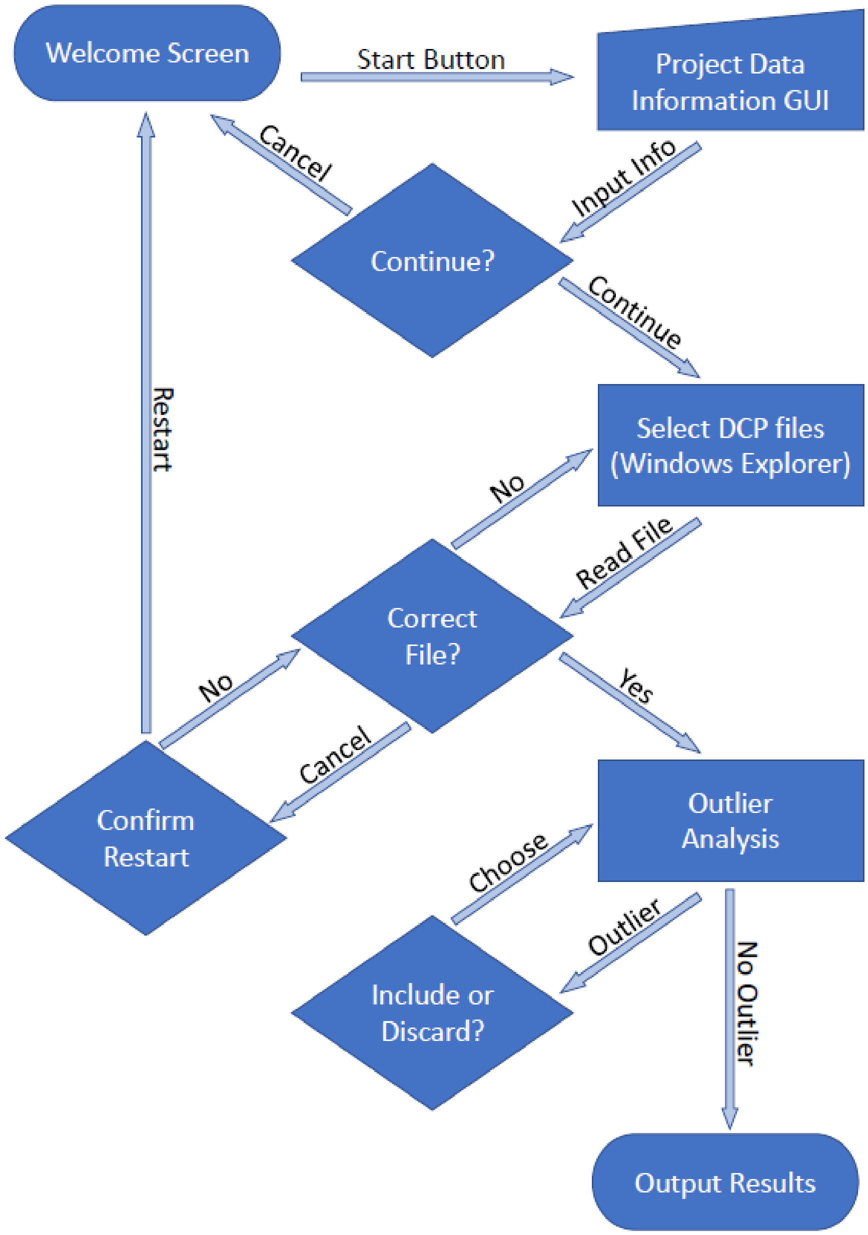

Figure 0.2: Flow chart of DCPAL logic

1.13.1.1 Initial, Details, and Change Userforms

Once the software has been initiated, the first userform to display is the *Initial* userform. The Initial userform is where all pertinent project information is input and can be seen in Figure 0.3. The inputs consist of the Date, Operator Name, Project Name, DCP Test Station, Number of DCP Tests, Analysis Depth, Outlier Error Range, Strength-to-DCP Relationship, and Strength

Limits. The ALDOT default values are automatically generated to streamline the analysis process for ALDOT operators.

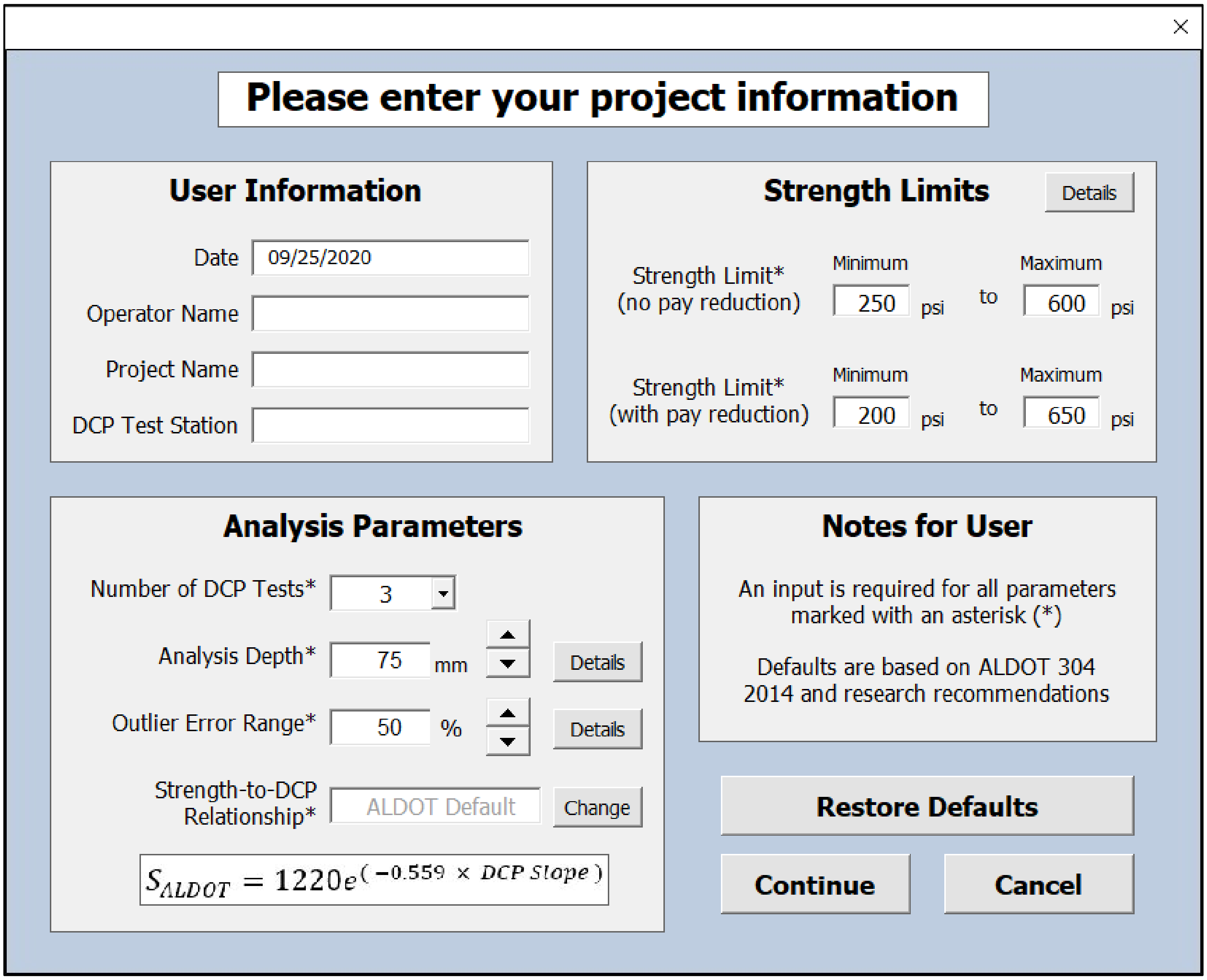

Figure 0.3: Initial Userform

The date is automatically generated from the date and time settings of the device running DCPAL. Most devices will update their date and time after connecting to the internet. In the case that a device's date is not correct, the Date field is editable by the user. The inputs for Operator Name, Project Name, and DCP Test Station are solely for user documentation and have no impact on the calculations.

The Number of DCP Tests input is determined by the DCP operator. If at a given location the operator conducted three DCP tests, then the user would select "3". This is similarly the case for “4” or “5” DCP tests. The default value is three because this is the recommended number of tests at a given location (Scales 2020). A drop-down menu option is provided for the user to select three, four, and five DCP tests.

The Analysis Depth input is based on the depth over which the operator is required to conduct the DCP slope analysis. Scales (2020) concluded that 75 millimeters was an optimal analysis depth to match acceptable accuracy with operator effort. The user can choose from 25, 50, 75, 100, and 175 millimeters by clicking the up and down arrows to the right of the textbox. If the user is unsure of the parameters of the analysis depth that DCPAL requires, a button has been added to the right of the spinner titled “Details” that provides further information. If the user clicks the Details button, the *Depth* userform is displayed. This userform informs the user of the method by which the analysis depth input should be determined for DCPAL and can be seen in Figure 0.4.

ASTM D6951 (2018) details the difference between the total depth at which the DCP cone tip has penetrated and the depth that is considered the analysis depth. The analysis depth is measured after the first 25 millimeters have been penetrated to ensure secure contact between the material and the DCP cone tip. These first 25 millimeters are usually referred to as the seating depth. For example, if the required analysis depth by ALDOT is 75 millimeters, the DCP will actually penetrate at total depth of 100 millimeters into the material. Once the user is ready to return to the previous window, the user must click the “Return” button.

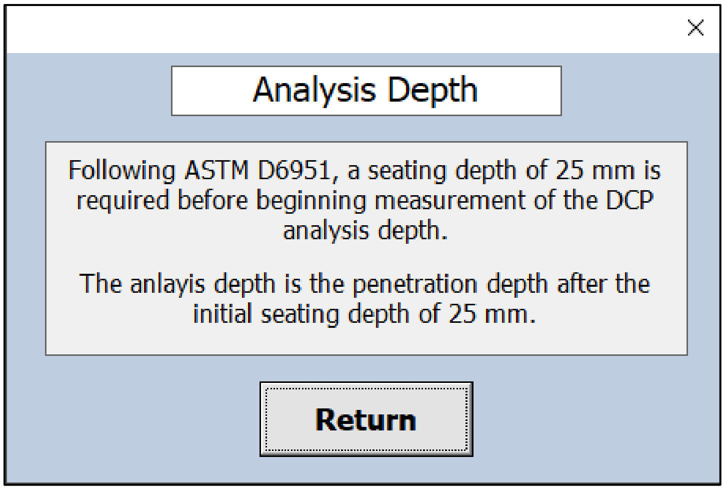

Figure 0.4: Depth Userform

The next input is the Outlier Error Range, which is similarly chosen by the up and down arrows to the right of this input. The Outlier Error Range is limited to lower and upper bounds of 5 and 100 percent, respectively. It would not be ideal to use these upper and lower bound limits for an outlier analysis of this type. A limit of five percent would require the data to be extremely precise in comparison to the recommended default outlier error range of 50 percent (McLaughlin 2017). A limit of 100 percent would only return outliers that are extremely different from the other datasets, resulting in a less reliable final compressive strength value. The upper and lower bounds were set with future modularity of the software in mind.

If the user is unsure of how the outlier error range is determined or used to determine outliers, a “Details” button is provided. If the user clicks this button, the *Error* userform is displayed as shown in Figure 0.5. This userform offers further information about this parameter and how the outlier analysis is conducted. If the user wants to check the software results by hand, following the steps outlined on this userform should result in the same outlier analysis results. The steps provided follow the description given by Scales (2020). Once the user is ready to return to the previous window, the user must click the “Return” button.

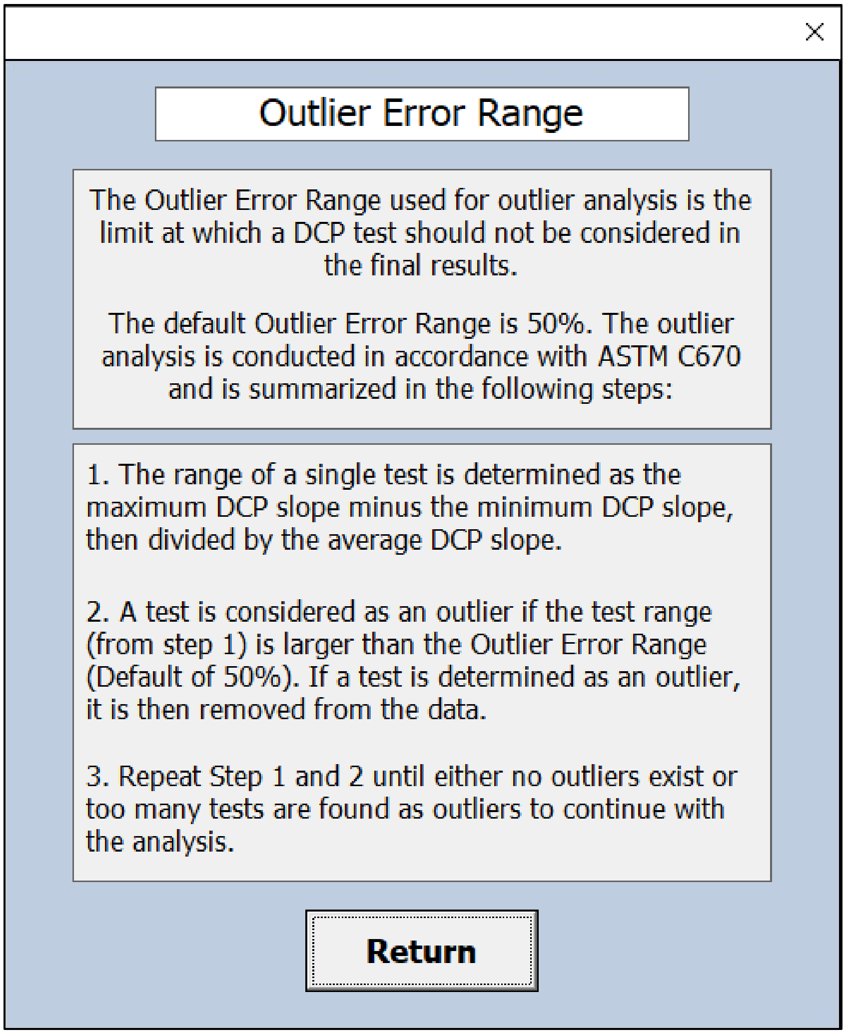

Figure 0.5: Error Userform

The Strength-to-DCP Relationship is the next editable parameter on the Initial userform. This relationship has been developed as a result of soil cement research conducted by Nemiroff (2016) and Scales (2020). The equation was developed to relate the penetration depth per blow count slope of DCP results to the unconfined compressive strength of the soil cement. The default equation for ALDOT is displayed just below the textbox and “ALDOT Default” is the default option in this textbox. This textbox is not editable in this userform, as indicated by the gray colored text instead of the black editable text color. Edits to this box have been disabled because the format required by DCPAL for this equation cannot simply be typed into a textbox.

Therefore, a “Change” button has been added to the right side of the textbox. It is unlikely that this relationship would need to be changed unless further research is conducted that is similar to that completed by Scales (2020). Should a new equation be developed in the future, this option has been included to accommodate future changes in the software.

Once the user clicks the “Change” button, the *Relationship* userform displays and it can be seen in Figure 0.6. The exponential format of the equation will remain the same, but the numerical constants are the values that could be updated based on further research. These constants are listed as “A” and “B” on the userform based on the general format of the Strength-to-DCP relationship equation. The default values for “A” and “B” are 1220 psi and -0.559 blow/mm respectively (Scales 2020). If the user inputs new constants for the equation, the parameters must be input into the designated text boxes at the bottom of the userform. If the user clicks the “Cancel” button, the user will return to the Initial userform with the relationship equation unchanged. If the user clicks the “Enter” button, the parameters input in the A and B textboxes will become the new constants displayed on the Initial userform.

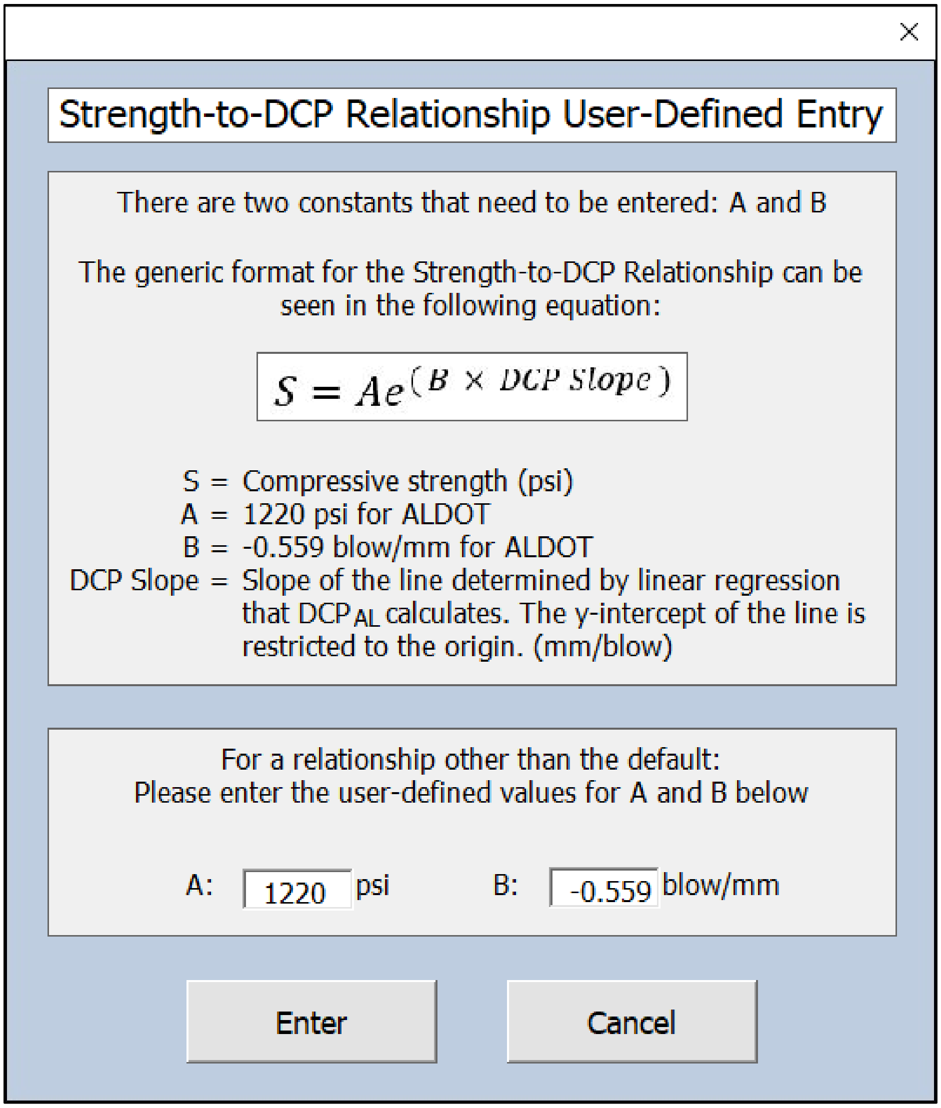

Figure 0.6: Relationship Userform

After completing the Relationship userform, the user will be returned to the Initial userform. For example, if the user changed the "A" parameter to 1221, this would be reflected in the Strength-to-DCP Relationship section as shown in Figure 0.7. First, the textbox that displays the equation option will now read "User-Defined" in gray, non-editable, text. Then, the default equation illustration is replaced with the "A" and "B" user-defined parameters to allow the user to confirm that the input parameters are as intended before proceeding.

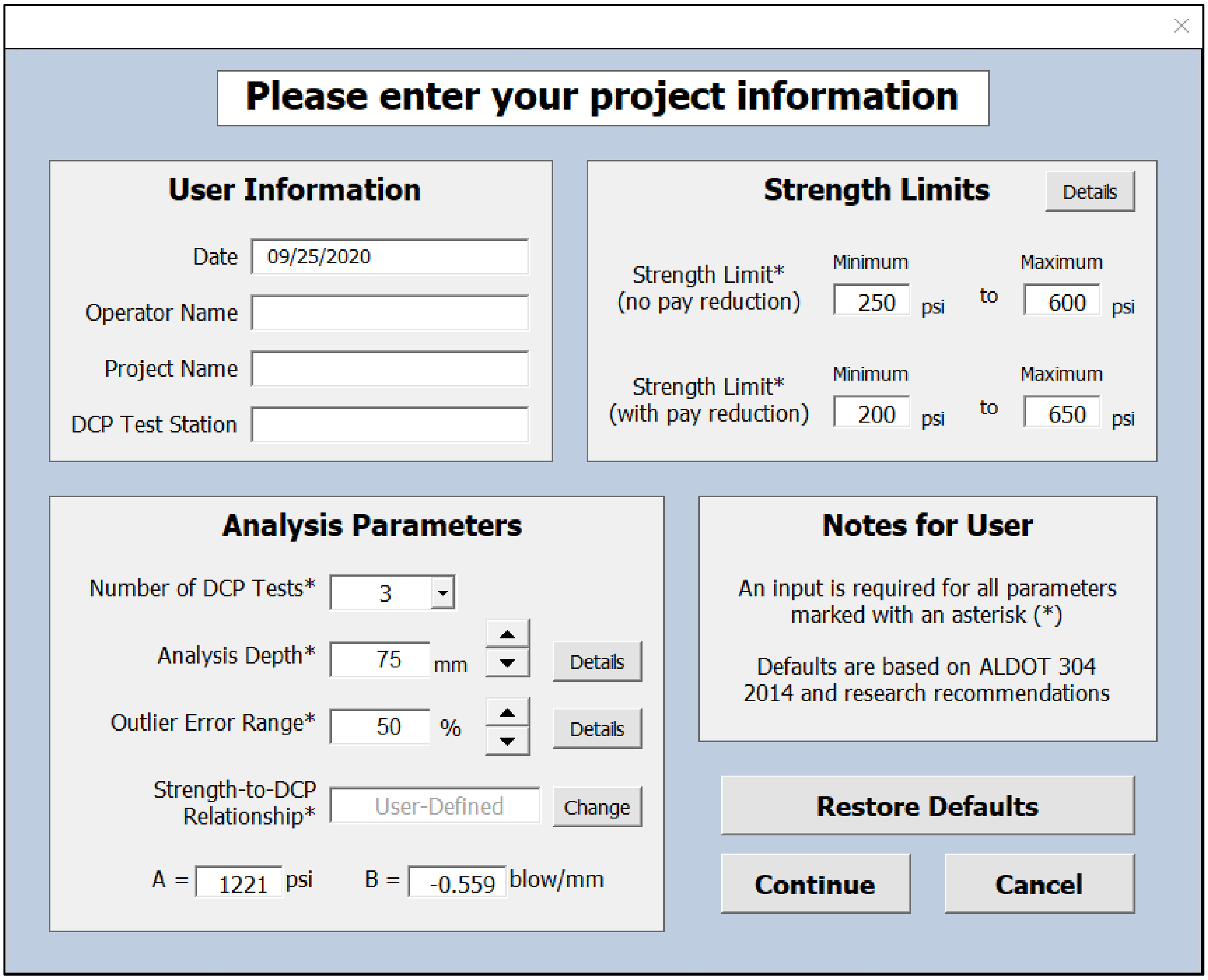

Figure 0.7: Edited Initial Userform

The last input parameters on the Initial userform are the Strength Limits. The default limits are set according to ALDOT 304 (2014). All inputs follow the same guidance as described in Table 0.4. To pursue a customizable model, the strength limit values are editable if a future project requires different limits. These values can be changed directly on this sheet by editing the text in the text boxes. If the user needs to change the values but is unsure of how DCPAL defines the parameters, a "Details" button has once again been provided. Once clicked, the *Strength* userform will display as shown in Figure 0.8. This userforms gives context on how DCPAL requires the inputs for the best use of the software possible. This userform displays a color-coded bar ranging from 0 psi on the left side to a value greater than the maximum input psi. The test boxes underneath the edges of the green range of this bar indicate the boundaries of compressive strength values that meet the quality assurance requirements and ensure full payment to the contractor as described in the contract. The test boxes underneath the outer edges of the yellow ranges indicate the boundaries of compressive strength values that meet quality assurance requirements but recommend a payment reduction to the contractor as described in the contract. Therefore, any compressive strength values outside of the yellow section will indicate that this section failed to meet quality assurance requirements. Any values input into these boxes will not affect the calculated compressive strength result. These values will only affect the payment and acceptance summary statements. Any changes made on this userform will be passed to the Initial userform if the user clicks “Enter”. If the user clicks “Cancel”, any changes made on this userform will not be reflected on the Initial userform once returned.

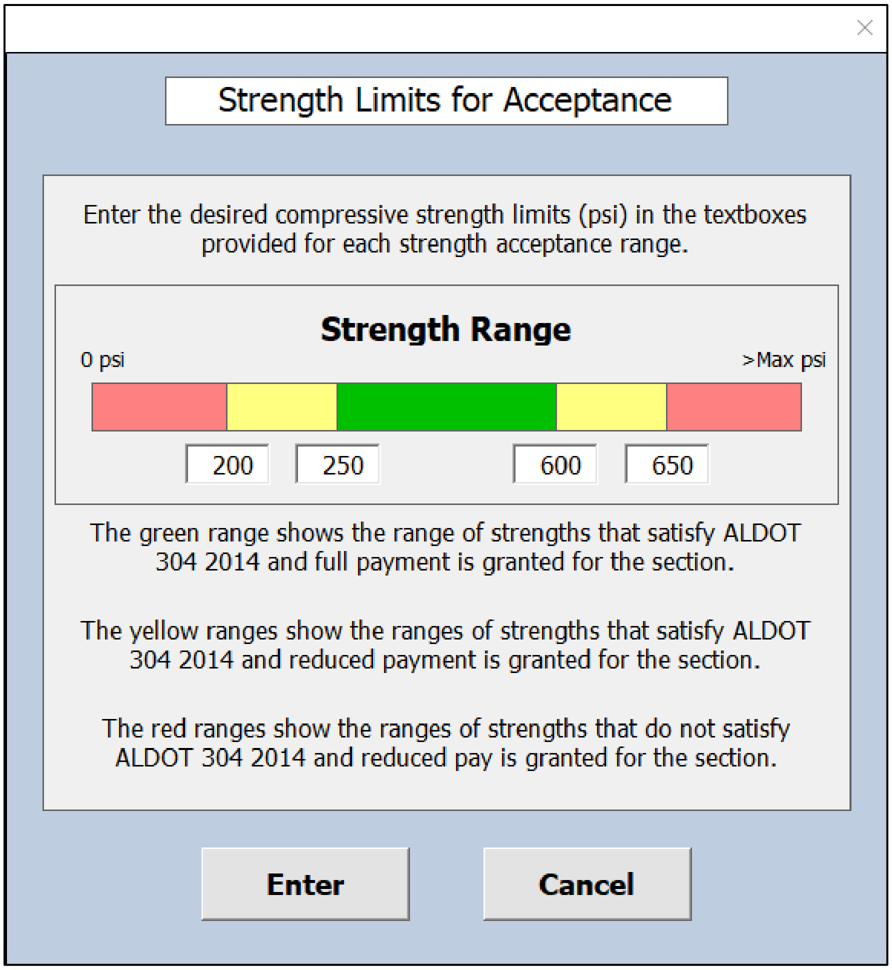

Figure 0.8: Strength Userform

1.13.1.2 File Selection and Confirmation Userforms

If the user has decided to discontinue the analysis, the "Cancel" button on the Initial userform will return the user to the original welcome screen. If the user is satisfied with the input parameters on the Initial userform, the calculations can commence by clicking the "Continue" button. Once the user begins the analysis, the next prompt DCPAL gives is to select the appropriate data text files that are saved to the device. The prompt is a userform with a single "Continue" button to acknowledge what is being asked of the user. The userform changes depending on which file is being asked of the user. For the first file, the *FirstFile* userform is displayed as can be seen in Figure 0.9.

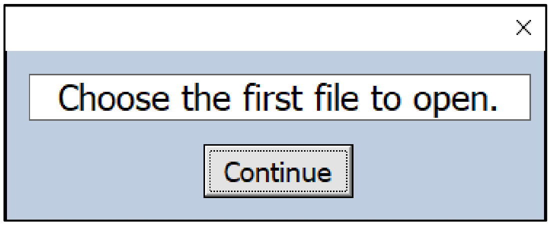

Figure 0.9: FirstFile Userform

Once the user clicks the Continue button, the Windows Explorer software will display all files and folders the user currently has on the device as shown in Figure 0.10. The user can then search for the first DCP data text file for the current analysis station. Selecting a file can be accomplished by either double-clicking the text file, or single clicking the text file then selecting “Open” in the bottom right of the windows explorer window.

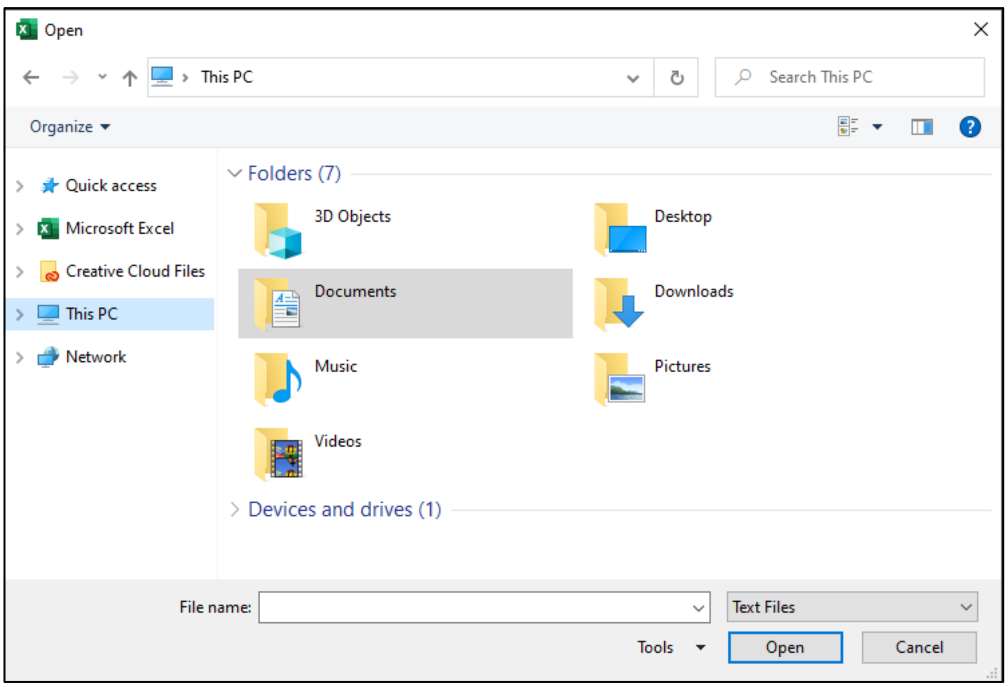

Figure 0.10: Example Windows Explorer window to open files

If the user decides to stop the analysis at this point, the user must click the “Cancel” button in the bottom right of the window. If the window is closed without a file selected, the user is then returned to the welcome screen.

Once the user successfully selects and opens a file, DCPAL reads the text in the file and copies it to the designated worksheet. Once copying is complete, the *Confirm* userform is displayed as shown in Figure 0.11 and the worksheet is displayed in the background with the copied data. The function of this userform is to allow the user to check the information that has been copied to the worksheet and to confirm that the correct data were selected. Inspection can be done visually by scrolling up and down the worksheet as needed. If the user clicks the worksheet to use the scroll bar, the userform may be hidden behind the window. If the user has inspected the data and determined that the wrong file was selected, the "No, select a new file" button must be clicked. This decision will return the user to the FirstFile userform. If the user were selecting the second file, the SecondFile userform would be displayed instead. This process repeats for all consecutive file selections. This procedure was created to avoid a complete restart after only a single mis-click in the file selection process. If the inspection of the data proves that the correct data file was selected, the user can click the "Yes, continue" button to proceed to the next file.

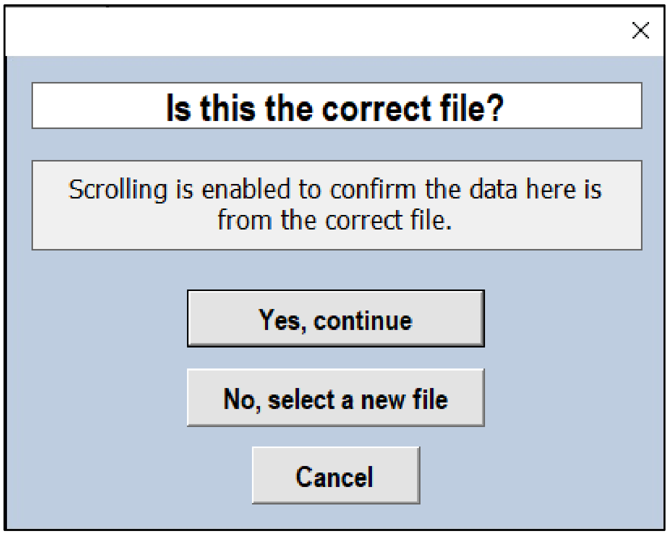

Figure 0.11: Confirm Userform

If the user decides at this point to stop the analysis, the “Cancel” button must be clicked. The *Sure* userform is then displayed as can be seen in Figure 0.12. The function of this userform is to return to the previous screen if the Cancel button was selected by accident. If the user did not intend to cancel the analysis, the “No” button must be clicked. Otherwise, by clicking the “Yes” button, the user will be returned to the welcome screen.

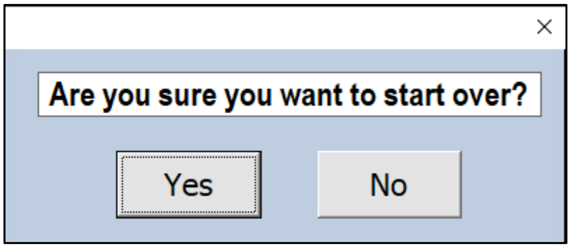

Figure 0.12: Sure Userform

Once all files are successfully loaded, the files are checked for errors. If any data points in the file are left blank or filled with any non-numerical characters, the user is notified by displaying the *DataError* userform. As an example, shown in Figure 0.13, an error was found in the second imported data file at the listed blow count.

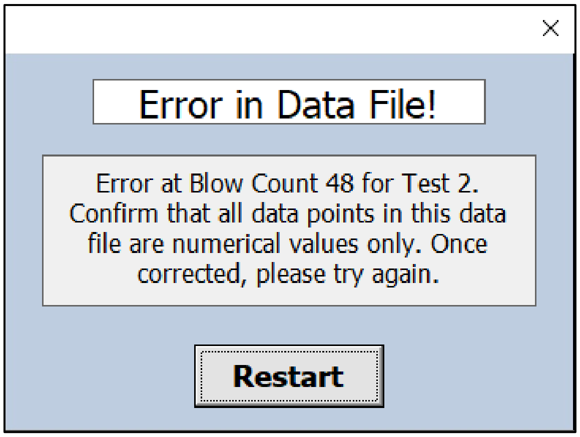

Figure 0.13: DataError Userform

During the DCP test, if a material is exceedingly strong or if a large particle is hit by the DCP cone, refusal may occur (Scales 2020). As prescribed in ASTM D6951 (2018), if at least two millimeters of depth are not reached for any five drops of the DCP hammer, then it is assumed that the material is too strong for the DCP to test. If refusal is determined, then the refusal userform is displayed and lists the test and blow count at which refusal was met as shown in Figure 0.14. This test is automatically discarded and is not considered to determine the final compressive strength.

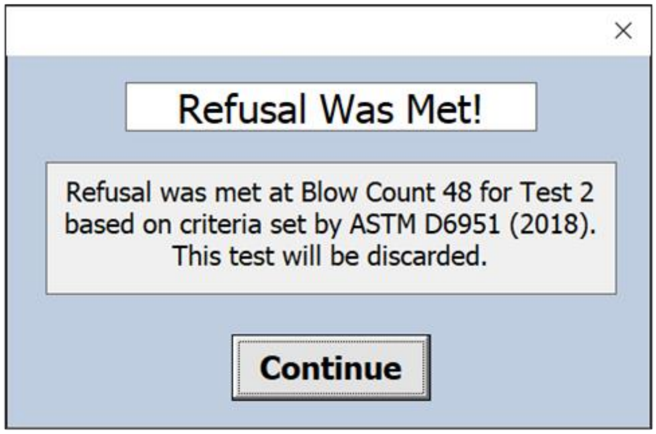

Figure 0.14: Refusal Userform

1.13.1.3 Outlier Analysis and Results Userforms

Once all files have been successfully loaded into DCPAL, the calculations are executed in the background. If an outlier is found during the outlier analysis portion of the calculations, the software is paused and the *Outlier* userform, shown in Figure 0.15, is displayed. This userform will tell the user which test was determined as an outlier and what the error range was for the whole data set including that test. The test number corresponds to the order in which the tests were input into DCPAL. Therefore, the first test that was selected during the file selection process would be considered Test 1, the second file input would be Test 2, and so on.

If an outlier was detected, the error range shown will be a higher percentage value than the Outlier Error Range input into the Initial userform. This is how the outlier was mathematically determined. Due to the processing limitations of computers, if the error range of the outlier were just slightly over 50 percent, the software will still consider this an outlier. If no option were given to the user to confirm the validity of outliers found, something as simple as rounding during the calculations would discard the test from the dataset. This userform allows the user to intervene and manually decide the fate of a potential outlier test. If the guidelines given by McLaughlin (2017) are strictly followed at the 50 percent limit, then the user would click the "Discard" button. This would instruct DCPAL to discard the test that was identified as an outlier. Otherwise, if the user's experience has proven that, say 50.1 percent for this example, is close enough to the outlier error range of 50 percent, then this userform provides the ability to keep the mathematically determined outlier. To not consider the test an outlier, the user must click the "Include" button to retain the test in the final dataset.

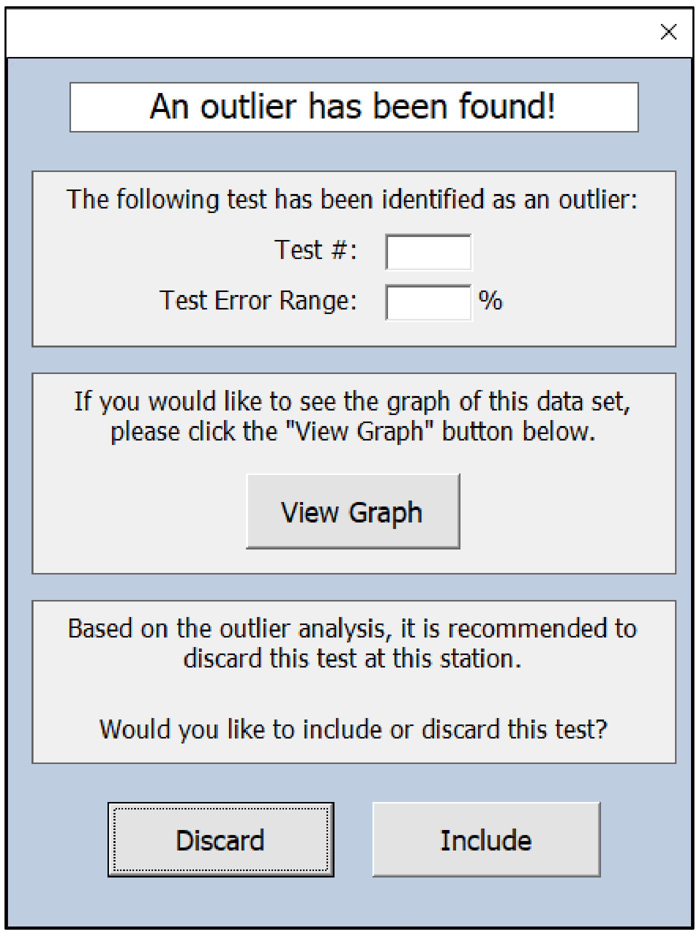

Figure 0.15: Outlier Userform

If the user would like to inspect the data visually before deciding to include or discard the outlier test, a graph of the data can be viewed by clicking the "View Graph" button. The *Graph* userform will then be displayed as shown in Figure 0.16. This userform presents the appropriate graph if all tests were included. The graph displayed shows the penetration depth in millimeters on the y-axis and the blow count on the x-axis. The slope of the line and the R^2 value are displayed in a box to the right of the data. The legend is displayed at the bottom of the graph which shows the marker legend for each test as well as the corresponding linear regression line. Once the user has finished inspecting the data on the graph, clicking the “Return” button will take the user back to the previous userform.

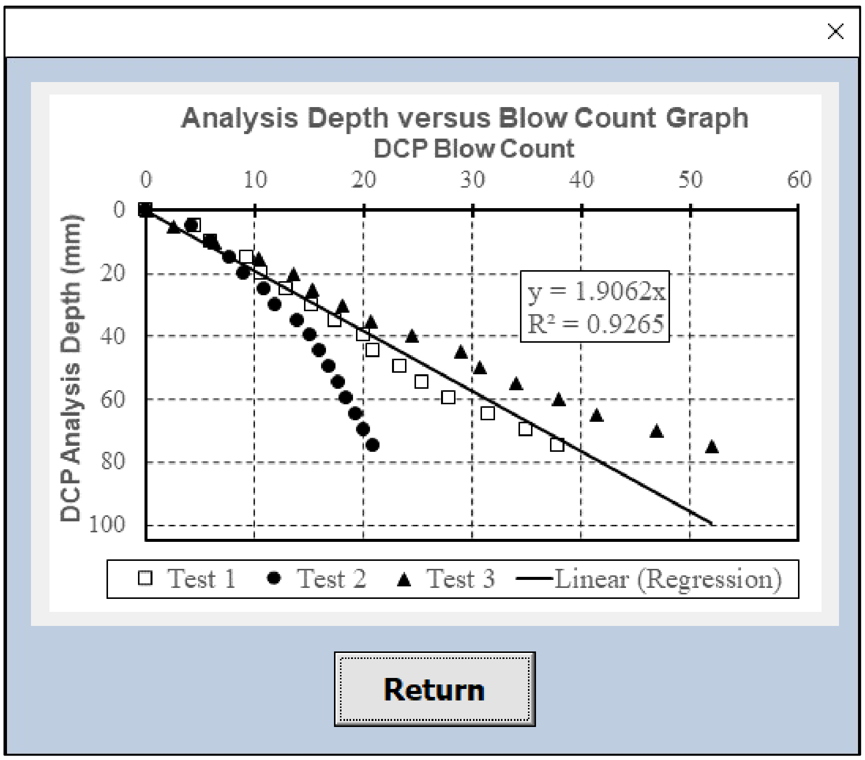

Figure 0.16: Graph Userform

Sometimes, the data collected are too variable for an outlier analysis to be successfully completed. This would occur if the outlier error range of all tests except for one was larger than the outlier error range set. High variability could occur if the material tested was not properly produced or if the DCP operator did not properly conduct the analysis. If this occurs, it is recommended that the operator return to this testing station and collect more data to test. DCPAL informs the user if this occurs by displaying the *OutlierError* userform. An example of this userform can be seen in Figure 0.17.

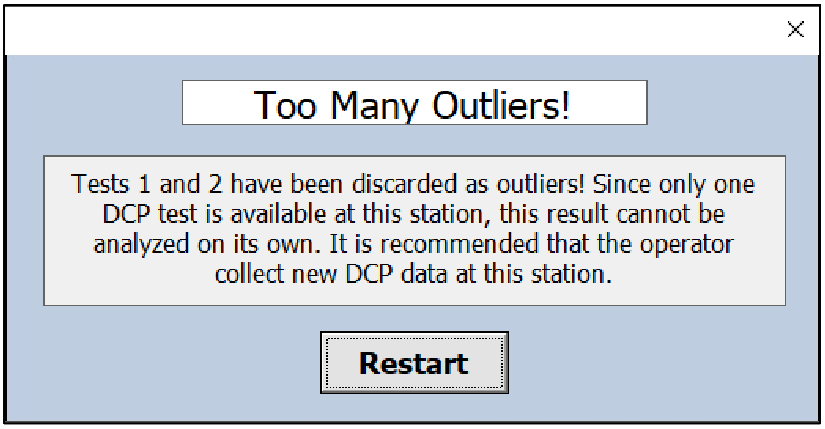

Figure 0.17: OutlierError Userform

After the outlier analysis has been completed, the *Results* userform is then displayed as shown in Figure 0.18. The only function of this form is to confirm to the user that the calculations were successfully completed and to give further information for outputting results. Once the user is ready to view the results of the analysis, the “View My Results” button must be clicked. The Results worksheet is then displayed for the user to view a summary of the input parameters and the results of the analysis.

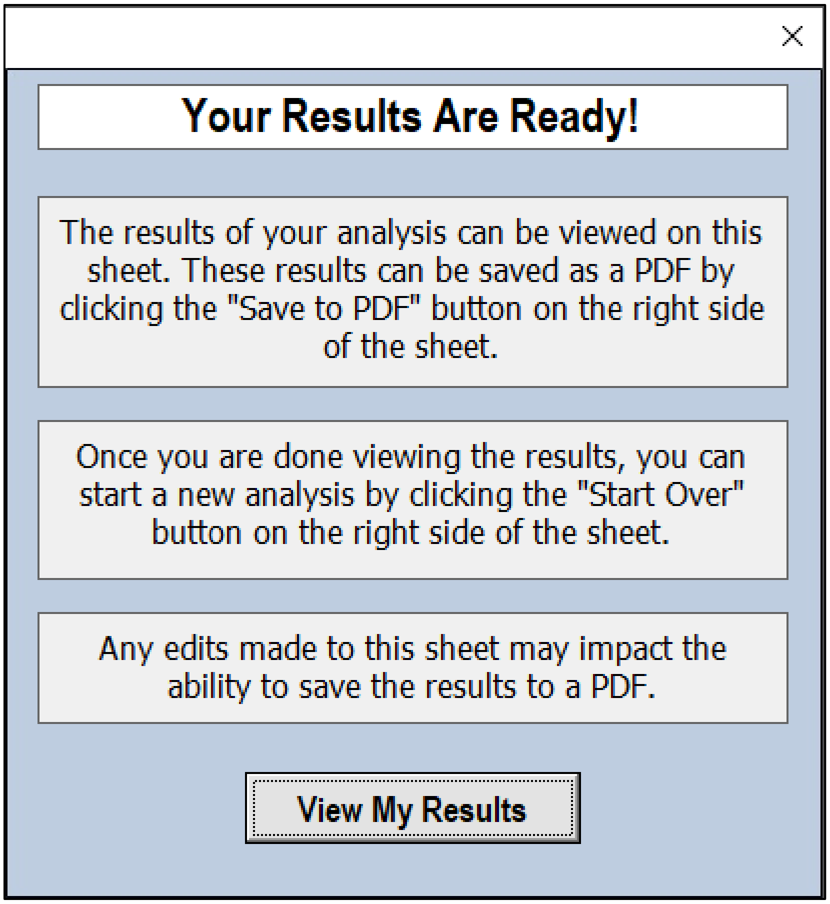

Figure 0.18: Results Userform

If the user would like to print the results to a PDF file, the *PDF* userform is then displayed as shown in Figure 0.19. The function of this userform is simply to allow the user to save the formatted Results sheet to a printable format. If the user decides to not print to a PDF, the “No” button will return the user to the Results worksheet. Otherwise, clicking the “Yes” button will prompt the user to save the file. This is done by using the Windows Explorer software again and allowing the user to navigate to the desired save location.

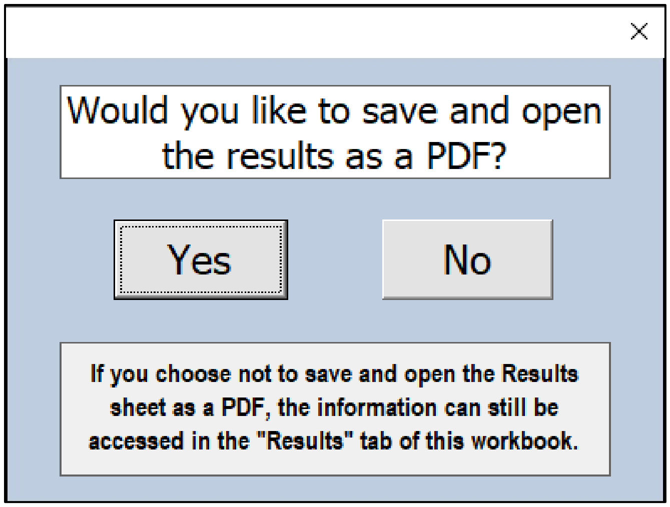

Figure 0.19: PDF Userform

To streamline the file saving process, the Project Name and Station input parameters are automatically displayed in the File Name textbox on the windows explorer window to save. An example of this window with an example file name with input parameters in brackets can be seen in Figure 0.20. The user may still edit the suggested file name at this time. If the appropriate location is already chosen, then the only action needed by the user would be to click “Save”. The PDF is then created, saved, and opened for review by the user. By clicking “Cancel” the user is returned to the Results worksheet.

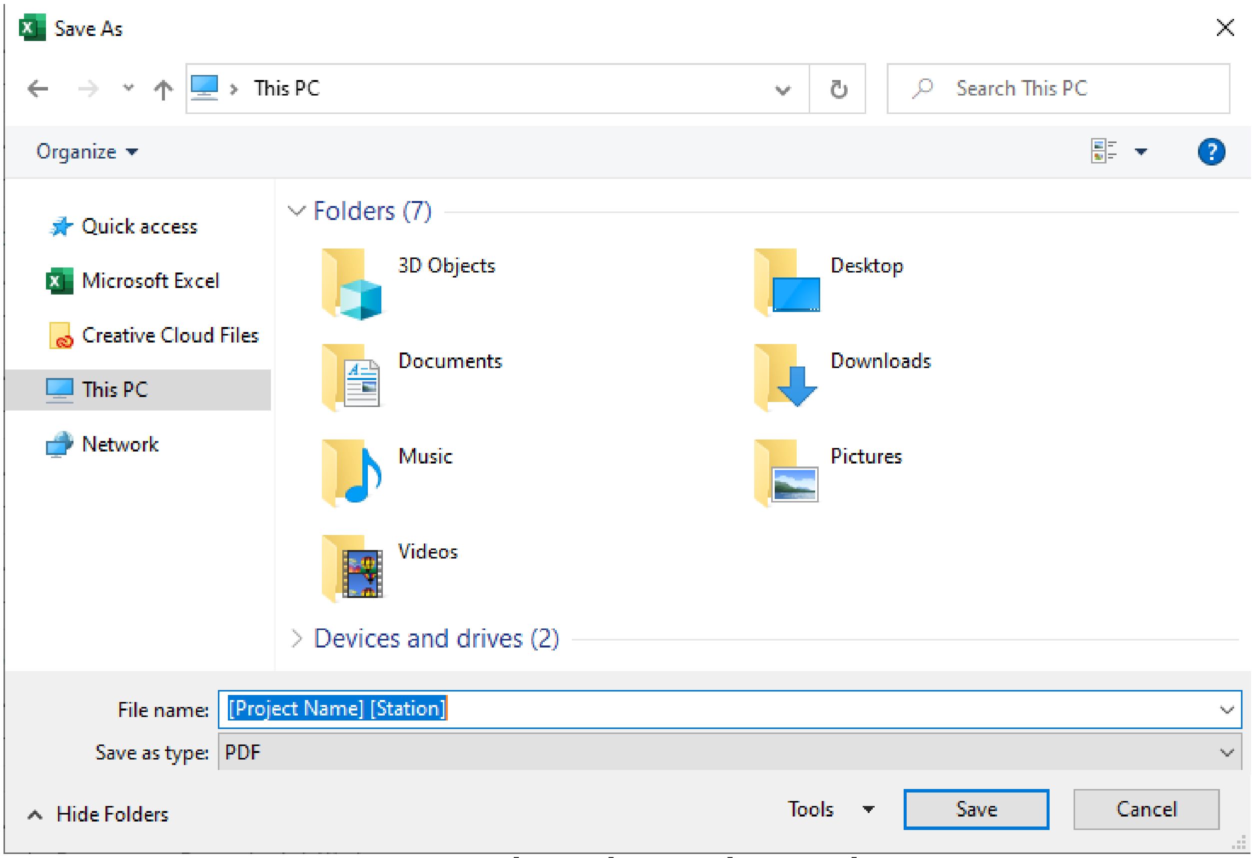

Figure 0.20: Example Windows Explorer window to save

1.13.2 Worksheets in the Workbook File

Many of the worksheets created are not interacted with by the user when using the executable application of DCPAL. In fact, most of the worksheets stay hidden to visually optimize the user experience. Some worksheets contain embedded equations, while others were created as a type of user interface for the user to interact with. A combination of embedded formulas and code manipulation was a more effective approach in comparison to inserting all calculations into the code itself. Each spreadsheet is briefly discussed in this section. The calculations conducted throughout the spreadsheets consist of three major components:

- A linear regression at every 5mm of penetration depth as done by (Scales 2020)
- An outlier analysis in accordance with ASTM C670 (2015)

- A compressive strength computation determined by the Strength-to-DCP relationship developed by Nemiroff (2016) and updated by Scales (2020).

1.13.2.1 Startup

When starting up the workbook file for the first time, if macros are not enabled, the *MACRO* sheet is displayed, which can be seen in Figure 0.21. This sheet gives instructions to the user on methods of enabling macros in Microsoft Excel. DCPAL only works if macros are enabled and this function keeps the program out of error mode.

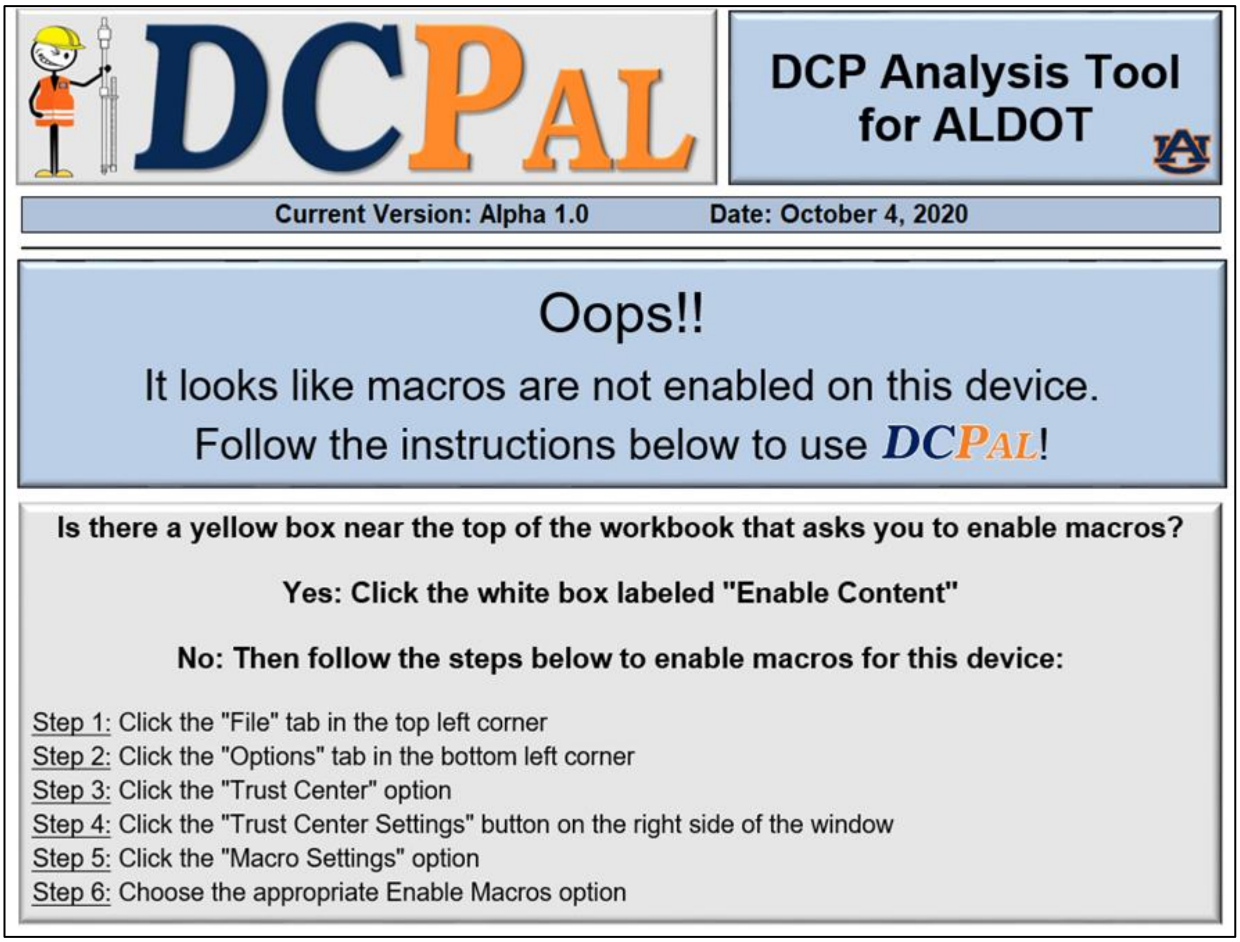

Figure 0.21: MACRO sheet

Once macros are enabled, the *Starting Page* sheet is displayed as shown in Figure 0.22. A description of how to show all worksheets is given in Section 1.13.3. This page includes general information for the user before beginning an analysis. The user can click the “Import Data” button to begin an analysis.

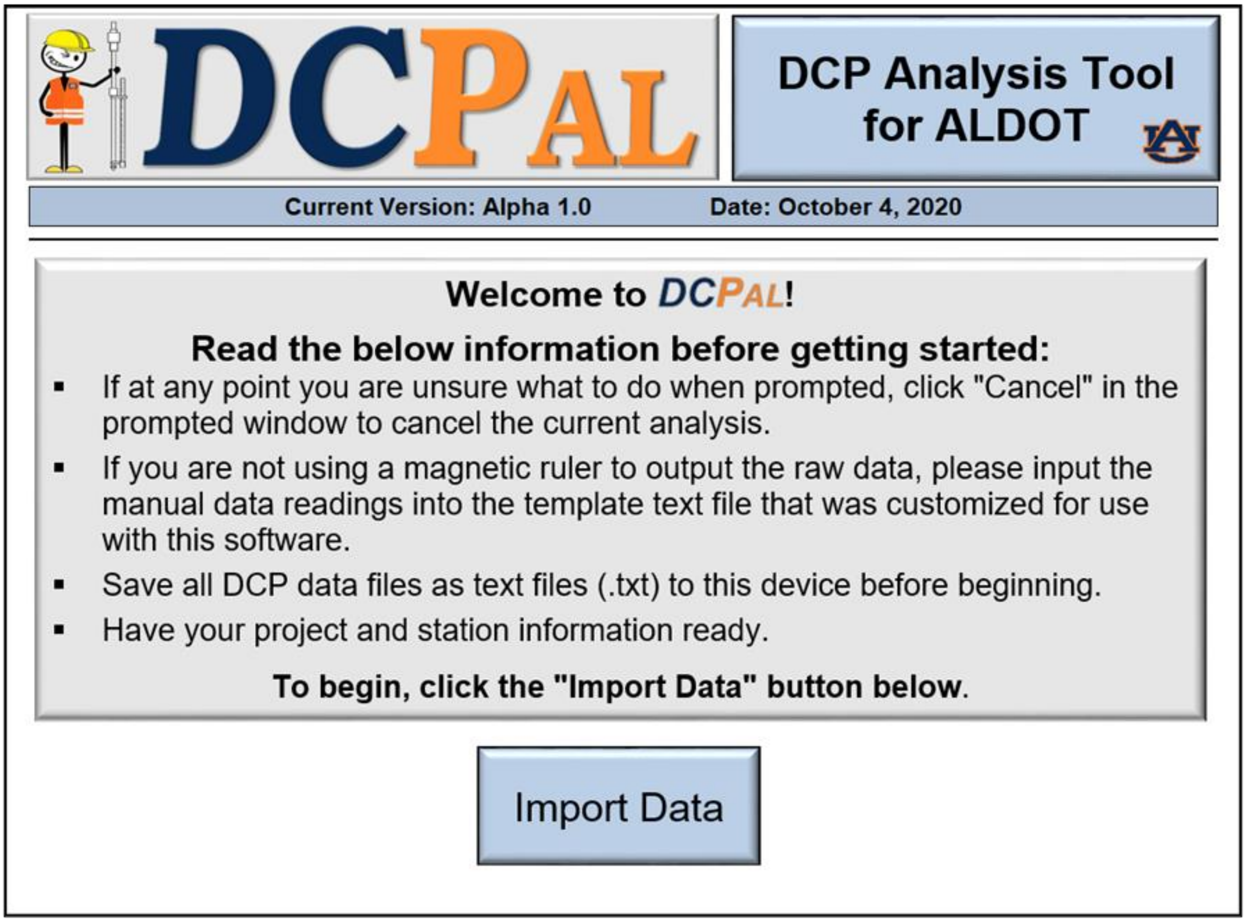

Figure 0.22: Starting Page sheet

1.13.2.2 DCP Data

The next series of sheets titled “DCP 01” through “DCP 05” are simply placeholders for the collected DCP data. If only three tests are being input into DCPAL, then only the first three sheets would be used. Excel cannot easily manipulate data on a different file. It is more efficient to have the data on an Excel sheet. Therefore, all data that is on the corresponding text file for each test at a given station is stored on each of these sheets.

If the operator was using a magnetic ruler during DCP testing, the data are automatically collected and stored on an internal storage device. The internal storage device outputs text files of the collected data once connected to the user's computer. If the operator manually collected the DCP data, the data would need to be entered into a text file if the user plans to use DCPAL for the calculations. To streamline this process, a template text file has been developed to accompany DCPAL. Once the data are entered into the template text file, DCPAL will be able to read it as if the text files were from a magnetic ruler.

1.13.2.3 Linear Regression

The next set of sheets titled "Compile and Linear3" through "Compile and Linear5" are used to reorganize the raw data from the previously discussed sheets. One sheet is used that corresponds to each test being analyzed at the current station. Before beginning to analyze the data, the data are first checked for validity. Each test is scanned for invalid characters and DCP refusal. An invalid character is anything that is not a numerical value in the cell where either depth or number of blows data points should be. This includes any special characters, any alphanumeric combinations, or simply a blank cell. The validity of a cell is checked on this sheet. Refusal is checked by subtracting the fifth depth from the first depth and is affirmative if the result complies with the ASTM D6951 (2018) limit.

It was determined that data were needed at every five millimeters of penetration depth to achieve comparable results using Microsoft Excel (Scales 2020). Although, when using the DCP in the field, determining a blow count for every five millimeters is impractical when collecting data manually. Therefore, the raw data must first be organized in such a way as to conduct a linear regression to achieve a corresponding blow count for every five millimeters of depth. A linear regression is used because the data are mostly linear, making it a reliable method of analysis for this research (Scales 2020).

In order to streamline the regression analysis process, embedded functions in Excel were utilized. The "LINEST" function is used to calculate a linear regression function using the least squares method. This sheet is used to create a table to output the slope of the data in millimeters per blow for every five millimeters of depth for all tests input into DCPAL. One issue with this embedded function is the potential for an error code output in a cell if the last value on the table is not between two points from the data set. This would occur if, for example, the final depth collected was 175 millimeters and the last depth on the created table was 175. To avoid this error code, a maximum value check is performed. The sheet automatically outputs the maximum values from a data set and displays them above the created table. The code will fix the error if the final value in the table is the maximum value of a dataset.

1.13.2.4 Outlier Analysis

Part of the outlier analysis is conducted on the sheets titled "Outlier3" through "Outlier5". One sheet is used that corresponds to each test being analyzed at the current station. First, the tables for final slope determination are automatically filled from the previous sheet data. The number of tables created corresponds to the number of potential outcomes from the outlier analysis. For example, if three DCP tests are used, only one outlier may be found. If more than one outlier is found, then there are too many outliers to complete the analysis. Therefore, there are only four possible outcomes of the analysis: 1) All tests are included, 2) Test 1 is discarded, 3) Test 2 is discarded, or 4) Test 3 is discarded. These four possibilities will result in four different slope values used to later calculate the strength. This same idea is repeated for four DCP tests and five DCP tests, but with many more possibilities to consider. These separate tables were necessary because the embedded function used to determine the slope requires the dataset to be a continuous range of cells. A summary table of all potential outcomes is automatically generated for later use in the code. Next, the slope values and computed error ranges at each depth are automatically displayed on this sheet. The remaining outputs include designation of outliers based on calculated error ranges, output of final slope values at each depth after giving the user a chance to decide on outliers found at the analysis depth, and summarization of the user options to output on the results sheet.

1.13.2.5 Results Sheet

This sheet is where all final results are displayed that may be of importance to the user. This sheet has been formatted such that it is printable to a PDF in a presentable format for submittal on an ALDOT project as shown in Figure 0.23. This sheet includes all inputs from the Initial userform, as well as computed strength, quality assurance acceptance, payment reduction recommendations, outlier analysis results, and the final slope value for the chosen analysis depth. Additionally, the corresponding graph is shown on the second page to visually display the results of the regression analysis with the included tests. If an outlier was discarded during the analysis, an additional graph is displayed on the third page. This sheet is not used for acceptance, but merely for visual representation of the entire dataset should a review of the submittal be necessary later. By including a graph with all tests, this would show the user the discarded test in comparison to the accepted tests, with the outlier often being visually apparent.

To save the Results sheet as a PDF file for easy printing and submission, the user must click the "Save to PDF" button on the right side of the screen. To start a new analysis, the user must click the "Start Over" button on the right side of the screen. The Starting Page would then be displayed again allowing the user to start a new analysis. If the results need to be viewed again, the Results sheet tab at the bottom of the screen is accessible until a new analysis is initiated.

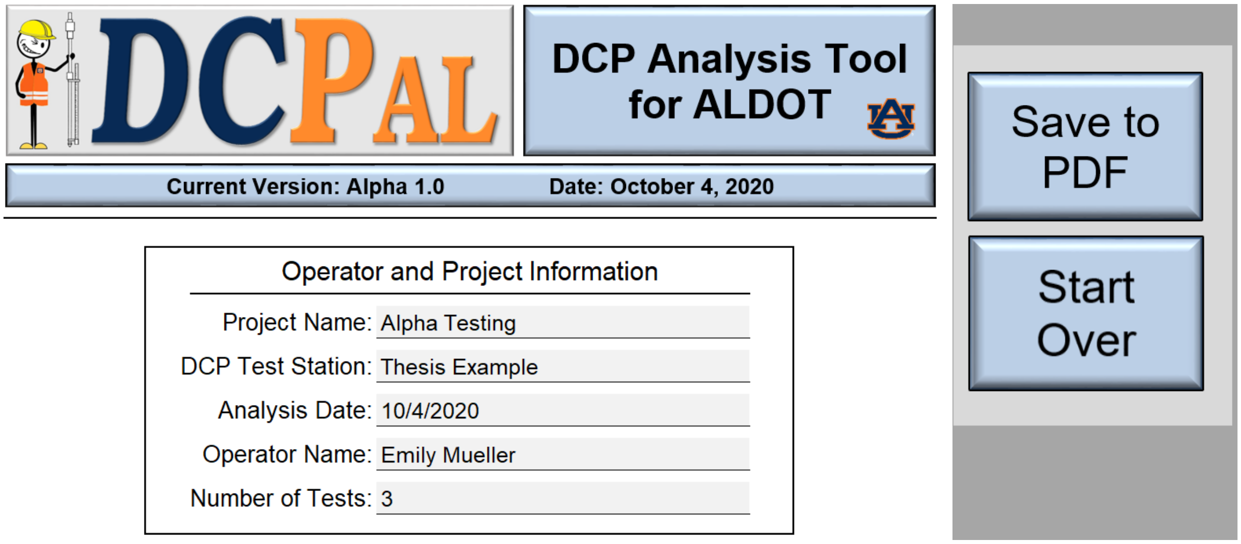

Figure 0.23: Screenshot of Results sheet: PDF and Start Over buttons

An example of the output results in PDF format can be seen in Appendix E. The header of each sheet includes the logo of DCPAL, the name of the program, and the current version of DCPAL with the corresponding version date. The first box, “Operator and Project Information”, provides general information to categorize this analysis. An example of this section can be seen in Figure 0.23.

The next box, “Calculated Strength and Acceptance Results” is the main focus for the user. An example of this section of the results sheet can be seen in Figure 0.24. This section on the results sheet displays results for quality assurance testing, payment recommendations, and calculated compressive strength based on the Strength-to-DCP relationship selected by the user. If new payment reduction equations are developed by ALDOT in the future, this section would need to be updated to be useful for payment recommendations.

Calculated Strength and Acceptance Results

Station Test Outcome = **Pass w/o Pay Reduction**

Compressive Strength = **460 psi**

Pay Reduction* = **0.0 %**

* Calculated in accordance with ALDOT 304 2014

Figure 0.24: Screenshot of output: Calculated Strength and Acceptance Results

The last box on this sheet includes a "Summary of Outlier Error Input and Analysis Results" that includes the outlier error range, the calculated error ranges of each test, and information indicating whether each test was included or discarded. An example of this section of the results sheet can be seen in Figure 0.25. The test numbers in this box correspond to the order in which the user selected the data files to be uploaded to DCPAL. If no outliers were calculated, all range values will be the same and all uploaded tests will be included. If an outlier was calculated, its individual range will be recorded and the user decision on whether to include or discard the test will be listed in the "Used in Analysis?" column.

Summary of Outlier Error Input & Analysis Results

Test	Range**	Used in Analysis?
1	**28%**	Included
2	**28%**	Included
3	**28%**	Included
4	**N/A**	N/A
5	**N/A**	N/A

Outlier Error Range Limit: 50 %

** Range determined by all included tests

Figure 0.25: Screenshot of output: Summary of Outlier Error Input and Analysis Results

On the second page of the results output is first the "Summary of User-Defined Strength Limits" box. This section is included simply to record the strength limits that were used in determining the outputs from the "Calculated Strength and Acceptance Results" box on the first page. An example of this section of the second page of the results sheet can be seen in Figure 0.26.

Summary of User-Defined Strength Limits			
Accept Without Pay Reduction	Minimum 250 psi	to	Maximum 600 psi
Accept With Pay Reduction	Minimum 200 psi	to	Maximum 650 psi

Figure 0.26: Screenshot of output: Summary of User-Defined Strength Limits

The “Summary of Strength-to-DCP Relationship” box details the Strength-to-DCP equation constants used, the analysis depth chosen, and the final DCP slope calculated after the outlier analysis. In Excel, displaying an exponential equation with variable portions is not a simple matter, and a simplified approach was implemented. An example of this results section can be seen in Figure 0.27.

Summary of Strength-to-DCP Relationship	
Relationship Equation:	S = 1220 x e (-0.559 x slope)
Analysis Depth:	75 mm
Calculated DCP Slope =	**1.737** mm/blow

Figure 0.27: Screenshot of output: Summary of Strength-to-DCP Relationship

The last item on this page is an graph that illustrates the DCP data, as was computed by Nemiroff (2016) and Scales (2020). An example of this graph shown on the second page of the results output can be seen in Figure 0.28. This graph displays the penetration depth versus blow count data with the slope of the best-fit linear-regression line, displayed with units of millimeters per blow. The equation of the line displayed on the graph is equivalent to the DCP slope that is used in the Strength-to-DCP relationship equation.

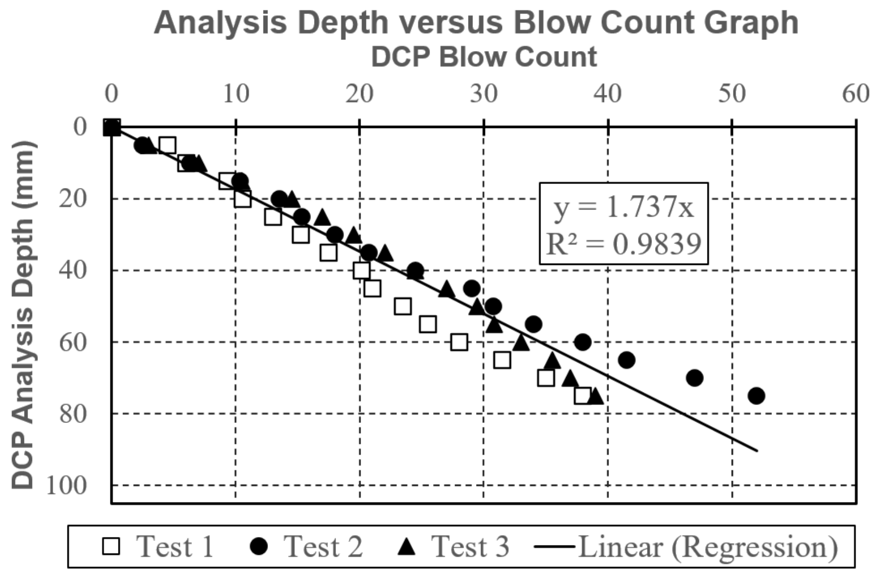

Figure 0.28: Screenshot of output: Analysis Depth versus Blow Count Graph

If an outlier was discarded, a third page is included in the results output. This page contains an "Information for All Tests Included" box with the analysis depth and the slope of all tests included. A corresponding graph is included below. An example of this additional information and graph shown on the third page of the results output can be seen in Figure 0.29. A note is provided to the user that stresses the importance of not using this slope value for final acceptance decisions. Should the results need to be reviewed later, this page allows the reviewer to analyze all test data on a graph.

Information for All Tests Included	
Depth	Slope
75 mm	**1.737** mm/blow

NOTICE: This sheet is only provided to help the user evaluate the effect of analyzing all test data. However, because a test was discarded, this graph should not be used for acceptance in accordance with ALDOT 304 (2014).

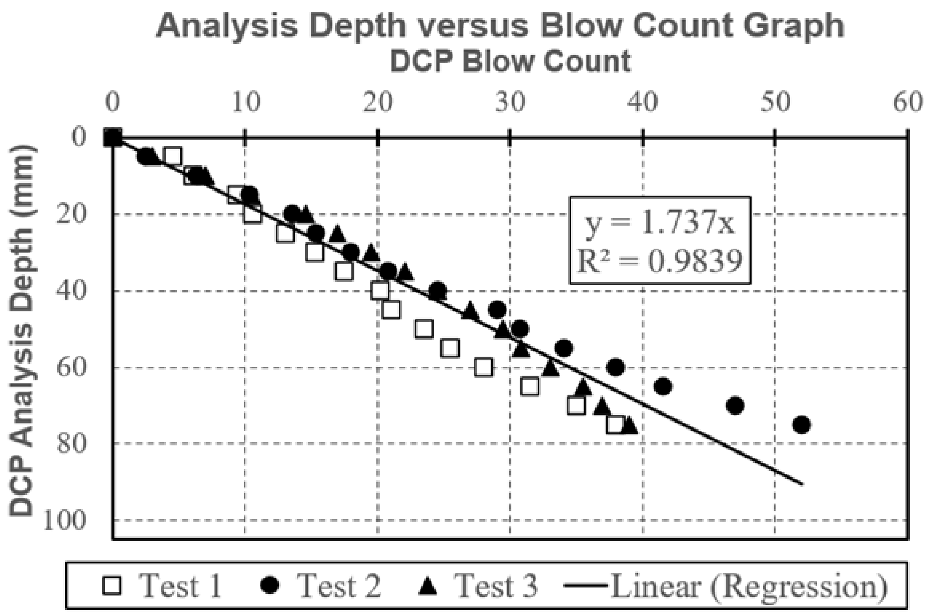

Figure 0.29: Screenshot of output: Information for All Tests Included and additional graph

After gaining experience viewing DCP data plotted in this way, it becomes apparent to the viewer when a test may be skewed by potential outliers. For example, if a test trends sharply downwards while all other tests follow more closely along the regression line, it indicates that the location assessed by this test was not as strong as the other test locations. Alternatively, if a test tends to slope towards the horizontal away from the regression line, this indicates a stronger location or potential localized hard spot (e.g. rocks) of the soil cement base. It is ideal for all tests to trend around the regression line without any major bias visually observed on this graph. This would indicate that the DCP tests conducted at the same station exhibit similar results and the material was uniform, as intended. Therefore, it is important to include a third page with all tests included in preparation for future review potential of discarded tests.

1.13.2.6 Graph Sheet

The *Graph* sheet is the worksheet in which all the plotting information is generated, and each potential outcome graph is populated with the appropriate data. This sheet stays hidden throughout the analysis when a graph is not being pulled to show in either a userform or copied to the results sheet. When creating a default graph in Excel, the axes values are set based on a default method that is not generally effective for the graph data. For this case, if an analysis had more blow counts than the default, some of the data would be cut off the bottom due to the default axes scaling by Excel. To optimize the visual output of the graphs, the y-axis of the graphs are dynamically changed based on the maximum x-axis value for each plot. This extra step ensures that the entire dataset and regression line is visible on the final output graph.

1.13.2.7 Stored Information Sheet

It is assumed that multiple analyses will be conducted for the same project but at different locations, or stations. In this scenario, the inputs would generally stay the same, with only the DCP Test Station input changing between analyses. The *Stored Information* sheet keeps the previous analysis data and generates the Initial userform with these data the next time an analysis is started. This streamlines the process for the user, making the next analysis even easier than the first. This information is discarded once the application is closed. This ensures that the default ALDOT values persist the next time DCPAL is used.

1.13.3 Code

The code is viewable by accessing the Developer Tab on the Excel Ribbon and clicking the Visual Basic button on the left side of the ribbon. The total length of code used in the process was approximately 6,000 lines. This includes the main code, all associated functions, debugging code, and userform operations. The main body code is the code that calls userforms or functions to complete operations necessary to give the desired output.

DCPAL generates results for one testing station at a time. This code can be seen in Appendix A. Functions were used to minimize the overall length of the code. This makes the code process faster and decreases the number of lines of code that must be loaded each time the program is run.

Debugging code is used to see all sheets when manual error correcting is to be completed in edit mode. Associated functions and debugging code can be seen in Appendix B. Each userform included embedded code to complete tasks within the userform. Buttons on the userform must be coded in the userform instead of in the modules in which other code is written. The userform operations are presented in Appendix C.

Throughout the coding process, a few different optimization techniques were utilized. When addressing cells in VBA, it is common to use either the row-column addressing method or the range method. Either of these methods require that nothing is moved on the sheet. During edits and development, the cells on sheets constantly changed locations. Therefore, a less common method was used to ensure the correct cell was being edited during coding called the Application.GoTo method. This required that important cells be named using the formula name manager included with Excel. Using this method drastically decreased the amount of work required to reorient the code when inevitable changes in the sheets occurred.

The next technique worth noting was the method by which the text files were utilized. Any time a file is opened in the background, the file is using some of the random-access memory (RAM) that is available on the device. The more files that are open, the more RAM is used. It is generally good programming practice to minimize the number of files open at once to ensure optimal performance of the device being used by not reaching the maximum RAM available. Therefore, any file that was opened was immediately closed upon completion of data copying. This step was taken in an effort to keep the device from slowing down due to lack of available RAM and to keep DCPAL running smoothly.

The last technique used worth noting involves the method by which the graph is displayed in the Graph userform. Generally, each device has a hidden clipboard in which copied information is stored temporarily and can be pasted in most formats between applications. Within VBA, this is not an option for userforms. The image option on a userform requires the upload of a saved image in the form of a JPEG, GIF, or PNG. Therefore, the appropriate graph would have to be saved to the device to be loaded on the userform all while the code is running. The only viable option found for accomplishing this task was the temporary file save method. This method would find the appropriate graph based on user inputs, save it as a temporary image on the user's device, load it into the userform when necessary, and delete the file upon closing the application. This technique ensures that the user's device is not cluttered with temporary graph images and keeps the software running smoothly in the process.

1.14 DCPAL Examples

1.14.1 Introduction

In this section, the DCPAL procedures described in the previous section are demonstrated with three examples. These examples were designed to cover the potential compressive strength acceptance outcomes outlined in ALDOT 304 (2014). Demonstrations of what DCPAL would display in each example are presented in the following sections. The results of each section are briefly reviewed. Sample input files and output results files for each of the three examples can be seen in Appendices F, G, and H respectively. The three possible acceptance outcomes are described in Section 1.6.5 and summarized in Table 0.4, and are defined as follows:

- Outcome 1: The soil cement base is constructed to meet ALDOT strength requirements and the contractor receives full payment for the work.
- Outcome 2: The soil cement base is constructed to a strength less than the ALDOT requirements and the contractor receives a reduction in payment for the work.
- Outcome 3: The soil cement base is constructed to not meet ALDOT strength requirements and the recommendation is to remove and replace the section.

1.14.2 Outcome 1

For this example, three DCP tests are conducted at a station selected by the project engineer labelled "Station 01" on a project called "ALDOT Highway". The contractor has been tasked to produce a soil cement base with a compressive strength within the limits defined in ALDOT 304 (2014). DCP data were recorded using a magnetic ruler and saved to the computer on which DCPAL will be used. After starting the program, the inputs for this example were entered as shown in Figure 0.30.

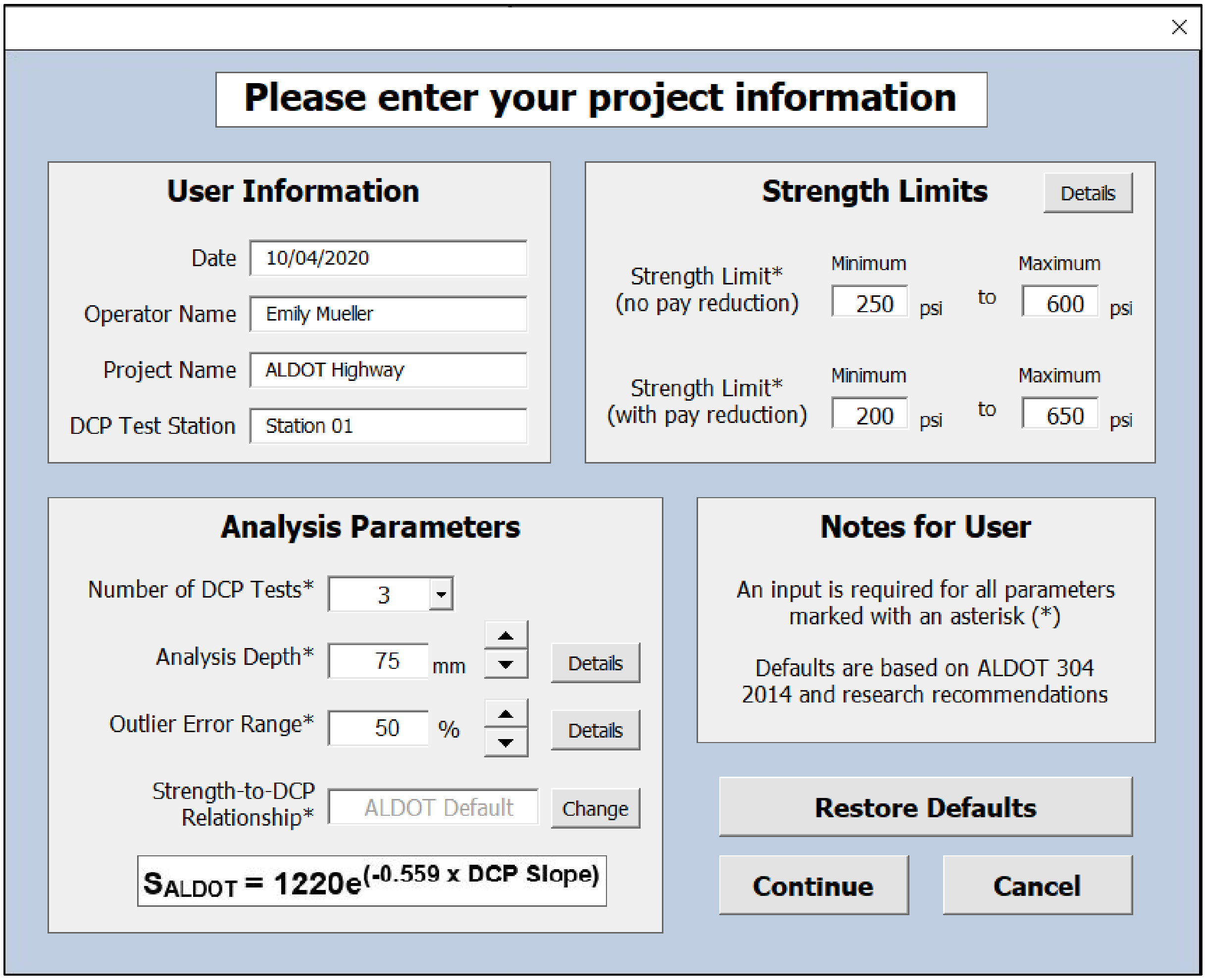

Figure 0.30: Initial userform filled out for Outcome 1

Then, the three files were selected and opened successfully. These files were opened in the order shown in Appendix E. DCPAL then produced the results screen shown in Figure 0.31.

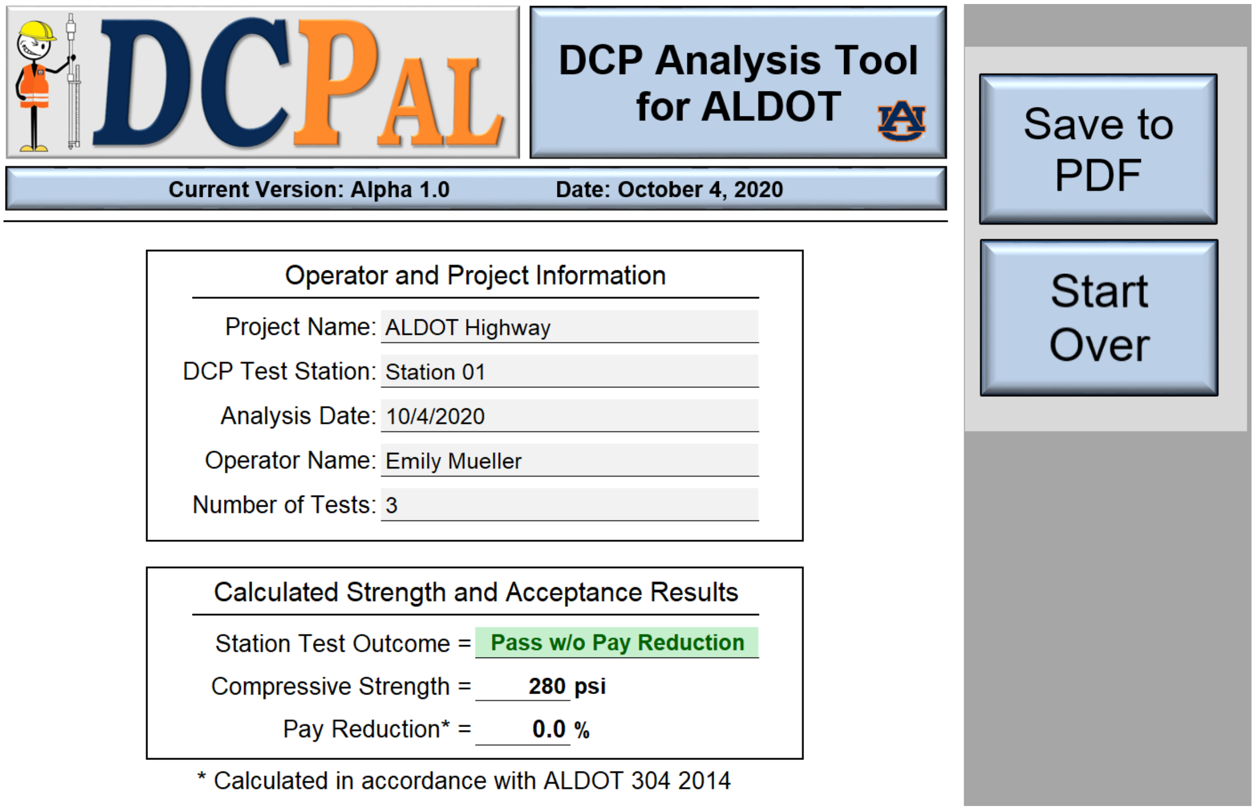

Figure 0.31: Results sheet view for Outcome 1

Once the Results sheet has been reviewed, the results were saved as a PDF file by selecting the appropriate button on the right. The results are then saved to the output file that indicates that the compressive strength of the soil cement base was 280 psi, which falls within the strength range limit for acceptance and full payment. This is denoted by the green label that reads "Pass w/o Pay Reduction". The PDF file only includes the first two pages because no tests were discarded as outliers, and all test data are displayed on the graph on the second page. The PDF file for Outcome 1 can be seen in Appendix E.

1.14.3 Outcome 2

For this example, three DCP tests are conducted at a station selected by the project engineer labelled "Station 02" on the same project as for Outcome 1. DCP data were recorded using a magnetic ruler and saved to the device on which DCPAL will be used. This analysis was conducted immediately following the analysis for Outcome 1, and therefore all the previous inputs were stored on the userform. Other than the DCP output files, the only difference from the previous example would be the DCP Test Station input. Then, the three new DCP output files were selected and opened successfully. These files were opened in the order shown in Appendix F. DCPAL is then run and an outlier found as can be seen on the user interface in Figure 0.32.

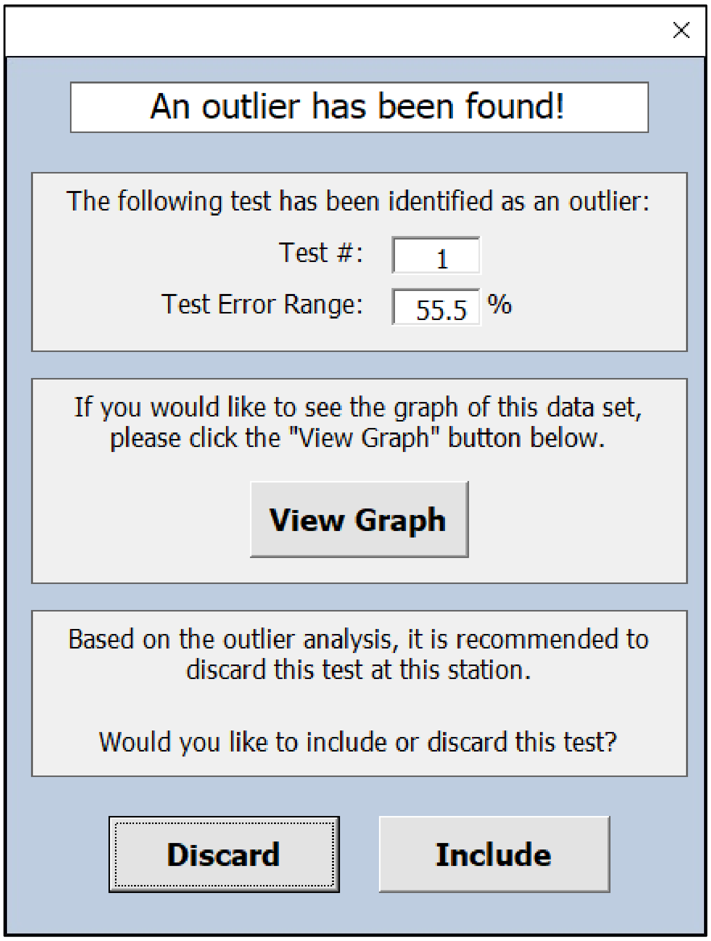

Figure 0.32: Outlier userform for Outcome 2

It is recommended to follow the guidelines in place for outlier analysis, and thus the outlier was discarded from the dataset. DCPAL then runs the remaining calculations with no further outliers found. The results screen that can be seen upon completion of the analysis is shown in Figure 0.33.

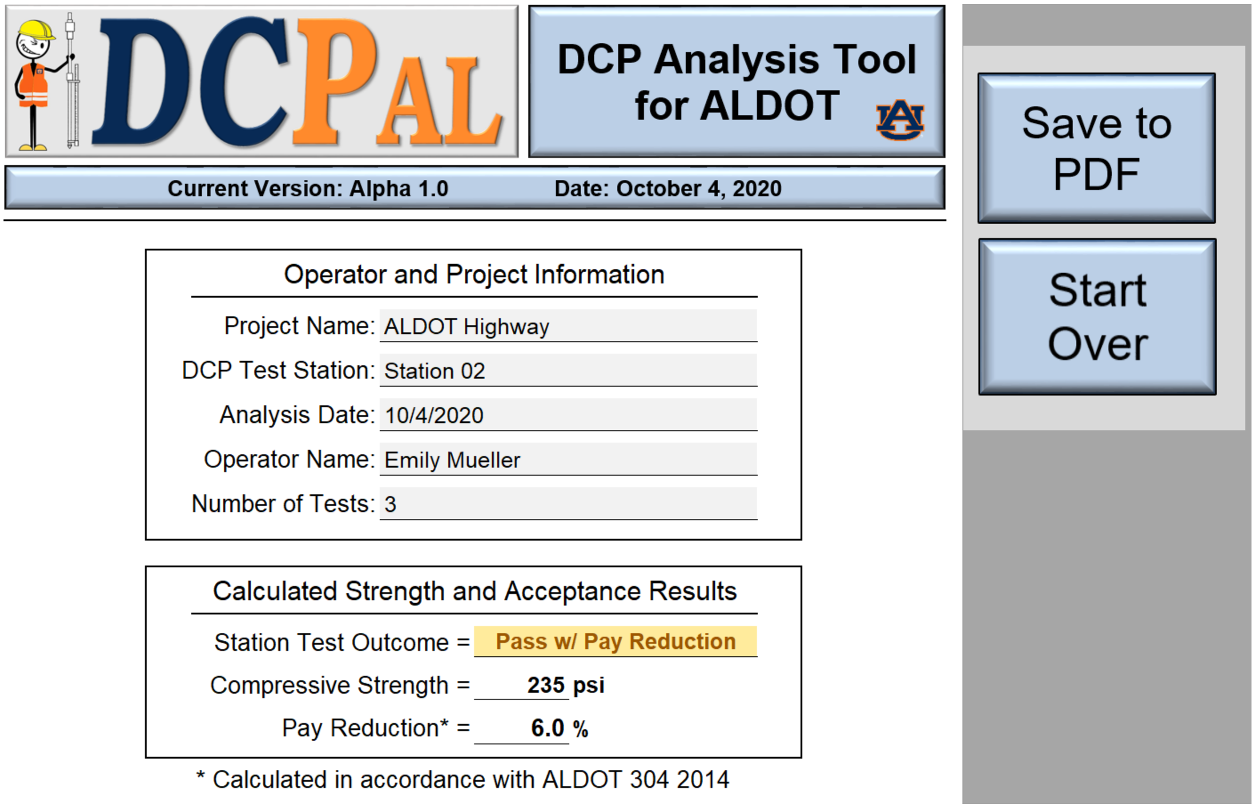

Figure 0.33: Results sheet view for Outcome 2

Once the Results sheet has been reviewed, the results were saved as a PDF file by selecting the appropriate button on the right. The results are then saved to the output file that indicates that the compressive strength of the soil cement base was 235 psi, which falls within the lower strength range limit for acceptance and a payment reduction is shown in the output screen. This is denoted by the yellow label that reads “Pass w/ Pay Reduction”. The pay reduction percentage is calculated in accordance with ALDOT 304 (2014). Additionally, it can be seen that the test that was discarded displays the range of error and is labeled as a discarded test on the “Summary of Outlier Error Input & Analysis Results” section. This can be visually confirmed by comparing the error range of the discarded test to the Outlier Error Range listed below the table. Further confirmation of the outlier can be seen in the graph on the third page of the PDF file. The PDF file for Outcome 2 can be seen in Appendix F.

1.14.4 Outcome 3

For this example, three DCP tests are conducted at a station selected by the project engineer labeled “Station 03” on the same project as for Outcome 1 and 2. DCP data were recorded by manual readings due to the magnetic ruler malfunctioning. Test data were recorded on paper and then input into the “DCPAL Text File Template.txt” that was developed to accompany DCPAL. Each text file was saved to the device that would be used to run DCPAL. This analysis was conducted immediately following the analysis for Outcome 2, and thus the only input changes needed for Outcome 3 were to update the DCP Test Station and upload new DCP output files. Then, the three manually entered test files were selected and opened successfully. The new DCP output files were opened in the order shown in Appendix G. DCPAL is then run and an outlier found as shown in the user interface in Figure 0.34.

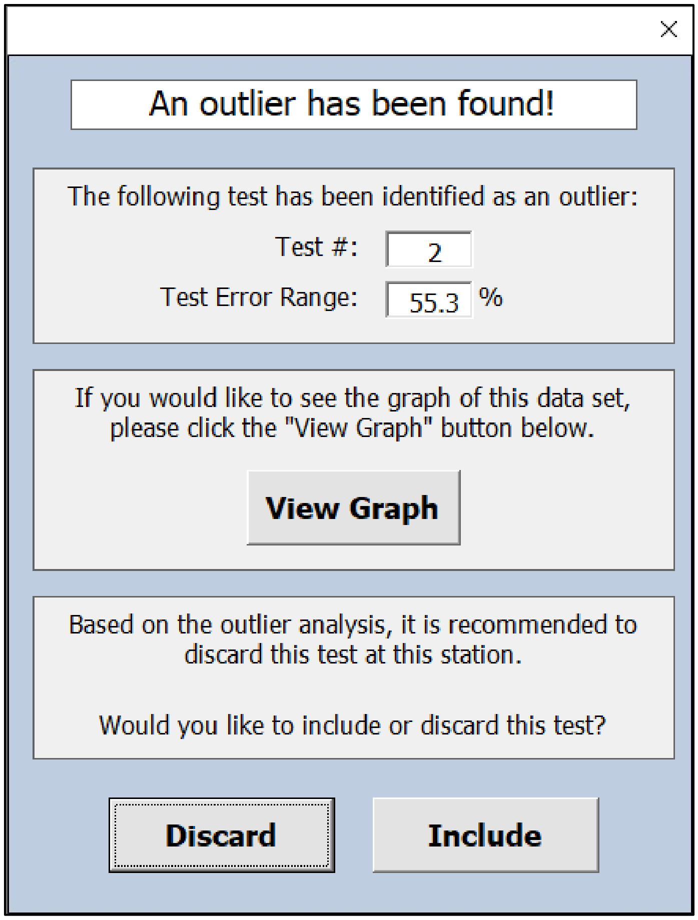

Figure 0.34: Outlier userform for Outcome 3

Due to the potential inaccuracies of the manual readings of the DCP depth at each blow, the user decided to include the test that was mathematically considered an outlier. The user felt that 55 percent was close enough to the recommended limit. DCPAL then runs the remaining calculations in the background, with no further outliers found. The results screen that can be seen upon completion of the analysis is shown in Figure 0.35.

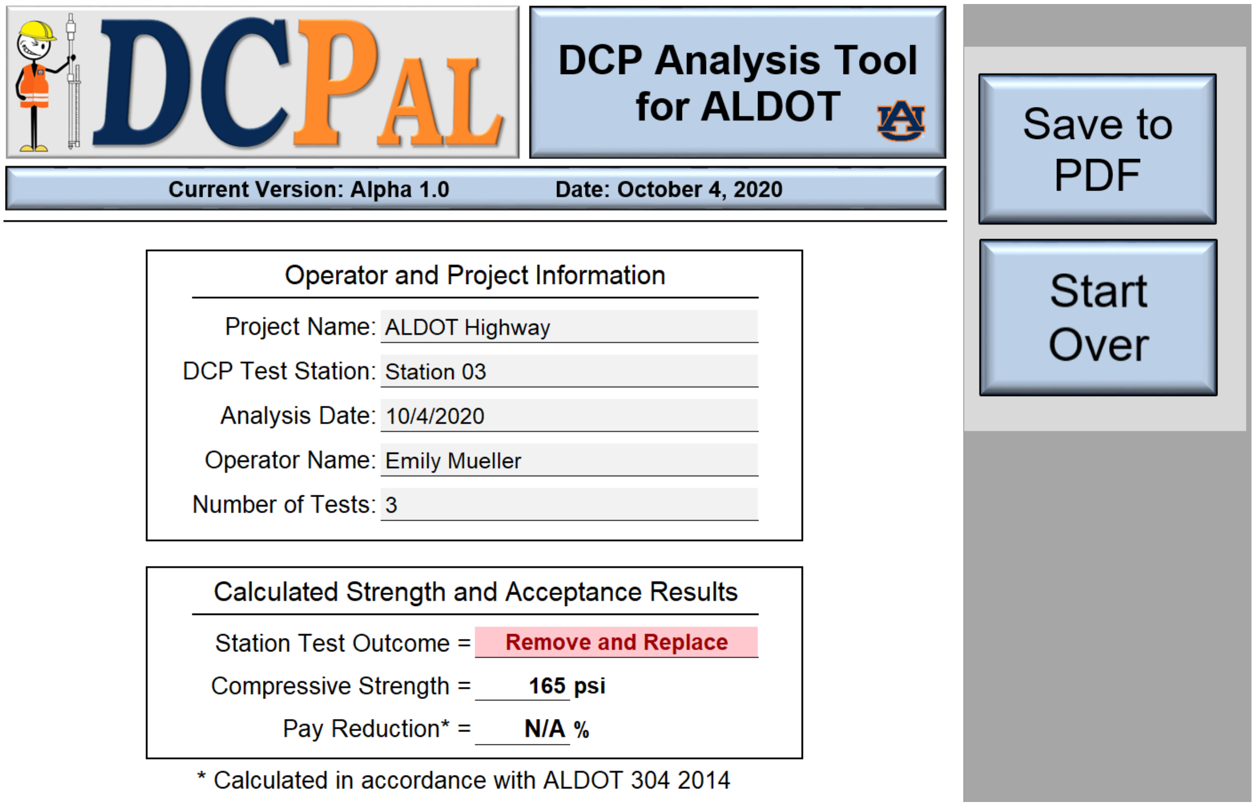

Figure 0.35: Results sheet view for Outcome 3

Once the Results sheet has been reviewed, the results were saved as a PDF file by selecting the appropriate button on the right. The results are then saved to the output file that indicates that the compressive strength of the soil cement base was 165 psi, which was lower than the minimum strength limit for acceptance, therefore recommending the section be removed and replaced. This is denoted by the red label that reads “Remove and Replace”. The pay reduction percentage is set to N/A% to indicate that the costs incurred for the removal of the disapproved section is not covered under ALDOT 304 (2014) restrictions. Additionally, it can be seen that the test that was included manually displays the range of error it was calculated to have and is labeled as an included test on the “Summary of Outlier Error Input & Analysis Results” section. The PDF file for Outcome 3 can be seen in Appendix G.

Chapter 6

Implementation Recommendation for Soil Cement Base

1.15 Implementation Recommendation

It is recommended that ALDOT implement a new testing procedure to assess the strength of soil cement base. The recommendation, based on results from the laboratory tests performed and subsequent analyses, is to use the PM method for strength assessment of soil cement base. Therefore, the PM method should be used for quality assurance testing in the field to assess the soil cement strength.

The process would include picking two random sampling locations along the 1/10 of a mile section, and making three specimens at each location using the PM method during placement of the soil cement base once all mixing is complete but before compaction. As discussed in Section 1.6.5.2, the plastic mold shall be prepared by cutting a slit down the side with one piece of aluminum tape covering the slit along the length of the mold. Two additional pieces of aluminum tape should be wrapped one-third of the circumference around the top and middle of the cylinder mold, centered on the longitudinal tape over the slit as shown in Figure 0.32.

Compaction of the PM cylinders shall be completed using three equal lifts at seven blows per lift (McLaughlin 2017). Between each lift, the top surface of the layer must be scarified after compaction. The cylinders should be capped and placed in a shady area to allow for initial curing on-site for 24 to 48 hours before being transported to the laboratory for final curing and testing. The shady area used for initial curing should be protected from wind, rain, and any major disturbances that could affect the cylinders. Final curing should include demolding of the cylinders, sealing the cylinders in plastic bags, and placing the sealed cylinders in a moist-curing room as discussed in Section 1.6.5.2.

On the seventh day, the cylinders should be tested to determine their compressive strength. Once all cylinders have been tested for their compressive strength, an outlier analysis must be conducted as discussed in Section 1.9.10. The error range must first be determined by taking the difference between the maximum and minimum compressive strengths and dividing that by the average compressive strength of the cylinders (ASTM C670 2015). The outlier error range for molded soil cement cylinders is 7.1 percent multiplied by the appropriate multiplier from Table 0.1 based on the number of cylinders tested (Wilson 2013). If the error range is larger than the outlier error range, then the cylinder with the largest percent difference from the average compressive strength is considered the outlier and must be removed from the data set. This process is repeated until either no outliers remain or too few tests remain to determine an average compressive strength. The average compressive strength between the two testing locations must then be determined.

The single average compression strength of all valid cylinders for the 1/10-mile section tested will be used as an indicator of strength for the entire section. Passing or failing of the section will be decided by the acceptable strength ranges for the average PM cylinder strength set by ALDOT. Therefore, full payment is awarded if the average cylinder strength is equal to, or between, 250 psi and 600 psi.

If the average cylinder strength is not within this range, three DCP tests shall be conducted on the soil cement base section (McLaughlin 2017). The three DCP test locations shall be randomly selected by the engineer and three DCP tests shall be conducted at each of the three locations. Based on the findings of Scales (2020), it is recommended to use a magnetic ruler to assist with DCP data collection.

The DCP test should be conducted by first properly seating the DCP to a depth of 25 millimeters (1 inch). Next, the DCP test should be performed until penetrating an additional 75 millimeters (3 inches) past the initial seating depth. Therefore, the DCP needs to penetrate at least a total depth of 100 millimeters (4 inches) or more below the surface. Then, the procedures outlined in Chapter 5 for using DCPAL should be followed to determine a compressive strength of the soil cement base at each testing location.

First, the user must input all required information into the software, uploading the DCP tests one at a time when prompted. The recommended values are the default values on the software. The default values include the Number of DCP Tests as three, the Analysis Depth as 75 millimeters, the Outlier Error Range as 50 percent, the Strength-to-DCP Relationship as described by Equation 2.10, and the Strength Limits as described by Table 0.4. If refusal was met for a DCP test in accordance with ASTM D6951 (2018), DCPAL will notify the user of which DCP test met refusal and at what blow count refusal was met. DCPAL will not include the DCP test that met refusal in the average compressive strength calculation. If a test is determined as an outlier, the user will be prompted to choose to include or discard the test. If too many tests are discarded due to refusal and outlier analysis results, DCPAL will notify the user that an average compressive strength cannot be determined from the DCP tests that were uploaded. If an average compressive strength cannot be determined, it is recommended to collect new DCP data and run the analysis with the new data. If DCPAL is able to determine an average compressive strength result for each of the three DCP test locations, the results should be averaged as a single value of average compressive strength of the soil cement base.

The single average compressive strength determined from DCP testing for the 1/10-mile section tested should be used as an indicator of strength for the entire section. Passing or failing of the section should then be decided by the acceptable strength ranges set by ALDOT. If the determined average compressive strength is equal to or between 250 psi and 600 psi, then full payment for the section should be rewarded. Otherwise, if the average compressive strength is greater than or equal to 200 psi but less than 250 psi, or greater than 600 psi but less than or equal to 650 psi, then reduced payment should be awarded in accordance with Equations 1.1 and 1.2. Otherwise, if the average compressive strength is below 200 psi or above 650 psi, the section of soil cement base should be removed and replaced at the expense of the contractor in accordance with ALDOT 304 (2014).

Chapter 7

Summary, Conclusions, and Recommendations

1.16 Summary

Soil cement is a mixture of soil, portland cement, and water that, once properly compacted and cured, creates a strong, durable, frost-resistant pavement base layer (Halsted, Luhr and Adaska 2006). Laboratory testing was conducted to assess the results obtained from the two methods of producing soil cement cylinders for quality assurance testing: Plastic Mold (PM) and Steel Mold (SM). The correlation between the two methods was evaluated using an Identity Line graph. A total of 200 cylinders were created and tested over the course of the laboratory testing phase of this project.

In addition to performing the laboratory testing phase, an effort was made to develop software to assist with the analysis of field-testing results collected during ALDOT projects. Research conducted to correlate the Dynamic Cone Penetrometer (DCP) to the soil cement base compressive strength required a series of calculations to determine the DCP relationship and to check for outliers in the collected data. These calculations can be very rigorous and time-intensive and must be repeated each time the DCP is used for on-site quality assurance testing. These calculations often take much time to complete and require a competent technician with necessary computational skills. A solution to obtain faster results for any technician, regardless of skill level, was designed by developing a new automated calculation software developed for ALDOT called DCP Analysis Tool for ALDOT (DCPAL).

1.17 Conclusions

Based on the laboratory testing phase, the following key conclusions can be made:

- The PM method and SM method are very similar when comparing percent compaction, moisture capture, and compressive strength of the cylinders produced.
- The SM method is more variable, indicated by more outliers being discarded after compressive testing.
- The PM method is recommended to be used on ALDOT projects, because the SM method requires more effort to prepare, create, and extract the specimen than the PM method.

The development of DCPAL was designed for ALDOT to use in conjunction with the DCP for on-site quality assurance testing in the place of the current testing practice. DCPAL was created to be intuitive and accommodating in the following key ways:

- Using DCPAL allows for results within minutes for anyone with access to a computer instead of multiple hours of calculating by a learned professional.
- The allowable inputs into the software allow for any numerical series of numbers regardless of which analysis depth is chosen for analysis.
- Regardless of which test is input first, DCPAL creates its own numbering system.
- The compressive strength results output is based on all included data input and is not affected by state specific specifications.
- The workbook is editable for new or updated relationships between the DCP and compressive strength obtained in the future as the result of new research.

1.18 Recommendations

A recommendation for future research is to test DCPAL in the field to assess its performance and usefulness. The current version of DCPAL developed is Alpha 1.0 because no testing by the end user has been conducted. Further research development of DCPAL would be required to accommodate any input and/or special requests from ALDOT professionals for its use on actual soil cement base projects.

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Appendix A

Main Code

```
Public Answer As String, Stopper As String, Outlier As String
Public EndMainSub As String, Refusal1 As String, Refusal2 As String
Public Refusal3 As String, Refusal4 As String, Refusal5 As String
Public Subtracter As String
```

```
Sub Automated()

Dim FilePath As Variant, LineFromFile As Variant
Dim row_number As Integer, n As Integer, m As Integer
Dim ws As Worksheet
Dim Coeff1 As Single, Coeff2 As Single, Strength As Single
Dim Slope1 As Single, Slope2 As Single, Slope3 As Single, Slope4 As Single, Slope5 As Single
Dim NoRedMin As Single, NoRedMax As Single, RedMin As Single, RedMax As Single
Dim Depth As Single, Analysis As Single, Error As Single

'Remove the file options ribbons to only show the sheet behind Initial userform
Application.DisplayFullScreen = True
Application.ScreenUpdating = True
Worksheets("Starting Page Begin").Visible = xlSheetVisible
Worksheets("Starting Page Begin").Activate
Worksheets("Starting Page Begin").Shapes("StartOverlay").Visible = True
Worksheets("Starting Page Begin").Range("A1:O28").Select 'set range zoom
ActiveWindow.zoom = True
Application.Goto Reference:="StartCell2"
ActiveCell.Select
ActiveWindow.ScrollRow = 1
Application.CutCopyMode = False

'reset all screen views as necessary
Application.ScreenUpdating = False
Worksheets("DCP 01").Visible = xlSheetVisible
Worksheets("DCP 02").Visible = xlSheetVisible
Worksheets("DCP 03").Visible = xlSheetVisible
Worksheets("DCP 04").Visible = xlSheetVisible
Worksheets("DCP 05").Visible = xlSheetVisible
Worksheets("DCP 01").Activate
ActiveWindow.zoom = 100
Worksheets("DCP 02").Activate
ActiveWindow.zoom = 100
Worksheets("DCP 03").Activate
ActiveWindow.zoom = 100
Worksheets("DCP 04").Activate
ActiveWindow.zoom = 100
Worksheets("DCP 05").Activate
ActiveWindow.zoom = 100

Worksheets("Starting Page Begin").Activate
For Each ws In ThisWorkbook.Worksheets
   If ws.Name <> "Starting Page Begin" Then
      ws.Visible = xlVeryHidden
   End If
Next ws

'Ensure the sheets are cleared
Call ClearAll
```

```
'Set the screen view
Application.ScreenUpdating = True
Worksheets("Starting Page Begin").Visible = xlSheetVisible
Worksheets("Starting Page Begin").Activate
Worksheets("Starting Page Begin").Shapes("StartOverlay").Visible = True
Worksheets("Starting Page Begin").Range("A1:O28").Select 'set range zoom
ActiveWindow.zoom = True
Application.Goto Reference:="StartCell2"
ActiveCell.Select
ActiveWindow.ScrollRow = 1
Application.CutCopyMode = False

'Get project information
Initial.Show

'Hold the code until all input information has been given
Do Until Initial.Visible = False
   DoEvents
Loop

'If initial inputs was closed, start over code. Otherwise continue on
If Answer = "YES" Or Answer = "READY" Then
   Call LoadStartPage(" Begin")
ElseIf Answer = "NO" Then
   Call ClearAll
   Call LoadStartPage("")
   For Each ws In ThisWorkbook.Worksheets
      If ws.Name <> "Starting Page" Then
         ws.Visible = xlVeryHidden
      End If
   Next ws
   Call LoadStartPage("")
   Exit Sub
ElseIf Answer = "" Then
   MsgBox ("Please restart and ensure the form is correctly filled out to proceed")
   Call LoadStartPage("")
   For Each ws In ThisWorkbook.Worksheets
      If ws.Name <> "Starting Page" Then
         ws.Visible = xlVeryHidden
      End If
   Next ws
   Call LoadStartPage("")
   Exit Sub
End If

'Optimize code by regularly confirming the screen is not updating unless needed
Application.ScreenUpdating = True
Application.ScreenUpdating = False

'
'.......................COPY TXT FILE DATA.......................
'

'Load in all files depending upon how many DCP tests were conducted
Worksheets("Results").Visible = xlSheetVisible
Application.Goto Reference:="DCPTest"
DCP = ActiveCell
Worksheets("Results").Visible = xlVeryHidden
Stopper = "No"

Worksheets("DCP 01").Visible = xlSheetVisible
Worksheets("DCP 02").Visible = xlSheetVisible
```

```
Worksheets("DCP 03").Visible = xlSheetVisible

If DCP = 3 Then
    Call LoadStartPage(" Begin")
    Msg1.Show
    Call TXTFileOpen(1, "01")
    If Stopper = "Yes" Then
        Call StopFileLoad
        Exit Sub
    End If
    Msg2.Show
    Call TXTFileOpen(2, "02")
    If Stopper = "Yes" Then
        Call StopFileLoad
        Exit Sub
    End If
    Msg3.Show
    Call TXTFileOpen(3, "03")
    If Stopper = "Yes" Then
        Call StopFileLoad
        Exit Sub
    End If

ElseIf DCP = 4 Then
    Worksheets("DCP 04").Visible = xlSheetVisible
    Call LoadStartPage(" Begin")
    Msg1.Show
    Call TXTFileOpen(1, "01")
    If Stopper = "Yes" Then
        Call StopFileLoad
        Exit Sub
    End If
    Msg2.Show
    Call TXTFileOpen(2, "02")
    If Stopper = "Yes" Then
        Call StopFileLoad
        Exit Sub
    End If
    Msg3.Show
    Call TXTFileOpen(3, "03")
    If Stopper = "Yes" Then
        Call StopFileLoad
        Exit Sub
    End If
    Msg4.Show
    Call TXTFileOpen(4, "04")
    If Stopper = "Yes" Then
        Call StopFileLoad
        Exit Sub
    End If

ElseIf DCP = 5 Then
    Worksheets("DCP 04").Visible = xlSheetVisible
    Worksheets("DCP 05").Visible = xlSheetVisible
    Call LoadStartPage(" Begin")
    Msg1.Show
    Call TXTFileOpen(1, "01")
    If Stopper = "Yes" Then
        Call StopFileLoad
        Exit Sub
    End If
    Msg2.Show
```

```
    Call TXTFileOpen(2, "02")
    If Stopper = "Yes" Then
        Call StopFileLoad
        Exit Sub
    End If
    Msg3.Show
    Call TXTFileOpen(3, "03")
    If Stopper = "Yes" Then
        Call StopFileLoad
        Exit Sub
    End If
    Msg4.Show
    Call TXTFileOpen(4, "04")
    If Stopper = "Yes" Then
        Call StopFileLoad
        Exit Sub
    End If
    Msg5.Show
    Call TXTFileOpen(5, "05")
    If Stopper = "Yes" Then
        Call StopFileLoad
        Exit Sub
    End If
End If

Application.ScreenUpdating = False

'
'.......................ORGANIZE RAW DATA.......................
'

'Pull the data into the compile and linear sheets to organize for regression
Dim DCP1 As String, DCP2 As String, DCP3 As String, DCP4 As String, DCP5 As String
Dim CL3 As String, CL4 As String, CL5 As String

DCP1 = "DCP 01"
DCP2 = "DCP 02"
DCP3 = "DCP 03"
DCP4 = "DCP 04"
DCP5 = "DCP 05"
CL3 = "Compile and Linear3"
CL4 = "Compile and Linear4"
CL5 = "Compile and Linear5"
EndMainSub = "No"

If DCP = 3 Then
    Worksheets("Compile and Linear3").Visible = xlSheetVisible
    Worksheets("Outlier3").Visible = xlSheetVisible
    Call CandL(DCP1, CL3, 1, 1, DCP)
    Call CandL(DCP2, CL3, 3, 2, DCP)
    Call CandL(DCP3, CL3, 5, 3, DCP)
ElseIf DCP = 4 Then
    Worksheets("Compile and Linear4").Visible = xlSheetVisible
    Worksheets("Outlier4").Visible = xlSheetVisible
    Call CandL(DCP1, CL4, 1, 1, DCP)
    Call CandL(DCP2, CL4, 3, 2, DCP)
    Call CandL(DCP3, CL4, 5, 3, DCP)
    Call CandL(DCP4, CL4, 7, 4, DCP)
ElseIf DCP = 5 Then
    Worksheets("Compile and Linear5").Visible = xlSheetVisible
    Worksheets("Outlier5").Visible = xlSheetVisible
    Call CandL(DCP1, CL5, 1, 1, DCP)
```

```
    Call CandL(DCP2, CL5, 3, 2, DCP)
    Call CandL(DCP3, CL5, 5, 3, DCP)
    Call CandL(DCP4, CL5, 7, 4, DCP)
    Call CandL(DCP5, CL5, 9, 5, DCP)
End If

If EndMainSub = "Yes" Then
    Call LoadStartPage("")
    For Each ws In ThisWorkbook.Worksheets
        If ws.Name <> "Starting Page" Then
            ws.Visible = xlVeryHidden
        End If
    Next ws
    Exit Sub
End If

Worksheets("DCP 01").Visible = xlVeryHidden
Worksheets("DCP 02").Visible = xlVeryHidden
Worksheets("DCP 03").Visible = xlVeryHidden
Worksheets("DCP 04").Visible = xlVeryHidden
Worksheets("DCP 05").Visible = xlVeryHidden
Application.CutCopyMode = False

'A
'If the depth begins to decrease, this causes an issue for the code
'Therefore, any values after the maximum found value that decrease
'in depth will be removed to use the LINEST function properly
'
'B
'Find the largest depth for the forecast sheet
'This has been disabled but still an option if needed for future testing
'
'C
'If the maximum value is the same as any of the individual max values,
'an error will occur. This code forces the max value's # of blows to
'populate instead of using the forecast function.
Dim Rng As String

Application.ScreenUpdating = False

Worksheets("Graph").Visible = xlSheetVisible
Application.Goto Reference:="DepthSpot"
Analysis = ActiveCell

Refusal1 = ""
Refusal2 = ""
Refusal3 = ""
Refusal4 = ""
Refusal5 = ""

If DCP = 3 Then
    Sheets("Compile and Linear3").Activate
    Application.Goto Reference:="CL3.1"
    CL31 = ActiveCell
    Application.Goto Reference:="CL3.2"
    CL32 = ActiveCell
    Application.Goto Reference:="CL3.3"
    CL33 = ActiveCell

    Call Subtract(2, CL31, 1, Analysis, DCP) 'A
    If Subtracter = "Yes" Then
        Refusal1 = "Yes"
```

```
    End If
    Call Subtract(4, CL32, 2, Analysis, DCP)
    If Subtracter = "Yes" Then
        Refusal2 = "Yes"
    End If
    Call Subtract(6, CL33, 3, Analysis, DCP)
    If Subtracter = "Yes" Then
        Refusal3 = "Yes"
    End If

    'Call Max(2, 8) 'B
    'Call Max(4, 9)
    'Call Max(6, 10)

    MaxVal = Cells(3, 11) 'C
    n = MaxVal / 5
    Rng = "I9:Q9"
    Call Table(n, 8, Rng)

    If MaxVal = Range("H3") Then
        Call CheckMax("A4", "I9")
        If MaxVal = Range("I3") Then
            Call CheckMax("C4", "L9")
            If MaxVal = Range("J3") Then
                Call CheckMax("E4", "O9")
            End If
        End If
    ElseIf MaxVal = Range("I3") Then
        Call CheckMax("C4", "L9")
        If MaxVal = Range("J3") Then
            Call CheckMax("E4", "O9")
        End If
    ElseIf MaxVal = Range("J3") Then
        Call CheckMax("E4", "O9")
    End If

ElseIf DCP = 4 Then
    Sheets("Compile and Linear4").Activate
    Application.Goto Reference:="CL4.1"
    CL41 = ActiveCell
    Application.Goto Reference:="CL4.2"
    CL42 = ActiveCell
    Application.Goto Reference:="CL4.3"
    CL43 = ActiveCell
    Application.Goto Reference:="CL4.4"
    CL44 = ActiveCell

    Call Subtract(2, CL41, 1, Analysis, DCP) 'A
    If Subtracter = "Yes" Then
        Refusal1 = "Yes"
    End If
    Call Subtract(4, CL42, 2, Analysis, DCP)
    If Subtracter = "Yes" Then
        Refusal2 = "Yes"
    End If
    Call Subtract(6, CL43, 3, Analysis, DCP)
    If Subtracter = "Yes" Then
        Refusal3 = "Yes"
    End If
    Call Subtract(8, CL44, 4, Analysis, DCP)
    If Subtracter = "Yes" Then
        Refusal4 = "Yes"
```

```
    End If

    'Call Max(2, 10) 'B
    'Call Max(4, 11)
    'Call Max(6, 12)
    'Call Max(8, 13)

    MaxVal = Cells(3, 14) 'C
    n = MaxVal / 5
    Rng = "K9:V9"
    Call Table(n, 10, Rng)

    If MaxVal = Range("J3") Then
       Call CheckMax("A4", "K9")
       If MaxVal = Range("K3") Then
          Call CheckMax("C4", "N9")
          If MaxVal = Range("L3") Then
             Call CheckMax("E4", "Q9")
             If MaxVal = Range("M3") Then
                Call CheckMax("G4", "T9")
             End If
          End If
       End If
    ElseIf MaxVal = Range("K3") Then
       Call CheckMax("C4", "N9")
       If MaxVal = Range("L3") Then
          Call CheckMax("E4", "Q9")
          If MaxVal = Range("M3") Then
             Call CheckMax("G4", "T9")
          End If
       End If
    ElseIf MaxVal = Range("L3") Then
       Call CheckMax("E4", "Q9")
       If MaxVal = Range("M3") Then
          Call CheckMax("G4", "T9")
       End If
    ElseIf MaxVal = Range("M3") Then
       Call CheckMax("G4", "T9")
    End If

ElseIf DCP = 5 Then
    Sheets("Compile and Linear5").Activate
    Application.Goto Reference:="CL5.1"
    CL51 = ActiveCell
    Application.Goto Reference:="CL5.2"
    CL52 = ActiveCell
    Application.Goto Reference:="CL5.3"
    CL53 = ActiveCell
    Application.Goto Reference:="CL5.4"
    CL54 = ActiveCell
    Application.Goto Reference:="CL5.5"
    CL55 = ActiveCell

    Call Subtract(2, CL51, 1, Analysis, DCP) 'A
    If Subtracter = "Yes" Then
       Refusal1 = "Yes"
    End If
    Call Subtract(4, CL52, 2, Analysis, DCP)
    If Subtracter = "Yes" Then
       Refusal2 = "Yes"
    End If
    Call Subtract(6, CL53, 3, Analysis, DCP)
```

```
If Subtracter = "Yes" Then
    Refusal3 = "Yes"
End If
Call Subtract(8, CL54, 4, Analysis, DCP)
If Subtracter = "Yes" Then
    Refusal4 = "Yes"
End If
Call Subtract(10, CL55, 5, Analysis, DCP)
If Subtracter = "Yes" Then
    Refusal5 = "Yes"
End If

'Call Max(2, 12) 'B
'Call Max(4, 13)
'Call Max(6, 14)
'Call Max(8, 15)
'Call Max(10, 16)

MaxVal = Cells(3, 17) 'C
n = MaxVal / 5
Rng = "M9:AA9"
Call Table(n, 12, Rng)

If MaxVal = Range("L3") Then
    Call CheckMax("A4", "M9")
    If MaxVal = Range("M3") Then
        Call CheckMax("C4", "P9")
        If MaxVal = Range("N3") Then
            Call CheckMax("E4", "S9")
            If MaxVal = Range("O3") Then
                Call CheckMax("G4", "V9")
                If MaxVal = Range("P3") Then
                    Call CheckMax("I4", "Y9")
                End If
            End If
        End If
    End If
ElseIf MaxVal = Range("M3") Then
    Call CheckMax("C4", "P9")
    If MaxVal = Range("N3") Then
        Call CheckMax("E4", "S9")
        If MaxVal = Range("O3") Then
            Call CheckMax("G4", "V9")
            If MaxVal = Range("P3") Then
                Call CheckMax("I4", "Y9")
            End If
        End If
    End If
ElseIf MaxVal = Range("N3") Then
    Call CheckMax("E4", "S9")
    If MaxVal = Range("O3") Then
        Call CheckMax("G4", "V9")
        If MaxVal = Range("P3") Then
            Call CheckMax("I4", "Y9")
        End If
    End If
ElseIf MaxVal = Range("O3") Then
    Call CheckMax("G4", "V9")
    If MaxVal = Range("P3") Then
        Call CheckMax("I4", "Y9")
    End If
ElseIf MaxVal = Range("P3") Then
```

```
    Call CheckMax("I4", "Y9")
  End If
End If

If EndMainSub = "Yes" Then
  Call LoadStartPage("")
  For Each ws In ThisWorkbook.Worksheets
    If ws.Name <> "Starting Page" Then
      ws.Visible = xlVeryHidden
    End If
  Next ws
  Exit Sub
End If

Application.CutCopyMode = False
Application.ScreenUpdating = False

'
'.......................GRAPHS CREATION.......................
'
Worksheets("Graph").Visible = xlSheetVisible
'Pull graph data here so we can display it during outlier option windows

'Fill in slopes to create the graphs
If Analysis = 25 Then
  Call GraphDataFill(14)
ElseIf Analysis = 50 Then
  Call GraphDataFill(19)
ElseIf Analysis = 75 Then
  Call GraphDataFill(24)
ElseIf Analysis = 100 Then
  Call GraphDataFill(29)
ElseIf Analysis = 175 Then
  Call GraphDataFill(44)
Else
  MsgBox ("An analysis penetration depth was not found from the inputs")
End If

'maximum x-scale is defaulted on graphs, but used for y-scale variation
If DCP = 3 Then
  ScaleX = Range("AB3")
ElseIf DCP = 4 Then
  ScaleX = Range("AF3")
ElseIf DCP = 5 Then
  ScaleX = Range("AJ3")
End If

ScaleY = Range("C3")

If Analysis = 25 Then
  If ScaleY < 2 * ScaleX Then
  ScaleY = ScaleY + 10
  End If
ElseIf Analysis = 50 Then
  If ScaleY < 2 * ScaleX Then
  ScaleY = ScaleY + 10
  End If
ElseIf Analysis = 75 Then
  If ScaleY < 2 * ScaleX Then
  ScaleY = ScaleY + 10
  End If
ElseIf Analysis = 100 Then
```

```
   If ScaleY < 2 * ScaleX Then
   ScaleY = ScaleY + 25
   End If
ElseIf Analysis = 175 Then
   If ScaleY < 2 * ScaleX Then
   ScaleY = ScaleY + 40
   End If
End If

If DCP = 3 Then
ActiveSheet.ChartObjects("ResultsGraph3").Activate
ActiveChart.Axes(xlValue).Select
ActiveChart.Axes(xlValue).MaximumScale = ScaleY
Call UpdateGraph(3, ScaleY)
Call UpdateGraph(3.1, ScaleY)
Call UpdateGraph(3.2, ScaleY)
Call UpdateGraph(3.3, ScaleY)

ElseIf DCP = 4 Then
ActiveSheet.ChartObjects("ResultsGraph4").Activate
ActiveChart.Axes(xlValue).Select
ActiveChart.Axes(xlValue).MaximumScale = ScaleY
Call UpdateGraph(4, ScaleY)
Call UpdateGraph(4.1, ScaleY)
Call UpdateGraph(4.2, ScaleY)
Call UpdateGraph(4.3, ScaleY)
Call UpdateGraph(4.4, ScaleY)
Call UpdateGraph(4.12, ScaleY)
Call UpdateGraph(4.13, ScaleY)
Call UpdateGraph(4.14, ScaleY)
Call UpdateGraph(4.23, ScaleY)
Call UpdateGraph(4.24, ScaleY)
Call UpdateGraph(4.34, ScaleY)

ElseIf DCP = 5 Then
ActiveSheet.ChartObjects("ResultsGraph5").Activate
ActiveChart.Axes(xlValue).Select
ActiveChart.Axes(xlValue).MaximumScale = ScaleY
Call UpdateGraph(5, ScaleY)
Call UpdateGraph(5.1, ScaleY)
Call UpdateGraph(5.2, ScaleY)
Call UpdateGraph(5.3, ScaleY)
Call UpdateGraph(5.4, ScaleY)
Call UpdateGraph(5.5, ScaleY)
Call UpdateGraph(5.12, ScaleY)
Call UpdateGraph(5.13, ScaleY)
Call UpdateGraph(5.14, ScaleY)
Call UpdateGraph(5.15, ScaleY)
Call UpdateGraph(5.23, ScaleY)
Call UpdateGraph(5.24, ScaleY)
Call UpdateGraph(5.25, ScaleY)
Call UpdateGraph(5.34, ScaleY)
Call UpdateGraph(5.35, ScaleY)
Call UpdateGraph(5.45, ScaleY)
Call UpdateGraph(5.123, ScaleY)
Call UpdateGraph(5.124, ScaleY)
Call UpdateGraph(5.125, ScaleY)
Call UpdateGraph(5.134, ScaleY)
Call UpdateGraph(5.135, ScaleY)
Call UpdateGraph(5.145, ScaleY)
Call UpdateGraph(5.234, ScaleY)
Call UpdateGraph(5.235, ScaleY)
```

```
Call UpdateGraph(5.345, ScaleY)

End If

Worksheets("DCP 01").Visible = xlVeryHidden
Worksheets("DCP 02").Visible = xlVeryHidden
Worksheets("DCP 03").Visible = xlVeryHidden
Worksheets("DCP 04").Visible = xlVeryHidden
Worksheets("DCP 05").Visible = xlVeryHidden
Worksheets("Compile and Linear3").Visible = xlVeryHidden
Worksheets("Compile and Linear4").Visible = xlVeryHidden
Worksheets("Compile and Linear5").Visible = xlVeryHidden
Worksheets("Graph").Visible = xlVeryHidden
Worksheets("Stored Information").Visible = xlVeryHidden

'
'.......................OUTLIERS ANALYSIS.......................
'

'Broken up into multiple parts and functions to simplify
'The analysis is looped for each depth 25 to 175 mm
'First, all outliers as well as ranges (past range 2) are populated on the sheet
'Second, the slope is determined while giving the user an option to
'include or discard a potential outlier
'Lastly, output all outlier results

'Set the size of the Results sheet ahead of time to avoid visual error
Application.ScreenUpdating = True
Worksheets("Results").Visible = xlSheetVisible
Worksheets("Results").Activate
Worksheets("Results").Range("A1:R10").Select 'set range zoom
ActiveWindow.zoom = True
Range("A1").Select
ActiveWindow.ScrollRow = 1
Application.CutCopyMode = False
Application.ScreenUpdating = False

'What is the selected Outlier Error Range?
Application.Goto Reference:="ErrorLim"
Error = ActiveCell
Application.Goto Reference:="ADep"
Analysis = ActiveCell
Worksheets("Graph").Visible = xlVeryHidden

Dim i As Integer, mmRow As Integer
Dim out1 As String, out2 As String, out3 As String, out4 As String, out5 As String
Dim R1 As Single, R2 As Single, R3 As Single, R4 As Single

EndMainSub = "No"
On Error Resume Next
For i = 3 To 7

  mmRow = i

  If i = 3 Then
    Depth = 25
  ElseIf i = 4 Then
    Depth = 50
  ElseIf i = 5 Then
    Depth = 75
  ElseIf i = 6 Then
    Depth = 100
```

```
    ElseIf i = 7 Then
        Depth = 175
    End If
'Get the outliers (and ranges) for 3 DCP tests
    If DCP = 3 Then
        Worksheets("Outlier3").Activate
        Range("A10") = Error
        Call Outlier3(i, Error)
        out1 = Cells(i, 8)
        out2 = Cells(i, 10)
        Call Slope3a(out1, out2, Depth, mmRow, Analysis)
        If EndMainSub = "Yes" Then
            Call LoadStartPage("")
            For Each ws In ThisWorkbook.Worksheets
                If ws.Name <> "Starting Page" Then
                    ws.Visible = xlVeryHidden
                End If
            Next ws
            Exit Sub
        End If
        If Analysis = Depth Then
            SlopeOut = Cells(mmRow, 15)
        End If
'Get the outliers (and ranges) for 4 DCP tests
    ElseIf DCP = 4 Then
        Worksheets("Outlier4").Activate
        Range("A10") = Error
        Call Outlier4(i, Error)
        out1 = Cells(i, 9)
        out2 = Cells(i, 11)
        out3 = Cells(i, 13)
        Call Slope4a(out1, out2, out3, Depth, mmRow, Analysis)
        If EndMainSub = "Yes" Then
            Call LoadStartPage("")
            For Each ws In ThisWorkbook.Worksheets
                If ws.Name <> "Starting Page" Then
                    ws.Visible = xlVeryHidden
                End If
            Next ws
            Exit Sub
        End If
        If Analysis = Depth Then
            SlopeOut = Cells(mmRow, 14)
        End If

'Get the outliers (and ranges) for 5 DCP tests
    ElseIf DCP = 5 Then
        Worksheets("Outlier5").Activate
        Range("A10") = Error
        Call Outlier5(i, Error)
        out1 = Cells(i, 10)
        out2 = Cells(i, 12)
        out3 = Cells(i, 14)
        out4 = Cells(i, 16)
        Call Slope5a(out1, out2, out3, out4, Depth, mmRow, Analysis)
        If EndMainSub = "Yes" Then
            Call LoadStartPage("")
            For Each ws In ThisWorkbook.Worksheets
                If ws.Name <> "Starting Page" Then
                    ws.Visible = xlVeryHidden
                End If
            Next ws
```

```
            Exit Sub
        End If
        If Analysis = Depth Then
            SlopeOut = Cells(mmRow, 17)
        End If
    End If
Next i

'Output results of outliers onto Results sheet
Application.ScreenUpdating = False

If DCP = 3 Then
    Worksheets("Outlier3").Activate
    Call IDOp3(DCP, Analysis)
    Call OutlierResults3(DCP)
    Worksheets("Outlier3").Activate
    Test4 = "N/A"
    Test5 = "N/A"
    Op4 = "N/A"
    Op5 = "N/A"
ElseIf DCP = 4 Then
    Worksheets("Outlier4").Activate
    Call IDOp4(DCP, Analysis)
    Call OutlierResults3(DCP)
    Worksheets("Outlier4").Activate
    Test5 = "N/A"
    Op5 = "N/A"
    Test4 = Range("g14")
    If Range("C14") <> "" Then
        If Range("C11") = "" Then
        Op4 = Range("C14")
        ElseIf Range("C12") = "" Then
        Op4 = Range("C14")
        ElseIf Range("C13") = "" Then
        Op4 = Range("C14")
        End If
    Else
        Op4 = Range("B14")
    End If
ElseIf DCP = 5 Then
    Worksheets("Outlier5").Activate
    Call IDOp5(DCP, Analysis)
    Call OutlierResults3(DCP)
    Worksheets("Outlier5").Activate
    Test4 = Range("g14")
    Test5 = Range("g15")
    If Range("C14") <> "" Then
        If Range("C11") = "" Then
        Op4 = Range("C14")
        ElseIf Range("C12") = "" Then
        Op4 = Range("C14")
        ElseIf Range("C13") = "" Then
        Op4 = Range("C14")
        ElseIf Range("C15") = "" Then
        Op4 = Range("C14")
        End If
    Else
        Op4 = Range("B14")
    End If
    If Range("C15") <> "" Then
        If Range("C11") = "" Then
        Op5 = Range("C15")
```

```
      ElseIf Range("C12") = "" Then
      Op5 = Range("C15")
      ElseIf Range("C13") = "" Then
      Op5 = Range("C15")
      ElseIf Range("C14") = "" Then
      Op5 = Range("C15")
      End If
   Else
      Op5 = Range("B15")
   End If
End If

Application.ScreenUpdating = False

'Output the results for test 4 and test 5 outliers
'First three tests were done above
Application.Goto Reference:="Range4"
ActiveCell = Test4
Application.Goto Reference:="Range5"
ActiveCell = Test5
Application.Goto Reference:="IncDisc4"
ActiveCell = Op4
Application.Goto Reference:="IncDisc5"
ActiveCell = Op5

'Output the Analysis Depth slope onto the results sheet (pulled from above Ifs)
Worksheets("Results").Activate
Application.Goto Reference:="ASlope"
ActiveCell = SlopeOut

If Refusal1 = "Yes" Then
   Application.Goto Reference:="Range1"
   ActiveCell = "Refusal"
End If
If Refusal2 = "Yes" Then
   Application.Goto Reference:="Range2"
   ActiveCell = "Refusal"
End If
If Refusal3 = "Yes" Then
   Application.Goto Reference:="Range3"
   ActiveCell = "Refusal"
End If
If Refusal4 = "Yes" Then
   Application.Goto Reference:="Range4"
   ActiveCell = "Refusal"
End If
If Refusal5 = "Yes" Then
   Application.Goto Reference:="Range5"
   ActiveCell = "Refusal"
End If

'Output all in analysis depth slopes last page of results sheets
If DCP = 3 Then
   Call DropGraph(3, Analysis)
ElseIf DCP = 4 Then
   Call DropGraph(4, Analysis)
ElseIf DCP = 5 Then
   Call DropGraph(5, Analysis)
End If

'
'.......................STRENGTH & PAY CALCULATION.......................
```

```
'

'Set the strength pay limits into variables
Application.ScreenUpdating = False
Application.Goto Reference:="NRMin"
NoRedMin = ActiveCell
Application.Goto Reference:="NRMax"
NoRedMax = ActiveCell
Application.Goto Reference:="RMin"
RedMin = ActiveCell
Application.Goto Reference:="RMax"
RedMax = ActiveCell

'Set the Coefficient values for the regression calculation
Application.Goto Reference:="Coef1"
Coeff1 = ActiveCell
Application.Goto Reference:="Coef2"
Coeff2 = ActiveCell

'Calculate the strength based on the mm/blow relationship
Strength = Coeff1 * Exp(Coeff2 * SlopeOut)
StrengthRnd = WorksheetFunction.MRound(Arg1:=Strength, Arg2:=5)
Application.Goto Reference:="Streng"
ActiveCell = StrengthRnd

'Output a pass/fail visual result
If StrengthRnd >= NoRedMin And StrengthRnd <= NoRedMax Then
   Application.Goto Reference:="PassFail"
   ActiveCell = "Pass w/o Pay Reduction"
   PayStatus = "No"
ElseIf StrengthRnd >= RedMin And StrengthRnd <= RedMax Then
   Application.Goto Reference:="PassFail"
   ActiveCell = "Pass w/ Pay Reduction"
   PayStatus = "Yes"
ElseIf StrengthRnd < RedMin Or StrengthRnd > RedMax Then
   Application.Goto Reference:="PassFail"
   ActiveCell = "Remove and Replace"
   PayStatus = "Fail"
End If

'Calculate the pay reduction if applicable
If PayStatus = "Fail" Then
   PayRed = "N/A"
ElseIf PayStatus = "Yes" Then

   If StrengthRnd > NoRedMax Then 'S is larger than no reduce upper limit 600 psi
      PayRed = Abs(20 - (0.4 * (RedMax - StrengthRnd)))
   ElseIf StrengthRnd < NoRedMin Then 'S is less than no reduce lower limit 250 psi
      PayRed = Abs((0.4 * (NoRedMin - StrengthRnd)))
   End If

ElseIf PayStatus = "No" Then
   PayRed = 0
End If

Application.Goto Reference:="Pay"
ActiveCell = PayRed

'
'........................INSERT CORRECT GRAPH........................
'
```

```
'Put the correct graphs on the results sheet based on the outliers
'chosen or found during outlier analysis
Application.DisplayFullScreen = True
Application.ScreenUpdating = True
Worksheets("Results").Visible = xlSheetVisible
Worksheets("Results").Activate
Worksheets("Results").Range("A1:R10").Select 'set range zoom
ActiveWindow.zoom = True
Range("A1").Select
ActiveWindow.ScrollRow = 1
Application.CutCopyMode = False
Application.ScreenUpdating = False

'Default the number of pdf print sheets unless specified  in If Statement
PrintArea = 3

If DCP = 3 Then
    Application.Goto Reference:="OutPlot3"
    PlotCall = ActiveCell
    Worksheets("Graph").Activate
    Call GrabGraph2(3)
    Worksheets("Graph").Activate
    If PlotCall = "0" Then
        Call GrabGraph(3)
        PrintArea = 2
    ElseIf PlotCall = "1" Then
        Call GrabGraph(3.1)
    ElseIf PlotCall = "2" Then
        Call GrabGraph(3.2)
    ElseIf PlotCall = "3" Then
        Call GrabGraph(3.3)
    End If

ElseIf DCP = 4 Then
    Application.Goto Reference:="OutPlot4"
    PlotCall = ActiveCell
    Worksheets("Graph").Activate
    Call GrabGraph2(4)
    Worksheets("Graph").Activate
    If PlotCall = "0" Then
        Call GrabGraph(4)
        PrintArea = 2
    ElseIf PlotCall = "1" Then
        Call GrabGraph(4.1)
    ElseIf PlotCall = "1,2" Then
        Call GrabGraph(4.12)
    ElseIf PlotCall = "1,3" Then
        Call GrabGraph(4.13)
    ElseIf PlotCall = "1,4" Then
        Call GrabGraph(4.14)
    ElseIf PlotCall = "2" Then
        Call GrabGraph(4.2)
    ElseIf PlotCall = "2,3" Then
        Call GrabGraph(4.23)
    ElseIf PlotCall = "2,4" Then
        Call GrabGraph(4.24)
    ElseIf PlotCall = "3" Then
        Call GrabGraph(4.3)
    ElseIf PlotCall = "3,4" Then
        Call GrabGraph(4.34)
    ElseIf PlotCall = "4" Then
        Call GrabGraph(4.4)
```

```
    End If

ElseIf DCP = 5 Then
Application.Goto Reference:="OutPlot5"
    PlotCall = ActiveCell
    Worksheets("Graph").Activate
    Call GrabGraph2(5)
    Worksheets("Graph").Activate
    If PlotCall = "0" Then
        Call GrabGraph(5)
        PrintArea = 2
    ElseIf PlotCall = "1" Then
        Call GrabGraph(5.1)
    ElseIf PlotCall = "1,2" Then
        Call GrabGraph(5.12)
    ElseIf PlotCall = "1,2,3" Then
        Call GrabGraph(5.123)
    ElseIf PlotCall = "1,2,4" Then
        Call GrabGraph(5.124)
    ElseIf PlotCall = "1,2,5" Then
        Call GrabGraph(5.125)
    ElseIf PlotCall = "1,3" Then
        Call GrabGraph(5.13)
    ElseIf PlotCall = "1,3,4" Then
        Call GrabGraph(5.134)
    ElseIf PlotCall = "1,3,5" Then
        Call GrabGraph(5.135)
    ElseIf PlotCall = "1,4" Then
        Call GrabGraph(5.14)
    ElseIf PlotCall = "1,4,5" Then
        Call GrabGraph(5.145)
    ElseIf PlotCall = "1,5" Then
        Call GrabGraph(5.15)
    ElseIf PlotCall = "2" Then
        Call GrabGraph(5.2)
    ElseIf PlotCall = "2,3" Then
        Call GrabGraph(5.23)
    ElseIf PlotCall = "2,3,4" Then
        Call GrabGraph(5.234)
    ElseIf PlotCall = "2,3,5" Then
        Call GrabGraph(5.235)
    ElseIf PlotCall = "2,4" Then
        Call GrabGraph(5.24)
    ElseIf PlotCall = "2,4,5" Then
        Call GrabGraph(5.245)
    ElseIf PlotCall = "2,5" Then
        Call GrabGraph(5.25)
    ElseIf PlotCall = "3" Then
        Call GrabGraph(5.3)
    ElseIf PlotCall = "3,4" Then
        Call GrabGraph(5.34)
    ElseIf PlotCall = "3,4,5" Then
        Call GrabGraph(5.345)
    ElseIf PlotCall = "3,5" Then
        Call GrabGraph(5.35)
    ElseIf PlotCall = "4" Then
        Call GrabGraph(5.4)
    ElseIf PlotCall = "4,5" Then
        Call GrabGraph(5.45)
    ElseIf PlotCall = "5" Then
        Call GrabGraph(5.5)
    End If
```

```
Else
   MsgBox ("A Number of DCP tests was not selected, a results graph cannot be displayed")
End If

Application.Goto Reference:="PrintA"
ActiveCell = PrintArea

'Hide unessential sheets
Worksheets("DCP 01").Visible = xlVeryHidden
Worksheets("DCP 02").Visible = xlVeryHidden
Worksheets("DCP 03").Visible = xlVeryHidden
Worksheets("DCP 04").Visible = xlVeryHidden
Worksheets("DCP 05").Visible = xlVeryHidden
Worksheets("Compile and Linear3").Visible = xlVeryHidden
Worksheets("Outlier3").Visible = xlVeryHidden
Worksheets("Compile and Linear4").Visible = xlVeryHidden
Worksheets("Outlier4").Visible = xlVeryHidden
Worksheets("Compile and Linear5").Visible = xlVeryHidden
Worksheets("Outlier5").Visible = xlVeryHidden
Worksheets("Graph").Visible = xlVeryHidden
Worksheets("Stored Information").Visible = xlVeryHidden

Application.DisplayFullScreen = True
Application.ScreenUpdating = True
Worksheets("Results").Visible = xlSheetVisible
Worksheets("Results").Activate
Worksheets("Results").Range("A1:R10").Select 'set range zoom
ActiveWindow.zoom = True
Range("A1").Select
ActiveWindow.ScrollRow = 1
Application.CutCopyMode = False
Worksheets("Starting Page Begin").Visible = xlVeryHidden

ResultsNote.Show
Do Until ResultsNote.Visible = False
   DoEvents
Loop

Answer = ""
End Sub
```

Appendix B

Support Functions and Debugging Routines

```
Function LoadStartPage(Addition)

Worksheets("Starting Page" & Addition).Visible = xlSheetVisible
Worksheets("Starting Page" & Addition).Activate
Worksheets("Starting Page" & Addition).Range("A1:O28").Select 'set range zoom
ActiveWindow.zoom = True
Range("A1").Select
ActiveWindow.ScrollRow = 1
Application.CutCopyMode = False
Application.ScreenUpdating = True

End Function
```

```
Function StopFileLoad()

Call LoadStartPage("")
Worksheets("Starting Page Begin").Visible = xlVeryHidden
Worksheets("DCP 01").Visible = xlVeryHidden
Worksheets("DCP 02").Visible = xlVeryHidden
Worksheets("DCP 03").Visible = xlVeryHidden
Worksheets("DCP 04").Visible = xlVeryHidden
Worksheets("DCP 05").Visible = xlVeryHidden

End Function
```

```
Function TXTFileOpen(CloseInput As Single, SheetNumb As String)

'Push the cursor to the top of the sheet before starting to avoid improper copying
Worksheets("DCP " & SheetNumb).Activate
Range("A1").Select
ActiveWindow.ScrollRow = 1
Application.CutCopyMode = False

Application.ScreenUpdating = False
ReturnA:
  Close #CloseInput

'Let User choose which text files to open
FilePath = Application.GetOpenFilename("Text Files (*.txt), *.txt")

'If the user closes without selecting a file, an error message pops up
If FilePath = False Then
  MsgBox ("Please restart and select a file to continue")
  Worksheets("Starting Page").Activate
  Stopper = "Yes"
  Exit Function 'The routine ends and allows the user to start again
Else
  Open FilePath For Input As #CloseInput 'Opens the file in the background

  Worksheets("DCP " & SheetNumb).Activate 'Selects the desired pasting sheet
  Range("A1").Select 'Selects the desired pasting cell

  'To help speed up the computer, you will not see incremental printing
  Application.ScreenUpdating = False
```

```
    row_number = 1 'Set starting row for pasting at 1
    'The number of columns in the text file is fixed
    'so the only changing variable in this loop is the row number

    Do Until EOF(CloseInput) 'follow loop until the end of the file is reached

        Line Input #CloseInput, LineFromFile 'reads the first row of text

        'split the text based on desired delimiter as TAB
        LineItems = Split(LineFromFile, vbTab)

        'Empty rows will return an error and stop the program
        'this line prevents the error from stopping the program
        On Error Resume Next

        'The next lines copy the text from a column into the appropriate
        'cells in excel to keep the same format as the text file
        Cells(row_number, 1) = LineItems(0)
        Cells(row_number, 2) = LineItems(1)
        Cells(row_number, 3) = LineItems(2)
        Cells(row_number, 4) = LineItems(3)
        Cells(row_number, 5) = LineItems(4)
        Cells(row_number, 6) = LineItems(5)
        Cells(row_number, 7) = LineItems(6)
        Cells(row_number, 8) = LineItems(7)

        'Push excel to the next row in the spreadsheet for column copying
        row_number = row_number + 1

    'restart the process
    Loop

    'For debugging purposes to resume
    On Error GoTo 0

    'Once the process is complete, the screen will update
    Application.ScreenUpdating = True
    Worksheets("DCP " & SheetNumb).Activate

'Used for user error return option
ReshowA:

    'Give the operator a chance to confirm the correct file has been selected
    Confirm.Show vbModeless
    Answer = ""

    'For as long as the userform is open, hold the code in this loop
    'Each option in the loop will close upon performing it's event
    Do Until Confirm.Visible = False
        DoEvents
    Loop

    If Answer = "No" Then
        Worksheets("DCP " & SheetNumb).Select
        Range("A1").Select
        Cells.ClearContents
        GoTo ReturnA
    ElseIf Answer = "Exit" Then
    'Give the user a chance to return if mistakenly canceled
        Application.ScreenUpdating = True
        Sure.Show vbModeless
```

```
        Do Until Sure.Visible = False
            DoEvents
        Loop
        Application.ScreenUpdating = False
        If Answer = "No" Then
            GoTo ReshowA
        ElseIf Answer = "Yes" Then
            Call ClearAll
            Stopper = "Yes"
            Exit Function
        End If

    ElseIf Answer = "" Then
        Call ClearAll
        Worksheets("Starting Page").Select
        Stopper = "Yes"
        Exit Function

    End If

    'Optimize code by closing the file that was open in the bckground
    Close #InputNumb

End If

Application.ScreenUpdating = False
End Function
```

```
Function CandL(Sheet1 As String, Sheet2 As String, col As Single, Test As Integer, DCP)
Application.ScreenUpdating = False

Dim ws1 As Worksheet, ws2 As Worksheet

Set ws1 = Worksheets(Sheet1) 'DCP 01, 02, 03, 04, 05
Set ws2 = Worksheets(Sheet2) 'C&L 3, 4, 5

'Search for Blow# row, then # underneath
'This is to allow for a manual entry text file in the case that
'the mag ruler malfunctions and manual readings are necessary
ws1.Activate
Range("A1").Select

For i = 1 To 300
    If Cells(i, 1) = "Blow" Or Cells(i, 1) = "Blow #" Then
        Cells(i, 1).Select
        ActiveCell.Offset(1, 0).Select
        If ActiveCell = "" Or ActiveCell = "#" Then
            ActiveCell.Offset(1, 0).Select
            If ActiveCell = "0" Then
                StartRow = ActiveCell.Row
                Selection.End(xlDown).Select
                EndRow = ActiveCell.Row
                Exit For
            Else
                GoTo NextI
            End If
        ElseIf ActiveCell = "0" Then
            StartRow = ActiveCell.Row
            Selection.End(xlDown).Select
            EndRow = ActiveCell.Row
            Exit For
```

```
      Else
         GoTo NextI
      End If
   ElseIf Cells(i, 1) = "0" Then
      StartRow = ActiveCell.Row
      Selection.End(xlDown).Select
      EndRow = ActiveCell.Row
      Exit For
   Else
      GoTo NextI
   End If
NextI:
Next i

'Once the start row is found, copy all data from it to end
ws1.Select
   Cells(StartRow, 1).Select
   ActiveCell.Range("A1:B1").Select
   Range(Selection, Selection.End(xlDown)).Select
   Application.CutCopyMode = False
   Selection.Copy
ws2.Select
   Cells(4, col).Select
   ActiveSheet.Paste

'check to make sure all cells are valid
'no characters other than numbers are input

Dim Rng As Range, Text As String

TotRow = EndRow - StartRow
Application.Goto Reference:="CheckStart" & DCP & Test
ActiveCell.Range("A1:B1").Select
Selection.Copy

For i = 1 To TotRow
   ActiveCell.Offset(1, 0).Select
   ActiveSheet.Paste
Next i

Range(Selection, Selection.End(xlUp)).Select
Set Rng = Selection
Text = "FALSE"
For Each cell In Rng
   If InStr(1, LCase(cell.Value), LCase(Text)) <> 0 Then
      Row = cell.Row - 4
      Call DataErr(Row, Test)
      EndMainSub = "Yes"
   End If
Next

End Function
```

```
Function Subtract(col, CL, Test As Integer, Analysis, DCP) As String
Application.ScreenUpdating = False

Subtracter = "No"

m = 300

'Cycle through rows looking for a decrease in depth past maximum
For i = 1 To m
```

```
    If Cells(3 + i, col) > Cells(4 + i, col) And Cells(3 + i, col) > (CL - 1) Then
        Cells(4 + i, col).Select
        Range(Selection, Selection.End(xlDown)).Select
        Selection.ClearContents
        ActiveCell.Offset(0, -1).Range("A1").Select
        Range(Selection, Selection.End(xlDown)).Select
        Selection.ClearContents
        Exit For
    End If
Next i

Dim Rng As Range

'check to make sure all cells are valid
'no blank spots in the data

Application.Goto Reference:="TestBlowStart" & DCP & Test
ActiveCell.Offset(1, 0).Select
ActiveCell.Range("A1:B1").Select
Range(Selection, Selection.End(xlDown)).Select

Set Rng = Selection

For Each cell In Rng
    If cell.Value = "" Then
        Row = cell.Row - 4
        Call DataErr(Row, Test)
        EndMainSub = "Yes"
        Exit Function
    End If
Next

'Check to make sure refusal was not met for any of the tests
'if refusal was met, inform user automatic discarded as outlier

Application.Goto Reference:="TestBlowStart" & DCP & Test
ActiveCell.Offset(1, 0).Select
StartRow = ActiveCell.Row
Selection.End(xlDown).Select
EndRow = ActiveCell.Row
TotRow = EndRow - StartRow

Application.Goto Reference:="TestBlowStart" & DCP & Test
ActiveCell.Offset(1, 1).Select
Refusal = ""

For i = StartRow To TotRow
    Drop = Cells(i + 4, col) - Cells(i, col)
    If Drop < 2 Then
        Cells(i + 4, col).Select
        If ActiveCell < Analysis Then
            Refusal = "Yes"
            Row = i - 1
            Call RefusalMet(Row, Test)
            Exit For
        End If
    End If
Next

If Refusal = "Yes" Then
    Subtracter = "Yes"
End If
```

```
End Function
```

```
Function DataErr(Blow As Variant, TNum As Variant)

DataError.DataLabel.Caption = "Error at Blow Count " & Blow & " for Test " & TNum & ". Confirm that all data points in this data file are numerical values only. Once corrected, please try again."
DataError.Show
Do Until DataError.Visible = False
   DoEvents
Loop

End Function
```

```
Function RefusalMet(BlowC As Variant, TVal As Variant)

RefusalNote.RefusalLabel.Caption = "Refusal was met at Blow Count " & BlowC & " for Test " & TVal & " based on criteria set by ASTM D6951 (2018). This test will be discarded."
RefusalNote.Show
Do Until RefusalNote.Visible = False
   DoEvents
Loop

End Function
```

```
Function Max(col1, col2) As Single
Application.ScreenUpdating = False

'Find the maximum value in the organized data
Cells(4, col1).Select
Selection.End(xlDown).Select
Selection.Copy
Cells(3, col2).Select
ActiveSheet.Paste

End Function
```

```
Function Table(n As Integer, col As Single, Rng As String)
Application.ScreenUpdating = False

'Create table left column size
For i = 1 To n
   Cells(8 + i, col) = Cells(7 + i, col) + 5
Next i

'Copy down all equations to the last row
Range(Rng).Select
Selection.Copy
For i = 1 To n - 1
   Cells(9 + i, col + 1).Select
   ActiveSheet.Paste
Next i

End Function
```

```
Function CheckMax(rng1 As String, rng2 As String)
Application.ScreenUpdating = False

'Used to avoid a max value error for LINEST
Range(rng1).Select
Selection.End(xlDown).Select
```

```
Selection.Copy
Range(rng2).Select
Selection.End(xlDown).Select
ActiveSheet.Paste

End Function
```

```
Function UpdateGraph(x, ScaleY)
Application.ScreenUpdating = False

'Set graph Y-Axis values
ActiveSheet.ChartObjects("Results Graph" & x).Activate
ActiveChart.Axes(xlValue).Select
ActiveChart.Axes(xlValue).MaximumScale = ScaleY

End Function
```

```
Function Outlier3(mmRow As Integer, Error As Single)
'this checks for outliers instead of the functions being
'stuck into the cell as long functions and addresses
Application.ScreenUpdating = False

Worksheets("Outlier3").Activate

Rng = Cells(mmRow, 7)

If Rng > (Error / 100) + 0.000001 Then

Test1 = Cells(mmRow, 2)
Test2 = Cells(mmRow, 3)
Test3 = Cells(mmRow, 4)

Avg3Tests = (Test1 + Test2 + Test3) / 3

Max1 = Abs(Test1 - Avg3Tests)
Max2 = Abs(Test2 - Avg3Tests)
Max3 = Abs(Test3 - Avg3Tests)

  If Max1 > Max2 And Max1 > Max3 Then
    Cells(mmRow, 8) = "Test 1"
    TestB = Test2
    TestBT = "Test 2"
    TestC = Test3
    TestCT = "Test 3"
  ElseIf Max2 > Max1 And Max2 > Max3 Then
    Cells(mmRow, 8) = "Test 2"
    TestB = Test1
    TestBT = "Test 1"
    TestC = Test3
    TestCT = "Test 3"
  ElseIf Max3 > Max1 And Max3 > Max2 Then
    Cells(mmRow, 8) = "Test 3"
    TestB = Test1
    TestBT = "Test 1"
    TestC = Test2
    TestCT = "Test 2"
  End If

Else
  Cells(mmRow, 8) = "None"
End If
```

```
'Now what if a second outlier is found?
If Cells(mmRow, 8) <> "None" And Cells(mmRow, 9) > (Error / 100) + 0.000001 Then

Avg2Tests = (TestB + TestC) / 2

MaxB = Abs(TestB - Avg2Tests)
MaxC = Abs(TestC - Avg2Tests)

   If MaxB >= MaxC Then
      Cells(mmRow, 10) = TestBT
   ElseIf MaxC > MaxB Then
      Cells(mmRow, 10) = TestCT
   End If

Else
   Cells(mmRow, 10) = "None"
End If

End Function
```

```
Function Outlier4(mmRow As Integer, Error As Single)
'this checks for outliers instead of the functions being
'stuck into the cell as long functions and addresses
Application.ScreenUpdating = False

Worksheets("Outlier4").Activate

Rng = Cells(mmRow, 8)

If Rng > (Error / 100) + 0.000001 Then

Test1 = Cells(mmRow, 2)
Test2 = Cells(mmRow, 3)
Test3 = Cells(mmRow, 4)
Test4 = Cells(mmRow, 5)

Avg4Tests = (Test1 + Test2 + Test3 + Test4) / 4

Max1 = Abs(Test1 - Avg4Tests)
Max2 = Abs(Test2 - Avg4Tests)
Max3 = Abs(Test3 - Avg4Tests)
Max4 = Abs(Test4 - Avg4Tests)

   If Max1 > Max2 And Max1 > Max3 And Max1 > Max4 Then
      Cells(mmRow, 9) = "Test 1"
      TestB = Test2
      TestBT = "Test 2"
      TestC = Test3
      TestCT = "Test 3"
      TestD = Test4
      TestDT = "Test 4"
   ElseIf Max2 > Max1 And Max2 > Max3 And Max2 > Max4 Then
      Cells(mmRow, 9) = "Test 2"
      TestB = Test1
      TestBT = "Test 1"
      TestC = Test3
      TestCT = "Test 3"
      TestD = Test4
      TestDT = "Test 4"
   ElseIf Max3 > Max1 And Max3 > Max2 And Max3 > Max4 Then
      Cells(mmRow, 9) = "Test 3"
      TestB = Test1
```

```
      TestBT = "Test 1"
      TestC = Test2
      TestCT = "Test 2"
      TestD = Test4
      TestDT = "Test 4"
   ElseIf Max4 > Max1 And Max4 > Max2 And Max4 > Max3 Then
      Cells(mmRow, 9) = "Test 4"
      TestB = Test1
      TestBT = "Test 1"
      TestC = Test2
      TestCT = "Test 2"
      TestD = Test3
      TestDT = "Test 3"
   End If

Else
   Cells(mmRow, 9) = "None"
End If

'Now what if a second outlier is found?
If Cells(mmRow, 10) > (Error / 100) + 0.000001 Then

Avg3Tests = (TestB + TestC + TestD) / 3

MaxB = Abs(TestB - Avg3Tests)
MaxC = Abs(TestC - Avg3Tests)
MaxD = Abs(TestD - Avg3Tests)

   If MaxB >= MaxC And MaxB >= MaxD Then
      Cells(mmRow, 11) = TestBT
      TestE = TestC
      TestET = TestCT
      TestF = TestD
      TestFT = TestDT
   ElseIf MaxC > MaxB And MaxC > MaxD Then
      Cells(mmRow, 11) = TestCT
      TestE = TestB
      TestET = TestBT
      TestF = TestD
      TestFT = TestDT
   ElseIf MaxD > MaxB And MaxD > MaxC Then
      Cells(mmRow, 11) = TestDT
      TestE = TestB
      TestET = TestBT
      TestF = TestC
      TestFT = TestCT
   End If

Else
   Cells(mmRow, 11) = "None"
End If

'Now what if a third outlier is found?
'Get the new range from the sub routine
Call Range34T(mmRow)

If Cells(mmRow, 11) <> "None" And Cells(mmRow, 12) > (Error / 100) + 0.000001 Then

Avg2Tests = (TestB + TestC) / 2

MaxE = Abs(TestE - Avg2Tests)
MaxF = Abs(TestF - Avg2Tests)
```

```
   If MaxE >= MaxF Then
      Cells(mmRow, 13) = TestET
   ElseIf MaxF > MaxE Then
      Cells(mmRow, 13) = TestFT
   End If

Else
   Cells(mmRow, 13) = "None"
End If

End Function
```

```
Function Outlier5(mmRow As Integer, Error As Single)
'this checks for outliers instead of the functions being
'stuck into the cell as long functions and addresses
Application.ScreenUpdating = False

Worksheets("Outlier5").Activate

Rng = Cells(mmRow, 9)

If Rng > (Error / 100) + 0.000001 Then

Test1 = Cells(mmRow, 2)
Test2 = Cells(mmRow, 3)
Test3 = Cells(mmRow, 4)
Test4 = Cells(mmRow, 5)
Test5 = Cells(mmRow, 6)

Avg5Tests = (Test1 + Test2 + Test3 + Test4 + Test5) / 5

Max1 = Abs(Test1 - Avg5Tests)
Max2 = Abs(Test2 - Avg5Tests)
Max3 = Abs(Test3 - Avg5Tests)
Max4 = Abs(Test4 - Avg5Tests)
Max5 = Abs(Test5 - Avg5Tests)

   If Max1 > Max2 And Max1 > Max3 And Max1 > Max4 And Max1 > Max5 Then
      Cells(mmRow, 10) = "Test 1"
      TestA = Test2
      TestAT = "Test 2"
      TestB = Test3
      TestBT = "Test 3"
      TestC = Test4
      TestCT = "Test 4"
      TestD = Test5
      TestDT = "Test 5"
   ElseIf Max2 > Max1 And Max2 > Max3 And Max2 > Max4 And Max2 > Max5 Then
      Cells(mmRow, 10) = "Test 2"
      TestA = Test1
      TestAT = "Test 1"
      TestB = Test3
      TestBT = "Test 3"
      TestC = Test4
      TestCT = "Test 4"
      TestD = Test5
      TestDT = "Test 5"
   ElseIf Max3 > Max1 And Max3 > Max2 And Max3 > Max4 And Max3 > Max5 Then
      Cells(mmRow, 10) = "Test 3"
      TestA = Test1
      TestAT = "Test 1"
```

```
      TestB = Test2
      TestBT = "Test 2"
      TestC = Test4
      TestCT = "Test 4"
      TestD = Test5
      TestDT = "Test 5"
    ElseIf Max4 > Max1 And Max4 > Max2 And Max4 > Max3 And Max4 > Max5 Then
      Cells(mmRow, 10) = "Test 4"
      TestA = Test1
      TestAT = "Test 1"
      TestB = Test2
      TestBT = "Test 2"
      TestC = Test3
      TestCT = "Test 3"
      TestD = Test5
      TestDT = "Test 5"
    ElseIf Max5 > Max1 And Max5 > Max2 And Max5 > Max3 And Max5 > Max4 Then
      Cells(mmRow, 10) = "Test 5"
      TestA = Test1
      TestAT = "Test 1"
      TestB = Test2
      TestBT = "Test 2"
      TestC = Test3
      TestCT = "Test 3"
      TestD = Test4
      TestDT = "Test 4"
    End If

Else
    Cells(mmRow, 10) = "None"
End If

'Now what if a second outlier is found?
If Cells(mmRow, 11) > (Error / 100) + 0.000001 Then

Avg4Tests = (TestA + TestB + TestC + TestD) / 4

Maxa = Abs(TestA - Avg4Tests)
MaxB = Abs(TestB - Avg4Tests)
MaxC = Abs(TestC - Avg4Tests)
MaxD = Abs(TestD - Avg4Tests)

    If Maxa >= MaxB And Maxa >= MaxC And Maxa >= MaxD Then
      Cells(mmRow, 12) = TestAT
      TestE = TestB
      TestET = TestBT
      TestF = TestC
      TestFT = TestCT
      TestG = TestD
      TestGT = TestDT
    ElseIf MaxB > Maxa And MaxB > MaxC And MaxB > MaxD Then
      Cells(mmRow, 12) = TestBT
      TestE = TestA
      TestET = TestAT
      TestF = TestC
      TestFT = TestCT
      TestG = TestD
      TestGT = TestDT
    ElseIf MaxC > Maxa And MaxC > MaxB And MaxC > MaxD Then
      Cells(mmRow, 12) = TestCT
      TestE = TestA
      TestET = TestAT
```

```
        TestF = TestB
        TestFT = TestBT
        TestG = TestD
        TestGT = TestDT
    ElseIf MaxD > Maxa And MaxD > MaxB And MaxD > MaxC Then
        Cells(mmRow, 12) = TestDT
        TestE = TestA
        TestET = TestAT
        TestF = TestB
        TestFT = TestBT
        TestG = TestC
        TestGT = TestCT
    End If

Else
    Cells(mmRow, 12) = "None"
End If

'Now what if a third outlier is found?
'Get the new range from the sub routine
Call Range35T(mmRow)

If Cells(mmRow, 13) > (Error / 100) + 0.000001 Then

Avg3Tests = (TestB + TestC + TestD) / 3

MaxE = Abs(TestE - Avg3Tests)
MaxF = Abs(TestF - Avg3Tests)
MaxG = Abs(TestG - Avg3Tests)

    If MaxE >= MaxF And MaxE >= MaxG Then
        Cells(mmRow, 14) = TestET
        TestH = TestF
        TestHT = TestFT
        TestI = TestG
        TestIT = TestGT
    ElseIf MaxF > MaxE And MaxF > MaxG Then
        Cells(mmRow, 14) = TestFT
        TestH = TestE
        TestHT = TestET
        TestI = TestG
        TestIT = TestGT
    ElseIf MaxG > MaxE And MaxG > MaxF Then
        Cells(mmRow, 14) = TestGT
        TestH = TestE
        TestHT = TestET
        TestI = TestF
        TestIT = TestFT
    End If

Else
    Cells(mmRow, 14) = "None"
End If

'Now what if a fourth outlier is found?
'Get the new range from the sub routine
Call Range45T(mmRow)

If Cells(mmRow, 14) <> "None" And Cells(mmRow, 15) > (Error / 100) + 0.000001 Then

Avg2Tests = (TestH + TestI) / 2
```

```
MaxH = Abs(TestH - Avg2Tests)
MaxI = Abs(TestI - Avg2Tests)

   If MaxH >= MaxI Then
      Cells(mmRow, 16) = TestHT
   ElseIf MaxI > MaxH Then
      Cells(mmRow, 16) = TestIT
   End If

Else
   Cells(mmRow, 16) = "None"
End If

End Function
```

```
Function AssistRanges(mmRow As Integer, Numb1, Numb2, Numb3)
Application.ScreenUpdating = False

'optimize duplicate range calculations for 4 Tests
Maxa = WorksheetFunction.Max(Cells(mmRow, Numb1), Cells(mmRow, Numb2))
Mina = WorksheetFunction.Min(Cells(mmRow, Numb1), Cells(mmRow, Numb2))
Avga = WorksheetFunction.Average(Cells(mmRow, Numb1), Cells(mmRow, Numb2))
Rng = (Maxa - Mina) / Avga
Cells(mmRow, Numb3) = Rng

End Function
```

```
Function AssistRangesB(mmRow, Num1, Num2, Num3, Num4)
Application.ScreenUpdating = False

'optimize duplicate range calculations for 5 Tests
Max1 = WorksheetFunction.Max(Cells(mmRow, Num1), Cells(mmRow, Num2), Cells(mmRow, Num3))
Min1 = WorksheetFunction.Min(Cells(mmRow, Num1), Cells(mmRow, Num2), Cells(mmRow, Num3))
Avg1 = WorksheetFunction.Average(Cells(mmRow, Num1), Cells(mmRow, Num2), Cells(mmRow, Num3))
Rng = (Max1 - Min1) / Avg1
Cells(mmRow, Num4) = Rng

End Function
```

```
Function Range34T(mmRow As Integer)
Application.ScreenUpdating = False
'This is to optimize the calculations for the third outlier
'for 4 DCP tests

Outlier1 = Cells(mmRow, 9)
Outlier2 = Cells(mmRow, 11)

If Outlier1 = "None" Then
   Cells(mmRow, 12) = Cells(mmRow, 10)
ElseIf Outlier1 = "Test 1" Then
   If Outlier2 = "Test 2" Then
      Call AssistRanges(mmRow, 4, 5, 12)
   ElseIf Outlier2 = "Test 3" Then
      Call AssistRanges(mmRow, 3, 5, 12)
   ElseIf Outlier2 = "Test 4" Then
      Call AssistRanges(mmRow, 3, 4, 12)
   ElseIf Outlier2 = "None" Then
      Cells(mmRow, 12) = Cells(mmRow, 10)
   End If
ElseIf Outlier1 = "Test 2" Then
   If Outlier2 = "Test 1" Then
```

```
      Call AssistRanges(mmRow, 4, 5, 12)
   ElseIf Outlier2 = "Test 3" Then
      Call AssistRanges(mmRow, 2, 5, 12)
   ElseIf Outlier2 = "Test 4" Then
      Call AssistRanges(mmRow, 2, 4, 12)
   ElseIf Outlier2 = "None" Then
      Cells(mmRow, 12) = Cells(mmRow, 10)
   End If
ElseIf Outlier1 = "Test 3" Then
   If Outlier2 = "Test 1" Then
      Call AssistRanges(mmRow, 3, 5, 12)
   ElseIf Outlier2 = "Test 2" Then
      Call AssistRanges(mmRow, 2, 5, 12)
   ElseIf Outlier2 = "Test 4" Then
      Call AssistRanges(mmRow, 2, 3, 12)
   ElseIf Outlier2 = "None" Then
      Cells(mmRow, 12) = Cells(mmRow, 10)
   End If
ElseIf Outlier1 = "Test 4" Then
   If Outlier2 = "Test 1" Then
      Call AssistRanges(mmRow, 3, 4, 12)
   ElseIf Outlier2 = "Test 2" Then
      Call AssistRanges(mmRow, 2, 4, 12)
   ElseIf Outlier2 = "Test 3" Then
      Call AssistRanges(mmRow, 2, 3, 12)
   ElseIf Outlier2 = "None" Then
      Cells(mmRow, 12) = Cells(mmRow, 10)
   End If
End If

End Function
```

```
Function Range35T(mmRow As Integer)
Application.ScreenUpdating = False
'This is to optimize the calculations for the third outlier
'for 5 DCP tests

Outlier1 = Cells(mmRow, 10)
Outlier2 = Cells(mmRow, 12)

If Outlier1 = "None" Then
   Cells(mmRow, 13) = Cells(mmRow, 11)
ElseIf Outlier1 = "Test 1" Then
   If Outlier2 = "Test 2" Then
      Call AssistRangesB(mmRow, 4, 5, 6, 13)
   ElseIf Outlier2 = "Test 3" Then
      Call AssistRangesB(mmRow, 3, 5, 6, 13)
   ElseIf Outlier2 = "Test 4" Then
      Call AssistRangesB(mmRow, 3, 4, 6, 13)
   ElseIf Outlier2 = "Test 5" Then
      Call AssistRangesB(mmRow, 3, 4, 5, 13)
   ElseIf Outlier2 = "None" Then
      Cells(mmRow, 13) = Cells(mmRow, 11)
   End If
ElseIf Outlier1 = "Test 2" Then
   If Outlier2 = "Test 1" Then
      Call AssistRangesB(mmRow, 4, 5, 6, 13)
   ElseIf Outlier2 = "Test 3" Then
      Call AssistRangesB(mmRow, 2, 5, 6, 13)
   ElseIf Outlier2 = "Test 4" Then
      Call AssistRangesB(mmRow, 2, 4, 6, 13)
   ElseIf Outlier2 = "Test 5" Then
```

```
      Call AssistRangesB(mmRow, 2, 4, 5, 13)
   ElseIf Outlier2 = "None" Then
      Cells(mmRow, 13) = Cells(mmRow, 11)
   End If
ElseIf Outlier1 = "Test 3" Then
   If Outlier2 = "Test 1" Then
      Call AssistRangesB(mmRow, 3, 5, 6, 13)
   ElseIf Outlier2 = "Test 2" Then
      Call AssistRangesB(mmRow, 2, 5, 6, 13)
   ElseIf Outlier2 = "Test 4" Then
      Call AssistRangesB(mmRow, 2, 3, 6, 13)
   ElseIf Outlier2 = "Test 5" Then
      Call AssistRangesB(mmRow, 2, 3, 5, 13)
   ElseIf Outlier2 = "None" Then
      Cells(mmRow, 13) = Cells(mmRow, 11)
   End If
ElseIf Outlier1 = "Test 4" Then
   If Outlier2 = "Test 1" Then
      Call AssistRangesB(mmRow, 3, 4, 6, 13)
   ElseIf Outlier2 = "Test 2" Then
      Call AssistRangesB(mmRow, 2, 4, 6, 13)
   ElseIf Outlier2 = "Test 3" Then
      Call AssistRangesB(mmRow, 2, 3, 6, 13)
   ElseIf Outlier2 = "Test 5" Then
      Call AssistRangesB(mmRow, 2, 3, 4, 13)
   ElseIf Outlier2 = "None" Then
      Cells(mmRow, 13) = Cells(mmRow, 11)
   End If
ElseIf Outlier1 = "Test 5" Then
   If Outlier2 = "Test 1" Then
      Call AssistRangesB(mmRow, 3, 4, 5, 13)
   ElseIf Outlier2 = "Test 2" Then
      Call AssistRangesB(mmRow, 2, 4, 5, 13)
   ElseIf Outlier2 = "Test 3" Then
      Call AssistRangesB(mmRow, 2, 3, 5, 13)
   ElseIf Outlier2 = "Test 4" Then
      Call AssistRangesB(mmRow, 2, 3, 4, 13)
   ElseIf Outlier2 = "None" Then
      Cells(mmRow, 13) = Cells(mmRow, 11)
   End If
End If

End Function
```

```
Function Range45T(mmRow As Integer)
Application.ScreenUpdating = False
'This is to optimize the calculations for the fourth outlier
'for 5 DCP tests

Outlier1 = Cells(mmRow, 10)
Outlier2 = Cells(mmRow, 12)
Outlier3a = Cells(mmRow, 14)

If Outlier1 = "None" Then
   Cells(mmRow, 13) = Cells(mmRow, 11)
   Cells(mmRow, 15) = Cells(mmRow, 13)
ElseIf Outlier1 = "Test 1" Then
   If Outlier2 = "Test 2" Then
      If Outlier3a = "Test 3" Then
         Call AssistRanges(mmRow, 5, 6, 15)
      ElseIf Outlier3a = "Test 4" Then
         Call AssistRanges(mmRow, 4, 6, 15)
```

```
        ElseIf Outlier3a = "Test 5" Then
            Call AssistRanges(mmRow, 4, 5, 15)
        ElseIf Outlier3a = "None" Then
            Cells(mmRow, 15) = Cells(mmRow, 13)
        End If
    ElseIf Outlier2 = "Test 3" Then
        If Outlier3a = "Test 2" Then
            Call AssistRanges(mmRow, 5, 6, 15)
        ElseIf Outlier3a = "Test 4" Then
            Call AssistRanges(mmRow, 3, 6, 15)
        ElseIf Outlier3a = "Test 5" Then
            Call AssistRanges(mmRow, 3, 5, 15)
        ElseIf Outlier3a = "None" Then
            Cells(mmRow, 15) = Cells(mmRow, 13)
        End If
    ElseIf Outlier2 = "Test 4" Then
        If Outlier3a = "Test 2" Then
            Call AssistRanges(mmRow, 4, 6, 15)
        ElseIf Outlier3a = "Test 3" Then
            Call AssistRanges(mmRow, 3, 6, 15)
        ElseIf Outlier3a = "Test 5" Then
            Call AssistRanges(mmRow, 3, 4, 15)
        ElseIf Outlier3a = "None" Then
            Cells(mmRow, 15) = Cells(mmRow, 13)
        End If
    ElseIf Outlier2 = "Test 5" Then
        If Outlier3a = "Test 2" Then
            Call AssistRanges(mmRow, 4, 5, 15)
        ElseIf Outlier3a = "Test 3" Then
            Call AssistRanges(mmRow, 3, 5, 15)
        ElseIf Outlier3a = "Test 4" Then
            Call AssistRanges(mmRow, 3, 4, 15)
        ElseIf Outlier3a = "None" Then
            Cells(mmRow, 15) = Cells(mmRow, 13)
        End If
    ElseIf Outlier2 = "None" Then
        Cells(mmRow, 15) = Cells(mmRow, 13)
    End If
ElseIf Outlier1 = "Test 2" Then
    If Outlier2 = "Test 1" Then
        If Outlier3a = "Test 3" Then
            Call AssistRanges(mmRow, 5, 6, 15)
        ElseIf Outlier3a = "Test 4" Then
            Call AssistRanges(mmRow, 4, 6, 15)
        ElseIf Outlier3a = "Test 5" Then
            Call AssistRanges(mmRow, 4, 5, 15)
        ElseIf Outlier3a = "None" Then
            Cells(mmRow, 15) = Cells(mmRow, 13)
        End If
    ElseIf Outlier2 = "Test 3" Then
        If Outlier3a = "Test 1" Then
            Call AssistRanges(mmRow, 5, 6, 15)
        ElseIf Outlier3a = "Test 4" Then
            Call AssistRanges(mmRow, 2, 6, 15)
        ElseIf Outlier3a = "Test 5" Then
            Call AssistRanges(mmRow, 2, 5, 15)
        ElseIf Outlier3a = "None" Then
            Cells(mmRow, 15) = Cells(mmRow, 13)
        End If
    ElseIf Outlier2 = "Test 4" Then
        If Outlier3a = "Test 1" Then
            Call AssistRanges(mmRow, 4, 6, 15)
```

```
        ElseIf Outlier3a = "Test 3" Then
            Call AssistRanges(mmRow, 2, 6, 15)
        ElseIf Outlier3a = "Test 5" Then
            Call AssistRanges(mmRow, 2, 4, 15)
        ElseIf Outlier3a = "None" Then
            Cells(mmRow, 15) = Cells(mmRow, 13)
        End If
    ElseIf Outlier2 = "Test 5" Then
        If Outlier3a = "Test 1" Then
            Call AssistRanges(mmRow, 4, 5, 15)
        ElseIf Outlier3a = "Test 3" Then
            Call AssistRanges(mmRow, 2, 5, 15)
        ElseIf Outlier3a = "Test 4" Then
            Call AssistRanges(mmRow, 2, 4, 15)
        ElseIf Outlier3a = "None" Then
            Cells(mmRow, 15) = Cells(mmRow, 13)
        End If
    ElseIf Outlier2 = "None" Then
        Cells(mmRow, 15) = Cells(mmRow, 13)
    End If
ElseIf Outlier1 = "Test 3" Then
    If Outlier2 = "Test 1" Then
        If Outlier3a = "Test 2" Then
            Call AssistRanges(mmRow, 5, 6, 15)
        ElseIf Outlier3a = "Test 4" Then
            Call AssistRanges(mmRow, 3, 6, 15)
        ElseIf Outlier3a = "Test 5" Then
            Call AssistRanges(mmRow, 3, 5, 15)
        ElseIf Outlier3a = "None" Then
            Cells(mmRow, 15) = Cells(mmRow, 13)
        End If
    ElseIf Outlier2 = "Test 2" Then
        If Outlier3a = "Test 1" Then
            Call AssistRanges(mmRow, 5, 6, 15)
        ElseIf Outlier3a = "Test 4" Then
            Call AssistRanges(mmRow, 2, 6, 15)
        ElseIf Outlier3a = "Test 5" Then
            Call AssistRanges(mmRow, 2, 5, 15)
        ElseIf Outlier3a = "None" Then
            Cells(mmRow, 15) = Cells(mmRow, 13)
        End If
    ElseIf Outlier2 = "Test 4" Then
        If Outlier3a = "Test 1" Then
            Call AssistRanges(mmRow, 3, 6, 15)
        ElseIf Outlier3a = "Test 2" Then
            Call AssistRanges(mmRow, 2, 6, 15)
        ElseIf Outlier3a = "Test 5" Then
            Call AssistRanges(mmRow, 2, 3, 15)
        ElseIf Outlier3a = "None" Then
            Cells(mmRow, 15) = Cells(mmRow, 13)
        End If
    ElseIf Outlier2 = "Test 5" Then
        If Outlier3a = "Test 1" Then
            Call AssistRanges(mmRow, 3, 5, 15)
        ElseIf Outlier3a = "Test 2" Then
            Call AssistRanges(mmRow, 2, 5, 15)
        ElseIf Outlier3a = "Test 4" Then
            Call AssistRanges(mmRow, 2, 3, 15)
        ElseIf Outlier3a = "None" Then
            Cells(mmRow, 15) = Cells(mmRow, 13)
        End If
    ElseIf Outlier2 = "None" Then
```

```
      Cells(mmRow, 15) = Cells(mmRow, 13)
    End If
  ElseIf Outlier1 = "Test 4" Then
    If Outlier2 = "Test 1" Then
      If Outlier3a = "Test 2" Then
        Call AssistRanges(mmRow, 4, 6, 15)
      ElseIf Outlier3a = "Test 3" Then
        Call AssistRanges(mmRow, 3, 6, 15)
      ElseIf Outlier3a = "Test 5" Then
        Call AssistRanges(mmRow, 3, 4, 15)
      ElseIf Outlier3a = "None" Then
        Cells(mmRow, 15) = Cells(mmRow, 13)
      End If
    ElseIf Outlier2 = "Test 2" Then
      If Outlier3a = "Test 1" Then
        Call AssistRanges(mmRow, 4, 6, 15)
      ElseIf Outlier3a = "Test 3" Then
        Call AssistRanges(mmRow, 2, 6, 15)
      ElseIf Outlier3a = "Test 5" Then
        Call AssistRanges(mmRow, 2, 4, 15)
      ElseIf Outlier3a = "None" Then
        Cells(mmRow, 15) = Cells(mmRow, 13)
      End If
    ElseIf Outlier2 = "Test 3" Then
      If Outlier3a = "Test 1" Then
        Call AssistRanges(mmRow, 3, 6, 15)
      ElseIf Outlier3a = "Test 2" Then
        Call AssistRanges(mmRow, 2, 6, 15)
      ElseIf Outlier3a = "Test 5" Then
        Call AssistRanges(mmRow, 2, 3, 15)
      ElseIf Outlier3a = "None" Then
        Cells(mmRow, 15) = Cells(mmRow, 13)
      End If
    ElseIf Outlier2 = "Test 5" Then
      If Outlier3a = "Test 1" Then
        Call AssistRanges(mmRow, 3, 4, 15)
      ElseIf Outlier3a = "Test 2" Then
        Call AssistRanges(mmRow, 2, 4, 15)
      ElseIf Outlier3a = "Test 3" Then
        Call AssistRanges(mmRow, 2, 3, 15)
      ElseIf Outlier3a = "None" Then
        Cells(mmRow, 15) = Cells(mmRow, 13)
      End If
    ElseIf Outlier2 = "None" Then
      Cells(mmRow, 15) = Cells(mmRow, 13)
    End If
  ElseIf Outlier1 = "Test 5" Then
    If Outlier2 = "Test 1" Then
      If Outlier3a = "Test 2" Then
        Call AssistRanges(mmRow, 4, 5, 15)
      ElseIf Outlier3a = "Test 3" Then
        Call AssistRanges(mmRow, 3, 5, 15)
      ElseIf Outlier3a = "Test 4" Then
        Call AssistRanges(mmRow, 3, 4, 15)
      ElseIf Outlier3a = "None" Then
        Cells(mmRow, 15) = Cells(mmRow, 13)
      End If
    ElseIf Outlier2 = "Test 2" Then
      If Outlier3a = "Test 1" Then
        Call AssistRanges(mmRow, 4, 5, 15)
      ElseIf Outlier3a = "Test 3" Then
        Call AssistRanges(mmRow, 2, 5, 15)
```

```
    ElseIf Outlier3a = "Test 4" Then
      Call AssistRanges(mmRow, 2, 4, 15)
    ElseIf Outlier3a = "None" Then
      Cells(mmRow, 15) = Cells(mmRow, 13)
    End If
  ElseIf Outlier2 = "Test 3" Then
    If Outlier3a = "Test 1" Then
      Call AssistRanges(mmRow, 3, 5, 15)
    ElseIf Outlier3a = "Test 2" Then
      Call AssistRanges(mmRow, 2, 5, 15)
    ElseIf Outlier3a = "Test 4" Then
      Call AssistRanges(mmRow, 2, 3, 15)
    ElseIf Outlier3a = "None" Then
      Cells(mmRow, 15) = Cells(mmRow, 13)
    End If
  ElseIf Outlier2 = "Test 4" Then
    If Outlier3a = "Test 1" Then
      Call AssistRanges(mmRow, 3, 4, 15)
    ElseIf Outlier3a = "Test 2" Then
      Call AssistRanges(mmRow, 2, 4, 15)
    ElseIf Outlier3a = "Test 3" Then
      Call AssistRanges(mmRow, 2, 3, 15)
    ElseIf Outlier3a = "None" Then
      Cells(mmRow, 15) = Cells(mmRow, 13)
    End If
  ElseIf Outlier2 = "None" Then
    Cells(mmRow, 15) = Cells(mmRow, 13)
  End If
End If

End Function
```

```
Function OutOp(Test As String, Rng As Single, DCPs As Single)
Worksheets("Starting Page").Activate
Range("A1").Select
ActiveWindow.ScrollRow = 1
Application.CutCopyMode = False
Application.ScreenUpdating = True

'This is the option pop up for users to decide outliers
OutlierCheck.OutlierTest.Value = Test
OutlierCheck.OutlierRange.Value = Rng
OutlierCheck.Show

Do Until OutlierCheck.Visible = False
  DoEvents
Loop

Application.ScreenUpdating = False
Worksheets("Outlier" & DCPs).Activate

End Function
```

```
Function OutRFind(DCP As Single, mmRow As Integer, out As String, col As Single, R1a As String, R2a As String, R3a As String, R4a As String, R5a As String)
Application.ScreenUpdating = False
'This matches the range values to the noted outliers

If DCP = 3 Then
  If out = "Test 1" Then
    R1 = Cells(mmRow, col)
  ElseIf out = "Test 2" Then
```

```
      R2 = Cells(mmRow, col)
   ElseIf out = "Test 3" Then
      R3 = Cells(mmRow, col)
   End If

   If R1a <> "No" Then
      Cells(mmRow - 1, 18) = R1
   End If
   If R2a <> "No" Then
      Cells(mmRow - 1, 19) = R2
   End If
   If R3a <> "No" Then
      Cells(mmRow - 1, 20) = R3
   End If


ElseIf DCP = 4 Then
   If out = "Test 1" Then
      R1 = Cells(mmRow, col)
   ElseIf out = "Test 2" Then
      R2 = Cells(mmRow, col)
   ElseIf out = "Test 3" Then
      R3 = Cells(mmRow, col)
   ElseIf out = "Test 4" Then
      R4 = Cells(mmRow, col)
   End If

   If R1a <> "No" Then
      Cells(mmRow + 8, 18) = R1
   End If
   If R2a <> "No" Then
      Cells(mmRow + 8, 19) = R2
   End If
   If R3a <> "No" Then
      Cells(mmRow + 8, 20) = R3
   End If
   If R4a <> "No" Then
      Cells(mmRow + 8, 21) = R4
   End If

ElseIf DCP = 5 Then
   If out = "Test 1" Then
      R1 = Cells(mmRow, col)
   ElseIf out = "Test 2" Then
      R2 = Cells(mmRow, col)
   ElseIf out = "Test 3" Then
      R3 = Cells(mmRow, col)
   ElseIf out = "Test 4" Then
      R4 = Cells(mmRow, col)
   ElseIf out = "Test 5" Then
      R5 = Cells(mmRow, col)
   End If

   If R1a <> "No" Then
      Cells(mmRow + 8, 20) = R1
   End If
   If R2a <> "No" Then
      Cells(mmRow + 8, 21) = R2
   End If
   If R3a <> "No" Then
      Cells(mmRow + 8, 22) = R3
   End If
```

```
   If R4a <> "No" Then
      Cells(mmRow + 8, 23) = R4
   End If
   If R5a <> "No" Then
      Cells(mmRow + 8, 24) = R5
   End If

End If

End Function
```

```
Function Decider(mmRow, outRow, ColA, ColB, DCP, Arow)
Application.ScreenUpdating = False
'Outputs slope values based on outliers found/chosen

Slope = Cells(mmRow, ColA)
Cells(mmRow, ColB) = Slope
Outs = Cells(outRow, ColA)

If mmRow = Arow Then
   Application.Goto Reference:="OutPlot" & DCP
   ActiveCell = Outs
End If

End Function
```

```
Function EndEarly(T1 As Variant, T2 As Variant)

OutlierErrors.ErLabel.Caption = "Tests " & T1 & " and " & T2 & " have been discarded as outliers! Since only one DCP test is available at this station, this result cannot be analyzed on its own. It is recommended that the operator collect new DCP data at this station."
OutlierErrors.Show
EndMainSub = "Yes"

End Function
```

```
Function Slope3a(out1 As String, out2 As String, Depth As Single, mmRow As Integer, Analysis As Single)
Application.ScreenUpdating = False
'Major outlier logic function for 3 DCP tests with user options

col = 15
outRow = 8
DCP = 3

If Analysis = 25 Then
   Arow = 3
ElseIf Analysis = 50 Then
   Arow = 4
ElseIf Analysis = 75 Then
   Arow = 5
ElseIf Analysis = 100 Then
   Arow = 6
ElseIf Analysis = 175 Then
   Arow = 7
End If

Dim R1 As Single, R2 As Single, R3 As Single
Dim R1a As String, R2a As String, R3a As String, R4a As String, R5a As String

'What are the ranges of each test if listed as outlier?
R1a = ""
```

```
R2a = ""
R3a = ""
R4a = ""
R5a = ""

Call OutRFind(3, mmRow, out1, 7, R1a, R2a, R3a, R4a, R5a)

R1 = Cells(mmRow - 1, 18)
R2 = Cells(mmRow - 1, 19)
R3 = Cells(mmRow - 1, 20)

If R1 <> 0 Then
   R1a = "No"
ElseIf R2 <> 0 Then
   R2a = "No"
ElseIf R3 <> 0 Then
   R3a = "No"
End If

Call OutRFind(3, mmRow, out2, 9, R1a, R2a, R3a, R4a, R5a)

R1 = Cells(mmRow - 1, 18) * 100
R2 = Cells(mmRow - 1, 19) * 100
R3 = Cells(mmRow - 1, 20) * 100

R1 = WorksheetFunction.MRound(Arg1:=R1, Arg2:=0.1)
R2 = WorksheetFunction.MRound(Arg1:=R2, Arg2:=0.1)
R3 = WorksheetFunction.MRound(Arg1:=R3, Arg2:=0.1)

'IS TEST 1 BAD??

If OutlierTest(out1) = "Test 1" Or OutlierTest(out2) = "Test 1" Or Refusal1 = "Yes" Then
   If Refusal1 <> "Yes" Then
      If Depth = Analysis Then
         Outlier = ""
         Application.ScreenUpdating = True
         Call OutOp(1, R1, 3)
         Application.ScreenUpdating = False
      ElseIf Depth <> Analysis Then
         Outlier = "YesD"
      End If
   Else
      Outlier = "Yes"
   End If
   Application.ScreenUpdating = False
   If Outlier = "No" Then
      Range("C11") = "Included"
      GoTo Test2Start
   ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
      If Outlier = "Yes" Then
         Range("C11") = "Discarded"
      End If
'Test1 yes, Test2?------
      If OutlierTest(out1) = "Test 2" Or OutlierTest(out2) = "Test 2" Or Refusal2 = "Yes" Then
         If Refusal2 <> "Yes" Then
            If Depth = Analysis Then
               Outlier = ""
               Application.ScreenUpdating = True
               Call OutOp(2, R2, 3)
               Application.ScreenUpdating = False
            ElseIf Depth <> Analysis Then
               Outlier = "YesD"
```

```
            End If
         Else
            Outlier = "Yes"
         End If
         Application.ScreenUpdating = False
         If Outlier = "No" Then
            Range("C12") = "Included"
            GoTo Test1Test3
         ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
            If Outlier = "Yes" Then
               Range("C12") = "Discarded"
            End If
            If Depth = Analysis Then
               Call EndEarly(1, 2)
               GoTo FinishEarly
            End If
         End If

'Test1 yes, Test3?------
      ElseIf OutlierTest(out1) = "Test 3" Or OutlierTest(out2) = "Test 3" Or Refusal3 = "Yes" Then
Test1Test3:
         If Refusal3 <> "Yes" Then
            If Depth = Analysis Then
               Outlier = ""
               Application.ScreenUpdating = True
               Call OutOp(3, R3, 3)
               Application.ScreenUpdating = False
            ElseIf Depth <> Analysis Then
               Outlier = "YesD"
            End If
         Else
            Outlier = "Yes"
         End If
         Application.ScreenUpdating = False
         If Outlier = "No" Then
            Range("C13") = "Included"
            'outliers are 1 ....
            Call Decider(mmRow, outRow, 13, col, DCP, Arow)
         ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
            If Outlier = "Yes" Then
               Range("C13") = "Discarded"
            End If
            If Depth = Analysis Then
               Call EndEarly(1, 3)
               GoTo FinishEarly
            End If
         End If
'Test 1 Only?------
      Else
         'outliers are 1 ....
         Call Decider(mmRow, outRow, 13, col, DCP, Arow)
      End If
   End If


'IS TEST 2 BAD??

ElseIf OutlierTest(out1) = "Test 2" Or OutlierTest(out2) = "Test 2" Or Refusal2 = "Yes" Then
Test2Start:
   If OutlierTest(out1) = "Test 2" Or OutlierTest(out2) = "Test 2" Or Refusal2 = "Yes" Then
   If Refusal2 <> "Yes" Then
      If Depth = Analysis Then
```

```
            Outlier = ""
            Application.ScreenUpdating = True
            Call OutOp(2, R2, 3)
            Application.ScreenUpdating = False
        ElseIf Depth <> Analysis Then
            Outlier = "YesD"
        End If
    Else
        Outlier = "Yes"
    End If
    Application.ScreenUpdating = False
    If Outlier = "No" Then
        Range("C12") = "Included"
        GoTo Test3Start
    ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
        If Outlier = "Yes" Then
            Range("C12") = "Discarded"
        End If
'Test2 yes, Test3?------
        If OutlierTest(out1) = "Test 3" Or OutlierTest(out2) = "Test 3" Or Refusal3 = "Yes" Then
            If Refusal3 <> "Yes" Then
                If Depth = Analysis Then
                    Outlier = ""
                    Application.ScreenUpdating = True
                    Call OutOp(3, R3, 3)
                    Application.ScreenUpdating = False
                ElseIf Depth <> Analysis Then
                    Outlier = "YesD"
                End If
            Else
                Outlier = "Yes"
            End If
            Application.ScreenUpdating = False
            If Outlier = "No" Then
                Range("C13") = "Included"
                'outliers are 2 ....
                Call Decider(mmRow, outRow, 14, col, DCP, Arow)
            ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
                If Outlier = "Yes" Then
                    Range("C13") = "Discarded"
                End If
                If Depth = Analysis Then
                    Call EndEarly(2, 3)
                    GoTo FinishEarly
                End If
            End If
'Test2 Only?------
        Else
            'outliers are 2 ....
            Call Decider(mmRow, outRow, 14, col, DCP, Arow)
        End If
    End If
    End If

    If Outlier = "No" Then
    GoTo Test3Start
    End If

'IS TEST 3 BAD??

ElseIf OutlierTest(out1) = "Test 3" Or OutlierTest(out2) = "Test 3" Or Refusal3 = "Yes" Then
Test3Start:
```

```
   If OutlierTest(out1) = "Test 3" Or OutlierTest(out2) = "Test 3" Or Refusal3 = "Yes" Then
   If Refusal3 <> "Yes" Then
      If Depth = Analysis Then
         Outlier = ""
         Application.ScreenUpdating = True
         Call OutOp(3, R3, 3)
         Application.ScreenUpdating = False
      ElseIf Depth <> Analysis Then
         Outlier = "YesD"
      End If
   Else
      Outlier = "Yes"
   End If
   Application.ScreenUpdating = False
   If Outlier = "No" Then
      Range("C13") = "Included"
      'NO OUTLIERS ....
      Call Decider(mmRow, outRow, 11, col, DCP, Arow)
   ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
      If Outlier = "Yes" Then
         Range("C13") = "Discarded"
      End If
      'outliers are 3 ....
      Call Decider(mmRow, outRow, 12, col, DCP, Arow)
   End If
   End If

   If Outlier = "No" Then
   GoTo AllIn
   End If

Else
AllIn:
   'NO OUTLIERS ....
   Call Decider(mmRow, outRow, 11, col, DCP, Arow)

End If

FinishEarly:
End Function
```

```
Function Slope4a(out1 As String, out2 As String, out3 As String, Depth As Single, mmRow As Integer, Analysis As Single)
Application.ScreenUpdating = False
'Major outlier logic function for 4 DCP tests with user options

col = 14
outRow = 8
DCP = 4

If Analysis = 25 Then
   Arow = 3
ElseIf Analysis = 50 Then
   Arow = 4
ElseIf Analysis = 75 Then
   Arow = 5
ElseIf Analysis = 100 Then
   Arow = 6
ElseIf Analysis = 175 Then
   Arow = 7
End If

Dim R1 As Single, R2 As Single, R3 As Single, R4 As Single
```

```
Dim R1a As String, R2a As String, R3a As String, R4a As String, R5a As String

'What are the ranges of each test if listed as outlier?
R1a = ""
R2a = ""
R3a = ""
R4a = ""
R5a = ""

Call OutRFind(4, mmRow, out1, 8, R1a, R2a, R3a, R4a, R5a)

R1 = Cells(mmRow + 8, 18)
R2 = Cells(mmRow + 8, 19)
R3 = Cells(mmRow + 8, 20)
R4 = Cells(mmRow + 8, 21)

If R1 <> 0 Then
   R1a = "No"
ElseIf R2 <> 0 Then
   R2a = "No"
ElseIf R3 <> 0 Then
   R3a = "No"
ElseIf R4 <> 0 Then
   R4a = "No"
End If

Call OutRFind(4, mmRow, out2, 10, R1a, R2a, R3a, R4a, R5a)

R1 = Cells(mmRow + 8, 18)
R2 = Cells(mmRow + 8, 19)
R3 = Cells(mmRow + 8, 20)
R4 = Cells(mmRow + 8, 21)

If R1 <> 0 And R1a <> "No" Then
   R1a = "No"
ElseIf R2 <> 0 And R2a <> "No" Then
   R2a = "No"
ElseIf R3 <> 0 And R3a <> "No" Then
   R3a = "No"
ElseIf R4 <> 0 And R4a <> "No" Then
   R4a = "No"
End If

Call OutRFind(4, mmRow, out2, 12, R1a, R2a, R3a, R4a, R5a)

R1 = Cells(mmRow + 8, 18) * 100
R2 = Cells(mmRow + 8, 19) * 100
R3 = Cells(mmRow + 8, 20) * 100
R4 = Cells(mmRow + 8, 21) * 100

R1 = WorksheetFunction.MRound(Arg1:=R1, Arg2:=0.1)
R2 = WorksheetFunction.MRound(Arg1:=R2, Arg2:=0.1)
R3 = WorksheetFunction.MRound(Arg1:=R3, Arg2:=0.1)
R4 = WorksheetFunction.MRound(Arg1:=R4, Arg2:=0.1)

'IS TEST 1 BAD??

If OutlierTest(out1) = "Test 1" Or OutlierTest(out2) = "Test 1" Or OutlierTest(out3) = "Test 1" Or Refusal1 = "Yes" Then
   If Refusal1 <> "Yes" Then
      If Depth = Analysis Then
         Outlier = ""
         Application.ScreenUpdating = True
```

```
            Call OutOp(1, R1, 4)
            Application.ScreenUpdating = False
        ElseIf Depth <> Analysis Then
            Outlier = "YesD"
        End If
    Else
        Outlier = "Yes"
    End If
    Application.ScreenUpdating = False
    If Outlier = "No" Then
        Range("C11") = "Included"
        GoTo Test2Start
    ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
        If Outlier = "Yes" Then
            Range("C11") = "Discarded"
        End If
'Test1 yes, Test2?------
        If OutlierTest(out1) = "Test 2" Or OutlierTest(out2) = "Test 2" Or OutlierTest(out3) = "Test 2" Or Refusal2 = "Yes" Then
            If Refusal2 <> "Yes" Then
                If Depth = Analysis Then
                    Outlier = ""
                    Application.ScreenUpdating = True
                    Call OutOp(2, R2, 4)
                    Application.ScreenUpdating = False
                ElseIf Depth <> Analysis Then
                    Outlier = "YesD"
                End If
            Else
                Outlier = "Yes"
            End If
            Application.ScreenUpdating = False
            If Outlier = "No" Then
                Range("C12") = "Included"
                GoTo Test1Test3
            ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
                If Outlier = "Yes" Then
                    Range("C12") = "Discarded"
                End If
'Test1 yes, Test2 yes, Test3?------
                If OutlierTest(out1) = "Test 3" Or OutlierTest(out2) = "Test 3" Or OutlierTest(out3) = "Test 3" Or Refusal3 = "Yes"
Then
                    If Refusal3 <> "Yes" Then
                        If Depth = Analysis Then
                            Outlier = ""
                            Application.ScreenUpdating = True
                            Call OutOp(3, R3, 4)
                            Application.ScreenUpdating = False
                        ElseIf Depth <> Analysis Then
                            Outlier = "YesD"
                        End If
                    Else
                        Outlier = "Yes"
                    End If
                    Application.ScreenUpdating = False
                    If Outlier = "No" Then
                        Range("C13") = "Included"
                        GoTo Test1Test2Test4
                    ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
                        If Outlier = "Yes" Then
                            Range("C13") = "Discarded"
                        End If
                        If Depth = Analysis Then
```

```
                Call EndEarly("1, 2,", 3)
                GoTo FinishEarly
              End If
            End If

'Test1 yes, Test2 yes, Test4?------
        ElseIf OutlierTest(out1) = "Test 4" Or OutlierTest(out2) = "Test 4" Or OutlierTest(out3) = "Test 4" Or Refusal4 =
"Yes" Then
Test1Test2Test4:
          If Refusal4 <> "Yes" Then
            If Depth = Analysis Then
              Outlier = ""
              Application.ScreenUpdating = True
              Call OutOp(4, R4, 4)
              Application.ScreenUpdating = False
            ElseIf Depth <> Analysis Then
              Outlier = "YesD"
            End If
          Else
            Outlier = "Yes"
          End If
          Application.ScreenUpdating = False
          If Outlier = "No" Then
            Range("C14") = "Included"
            'outliers are 1,2 ....
            Call Decider(mmRow, outRow, 22, col, DCP, Arow)
          ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
            If Outlier = "Yes" Then
              Range("C14") = "Discarded"
            End If
            If Depth = Analysis Then
              Call EndEarly("1, 2,", 4)
              GoTo FinishEarly
            End If
          End If

        Else
          'outliers are 1,2 ....
          Call Decider(mmRow, outRow, 22, col, DCP, Arow)
        End If
      End If

'Test1 yes, Test3?------
    ElseIf OutlierTest(out1) = "Test 3" Or OutlierTest(out2) = "Test 3" Or OutlierTest(out3) = "Test 3" Or Refusal3 = "Yes"
Then
Test1Test3:
      If Refusal3 <> "Yes" Then
        If Depth = Analysis Then
          Outlier = ""
          Application.ScreenUpdating = True
          Call OutOp(3, R3, 4)
          Application.ScreenUpdating = False
        ElseIf Depth <> Analysis Then
          Outlier = "YesD"
        End If
      Else
        Outlier = "Yes"
      End If
      Application.ScreenUpdating = False
      If Outlier = "No" Then
        Range("C13") = "Included"
        GoTo Test1Test4
```

```
            ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
                If Outlier = "Yes" Then
                    Range("C13") = "Discarded"
                End If
'Test1 yes, Test3 yes, Test4?------
                If OutlierTest(out1) = "Test 4" Or OutlierTest(out2) = "Test 4" Or OutlierTest(out3) = "Test 4" Or Refusal4 = "Yes"
Then
                    If Refusal4 <> "Yes" Then
                        If Depth = Analysis Then
                            Outlier = ""
                            Application.ScreenUpdating = True
                            Call OutOp(4, R4, 4)
                            Application.ScreenUpdating = False
                        ElseIf Depth <> Analysis Then
                            Outlier = "YesD"
                        End If
                    Else
                        Outlier = "Yes"
                    End If
                    Application.ScreenUpdating = False
                    If Outlier = "No" Then
                        Range("C14") = "Included"
                        'outliers are 1,3 ....
                        Call Decider(mmRow, outRow, 24, col, DCP, Arow)
                    ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
                        If Outlier = "Yes" Then
                            Range("C14") = "Discarded"
                        End If
                        If Depth = Analysis Then
                            Call EndEarly("1, 3,", 4)
                            GoTo FinishEarly
                        End If
                    End If

                Else
                    'outliers are 1,3 ....
                    Call Decider(mmRow, outRow, 24, col, DCP, Arow)
                End If
            End If

'Test1 yes, Test4?------
        ElseIf OutlierTest(out1) = "Test 4" Or OutlierTest(out2) = "Test 4" Or OutlierTest(out3) = "Test 4" Or Refusal4 = "Yes"
Then
Test1Test4:
            If Refusal4 <> "Yes" Then
                If Depth = Analysis Then
                    Outlier = ""
                    Application.ScreenUpdating = True
                    Call OutOp(4, R4, 4)
                    Application.ScreenUpdating = False
                ElseIf Depth <> Analysis Then
                    Outlier = "YesD"
                End If
            Else
                Outlier = "Yes"
            End If
            Application.ScreenUpdating = False
            If Outlier = "No" Then
                Range("C14") = "Included"
                'outliers are 1 ....
                Call Decider(mmRow, outRow, 19, col, DCP, Arow)
            ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
```

```
            If Outlier = "Yes" Then
               Range("C14") = "Discarded"
            End If
            'outliers are 1,4 ....
            Call Decider(mmRow, outRow, 21, col, DCP, Arow)
         End If
'Test1 Only?------
      Else
         'outliers are 1 ....
         Call Decider(mmRow, outRow, 19, col, DCP, Arow)
      End If
   End If


'IS TEST 2 BAD??

ElseIf OutlierTest(out1) = "Test 2" Or OutlierTest(out2) = "Test 2" Or OutlierTest(out3) = "Test 2" Or Refusal2 = "Yes" Then
Test2Start:
   If OutlierTest(out1) = "Test 2" Or OutlierTest(out2) = "Test 2" Or OutlierTest(out3) = "Test 2" Or Refusal2 = "Yes" Then
   If Refusal2 <> "Yes" Then
      If Depth = Analysis Then
         Outlier = ""
         Application.ScreenUpdating = True
         Call OutOp(2, R2, 4)
         Application.ScreenUpdating = False
      ElseIf Depth <> Analysis Then
         Outlier = "YesD"
      End If
   Else
      Outlier = "Yes"
   End If
   Application.ScreenUpdating = False
   If Outlier = "No" Then
      Range("C12") = "Included"
      GoTo Test3Start
   ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
      If Outlier = "Yes" Then
         Range("C12") = "Discarded"
      End If
'Test2 yes, Test3?------
      If OutlierTest(out1) = "Test 3" Or OutlierTest(out2) = "Test 3" Or OutlierTest(out3) = "Test 3" Or Refusal3 = "Yes" Then
         If Refusal3 <> "Yes" Then
            If Depth = Analysis Then
               Outlier = ""
               Application.ScreenUpdating = True
               Call OutOp(3, R3, 4)
               Application.ScreenUpdating = False
            ElseIf Depth <> Analysis Then
               Outlier = "YesD"
            End If
         Else
            Outlier = "Yes"
         End If
         Application.ScreenUpdating = False
         If Outlier = "No" Then
            Range("C13") = "Included"
            GoTo Test2Test4
         ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
            If Outlier = "Yes" Then
               Range("C13") = "Discarded"
            End If
'Test2 yes, Test3 yes, Test4?------
```

```
        If OutlierTest(out1) = "Test 4" Or OutlierTest(out2) = "Test 4" Or OutlierTest(out3) = "Test 4" Or Refusal4 = "Yes"
Then
          If Refusal4 <> "Yes" Then
            If Depth = Analysis Then
              Outlier = ""
              Application.ScreenUpdating = True
              Call OutOp(4, R4, 4)
              Application.ScreenUpdating = False
            ElseIf Depth <> Analysis Then
              Outlier = "YesD"
            End If
          Else
            Outlier = "Yes"
          End If
          Application.ScreenUpdating = False
          If Outlier = "No" Then
            Range("C14") = "Included"
            'outliers are 2,3 ....
            Call Decider(mmRow, outRow, 27, col, DCP, Arow)
          ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
            If Outlier = "Yes" Then
              Range("C14") = "Discarded"
            End If
            If Depth = Analysis Then
              Call EndEarly("2, 3,", 4)
              GoTo FinishEarly
            End If
          End If

        Else
          'outliers are 2,3 ....
          Call Decider(mmRow, outRow, 27, col, DCP, Arow)
        End If
      End If

'Test2 yes, Test4?------
    ElseIf OutlierTest(out1) = "Test 4" Or OutlierTest(out2) = "Test 4" Or OutlierTest(out3) = "Test 4" Or Refusal4 = "Yes"
Then
Test2Test4:
      If Refusal4 <> "Yes" Then
        If Depth = Analysis Then
          Outlier = ""
          Application.ScreenUpdating = True
          Call OutOp(4, R4, 4)
          Application.ScreenUpdating = False
        ElseIf Depth <> Analysis Then
          Outlier = "YesD"
        End If
      Else
        Outlier = "Yes"
      End If
      Application.ScreenUpdating = False
      If Outlier = "No" Then
        Range("C14") = "Included"
        'outliers are 2 ....
        Call Decider(mmRow, outRow, 25, col, DCP, Arow)
      ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
        If Outlier = "Yes" Then
          Range("C14") = "Discarded"
        End If
        'outliers are 2,4 ....
        Call Decider(mmRow, outRow, 26, col, DCP, Arow)
```

```
        End If
'Test2 Only?------
      Else
        'outliers are 2 ....
        Call Decider(mmRow, outRow, 25, col, DCP, Arow)
      End If
   End If
   End If

   If Outlier = "No" Then
   GoTo Test3Start
   End If

'IS TEST 3 BAD??

ElseIf OutlierTest(out1) = "Test 3" Or OutlierTest(out2) = "Test 3" Or OutlierTest(out3) = "Test 3" Or Refusal3 = "Yes" Then
Test3Start:
   If OutlierTest(out1) = "Test 3" Or OutlierTest(out2) = "Test 3" Or OutlierTest(out3) = "Test 3" Or Refusal3 = "Yes" Then
   If Refusal3 <> "Yes" Then
      If Depth = Analysis Then
        Outlier = ""
        Application.ScreenUpdating = True
        Call OutOp(3, R3, 4)
        Application.ScreenUpdating = False
      ElseIf Depth <> Analysis Then
        Outlier = "YesD"
      End If
   Else
      Outlier = "Yes"
   End If
   Application.ScreenUpdating = False
   If Outlier = "No" Then
      Range("C13") = "Included"
      GoTo Test4Start
   ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
      If Outlier = "Yes" Then
        Range("C13") = "Discarded"
      End If
'Test3 yes, Test4?------
      If OutlierTest(out1) = "Test 4" Or OutlierTest(out2) = "Test 4" Or OutlierTest(out3) = "Test 4" Or Refusal4 = "Yes" Then
        If Refusal4 <> "Yes" Then
           If Depth = Analysis Then
              Outlier = ""
              Application.ScreenUpdating = True
              Call OutOp(4, R4, 4)
              Application.ScreenUpdating = False
           ElseIf Depth <> Analysis Then
              Outlier = "YesD"
           End If
        Else
           Outlier = "Yes"
        End If
        Application.ScreenUpdating = False
        If Outlier = "No" Then
           Range("C14") = "Included"
           'outliers are 3 ....
           Call Decider(mmRow, outRow, 23, col, DCP, Arow)
        ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
           If Outlier = "Yes" Then
              Range("C14") = "Discarded"
           End If
           'outliers are 3,4 ....
```

```
            Call Decider(mmRow, outRow, 20, col, DCP, Arow)
          End If
'Test3 Only?------
      Else
         'outliers are 3 ....
         Call Decider(mmRow, outRow, 23, col, DCP, Arow)
      End If
   End If
   End If

   If Outlier = "No" Then
   GoTo Test4Start
   End If

'IS TEST 4 BAD??

ElseIf OutlierTest(out1) = "Test 4" Or OutlierTest(out2) = "Test 4" Or OutlierTest(out3) = "Test 4" Or Refusal4 = "Yes" Then
Test4Start:
   If OutlierTest(out1) = "Test 4" Or OutlierTest(out2) = "Test 4" Or OutlierTest(out3) = "Test 4" Or Refusal4 = "Yes" Then
   If Refusal4 <> "Yes" Then
      If Depth = Analysis Then
         Outlier = ""
         Application.ScreenUpdating = True
         Call OutOp(4, R4, 4)
         Application.ScreenUpdating = False
      ElseIf Depth <> Analysis Then
         Outlier = "YesD"
      End If
   Else
      Outlier = "Yes"
   End If
   Application.ScreenUpdating = False
   If Outlier = "No" Then
      Range("C14") = "Included"
      'NO OUTLIERS ....
      Call Decider(mmRow, outRow, 17, col, DCP, Arow)
   ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
      If Outlier = "Yes" Then
         Range("C14") = "Discarded"
      End If
      'outliers are 4 ....
      Call Decider(mmRow, outRow, 18, col, DCP, Arow)
   End If
   End If

   If Outlier = "No" Then
   GoTo AllIn
   End If

Else
AllIn:
   'NO OUTLIERS ....
   Call Decider(mmRow, outRow, 17, col, DCP, Arow)

End If

FinishEarly:
End Function
```

```
Function Slope5a(out1 As String, out2 As String, out3 As String, out4 As String, Depth As Single, mmRow As Integer, Analysis As Single)
Application.ScreenUpdating = False
```

```
'Major outlier logic function for 5 DCP tests with user options

col = 17
outRow = 8
DCP = 5

If Analysis = 25 Then
   Arow = 3
ElseIf Analysis = 50 Then
   Arow = 4
ElseIf Analysis = 75 Then
   Arow = 5
ElseIf Analysis = 100 Then
   Arow = 6
ElseIf Analysis = 175 Then
   Arow = 7
End If

Dim R1 As Single, R2 As Single, R3 As Single, R4 As Single, R5 As Single
Dim R1a As String, R2a As String, R3a As String, R4a As String, R5a As String

'What are the ranges of each test if listed as outlier?
R1a = ""
R2a = ""
R3a = ""
R4a = ""
R5a = ""

Call OutRFind(5, mmRow, out1, 9, R1a, R2a, R3a, R4a, R5a)

R1 = Cells(mmRow + 8, 20)
R2 = Cells(mmRow + 8, 21)
R3 = Cells(mmRow + 8, 22)
R4 = Cells(mmRow + 8, 23)
R5 = Cells(mmRow + 8, 24)

If R1 <> 0 Then
   R1a = "No"
ElseIf R2 <> 0 Then
   R2a = "No"
ElseIf R3 <> 0 Then
   R3a = "No"
ElseIf R4 <> 0 Then
   R4a = "No"
ElseIf R5 <> 0 Then
   R5a = "No"
End If

Call OutRFind(5, mmRow, out2, 11, R1a, R2a, R3a, R4a, R5a)

R1 = Cells(mmRow + 8, 20)
R2 = Cells(mmRow + 8, 21)
R3 = Cells(mmRow + 8, 22)
R4 = Cells(mmRow + 8, 23)
R5 = Cells(mmRow + 8, 24)

If R1 <> 0 And R1a <> "No" Then
   R1a = "No"
ElseIf R2 <> 0 And R2a <> "No" Then
   R2a = "No"
ElseIf R3 <> 0 And R3a <> "No" Then
   R3a = "No"
```

```
ElseIf R4 <> 0 And R4a <> "No" Then
    R4a = "No"
ElseIf R5 <> 0 And R5a <> "No" Then
    R5a = "No"
End If

Call OutRFind(5, mmRow, out3, 13, R1a, R2a, R3a, R4a, R5a)

R1 = Cells(mmRow + 8, 20)
R2 = Cells(mmRow + 8, 21)
R3 = Cells(mmRow + 8, 22)
R4 = Cells(mmRow + 8, 23)
R5 = Cells(mmRow + 8, 24)

If R1 <> 0 And R1a <> "No" Then
    R1a = "No"
ElseIf R2 <> 0 And R2a <> "No" Then
    R2a = "No"
ElseIf R3 <> 0 And R3a <> "No" Then
    R3a = "No"
ElseIf R4 <> 0 And R4a <> "No" Then
    R4a = "No"
ElseIf R5 <> 0 And R5a <> "No" Then
    R5a = "No"
End If

Call OutRFind(5, mmRow, out4, 15, R1a, R2a, R3a, R4a, R5a)

R1 = Cells(mmRow + 8, 20) * 100
R2 = Cells(mmRow + 8, 21) * 100
R3 = Cells(mmRow + 8, 22) * 100
R4 = Cells(mmRow + 8, 23) * 100
R5 = Cells(mmRow + 8, 24) * 100

R1 = WorksheetFunction.MRound(Arg1:=R1, Arg2:=0.1)
R2 = WorksheetFunction.MRound(Arg1:=R2, Arg2:=0.1)
R3 = WorksheetFunction.MRound(Arg1:=R3, Arg2:=0.1)
R4 = WorksheetFunction.MRound(Arg1:=R4, Arg2:=0.1)
R5 = WorksheetFunction.MRound(Arg1:=R5, Arg2:=0.1)

'IS TEST 1 BAD?
If OutlierTest(out1) = "Test 1" Or OutlierTest(out2) = "Test 1" Or OutlierTest(out3) = "Test 1" Or OutlierTest(out4) = "Test 1"
Or Refusal1 = "Yes" Then
    If Refusal1 <> "Yes" Then
        If Depth = Analysis Then
            Outlier = ""
            Application.ScreenUpdating = True
            Call OutOp(1, R1, 5)
            Application.ScreenUpdating = False
        ElseIf Depth <> Analysis Then
            Outlier = "YesD"
        End If
    Else
        Outlier = "Yes"
    End If
    Application.ScreenUpdating = False
    If Outlier = "No" Then
        Range("C11") = "Included"
        GoTo Test2Start
    ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
        If Outlier = "Yes" Then
            Range("C11") = "Discarded"
```

```
        End If
'Test1 yes, Test2?------
        If OutlierTest(out1) = "Test 2" Or OutlierTest(out2) = "Test 2" Or OutlierTest(out3) = "Test 2" Or OutlierTest(out4) = "Test
2" Or Refusal2 = "Yes" Then
            If Refusal2 <> "Yes" Then
                If Depth = Analysis Then
                    Outlier = ""
                    Application.ScreenUpdating = True
                    Call OutOp(2, R2, 5)
                    Application.ScreenUpdating = False
                ElseIf Depth <> Analysis Then
                    Outlier = "YesD"
                End If
            Else
                Outlier = "Yes"
            End If
            Application.ScreenUpdating = False
            If Outlier = "No" Then
                Range("C12") = "Included"
                GoTo Test1Test3
            ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
                If Outlier = "Yes" Then
                    Range("C12") = "Discarded"
                End If
'Test1 yes, Test2 yes, Test3?------
                If OutlierTest(out1) = "Test 3" Or OutlierTest(out2) = "Test 3" Or OutlierTest(out3) = "Test 3" Or OutlierTest(out4) =
"Test 3" Or Refusal3 = "Yes" Then
                    If Refusal3 <> "Yes" Then
                        If Depth = Analysis Then
                            Outlier = ""
                            Application.ScreenUpdating = True
                            Call OutOp(3, R3, 5)
                            Application.ScreenUpdating = False
                        ElseIf Depth <> Analysis Then
                            Outlier = "YesD"
                        End If
                    Else
                        Outlier = "Yes"
                    End If
                    Application.ScreenUpdating = False
                    If Outlier = "No" Then
                        Range("C13") = "Included"
                        GoTo Test1Test2Test4
                    ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
                        If Outlier = "Yes" Then
                            Range("C13") = "Discarded"
                        End If
'Test1 yes, Test2 yes, Test3 yes, Test4?------
                        If OutlierTest(out1) = "Test 4" Or OutlierTest(out2) = "Test 4" Or OutlierTest(out3) = "Test 4" Or
OutlierTest(out4) = "Test 4" Or Refusal4 = "Yes" Then
                            If Refusal4 <> "Yes" Then
                                If Depth = Analysis Then
                                    Outlier = ""
                                    Application.ScreenUpdating = True
                                    Call OutOp(4, R4, 5)
                                    Application.ScreenUpdating = False
                                ElseIf Depth <> Analysis Then
                                    Outlier = "YesD"
                                End If
                            Else
                                Outlier = "Yes"
                            End If
```

```
                Application.ScreenUpdating = False
                If Outlier = "No" Then
                    Range("C14") = "Included"
                    GoTo Test1Test2Test3Test5
                ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
                    If Outlier = "Yes" Then
                        Range("C14") = "Discarded"
                    End If
                    If Depth = Analysis Then
                        Call EndEarly("1, 2, 3,", 4)
                        GoTo FinishEarly
                    End If
                End If

'Test1 yes, Test2 yes, Test3 yes, Test5?------
            ElseIf OutlierTest(out1) = "Test 5" Or OutlierTest(out2) = "Test 5" Or OutlierTest(out3) = "Test 5" Or
OutlierTest(out4) = "Test 5" Or Refusal5 = "Yes" Then
Test1Test2Test3Test5:
                If Refusal5 <> "Yes" Then
                    If Depth = Analysis Then
                        Outlier = ""
                        Application.ScreenUpdating = True
                        Call OutOp(5, R5, 5)
                        Application.ScreenUpdating = False
                    ElseIf Depth <> Analysis Then
                        Outlier = "YesD"
                    End If
                Else
                    Outlier = "Yes"
                End If
                Application.ScreenUpdating = False
                If Outlier = "No" Then
                    Range("C15") = "Included"
                    'outliers are 1,2,3 ....
                    Call Decider(mmRow, outRow, 31, col, DCP, Arow)
                ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
                    If Outlier = "Yes" Then
                        Range("C15") = "Discarded"
                    End If
                    If Depth = Analysis Then
                        Call EndEarly("1, 2, 3,", 5)
                        GoTo FinishEarly
                    End If
                End If

            Else
                'outliers are 1,2,3 ....
                Call Decider(mmRow, outRow, 31, col, DCP, Arow)
            End If
        End If

'Test1 yes, Test2 yes, Test4?------
    ElseIf OutlierTest(out1) = "Test 4" Or OutlierTest(out2) = "Test 4" Or OutlierTest(out3) = "Test 4" Or
OutlierTest(out4) = "Test 4" Or Refusal4 = "Yes" Then
Test1Test2Test4:
        If Refusal4 <> "Yes" Then
            If Depth = Analysis Then
                Outlier = ""
                Application.ScreenUpdating = True
                Call OutOp(4, R4, 5)
                Application.ScreenUpdating = False
            ElseIf Depth <> Analysis Then
```

```
                Outlier = "YesD"
            End If
        Else
            Outlier = "Yes"
        End If
        Application.ScreenUpdating = False
        If Outlier = "No" Then
            Range("C14") = "Included"
            GoTo Test1Test2Test5
        ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
            If Outlier = "Yes" Then
                Range("C14") = "Discarded"
            End If
'Test1 yes, Test2 yes, Test4 yes, Test5?------
            If OutlierTest(out1) = "Test 5" Or OutlierTest(out2) = "Test 5" Or OutlierTest(out3) = "Test 5" Or
OutlierTest(out4) = "Test 5" Or Refusal5 = "Yes" Then
                If Refusal5 <> "Yes" Then
                    If Depth = Analysis Then
                        Outlier = ""
                        Application.ScreenUpdating = True
                        Call OutOp(5, R5, 5)
                        Application.ScreenUpdating = False
                    ElseIf Depth <> Analysis Then
                        Outlier = "YesD"
                    End If
                Else
                    Outlier = "Yes"
                End If
                Application.ScreenUpdating = False
                If Outlier = "No" Then
                    Range("C15") = "Included"
                    'outliers are 1,2,4 ....
                    Call Decider(mmRow, outRow, 34, col, DCP, Arow)
                ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
                    If Outlier = "Yes" Then
                        Range("C15") = "Discarded"
                    End If
                    If Depth = Analysis Then
                        Call EndEarly("1, 2, 4,", 5)
                        GoTo FinishEarly
                    End If
                End If

            Else
                'outliers are 1,2,4 ....
                Call Decider(mmRow, outRow, 34, col, DCP, Arow)
            End If
        End If

'Test1 yes, Test2 yes, Test5?------
    ElseIf OutlierTest(out1) = "Test 5" Or OutlierTest(out2) = "Test 5" Or OutlierTest(out3) = "Test 5" Or
OutlierTest(out4) = "Test 5" Or Refusal5 = "Yes" Then
Test1Test2Test5:
        If Refusal5 <> "Yes" Then
            If Depth = Analysis Then
                Outlier = ""
                Application.ScreenUpdating = True
                Call OutOp(5, R5, 5)
                Application.ScreenUpdating = False
            ElseIf Depth <> Analysis Then
                Outlier = "YesD"
            End If
```

```
            Else
               Outlier = "Yes"
            End If
            Application.ScreenUpdating = False
            If Outlier = "No" Then
               Range("C15") = "Included"
               'outliers are 1,2 ....
               Call Decider(mmRow, outRow, 27, col, DCP, Arow)
            ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
               If Outlier = "Yes" Then
                  Range("C15") = "Discarded"
               End If
               'outliers are 1,2,5 ....
               Call Decider(mmRow, outRow, 30, col, DCP, Arow)
            End If

         Else
            'outliers are 1,2 ....
            Call Decider(mmRow, outRow, 27, col, DCP, Arow)
         End If

      Else
         'outliers are 1 ....
         Call Decider(mmRow, outRow, 24, col, DCP, Arow)
      End If

'Test1 yes, Test3?------
   ElseIf OutlierTest(out1) = "Test 3" Or OutlierTest(out2) = "Test 3" Or OutlierTest(out3) = "Test 3" Or OutlierTest(out4) =
"Test 3" Or Refusal3 = "Yes" Then
Test1Test3:
      If Refusal3 <> "Yes" Then
         If Depth = Analysis Then
            Outlier = ""
            Application.ScreenUpdating = True
            Call OutOp(3, R3, 5)
            Application.ScreenUpdating = False
         ElseIf Depth <> Analysis Then
            Outlier = "YesD"
         End If
      Else
         Outlier = "Yes"
      End If
      Application.ScreenUpdating = False
      If Outlier = "No" Then
         Range("C13") = "Included"
         GoTo Test1Test4
      ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
         If Outlier = "Yes" Then
            Range("C13") = "Discarded"
         End If
'Test1 yes, Test3 yes, Test4?------
         If OutlierTest(out1) = "Test 4" Or OutlierTest(out2) = "Test 4" Or OutlierTest(out3) = "Test 4" Or OutlierTest(out4) =
"Test 4" Or Refusal4 = "Yes" Then
            If Refusal4 <> "Yes" Then
               If Depth = Analysis Then
                  Outlier = ""
                  Application.ScreenUpdating = True
                  Call OutOp(4, R4, 5)
                  Application.ScreenUpdating = False
               ElseIf Depth <> Analysis Then
                  Outlier = "YesD"
               End If
```

```
            Else
               Outlier = "Yes"
            End If
            Application.ScreenUpdating = False
            If Outlier = "No" Then
               Range("C14") = "Included"
               GoTo Test1Test3Test5
            ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
               If Outlier = "Yes" Then
                  Range("C14") = "Discarded"
               End If
'Test1 yes, Test3 yes, Test4 yes, Test5?------
               If OutlierTest(out1) = "Test 5" Or OutlierTest(out2) = "Test 5" Or OutlierTest(out3) = "Test 5" Or
OutlierTest(out4) = "Test 5" Or Refusal5 = "Yes" Then
                  If Refusal5 <> "Yes" Then
                     If Depth = Analysis Then
                        Outlier = ""
                        Application.ScreenUpdating = True
                        Call OutOp(5, R5, 5)
                        Application.ScreenUpdating = False
                     ElseIf Depth <> Analysis Then
                        Outlier = "YesD"
                     End If
                  Else
                     Outlier = "Yes"
                  End If
                  Application.ScreenUpdating = False
                  If Outlier = "No" Then
                     Range("C15") = "Included"
                     'outliers are 1,3,4 ....
                     Call Decider(mmRow, outRow, 43, col, DCP, Arow)
                  ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
                     If Outlier = "Yes" Then
                        Range("C15") = "Discarded"
                     End If
                     If Depth = Analysis Then
                        Call EndEarly("1, 3, 4,", 5)
                        GoTo FinishEarly
                     End If
                  End If

               Else
                  'outliers are 1,3,4 ....
                  Call Decider(mmRow, outRow, 43, col, DCP, Arow)
               End If
            End If

'Test1 yes, Test3 yes, Test5?------
         ElseIf OutlierTest(out1) = "Test 5" Or OutlierTest(out2) = "Test 5" Or OutlierTest(out3) = "Test 5" Or
OutlierTest(out4) = "Test 5" Or Refusal5 = "Yes" Then
Test1Test3Test5:
            If Refusal5 <> "Yes" Then
               If Depth = Analysis Then
                  Outlier = ""
                  Application.ScreenUpdating = True
                  Call OutOp(5, R5, 5)
                  Application.ScreenUpdating = False
               ElseIf Depth <> Analysis Then
                  Outlier = "YesD"
               End If
            Else
               Outlier = "Yes"
```

```
            End If
            Application.ScreenUpdating = False
            If Outlier = "No" Then
               Range("C15") = "Included"
               'outliers are 1,3 ....
               Call Decider(mmRow, outRow, 37, col, DCP, Arow)
            ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
               If Outlier = "Yes" Then
                  Range("C15") = "Discarded"
               End If
               'outliers are 1,3,5 ....
               Call Decider(mmRow, outRow, 38, col, DCP, Arow)
            End If

         Else
            'outliers are 1,3 ....
            Call Decider(mmRow, outRow, 37, col, DCP, Arow)
         End If
      End If

'Test1 yes, Test4?------
   ElseIf OutlierTest(out1) = "Test 4" Or OutlierTest(out2) = "Test 4" Or OutlierTest(out3) = "Test 4" Or OutlierTest(out4) =
"Test 4" Or Refusal4 = "Yes" Then
Test1Test4:
      If Refusal4 <> "Yes" Then
         If Depth = Analysis Then
            Outlier = ""
            Application.ScreenUpdating = True
            Call OutOp(4, R4, 5)
            Application.ScreenUpdating = False
         ElseIf Depth <> Analysis Then
            Outlier = "YesD"
         End If
      Else
         Outlier = "Yes"
      End If
      Application.ScreenUpdating = False
      If Outlier = "No" Then
         Range("C14") = "Included"
         GoTo Test1Test5
      ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
         If Outlier = "Yes" Then
            Range("C14") = "Discarded"
         End If
'Test1 yes, Test4 yes, Test5?------
         If OutlierTest(out1) = "Test 5" Or OutlierTest(out2) = "Test 5" Or OutlierTest(out3) = "Test 5" Or OutlierTest(out4) =
"Test 5" Or Refusal5 = "Yes" Then
            If Refusal5 <> "Yes" Then
               If Depth = Analysis Then
                  Outlier = ""
                  Application.ScreenUpdating = True
                  Call OutOp(5, R5, 5)
                  Application.ScreenUpdating = False
               ElseIf Depth <> Analysis Then
                  Outlier = "YesD"
               End If
            Else
               Outlier = "Yes"
            End If
            Application.ScreenUpdating = False
            If Outlier = "No" Then
               Range("C15") = "Included"
```

```
                'outliers are 1,4 ....
                Call Decider(mmRow, outRow, 33, col, DCP, Arow)
            ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
                If Outlier = "Yes" Then
                    Range("C15") = "Discarded"
                End If
                'outliers are 1,4,5 ....
                Call Decider(mmRow, outRow, 29, col, DCP, Arow)
            End If

        Else
            'outliers are 1,4 ....
            Call Decider(mmRow, outRow, 33, col, DCP, Arow)
        End If
    End If

'Test1 yes, Test5?------
    ElseIf OutlierTest(out1) = "Test 5" Or OutlierTest(out2) = "Test 5" Or OutlierTest(out3) = "Test 5" Or OutlierTest(out4) =
"Test 5" Or Refusal5 = "Yes" Then
Test1Test5:
        If Refusal5 <> "Yes" Then
            If Depth = Analysis Then
                Outlier = ""
                Application.ScreenUpdating = True
                Call OutOp(5, R5, 5)
                Application.ScreenUpdating = False
            ElseIf Depth <> Analysis Then
                Outlier = "YesD"
            End If
        Else
            Outlier = "Yes"
        End If
        Application.ScreenUpdating = False
        If Outlier = "No" Then
            Range("C15") = "Included"
            'outliers are 1 ....
            Call Decider(mmRow, outRow, 24, col, DCP, Arow)
        ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
            If Outlier = "Yes" Then
                Range("C15") = "Discarded"
            End If
            'outliers are 1,5 ....
            Call Decider(mmRow, outRow, 26, col, DCP, Arow)
        End If
'Test1 Only?------
    Else
        'outliers are 1 ....
        Call Decider(mmRow, outRow, 24, col, DCP, Arow)
    End If
  End If

'IS TEST 2 BAD??

ElseIf OutlierTest(out1) = "Test 2" Or OutlierTest(out2) = "Test 2" Or OutlierTest(out3) = "Test 2" Or OutlierTest(out4) = "Test
2" Or Refusal2 = "Yes" Then
Test2Start:
  If OutlierTest(out1) = "Test 2" Or OutlierTest(out2) = "Test 2" Or OutlierTest(out3) = "Test 2" Or OutlierTest(out4) = "Test 2"
Or Refusal2 = "Yes" Then
  If Refusal2 <> "Yes" Then
    If Depth = Analysis Then
        Outlier = ""
        Application.ScreenUpdating = True
```

```
            Call OutOp(2, R2, 5)
            Application.ScreenUpdating = False
        ElseIf Depth <> Analysis Then
            Outlier = "YesD"
        End If
    Else
        Outlier = "Yes"
    End If
    Application.ScreenUpdating = False
    If Outlier = "No" Then
        Range("C12") = "Included"
        GoTo Test3Start
    ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
        If Outlier = "Yes" Then
            Range("C12") = "Discarded"
        End If
'Test2 yes, Test3?------
        If OutlierTest(out1) = "Test 3" Or OutlierTest(out2) = "Test 3" Or OutlierTest(out3) = "Test 3" Or OutlierTest(out4) = "Test
3" Or Refusal3 = "Yes" Then
            If Refusal3 <> "Yes" Then
                If Depth = Analysis Then
                    Outlier = ""
                    Application.ScreenUpdating = True
                    Call OutOp(3, R3, 5)
                    Application.ScreenUpdating = False
                ElseIf Depth <> Analysis Then
                    Outlier = "YesD"
                End If
            Else
                Outlier = "Yes"
            End If
            Application.ScreenUpdating = False
            If Outlier = "No" Then
                Range("C13") = "Included"
                GoTo Test2Test4
            ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
                If Outlier = "Yes" Then
                    Range("C13") = "Discarded"
                End If
'Test2 yes, Test3 yes, Test4?------
                If OutlierTest(out1) = "Test 4" Or OutlierTest(out2) = "Test 4" Or OutlierTest(out3) = "Test 4" Or OutlierTest(out4) =
"Test 4" Or Refusal4 = "Yes" Then
                    If Refusal4 <> "Yes" Then
                        If Depth = Analysis Then
                            Outlier = ""
                            Application.ScreenUpdating = True
                            Call OutOp(4, R4, 5)
                            Application.ScreenUpdating = False
                        ElseIf Depth <> Analysis Then
                            Outlier = "YesD"
                        End If
                    Else
                        Outlier = "Yes"
                    End If
                    Application.ScreenUpdating = False
                    If Outlier = "No" Then
                        Range("C14") = "Included"
                        GoTo Test2Test3Test5
                    ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
                        If Outlier = "Yes" Then
                            Range("C14") = "Discarded"
                        End If
```

```
'Test2 yes, Test3 yes, Test4 yes, Test5?------
            If OutlierTest(out1) = "Test 5" Or OutlierTest(out2) = "Test 5" Or OutlierTest(out3) = "Test 5" Or
OutlierTest(out4) = "Test 5" Or Refusal5 = "Yes" Then
              If Refusal5 <> "Yes" Then
                If Depth = Analysis Then
                  Outlier = ""
                  Application.ScreenUpdating = True
                  Call OutOp(5, R5, 5)
                  Application.ScreenUpdating = False
                ElseIf Depth <> Analysis Then
                  Outlier = "YesD"
                End If
              Else
                Outlier = "Yes"
              End If
              Application.ScreenUpdating = False
              If Outlier = "No" Then
                Range("C15") = "Included"
                'outliers are 2,3,4 ....
                Call Decider(mmRow, outRow, 47, col, DCP, Arow)
              ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
                If Outlier = "Yes" Then
                  Range("C15") = "Discarded"
                End If
                If Depth = Analysis Then
                  Call EndEarly("2, 3, 4,", 5)
                  GoTo FinishEarly
                End If
              End If

            Else
              'outliers are 2,3,4 ....
              Call Decider(mmRow, outRow, 47, col, DCP, Arow)
            End If
          End If

'Test2 yes, Test3 yes, Test5?------
        ElseIf OutlierTest(out1) = "Test 5" Or OutlierTest(out2) = "Test 5" Or OutlierTest(out3) = "Test 5" Or
OutlierTest(out4) = "Test 5" Or Refusal5 = "Yes" Then
Test2Test3Test5:
          If Refusal5 <> "Yes" Then
            If Depth = Analysis Then
              Outlier = ""
              Application.ScreenUpdating = True
              Call OutOp(5, R5, 5)
              Application.ScreenUpdating = False
            ElseIf Depth <> Analysis Then
              Outlier = "YesD"
            End If
          Else
            Outlier = "Yes"
          End If
          Application.ScreenUpdating = False
          If Outlier = "No" Then
            Range("C15") = "Included"
            'outliers are 2,3 ....
            Call Decider(mmRow, outRow, 45, col, DCP, Arow)
          ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
            If Outlier = "Yes" Then
              Range("C15") = "Discarded"
            End If
            'outliers are 2,3,5 ....
```

```
            Call Decider(mmRow, outRow, 46, col, DCP, Arow)
          End If

        Else
          'outliers are 2,3 ....
          Call Decider(mmRow, outRow, 45, col, DCP, Arow)
        End If
      End If

'Test2 yes, Test4?------
    ElseIf OutlierTest(out1) = "Test 4" Or OutlierTest(out2) = "Test 4" Or OutlierTest(out3) = "Test 4" Or OutlierTest(out4) =
"Test 4" Or Refusal4 = "Yes" Then
Test2Test4:
      If Refusal4 <> "Yes" Then
        If Depth = Analysis Then
          Outlier = ""
          Application.ScreenUpdating = True
          Call OutOp(4, R4, 5)
          Application.ScreenUpdating = False
        ElseIf Depth <> Analysis Then
          Outlier = "YesD"
        End If
      Else
        Outlier = "Yes"
      End If
      Application.ScreenUpdating = False
      If Outlier = "No" Then
        Range("C14") = "Included"
        GoTo Test2Test5
      ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
        If Outlier = "Yes" Then
          Range("C14") = "Discarded"
        End If
'Test2 yes, Test4 yes, Test5?------
        If OutlierTest(out1) = "Test 5" Or OutlierTest(out2) = "Test 5" Or OutlierTest(out3) = "Test 5" Or OutlierTest(out4) =
"Test 5" Or Refusal5 = "Yes" Then
          If Refusal5 <> "Yes" Then
            If Depth = Analysis Then
              Outlier = ""
              Application.ScreenUpdating = True
              Call OutOp(5, R5, 5)
              Application.ScreenUpdating = False
            ElseIf Depth <> Analysis Then
              Outlier = "YesD"
            End If
          Else
            Outlier = "Yes"
          End If
          Application.ScreenUpdating = False
          If Outlier = "No" Then
            Range("C15") = "Included"
            'outliers are 2,4 ....
            Call Decider(mmRow, outRow, 44, col, DCP, Arow)
          ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
            If Outlier = "Yes" Then
              Range("C15") = "Discarded"
            End If
            'outliers are 2,4,5 ....
            Call Decider(mmRow, outRow, 41, col, DCP, Arow)
          End If

        Else
```

```
            'outliers are 2,4 ....
            Call Decider(mmRow, outRow, 44, col, DCP, Arow)
          End If
        End If

'Test2 yes, Test5?------
      ElseIf OutlierTest(out1) = "Test 5" Or OutlierTest(out2) = "Test 5" Or OutlierTest(out3) = "Test 5" Or OutlierTest(out4) =
"Test 5" Or Refusal5 = "Yes" Then
Test2Test5:
        If Refusal5 <> "Yes" Then
          If Depth = Analysis Then
            Outlier = ""
            Application.ScreenUpdating = True
            Call OutOp(5, R5, 5)
            Application.ScreenUpdating = False
          ElseIf Depth <> Analysis Then
            Outlier = "YesD"
          End If
        Else
          Outlier = "Yes"
        End If
        Application.ScreenUpdating = False
        If Outlier = "No" Then
          Range("C15") = "Included"
          'outliers are 2 ....
          Call Decider(mmRow, outRow, 39, col, DCP, Arow)
        ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
          If Outlier = "Yes" Then
            Range("C15") = "Discarded"
          End If
          'outliers are 2,5 ....
          Call Decider(mmRow, outRow, 40, col, DCP, Arow)
        End If
'Test2 Only?------
      Else
        'outliers are 2 ....
        Call Decider(mmRow, outRow, 39, col, DCP, Arow)
      End If
  End If
  End If

  If Outlier = "No" Then
  GoTo Test3Start
  End If

'IS TEST 3 BAD??

ElseIf OutlierTest(out1) = "Test 3" Or OutlierTest(out2) = "Test 3" Or OutlierTest(out3) = "Test 3" Or OutlierTest(out4) = "Test
3" Or Refusal3 = "Yes" Then
Test3Start:
  If OutlierTest(out1) = "Test 3" Or OutlierTest(out2) = "Test 3" Or OutlierTest(out3) = "Test 3" Or OutlierTest(out4) = "Test 3"
Or Refusal3 = "Yes" Then
  If Refusal3 <> "Yes" Then
      If Depth = Analysis Then
        Outlier = ""
        Application.ScreenUpdating = True
        Call OutOp(3, R3, 5)
        Application.ScreenUpdating = False
      ElseIf Depth <> Analysis Then
        Outlier = "YesD"
      End If
  Else
```

```
      Outlier = "Yes"
   End If
   Application.ScreenUpdating = False
   If Outlier = "No" Then
      Range("C13") = "Included"
      GoTo Test4Start
   ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
      If Outlier = "Yes" Then
         Range("C13") = "Discarded"
      End If
'Test3 yes, Test4?------
      If OutlierTest(out1) = "Test 4" Or OutlierTest(out2) = "Test 4" Or OutlierTest(out3) = "Test 4" Or OutlierTest(out4) = "Test
4" Or Refusal4 = "Yes" Then
         If Refusal4 <> "Yes" Then
            If Depth = Analysis Then
               Outlier = ""
               Application.ScreenUpdating = True
               Call OutOp(4, R4, 5)
               Application.ScreenUpdating = False
            ElseIf Depth <> Analysis Then
               Outlier = "YesD"
            End If
         Else
            Outlier = "Yes"
         End If
         If Depth = Analysis Then
            Outlier = ""
            Application.ScreenUpdating = True
            Call OutOp(4, R4, 5)
         ElseIf Depth <> Analysis Then
            Outlier = "YesD"
         End If
         Application.ScreenUpdating = False
         If Outlier = "No" Then
            Range("C14") = "Included"
            GoTo Test3Test5
         ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
            If Outlier = "Yes" Then
               Range("C14") = "Discarded"
            End If
'Test3 yes, Test4 yes, Test5?------
            If OutlierTest(out1) = "Test 5" Or OutlierTest(out2) = "Test 5" Or OutlierTest(out3) = "Test 5" Or OutlierTest(out4) =
"Test 5" Or Refusal5 = "Yes" Then
               If Refusal5 <> "Yes" Then
                  If Depth = Analysis Then
                     Outlier = ""
                     Application.ScreenUpdating = True
                     Call OutOp(5, R5, 5)
                     Application.ScreenUpdating = False
                  ElseIf Depth <> Analysis Then
                     Outlier = "YesD"
                  End If
               Else
                  Outlier = "Yes"
               End If
               Application.ScreenUpdating = False
               If Outlier = "No" Then
                  Range("C15") = "Included"
                  'outliers are 3,4 ....
                  Call Decider(mmRow, outRow, 42, col, DCP, Arow)
               ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
                  If Outlier = "Yes" Then
```

```
            Range("C15") = "Discarded"
          End If
          'outliers are 3,4,5 ....
          Call Decider(mmRow, outRow, 28, col, DCP, Arow)
        End If

      Else
        'outliers are 3,4 ....
        Call Decider(mmRow, outRow, 42, col, DCP, Arow)
      End If
    End If

'Test3 yes, Test5?------
  ElseIf OutlierTest(out1) = "Test 5" Or OutlierTest(out2) = "Test 5" Or OutlierTest(out3) = "Test 5" Or OutlierTest(out4) =
"Test 5" Or Refusal5 = "Yes" Then
Test3Test5:
    If Refusal5 <> "Yes" Then
      If Depth = Analysis Then
        Outlier = ""
        Application.ScreenUpdating = True
        Call OutOp(5, R5, 5)
        Application.ScreenUpdating = False
      ElseIf Depth <> Analysis Then
        Outlier = "YesD"
      End If
    Else
      Outlier = "Yes"
    End If
    Application.ScreenUpdating = False
    If Outlier = "No" Then
      Range("C15") = "Included"
      'outliers are 3 ....
      Call Decider(mmRow, outRow, 35, col, DCP, Arow)
    ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
      If Outlier = "Yes" Then
        Range("C15") = "Discarded"
      End If
      'outliers are 3,5 ....
      Call Decider(mmRow, outRow, 36, col, DCP, Arow)
    End If
'Test3 Only?------
  Else
    'outliers are 3 ....
    Call Decider(mmRow, outRow, 35, col, DCP, Arow)
  End If
 End If
 End If

 If Outlier = "No" Then
 GoTo Test4Start
 End If

'IS TEST 4 BAD??

ElseIf OutlierTest(out1) = "Test 4" Or OutlierTest(out2) = "Test 4" Or OutlierTest(out3) = "Test 4" Or OutlierTest(out4) = "Test
4" Or Refusal4 = "Yes" Then
Test4Start:
 If OutlierTest(out1) = "Test 4" Or OutlierTest(out2) = "Test 4" Or OutlierTest(out3) = "Test 4" Or OutlierTest(out4) = "Test 4"
Or Refusal4 = "Yes" Then
 If Refusal4 <> "Yes" Then
  If Depth = Analysis Then
    Outlier = ""
```

```
            Application.ScreenUpdating = True
            Call OutOp(4, R4, 5)
            Application.ScreenUpdating = False
        ElseIf Depth <> Analysis Then
            Outlier = "YesD"
        End If
    Else
        Outlier = "Yes"
    End If
    Application.ScreenUpdating = False
    If Outlier = "No" Then
        Range("C14") = "Included"
        GoTo Test5Start
    ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
        If Outlier = "Yes" Then
            Range("C14") = "Discarded"
        End If
'Test4 yes, Test5?------
        If OutlierTest(out1) = "Test 5" Or OutlierTest(out2) = "Test 5" Or OutlierTest(out3) = "Test 5" Or OutlierTest(out4) = "Test
5" Or Refusal5 = "Yes" Then
            If Refusal5 <> "Yes" Then
                If Depth = Analysis Then
                    Outlier = ""
                    Application.ScreenUpdating = True
                    Call OutOp(5, R5, 5)
                    Application.ScreenUpdating = False
                ElseIf Depth <> Analysis Then
                    Outlier = "YesD"
                End If
            Else
                Outlier = "Yes"
            End If
            Application.ScreenUpdating = False
            If Outlier = "No" Then
                Range("C15") = "Included"
                'outliers are 4 ....
                Call Decider(mmRow, outRow, 32, col, DCP, Arow)
            ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
                If Outlier = "Yes" Then
                    Range("C15") = "Discarded"
                End If
                'outliers are 4,5 ....
                Call Decider(mmRow, outRow, 25, col, DCP, Arow)
            End If
'Test4 Only?------
        Else
            'outliers are 4 ....
            Call Decider(mmRow, outRow, 32, col, DCP, Arow)
        End If
    End If
    End If

    If Outlier = "No" Then
    GoTo Test5Start
    End If

'IS TEST 5 BAD??

ElseIf OutlierTest(out1) = "Test 5" Or OutlierTest(out2) = "Test 5" Or OutlierTest(out3) = "Test 5" Or OutlierTest(out4) = "Test
5" Or Refusal5 = "Yes" Then
Test5Start:
```

```
   If OutlierTest(out1) = "Test 5" Or OutlierTest(out2) = "Test 5" Or OutlierTest(out3) = "Test 5" Or OutlierTest(out4) = "Test 5"
Or Refusal5 = "Yes" Then
   If Refusal5 <> "Yes" Then
      If Depth = Analysis Then
         Outlier = ""
         Application.ScreenUpdating = True
         Call OutOp(5, R5, 5)
         Application.ScreenUpdating = False
      ElseIf Depth <> Analysis Then
         Outlier = "YesD"
      End If
   Else
      Outlier = "Yes"
   End If
   Application.ScreenUpdating = False
   If Outlier = "No" Then
      Range("C15") = "Included"
      'NO OUTLIERS ....
      Call Decider(mmRow, outRow, 22, col, DCP, Arow)
   ElseIf Outlier = "Yes" Or Outlier = "YesD" Then
      If Outlier = "Yes" Then
         Range("C15") = "Discarded"
      End If
      'outliers are 5 ....
      Call Decider(mmRow, outRow, 23, col, DCP, Arow)
   End If
   End If

   If Outlier = "No" Then
   GoTo AllIn
   End If

Else
AllIn:
   'NO OUTLIERS ....
   Call Decider(mmRow, outRow, 22, col, DCP, Arow)

End If

FinishEarly:
End Function
```

```
Function IDOp3(DCP, Analysis)
Application.ScreenUpdating = False
'Prepare the found/chosen outlier ranges for results output for 3 Tests

If Analysis = 25 Then
   Row = 1
ElseIf Analysis = 50 Then
   Row = 2
ElseIf Analysis = 75 Then
   Row = 3
ElseIf Analysis = 100 Then
   Row = 4
ElseIf Analysis = 175 Then
   Row = 5
End If

Sheets("Outlier3").Activate
Range("D11") = Row
Range("D12") = Row
Range("D13") = Row
```

```
If Row = 1 Then
    Range("f11") = "=Index(J11:K15,D11,Match(E11, L11:M11, 0))"
    Range("f12") = "=Index(J11:K15,D12,Match(E12, L11:M11, 0))"
    Range("f13") = "=Index(J11:K15,D13,Match(E13, L11:M11, 0))"
ElseIf Row = 2 Then
    Range("f11") = "=Index(J11:K15,D11,Match(E11, L12:M12, 0))"
    Range("f12") = "=Index(J11:K15,D12,Match(E12, L12:M12, 0))"
    Range("f13") = "=Index(J11:K15,D13,Match(E13, L12:M12, 0))"
ElseIf Row = 3 Then
    Range("f11") = "=Index(J11:K15,D11,Match(E11, L13:M13, 0))"
    Range("f12") = "=Index(J11:K15,D12,Match(E12, L13:M13, 0))"
    Range("f13") = "=Index(J11:K15,D13,Match(E13, L13:M13, 0))"
ElseIf Row = 4 Then
    Range("f11") = "=Index(J11:K15,D11,Match(E11, L14:M14, 0))"
    Range("f12") = "=Index(J11:K15,D12,Match(E12, L14:M14, 0))"
    Range("f13") = "=Index(J11:K15,D13,Match(E13, L14:M14, 0))"
ElseIf Row = 5 Then
    Range("f11") = "=Index(J11:K15,D11,Match(E11, L15:M15, 0))"
    Range("f12") = "=Index(J11:K15,D12,Match(E12, L15:M15, 0))"
    Range("f13") = "=Index(J11:K15,D13,Match(E13, L15:M15, 0))"
End If

End Function
```

```
Function IDOp4(DCP, Analysis)
Application.ScreenUpdating = False
'Prepare the found/chosen outlier ranges for results output for 4 Tests

If Analysis = 25 Then
    Row = 1
ElseIf Analysis = 50 Then
    Row = 2
ElseIf Analysis = 75 Then
    Row = 3
ElseIf Analysis = 100 Then
    Row = 4
ElseIf Analysis = 175 Then
    Row = 5
End If

Sheets("Outlier4").Activate
Range("D11") = Row
Range("D12") = Row
Range("D13") = Row
Range("D14") = Row

If Row = 1 Then
    Range("f11") = "=Index(J11:L15,D11,Match(E11, M11:O11, 0))"
    Range("f12") = "=Index(J11:L15,D12,Match(E12, M11:O11, 0))"
    Range("f13") = "=Index(J11:L15,D13,Match(E13, M11:O11, 0))"
    Range("f14") = "=Index(J11:L15,D14,Match(E14, M11:O11, 0))"
ElseIf Row = 2 Then
    Range("f11") = "=Index(J11:L15,D11,Match(E11, M12:O12, 0))"
    Range("f12") = "=Index(J11:L15,D12,Match(E12, M12:O12, 0))"
    Range("f13") = "=Index(J11:L15,D13,Match(E13, M12:O12, 0))"
    Range("f14") = "=Index(J11:L15,D14,Match(E14, M12:O12, 0))"
ElseIf Row = 3 Then
    Range("f11") = "=Index(J11:L15,D11,Match(E11, M13:O13, 0))"
    Range("f12") = "=Index(J11:L15,D12,Match(E12, M13:O13, 0))"
    Range("f13") = "=Index(J11:L15,D13,Match(E13, M13:O13, 0))"
    Range("f14") = "=Index(J11:L15,D14,Match(E14, M13:O13, 0))"
```

```
ElseIf Row = 4 Then
    Range("f11") = "=Index(J11:L15,D11,Match(E11, M14:O14, 0))"
    Range("f12") = "=Index(J11:L15,D12,Match(E12, M14:O14, 0))"
    Range("f13") = "=Index(J11:L15,D13,Match(E13, M14:O14, 0))"
    Range("f14") = "=Index(J11:L15,D14,Match(E14, M14:O14, 0))"
ElseIf Row = 5 Then
    Range("f11") = "=Index(J11:L15,D11,Match(E11, M15:O15, 0))"
    Range("f12") = "=Index(J11:L15,D12,Match(E12, M15:O15, 0))"
    Range("f13") = "=Index(J11:L15,D13,Match(E13, M15:O15, 0))"
    Range("f14") = "=Index(J11:L15,D14,Match(E14, M15:O15, 0))"
End If

End Function
```

```
Function IDOp5(DCP, Analysis)
Application.ScreenUpdating = False
'Prepare the found/chosen outlier ranges for results output for 5 Tests

If Analysis = 25 Then
    Row = 1
ElseIf Analysis = 50 Then
    Row = 2
ElseIf Analysis = 75 Then
    Row = 3
ElseIf Analysis = 100 Then
    Row = 4
ElseIf Analysis = 175 Then
    Row = 5
End If

Sheets("Outlier5").Activate
Range("D11") = Row
Range("D12") = Row
Range("D13") = Row
Range("D14") = Row
Range("D15") = Row

If Row = 1 Then
    Range("f11") = "=Index(J11:M15,D11,Match(E11, N11:Q11, 0))"
    Range("f12") = "=Index(J11:M15,D12,Match(E12, N11:Q11, 0))"
    Range("f13") = "=Index(J11:M15,D13,Match(E13, N11:Q11, 0))"
    Range("f14") = "=Index(J11:M15,D14,Match(E14, N11:Q11, 0))"
    Range("f15") = "=Index(J11:M15,D15,Match(E15, N11:Q11, 0))"
ElseIf Row = 2 Then
    Range("f11") = "=Index(J11:M15,D11,Match(E11, N12:Q12, 0))"
    Range("f12") = "=Index(J11:M15,D12,Match(E12, N12:Q12, 0))"
    Range("f13") = "=Index(J11:M15,D13,Match(E13, N12:Q12, 0))"
    Range("f14") = "=Index(J11:M15,D14,Match(E14, N12:Q12, 0))"
    Range("f15") = "=Index(J11:M15,D15,Match(E15, N12:Q12, 0))"
ElseIf Row = 3 Then
    Range("f11") = "=Index(J11:M15,D11,Match(E11, N13:Q13, 0))"
    Range("f12") = "=Index(J11:M15,D12,Match(E12, N13:Q13, 0))"
    Range("f13") = "=Index(J11:M15,D13,Match(E13, N13:Q13, 0))"
    Range("f14") = "=Index(J11:M15,D14,Match(E14, N13:Q13, 0))"
    Range("f15") = "=Index(J11:M15,D15,Match(E15, N13:Q13, 0))"
ElseIf Row = 4 Then
    Range("f11") = "=Index(J11:M15,D11,Match(E11, N14:Q14, 0))"
    Range("f12") = "=Index(J11:M15,D12,Match(E12, N14:Q14, 0))"
    Range("f13") = "=Index(J11:M15,D13,Match(E13, N14:Q14, 0))"
    Range("f14") = "=Index(J11:M15,D14,Match(E14, N14:Q14, 0))"
    Range("f15") = "=Index(J11:M15,D15,Match(E15, N14:Q14, 0))"
ElseIf Row = 5 Then
```

```
   Range("f11") = "=Index(J11:M15,D11,Match(E11, N15:Q15, 0))"
   Range("f12") = "=Index(J11:M15,D12,Match(E12, N15:Q15, 0))"
   Range("f13") = "=Index(J11:M15,D13,Match(E13, N15:Q15, 0))"
   Range("f14") = "=Index(J11:M15,D14,Match(E14, N15:Q15, 0))"
   Range("f15") = "=Index(J11:M15,D15,Match(E15, N15:Q15, 0))"
End If

End Function
```

```
Function OutlierResults3(DCP)
Application.ScreenUpdating = False
'Take the user options for outliers as priority over the inclusion
'or discardance of outliers purely from the calculations for
'the first 3 tests... if more than 3 tests used, those are done on
'the main body code

Test1 = Range("g11")
Test2 = Range("g12")
Test3 = Range("g13")

If DCP = 3 Then
   If Range("C11") <> "" Then
      If Range("C12") = "" Then
         Op1 = Range("C11")
      ElseIf Range("C13") = "" Then
         Op1 = Range("C11")
      End If
   Else
      Op1 = Range("B11")
   End If
   If Range("C12") <> "" Then
      If Range("C11") = "" Then
         Op2 = Range("C12")
      ElseIf Range("C13") = "" Then
         Op2 = Range("C12")
      End If
   Else
      Op2 = Range("B12")
   End If
   If Range("C13") <> "" Then
      If Range("C11") = "" Then
         Op3 = Range("C13")
      ElseIf Range("C12") = "" Then
         Op3 = Range("C13")
      End If
   Else
      Op3 = Range("B13")
   End If

ElseIf DCP = 4 Then
   If Range("C11") <> "" Then
      If Range("C12") = "" Then
         Op1 = Range("C11")
      ElseIf Range("C13") = "" Then
         Op1 = Range("C11")
      ElseIf Range("C14") = "" Then
         Op1 = Range("C11")
      End If
   Else
      Op1 = Range("B11")
   End If
   If Range("C12") <> "" Then
```

```
      If Range("C11") = "" Then
        Op2 = Range("C12")
      ElseIf Range("C13") = "" Then
        Op2 = Range("C12")
      ElseIf Range("C14") = "" Then
        Op2 = Range("C12")
      End If
    Else
      Op2 = Range("B12")
    End If
    If Range("C13") <> "" Then
      If Range("C11") = "" Then
        Op3 = Range("C13")
      ElseIf Range("C12") = "" Then
        Op3 = Range("C13")
      ElseIf Range("C14") = "" Then
        Op3 = Range("C13")
      End If
    Else
      Op3 = Range("B13")
    End If

  ElseIf DCP = 5 Then
    If Range("C11") <> "" Then
      If Range("C12") = "" Then
        Op1 = Range("C11")
      ElseIf Range("C13") = "" Then
        Op1 = Range("C11")
      ElseIf Range("C14") = "" Then
        Op1 = Range("C11")
      ElseIf Range("C15") = "" Then
        Op1 = Range("C11")
      End If
    Else
      Op1 = Range("B11")
    End If
    If Range("C12") <> "" Then
      If Range("C11") = "" Then
        Op2 = Range("C12")
      ElseIf Range("C13") = "" Then
        Op2 = Range("C12")
      ElseIf Range("C14") = "" Then
        Op2 = Range("C12")
      ElseIf Range("C15") = "" Then
        Op2 = Range("C12")
      End If
    Else
      Op2 = Range("B12")
    End If
    If Range("C13") <> "" Then
      If Range("C11") = "" Then
        Op3 = Range("C13")
      ElseIf Range("C12") = "" Then
        Op3 = Range("C13")
      ElseIf Range("C14") = "" Then
        Op3 = Range("C13")
      ElseIf Range("C15") = "" Then
        Op3 = Range("C13")
      End If
    Else
      Op3 = Range("B13")
    End If
```

```
End If

'Output these three here in the function
Application.Goto Reference:="Range1"
ActiveCell = Test1
Application.Goto Reference:="Range2"
ActiveCell = Test2
Application.Goto Reference:="Range3"
ActiveCell = Test3
Application.Goto Reference:="IncDisc1"
ActiveCell = Op1
Application.Goto Reference:="IncDisc2"
ActiveCell = Op2
Application.Goto Reference:="IncDisc3"
ActiveCell = Op3

End Function
```

```
Function OutlierTest(mm) As String
Application.ScreenUpdating = False
'This actually checks for matching outlier test names from the sheet

If mm = "Test 1" Then
   Result = "Test 1"
ElseIf mm = "Test 2" Then
   Result = "Test 2"
ElseIf mm = "Test 3" Then
   Result = "Test 3"
ElseIf mm = "Test 4" Then
   Result = "Test 4"
ElseIf mm = "Test 5" Then
   Result = "Test 5"
ElseIf mm = "None" Then
   Result = "None"
Else
   Result = "Error"
End If

OutlierTest = Result

End Function
```

```
Function GraphDataFill(Finish) As Single
Application.ScreenUpdating = False
'The depth and blowcount values found at every 5 mm are organized
'so the premade graphs can pull the information

Worksheets("Graph").Activate

Range("B10:D10").Select
Selection.Copy
   For i = 11 To Finish
      Cells(i, 2).Select
      ActiveSheet.Paste
   Next i

Range("J10:M10").Select
Selection.Copy
   For i = 11 To Finish
      Cells(i, 10).Select
      ActiveSheet.Paste
   Next i
```

```
Range("S10:W10").Select
Selection.Copy
  For i = 11 To Finish
    Cells(i, 19).Select
    ActiveSheet.Paste
  Next i

End Function
```

```
Function DropGraph(x, Depth)
Application.ScreenUpdating = False
'This simply pulls the proper information so the
'graph that includes all tests for extra visual can be pulled

Application.Goto Reference:="SlopeAll" & x & "." & Depth
SlopeVal = ActiveCell
Application.Goto Reference:="SlopeAllout"
ActiveCell = SlopeVal

End Function
```

```
Function GrabGraph(x)
Application.ScreenUpdating = False
'This pulls the correct graph based on outlier option results and
'puts it on the results sheet

ActiveSheet.ChartObjects("Results Graph" & x).Activate
ActiveChart.ChartArea.Copy
Sheets("Results").Select
Application.Goto Reference:="GraphSpot"
ActiveSheet.Paste
'ActiveSheet.ChartObjects("Results Graph" & x).Activate
'ActiveSheet.Shapes("Results Graph" & x).IncrementLeft 20.5
'ActiveSheet.Shapes("Results Graph" & x).IncrementTop 10.4

End Function
```

```
Function GrabGraph2(x)
Application.ScreenUpdating = False
'This pulls the correct all inclusion graph

ActiveSheet.ChartObjects("ResultsGraph" & x).Activate
ActiveChart.ChartArea.Copy
Sheets("Results").Select
Application.Goto Reference:="GraphSpot2"
ActiveSheet.Paste
'ActiveSheet.ChartObjects("ResultsGraph" & x).Activate
'ActiveSheet.Shapes("ResultsGraph" & x).IncrementLeft -5.5
'ActiveSheet.Shapes("ResultsGraph" & x).IncrementTop 10.4

End Function
```

```
Sub PrintPDF()
Application.ScreenUpdating = False
'For the output of results to a PDF

Dim PName As String, SName As String, InitialName As String

On Error GoTo 0
'Give the user an option to save the results to a PDF and view it
```

```
PDF.Show

If Answer = "Yes" Then
   Application.Goto Reference:="ProjName"
   PName = ActiveCell
   Application.Goto Reference:="Station"
   SName = ActiveCell
   InitialName = PName & " " & SName & ".pdf"
   Call SavePDF(InitialName)
ElseIf Answer = "No" Then
   Exit Sub
Else
   MsgBox ("A valid choice was not selected, please view the results in the Results sheet")
End If

Application.ScreenUpdating = True
End Sub
```

```
Function SavePDF(InitialName As String)
Application.ScreenUpdating = False
'Saves the PDF so it can be opened

Dim PdfFileName As Variant
On Error Resume Next

PdfFileName = Application.GetSaveAsFilename( _
   InitialFileName:=InitialName, _
   FileFilter:="PDF, *.pdf")

Application.Goto Reference:="PrintA"
PrintOp = ActiveCell

If PrintOp = 2 Then
PrintArea = "$A$2:$L$111"
ElseIf PrintOp = 3 Then
PrintArea = "$A$2:$L$154"
End If

Worksheets("Results").Activate

If PdfFileName <> False Then
   With ActiveSheet.PageSetup
      .CenterHeader = ""
      .Orientation = xlPortrait
      .PrintArea = PrintArea
      .PrintTitleRows = ActiveSheet.Rows(1).Address
      .zoom = False
      .FitToPagesTall = False
      .FitToPagesWide = 1
   End With

   ActiveSheet.ExportAsFixedFormat _
      Type:=xlTypePDF, _
      FileName:=PdfFileName, _
      Quality:=xlQualityStandard, _
      IncludeDocProperties:=False, _
      IgnorePrintAreas:=False, _
      OpenAfterPublish:=True

End If
On Error GoTo 0
```

```
End Function
```

```
Sub ClearAll()
Application.ScreenUpdating = False
'This clears the sheets for start over

Worksheets("DCP 01").Visible = xlSheetVisible
Worksheets("DCP 02").Visible = xlSheetVisible
Worksheets("DCP 03").Visible = xlSheetVisible
Worksheets("DCP 04").Visible = xlSheetVisible
Worksheets("DCP 05").Visible = xlSheetVisible
Worksheets("Compile and Linear3").Visible = xlSheetVisible
Worksheets("Outlier3").Visible = xlSheetVisible
Worksheets("Compile and Linear4").Visible = xlSheetVisible
Worksheets("Outlier4").Visible = xlSheetVisible
Worksheets("Compile and Linear5").Visible = xlSheetVisible
Worksheets("Outlier5").Visible = xlSheetVisible
Worksheets("Graph").Visible = xlSheetVisible
Worksheets("Results").Visible = xlSheetVisible
Worksheets("Stored Information").Visible = xlSheetVisible

Worksheets("DCP 01").Select
Range("A1").Select
Cells.ClearContents

Worksheets("DCP 02").Activate
Range("A1").Select
Cells.ClearContents

Worksheets("DCP 03").Activate
Range("A1").Select
Cells.ClearContents

Worksheets("DCP 04").Activate
Range("A1").Select
Cells.ClearContents

Worksheets("DCP 05").Activate
Range("A1").Select
Cells.ClearContents

'DCP = 3 SET
Worksheets("Compile and Linear3").Activate
Range("A4:F300").Select
Selection.ClearContents
Range("H10:Q100").Select
Selection.ClearContents
Range("S5:X300").Select
Selection.ClearContents
Application.CutCopyMode = False

Worksheets("Outlier3").Activate
Range("A10").Select
Selection.ClearContents

For i = 3 To 7
   Cells(i, 8) = "None"
   Cells(i, 10) = "None"
   Cells(i, 15) = ""
Next i
For i = 11 To 13
   Cells(i, 3) = ""
```

```
    Cells(i, 4) = ""
    Cells(i, 6) = ""
Next i

Range("R2:T6").Select
Selection.ClearContents

Application.Goto Reference:="OutPlot3"
ActiveCell.ClearContents

'DCP = 4 SET
Worksheets("Compile and Linear4").Activate
Range("A4:H300").Select
Selection.ClearContents
Range("J10:V100").Select
Selection.ClearContents
Range("X5:AE300").Select
Selection.ClearContents
Application.CutCopyMode = False

Worksheets("Outlier4").Activate
Range("A10").Select
Selection.ClearContents

For i = 3 To 7
    Cells(i, 9) = "None"
    Cells(i, 11) = "None"
    Cells(i, 12) = ""
    Cells(i, 13) = "None"
    Cells(i, 14) = ""
Next i
For i = 11 To 14
    Cells(i, 3) = ""
    Cells(i, 4) = ""
    Cells(i, 6) = ""
Next i

Range("R11:U15").Select
Selection.ClearContents

Application.Goto Reference:="OutPlot4"
ActiveCell.ClearContents

'DCP = 5 SET
Worksheets("Compile and Linear5").Activate
Range("A4:J300").Select
Selection.ClearContents
Range("L10:AA100").Select
Selection.ClearContents
Range("AC5:AL300").Select
Selection.ClearContents
Application.CutCopyMode = False

Worksheets("Outlier5").Activate
Range("A10").Select
Selection.ClearContents

For i = 3 To 7
    Cells(i, 10) = "None"
    Cells(i, 12) = "None"
    Cells(i, 13) = ""
    Cells(i, 14) = "None"
```

```
    Cells(i, 15) = ""
    Cells(i, 16) = "None"
    Cells(i, 17) = ""
Next i
For i = 11 To 15
    Cells(i, 3) = ""
    Cells(i, 4) = ""
    Cells(i, 6) = ""
Next i

Range("T11:X15").Select
Selection.ClearContents

Application.Goto Reference:="OutPlot5"
ActiveCell.ClearContents

Worksheets("Results").Activate
Application.Goto Reference:="ProjName"
Selection.ClearContents
Application.Goto Reference:="Station"
Selection.ClearContents
Application.Goto Reference:="Date"
Selection.ClearContents
Application.Goto Reference:="OpName"
Selection.ClearContents
Application.Goto Reference:="DCPTest"
Selection.ClearContents
Application.Goto Reference:="PassFail"
Selection.ClearContents
Application.Goto Reference:="Streng"
Selection.ClearContents
Application.Goto Reference:="Pay"
Selection.ClearContents
Application.Goto Reference:="Range1"
Selection.ClearContents
Application.Goto Reference:="Range2"
Selection.ClearContents
Application.Goto Reference:="Range3"
Selection.ClearContents
Application.Goto Reference:="Range4"
Selection.ClearContents
Application.Goto Reference:="Range5"
Selection.ClearContents
Application.Goto Reference:="IncDisc1"
Selection.ClearContents
Application.Goto Reference:="IncDisc2"
Selection.ClearContents
Application.Goto Reference:="IncDisc3"
Selection.ClearContents
Application.Goto Reference:="IncDisc4"
Selection.ClearContents
Application.Goto Reference:="IncDisc5"
Selection.ClearContents
Application.Goto Reference:="ErrorLim"
Selection.ClearContents
Application.Goto Reference:="NRMin"
Selection.ClearContents
Application.Goto Reference:="NRMax"
Selection.ClearContents
Application.Goto Reference:="RMin"
Selection.ClearContents
Application.Goto Reference:="RMax"
```

```
Selection.ClearContents
Application.Goto Reference:="Coef1"
Selection.ClearContents
Application.Goto Reference:="Coef2"
Selection.ClearContents
Application.Goto Reference:="ADep"
Selection.ClearContents
Application.Goto Reference:="ASlope"
Selection.ClearContents
Application.Goto Reference:="ADepB"
Selection.ClearContents
Application.Goto Reference:="SlopeAllout"
Selection.ClearContents
Application.Goto Reference:="PrintA"
Selection.ClearContents

On Error Resume Next
ActiveSheet.ChartObjects("ResultsGraph3").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph3").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph3.1").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph3.2").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph3.3").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("ResultsGraph4").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph4").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph4.1").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph4.2").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph4.3").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph4.4").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph4.12").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph4.13").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph4.14").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph4.23").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph4.24").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph4.34").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("ResultsGraph5").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.1").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.2").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.3").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.4").Activate
```

```
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.5").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.12").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.13").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.14").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.15").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.23").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.24").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.25").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.34").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.35").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.45").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.123").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.124").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.125").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.134").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.135").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.145").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.234").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.235").Activate
ActiveChart.ChartArea.Clear
ActiveSheet.ChartObjects("Results Graph5.345").Activate
ActiveChart.ChartArea.Clear
On Error GoTo 0

Worksheets("Graph").Activate
Application.Goto Reference:="DepthSpot"
Selection.ClearContents
Range("B11:D44").Select
Selection.ClearContents
Range("J11:M44").Select
Selection.ClearContents
Range("S11:W44").Select
Selection.ClearContents

Worksheets("DCP 01").Visible = xlVeryHidden
Worksheets("DCP 02").Visible = xlVeryHidden
Worksheets("DCP 03").Visible = xlVeryHidden
Worksheets("DCP 04").Visible = xlVeryHidden
Worksheets("DCP 05").Visible = xlVeryHidden
Worksheets("Compile and Linear3").Visible = xlVeryHidden
Worksheets("Outlier3").Visible = xlVeryHidden
Worksheets("Compile and Linear4").Visible = xlVeryHidden
Worksheets("Outlier4").Visible = xlVeryHidden
```

```
Worksheets("Compile and Linear5").Visible = xlVeryHidden
Worksheets("Outlier5").Visible = xlVeryHidden
Worksheets("Results").Visible = xlVeryHidden
Worksheets("Graph").Visible = xlVeryHidden
Worksheets("Stored Information").Visible = xlVeryHidden

Application.CutCopyMode = False
Application.ScreenUpdating = True

End Sub
```

```
Private Sub Workbook_Open()

Dim ws As Worksheet

Application.DisplayFullScreen = True
Application.ScreenUpdating = True
Worksheets("Starting Page").Visible = xlSheetVisible
Worksheets("Starting Page").Activate
Worksheets("Starting Page").Range("A1:O28").Select 'set range zoom
ActiveWindow.zoom = True
Application.Goto Reference:="StartCell"
ActiveCell.Select
ActiveWindow.ScrollRow = 1
Application.CutCopyMode = False
Application.ScreenUpdating = False

'Set View and Clear Manual Print Page Breaks
Worksheets("Results").Visible = xlSheetVisible
Worksheets("Results").Activate
ActiveWindow.View = xlNormalView
ActiveSheet.Cells.PageBreak = xlPageBreakNone
Worksheets("Results").Columns("M").PageBreak = xlPageBreakManual
Worksheets("Results").Rows(61).PageBreak = xlPageBreakManual
Worksheets("Results").Rows(112).PageBreak = xlPageBreakManual
Worksheets("Results").Rows(155).PageBreak = xlPageBreakManual
Range("A1").Select
ActiveWindow.ScrollRow = 1
Application.CutCopyMode = False
Worksheets("Results").Visible = xlVeryHidden

'Set Zoom needed for graphs
Application.DisplayFullScreen = True
Worksheets("Graph").Visible = xlSheetVisible
Worksheets("Graph").Activate
ActiveWindow.zoom = 85
Sheets("Graph").Visible = xlVeryHidden
Application.ScreenUpdating = True

'Size the window and go to the startup screen
'Application.DisplayFullScreen = True
Worksheets("Starting Page").Visible = xlSheetVisible
Worksheets("Starting Page").Activate
Worksheets("Starting Page").Range("A1:O28").Select 'set range zoom
ActiveWindow.zoom = True
Application.Goto Reference:="StartCell"
ActiveCell.Select
ActiveWindow.ScrollRow = 1
Application.CutCopyMode = False
Application.ScreenUpdating = False

'Hide the unecessary macro check sheet to simplify the UI
```

```
For Each ws In ThisWorkbook.Worksheets
    If ws.Name <> "Starting Page" Then
        ws.Visible = xlVeryHidden
    End If
Next ws

End Sub
```

```
Private Sub Workbook_BeforeClose(Cancel As Boolean)

Dim ws As Worksheet

Application.ScreenUpdating = False

'delete the temp graph image from the device
FilePath = Application.DefaultFilePath & Application.PathSeparator & "TempChart.gif"

If Len(Dir(FilePath)) > 0 Then
   SetAttr FilePath, vbNormal
   Kill FilePath
End If

'Delete the stored info for quick re-analyses
Worksheets("Stored Information").Visible = xlSheetVisible
Worksheets("Stored Information").Activate

Application.Goto Reference:="ProjName2"
Selection.ClearContents
Application.Goto Reference:="Station2"
Selection.ClearContents
Application.Goto Reference:="Date2"
Selection.ClearContents
Application.Goto Reference:="OpName2"
Selection.ClearContents
Application.Goto Reference:="DCPTest2"
Selection.ClearContents
Application.Goto Reference:="ErrorLim2"
Selection.ClearContents
Application.Goto Reference:="NRMin2"
Selection.ClearContents
Application.Goto Reference:="NRMax2"
Selection.ClearContents
Application.Goto Reference:="RMin2"
Selection.ClearContents
Application.Goto Reference:="RMax2"
Selection.ClearContents
Application.Goto Reference:="Coef12"
Selection.ClearContents
Application.Goto Reference:="Coef22"
Selection.ClearContents
Application.Goto Reference:="ADep2"
Selection.ClearContents

'Hide all sheets not the Macro Check Sheet for next loadup
Worksheets("MACRO").Visible = xlSheetVisible
Worksheets("MACRO").Activate
Worksheets("MACRO").Range("A1:R34").Select 'set range zoom
ActiveWindow.zoom = True
Range("A1").Select
ActiveWindow.ScrollRow = 1
Application.CutCopyMode = False
```

```
For Each ws In ThisWorkbook.Worksheets
    If ws.Name <> "MACRO" Then
        ws.Visible = xlVeryHidden
    End If
Next ws

'Save these changes to the workbook file path
ActiveWorkbook.Save

'Update the screen so the file can close properly on all devices
Application.ScreenUpdating = True

End Sub
```

```
Sub LoadAllSheets()
'
' This unhides all sheets for editting
'
For Each ws In ThisWorkbook.Worksheets
    ws.Visible = xlSheetVisible
Next ws

'
End Sub
```

```
Sub StartOver()
'For the start over button on the results sheet

Worksheets("Starting Page").Visible = xlSheetVisible
Worksheets("Starting Page").Activate
Worksheets("Starting Page").Range("A1:O28").Select 'set range zoom
ActiveWindow.zoom = True
Range("A30").Select
ActiveWindow.ScrollRow = 1
Application.CutCopyMode = False

End Sub
```

Appendix C

Userform Code

Confirm

```
Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As Integer)

'this initialization sub routine will disable the top right cancel button
If CloseMode = vbFormControlMenu Then
Cancel = True
End If

End Sub

Private Sub Cancel_Click()

Answer = "Exit"
Unload Me

End Sub

Private Sub Continue_Click()

Answer = "Yes"
Unload Me

End Sub

Private Sub GoBack_Click()

Answer = "No"
Unload Me

End Sub
```

DataError

```
Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As Integer)

'this initialization sub routine will disable the top right cancel button
If CloseMode = vbFormControlMenu Then
Cancel = True
End If

End Sub

Private Sub RestartButton_Click()

Answer = "Exit"
Unload Me

End Sub
```

DepthInfo

```
Private Sub ReturnButton_Click()

Unload Me
```

```
End Sub

Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As Integer)

'this initialization sub routine will disable the top right cancel button
If CloseMode = vbFormControlMenu Then
Cancel = True
End If

End Sub
```

Error Form

```
Private Sub ReturnButton_Click()

Unload Me

End Sub

Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As Integer)

'this initialization sub routine will disable the top right cancel button
If CloseMode = vbFormControlMenu Then
Cancel = True
End If

End Sub
```

Initial

```
Private Sub DefaultVals_Click()

Application.ScreenUpdating = True
TestOps.Value = 3
Depth.Value = 75
Range.Value = 50
RegFunc.Value = "ALDOT Default"
EquCoeff1New.Value = 1220
EquCoeff2New.Value = -0.559
NoRedMin.Value = 250
NoRedMax.Value = 600
RedMin.Value = 200
RedMax.Value = 650

End Sub

Private Sub UserForm_Initialize()
Dim Percentage As Range, Depths As Range
Dim ws As Worksheet

Application.ScreenUpdating = True
RegFuncImage.Visible = True
Worksheets("Starting Page Begin").Visible = xlSheetVisible
Worksheets("Starting Page Begin").Activate
Worksheets("Starting Page Begin").Shapes("StartOverlay").Visible = True
Worksheets("Starting Page Begin").Range("A1:O28").Select 'set range zoom
ActiveWindow.zoom = True
Application.Goto Reference:="StartCell2"
ActiveCell.Select
ActiveWindow.ScrollRow = 1
```

```
Application.CutCopyMode = False
Application.ScreenUpdating = False

'Re-Enter any information stored from the last use
Worksheets("Stored Information").Visible = xlSheetVisible
Application.Goto Reference:="ProjName2"
If ActiveCell <> "" Then ProjectName.Value = ActiveCell
Application.Goto Reference:="Station2"
If ActiveCell <> "" Then Stations.Value = ActiveCell
Application.Goto Reference:="Date2"
If ActiveCell <> "" Then DateBox.Value = ActiveCell
Application.Goto Reference:="OpName2"
If ActiveCell <> "" Then OperatorName.Value = ActiveCell
Application.Goto Reference:="DCPTest2"
If ActiveCell <> "" Then TestSave = ActiveCell
Application.Goto Reference:="ErrorLim2"
If ActiveCell <> "" Then
   Range.Value = ActiveCell
Else
   Range.Value = 50
End If
Application.Goto Reference:="ADep2"
If ActiveCell <> "" Then
   Depth.Value = ActiveCell
Else
   Depth.Value = 75
End If
Application.Goto Reference:="NRMin2"
If ActiveCell <> "" Then
   NoRedMin.Value = ActiveCell
Else
   NoRedMin.Value = 250
End If
Application.Goto Reference:="NRMax2"
If ActiveCell <> "" Then
   NoRedMax.Value = ActiveCell
Else
   NoRedMax.Value = 600
End If
Application.Goto Reference:="RMin2"
If ActiveCell <> "" Then
   RedMin.Value = ActiveCell
Else
   RedMin.Value = 200
End If
Application.Goto Reference:="RMax2"
If ActiveCell <> "" Then
   RedMax.Value = ActiveCell
Else
   RedMax.Value = 650
End If
Application.Goto Reference:="Coef12"
If ActiveCell <> "" Then
   EquCoeff1New.Value = ActiveCell
Else
   EquCoeff1New.Value = 1220
End If
Application.Goto Reference:="Coef22"
If ActiveCell <> "" Then
   EquCoeff2New.Value = ActiveCell
Else
   EquCoeff2New.Value = -0.559
```

```
End If

If EquCoeff1New.Value = 1220 And EquCoeff2New.Value = -0.559 Then
   RegFunc.Value = "ALDOT Default"
   RegFuncImage.Visible = True
Else
   RegFunc.Value = "User-Defined"
   RegFuncImage.Visible = False
End If
Worksheets("Stored Information").Visible = xlVeryHidden

TestOps.AddItem "3"
TestOps.AddItem "4"
TestOps.AddItem "5"

If TestSave = "" Then
   TestOps.Value = "3"
Else
   TestOps.Value = TestSave
End If

'Load in Depth and Outlier Range values
Worksheets("Outlier3").Visible = xlSheetVisible
Worksheets("Outlier3").Activate
Set ws = Worksheets("Outlier3")
For Each Percentage In ws.Range("OutlierSpinValues") 'name of cell range on the worksheet
   Me.Range.AddItem Percentage.Value ' Add the range of cells as available values for the spin button
Next Percentage
For Each Depths In ws.Range("DepthSpinValues") 'name of cell range on the worksheet
   Me.Depth.AddItem Depths.Value ' Add the range of cells as available values for the spin button
Next Depths
Application.ScreenUpdating = True
Worksheets("Outlier3").Visible = xlVeryHidden

Worksheets("Starting Page Begin").Visible = xlSheetVisible
Worksheets("Starting Page Begin").Activate
Worksheets("Starting Page Begin").Shapes("StartOverlay").Visible = True
Worksheets("Starting Page Begin").Range("A1:O28").Select 'set range zoom
ActiveWindow.zoom = True
Application.Goto Reference:="StartCell2"
ActiveCell.Select
ActiveWindow.ScrollRow = 1
Application.CutCopyMode = False
Application.ScreenUpdating = True
Worksheets("Starting Page").Visible = xlVeryHidden
Application.Wait (Now + TimeValue("0:00:01"))
Application.ScreenUpdating = False

End Sub

Private Sub UserForm_Activate()

'To auto generate a date based on the devices date settings
DateBox.Value = Format(Date, "mm/dd/yyyy")

End Sub

Private Sub DepthChange_Click()
Application.ScreenUpdating = False

DepthInfo.Show
Do Until DepthInfo.Visible = False
```

```
    DoEvents
Loop

Application.ScreenUpdating = True
End Sub

Private Sub EquCoeff1New_Change()

If EquCoeff1New.Value <> "1220" Then
    RegFunc = "User-Defined"
    RegFuncImage.Visible = False
ElseIf EquCoeff1New.Value = "1220" Then
    RegFunc = "ALDOT Default"
    RegFuncImage.Visible = True
End If

End Sub

Private Sub EquCoeff2New_Change()

If EquCoeff2New.Value <> "-0.559" Then
    RegFunc = "User-Defined"
    RegFuncImage.Visible = False
ElseIf EquCoeff2New.Value = "-0.559" Then
    RegFunc = "ALDOT Default"
    RegFuncImage.Visible = True
End If

End Sub

Private Sub FunctionChange_Click()
Application.ScreenUpdating = False

RelationshipForm.Show
Do Until RelationshipForm.Visible = False
    DoEvents
Loop

Application.ScreenUpdating = True
End Sub

Private Sub RangeChange_Click()
Application.ScreenUpdating = False

ErrorForm.Show
Do Until ErrorForm.Visible = False
    DoEvents
Loop

Application.ScreenUpdating = True
End Sub

Private Sub StrengthChange_Click()
Application.ScreenUpdating = False

StrengthForm.Show
Do Until StrengthForm.Visible = False
    DoEvents
Loop

Application.ScreenUpdating = True
End Sub
```

```
Private Sub OutlierSpin_SpinUp()
If Me.Range.ListIndex = Me.Range.ListCount - 1 Then Exit Sub
Me.Range.ListIndex = Me.Range.ListIndex + 1

End Sub

Private Sub OutlierSpin_SpinDown()
If Me.Range.ListIndex = -1 Then Exit Sub
Me.Range.ListIndex = Me.Range.ListIndex - 1

End Sub

Private Sub DepthSpin_SpinUp()
If Me.Depth.ListIndex = Me.Depth.ListCount - 1 Then Exit Sub
Me.Depth.ListIndex = Me.Depth.ListIndex + 1

End Sub

Private Sub DepthSpin_SpinDown()
If Me.Depth.ListIndex = -1 Then Exit Sub
Me.Depth.ListIndex = Me.Depth.ListIndex - 1

End Sub

Private Sub ContinueButton_Click()
Application.ScreenUpdating = False

'Make sure crucial boxes are not left blank before continuing
If TestOps.Value = "" Then
   MsgBox ("You must select a Number of DCP Tests to continue")
   GoTo TryAgain
End If

If EquCoeff1New.Value = "" Or EquCoeff2New.Value = "" Then
   MsgBox ("You must enter constant values for A & B for the Strength-to-DCP Relationship to continue")
   GoTo TryAgain
End If

If Depth.Value = "" Then
   MsgBox ("You must select an Analysis Depth to continue")
   GoTo TryAgain
End If

If Range.Value = "" Then
   MsgBox ("You must select an Outlier Error Range to continue")
   GoTo TryAgain
End If

If NoRedMin.Value = "" Or NoRedMax.Value = "" Or RedMin.Value = "" Or RedMax.Value = "" Then
   MsgBox ("You must select a number for all four Strength values to continue")
   GoTo TryAgain
End If

'All inputs are valid, copy to results sheet and continue main code
Worksheets("Results").Visible = xlSheetVisible
Worksheets("Graph").Visible = xlSheetVisible
Worksheets("Stored Information").Visible = xlSheetVisible

Worksheets("Results").Activate
Application.Goto Reference:="ProjName"
ActiveCell = ProjectName.Value
```

```
Application.Goto Reference:="Station"
ActiveCell = Stations.Value
Application.Goto Reference:="Date"
ActiveCell = DateBox.Value
Application.Goto Reference:="OpName"
ActiveCell = OperatorName.Value
Application.Goto Reference:="DCPTest"
ActiveCell = TestOps.Value
Application.Goto Reference:="Coef1"
ActiveCell = EquCoeff1New.Value
Application.Goto Reference:="Coef2"
ActiveCell = EquCoeff2New.Value
Application.Goto Reference:="ADep"
ActiveCell = Depth.Value
Application.Goto Reference:="ADepB"
ActiveCell = Depth.Value
Application.Goto Reference:="ErrorLim"
ActiveCell = Range.Value
Application.Goto Reference:="NRMin"
ActiveCell = NoRedMin.Value
Application.Goto Reference:="NRMax"
ActiveCell = NoRedMax.Value
Application.Goto Reference:="RMin"
ActiveCell = RedMin.Value
Application.Goto Reference:="RMax"
ActiveCell = RedMax.Value

Worksheets("Graph").Activate
Application.Goto Reference:="DepthSpot"
ActiveCell = Depth.Value

Worksheets("Stored Information").Activate
Application.Goto Reference:="ProjName2"
ActiveCell = ProjectName.Value
Application.Goto Reference:="Station2"
ActiveCell = Stations.Value
Application.Goto Reference:="Date2"
ActiveCell = DateBox.Value
Application.Goto Reference:="OpName2"
ActiveCell = OperatorName.Value
Application.Goto Reference:="DCPTest2"
ActiveCell = TestOps.Value
Application.Goto Reference:="ErrorLim2"
ActiveCell = Range.Value
Application.Goto Reference:="ADep2"
ActiveCell = Depth.Value
Application.Goto Reference:="NRMin2"
ActiveCell = NoRedMin.Value
Application.Goto Reference:="NRMax2"
ActiveCell = NoRedMax.Value
Application.Goto Reference:="RMin2"
ActiveCell = RedMin.Value
Application.Goto Reference:="RMax2"
ActiveCell = RedMax.Value
Application.Goto Reference:="Coef12"
ActiveCell = EquCoeff1New.Value
Application.Goto Reference:="Coef22"
ActiveCell = EquCoeff2New.Value

Answer = "READY"

Worksheets("Results").Visible = xlVeryHidden
```

```
Worksheets("Graph").Visible = xlVeryHidden
Worksheets("Stored Information").Visible = xlVeryHidden

Unload Me

TryAgain:
End Sub
Private Sub CancelButton_Click()

Answer = "NO"
Unload Me

End Sub

Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As Integer)

'this initialization sub routine will disable the top right cancel button
If CloseMode = vbFormControlMenu Then
Cancel = True
End If

End Sub
```

Msg 1 – 5

```
Private Sub OkayButton_Click()

Unload Me

End Sub
Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As Integer)

'this initialization sub routine will disable the top right cancel button
If CloseMode = vbFormControlMenu Then
Cancel = True
End If

End Sub
```

OutlierCheck

```
Private Sub KeepButton_Click()

Outlier = "No"
Unload Me

End Sub

Private Sub RemoveButton_Click()

Outlier = "Yes"
Unload Me

End Sub

Private Sub SeeGraph_Click()
Application.ScreenUpdating = True
'This saves the correct graph as a temp file to open on the outlier graph
'option pop-up if desired to observe the all inclusive graph
Worksheets("Results").Visible = xlSheetVisible
Application.Goto Reference:="DCPTest"
```

```
DCP = ActiveCell

Dim WBook As Workbook, WSheet As Worksheet
Dim CurrentChart As Chart
Dim FName As String, GraphName As String
Dim ws As Worksheet

Worksheets("Graph").Visible = xlSheetVisible
GraphName = "ResultsGraph" & DCP
FName = Application.DefaultFilePath & Application.PathSeparator & "TempChart.gif"
Set CurrentChart = ThisWorkbook.Worksheets("Graph").ChartObjects(GraphName).Chart
CurrentChart.Export FileName:=FName, Filtername:="GIF"
SeeTheGraph.GraphImage.Picture = LoadPicture(FName)

Application.ScreenUpdating = True
Worksheets("Results").Visible = xlSheetVisible
Worksheets("Results").Activate
Worksheets("Starting Page Begin").Visible = xlVeryHidden

SeeTheGraph.Show
Do Until SeeTheGraph.Visible = False
   DoEvents
Loop

End Sub

Private Sub UserForm_Initialize()

'Application.ScreenUpdating = True
'Worksheets("Results").Activate
'Range("A1").Select
'ActiveWindow.ScrollRow = 1

End Sub

Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As Integer)

'this initialization sub routine will disable the top right cancel button
If CloseMode = vbFormControlMenu Then
Cancel = True
End If

End Sub
```

OutlierErrors

```
Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As Integer)

'this initialization sub routine will disable the top right cancel button
If CloseMode = vbFormControlMenu Then
Cancel = True
End If

End Sub

Private Sub RestartButton_Click()

Answer = "Exit"
Unload Me

End Sub
```

PDF

```
Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As Integer)

'this initialization sub routine will disable the top right cancel button
If CloseMode = vbFormControlMenu Then
Cancel = True
End If

End Sub

Private Sub SaveButton_Click()

Answer = "Yes"
Unload Me

End Sub

Private Sub DontSaveButton_Click()

Answer = "No"
Unload Me

End Sub
```

RefusalNote

```
Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As Integer)

'this initialization sub routine will disable the top right cancel button
If CloseMode = vbFormControlMenu Then
Cancel = True
End If

End Sub

Private Sub RestartButton_Click()

Answer = "Exit"
Unload Me

End Sub
```

RelationshipForm

```
Private Sub UserForm_Initialize()

EquCoeff1New = 1220
EquCoeff2New = -0.559

End Sub

Private Sub EnterButton_Click()

Initial.EquCoeff1New.Value = RelationshipForm.EquCoeff1New.Value
Initial.EquCoeff2New.Value = RelationshipForm.EquCoeff2New.Value

Unload Me

End Sub
```

```
Private Sub ReturnButton_Click()

Unload Me

End Sub

Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As Integer)

'this initialization sub routine will disable the top right cancel button
If CloseMode = vbFormControlMenu Then
Cancel = True
End If

End Sub
```

ResultsNote

```
Private Sub View_Click()

Unload Me

End Sub

Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As Integer)

'this initialization sub routine will disable the top right cancel button
If CloseMode = vbFormControlMenu Then
Cancel = True
End If

End Sub
```

SeeTheGraph

```
Private Sub GoBack_Click()

Unload Me

End Sub

Private Sub UserForm_Initialize()
'This pulls the temp image file to show on the userform

FName = Application.DefaultFilePath & Application.PathSeparator & "TempChart.gif"
SeeTheGraph.GraphImage.Picture = LoadPicture(FName)

End Sub

Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As Integer)

'this initialization sub routine will disable the top right cancel button
If CloseMode = vbFormControlMenu Then
Cancel = True
End If

End Sub
```

StrengthForm

```
Private Sub UserForm_Initialize()
```

```
NoRedMinNew = 250
NoRedMaxNew = 600
RedMinNew = 200
RedMaxNew = 650

End Sub

Private Sub EnterButton_Click()

Initial.NoRedMin = StrengthForm.NoRedMinNew
Initial.NoRedMax = StrengthForm.NoRedMaxNew
Initial.RedMin = StrengthForm.RedMinNew
Initial.RedMax = StrengthForm.RedMaxNew

Unload Me

End Sub

Private Sub ReturnButton_Click()

Unload Me

End Sub

Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As Integer)

'this initialization sub routine will disable the top right cancel button
If CloseMode = vbFormControlMenu Then
Cancel = True
End If

End Sub
```

Sure

```
Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As Integer)

'this initialization sub routine will disable the top right cancel button
If CloseMode = vbFormControlMenu Then
Cancel = True
End If

End Sub

Private Sub YesButton_Click()

Answer = "Yes"
Unload Me

End Sub

Private Sub NoButton_Click()

Answer = "No"
Unload Me

End Sub
```

Appendix D

Density, Moisture Content, and Strength Results Tables

Table D.1: Strength Data Summary

7-Day Strength

Soil Type	Mix Date	Cement	SM	PM
ELBA	11.12.19	8.0%	465	545
	11.19.19	6.5%	320	360
	12.03.19	5.0%	310	320
	02.18.20	6.5%	390	295
LUCAS	03.02.20	5.0%	275	280
COARSE	06.02.20	10.0%	1100	1080
	06.09.20	8.0%	510	605
	06.16.20	6.0%	250	310
	06.22.20	4.0%	110	140
	06.23.20	9.0%	755	860

Table D.2: Density Data Summary

7-Day Density

Soil Type	Mix Date	Cement	SM	PM
ELBA	11.12.19	8.0%	115.1	114.1
	11.19.19	6.5%	113.4	115.9
	12.03.19	5.0%	113.0	114.2
	02.18.20	6.5%	113.7	114.9
LUCAS	03.02.20	5.0%	115.8	116.0
COARSE	06.02.20	10.0%	125.4	123.0
	06.09.20	8.0%	121.8	121.8
	06.16.20	6.0%	121.0	119.4
	06.22.20	4.0%	117.0	120.0
	06.23.20	9.0%	123.3	124.6

Table D.3: Moisture Content Data Summary

7-Day Moisture Content

Soil Type	Mix Date	Cement	SM	PM
ELBA	11.12.19	8.0%	11.6%	11.9%
	11.19.19	6.5%	13.2%	13.3%
	12.03.19	5.0%	12.0%	12.1%
	02.18.20	6.5%	13.5%	13.5%
LUCAS	03.02.20	5.0%	11.0%	11.0%
COARSE	06.02.20	10.0%	8.5%	8.6%
	06.09.20	8.0%	9.8%	9.7%
	06.16.20	6.0%	9.9%	10.0%
	06.22.20	4.0%	12.2%	12.4%
	06.23.20	9.0%	9.8%	9.8%

Appendix E

Outcome #1

Data File #1

DCP - Survey Report
Date/Time: 09/29/19 14:26:35
File Name: 09291426.TXT
Serial Number: A330
Test Number: 00319
Company: AUBURN UNIV
Project: ELBA ,
Operator: MCS
Location: TEST B1 ,
Station: +
Soil Type: O (Other)
Soil Class: SOIL CEMENT
Hammer Mass: 8.0 kg
Comments:
End Comments:

Blow #	Depth	D/B	Total	CBR	Bearing	Uc	Bearing		
	mm	mm/Blow		mm/Blow		%	psf	psi	Kpa
0	0	0	0	0.0	0	0.0	0		
1	2	2	2	100.0	11600	450.0	555		
2	4	2	2	100.0	11600	450.0	555		
3	7	3	2	85.3	10400	383.8	498		
4	10	3	2	85.3	10400	383.8	498		
5	13	3	2	85.3	10400	383.8	498		
6	15	2	2	100.0	11600	450.0	555		
7	18	3	2	85.3	10400	383.8	498		
8	20	2	2	100.0	11600	450.0	555		
9	24	4	2	61.8	8400	278.1	402		
10	26	2	2	100.0	11600	450.0	555		
11	29	3	2	85.3	10400	383.8	498		
12	32	3	2	85.3	10400	383.8	498		
13	35	3	2	85.3	10400	383.8	498		
14	39	4	2	61.8	8400	278.1	402		
15	41	2	2	100.0	11600	450.0	555		
16	43	2	2	100.0	11600	450.0	555		
17	45	2	2	100.0	11600	450.0	555		
18	48	3	2	85.3	10400	383.8	498		
19	51	3	2	85.3	10400	383.8	498		
20	54	3	2	85.3	10400	383.8	498		
21	56	2	2	100.0	11600	450.0	555		
22	58	2	2	100.0	11600	450.0	555		
23	61	3	2	85.3	10400	383.8	498		
24	63	2	2	100.0	11600	450.0	555		
25	66	3	2	85.3	10400	383.8	498		
26	69	3	2	85.3	10400	383.8	498		
27	71	2	2	100.0	11600	450.0	555		
28	73	2	2	100.0	11600	450.0	555		
29	74	1	2	100.0	11600	450.0	555		
30	77	3	2	85.3	10400	383.8	498		
31	80	3	2	85.3	10400	383.8	498		
32	81	1	2	100.0	11600	450.0	555		
33	82	1	2	100.0	11600	450.0	555		
34	85	3	2	85.3	10400	383.8	498		

35	87	2	2	100.0	11600	450.0	555
36	88	1	2	100.0	11600	450.0	555
37	90	2	2	100.0	11600	450.0	555
38	92	2	2	100.0	11600	450.0	555
39	93	1	2	100.0	11600	450.0	555
40	96	3	2	85.3	10400	383.8	498
41	98	2	2	100.0	11600	450.0	555
42	100	2	2	100.0	11600	450.0	555
43	102	2	2	100.0	11600	450.0	555
44	104	2	2	100.0	11600	450.0	555
45	105	1	2	100.0	11600	450.0	555
46	108	3	2	85.3	10400	383.8	498
47	109	1	2	100.0	11600	450.0	555
48	112	3	2	85.3	10400	383.8	498
49	114	2	2	100.0	11600	450.0	555
50	117	3	2	85.3	10400	383.8	498
51	117	0	2	100.0	11600	450.0	555
52	120	3	2	85.3	10400	383.8	498
53	122	2	2	100.0	11600	450.0	555
54	124	2	2	100.0	11600	450.0	555
55	127	3	2	85.3	10400	383.8	498
56	128	1	2	100.0	11600	450.0	555
57	131	3	2	85.3	10400	383.8	498
58	133	2	2	100.0	11600	450.0	555
59	136	3	2	85.3	10400	383.8	498
60	139	3	2	85.3	10400	383.8	498
61	140	1	2	100.0	11600	450.0	555
62	141	1	2	100.0	11600	450.0	555
63	144	3	2	85.3	10400	383.8	498
64	145	1	2	100.0	11600	450.0	555
65	146	1	2	100.0	11600	450.0	555
66	148	2	2	100.0	11600	450.0	555
67	150	2	2	100.0	11600	450.0	555
68	153	3	2	85.3	10400	383.8	498
69	155	2	2	100.0	11600	450.0	555
70	157	2	2	100.0	11600	450.0	555
71	159	2	2	100.0	11600	450.0	555
72	161	2	2	100.0	11600	450.0	555
73	163	2	2	100.0	11600	450.0	555
74	166	3	2	85.3	10400	383.8	498
75	168	2	2	100.0	11600	450.0	555
76	170	2	2	100.0	11600	450.0	555
77	172	2	2	100.0	11600	450.0	555
78	175	3	2	85.3	10400	383.8	498
79	179	4	2	61.8	8400	278.1	402
80	180	1	2	100.0	11600	450.0	555

Data File #2

DCP - Survey Report
Date/Time: 09/29/19 14:36:48
File Name: 09291436.TXT
Serial Number: A330
Test Number: 00320
Company: AUBURN UNIV
Project: ELBA ,____________________
Operator: MCS
Location: TEST B2 ,____________________
Station: +

Soil Type: O (Other)
Soil Class: SOIL CEMENT
Hammer Mass: 8.0 kg
Comments:
End Comments:

Blow #	Depth mm	D/B mm/Blow	Total	CBR mm/Blow	Bearing	Uc %	Bearing psf	psi	Kpa
0	0	0	0	0.0	0	0.0	0		
1	5	5	5	48.1	7100	216.4	340		
2	6	1	3	100.0	11600	450.0	555		
3	10	4	3	61.8	8400	278.1	402		
4	15	5	3	48.1	7100	216.4	340		
5	19	4	3	61.8	8400	278.1	402		
6	24	5	4	48.1	7100	216.4	340		
7	25	1	3	100.0	11600	450.0	555		
8	28	3	3	85.3	10400	383.8	498		
9	31	3	3	85.3	10400	383.8	498		
10	33	2	3	100.0	11600	450.0	555		
11	37	4	3	61.8	8400	278.1	402		
12	38	1	3	100.0	11600	450.0	555		
13	41	3	3	85.3	10400	383.8	498		
14	43	2	3	100.0	11600	450.0	555		
15	46	3	3	85.3	10400	383.8	498		
16	48	2	3	100.0	11600	450.0	555		
17	50	2	2	100.0	11600	450.0	555		
18	53	3	2	85.3	10400	383.8	498		
19	55	2	2	100.0	11600	450.0	555		
20	57	2	2	100.0	11600	450.0	555		
21	59	2	2	100.0	11600	450.0	555		
22	61	2	2	100.0	11600	450.0	555		
23	63	2	2	100.0	11600	450.0	555		
24	65	2	2	100.0	11600	450.0	555		
25	67	2	2	100.0	11600	450.0	555		
26	71	4	2	61.8	8400	278.1	402		
27	71	0	2	100.0	11600	450.0	555		
28	73	2	2	100.0	11600	450.0	555		
29	75	2	2	100.0	11600	450.0	555		
30	77	2	2	100.0	11600	450.0	555		
31	79	2	2	100.0	11600	450.0	555		
32	81	2	2	100.0	11600	450.0	555		
33	81	0	2	100.0	11600	450.0	555		
34	84	3	2	85.3	10400	383.8	498		
35	84	0	2	100.0	11600	450.0	555		
36	87	3	2	85.3	10400	383.8	498		
37	89	2	2	100.0	11600	450.0	555		
38	92	3	2	85.3	10400	383.8	498		
39	93	1	2	100.0	11600	450.0	555		
40	95	2	2	100.0	11600	450.0	555		
41	98	3	2	85.3	10400	383.8	498		
42	98	0	2	100.0	11600	450.0	555		
43	100	2	2	100.0	11600	450.0	555		
44	101	1	2	100.0	11600	450.0	555		
45	102	1	2	100.0	11600	450.0	555		
46	103	1	2	100.0	11600	450.0	555		
47	107	4	2	61.8	8400	278.1	402		
48	109	2	2	100.0	11600	450.0	555		
49	110	1	2	100.0	11600	450.0	555		
50	111	1	2	100.0	11600	450.0	555		
51	113	2	2	100.0	11600	450.0	555		
52	116	3	2	85.3	10400	383.8	498		
53	118	2	2	100.0	11600	450.0	555		

54	120	2	2	100.0	11600	450.0	555
55	122	2	2	100.0	11600	450.0	555
56	124	2	2	100.0	11600	450.0	555
57	125	1	2	100.0	11600	450.0	555
58	127	2	2	100.0	11600	450.0	555
59	129	2	2	100.0	11600	450.0	555
60	132	3	2	85.3	10400	383.8	498
61	134	2	2	100.0	11600	450.0	555
62	136	2	2	100.0	11600	450.0	555
63	136	0	2	100.0	11600	450.0	555
64	138	2	2	100.0	11600	450.0	555
65	141	3	2	85.3	10400	383.8	498
66	141	0	2	100.0	11600	450.0	555
67	145	4	2	61.8	8400	278.1	402
68	146	1	2	100.0	11600	450.0	555
69	148	2	2	100.0	11600	450.0	555
70	150	2	2	100.0	11600	450.0	555
71	151	1	2	100.0	11600	450.0	555
72	153	2	2	100.0	11600	450.0	555
73	155	2	2	100.0	11600	450.0	555
74	157	2	2	100.0	11600	450.0	555
75	159	2	2	100.0	11600	450.0	555
76	161	2	2	100.0	11600	450.0	555
77	163	2	2	100.0	11600	450.0	555
78	164	1	2	100.0	11600	450.0	555
79	166	2	2	100.0	11600	450.0	555
80	169	3	2	85.3	10400	383.8	498
81	172	3	2	85.3	10400	383.8	498
82	175	3	2	85.3	10400	383.8	498
83	176	1	2	100.0	11600	450.0	555
84	179	3	2	85.3	10400	383.8	498
85	182	3	2	85.3	10400	383.8	498

Data File #3

DCP - Survey Report
Date/Time: 09/29/19 14:47:44
File Name: 09291447.TXT
Serial Number: A330
Test Number: 00321
Company: AUBURN UNIV
Project: ELBA ,
Operator: MCS
Location: TEST B3 ,
Station: +
Soil Type: O (Other)
Soil Class: SOIL CEMENT
Hammer Mass: 8.0 kg
Comments:
End Comments:

Blow #	Depth	D/B	Total	CBR	Bearing	Uc	Bearing		
	mm	mm/Blow		mm/Blow		%	psf	psi	Kpa
0	0	0	0	0.0	0	0.0	0		
1	3	3	3	85.3	10400	383.8	498		
2	3	0	1	100.0	11600	450.0	555		
3	5	2	1	100.0	11600	450.0	555		
4	5	0	1	100.0	11600	450.0	555		
5	9	4	1	61.8	8400	278.1	402		

6	13	4	2	61.8	8400	278.1	402
7	14	1	2	100.0	11600	450.0	555
8	17	3	2	85.3	10400	383.8	498
9	20	3	2	85.3	10400	383.8	498
10	23	3	2	85.3	10400	383.8	498
11	25	2	2	100.0	11600	450.0	555
12	28	3	2	85.3	10400	383.8	498
13	29	1	2	100.0	11600	450.0	555
14	32	3	2	85.3	10400	383.8	498
15	36	4	2	61.8	8400	278.1	402
16	41	5	2	48.1	7100	216.4	340
17	42	1	2	100.0	11600	450.0	555
18	46	4	2	61.8	8400	278.1	402
19	50	4	2	61.8	8400	278.1	402
20	52	2	2	100.0	11600	450.0	555
21	55	3	2	85.3	10400	383.8	498
22	56	1	2	100.0	11600	450.0	555
23	59	3	2	85.3	10400	383.8	498
24	62	3	2	85.3	10400	383.8	498
25	65	3	2	85.3	10400	383.8	498
26	67	2	2	100.0	11600	450.0	555
27	67	0	2	100.0	11600	450.0	555
28	70	3	2	85.3	10400	383.8	498
29	72	2	2	100.0	11600	450.0	555
30	76	4	2	61.8	8400	278.1	402
31	79	3	2	85.3	10400	383.8	498
32	81	2	2	100.0	11600	450.0	555
33	81	0	2	100.0	11600	450.0	555
34	84	3	2	85.3	10400	383.8	498
35	86	2	2	100.0	11600	450.0	555
36	87	1	2	100.0	11600	450.0	555
37	90	3	2	85.3	10400	383.8	498
38	91	1	2	100.0	11600	450.0	555
39	93	2	2	100.0	11600	450.0	555
40	93	0	2	100.0	11600	450.0	555
41	97	4	2	61.8	8400	278.1	402
42	100	3	2	85.3	10400	383.8	498
43	100	0	2	100.0	11600	450.0	555
44	102	2	2	100.0	11600	450.0	555
45	104	2	2	100.0	11600	450.0	555
46	105	1	2	100.0	11600	450.0	555
47	108	3	2	85.3	10400	383.8	498
48	107	0	2	100.0	11600	450.0	555
49	109	2	2	100.0	11600	450.0	555
50	111	2	2	100.0	11600	450.0	555
51	114	3	2	85.3	10400	383.8	498
52	115	1	2	100.0	11600	450.0	555
53	118	3	2	85.3	10400	383.8	498
54	120	2	2	100.0	11600	450.0	555
55	119	0	2	100.0	11600	450.0	555
56	121	2	2	100.0	11600	450.0	555
57	123	2	2	100.0	11600	450.0	555
58	125	2	2	100.0	11600	450.0	555
59	128	3	2	85.3	10400	383.8	498
60	130	2	2	100.0	11600	450.0	555
61	131	1	2	100.0	11600	450.0	555
62	133	2	2	100.0	11600	450.0	555
63	133	0	2	100.0	11600	450.0	555
64	136	3	2	85.3	10400	383.8	498
65	137	1	2	100.0	11600	450.0	555
66	139	2	2	100.0	11600	450.0	555
67	142	3	2	85.3	10400	383.8	498

68	143	1	2	100.0	11600	450.0	555
69	146	3	2	85.3	10400	383.8	498
70	146	0	2	100.0	11600	450.0	555
71	148	2	2	100.0	11600	450.0	555
72	150	2	2	100.0	11600	450.0	555
73	151	1	2	100.0	11600	450.0	555
74	154	3	2	85.3	10400	383.8	498
75	156	2	2	100.0	11600	450.0	555
76	157	1	2	100.0	11600	450.0	555
77	160	3	2	85.3	10400	383.8	498
78	160	0	2	100.0	11600	450.0	555
79	161	1	2	100.0	11600	450.0	555
80	163	2	2	100.0	11600	450.0	555
81	166	3	2	85.3	10400	383.8	498
82	168	2	2	100.0	11600	450.0	555
83	170	2	2	100.0	11600	450.0	555
84	172	2	2	100.0	11600	450.0	555
85	172	0	2	100.0	11600	450.0	555
86	174	2	2	100.0	11600	450.0	555
87	177	3	2	85.3	10400	383.8	498
88	179	2	2	100.0	11600	450.0	555
89	184	5	2	48.1	7100	216.4	340
90	185	1	2	100.0	11600	450.0	555

Output Results PDF Pages

DCPAL

DCP Analysis Tool for ALDOT

Current Version: Alpha 1.0 Date: October 4, 2020

Operator and Project Information

Project Name: ALDOT Highway
DCP Test Station: Station 01
Analysis Date: 10/4/2020
Operator Name: Emily Mueller
Number of Tests: 3

Calculated Strength and Acceptance Results

Station Test Outcome = **Pass w/o Pay Reduction**
Compressive Strength = **280** **psi**
Pay Reduction* = **0.0** %

* Calculated in accordance with ALDOT 304 2014

Summary of Outlier Error Input & Analysis Results

Test	Range**	Used in Analysis?
1	**12%**	Included
2	**12%**	Included
3	**12%**	Included
4	**N/A**	N/A
5	**N/A**	N/A

Outlier Error Range Limit: 50 %

** Range determined by all included tests

Note:
If all tests are listed as "Included" but one test Range is different, this indicates that the user chose to include a test that was calculated as an outlier.

1 Developer: Emily Mueller, 2020

DCPAL	DCP Analysis Tool for ALDOT	Current Version: Alpha 1.0 Date: October 4, 2020

Summary of User-Defined Strength Limits

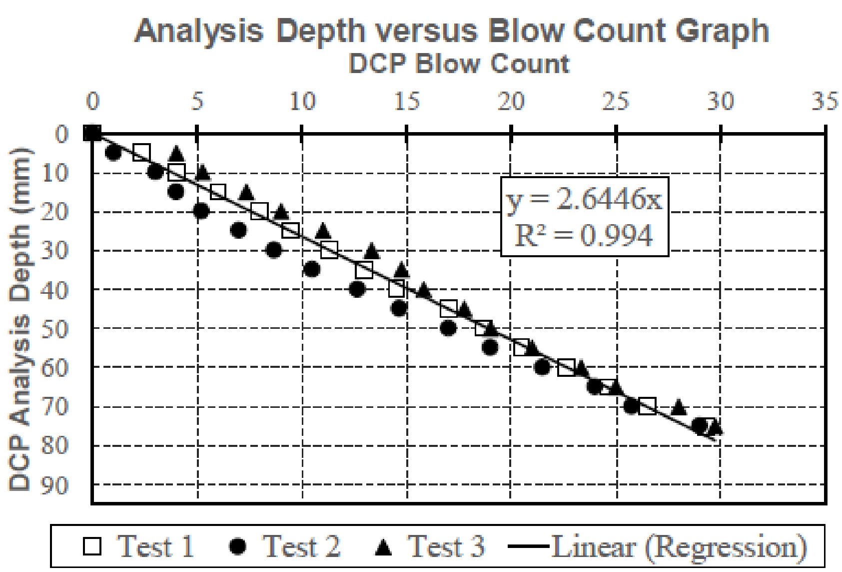
	Minimum		Maximum
Accept Without Pay Reduction	250 psi	to	600 psi
Accept With Pay Reduction	200 psi	to	650 psi

Summary of Strength-to-DCP Relationship

Relationship Equation: S = 1220 x e (-0.559 x slope)

Analysis Depth: 75 mm

Calculated DCP Slope = **2.645** mm/blow



Developer: Emily Mueller, 2020

Appendix F

Outcome #2

Data File #1

DCP - Survey Report
Date/Time: Sample
File Name: Sample
Serial Number: A330
Test Number: Sample
Company: AUBURN UNIV
Project: Sample ,
Operator: Sample
Location: Sample ,
Station: +
Soil Type: O (Other)
Soil Class: SOIL CEMENT
Hammer Mass: 8.0 kg
Comments:
End Comments:

Blow #	Depth	D/B	Total	CBR	Bearing	Uc	Bearing		
	mm	mm/Blow		mm/Blow		%	psf	psi	Kpa
0	0	0	0	0.0	0	0.0	0		
1	4	4	4	61.8	8400	278.1	402		
2	5	1	2	100.0	11600	450.0	555		
3	11	4	3	61.8	8400	278.1	402		
4	15	2	2	100.0	11600	450.0	555		
5	20	1	2	100.0	11600	450.0	555		
6	26	3	2	85.3	10400	383.8	498		
7	31	3	2	85.3	10400	383.8	498		
8	37	2	2	100.0	11600	450.0	555		
9	45	3	2	85.3	10400	383.8	498		
10	49	3	2	85.3	10400	383.8	498		
11	53	3	2	85.3	10400	383.8	498		
12	59	2	2	100.0	11600	450.0	555		
13	62	4	2	61.8	8400	278.1	402		
14	69	3	2	85.3	10400	383.8	498		
15	78	2	2	100.0	11600	450.0	555		
16	86	4	2	61.8	8400	278.1	402		
17	95	3	2	85.3	10400	383.8	498		
18	105	4	2	61.8	8400	278.1	402		
19	114	2	2	100.0	11600	450.0	555		
20	121	3	2	85.3	10400	383.8	498		
21	126	3	2	85.3	10400	383.8	498		
22	129	1	2	100.0	11600	450.0	555		
23	133	4	2	61.8	8400	278.1	402		
24	136	1	2	100.0	11600	450.0	555		
25	139	2	2	100.0	11600	450.0	555		
26	145	3	2	85.3	10400	383.8	498		
27	153	2	2	100.0	11600	450.0	555		
28	159	3	2	85.3	10400	383.8	498		
29	168	1	2	100.0	11600	450.0	555		
30	174	3	2	85.3	10400	383.8	498		
31	177	2	2	100.0	11600	450.0	555		
32	181	3	2	85.3	10400	383.8	498		

Data File #2

DCP - Survey Report
Date/Time: Sample
File Name: Sample
Serial Number: A330
Test Number: Sample
Company: AUBURN UNIV
Project: Sample ,
Operator: Sample
Location: Sample ,
Station: +
Soil Type: O (Other)
Soil Class: SOIL CEMENT
Hammer Mass: 8.0 kg
Comments:
End Comments:

Blow #	Depth	D/B	Total	CBR	Bearing	Uc	Bearing		
	mm	mm/Blow		mm/Blow		%	psf	psi	Kpa
0	0	0	0	0.0	0	0.0	0		
1	4	4	4	61.8	8400	278.1	402		
2	6	2	3	100.0	11600	450.0	555		
3	8	2	2	100.0	11600	450.0	555		
4	10	2	2	100.0	11600	450.0	555		
5	12	2	2	100.0	11600	450.0	555		
6	14	2	2	100.0	11600	450.0	555		
7	17	3	2	85.3	10400	383.8	498		
8	20	3	2	85.3	10400	383.8	498		
9	22	2	2	100.0	11600	450.0	555		
10	26	4	2	61.8	8400	278.1	402		
11	29	3	2	85.3	10400	383.8	498		
12	31	2	2	100.0	11600	450.0	555		
13	34	3	2	85.3	10400	383.8	498		
14	38	4	2	61.8	8400	278.1	402		
15	41	3	2	85.3	10400	383.8	498		
16	45	4	2	61.8	8400	278.1	402		
17	48	3	2	85.3	10400	383.8	498		
18	51	3	2	85.3	10400	383.8	498		
19	55	4	2	61.8	8400	278.1	402		
20	59	4	2	61.8	8400	278.1	402		
21	61	2	2	100.0	11600	450.0	555		
22	64	3	2	85.3	10400	383.8	498		
23	67	3	2	85.3	10400	383.8	498		
24	70	3	2	85.3	10400	383.8	498		
25	72	2	2	100.0	11600	450.0	555		
26	75	3	2	85.3	10400	383.8	498		
27	77	2	2	100.0	11600	450.0	555		
28	79	2	2	100.0	11600	450.0	555		
29	82	3	2	85.3	10400	383.8	498		
30	84	2	2	100.0	11600	450.0	555		
31	85	1	2	100.0	11600	450.0	555		
32	88	3	2	85.3	10400	383.8	498		
33	89	1	2	100.0	11600	450.0	555		
34	91	2	2	100.0	11600	450.0	555		
35	93	2	2	100.0	11600	450.0	555		
36	95	2	2	100.0	11600	450.0	555		
37	97	2	2	100.0	11600	450.0	555		
38	99	2	2	100.0	11600	450.0	555		
39	101	2	2	100.0	11600	450.0	555		
40	103	2	2	100.0	11600	450.0	555		

41	106	3	2	85.3	10400	383.8	498
42	107	1	2	100.0	11600	450.0	555
43	110	3	2	85.3	10400	383.8	498
44	112	2	2	100.0	11600	450.0	555
45	115	3	2	85.3	10400	383.8	498
46	118	3	2	85.3	10400	383.8	498
47	121	3	2	85.3	10400	383.8	498
48	125	4	2	61.8	8400	278.1	402
49	129	4	2	61.8	8400	278.1	402
50	130	1	2	100.0	11600	450.0	555
51	134	4	2	61.8	8400	278.1	402
52	138	4	2	61.8	8400	278.1	402
53	144	6	2	39.3	6200	176.8	296
54	150	6	2	39.3	6200	176.8	296
55	157	7	2	33.0	5600	148.5	268
56	165	8	2	28.4	5000	127.8	239
57	175	10	3	22.2	4300	99.9	205
58	190	15	3	14.1	3200	63.4	153

Data File #3

DCP - Survey Report
Date/Time: Sample
File Name: Sample
Serial Number: A330
Test Number: Sample
Company: Sample
Project: Sample ,
Operator: Sample
Location: Sample ,
Station: +
Soil Type: O (Other)
Soil Class: SOIL CEMENT
Hammer Mass: 8.0 kg
Comments:
End Comments:

Blow #	Depth	D/B	Total	CBR	Bearing	Uc	Bearing		
	mm	mm/Blow		mm/Blow		%	psf	psi	Kpa
0	0	0	0	0.0	0	0.0	0		
1	4	4	4	61.8	8400	278.1	402		
2	6	2	3	100.0	11600	450.0	555		
3	9	3	3	85.3	10400	383.8	498		
4	12	3	3	85.3	10400	383.8	498		
5	14	2	2	100.0	11600	450.0	555		
6	16	2	2	100.0	11600	450.0	555		
7	20	4	2	61.8	8400	278.1	402		
8	23	3	2	85.3	10400	383.8	498		
9	27	4	3	61.8	8400	278.1	402		
10	29	2	2	100.0	11600	450.0	555		
11	33	4	3	61.8	8400	278.1	402		
12	37	4	3	61.8	8400	278.1	402		
13	40	3	3	85.3	10400	383.8	498		
14	43	3	3	85.3	10400	383.8	498		
15	46	3	3	85.3	10400	383.8	498		
16	50	4	3	61.8	8400	278.1	402		
17	54	4	3	61.8	8400	278.1	402		
18	57	3	3	85.3	10400	383.8	498		
19	61	4	3	61.8	8400	278.1	402		
20	63	2	3	100.0	11600	450.0	555		

21	66	3	3	85.3	10400	383.8	498
22	68	2	3	100.0	11600	450.0	555
23	71	3	3	85.3	10400	383.8	498
24	73	2	3	100.0	11600	450.0	555
25	77	4	3	61.8	8400	278.1	402
26	80	3	3	85.3	10400	383.8	498
27	82	2	3	100.0	11600	450.0	555
28	84	2	3	100.0	11600	450.0	555
29	87	3	3	85.3	10400	383.8	498
30	89	2	2	100.0	11600	450.0	555
31	92	3	2	85.3	10400	383.8	498
32	94	2	2	100.0	11600	450.0	555
33	96	2	2	100.0	11600	450.0	555
34	98	2	2	100.0	11600	450.0	555
35	101	3	2	85.3	10400	383.8	498
36	103	2	2	100.0	11600	450.0	555
37	105	2	2	100.0	11600	450.0	555
38	107	2	2	100.0	11600	450.0	555
39	109	2	2	100.0	11600	450.0	555
40	111	2	2	100.0	11600	450.0	555
41	113	2	2	100.0	11600	450.0	555
42	115	2	2	100.0	11600	450.0	555
43	117	2	2	100.0	11600	450.0	555
44	119	2	2	100.0	11600	450.0	555
45	121	2	2	100.0	11600	450.0	555
46	122	1	2	100.0	11600	450.0	555
47	124	2	2	100.0	11600	450.0	555
48	126	2	2	100.0	11600	450.0	555
49	129	3	2	85.3	10400	383.8	498
50	130	1	2	100.0	11600	450.0	555
51	133	3	2	85.3	10400	383.8	498
52	135	2	2	100.0	11600	450.0	555
53	136	1	2	100.0	11600	450.0	555
54	139	3	2	85.3	10400	383.8	498
55	140	1	2	100.0	11600	450.0	555
56	143	3	2	85.3	10400	383.8	498
57	145	2	2	100.0	11600	450.0	555
58	147	2	2	100.0	11600	450.0	555
59	149	2	2	100.0	11600	450.0	555
60	151	2	2	100.0	11600	450.0	555
61	153	2	2	100.0	11600	450.0	555
62	155	2	2	100.0	11600	450.0	555
63	156	1	2	100.0	11600	450.0	555
64	159	3	2	85.3	10400	383.8	498
65	160	1	2	100.0	11600	450.0	555
66	163	3	2	85.3	10400	383.8	498
67	165	2	2	100.0	11600	450.0	555
68	168	3	2	85.3	10400	383.8	498
69	173	5	2	48.1	7100	216.4	340
70	181	8	2	28.4	5000	127.8	239

Output Results PDF Pages

DCPAL

DCP Analysis Tool for ALDOT

Current Version: Alpha 1.0 Date: October 4, 2020

Operator and Project Information

Project Name: ALDOT Highway

DCP Test Station: Station 02

Analysis Date: 10/4/2020

Operator Name: Emily Mueller

Number of Tests: 3

Calculated Strength and Acceptance Results

Station Test Outcome = Pass w/ Pay Reduction

Compressive Strength = 235 psi

Pay Reduction* = 6.0 %

* Calculated in accordance with ALDOT 304 2014

Summary of Outlier Error Input & Analysis Results

Test	Range**	Used in Analysis?
1	56%	Discarded
2	9%	Included
3	9%	Included
4	N/A	N/A
5	N/A	N/A

Outlier Error Range Limit: 50 %

** Range determined by all included tests

Note:
If all tests are listed as "Included" but one test Range is different, this indicates that the user chose to include a test that was calculated as an outlier.

1 Developer: Emily Mueller, 2020

DCPAL

DCP Analysis Tool for ALDOT

Current Version: Alpha 1.0
Date: October 4, 2020

Summary of User-Defined Strength Limits

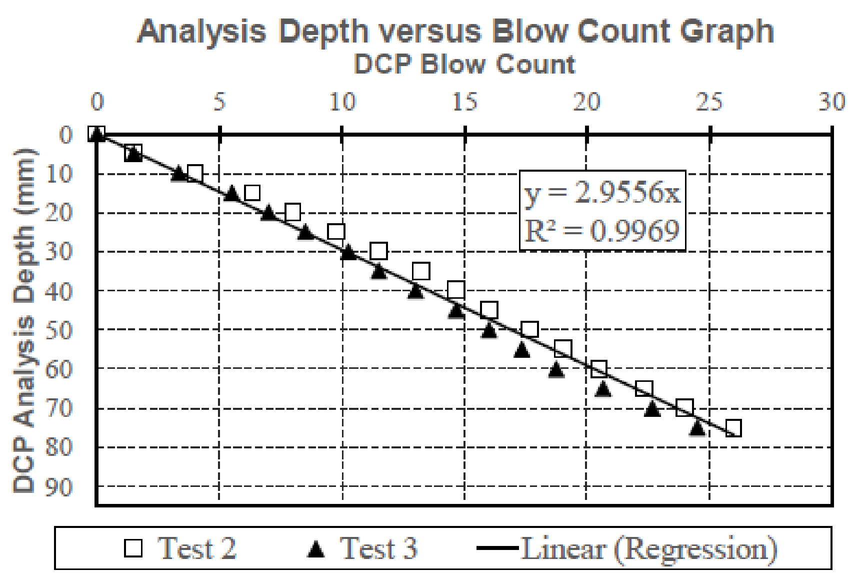
	Minimum		Maximum
Accept Without Pay Reduction	250 psi	to	600 psi
Accept With Pay Reduction	200 psi	to	650 psi

Summary of Strength-to-DCP Relationship

Relationship Equation: S = 1220 x e (-0.559 x slope)

Analysis Depth: 75 mm

Calculated DCP Slope = **2.956** mm/blow

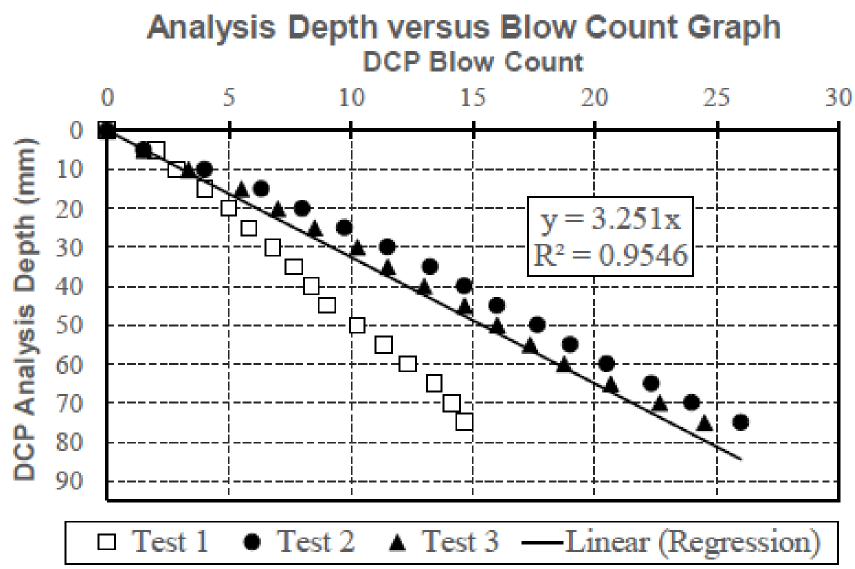


Developer: Emily Mueller, 2020

DCPAL	DCP Analysis Tool for ALDOT	Current Version: Alpha 1.0 Date: October 4, 2020

Information for All Tests Included	
Depth	Slope
75 mm	3.251 mm/blow

NOTICE: This sheet is only provided to help the user evaluate the effect of analyzing all test data. However, because a test was discarded, this graph should not be used for acceptance in accordance with ALDOT 304 2014.



Developer: Emily Mueller, 2020

Appendix G

Outcome #3

Data File #1

This is a template file to be used with DCPAL if a magnetic ruler was not used to collect data.

Please type the Blow Count (number) and the Depth (millimeters) in the designated locations as shown by the sample Depth values.

The depth values in this file are after the seating depth of 25 millimeters as designated by ASTM D6951 (2018) These values correspond to the Analysis Depth in the software.

If additional rows are needed, separate the Blow Count # and the Depth by a "tab" using the Tab key instead of using the Spacebar.

Test Date: 10/04/2020
Test #: 01
Additional Info: Sample File

Blow #	Depth mm
0	0
1	4
2	6
3	9
4	11
5	14
6	18
7	20
8	23
9	27
10	31
11	35
12	39
13	42
14	45
15	49
16	52
17	55
18	58
19	61
20	64
21	68
22	69
23	71
24	74
25	76
26	79
27	81
28	83
29	84
30	87
31	89
32	90
33	93
34	95
35	96

36	100
37	102
38	105
39	108
40	110
41	112
42	115
43	118
44	121
45	124
46	127
47	130
48	134
49	137
50	143
51	154
52	162
53	172
54	185
55	205

Data File #2

This is a template file to be used with DCPAL if a magnetic ruler was not used to collect data.

Please type the Blow Count (number) and the Depth (millimeters) in the designated locations as shown by the sample Depth values.

The depth values in this file are after the seating depth of 25 millimeters as designated by ASTM D6951 (2018) These values correspond to the Analysis Depth in the software.

If additional rows are needed, separate the Blow Count # and the Depth by a "tab" using the Tab key instead of using the Spacebar.

Test Date: 10/04/2020
Test #: 02
Additional Info: Sample File

Blow #	Depth mm
0	0
1	4
2	6
3	11
4	15
5	20
6	26
7	33
8	39
9	48
10	53
11	60
12	69
13	78
14	89
15	101
16	115
17	120
18	125
19	127

20	129
21	130
22	131
23	131
24	132
25	135
26	140
27	144
28	147
29	151
30	155
31	159
32	163
33	169
34	171
35	172
36	174
37	176
38	178
39	184

Data File #3

This is a template file to be used with DCPAL if a magnetic ruler was not used to collect data.

Please type the Blow Count (number) and the Depth (millimeters) in the designated locations as shown by the sample Depth values.

The depth values in this file are after the seating depth of 25 millimeters as designated by ASTM D6951 (2018)
These values correspond to the Analysis Depth in the software.

If additional rows are needed, separate the Blow Count # and the Depth by a "tab" using the Tab key instead of using the Spacebar.

Test Date: 10/04/2020
Test #: 03
Additional Info: Sample File

Blow #	Depth mm
0	0
1	4
2	7
3	9
4	11
5	14
6	19
7	21
8	22
9	27
10	30
11	36
12	40
13	43
14	48
15	52
16	56
17	61
18	63
19	66

20	67
21	70
22	73
23	75
24	78
25	79
26	82
27	85
28	88
29	90
30	92
31	93
32	96
33	98
34	100
35	102
36	104
37	106
38	107
39	109
40	112
41	115
42	118
43	120
44	123
45	126
46	129
47	131
48	133
49	136
50	143
51	145
52	147
53	149
54	153
55	156
56	158
57	160
58	167
59	173
60	182

Output Results PDF Pages

DCPAL

DCP Analysis Tool for ALDOT

Current Version: Alpha 1.0 **Date: October 4, 2020**

Operator and Project Information

Project Name:	ALDOT Highway
DCP Test Station:	Station 03
Analysis Date:	10/4/2020
Operator Name:	Emily Mueller
Number of Tests:	3

Calculated Strength and Acceptance Results

Station Test Outcome =	Remove and Replace
Compressive Strength =	**165** psi
Pay Reduction* =	**N/A** %

* Calculated in accordance with ALDOT 304 2014

Summary of Outlier Error Input & Analysis Results

Test	Range**	Used in Analysis?
1	6%	Included
2	55%	Included
3	6%	Included
4	N/A	N/A
5	N/A	N/A

Outlier Error Range Limit: 50 %

** Range determined by all included tests

Note:
If all tests are listed as "Included" but one test Range is different, this indicates that the user chose to include a test that was calculated as an outlier.

1 Developer: Emily Mueller, 2020

DCPAL

DCP Analysis Tool for ALDOT

Current Version: Alpha 1.0
Date: October 4, 2020

Summary of User-Defined Strength Limits

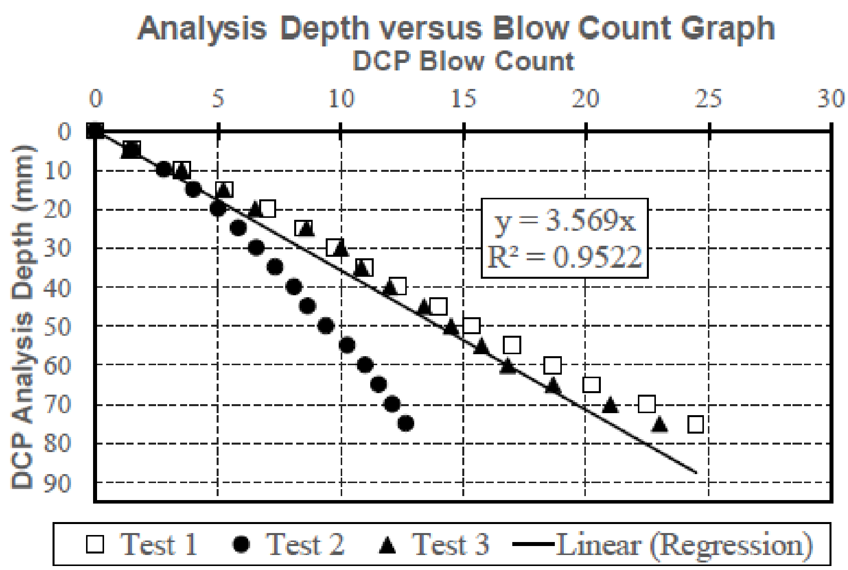
Accept Without Pay Reduction	Minimum 250 psi	to	Maximum 600 psi
Accept With Pay Reduction	Minimum 200 psi	to	Maximum 650 psi

Summary of Strength-to-DCP Relationship

Relationship Equation: S = 1220 x e (-0.559 x slope)

Analysis Depth: 75 mm

Calculated DCP Slope = 3.569 mm/blow



Developer: Emily Mueller, 2020