Low-Cost Rural Surface Alternatives Phase III: Demonstration Project

Final Report
April 2022

IOWA STATE UNIVERSITY
Institute for Transportation

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16. Abstract

The goal of this project was to identify effective and economical methods for stabilizing Iowa granular-surfaced roads to reduce freeze-thaw-related damage using materials and construction equipment that are readily available to county engineer's offices. To study a range of representative Iowa aggregate sources, subgrade soil types, and weather conditions, 31 test sections were constructed and/or monitored in four counties across Iowa. The test sections included one control section in each county and several mechanical and chemical stabilization methods.

The performance of the stabilized and control sections was evaluated over two years using extensive field and laboratory tests, as well as digital image surveys and surface condition rating reports completed by the grader operators. The field tests included falling weight deflectometer (FWD), lightweight deflectometer (LWD), dynamic cone penetrometer (DCP), and nuclear density gauge (NDG) tests. Samples of the surfacing materials were collected on several occasions before and after each winter and were evaluated through laboratory tests including sieve analysis, Atterberg limits, compaction, shear strength, and durability tests. The construction costs and maintenance costs were tracked with the assistance of the county engineers, and an economic analysis was conducted to compare the relative cost effectiveness of the different stabilization methods.

Among the stabilization methods examined, the most economical and potentially effective were optimized gradation with clay slurry (OGCS), 4 in. cement-treated surface course, and the liquid chemical stabilizers BASE ONE, EMC SQUARED, and Claycrete.

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EXECUTIVE SUMMARY

The goal of this project was to identify effective and economical methods for stabilizing Iowa granular-surfaced roads to reduce freeze-thaw-related damage using materials and construction equipment that are readily available to county engineer's offices.

To study a range of representative Iowa aggregate sources, subgrade soil types, and weather conditions, 31 test sections were constructed and/or monitored in four counties across Iowa. The test sections included one control section in each county, and several mechanical and chemical stabilization methods. The following eight types of mechanically stabilized test sections were selected for construction in Howard and Cherokee counties:

1. Aggregate columns
2. Optimized gradation with clay slurry (OGCS)
3. Ground tire rubber mixed at 20% by volume in a 2 in. base layer of aggregate and covered by a 2 in. surface layer of aggregate (in Howard County only)
4. Recycled asphalt pavement (RAP) mixed at 50% by volume with aggregates
5. 2 in. Harsco slag surface over 2 in. existing aggregate base
6. 2 in. Phoenix slag surface over 2 in. existing aggregate base
7. 4 in. Harsco slag surface over subgrade
8. 4 in. Phoenix slag surface over subgrade

The following five types of chemically stabilized test sections were constructed in Washington and Hamilton counties:

1. Cement-treated subgrade (in Washington County only)
2. Cement-treated aggregate surface course (in Washington County only)
3. BASE ONE (a silicic acid, sodium salt, concentrated liquid stabilizer)
4. EMC SQUARED 1000 (a neutral pH, non-ionic, concentrated liquid stabilizer)
5. Claycrete (an ionic, concentrated liquid stabilizer)

Additionally, because of the favorable performance of the aggregate columns and OGCS methods in the Phase II project, they were also used to construct mechanically stabilized test sections using these methods in Washington and Howard counties.

The performance of the stabilized and control sections was evaluated over two years using extensive field and laboratory tests, as well as digital image surveys and surface condition rating reports, which were completed by the grader operators.

The field tests included falling weight deflectometer (FWD), lightweight deflectometer (LWD), dynamic cone penetrometer (DCP), and nuclear density gauge (NDG) tests. Samples of the surfacing materials were collected on several occasions before and after each winter and were evaluated through laboratory tests including sieve analysis, Atterberg limits, compaction, shear strength, and durability tests.

Construction and maintenance costs were tracked with the assistance of the county engineers, and an economic analysis was conducted to compare the relative cost effectiveness of the different stabilization methods.

The construction and maintenance costs were analyzed using data provided by the county engineers. Except for the cement-stabilized subgrade method, which had the highest construction cost due to the equipment and materials required, the other stabilization methods examined were relatively economical as they required materials and equipment that are readily obtainable by counties and used conventional construction methods.

Overall, the Claycrete, EMC SQUARED, and BASE ONE sections had the lowest construction plus maintenance costs, followed by the average costs of the OGCS and aggregate columns sections, and then the 4 in. cement-treated surface course. The RAP sections had relatively high materials cost with little improvement in performance, while the four types of slag sections had relatively higher construction costs, primarily due to the large hauling costs involved.

The laboratory and field tests revealed that many of the test sections remained stabilized long after construction, but their performance varied considerably. Additionally, the ground tire rubber section failed because the surface course was too unstable immediately after construction.

Overall observations and conclusions based on the results of this project are as follows:

The OGCS sections generally exhibited good strength performance based on DCP-California bearing ratio (-CBR) tests and good surface course elastic modulus values from LWD and FWD tests. Based on the improved performance and relatively economical construction and maintenance costs, the OGCS method is considered cost-effective. The manufacturer now offers a pre-treated and dried aggregate instead of a clay slurry, which should reduce construction costs.

The RAP sections showed marginal improvements in strength over that of the control sections and no improvement in modulus from LWD and FWD tests. Considering the lack of performance and the rising cost of RAP due to its increasing demand for pavement construction, it is not considered to be a cost-effective stabilization method.

All of the steel slag sections showed good initial strength and stiffness after construction, but strength decreased significantly over the two-year period of the study. Due to the high hauling costs involved, this method may only be economical for counties located near slag sources.

The aggregate columns sections did not perform better than the control sections in this Phase III study. The columns used in this study were larger 12 in. diameter by 7 ft deep ones, whereas, smaller 8 in. diameter by 6 ft deep columns performed very well in the previous Phase II study.

The 12 in. cement-treated subgrade section showed extraordinary improvements in strength and stiffness. However, it was not economical compared to the other stabilization methods examined.

The 4 in. cement-treated surface section showed excellent strength performance and was relatively economical to construct. However, it did exhibit several potholes requiring application of surfacing aggregates after two years. For this method, engineers need to factor in the material and hauling costs for portland cement, as well as the cost to rent a milling attachment if they do not already own one.

The three concentrated liquid stabilizers (BASE ONE, EMC SQUARED, and Claycrete) had similar construction costs that were among the most economical of all stabilization methods examined. These methods all showed good performance in Hamilton County, but did not perform as well in Washington County. Further studies are recommended to examine how their effectiveness using Iowa soils and aggregates can be improved and to study the influence of the type and gradation of both surfacing aggregates and subgrade soils using careful construction control measures.

CHAPTER 1 INTRODUCTION

1.1 Problem Statement

Granular-surfaced roads throughout Iowa are subjected to large numbers of freeze-thaw cycles and significant traffic loads from heavy agricultural machinery. Frost boils, potholes, and rutting occur on granular road surfaces after each freeze-thaw cycle season. Under these conditions, granular roadways deteriorate significantly and can require significant maintenance and rehabilitation. As a result, many counties spend significant portions of their roadway budgets on maintenance and rehabilitation.

Most of the damage occurs in the spring thaw period, when liquid water cannot drain efficiently and becomes trapped above the zone of frozen soil, causing the saturated unbound granular materials to lose strength. Moreover, heavy agricultural traffic loads in spring and low-strength aggregate sources in some regions of Iowa further compound the problems, leading some county engineers to post load restrictions or frost embargos.

The approaches typically used by county engineers to deal with moisture-related damage include temporarily spreading rock on the affected areas, lowering or improving drainage ditches, tiling, bridging the areas with stone and geosynthetic covered by a top course of aggregate or gravel, coring boreholes and filling them with calcium chloride to melt lenses and provide drainage, and regrading the crown to a slope of 4% to 6% to maximize spring drainage. However, most of these maintenance solutions are aimed at dealing with frost boils after they occur.

To prevent or minimize freeze-thaw damage in the first place, literature on a range of potential stabilization technologies, including chemical (e.g., fly ash, polymers), mechanical (e.g., geogrids, geocomposites), and biological methods (e.g., lignin, enzymes, organic liquids), was studied in a previous Iowa Highway Research Board (IHRB) project (White and Vennapusa 2013).

In the previous Phase II IHRB Low-Cost Rural Surface Alternatives: Demonstration Project (Li et al. 2015), several of the identified stabilization methods were implemented to improve the performance and minimize freeze-thaw damage of granular-surfaced roads. Test sections were constructed over a two-mile stretch of heavily traveled roadway that required frequent maintenance, and the performance of test and control sections was assessed via extensive field testing over a period of two years. Several of the stabilization methods were demonstrated to greatly improve performance and reduce maintenance costs over the duration of the project.

1.2 Goal and Objectives of the Research

This Phase III project was a continued investigation for which additional chemical and mechanical stabilization methods were studied. The primary goal of this project was to identify additional practical and effective stabilization methods for granular roadways in Iowa by testing the performance and evaluating the construction and maintenance costs of several stabilization methods selected in consultation with the project technical advisory committee (TAC).

Additional goals of this Phase III demonstration project were to distribute test sections in four counties across Iowa to cover a wider range of aggregate sources, subgrade soil types, and weather conditions than the previous Phase II project and identify methods that counties can implement using their own staff and equipment or equipment that can easily be rented.

The specific objectives of this research project were as follows:

- Construct mechanically and chemically stabilized test sections in four counties across Iowa
- Perform extensive laboratory and field tests to characterize the materials and assess the field performance and maintenance requirements of the various stabilization methods after seasonal freeze-thaw cycles
- Assess the construction and maintenance costs and identify effective and economical stabilization methods for the soil and climate conditions of Iowa
- Translate the research results into practice

1.3 Test Sites and Stabilization Methods

For this study, 31 test sections were constructed and/or monitored in four counties across Iowa. The selected test sites were as follows: (1) Vail Avenue between 300th Street and 310th Street in Hamilton County, (2) Old 21 Road between 480th Street and 490th Street in Cherokee County, (3) 100th Street between Pine Avenue and Quail Avenue in Howard County, and (4) 260th Street between Palm Avenue and Quince Avenue in Washington County.

All four locations had similar annual average daily traffic (AADT) levels, which were estimated at 70 vehicles per day (vpd) for Hamilton County, 100 vpd for Cherokee County (increasing to 160 vpd for the aggregate columns section), 90 vpd for Washington County, and 110 vpd for Howard County. These test sites were also selected because they exhibited frost boil problems and experienced high volumes of heavy truck and concentrated animal feeding operation (CAFO) traffic.

In consultation with the TAC, the following eight types of mechanically stabilized test sections were selected for construction in Howard and Cherokee counties:

1. Aggregate columns
2. Optimized gradation with clay slurry (OGCS)
3. Ground tire rubber mixed at 20% by volume in a 2 in. base layer of aggregate and covered by a 2 in. surface layer of aggregate (in Howard County only)
4. Recycled asphalt pavement (RAP) mixed at 50% by volume with aggregates
5. 2 in. Harsco slag surface over 2 in. existing aggregate base
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The following five types of chemically stabilized test sections were constructed in Washington and Hamilton counties:

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3. BASE ONE (a silicic acid, sodium salt, concentrated liquid stabilizer)
4. EMC SQUARED 1000 (a neutral pH, non-ionic, concentrated liquid stabilizer)
5. Claycrete (an ionic, concentrated liquid stabilizer)

Based on the favorable performance of the mechanical aggregate columns and OGCS methods in the Phase II project, they were also used to construct additional construct mechanically stabilized test sections using these methods in Washington and Hamilton counties. This enabled additional data on the performance of these two methods to be obtained for the full range of material and weather types encountered in the four counties.

The performance of the stabilized test sections was evaluated over a period of two years through extensive field and laboratory tests, as well as digital image surveys and surface condition rating reports, which were completed by the grader operators.

The field tests included falling weight deflectometer (FWD), lightweight deflectometer (LWD), dynamic cone penetrometer (DCP), and nuclear density gauge (NDG) tests. Samples of the surfacing materials were collected on several occasions before and after each winter and were evaluated through laboratory tests including sieve analysis, Atterberg limits, compaction, shear strength, and durability tests.

Construction and maintenance costs were tracked with the assistance of the county engineers, and an economic analysis was conducted to compare the relative cost effectiveness of the different stabilization methods.

1.4 Organization of the Report

Chapter 2 of this report provides a discussion of background information including results of the previous Phase II study. Chapter 3 details the laboratory and field test methods used. Chapter 4 provides information on the sources and properties of the various surfacing and stabilization materials used in the study. Chapter 5 describes the methods and procedures used during the construction of the field test sections. Chapter 6 summarizes the field and laboratory performance results and cost analyses. Chapter 7 includes conclusions and recommendations for further research. Supporting materials are provided in Appendices A through E.

CHAPTER 2 BACKGROUND

Freeze-thaw damage can be caused by several factors, such as frost-susceptible soils, a high groundwater table, poor subgrade drainage, heavy traffic loading, and frequent freeze-thaw cycling (Hoover et al. 1981, Kestler 2003, Henry et al. 2005, Saarenketo and Aho 2005, White and Vennapusa 2013). In the IHRB Low-Cost Rural Surface Alternatives Phase II: Demonstration Project (Li et al. 2015), several stabilization methods were implemented to improve the performance and minimize the freeze-thaw damage of granular-surfaced roads.

Twenty-two test sections (including five control sections) were constructed in Hamilton County on a heavily traveled two-mile section of granular-surfaced road that required frequent maintenance during previous spring thaw periods. Construction procedures and costs for the test sections were documented, and the maintenance requirements were tabulated through two winter-spring freeze-thaw seasons.

To monitor the performance of the test sections, extensive laboratory and field tests were performed prior to construction and before and after both freeze-thaw seasons.

A cost analysis was performed using the documented construction and maintenance costs, and the estimated cumulative costs per square yard were projected over a 20-year timeframe to determine break-even periods relative to the costs of the pre-existing maintenance practices.

The most effective and economical stabilization methods for the soil and climate conditions of Iowa were identified, with several of them greatly improving the longevity and performance of the roadway materials. Among the methods examined, aggregate columns had the lowest initial cost and were found to improve freeze-thaw performance by reducing the occurrence of frost-boils. However, rutting was occasionally observed near the shoulders outside the footprint of the columns.

In this Phase III study, a new pattern of aggregate columns with a denser grid was used to minimize such shoulder rutting.

In a later IHRB project titled Feasibility of Granular Road and Shoulder Recycling (Li et al. 2018a), pre-existing abraded granular surface materials were recycled by blending them with virgin aggregates in optimal proportions, and recommended construction procedures were developed. Using California bearing ratio (CBR) laboratory tests of existing granular surface materials and virgin aggregates blended in various ratios, the study showed that an optimized gradation of surface aggregates can greatly improve the strength and longevity of roadway surfaces while reducing freeze-thaw damage.

In this Phase III study, the gradation optimization program developed by Li and Ashlock (Li et al. 2018a, 2018b) was used to calculate the mixture proportions of existing aggregates with various virgin quarry materials to approach the optimal design gradations. To help bind the coarse aggregates and reduce material loss, the study also recommended mixing plastic fines into the top 2 to 3 in. of the granular surface course. The goal of this is to form a cohesive surface crust while preserving a cleaner, load-bearing, aggregate layer underneath, because, although the fines offer the benefit of cohesion, they can also greatly reduce the shear strength of granular materials under prolonged wet conditions (Li et al. 2018a).

By blending clay into the top few inches of the surface course, the fines can perform the desired function of binding the larger aggregates to reduce material loss while also preserving the shear strength of the aggregates in the lower layer. The previous study employed bags of powdered bentonite to achieve the desired plasticity, but this material was labor intensive to incorporate, and the bentonite content decreased significantly after one freeze-thaw season. Instead of using bentonite powder or searching for local clays, a newly available clay slurry from Pattison Sand Company in Clayton, Iowa, was blended into the top few inches of the optimized gradation mixture to achieve the desired increase in plasticity. The combination of the gradation optimization method with clay slurry added is referred to in this study as the optimized gradation with clay slurry or OGCS method.

Ramaji (2012) reviewed prior literature and reported that various types and sizes of waste rubber could provide low-cost and effective soil stabilization. In one case, triaxial tests of 3/16 in. × 3/16 in. (5 × 5 mm) tire shreds mixed with sand showed the greatest improvement in shear strength at a rubber content of 6% by weight (20% by volume), while CBR tests provided the highest penetration resistance at a rubber content of 3% by weight (10% by volume) for the same shred size (Hassona et al. 2003). In this Phase III study, ground tire rubber having a maximum size of 3/8 in. (9.5 × 9.5 mm) was mixed with aggregate at 20% by volume in the bottom half of a 4 in. thick granular surface course in Howard County.

RAP has been used in granular roads for many years. One of the beneficial effects of RAP is that it can help bind fines and coarse aggregates in the surface layer. Koch et al. (2011) investigated the use of RAP in gravel roads in two Wyoming counties and found that RAP was helpful for reducing dust but gave no improvement in road condition. However, the study also concluded that compacting a RAP blend with gravel can help maintain long-term road serviceability.

The two RAP demonstration sections in this Phase III study were constructed using a 50/50 mixture of locally available RAP and existing granular surface materials, which were sprayed with water and blade-mixed, then roller compacted.

Mathur et al. (1999) investigated the utilization of industrial wastes in low-volume roads and reported that steel slag, which is a very dense and hard material that can be readily crushed to a suitable particle shape and size, produces an excellent aggregate with high crushing strength, low abrasion, and excellent skid resistance. The researchers also concluded that the slag mixture initially behaves like an unbound material but generally stabilizes as it turns into a bound material.

In this Phase III study, eight steel slag sections were constructed in Howard and Cherokee counties using slag from two different sources. Because of the hardness of steel slag, it could accelerate the deterioration of natural aggregates if the two were blended. Therefore, the slag was not mixed with aggregates but was placed in uniform layers resting either on top of the subgrade or on top of a 2 in. thick aggregate layer.

In Henry et al. (2005), portland cement was mixed into native road surface materials at 6% to 8% by weight to create a stabilized surface course, which showed significantly improved CBR values in the top 3 in. of cement-treated soil during spring thawing.

In this Phase III study, two types of cement-treated test sections were constructed: 7% portland cement by weight mixed into a 4 in. thick surface aggregate course with an untreated subgrade and a 12 in. thick subgrade layer treated at 5% by weight with an untreated surface course.

A study by Jahren et al. (2011) showed that the liquid stabilizer BASE ONE can mechanically bind fine particles. Although it did not provide noticeable improvements on highway shoulders in that particular study, it can be easily applied with typical department of transportation (DOT) maintenance equipment, and other county engineers have reported performance improvements after using the product.

In this Phase III study, a representative from the manufacturer was present to oversee construction of the test sections to ensure good performance. Based on the manufacturer's recommendations, 0.5 in. of the subgrade was incorporated into a mixture of existing and virgin aggregate materials along with the liquid stabilizer to construct the test sections.

According to several case studies provided by Stabilization Products, LLC, their EMC SQUARED liquid stabilizer system has been used for more than three decades to improve several properties of earth materials, including freeze-thaw resistance, at low cost. To achieve the expected performance, the manufacturer recommended incorporating subgrade soils within the surface course to a total depth of 10 in. during treatment.

In this Phase III study, EMC SQUARED Stabilizer (1000) was incorporated into 4 in. of surface aggregate and 6 in. of subgrade materials in Washington County as targeted, but a reduced total depth of 7.5 in. (4.5 in. surface aggregate and 3 in. subgrade) was required in Hamilton County due to the presence of numerous large cobbles embedded in the subgrade.

Claycrete is an ionic liquid stabilizer for improving soils by removing the potential of clay platelets to bond with water. The effectiveness of Claycrete depends on the cation exchange capacity (CEC) of the minus #200 fraction, which is calculated as the product of the soil's plasticity index (PI) and the percent passing the #200 sieve. For example, a soil having 20% fines and a PI of 15 would have a CEC of 300. Claycrete is designed to be effective in soils with a CEC up to 400.

In this Phase III study, a representative from the manufacturer was on-site and instructed the county's crews in construction of the Claycrete test sections. Based on the representative's recommendations, about 0.5 in. of subgrade was incorporated with the surface course materials and liquid stabilizer to add the necessary percentage of fines while keeping the CEC within the acceptable range.

CHAPTER 3 TEST METHODS

This chapter details the methods used in this Phase III study for both laboratory and field tests. Laboratory tests were conducted to determine soil classification, index properties, abrasion resistance, and compaction behavior of the surface and subgrade materials, while field tests were performed to investigate the mechanistic properties of the surface and subgrade layers including strength, stiffness, in situ moisture content, dry unit weight, and dust generation.

3.1 Laboratory Tests

Laboratory tests including sieve analysis, Atterberg limits, Proctor compaction, and CBR were conducted to determine the particle size distributions, consistency limits, maximum dry unit weights (γ_{dmax}), optimum moisture contents (w_{opt}), shear strengths, and compaction characteristics of the various subgrade and surface materials.

3.1.1 Soil Index Properties Tests

Soil index properties were determined for the classification of soils and other geomaterials. The tests included sieve analysis, hydrometer tests, and Atterberg limit tests. Soil classifications were determined according to the Unified Soil Classification System (USCS) and American Association of State Highway and Transportation Officials (AASHTO) system.

3.1.1.1 Particle Size Distribution Tests

Particle size analyses were performed in accordance with ASTM D6913/D6913M-17 *Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis* and D7928-17 *Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis*. Sieve sizes were in the range of 1.5 in. (75 mm) to sieve #200 (75 µm). To determine the size distribution of fine particles (i.e., particles passing the #200 sieve), hydrometer tests were conducted on air-dried samples passing the #10 (2 mm) sieve. To obtain representative samples, a riffle sample splitter was used according to the method in ASTM D6913. Figure 1 and Figure 2 show the equipment used for sieve analysis and hydrometer analysis, respectively.

Figure 1. Sieves and shaker

Figure 2. Hydrometer test equipment

3.1.1.2 Atterberg Limit Tests

Liquid limit and plastic limit tests were performed on materials passing the #40 (425 μm) sieve. The liquid limit was determined using the fall cone test method as described in Wasti (1987), and the plastic limit test was performed using an acrylic plastic limit rolling device as per ASTM D4318-17e1 *Standard Test Methods for Liquid, Plastic Limits, and Plasticity Index of Soils*. The liquid limit (LL) and plastic limit (PL) values were rounded to the nearest integers for calculation of the PI. In accordance with the ASTM standard, if either the LL or PL could not be determined or the PL was greater than or equal to the LL, the material was reported as nonplastic (NP). The devices used for the fall cone and plastic limit tests are shown in Figure 3.

Figure 3. Fall cone test device and plastic limit rolling device

3.1.1.3 Soil Classification

The results of the sieve analyses and Atterberg limit tests were used to classify the materials in accordance with ASTM D2487-17 *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)* and ASTM D3282-15 *Standard Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes* according to the AASHTO classification system.

3.1.2 Compaction Behavior/Standard Proctor Tests

Standard Proctor tests were performed on all surface aggregates and subgrade materials following ASTM D698-12e2 *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort* to determine their optimum water content (w_{opt}) and maximum dry unit weight (γ_{dmax}). The mixer shown in Figure 4 was used to prepare geomaterials with a predetermined moisture content before compaction.

Figure 4. Hobart mixer

3.1.3 Shear Strength Tests

The undrained shear strength properties of compacted materials were determined using unconfined compressive strength (UCS) tests following ASTM D2166/D2166M-16 *Standard Test Method for Unconfined Compressive Strength of Cohesive Soil* and CBR tests following ASTM D1883-16 *Standard Test Method for California Bearing Ratio (CBR) of Laboratory-Compacted Soils*. The Iowa State University 2 × 2 compaction device was used to prepare UCS specimens with much greater efficiency than using a standard Proctor compaction mold (O'Flaherty et al. 1963). The 2 × 2 compaction device is shown, along with a prepared UCS test device, in Figure 5, and the CBR test device is shown in Figure 6.

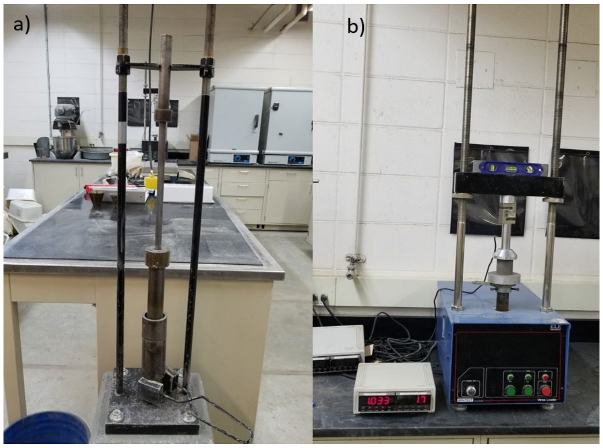


Figure 5. (a) 2 × 2 compaction device and (b) UCS test device

Figure 6. CBR test device

3.1.4 Slaking Durability Tests

Slaking tests were conducted to determine the stability and erosion resistance of untreated and treated geomaterials under saturated conditions. Samples were first sieved through a #40 sieve and compacted at optimum moisture content with standard Proctor energy. Each specimen was then placed on a #4 sieve and soaked under water at room temperature. The dissolution of each specimen with time was recorded (McMullen 2000). Figure 7 shows that the specimens of existing surface aggregates treated with the clay slurry in Washington County lost stability and broke into fragments after 20 minutes of soaking.

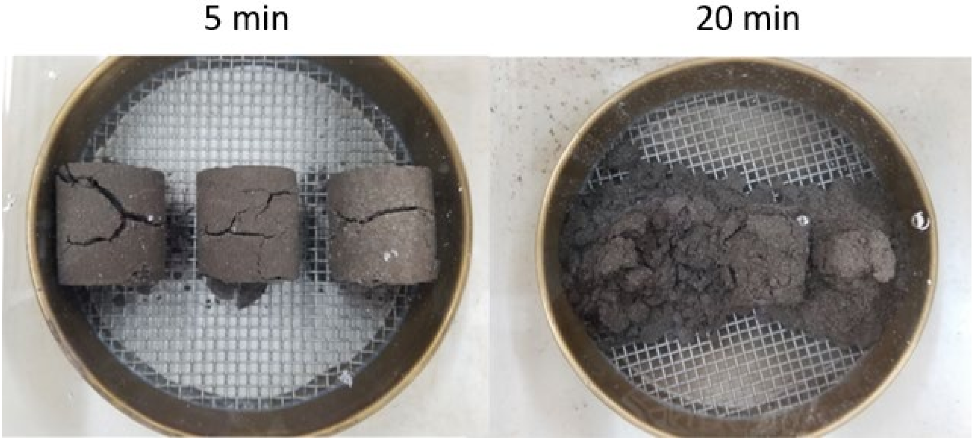


Figure 7. Slaking test for 2 × 2 specimens of existing surface aggregates from Washington County mixed with 7% clay slurry by dry weight

3.2 Field Tests

Field LWD, FWD, DCP, dustometer, and NDG tests were performed on all test sections before winter and after the spring thaw in two consecutive years. Additionally, a set of road surface condition rating report forms were developed and distributed to county engineers and grader operators in the four test counties so the counties could help report on the conditions of each test section. The surface condition reports completed by the counties in this study are included in Appendix A.

3.2.1 Lightweight Deflectometer Tests

The LWD tests were used to rapidly evaluate the composite elastic modulus of the surface and subgrade layers of the test sections. The LWD test involves a falling weight impacting a circular plate through a buffer spring, while the corresponding peak deflection of the ground surface is recorded using an embedded accelerometer. For this project, a Zorn ZFG 3000 LWD device was used (Figure 8), having the properties shown in Table 1.

Figure 8. Zorn ZFG 3000 LWD

Table 1. Properties of Zorn ZFG 3000 LWD device

Parameter	Value
Falling Weight	22.05 lb
Drop Height	27.95 in.
Maximum Applied Force	1,589 lb
Total Load Pulse	18 ± 2 ms
Measuring Range	0.0079 to 1.18 (± 0.00079)
Plate Diameter	11.8 in.
Plate Thickness	0.79 in.
Type of Buffer	Steel spring
Buffer Stiffness	24,832 lb/ft
Deflection Transducer	Accelerometer in plate

The device features a 22.05 lb (10 kg) falling weight with a drop height of 27.95 in. (710 mm), and a base plate diameter of 11.81 in. (300 mm). The FWD tests were performed at five points within each test section.

Assuming no energy losses during the weight drop, the applied force *F* during an LWD test can be calculated using equation 1:

$$F = \sqrt{2mghC} \tag{1}$$

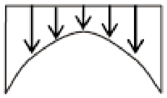
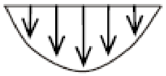
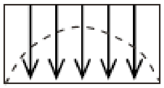
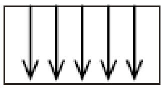
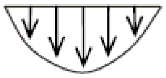
where *m* is the mass of the falling weight, *g* is the acceleration due to gravity, *h* is the drop height, and *C* is the spring constant of the buffer.

According to elasticity theory, the composite elastic modulus of the material under the LWD plate can be calculated using equation 2:

$$E_{LWD} = \frac{(1-v^2)\sigma_0 a}{d_0} f \tag{2}$$

where v is the Poisson's ratio (assumed to be 0.4 for this study), σ_0(MPa) is the normalized applied peak stress, a (mm) is the plate radius, f is a shape factor dependent on the assumed stress distribution (taken as 2 for this study, see Table 2), and d_0 (mm) is the average peak deflection measured by the device.

Table 2. Summary of shape factors in elastic modulus estimation

Plate type	Soil type	Stress distribution (shape)		Shape factor (*f*)
Rigid	Clay (elastic material)	Inverse Parabolic		π/2
Rigid	Cohesionless sand	Parabolic		8/3
Rigid	Material with intermediate characteristics	Inverse Parabolic to Uniform		π/2 to 2
Flexible	Clay (elastic material)	Uniform		2
Flexible	Cohesionless Sand	Parabolic		8/3

Vennapusa and White 2009, with source data from Terzaghi and Peck 1967 and Holtz 1991, © 2009 ASTM International, used with permission, https://www.astm.org/

According to Vennapusa and White (2009), the measurement influence depth of the LWD device is approximately equal to its plate diameter.

3.2.2 Falling Weight Deflectometer Tests

The FWD tests were performed in accordance with the *AASHTO Guide for Design of Pavement Structures* (AASHTO 1993) using the JILS-20-FWD shown in Figure 9.

Figure 9. Trailer-mounted JILS-20-FWD

To avoid over-ranging the velocity transducers, three relatively small target dynamic loads of 4,000, 5,000, and 6,000 lb were applied and nine transducers recorded the surface deflections. A segmented loading plate was used to achieve a more uniform contact stress distribution (Crovetti et al. 1989).

According to AASHTO (1993), the FWD test data can be used to calculate elastic moduli for both surface and subgrade layers. The AASHTO approach combines Boussinesq theory (Boussinesq 1885) and Odemark's method of an equivalent layer-thickness (Odemark 1949). Boussinesq theory can be used to calculate stresses, strains, and deformations at a given radius and depth in a homogeneous linear elastic half-space resulting from a point load applied on the surface, as shown in equation 3:

$$d_{r,z} = \frac{(1+v)F_{max}}{2\pi E\sqrt{z^2+r^2}}[2(1-v)+\frac{z^2}{z^2+r^2}] \quad \textbf{(3)}$$

where r is the radius from the point load, z is vertical depth from the point load, $d_{r,z}$ is the vertical deflection at radius r and depth z, E is elastic modulus, F_{max} is maximum applied vertical force, and the remaining parameters are previously defined.

The FWD test applies a dynamic load over a circular contact area, for which the vertical surface deflection of a homogeneous material beneath the loading plate can be obtained by integrating equation 3 to obtain the following:

$$d_{0,z} = \frac{(1+v^2)F_{max}f}{\pi a E}\frac{1}{\sqrt{1+(\frac{z}{R})^2}} \quad \textbf{(4)}$$

In pavement systems, deflections measured at a sufficiently large distance from the load are considered to be independent of the size of the loading-plate and are assumed to occur primarily due to subgrade deformation. Thus, the subgrade elastic modulus (E_{FWD-SG}) can be calculated as follows (AASHTO 1993):

$$E_{FWD-SG} = \frac{(1-v^2)F_{max}}{\pi r d_{r,0}} \tag{5}$$

where $d_{r,0}$ is the vertical deflection of the surface at radius r. The calculated deflection ($d_{0,z}$) in equation 4 can be used to determine the composite elastic modulus by substituting it into equation 5.

The deflection of a two-layer system under the applied load can be determined according to Odemark's assumption. Equation 6 is used to convert a top layer thickness into an equivalent thickness (h_e) of additional subgrade material:

$$h_e = h^3\sqrt{\frac{E_{FWD-\mathrm{AGG}}}{E_{FWD-SG}}} \tag{6}$$

where h is the thickness of the surface layer, $E_{FWD-\mathrm{AGG}}$ is the modulus of the surface aggregate layer, and E_{FWD-SG} is the modulus of the subgrade. According to AASHTO (1993), the surface deflection can be measured at a distance greater than the effective radius (a_e) of the stress bulb at the interface between the top and bottom layers. Equation 7 is used to obtain the effective radius:

$$a_e = \sqrt{a^2 + \left(h^3\sqrt{\frac{E_{FWD-\mathrm{AGG}}}{E_{FWD-SG}}}\right)^2} \tag{7}$$

With increasing distance from the load, the magnitude of deflection decreases and therefore measurement error increases. AASHTO (1993) recommends that the deflection ($d_{r,0}$) used for calculating the subgrade modulus in equation 5 be greater than or equal to $0.7a_e$ to minimize this error. Combining Boussinesq's point load theory and Odemark's equivalent layer assumption, the surface deflection under the loading plate caused by the deformation of both surface and subgrade layers can be calculated using equation 8:

$$d_{0,0} = \frac{(1-v^2)F_{max}f}{\pi a}\left\{\frac{1}{E\sqrt{1+\left(\frac{h^3}{a}\sqrt{\frac{E_{FWD-\mathrm{AGG}}}{E_{FWD-SG}}}\right)^2}} + \frac{\left(1-\frac{1}{\sqrt{1+(h/a)^2}}\right)}{E_{FWD-AGG}}\right\} \tag{8}$$

By matching the calculated deflection to the measured deflection under the loading plate, the granular surface layer's elastic modulus ($E_{FWD-AGG}$) can be determined using equation 8 (Grasmick 2013).

3.2.3 Dynamic Cone Penetrometer Tests

The DCP tests were performed in accordance with ASTM D6951/D6951M-18 *Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications* to determine the shear strength of the surface course and subgrade materials. The DCP device used in this project was a Kessler Soils Engineering Products K-100 (Figure 10).

Figure 10. Kessler K-100 DCP

For each blow in the test, a 17.6 lb (8 kg) hammer was dropped a distance of 22.6 in. (574 mm) to drive a disposable cone tip having a 60-degree apex angle and 0.79 in. (20 mm) base diameter into the ground. The measured penetration distance per blow is referred to as the DCP index (DCPI).

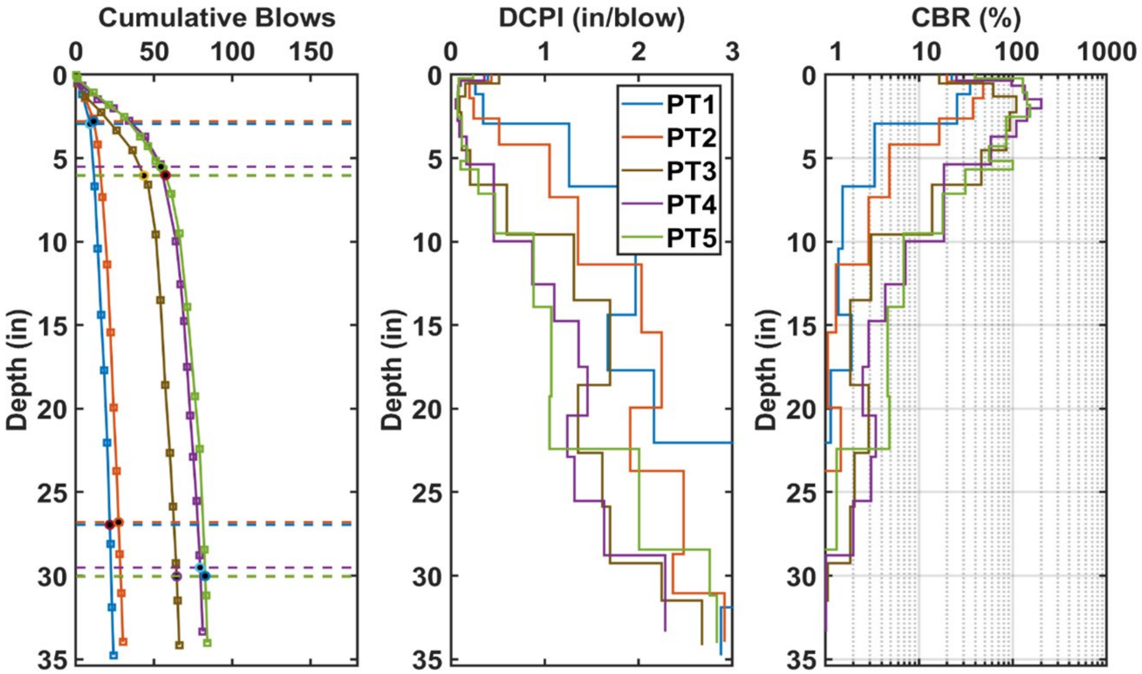
The DCPI values in units of millimeters per blow are used to estimate the in situ CBR values through the following empirical correlations from ASTM D6951/D6951M-18:

$$for\ CBR > 10, DCP\text{-}CBR = 292/(DCPI)^{1.12} \qquad \textbf{(9)}$$

$$for\ CL\ soils\ with\ CBR < 10, DCP\text{-}CBR = 1/(0.017019 \times DCPI)^2 \qquad \textbf{(10)}$$

$$for\ CH\ soils, DCP\text{-}CBR = 1/(0.002871 \times DCPI) \qquad \textbf{(11)}$$

For this study, each test section was analyzed as a two-layer system consisting of the surface course and a subgrade layer. As shown in Figure 11, the boundary between the two layers was identified by a sudden change in the slope of the cumulative blows versus the depth plot, which is typically accompanied by a jump in the DCPI, and the average DCP-CBR values were calculated for both resulting layers.



(a) (b) (c)

Figure 11. Example of DCP depth profiles: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR

The weighted average DCPI over the aggregate surface layer and subgrade layer was calculated using equation 9, where H_i is the depth increment for the i^{th} CBR value:

$$DCP\text{-}CBR_{AVG} = \frac{(CBR_i \times H_i) + (CBR_{i+1} \times H_{i+1}) \ldots (CBR_n \times H_n)}{\sum_i^n H_i} \quad \textbf{(12)}$$

The resulting weighted average DCP-CBR of the surface aggregate layer is denoted $DCP\text{-}CBR_{AGG}$, and the weighted average DCP-CBR of the underlying subgrade layer to the maximum DCP test depth of 35 in. is denoted as $DCP\text{-}CBR_{SG}$.

3.2.4 Nuclear Density Gauge Tests

The NDG tests were performed by Iowa DOT Construction and Materials personnel in accordance with ASTM D6938-17a *Standard Test Methods for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)*. The InstroTek MC-3 Elite NDG used for this study is shown in Figure 12.

Figure 12. InstrTtek MC-3 Elite NDG

3.2.5 Dustometer Tests

The dustometer test, developed by Colorado State University (Sanders and Addo 2000), was used to measure the fugitive dust emissions of the test sections. The dustometer device incorporates a metal housing mounted to a pickup truck's rear bumper behind the rear wheel, as shown in Figure 13.

Figure 13. (a, b, and c) Dustometer test setup, (d) test conducted on a granular-surfaced road test section, (e) EPM 2000 glass microfiber filters, and (f) filter sheet before and after a test

A 1/3 horsepower high-volume suction pump powered by a generator was attached to the metal housing of the dustometer, and for each test, an 8 × 10 in. EPM 2000 glass microfiber filter was placed in the metal box to capture the dust generated by the truck tires and drawn in by the vacuum pump.

3.2.6 Site Surveys with Images

During field testing, visual surveys were also performed and digital images were captured to document the conditions of the test sections. The locations and extent of rutting, potholes, frost boils, freeze-thaw damage, or any other surface distress were noted. Images from the visual surveys are included in Appendix B.

CHAPTER 4 MATERIALS AND STABILIZATION METHODS

As described in Chapter 1, 31 test sections, including one control section in each county, were constructed and/or monitored in four counties across Iowa. This chapter describes the stabilization methods applied in this study along with the index properties and sources of all construction materials used.

4.1 Existing Materials from Test Sites and Virgin Aggregates from Quarries

Before construction, samples of the existing surface and subgrade materials were collected from the four test sites located in Cherokee, Howard, Hamilton, and Washington counties. The surface aggregate samples were collected in July 2018, and subgrade samples were collected in August 2017. Particle size distributions, index properties, and soil classifications were determined as detailed in Chapter 3. The results are summarized in Table 3, and the corresponding particle size distribution curves are shown in Figure 14 and Figure 15 before the large table.

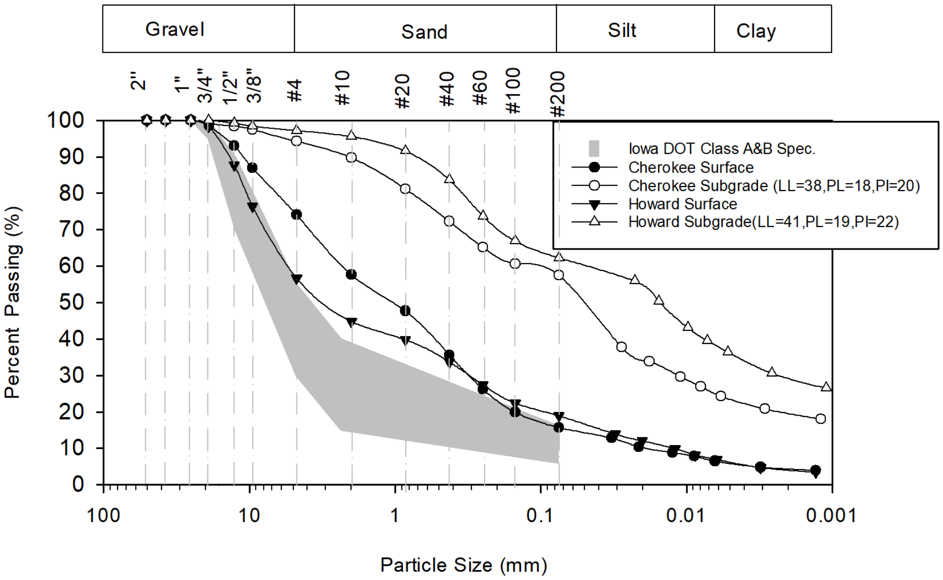


Figure 14. Particle size distribution curves for existing materials in Cherokee and Howard counties

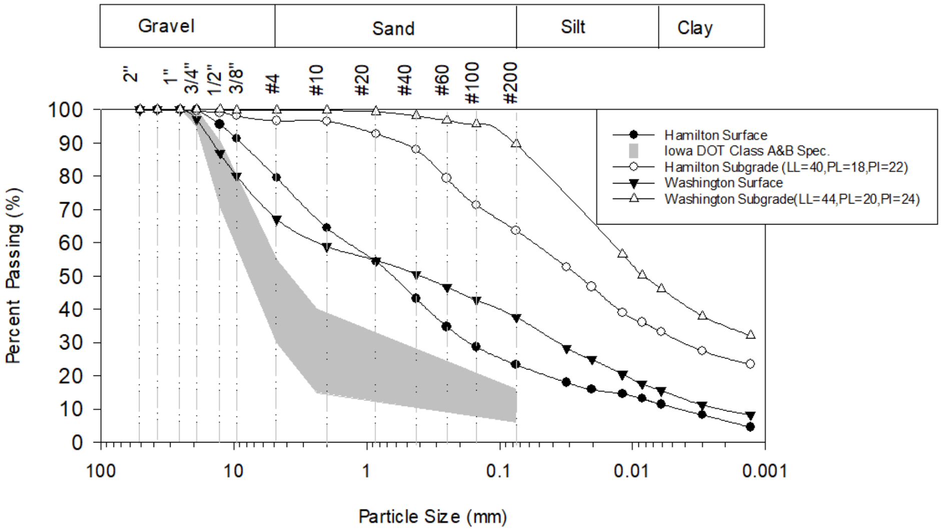


Figure 15. Particle size distribution curves for existing materials in Hamilton and Washington counties

The existing granular surface materials had been in service for some time and were therefore much sandier than the Iowa DOT granular surfacing materials specifications band shown in the two graphs (Iowa DOT 2012). An additional 14 types of aggregates from local quarries were considered for construction of the stabilized test sections, and samples of these materials were obtained from the quarries. The index properties and soil classifications for each of these virgin quarry materials are summarized in Table 4.

Table 3. Soil index properties of existing materials at test sites before stabilization

Parameter	Cherokee Surface	Cherokee Subgrade	Howard Surface	Howard Subgrade	Hamilton Surface	Hamilton Subgrade	Washington Surface	Washington Subgrade
Particle Size Distribution Results (ASTM D6913//D6913M-17)								
Gravel Content (%)	25.9	5.7	43.3	2.8	20.4	3.3	32.9	0.2
Sand Content (%)	58.4	36.8	37.8	34.9	56.3	33.0	29.4	5.4
Silt Content (%)	9.9	34.2	12.7	26.3	12.7	31.3	23.0	47.9
Clay Content (%)	5.8	23.3	6.2	36.0	10.6	32.4	14.7	46.5
D_{10} (mm)	0.019	–	0.012	–	0.004	–	0.002	–
D_{30} (mm)	0.31	0.011	0.32	0.002	0.17	0.004	0.032	–
D_{60} (mm)	2.33	0.12	5.52	0.039	1.38	0.050	2.37	0.010
Coefficient of Uniformity, c_u	121.12	–	449.19	–	312.73	–	1064.27	–
Coefficient of Curvature, c_c	2.22	–	1.43	–	4.74	–	0.19	–
Atterberg Limits Test Results (Wasti 1987 and ASTM D4318-17e1)								
Liquid Limit (%)	NA*	38	18	41	19	40	26	44
Plastic Limit (%)	NP	18	13	19	14	18	16	20
Plasticity Index	NP	20	5	22	5	22	10	24
AASHTO and USCS Soil Classification (AASHTO M 145-91, ASTM D3282-15, and ASTM D2487-17)								
AASHTO Classification	A-1-b	A-6(9)	A-1-b	A-7-6(11)	A-1-b	A-6(12)	A-4(0)	A-7-6(24)
USCS Classification	SM	CL	GC-GM	CL	SC-SM	CL	GC	CL
Group Name	Silty sand with gravel	Sandy lean clay	Silty clayey gravel with sand	Sandy lean clay	Silty clayey sand with gravel	Sandy lean clay	Clayey gravel with sand	Lean clay

*Not available because sample was too sandy to hold moisture, NA=not applicable, NP=nonplastic

Table 4. Soil index properties of virgin quarry materials

Parameter	Hamilton Grandgeorge Quarry, Road Stone	Hamilton Alden Quarry, 1 in. Road Stone	Hamilton Grandgeorge Quarry, 1 in. Clean	Cherokee DOT Quarry, River Rock	Cherokee Moore Quarry, Class A Road Stone	Cherokee Moore Quarry, D57 Concrete Stone	Howard County Dotzler Quarry, Class A
Particle Size Distribution Results (ASTM D6913)							
Gravel Content (%)	67.9	69.6	98.7	26.4	52.8	99.3	60.0
Sand Content (%)	25.2	24.4	1.3	70.6	34.6	0.3	25.0
Fines Content (%)[a]	6.9	6.0	0.0	3.0	12.6	0.4	15.0
D_{10} (mm)	0.28	0.23	6.90	0.47	–	8.77	–
D_{30} (mm)	4.24	4.67	10.19	1.06	1.87	11.92	2.75
D_{60} (mm)	12.58	11.91	14.73	2.65	7.13	15.78	9.01
Coefficient of Uniformity, c_u	44.56	51.74	2.13	5.58	–	1.80	–
Coefficient of Curvature, c_c	5.06	7.95	1.02	0.89	–	1.03	–
Atterberg Limits Test Results (Wasti 1987 and ASTM D4318-17e1)							
Liquid Limit (%)	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]
Plastic Limit (%)	NP	NP	NP	NP	NP	NP	NP
AASHTO and USCS Soil Classification (AASHTO M 145-91, ASTM D3282-15, and ASTM D2487-17)							
AASHTO Classification	A-1-a	A-1-a	GP	A-1-b	A-1-a	A-1-a	A-1-a
USCS Classification	GP-GM	GP-GM	A-1-a	SP	GM	GP	GM
Group Name	Poorly graded gravel with silt and sand	Poorly graded gravel with silt and sand	Poorly graded gravel	Poorly graded sand with gravel	Silty gravel with sand	Poorly graded gravel	Silty gravel with sand

Parameter	**Hamilton Grandgeorge Quarry, Road Stone**	**Hamilton Alden Quarry, 1 in. Road Stone**	**Hamilton Grandgeorge Quarry, 1 in. Clean**	**Cherokee DOT Quarry, River Rock**	**Cherokee Moore Quarry, Class A Road Stone**	**Cherokee Moore Quarry, D57 Concrete Stone**	**Howard County Dotzler Quarry, Class A**
Particle Size Distribution Results (ASTM D6913)							
Gravel Content (%)	58.0	69.5	100.0	66.1	51.5	40.1	0.0
Sand Content (%)	31.6	19.4	0.0	33.9	44.9	54.7	0.0
Silt Content (%)	10.4[a]	11.1[a]	0.0[a]	0.0[a]	3.6[a]	5.2[a]	55.2
Clay Content (%)							38.5
D_{10} (mm)	–	–	7.99	3.12	0.48	0.23	–
D_{30} (mm)	2.51	4.53	11.09	4.52	2.32	1.39	0.002
D_{60} (mm)	8.90	11.85	14.22	6.25	6.89	4.76	0.016
Coefficient of Uniformity, c_u	–	–	1.78	2.00	13.97	20.81	–
Coefficient of Curvature, c_c	–	–	1.08	1.05	1.59	1.76	–
Atterberg Limits Test Results (Wasti 1987 and ASTM D4318-17e1)							
Liquid Limit (%)	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	53
Plastic Limit (%)	NP	NP	NP	NP	NP	NP	22
Plasticity Index	NP	NP	NP	NP	NP	NP	31
AASHTO and USCS Soil Classification (AASHTO M 145-91, ASTM D3282-15, and ASTM D2487-17)							
AASHTO Classification	A-1-a	A-1-a	A-1-a	A-1-a	A-1-a	A-1-a	A-7-6(32)
USCS Classification	GP-GM	GP-GM	GP	GP	GW	SW-SM	CH
Group Name	Poorly graded gravel with silt and sand	Poorly graded gravel with silt and sand	Poorly graded gravel	Poorly graded gravel with sand	Well-graded gravel with sand	Well-graded sand with silt and gravel	Fat clay

[a] percentage shown includes both silt and clay content, [b] not available because sample was too sandy to hold moisture, NA=not applicable, NP=nonplastic

4.2 Materials for Mechanical Stabilization Methods

As mentioned in Chapter 1, the following eight types of mechanically stabilized test sections were selected for construction in Howard and Cherokee counties:

1. Aggregate columns
2. OGCS
3. Ground tire rubber mixed at 20% by volume in a 2 in. base layer of aggregate and covered by a 2 in. surface layer of aggregate (in Howard County only)
4. RAP mixed at 50% by volume with aggregates
5. 2 in. Harsco slag surface over 2 in. existing aggregate base
6. 2 in. Phoenix slag surface over 2 in. existing aggregate base
7. 4 in. Harsco slag surface over subgrade
8. 4 in. Phoenix slag surface over subgrade

These stabilization materials and methods are discussed in this chapter, and the construction methods used to build the test sections are discussed in Chapter 5.

4.2.1 Aggregate Columns

The aggregate columns method consists of auguring a pattern of boreholes 8 to 12 in. in diameter to depths of 5 to 7 ft and backfilling the boreholes with clean aggregate. The feasibility of the aggregate columns method was verified in the previous IHRB project, which demonstrated that the method can improve the freeze-thaw performance of the roadway by reducing the occurrence of frost-boils at relatively low cost (Li et al. 2015). In that project, 8 in. diameter by 6 ft deep columns were installed in an alternating 1-2-1-2 pattern that resulted in one column per 25 yd^2 of surface area. In this Phase III study, a denser grid and deeper columns were used to increase the effectiveness of the method and also to minimize rutting issues observed at the shoulders in the previous project.

4.2.2 Optimized Gradation with Clay Slurry

The previous IHRB project (Li et al. 2018a) demonstrated that a proper gradation of surface materials along with plastic fines added for binding can significantly improve the strength and longevity of roadway surfaces while also minimizing freeze-thaw damage. A gradation optimization spreadsheet tool was developed in the project for calculating the mixing ratios of fresh quarry materials and existing surface materials to achieve optimum gradations in terms of laboratory CBR strength.

When the aggregate surfacing materials are mixed with clay, the clay forms a matrix that binds the aggregates and helps to reduce material loss. While the clay adds significant cohesion when dry, it typically reduces the shear strength of the mixture when wet. Therefore, the aim of this stabilization method was to mix the clay into only the top few inches of aggregates to provide the desired binding effect while maintaining most of the shear strength of the underlying layer of cleaner aggregates.

In the previous study, the clay source was powdered bentonite, which was spread over the surfacing aggregates, then sprayed with water and mixed in using a tractor-mounted mixer. However, this construction method was time consuming and the bentonite concentration was determined to have decreased significantly after one freeze-thaw season.

For this Phase III study, a clay slurry obtained from the Pattison Sand Company in Clayton, Iowa was used instead of powdered bentonite. The clay slurry was sprayed over the surface of the optimized gradation mixture, then incorporated by blade mixing with a motor grader. Properties of the clay slurry are included in the rightmost column of Table 5, and the particle size distribution curve of a clay slurry sample is included in Figure 16.

Table 5. Properties of rubber tire chips, steel slag, and clay slurry

Parameter	7/8 in. Rubber Tire Chips	3/8 in. Rubber Tire Chips	Phoenix Steel Slag	Harsco Steel Slag	Pattison Clay Slurry
Dry Unit Weight (lb/ft^3)	46.6	46.6	144.5	153.0	–
Optimum Moisture Content (%)	–	–	4%	9%	–
Solids Content (%)	–	–	–	–	21%–29%

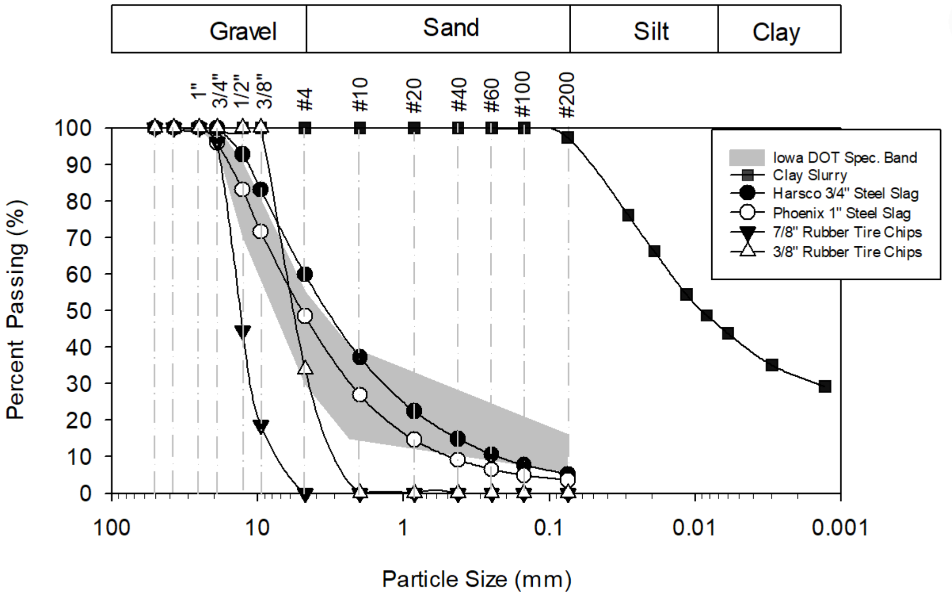


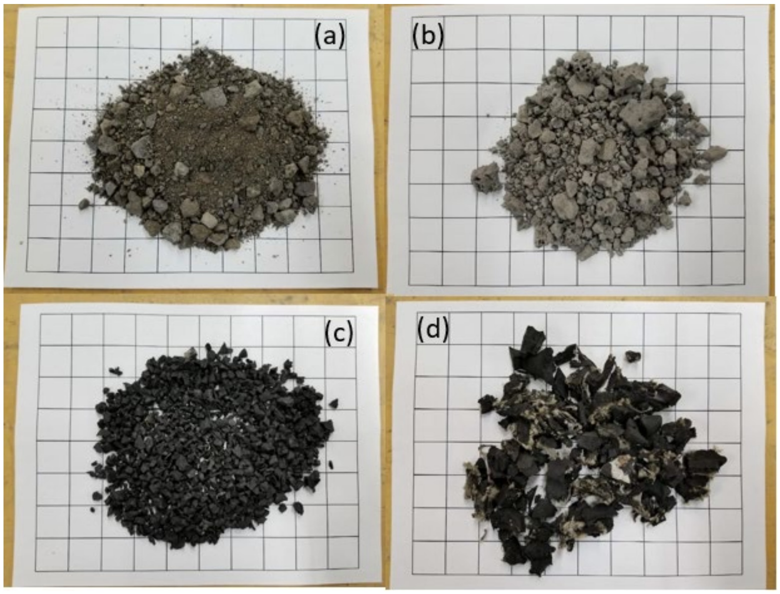
Figure 16. Particle size distribution curves of rubber tire chips, steel slag, and clay slurry

The measured solids content of the clay slurry samples taken during construction of the test sections ranged from 21% to 29%. The slurry producer measured higher solids contents up to

38% during filling of the tanker trucks, but some sedimentation likely occurred during transportation resulting in lower solids contents by the time the samples were collected in the field.

4.2.3 Ground Tire Rubber

Two types of ground tire rubber chips were evaluated in this study, with maximum sizes of 3/8 in. (Figure 17c) and 7/8 in. (Figure 17d).



Grid size = 1 in.

Figure 17. Samples of (a) Harsco 3/4 in. steel slag, (b) Phoenix 1 in. steel slag, (c) 3/8 in. rubber tire chips, and (d) 7/8 in. rubber tire chips

The source of rubber tire chips was Liberty Tire Recycling LLC in Des Moines, Iowa. Proctor compaction and CBR tests were performed on mixtures of the tire chips with existing and virgin aggregates, giving similar results for the two chip sizes. The CBR values of the mixtures consistently decreased with an increasing percentage of rubber chips. For construction of the test sections, the smaller 3/8 in. chips were selected because they resulted in mixture gradations closest to the theoretical target determined by the gradation optimization tool.

To minimize loss of stability due to the elastic and cohesionless nature of the rubber chips reducing binding of the aggregates, the chips were only mixed into the bottom 2 in. of the surface course, which was then overlain by 2 in. of aggregate. Based on the CBR results as well as recommendations from previous studies, the test sections were designed using 20% rubber tire chips by volume of the bottom 2 in. of the granular surface course. The characteristics of the rubber chips used in this study are summarized in the previous Table 5, and their particle size distribution curves are included in the previous Figure 16.

4.2.4 Recycled Asphalt Pavement Mixed with Aggregates

RAP has been widely used as an aggregate substitute and stabilizer in granular-surfaced roads. For this study, local sources of RAP were mixed at 50% by volume with existing and virgin aggregates to construct test sections in Howard and Cherokee counties. To calculate the required tonnages to construct the test sections, the dry unit weights of RAP and aggregate were multiplied by 50% of the test section's volume.

4.2.5 Steel Slag

Eight steel slag test sections were constructed with four each in Howard and Cherokee County. In both counties, two sections were constructed using slag from Phoenix Services LLC in Wilton, Iowa and two using slag from Harsco Metals & Minerals (see samples of each in the previous Figure 17b and a, respectively). For each slag source, one section contained a 2 in. thick slag layer over a 2 in. thick aggregate layer, while the other had a 4 in. thick slag layer over the subgrade. Properties of the steel slag are included in the previous Table 5, and the particle size distribution curves are included in the previous Figure 16.

4.3 Materials for Chemical Stabilization Methods

For this study, the following five chemical stabilization methods were used to construct test sections in Washington and Hamilton counties:

1. Cement-treated subgrade (in Washington County only)
2. Cement-treated aggregate surface course (in Washington County only)
3. BASE ONE, a silicic acid, sodium salt, concentrated liquid stabilizer
4. EMC SQUARED, a neutral pH, non-ionic, concentrated liquid stabilizer
5. Claycrete, an ionic, concentrated liquid stabilizer

These chemical stabilization materials are briefly discussed in the following subsections. As mentioned previously, two mechanically stabilized test sections were also constructed in each county using the OGCS and aggregate columns methods.

4.3.1 Cement-Treated Subgrade and Cement-Treated Aggregate Surface Course

Henry et al. (2005) reported that incorporating portland cement at 6% by weight into the top 12 in. of road surface materials for one county and 8% by weight in the top 8 in. for another county significantly improved weighted CBR values of the top 3 in. during spring thawing. Two types of cement-treated sections were examined in this Phase III study: 7% portland cement by weight in a 4 in. thick aggregate surface course with an untreated subgrade and a 12 in. thick subgrade layer treated at 5% cement by weight with an untreated aggregate surface course. The Type I/II portland cement was provided by the Ash Grove Cement Company in Des Moines, Iowa.

4.3.2 BASE ONE

T15 BASE ONE is a high pH, concentrated liquid base and aggregate stabilizer for improving strength and stability of aggregate and RAP materials (TEAM LAB 2015). It is typically diluted in the water used for compaction during construction. The manufacturer states that BASE ONE stabilizes through detergency, lubrication, and bonding actions, and forms a strong inorganic insoluble bond that lasts indefinitely. BASE ONE contains high concentrations of silicon dioxide and sodium oxide, which improve bonding through the formation of hydrated calcium silicate. BASE ONE had been used in the past to improve performance of granular-surfaced roads at several locations in Washington County among others.

For this Phase III study, a representative from the manufacturer was on site to help direct construction operations to ensure the best results. Based on the manufacturer's recommendations and the types of soil encountered, 0.5 in. of subgrade soil was mixed with the local aggregates and stabilizer during test section construction. The application rate was 0.005 gallons of undiluted stabilizer per yd^2 per in. of stabilized depth.

4.3.3 EMC SQUARED Stabilizer (1000)

EMC SQUARED Stabilizer (1000) is a neutral pH, non-ionic, concentrated liquid stabilizer produced by Stabilization Products, LLC (formerly Soil Stabilization Products Company, Inc. or SSPCo). According to the manufacturer, the EMC SQUARED system of stabilizers creates layers with improved flexural stiffness without a tendency to crack, while also reducing the rate of moisture flow, thus increasing water shedding and impeding capillary flow, which can improve the stability of the underlying subgrade soils. The product's construction handbook emphasizes that the optimum moisture content for compaction should be determined by laboratory testing of the materials to be stabilized, and the actual moisture content should be carefully controlled in the field.

This stabilizer has also been successfully used in Washington County in the past, resulting in granular road surfaces that stayed tight while significantly reducing the amount of required blading. In accordance with the manufacturer's recommendations, the test sections in this study were constructed by incorporating a target depth of 6 in. of subgrade material along with the 4 in. surface course, although the subgrade depth had to be reduced in Hamilton County due the presence of large cobbles and boulders. As recommended by the manufacturer (SSPCo 2017), the application rate of EMC SQUARED Stabilizer (1000) was 1 gallon per 15 yd^3 of aggregate or soil material.

4.3.4 Claycrete

Claycrete is a low-pH, ionic liquid soil stabilizer that can improve the resistance of soil to freeze-thaw cycle damage by removing the potential for clay platelets to bond with water. The source of the liquid Claycrete stabilizer was Claycrete North America in Sioux City, Iowa.

For this study, a representative from the product manufacturer was on site during construction to advise on construction operations to help ensure the best results. Based on their recommendation, about 0.5 in. of subgrade soil was incorporated into the surface course materials to give the resulting mixture an appropriate clay content.

Because the subgrades in both Washington and Hamilton counties consisted of silty lean clay (USCS classification CL but with significant silt content, see previous Table 3**),** the manufacturer's suggested application rate of 0.0404 gal/yd^3 (200 ml/m^3) was increased by the representative to about 0.062 gal/yd^3 (307 ml/m^3) in both counties. Aside from this adjustment, the construction procedures used in the field otherwise followed the *Claycrete Application and Road Construction Manual* (Road Pavement Products PTY LTD 2017).

CHAPTER 5 CONSTRUCTION METHODS

This chapter describes the construction procedures and equipment used to build the mechanically and chemically stabilized test sections. Each of the stabilization methods are listed in Table 6 along with the counties in which they were used.

Table 6. Types and locations of the 31 test sections in this study

Stabilization Type		Howard	Cherokee	Washington	Hamilton
None (control section)		X	X	X	X
Mechanical	Aggregate columns	X	X	X	X
	Optimized gradation with clay slurry	X	X	X	X
	Ground tire rubber	X			
	RAP mixed 50/50 with aggregate	X	X		
	2 in. slag surface above 2 in. existing aggregate base (Harsco 3/4 in. steel slag)	X	X		
	2 in. slag surface above 2 in. existing aggregate base (Phoenix 1 in. steel slag)	X	X		
	4 in. slag surface (Harsco 3/4 in. steel slag)	X	X		
	4 in. slag surface (Phoenix 1 in. steel slag)	X	X		
Chemical	12 in. Type I/II cement-treated subgrade			X	
	4 in. Type I/II cement-treated aggregate surface course			X	
	BASE ONE			X	X
	EMC SQUARED			X	X
	Claycrete			X	X

As previously described, the aggregate columns and OGCS methods were used in all four counties because of the TAC members' interest in evaluating the performance of these two methods in different regions of the state. The other six mechanical stabilization types were used for the test sections in Howard and Cherokee counties, and the five chemical stabilization types were used for the test sections in Washington and Hamilton counties. The ground tire rubber section in Howard County was deemed to have failed shortly after construction, so this method was not used in Cherokee County. Due to scheduling issues and prior commitments for the specialty contractor, the cement-treated sections could not be duplicated in Hamilton County.

Images of each test section after construction as well as throughout the project are included in Appendix B.

5.1 Site Selection

The four test sites were selected from different regions of Iowa to cover a range of aggregate sources, subgrade soil types, and weather conditions. The Hamilton County site was also included for continuity with the previous Phase II IHRB project, and the test sections for this project were located just north of those from the previous project. The Hamilton County site is located on Vail Avenue between 300th Street and 310th Street, the Cherokee County site is located on Old 21 Road between 480th Street and 490th Street, the Howard County site is located on 100th Street between Pine Avenue and Quail Avenue, and the Washington County site is located on 260th Street between Palm Avenue and Quince Avenue. A map of the site locations is shown in Figure 18 with counties shaded in bright green and a solid red square indicating the test site locations within the counties.

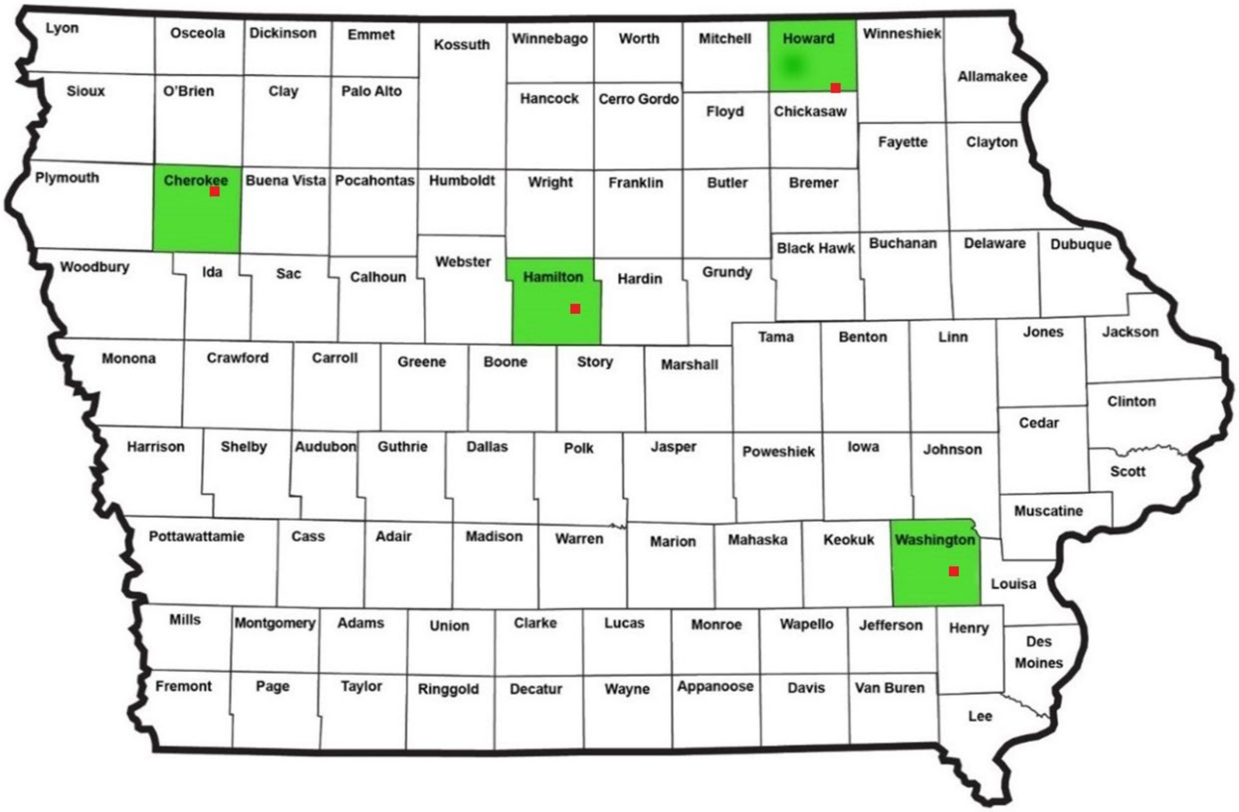


Figure 18. Locations of the test sites in Hamilton, Cherokee, Howard, and Washington counties

According to traffic counts and estimates provided by the Iowa DOT, these sites experienced similar AADT levels and truck percentages (see Table 7).

Table 7. Traffic counts and overall lengths of the test sites

County	Test Site	Length (ft)	AADT	AADT Year	Trucks
Hamilton	Vail Avenue between 300th and 310th Streets	5,210	70	2011	High
Cherokee	Old 21 Road between 480th and 490th Streets	3,233	100*	2011	Moderate
Howard	100th Street between Pine and Quail Avenues	5,333	110	2013	High
Washington	260th Street between Palm and Quince Avenue	3,936	90	2010	High

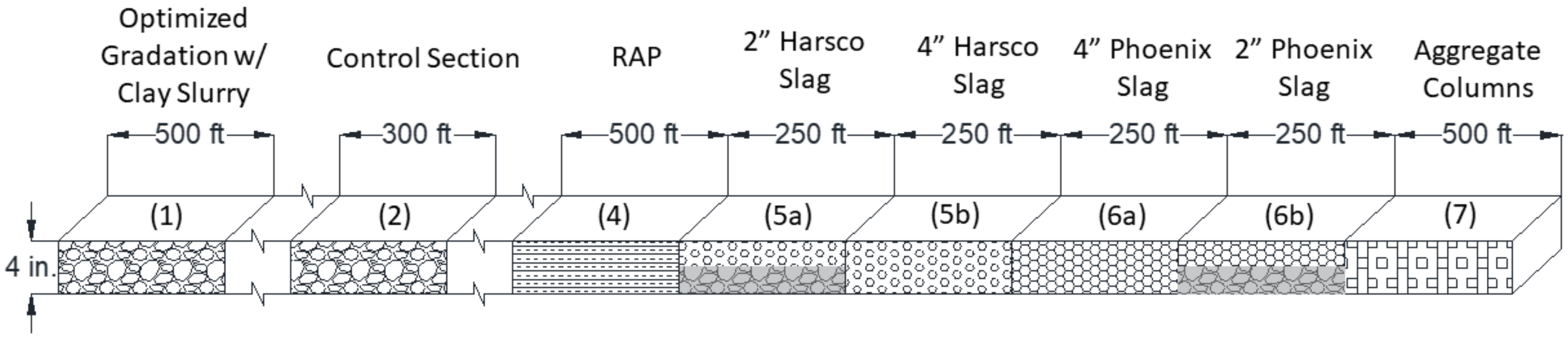
*160 vpd for aggregate columns section in Cherokee County

5.2 Mechanically Stabilized Test Sections

The following subsections detail the construction procedures, equipment used, and dates of construction for the mechanically stabilized test sections in Howard and Cherokee counties. Schematic diagrams of the test sections are shown in Figure 19, and examples of the construction equipment used are shown in Figure 20.

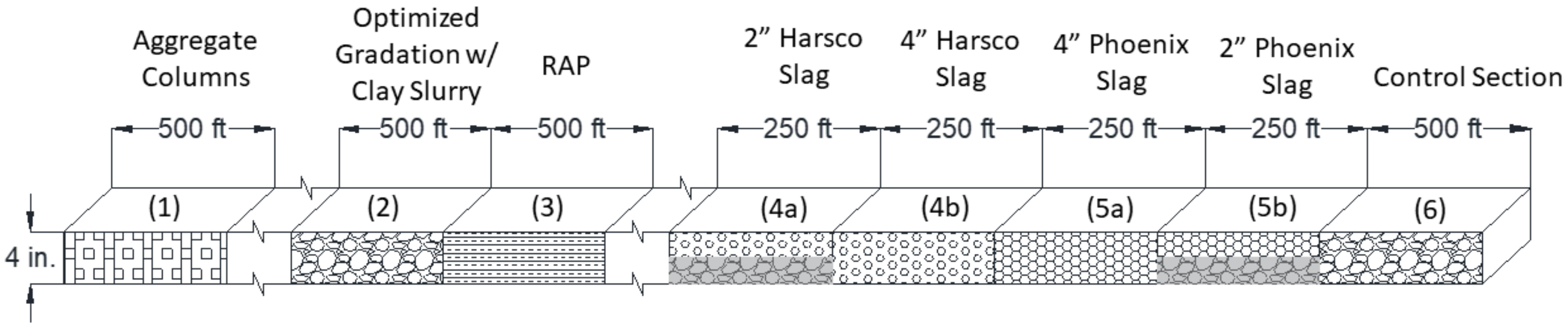
Additional figures in Appendix C show the layout of the test sections superimposed on satellite images of the sites.

Howard County:



Not to scale

Cherokee County:



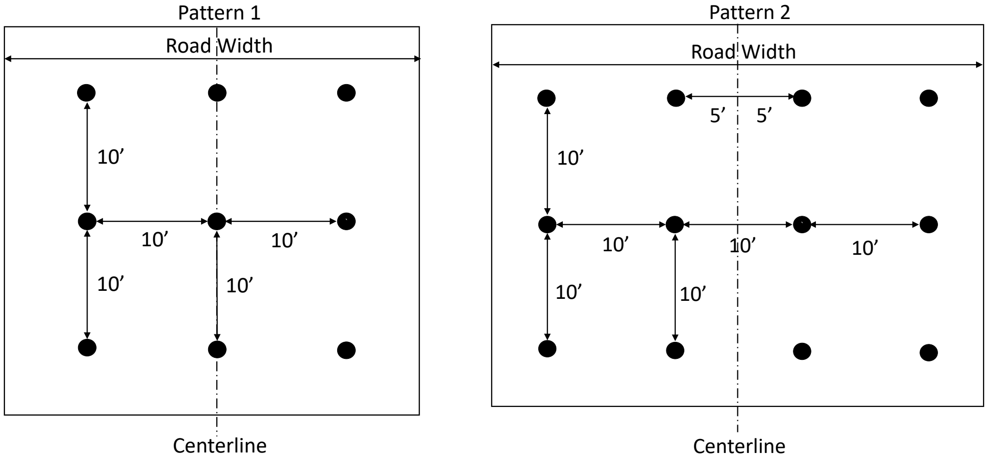
Not to scale

Figure 19. Layouts of mechanically stabilized test sections in Howard and Cherokee counties

Figure 20. Equipment used for construction of mechanically stabilized sections: (a) motor grader, (b) dump truck, (c) power auger, (d) disc plow harrow (Cherokee County), (e) water truck, (f) water trailer (Cherokee County), (g) smooth drum vibratory compactor, (h) rubber tire roller, and (i) self-unloading tanker trailer

5.2.1 Aggregate Columns Sections

The aggregate columns sections were constructed August 15–16, 2018 in Howard County, September 27–28, 2018 in Cherokee County, August 21–23, 2018 in Washington County, and September 4 and 6, 2018 in Hamilton County. The installation pattern of the aggregate columns is shown in Figure 21 with one column for approximately every 100 ft^2 of surface area.



(a) (b)

Figure 21. Aggregate columns layout patterns: (a) Cherokee, Hamilton, and Washington counties and (b) Howard County

A fourth line of columns was added for the test section in Howard County, because the roadway was about 10 ft wider than those in the other three counties. Estimating the dry unit weight at 110 lb/ft^3 for the clean column fill and 136.8 lb/ft^3 for a typical 4 in. thick aggregate surface course, and assuming a specific gravity of 2.75 for both materials, gives void ratios of 0.56 for the column fill and 0.25 for the surface aggregates. Using these void ratios, it can be shown that installing 12 in. diameter columns to a depth of 7 ft with the layout shown in Figure 21 increases the total void volume and therefore the water storage potential of the existing roadway surface by 29%.

For construction, each column was located on a 10 ft grid as shown in Figure 21, with the first and last rows drilled 5 ft from the ends of the test sections. As shown in Figure 22, a 12 in. power auger was used to drill boreholes to a depth of 7 ft, which were then backfilled with clean aggregate from dump trucks using conveyor belts, funnels, or side chutes.

(a)

(b) (c) (d)

Figure 22. Aggregate columns installation: (a) drilling hole with skid steer-mounted power auger, (b) completed hole, (c) backfilling hole with clean aggregate using side chute, and (d) backfilling with hopper

A total of 150 columns requiring 45.4 tons of 1 in. clean aggregate fill were installed in each of Cherokee, Hamilton, and Washington counties, and 200 columns requiring 60.5 tons of 1 in. clean backfill were installed in Howard County. In Hamilton County, the boreholes tended to partially collapse at the bottom due to soft saturated subgrade conditions, so each hole was backfilled with clean aggregate immediately after drilling and removing the auger cuttings with a skid steer. In the other counties, the boreholes were more stable, so an entire line of boreholes were first drilled and then backfilled by backing up a dump truck from one hole to the next.

5.2.2 Optimized Gradation with Clay Slurry Sections

As previously mentioned, the OGCS stabilization method developed in the previous IHRB project (Li et al. 2018a) was used in all four counties. The method combines a target optimum gradation using Fuller's model for tight particle packing to provide strength and clay fines to provide binding. The OGCS sections were constructed August 16, 2018 in Howard County, August 23, 2018 in Washington County, September 4, 2018 in Hamilton County, and September 27, 2018 in Cherokee County.

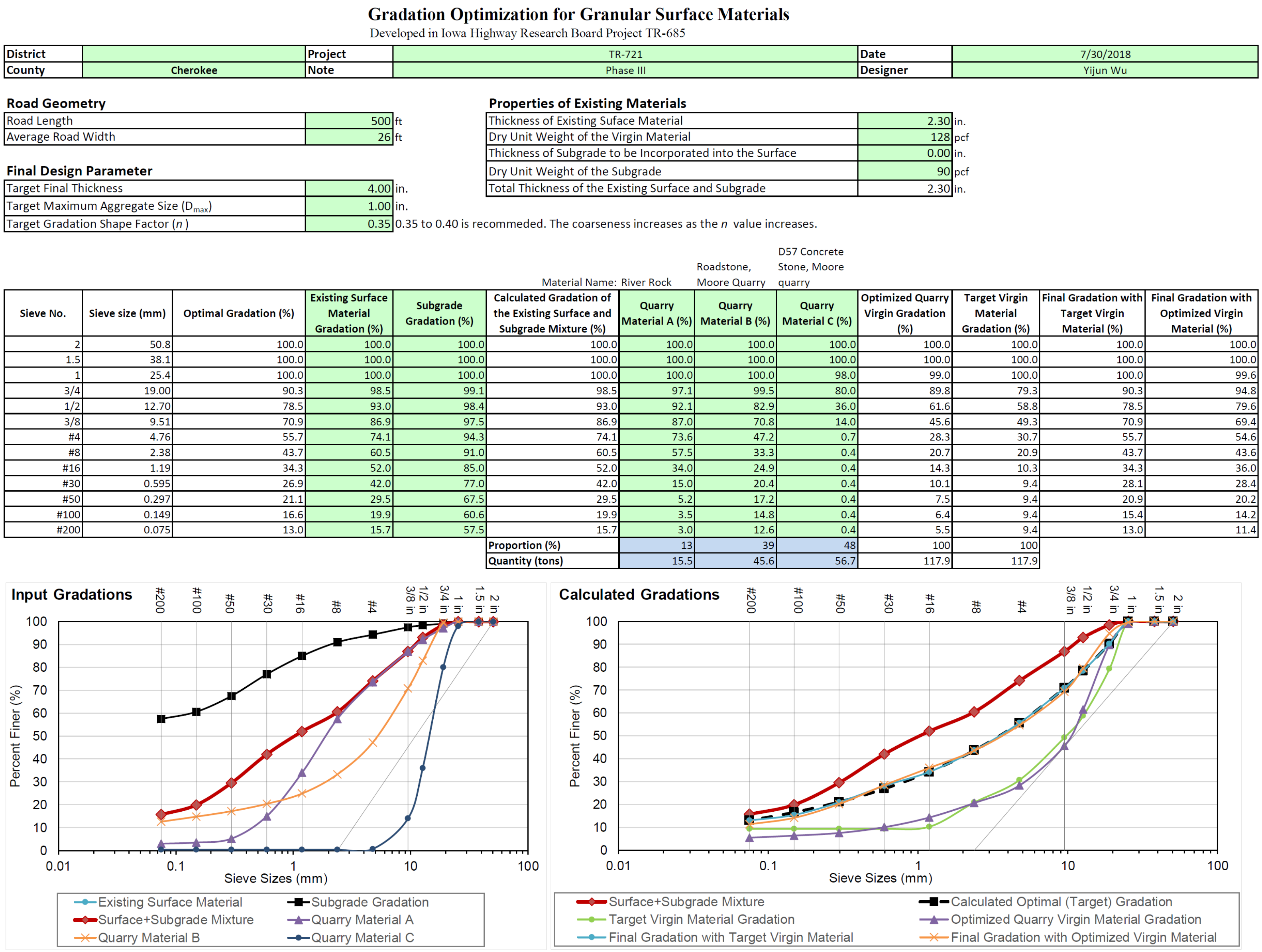
For each OGCS test section, the gradations of the existing surface and subgrade materials were entered into the optimization spreadsheet from the previous project (see Figure 23), along with gradations of either one, two, or three locally available quarry materials.

The thickness of the existing surface material to recycle within the total design thickness of 4 in. was also varied. Using the program, the optimum blend of materials that came closest to the target design gradation was determined and specified for construction. Note that the gradation optimization spreadsheet from Li et al. (2018a) can be downloaded from the project page at https://intrans.iastate.edu/research/completed/feasibility-of-granular-road-and-shoulder-recycling/ or directly at https://intrans.iastate.edu/app/uploads/2020/01/Gradation-design-for-unpaved-road-surface-materials_v4.xlsm.

The target application rate of the clay slurry was based on field trials performed on Erickson Avenue in Hamilton County in October 2017. In the trials, slurry application rates of 3, 4, and 5 gallons per linear ft were used on a 26 ft wide roadway, corresponding to 1.04, 1.38, and 1.73 gallons per yd^2, respectively. The higher application rates improved the stabilization results, but also made construction more difficult and time consuming due to the greater volume of water contained in the slurry.

For the four OGCS test sections in this Phase III project, the intermediate application rate of 1.38 gal/yd^2 was chosen, and the slurry was mixed into the top 2 in. of a 4 in. granular surface course. During filling of the tankers, the slurry supplier used a pulp density specific gravity suspension scale and measured an average value of 35% solids by weight for the Erickson Avenue trial and 35% to 38% solids for this project’s four OGCS test sections.

To construct the 4 in. thick surface courses of the OGCS test sections, a motor grader (previous Figure 20a) was typically used to rip the specified depth of existing surface aggregates to be reused, which were then windrowed to each side of the roadway.



Gradation Optimization for Granular Surface Materials

Developed in Iowa Highway Research Board Project TR-685

District		Project	TR-721	Date	7/30/2018
County	Cherokee	Note	Phase III	Designer	Yijun Wu

Road Geometry

Road Length	500	ft
Average Road Width	26	ft

Final Design Parameter

Target Final Thickness	4.00	in.
Target Maximum Aggregate Size (D_{max})	1.00	in.
Target Gradation Shape Factor (*n*)	0.35	0.35 to 0.40 is recommeded. The coarseness increases as the *n* value increases.

Properties of Existing Materials

Thickness of Existing Suface Material	2.30	in.
Dry Unit Weight of the Virgin Material	128	pcf
Thickness of Subgrade to be Incorporated into the Surface	0.00	in.
Dry Unit Weight of the Subgrade	90	pcf
Total Thickness of the Existing Surface and Subgrade	2.30	in.

						Material Name: River Rock	Roadstone, Moore Quarry	D57 Concrete Stone, Moore quarry				
Sieve No.	**Sieve size (mm)**	**Optimal Gradation (%)**	**Existing Surface Material Gradation (%)**	**Subgrade Gradation (%)**	**Calculated Gradation of the Existing Surface and Subgrade Mixture (%)**	**Quarry Material A (%)**	**Quarry Material B (%)**	**Quarry Material C (%)**	**Optimized Quarry Virgin Gradation (%)**	**Target Virgin Material Gradation (%)**	**Final Gradation with Target Virgin Material (%)**	**Final Gradation with Optimized Virgin Material (%)**
2	50.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1.5	38.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1	25.4	100.0	100.0	100.0	100.0	100.0	100.0	98.0	99.0	100.0	100.0	99.6
3/4	19.00	90.3	98.5	99.1	98.5	97.1	99.5	80.0	89.8	79.3	90.3	94.8
1/2	12.70	78.5	93.0	98.4	93.0	92.1	82.9	36.0	61.6	58.8	78.5	79.6
3/8	9.51	70.9	86.9	97.5	86.9	87.0	70.8	14.0	45.6	49.3	70.9	69.4
#4	4.76	55.7	74.1	94.3	74.1	73.6	47.2	0.7	28.3	30.7	55.7	54.6
#8	2.38	43.7	60.5	91.0	60.5	57.5	33.3	0.4	20.7	20.9	43.7	43.6
#16	1.19	34.3	52.0	85.0	52.0	34.0	24.9	0.4	14.3	10.3	34.3	36.0
#30	0.595	26.9	42.0	77.0	42.0	15.0	20.4	0.4	10.1	9.4	28.1	28.4
#50	0.297	21.1	29.5	67.5	29.5	5.2	17.2	0.4	7.5	9.4	20.9	20.2
#100	0.149	16.6	19.9	60.6	19.9	3.5	14.8	0.4	6.4	9.4	15.4	14.2
#200	0.075	13.0	15.7	57.5	15.7	3.0	12.6	0.4	5.5	9.4	13.0	11.4
					Proportion (%)	13	39	48	100	100		
					Quantity (tons)	15.5	45.6	56.7	117.9	117.9		

Figure 23. Sample results from gradation optimization spreadsheet for Cherokee County

For Washington County, however, a 60 in. wide RoadHog self-contained milling machine mounted on a Caterpillar 938M wheel loader was first used to loosen the existing 4 in. thick surface course before removing the top 3 in. and windrowing the last in.

For all counties, any additional existing surface material above the subgrade was then ripped and removed, except for Cherokee County, which did not have a clear clayey subgrade interface but instead gradually graded from gravel to sand to silt with increasing depth. The calculated optimum tonnages of virgin quarry aggregates (listed in Table 8) were spread over the test sections with dump trucks, then blade-mixed with the existing aggregates after bringing in the windrows.

Table 8. As-built properties of OGCS test sections

Property	Cherokee	Howard	Washington	Hamilton
Road width (ft)	26	40	31	28
Test section length (ft)	500	500	500	500
Existing surface material reused (in.)	2.3	0.6	1.0	2.0
Quarry aggregates added* (tons)	117.8	541	241	176
Clay slurry added (gal)	2,000	3,081	2,500	2,540
Actual slurry application rate (gal/yd^2)	1.38	1.39	1.45	1.63
Fines content before→after slurry	5.0→13.3	10.4→13.8	14.9→20.1	8.3→15.9
Fines content increase (%)	8.3	3.4	5.2	7.6
PL before→after adding slurry	NP→14	6→9	13→14	NP→13
LL before→after adding slurry	NP→28	20→26	20→27	17→23
PI before→after adding slurry	NP→14	14→17	7→13	NP→10

*Cherokee: 45.6 tons Moore Quarry Roadstone + 56.7 tons Moore D57 Concrete Stone + 15.5 tons River Rock
Howard: 360 tons Dotzler Class A + 46.3 tons Porous Backfill + 135.1 tons Special Backfill
Washington: 30.91 tons Conklin Quarry 1 in. Roadstone + 210.18 tons Conklin 3/4 in. Class A Crushed Stone
Hamilton: 90 tons Grand George Quarry Hamilton Roadstone, 86 tons Grand George 1 in. Clean

After thoroughly blending the virgin and existing aggregates, some of the material was used to form windrows of approximately 4 to 6 in. height at both shoulders to prevent the clay slurry from running off the road. The clay slurry was then sprayed over the road surface using three to six passes of a self-unloading tanker truck (Figure 24).

Figure 24. Tanker used to spread clay slurry in Hamilton, Howard, and Washington counties

During construction of the Cherokee County site, the large tanker truck used at the other three sites was not available, so a smaller tanker truck (Figure 25) was provided by the clay slurry supplier.

Figure 25. Tanker used for spreading clay slurry in Cherokee County

After spraying the clay slurry, the top 2 in. of aggregate and slurry were blade-mixed edge to edge, while gradually incorporating the windrowed material, using 10 to 15 passes of a motor grader (or two graders working in tandem) until the mixture dried sufficiently. Because of the large amount of water contained in the slurry, blade mixing was the most time-consuming part of the process. At the beginning of the blade-mixing process, the mixture was very watery and the graders' moldboards pushed a layer of liquid slurry on top of the aggregate (Figure 26).

Figure 26. Consistency of clay slurry and aggregate at beginning of blade mixing process in Washington County

By the end of blade mixing, the material was more homogenous with a consistency like that of very wet concrete (Figure 27 and Figure 28).

Figure 27. Clay slurry and aggregate near the end of the blade mixing process in Washington County

Figure 28. Consistency of clay slurry and aggregate near the end of blade mixing process in Washington County

After blade mixing was completed, surfaces were shaped using a grader and compacted using a smooth drum vibratory roller (previous Figure 20g). However, after a few passes, the material tended to stick to the roller drums and peel off the roadway. The vibratory roller was therefore taken off the surface and compaction was completed using 10 to 20 passes of a tow-behind rubber tire roller (previous Figure 20h). In Cherokee County, dump trucks were used for compaction because a rubber tire roller was not available.

Finally, a light cover of fresh dry aggregate was spread over the surface using dump trucks to minimize sticking of the aggregate-slurry mixture to tires. The light aggregate cover typically consisted of two 14-ton truckloads of 3/4 in. road rock equating to an average thickness of about 0.4 in. The dry aggregates were then lightly bladed and typically compacted using one pass of the vibratory roller followed by a few passes of the roller without vibration. The resulting surfaces were wet but passable by traffic and generally dried out and stiffened to very good conditions within a few days. The sections in Washington and Howard counties both had heavy overnight rain immediately after construction, but both held up well and did not get muddy.

Due to slight differences between the targeted and actual slurry volumes delivered by the tankers, the actual application rates were determined to be 1.39 gal/yd^2 in Howard County, 1.45 gal/yd^2 in Washington County, 1.63 gal/yd^2 in Hamilton County, and 1.38 gal/yd^2 in Cherokee County, as summarized in the previous Table 8.

The as-constructed data in that table also shows that the clay slurry increased the fines content of the surface aggregate mixtures by an average of 6%, resulting in fines content between 13% and 20% for the OGCS test sections. Note that most of the initial fines content before adding clay slurry come from the recycled existing surface aggregate, and to a lesser extent from the quarry materials, and are typically nonplastic fines from crushing of limestone aggregate. By adding the clay slurry, the PI of the test sections in Cherokee and Hamilton counties were increased from NP to values of 14 and 10, respectively; whereas, the PI in Washington County increased from 7 to 13, and the PI in Howard County increased from 14 to 17 by adding the clay slurry. These results suggest the desired effect of increasing the plasticity of the surface aggregate mixture, which should increase its binding action and therefore reduce gravel loss.

Although spraying the clay slurry on the surfacing aggregate was a quick process, the mixture required several hours to sufficiently dry by blading it back and forth because of the large volume of water it contains. After the test sections were completed, the clay slurry supplier developed an improved application method that involves applying the clay slurry to aggregate that is dried in piles and sold as pre-treated aggregate containing clay solids. This eliminates the requirement to transport and spray a slurry consisting of 65% water, which should greatly reduce the cost and time required for construction.

5.2.3 Ground Tire Rubber Section

The ground tire rubber section was constructed in Howard County on August 15, 2018 using conventional granular roadway construction methods. The goal was to incorporate rubber chips at 20% by volume in the bottom 2 in. of the surface course, covered by another 2 in. layer of aggregate.

First, a motor grader was used to rip an approximately 1 in. thick layer of existing surface aggregate, which was windrowed to the shoulders, and 75 tons or 0.6 in. of fresh aggregate was spread over the surface of the test section. The ground tire rubber chips (17.5 tons equating to 0.4 in. thickness) were then spread and mixed with the existing and fresh aggregate to create a 2 in. thick base layer, which was then covered with another 2 in. (213 tons) of fresh aggregate.

The water content was adjusted to 8.5% using 8,175 gallons of water, and both of the 2 in. lifts were compacted during construction using several passes of a rubber tire roller and a smooth drum vibratory roller. However, the finished road surface was loose and unstable due to the compressibility of the rubber chips in the base layer, which caused vehicle tires to sink in and made steering difficult. This also caused the rubber chips to work their way up to the surface.

Clay slurry was then applied to the section in an attempt to increase binding and improve stability, but it was not successful. The section was deemed to have failed, and the surfacing materials were removed and spread over several miles of surrounding roads to reclaim the significant amount of aggregate while thinning out the rubber chips.

5.2.4 Recycled Asphalt Pavement Sections

The RAP sections were constructed on August 15, 2018 in Howard County and on September 27, 2018 in Cherokee County using conventional granular roadway construction methods. A motor grader was used to rip the existing surface materials and create a 2 in. deep windrow on each side of the sections. In Howard County, the existing surface aggregates were less than 2 in. thick, so additional aggregate was borrowed from the spoil of other sections to reach a thickness of 2 in.

RAP was then spread over the test sections, sprayed with water, and mixed with the windrowed (existing) surface materials using a motor grader. In Cherokee County, a disc plow harrow (previous Figure 20d) was also used to mix the materials before finishing with a motor grader.

The target compaction water content determined by Proctor tests was 7%, corresponding to 4,652 gallons in Cherokee County and 7,158 gallons in Howard County. However, only about 1,000 gallons were required in Cherokee County because the material was already wet at the start of construction. The actual compaction water content during construction was gradually increased and checked by hand feel. After shaping the surface, six passes of a rubber tire roller were used for compaction, followed by one pass of a smooth drum vibratory roller.

5.2.5 Slag Sections

In Howard County, the two Phoenix slag sections were constructed on August 14, 2018 (Figure 29 through Figure 32), and the two Harsco slag sections were constructed on August 15, 2018 (Figure 33 and Figure 34). In Cherokee County, both the Phoenix and Harsco slag sections were constructed on October 25, 2018.

Figure 29. Spreading Phoenix slag over the subgrade in Howard County

Figure 30. Blading Phoenix slag in Howard County

Figure 31. Spraying compaction water over Phoenix slag in Howard County

Figure 32. Compacting Phoenix slag with smooth drum vibratory roller in Howard County

Figure 33. Dumping Harsco slag over the subgrade in Howard County

Figure 34. 4 in. completed surface of Harsco slag section in Howard County

All slag sections were constructed using the same conventional granular roadway construction methods used for the RAP sections. For the sections with 2 in. of slag over 2 in. of aggregate, the top 2 in. of the existing surface aggregate was first ripped and windrowed to both sides. The remaining aggregate was then ripped and removed, and the windrowed aggregate was spread back over each section. For the sections with 4 in. of slag alone, the existing aggregate was first ripped down to the subgrade surface and removed. However, in Cherokee County the existing aggregate surface did not have a clear subgrade interface but gradually graded from gravel to sand to silt; therefore, the slag sections were constructed on top of the existing aggregate surfaces.

For both Howard and Cherokee counties, slag was spread over the sections in thinner lifts than typically used for natural aggregate, because the slag is very angular and resists rutting and shoving. Water was also sprayed on the surfaces during construction to aid compaction. The design properties of the eight slag test sections, including the amount of water required to bring the materials from dry to OMC conditions, are listed in Table 9.

Table 9. Design properties of slag test sections in Cherokee and Howard counties

	Cherokee County		**Howard County**	
Property	**2 in./4 in. Harsco**	**2 in./4 in. Phoenix**	**2 in./4 in. Harsco**	**2 in./4 in. Phoenix**
Road width (ft)	26	26	40	40
Test section length (ft)	250	250	250	250
Aggregate unit weight (lb/ft^3)	128	128	128	128
Slag unit weight (lb/ft^3)	155	145	155	145
Aggregate amount (tons)	69.3/0	69.3/0	106.7/0	106.7/0
Slag amount (tons)	84.0/167.9	78.5/157.1	129.2/258.3	120.8/241.7
Compaction OMC	9%	4%	9%	4%
Compaction water if dry (gal)	3,306/3,622	1,418/1,506	5,087/5,572	2,181/2,317

However, because the materials were already wet, the actual amount of water used for construction was checked and adjusted by hand feel and was less than the amounts shown in the table.

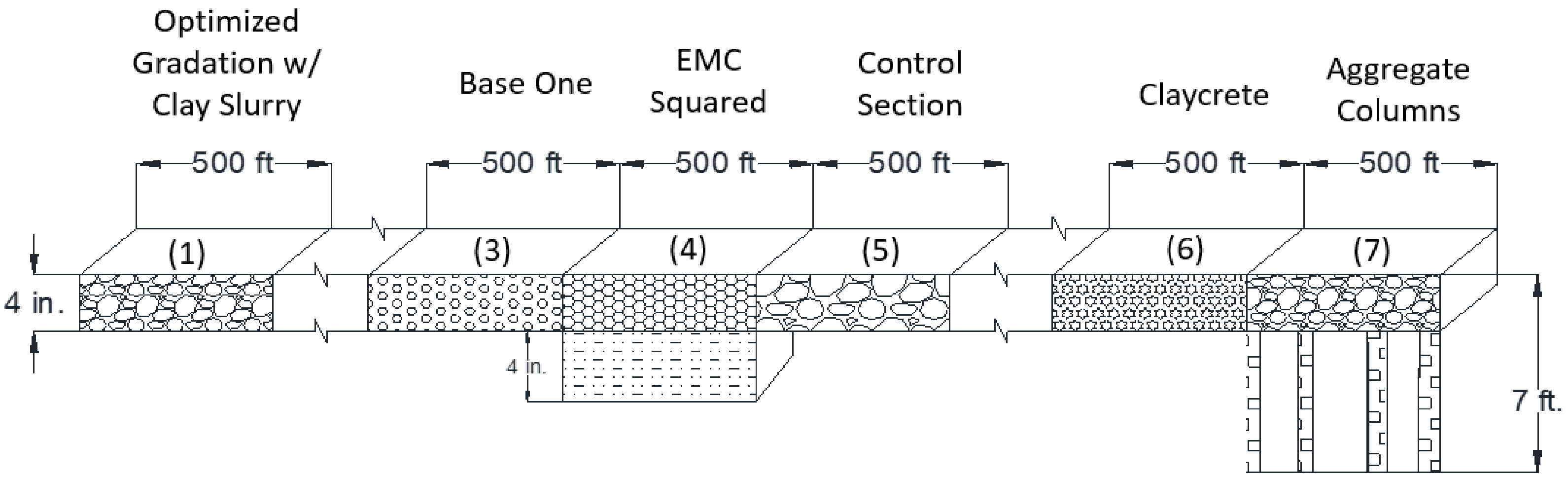
After blading and shaping the surfaces, compaction was performed using six passes of a rubber tire roller followed by at least four passes using a smooth drum vibratory roller. In Cherokee County, the 2 in. Phoenix slag section was shortened by 50 ft because the county had a smaller tonnage of slag than was specified.

5.3 Chemically Stabilized Test Sections

This section details the construction procedures, equipment used, and dates of construction for the chemically stabilized test sections in Washington and Hamilton counties. Schematic diagrams of the test sections are shown in Figure 35 35.

Additional figures in Appendix C show the layout of the test sections superimposed on satellite images of the sites.

Hamilton County:



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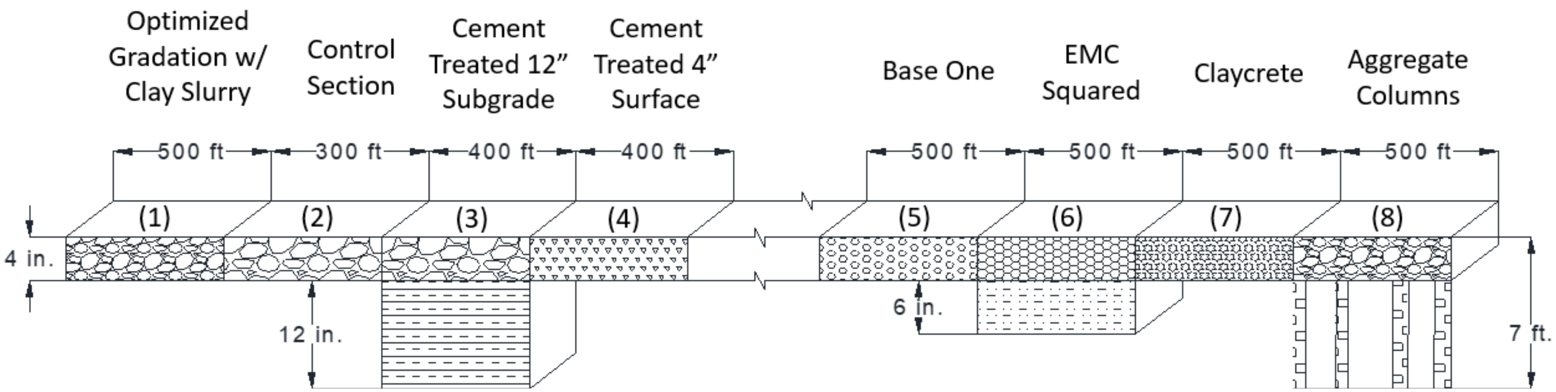
Washington County:



Not to scale

Figure 35. Layouts of chemically stabilized test sections in Hamilton and Washington counties

5.3.1 Cement-Treated Subgrade Section

The cement-treated subgrade section was constructed in Washington County on August 30, 2018. Equipment and labor for the section was donated by GEOMAX Soil Stabilization, Inc. in Iowa City, and the Type I/II portland cement was donated by Continental Cement Company in Davenport/Buffalo, Iowa.

A total of 29.4 tons of portland cement was used to stabilize the subgrade soil to a depth of 12 in. beneath the 500 ft by 26 ft test section. To construct the section, a motor grader was used to rip the existing 2 in. of surface aggregate, which was then windrowed to one side to expose the subgrade. A spreader truck was used to uniformly distribute several inches of portland cement over the subgrade surface, as shown in Figure 36a

A pneumatic tanker truck (Figure 36b) was used to transport the cement from the manufacturing plant and transfer it to a 10 ft wide cement spreader truck that had a horizontal auger (Figure 36c).

The cement was first dry-tilled into the top 12 in. of subgrade at a speed of about 0.2 mph using a Caterpillar RM300 rotary mixer with an 8 ft mixing width (Figure 36d), then followed by two forward and reverse passes using an 86 in. wide vibratory padfoot drum roller (Figure 36e) with vibration applied only during the forward passes.

Water was then applied using two passes from a side discharge water truck (Figure 36f). The milling machine was turned around, and the surface was tilled again at a higher speed of about 1 mph while additional water was sprayed as needed.

To reduce the compaction delay time, the rotary mixer was continuously followed by the padfoot roller operating in a forward gear with vibration, then in reverse without vibration. A total of 14 passes of the mixer were applied over the strip, after which the mixer was moved over 4 ft to start working on the next 8 ft wide strip while the compactor continued working on the first strip.

Before working on the final strip, the windrowed aggregates were moved to the centerline to free a path for the milling machine. After all sections were mixed and compacted, the cement-treated soil surface was compacted using six passes of a rubber tire roller, one pass of a smooth drum roller with vibration, and one pass of a smooth drum roller without vibration (Figure 36g with finished stabilized subgrade surface before replacing aggregate shown in Figure 36h).

Figure 36. Construction of cement-treated subgrade section in Washington County: (a) surface with aggregates windrowed to far side and cement spread on the subgrade, (b) pneumatic tanker, (c) cement spreader, (d) milling machine, (e) vibratory pad foot drum roller, (f) side discharge water truck, (g) smooth drum vibratory roller, and (h) finished stabilized subgrade surface before replacing aggregate

5.3.2 Cement-Treated Aggregate Surface Course Section

The cement-treated aggregate surface course section was constructed on August 30, 2018 by the Washington County Engineering & Secondary Roads crew using a 60 in. wide RoadHog milling attachment mounted on a Caterpillar 938M wheel loader (Figure 37a) and attached to a water truck using a hose system (Figure 37b).

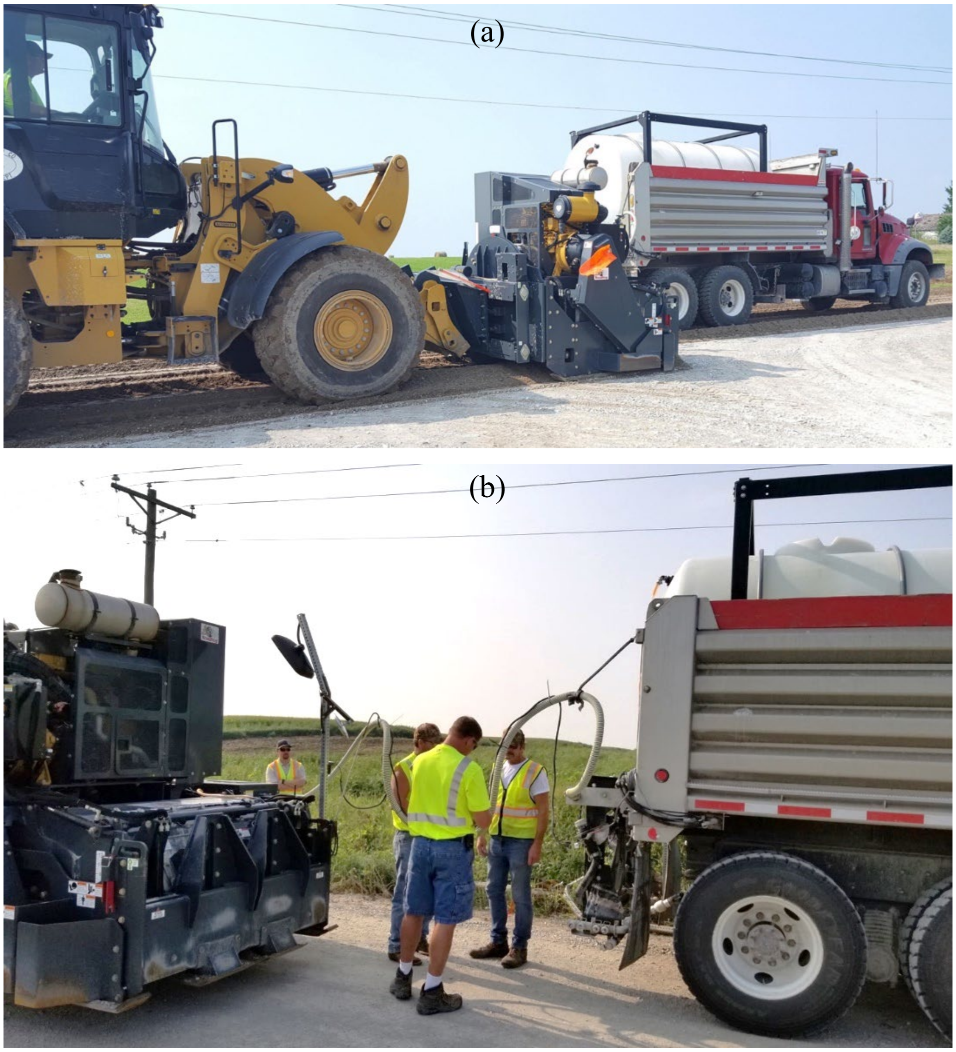


Figure 37. (a) RoadHog milling machine mounted on wheel loader and (b) hose connection to water truck

A total of 17.74 tons of Type I/II portland cement was used to stabilize the 4 in. surface course over the 500 ft by 26 ft test section. Before construction, fresh aggregate was spread on the section to a thickness of 4 in., and the GEOMAX cement spreader truck was used to uniformly distribute the cement over the road surface (Figure 38a).

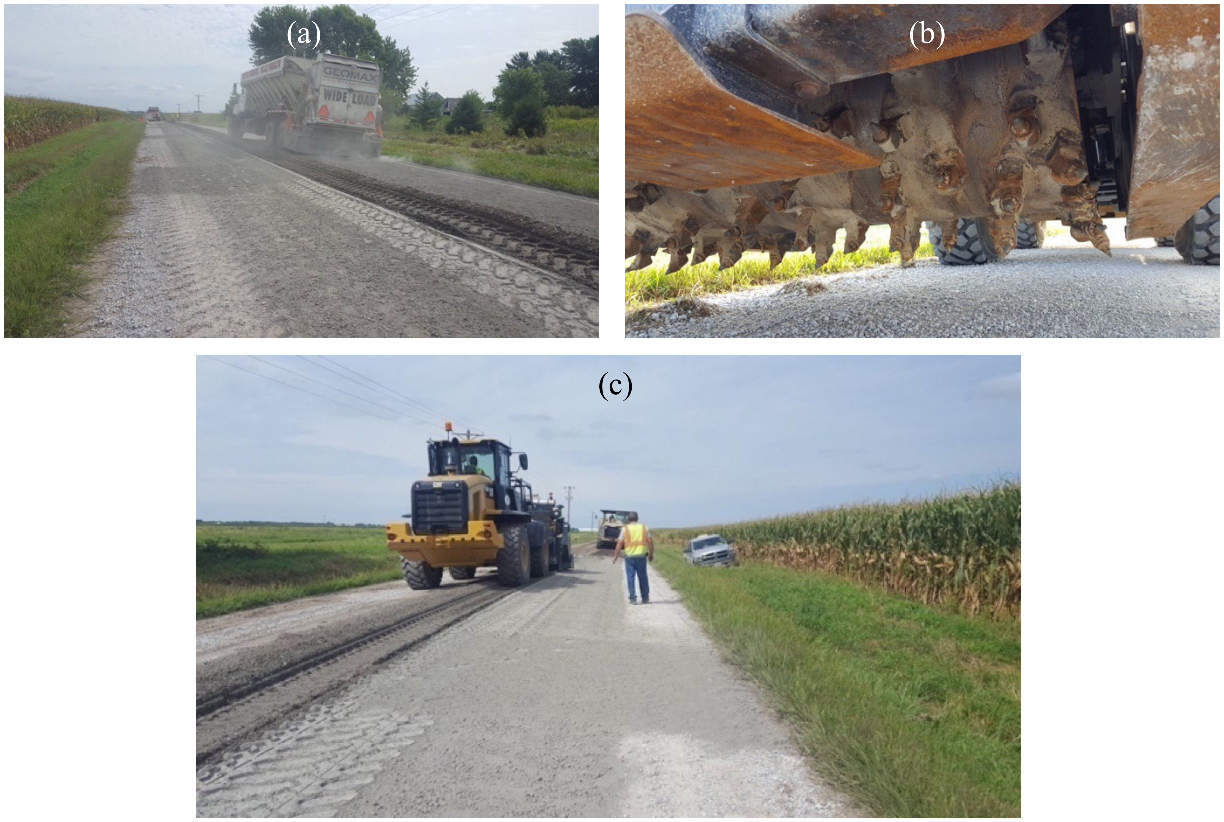


Figure 38. Construction of cement-treated aggregate surface section in Washington County: (a) spreading cement over aggregate surface, (b) depth of milling machine set to 4 in., and (c) mixing cement, aggregate, and water using milling machine

The mixing depth of the RoadHog was set to 4 in. (Figure 38b), and the fresh aggregate and cement were mixed using the RoadHog (Figure 38c) with the water feed rate adjusted to a water content near 7.5%, which was checked by hand feel.

After incorporating the cement, additional water was sprayed over the surface using a water truck and the surface was shaped by blading it using a motor grader. The mixture was then compacted using four passes of a rubber tire roller, one pass of a smooth drum roller with vibration, and one pass of a smooth drum roller without vibration. After construction, the road was closed overnight for curing.

5.3.3 Concentrated Liquid Chemical Stabilizer Sections

Three sections with concentrated liquid chemical stabilizers were constructed in both Washington County and Hamilton County. The stabilizers were mixed into the surfacing materials using the RoadHog milling machine. In Washington County, the BASE ONE and EMC SQUARED sections were constructed on August 21, 2018, and the Claycrete section was constructed on August 30, 2018. All three liquid chemical stabilizer sections in Hamilton County were constructed on September 6, 2018. The same equipment used in Washington County was transported to Hamilton County and used for construction of the three liquid stabilizer sections there using the same methods.

5.3.3.1 BASE ONE Sections

In accordance with the on-site representative's guidance, 0.5 in. of subgrade was targeted for incorporation into the existing aggregate surface materials to construct the BASE ONE test section in Washington County. The existing aggregate surface course was measured to be 4 in. thick, so the RoadHog mixing depth was set to 4.5 in. to include 0.5 in. of subgrade. The measured average width of the roadway for this section was 25.75 ft. This width and the 4.5 in. treatment depth were used to calculate the amounts of stabilizer and water needed, giving 32.2 gallons of stabilizer for the recommended incorporation rate of 0.005 gallons per yd^2 per in. of depth. Based on the manufacturer's recommended water to stabilizer dilution rate of 90:1, 2,898 gallons of water were required. Given the water truck capacity was limited to 2,000 gallons, 22 gallons of liquid stabilizer were first added to the tank, then 1,978 gallons of water were added to fill the tank. The RoadHog was then used to incorporate the stabilizer using two mixing passes in each 5 ft wide lane (Figure 39a).

Figure 39. Construction of BASE ONE section in Washington County: (a) incorporating stabilizer into surface course with RoadHog, (b) compacting with rubber tire roller, and (c) finished surface after final compaction and blading

When the water tank was nearly empty, another 10.2 gallons of stabilizer were added followed by 918 gallons of water. After all 32.2 gallons of stabilizer were incorporated, the treated surface was bladed and compacted using a rubber tire roller (Figure 39b).

Because of the preexisting moisture content of the section, the surface ended up being a little too wet after construction. To help dry out the section, the rubber tire roller was used on the section for a few hours, and a motor grader was used to cut back and blade 1 in. of the surface. When the surface had dried sufficiently, one pass of the smooth drum vibratory roller and two passes of the rubber tire roller were used, followed by a final tight-blading pass to create the finished surface shown in Figure 39c.

For the BASE ONE section in Hamilton County, the stabilized width was 27 ft, and the target incorporation depth was again set to 4.5 in. to include 0.5 in. of subgrade soil, requiring 34 gallons of liquid stabilizer. Because the site experienced 2 in. of heavy rain overnight and was still very wet, only 1,200 gallons of water were added to the stabilizer in the water truck. After incorporating the stabilizer using the RoadHog (Figure 40a), the surface was bladed level (Figure 40b) and shaped by mixing the top 1 to 2 in. of material.

Figure 40. Construction of BASE ONE section in Hamilton County: (a) incorporating stabilizer into surface course with RoadHog, (b) blading with motor grader, and (c) finished surface after final compaction and blading

One pass of a rubber tire roller was applied, followed by one pass using a smooth drum vibratory roller with the vibration on. The surface was bladed a few more times, followed by a few hours of rolling with the smooth drum roller without vibration.

The stabilizer was anticipated to set up and harden, which would help preserve the crown but may become harder to blade. The surface was therefore finished with a 5% crown (Figure 40c) rather than the 6% crown typically used in Hamilton County.

5.3.3.2 EMC SQUARED Sections

In accordance with the manufacturer's communicated recommendations for the use of EMC SQUARED Stabilizer (1000), 6 in. of subgrade materials were targeted for incorporation with the 4 in. surface aggregate for a total targeted stabilization depth of 10 in.

For construction of the 500 ft long by 31 ft wide by 10 in. deep section in Washington County, 32 gallons of stabilizer were required at the recommended incorporation rate of 1 gallon per 15 yd^3 of aggregate or soil material.

The RoadHog was first used to loosen and rip the 4 in. thick surface course of aggregate, which was removed to the end of the section. To treat the 6 in. of subgrade soil, about 60% (19 gallons) of the total required stabilizer amount was added to the water tank, followed by 1,981 gallons of water. The stabilizer was then incorporated into the subgrade soil to a depth of 6 in. using the RoadHog fed by the water truck (Figure 41a).

The subgrade soil was then compacted using six passes by a rubber tire roller followed by four passes using a smooth drum roller with vibration. Next, the 4 in. of surface aggregate was spread back over the subgrade, and the remaining 40% (13 gallons) of stabilizer was added to the empty tank, followed by 1,700 gallons of water. The diluted stabilizer was sprayed on top of the aggregate using a spreader bar on the water truck (Figure 41b).

Then, the RoadHog was used to till the 4 in. of treated surface aggregate. The section was then bladed using a motor grader and compacted using six passes by a rubber tire roller, one pass using a smooth drum roller with vibration, and six passes using a smooth drum roller without vibration to create the finished surface (Figure 41c).

Figure 41. Construction of EMC SQUARED section in Washington County: (a) incorporating stabilizer into the subgrade with RoadHog, (b) spraying stabilizer over aggregate surface, and (c) finished surface after mixing, blading, and final compaction

In Hamilton County, the stabilized area of the EMC SQUARED test section was 500 ft long by 25 ft wide, requiring 26 gallons of liquid stabilizer for the targeted stabilization depth of 10 in. (6 in. subgrade plus 4 in. aggregate). The existing 4 in. surface aggregate course was windrowed (Figure 42a) and removed to the end of the section using a motor grader and end loader.

To stabilize 6 in. of the subgrade, about 60% (16 gallons) of the total required stabilizer volume was added to the water tank, followed by 1,250 gallons of water. Because of recent rain, the volume of water used was less than the recommended water to stabilizer dilution ratio of 135:1 to avoid the compaction water increasing the subgrade moisture content beyond optimum.

The RoadHog was then calibrated to a mixing depth of 6 in., connected to the water truck, and used to incorporate the stabilizer into the subgrade (Figure 42b). During mixing of the subgrade, the RoadHog had to be stopped several times to remove large cobbles that became lodged in the teeth (Figure 42c). To enable the work to continue, the subgrade mixing depth had to be reduced to 3 in. on the two outside passes to avoid hitting more cobbles.

After subgrade mixing was completed, the aggregate was spread back over the section and bladed level (Figure 42d). The RoadHog was then set to a mixing depth of 4 in. and the surface aggregate course was stabilized using the remaining 10 gallons of stabilizer and 781 gallons of water (Figure 42e).

Figure 42. Construction of EMC SQUARED section in Hamilton County: (a) windrowing and removing existing aggregate, (b) stabilizing the subgrade, (c) removing large cobbles from RoadHog, (d) replacing aggregate course, (e) stabilizing aggregate course, (f) leveling surface, (g) blading and compacting surface, and (h) continued compaction

After mixing of the aggregate surface course was completed, the surface was bladed level (Figure 42f), then shaped using a motor grader (Figure 42g) and compacted with 6 to 8 passes per lane of a smooth drum roller without vibration (Figure 42h), followed by two passes using a rubber tire roller and a final trim blading pass.

5.3.3.3 Claycrete Sections

In accordance with guidance from the on-site Claycrete representative, the liquid stabilizer was mixed into the surface aggregate course along with 0.5 in. of the clayey subgrade soil in both counties.

For the Washington County Claycrete section, the thickness of the existing aggregate surface course was 3 in. To increase the thickness of the aggregate layer to 3.5 in, another 30 tons of aggregate was spread over the 500 ft long by 26 ft wide section. The RoadHog was then calibrated to a milling depth of 4 in. to include 0.5 in. of subgrade soils with the 3.5 in. of surface aggregate.

Based on the representative's instruction, 10 gallons of liquid Claycrete stabilizer were added to the water truck tank, followed by 1,200 gallons of water, for a Claycrete application rate of 0.062 gal/yd^3 (307 ml/m^3). The entire volume of stabilizer and water in the tank were then mixed into the aggregate and subgrade using the RoadHog connected to the water truck using one pass per 5 ft wide lane (Figure 43a).

A few passes using a rubber tire roller were applied next, but the roller was removed due to the depth of the ruts it was creating. The surface was then blade-mixed using a motor grader at a speed of about 10 mph with the blade pitched forward, then sprayed with additional water twice.

The resulting stabilized surface course was compacted using one pass of a steel drum roller with vibration followed by two passes without vibration (Figure 43b). The compaction passes started at the shoulders and worked toward the centerline while alternating sides and overlapping half the drum width for each pass.

The surface was finished using a motor grader trim cut to get as smooth and tight a surface as possible with little to no loose material on top (Figure 43c), along with the use of a drum roller without vibration compacting forward and backward behind the grader. The finished surface is shown in Figure 43d.

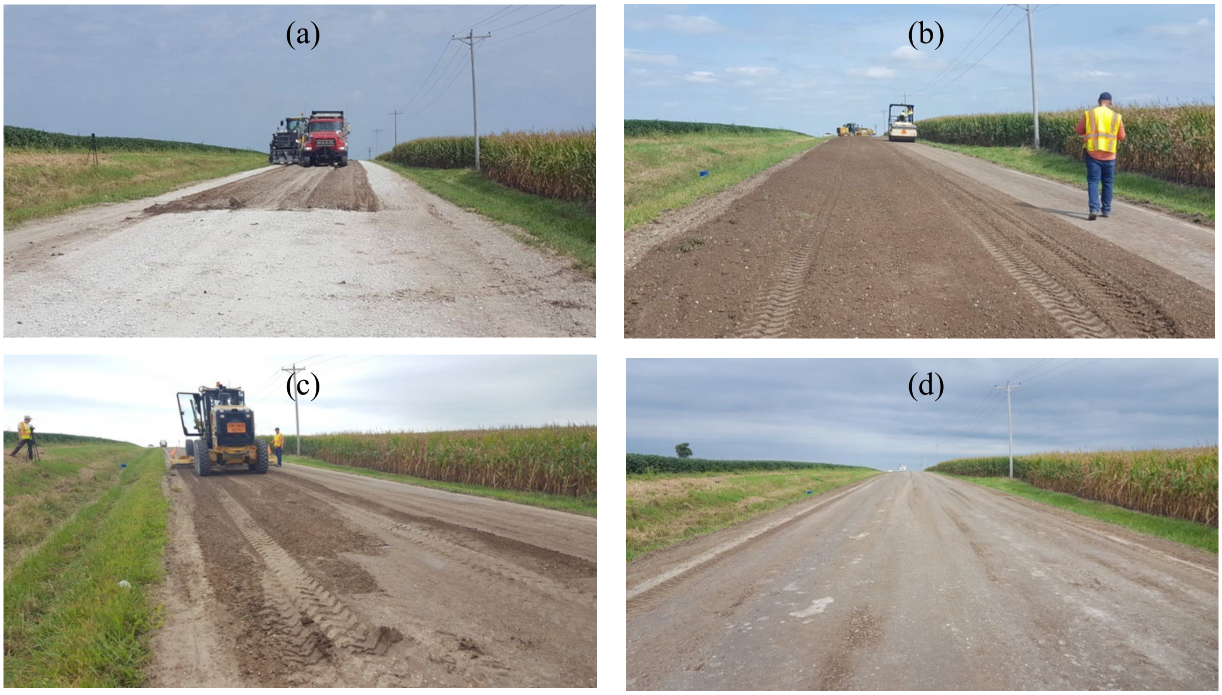


Figure 43. Construction of Claycrete section in Washington County: (a) milling stabilizer into aggregates and subgrade, (b) compacting with smooth drum vibratory roller, (c) blading surface, and (d) finished surface

In Hamilton County, the stabilized section was 500 ft long by 25 ft wide by 4.5 in. deep, which included 4 in. of surface aggregate plus 0.5 in. of clayey subgrade soil. Per the on-site representative's calculations, the Claycrete application rate of 0.062 gal/yd^3 (307 ml/m^3) was used, requiring 10.7 gallons of liquid stabilizer. The 10.7 gallons of Claycrete was first added to the water truck tank, followed by 1,200 gallons of water.

The milling depth was set to 4.5 in. on the RoadHog, and it was connected to the water truck and used to mill the stabilizer into the aggregate and subgrade using one pass per 5 ft wide lane (Figure 44a). The resulting surface course was then blade-mixed using several passes of a motor grader, one pass of a water truck, and a few more grader passes.

Compaction was applied next, working from alternate shoulders to the center using three passes of a smooth drum roller on high vibration with an overlap of half the drum width per pass (Figure 44b). The surface was then finished by blading for several passes with the blade pitched forward (Figure 44c), followed by several passes using a rubber tire roller (Figure 44d) and finally a smooth drum roller without vibration until the surface was sufficiently smooth and dry (Figure 44e).

Figure 44. Construction of Claycrete section in Hamilton County: (a) milling stabilizer into aggregates and subgrade, (b) compacting with smooth drum vibratory roller, (c) blading surface, (d) compacting with rubber tire roller, and (e) finished surface

5.3.4 Control Sections

Control sections in all four counties consisted of each county's existing road surfacing material types and maintenance practices without any changes. The maintenance aggregates were spread on each control section surface to ensure the surface thickness started at 4 in.

CHAPTER 6 RESULTS AND DISCUSSION

This chapter presents the results and analysis of field and laboratory tests performed over a period of two years, including the fall to spring freeze-thaw timeframes of 2018–2019 and 2019–2020.

6.1 Field and Laboratory Tests Prior to Construction

Before starting construction of the test sections, several field and laboratory tests were performed to evaluate the existing soil properties and local material conditions at all four test sites. Field DCP tests were performed to determine the shear strength and layering profiles, and LWD tests were performed to determine composite elastic modulus values. Laboratory particle size analysis, UCS, CBR, Proctor compaction, and slaking tests were performed to evaluate the material properties as well as the effects of mixing the local granular aggregate materials with different amounts of the various stabilizers.

6.1.1 Results of DCP Tests Prior to Construction

To assess the initial layering and strength profiles of the test sites, five pre-construction DCP tests per county were performed in August 2017; The DCP test locations were distributed over an approximately 1 mile long planned test site location in each county. The pre-construction DCP results for Cherokee and Howard counties (which were the mechanical stabilization locations) are shown in Figure 45 and Figure 46, and the results for Washington and Hamilton counties (which were the chemical stabilization locations) are shown in Figure 47 and Figure 48.

Refusal was reached at two of the test points (Point 2 and Point 5) in Howard County due to the presence of cobbles and boulders in the subgrade. The truncated results for Point 2 are shown in the Figure 46 charts for Howard County, but no results were available to show for Point 5.

From the DCP test results, the nominal thickness of the surface layer was estimated from the changes in the mean slopes of the cumulative blows vs. depth plots, or by sudden jumps in the DCPI values with depth:

- In Cherokee County, the slope changes smoothly with depth, so a surface layer thickness could not be clearly identified. Drilling and sampling later confirmed that this site consists of gravel-sized particles transitioning to sand-sized particles for the top 2 ft, gradually transitioning to silt underneath.
- In Howard County, the surface course thickness varied from 2.0 to 4.0 in.
- In Hamilton County, the surface course thickness varied from 2.3 to 3.5 in.
- In Washington County, the surface course thickness was about 4.0 in.

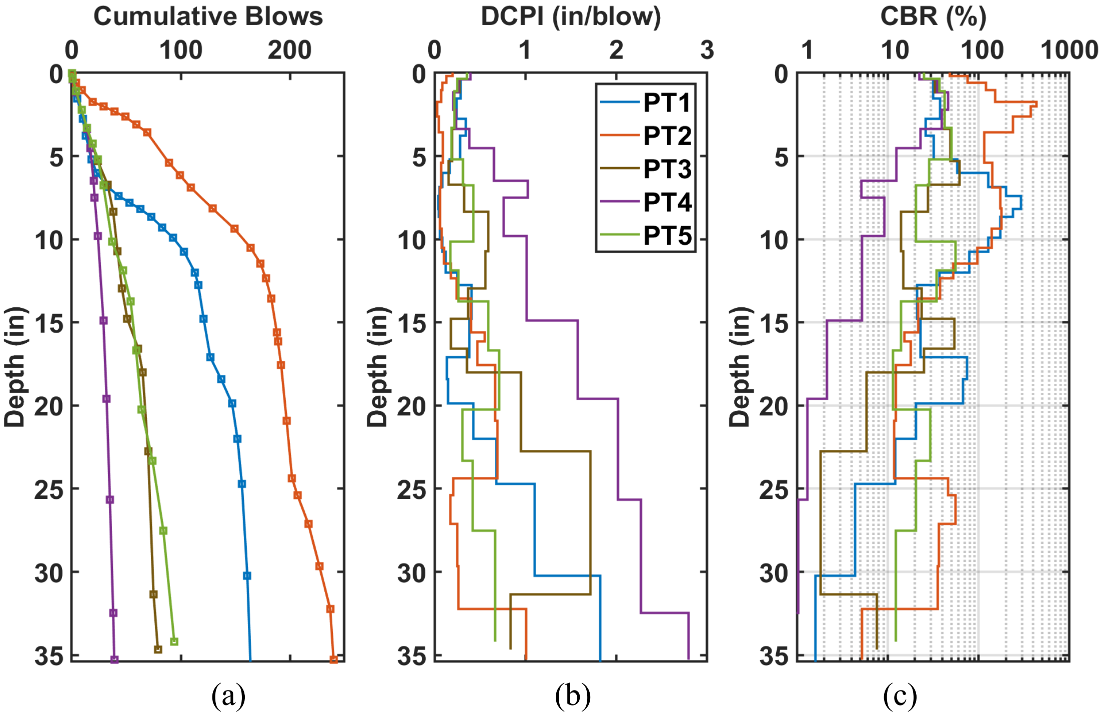


Figure 45. Pre-construction DCP results for Cherokee County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR

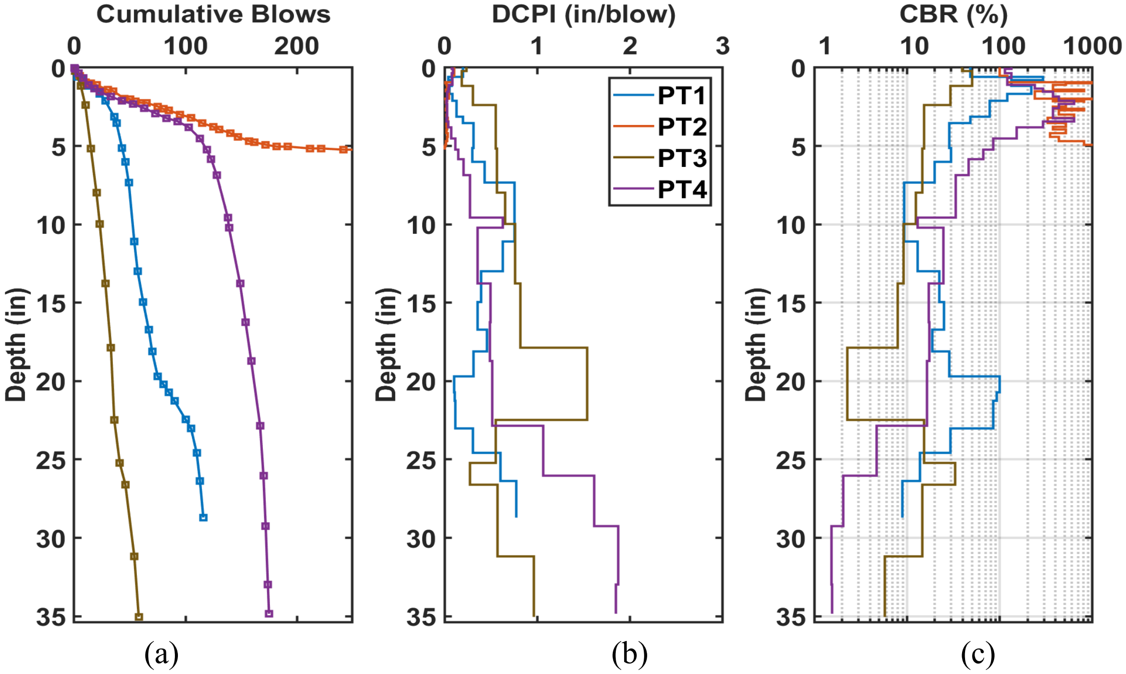
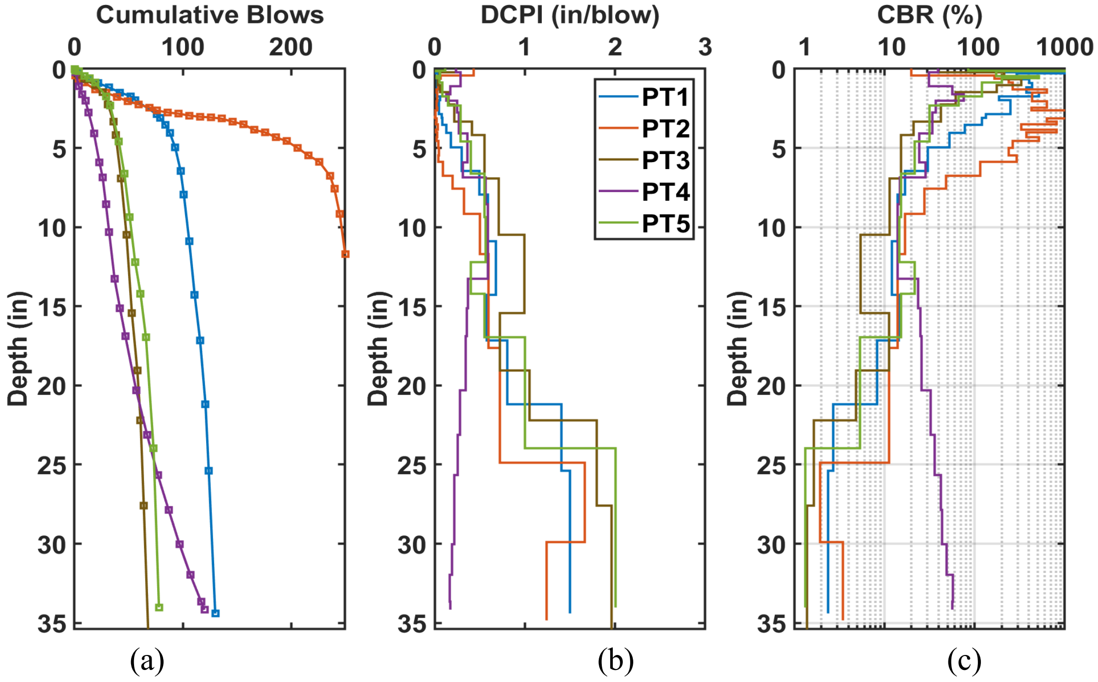
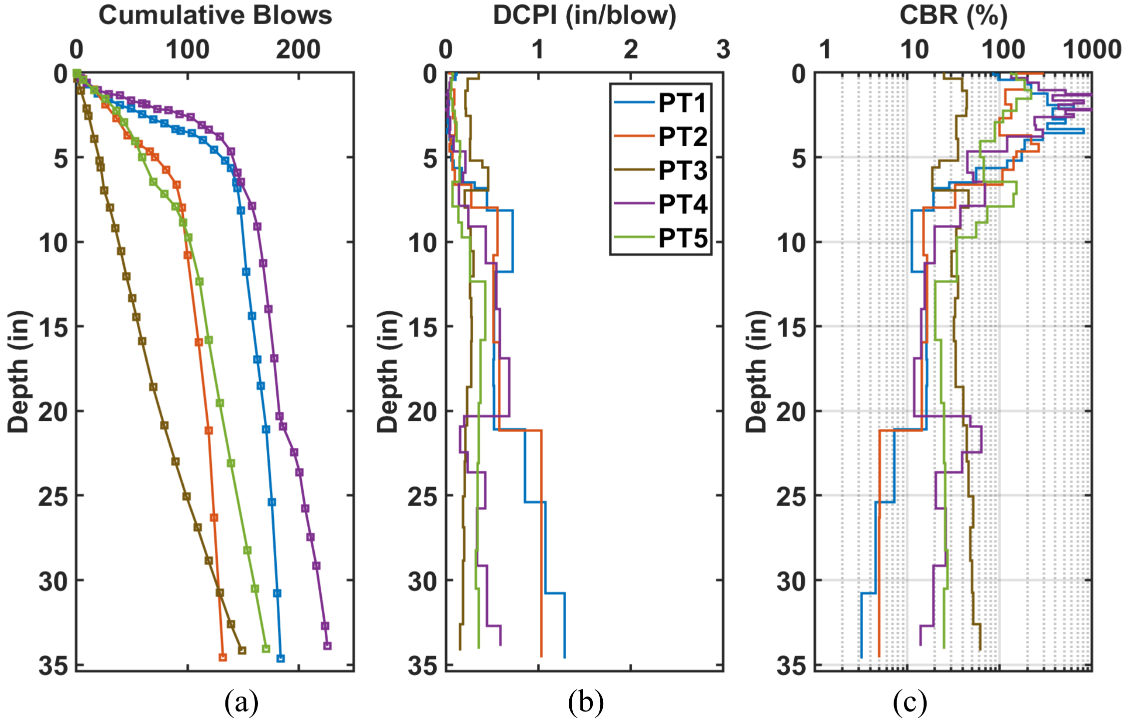


Figure 46. Pre-construction DCP results for Howard County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



(a) (b) (c)

Figure 47. Pre-construction DCP results for Hamilton County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



(a) (b) (c)

Figure 48. Pre-construction DCP results for Washington County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR

The average DCP-CBR values within the surface and subgrade layers were calculated, from which the corresponding Iowa Statewide Urban Design and Specifications (SUDAS) relative ratings of supporting strengths were determined according to Table 10.

Table 10. Iowa SUDAS relative support ratings based on CBR values for subbase and subgrade soils

CBR (%)	Material	Rating
>80	Subbase	E (excellent)
50 to 80	Subbase	VG (very good)
30 to 50	Subbase	G (good)
20 to 30	Subgrade	VG (very good)
10 to 20	Subgrade	F-G (fair–good)
5 to 10	Subgrade	P-G (poor–fair)
<5	Subgrade	VP (very poor)

Source: Iowa SUDAS 2016

The estimated surface layer thicknesses, average DCP-CBR values, and Iowa SUDAS ratings from all pre-construction DCP tests are shown in Table 11.

Table 11. Summary of pre-construction DCP results at test sites in the four counties

County	Test Point	Thickness of Surface Course (in.)	Avg. $DCP\text{-}CBR_{AGG}$ (%) / Rating	Avg. $DCP\text{-}CBR_{SG}$ (%) / Rating
Cherokee	1	4.0	31.2 / G	61.5 / >VG
	2	4.0	204.8/ E	59.7 / >VG
	3	4.0	40.2 / G	20.3 / VG
	4	4.0	35.7 / G	5.2 / P-F
	5	4.0	41.4 / G	29.1 / VG
Average		4.0	70.7 / VG	35.2 / VG
Coefficient of Variation		0.0 %	106.3 %	70.4 %
Howard	1	3.1	122.5 / E	29.2 / VG
	2	Refusal at 5 in.	–	–
	3	2.3	39.0 / G	11.1 / F-G
	4	4.5	290.7 / E	17.1 / F-G
Average		3.3	150.7 / E	19.1 / F-G
Coefficient of Variation		33.6 %	85.1 %	48.2 %

County	Test Point	Thickness of Surface Course (in.)	Avg. *DCP-CBR$_{AGG}$* (%) / Rating	Avg. *DCP-CBR$_{SG}$* (%) / Rating
Hamilton	1	3.4	279.9 / E	14.4 / F-G
	2	5.9	456.9 / E	19.8 / F-G
	3	2.2	151.1 / E	10.1 / F-G
	4	2.7	44.7 / G	28.0 / VG
	5	2.24	159.8 / E	15.4 / F-G
Average		3.3	218.5 / E	17.5 / F-G
Coefficient of Variation		45.9 %	71.9 %	38.7 %
Washington	1	5.5	290.9 / E	14.2 / F-G
	2	3.7	132.5 / E	34.1 / >VG
	3	3.9	38.0 / G	40.1 / >VG
	4	3.7	420.1 / E	32.4 / >VG
	5	4.0	140.5 / E	40.2 / >VG
Average		4.2	204.4 / E	32.2 / > VG
Coefficient of Variation		18.1 %	73.8 %	33.2 %

E=excellent, F-G=fair–good, G=good, P-G=poor–fair, VG=very good, VP=very poor

For Cherokee County, a surface layer thickness of 4.0 in. was assumed for calculation of the average DCP-CBR values in the surface course due to the absence of a clear interface. As shown in Table 11, at the time of the pre-construction tests, the average Iowa SUDAS support ratings for the surface courses were excellent in Howard, Hamilton, and Washington counties, and good to very good in Cherokee County. For the subgrades, the average Iowa SUDAS relative support ratings were very good in Cherokee and Washington counties and fair–good in Howard and Hamilton counties. The average DCP-CBR values for the surface course and subgrade layers in the four counties are plotted in Figure 49, which shows that the surface course DCP-CBR values were erratic; whereas, the subgrade values were lower but more uniform.

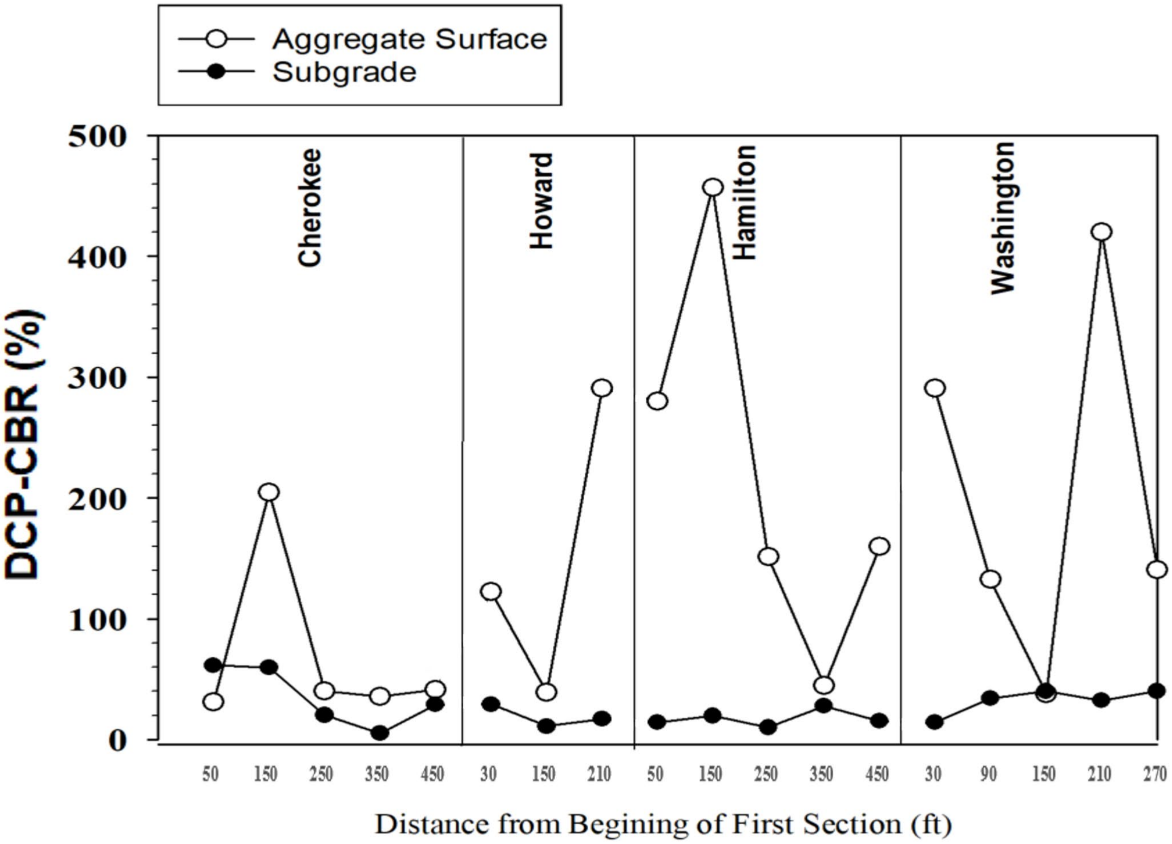


Figure 49. Pre-construction DCP results for test sites in the four counties

6.1.2 Results of LWD Tests Prior to Construction

Pre-construction LWD tests were also performed in each of the four county test site locations to determine in situ composite elastic modulus values (E_{LWD}). The pre-construction LWD test results are plotted in Figure 50, and average values of E_{LWD} for each county test site location are listed in Table 12.

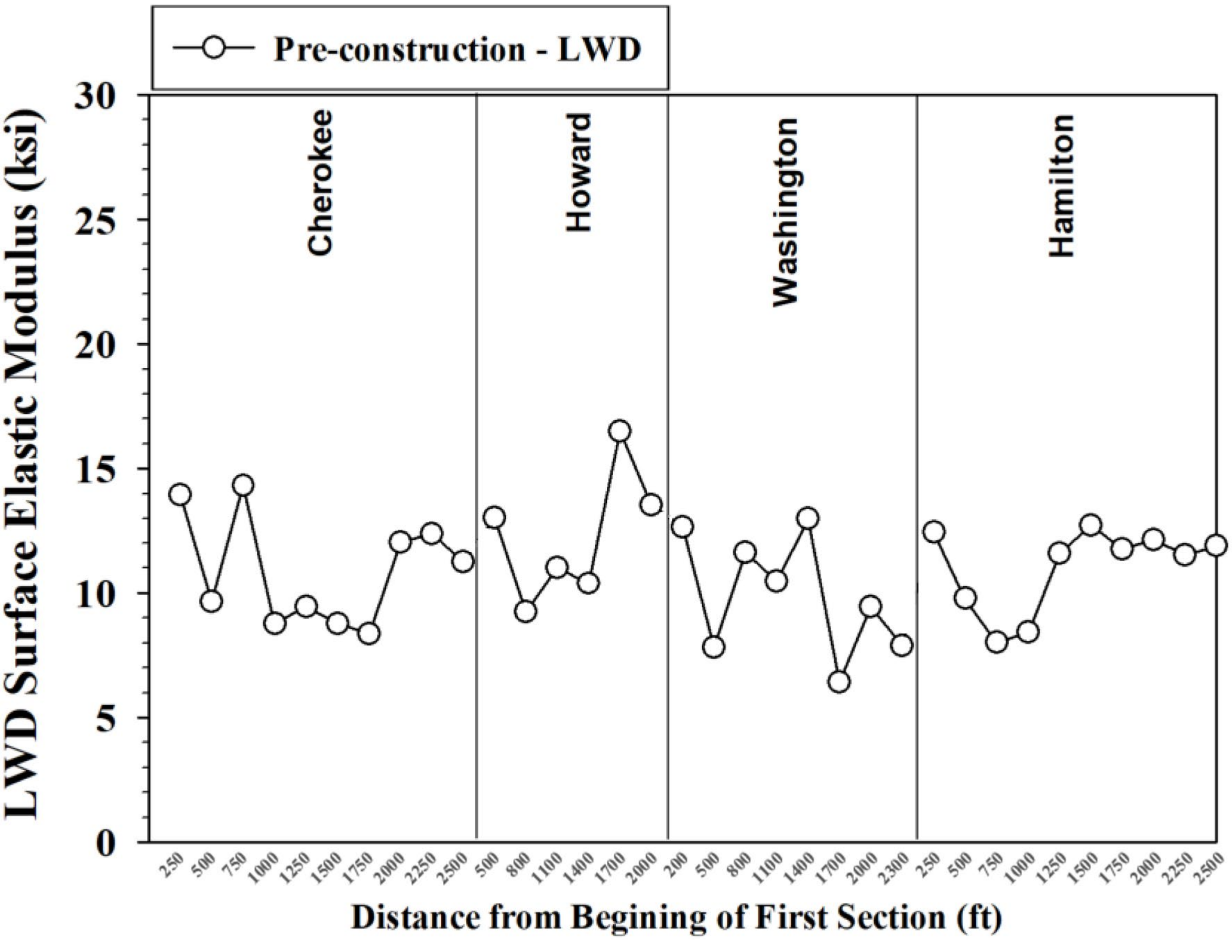


Figure 50. Pre-construction LWD results

Table 12. Summary of pre-construction LWD test results

Result	Cherokee	Howard	Washington	Hamilton
Average E_{LWD} (ksi)	10.9	12.3	9.9	11.0
Coefficient of Variation	20.2	21.3	24.5	15.2

The E_{LWD} values for all test sites prior to construction were relatively close to one another.

6.1.3 Results of CBR Tests on Aggregate Clay Slurry Mixtures Prior to Construction

CBR tests were performed to quantify the shear strength of mixtures of aggregates and clay slurry at the target rate of 7% clay solids by dry weight. This target was found to be the maximum concentration that could be practically applied during prior field trials in Hamilton County due to the high water content of the slurry.

The surface materials collected from the Washington County site were mixed with 7% clay slurry by dry weight in the laboratory. The mixtures were allowed to dry at 60°C for 24 hours; then, Proctor compaction tests were performed to determine the values of optimum moisture content (OMC) and maximum dry unit weight. Before performing the CBR tests, the CBR specimens were compacted in a 6 in. diameter mold at the OMC and soaked for more than 24 hours to achieve full saturation. A plot of shear stress versus penetration depth for the CBR tests on the mixture of surface aggregate and 7% clay slurry is shown in Figure 51.

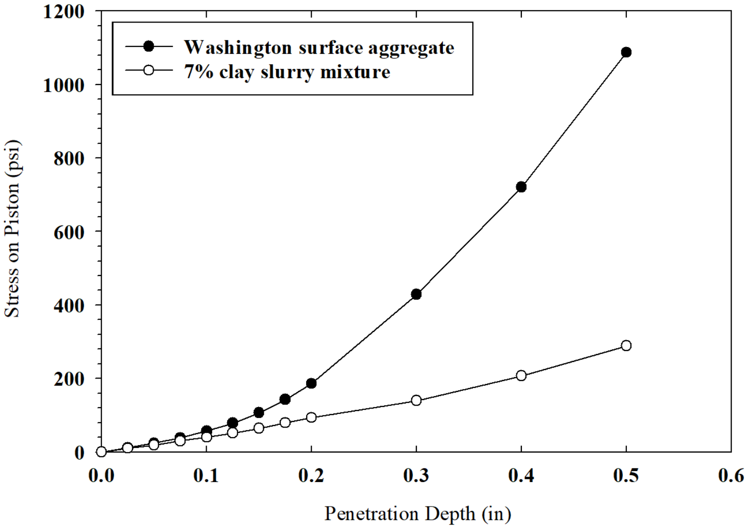


Figure 51. Uncorrected stress on piston versus penetration depth from CBR tests on Washington County surface aggregate with and without 7% clay slurry

The penetration resistance of the untreated soaked Washington County surface aggregate was three times greater than that of the surface aggregate with 7% clay slurry. The clay slurry therefore offers a trade-off between improved binding properties and reduced shear strength. The CBR ratings for the soaked Washington County surface aggregate specimens with and without clay slurry are provided in Table 13.

Table 13. Laboratory CBR test results for soaked specimens

Specimen	Dry Unit Weight (lb/ft^3)	Compaction Moisture Content (%)	Lab CBR (%) / Rating
Washington Surface Aggregate	141.6	7.1	28.0 / <G
Mixture with 7% Clay Slurry	134.8	7.7	11.0 / <G

G=good

6.1.4 Results of UCS Tests on Clay Slurry Mixtures Prior to Construction

The effect of the clay slurry on the shear strength of the matrix of fine sand, silt, and clay-sized particles, which bind the larger particles, can be determined using UCS tests. For this purpose, UCS tests were performed on samples taken from five points distributed evenly over a 500 ft long test section in Washington County. The UCS test specimens were prepared similar to those used for the CBR test (i.e., Washington County surface aggregate was mixed with 7% clay slurry by dry weight), except the surface aggregate materials were first passed through a #40 sieve and compacted in 4 in. diameter molds at the OMC determined by standard Proctor compaction tests. The UCS tests were then performed on both wet (as-compacted) and oven-dry specimens.

The UCS of the Washington County surface aggregate material alone had an average value of 14.5 psi under wet conditions and 325 psi under dry conditions. After mixing with the clay slurry, the average UCS values increased to 33.4 psi under wet conditions and 850 psi under dry conditions (Figure 52).

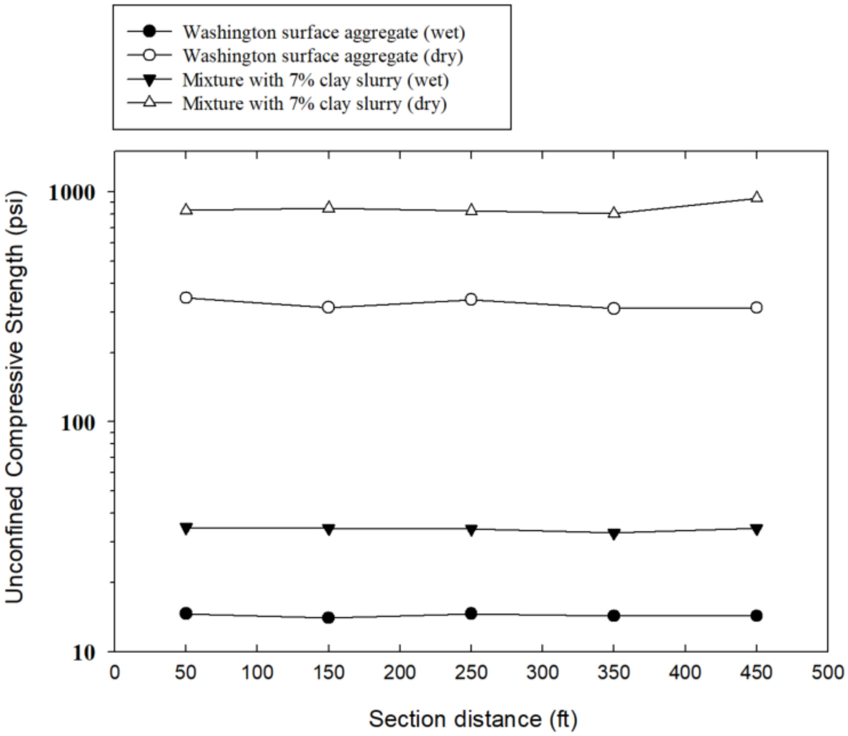


Figure 52. UCS test results for Washington County surface aggregate materials with and without 7% clay slurry

Stabilization of the surface aggregates by the clay slurry therefore produced an increase in UCS ranging from 130% under wet (OMC) conditions to approximately 160% under dry conditions.

6.1.5 Results of Slaking Tests on Clay Slurry Mixtures Prior to Construction

Slaking tests were also conducted on specimens of the existing Washington County surface aggregate with and without stabilization by the clay slurry. The slaking test specimens were compacted using the 2 × 2 compaction apparatus previously developed at Iowa State University. Results of the slaking tests are shown in Table 14.

Table 14. Slaking test results for Washington County surface aggregate materials with and without 7% clay slurry

Specimen	Slaking Time (min)			
Washington surface aggregate	11	12	11	10
Mixture with 7% clay slurry	21	20	24	20

The mixtures containing the clay slurry exhibited a slower dissolution rate of approximately half that of the existing surface materials alone, indicating that the clay slurry can improve the binding properties to help slow the rate of material loss from granular-surfaced roads.

6.2 Field and Laboratory Tests After Construction

After construction of the test sections, several series of field and laboratory tests were performed over a period of two years to evaluate changes in the subgrade soils and surfacing materials in all four counties. The tests were performed before winter freezing and after spring thawing in fall 2018, spring 2019, fall 2019, and spring 2020.

The field tests consisted of DCP, FWD, and LWD tests to characterize the shear strength and composite elastic modulus values, and nuclear-density gauge tests to determine the in situ density and moisture content of each test section. In addition, dustometer tests were performed to measure fugitive dust emissions, and visual surveys were performed to help evaluate the performance of the various test sections.

The laboratory tests included sieve analysis, hydrometer, and Atterberg limit tests on the surface aggregate materials in each section to analyze changes in particle size distribution and soil index properties over time.

6.2.1 DCP Test Results

DCP tests were performed to track changes in shear strength of the surface courses and subgrades of the test sections over time, including the crucial winter-spring freeze-thaw periods. Four series of DCP tests were conducted, with the first series following soon after construction in fall 2018, the second one after the spring thaw in 2019, and the final two performed in fall 2019 and after the spring thaw of 2020.

As a result of the COVID-19 pandemic, the university enforced safety policies that restricted the number of personnel traveling and working together in the field in spring 2020. This required the field tests to be completed by a single researcher rather than the typical team of four to six, and therefore the number of DCP test points in each section had to be reduced from five to three in spring 2020.

6.2.1.1 Cherokee County DCP Test Results

The DCP tests in Cherokee County were conducted on November 8, 2018; April 25, 2019; November 2, 2019; and May 18, 2020. Complete records of the cumulative blows, DCPI, and DCP-CBR values plotted versus depth for DCP tests in all eight Cherokee County test sections throughout the four-test series are provided in Appendix D.

The DCP test data were analyzed to determine the average DCP-CBR values and corresponding Iowa SUDAS ratings of the surface and subgrade layers. The results are summarized along with the measured in situ dry unit weight and moisture content values in Table 15 through Table 18 and are shown graphically in Figure 53 through Figure 56.

Table 15. Summary of Cherokee County test sections for DCP tests November 8, 2018

Section Name	Avg. Thickness (in.)	*DCP-* CBR_{AGG} (%)	Avg. *DCP-* CBR_{AGG} / Rating (%)	*DCP-* CBR_{SG} (%)	Avg. *DCP-* CBR_{SG} / Rating (%)	In Situ Dry Unit Weight (lb/ft^3)	In Situ Moisture Content	
							(%)	Avg.
(1) Aggregate Columns	4.0	76.3	72.4 / VG	17.6	19.9 / F-G	131.9	9.6	9.6
		48.7		20.6		140.2	9.6	
		84.9		23.1		128.5	9.8	
		59.2		20.1		130.6	10.1	
		93		18		132	8.9	
(2) Optimized Gradation w / Clay Slurry	4.0	125.7	114.4 / E	24.8	22.5 / VG	128.6	8.9	7.1
		99.7		17.1		137.5	5.7	
		141.1		20.3		135	7.1	
		106.8		28.2		137.5	7	
		98.8		22.2		132.6	6.7	
(3) RAP	4.0	35.7	28.9 / <G	19.5	16.4 / F-G	116.7	9.8	9.8
		27		20.9		113.4	9.1	
		21.1		19.5		113.8	9.9	
		26.9		11.1		109	10.8	
		33.8		10.8		115.8	9.3	
(4a) 2 in. Harsco Slag	4.0	35.6	40.5 / G	27	21.1 / VG	135.7	6.9	6.8
		44.4		22.1		144.7	7	
		42.1		26.8		140	6.9	
		33.4		14.7		142.5	6.2	
		46.8		15.1		146	7	
(4b) 4 in. Harsco Slag	4.0	17.6	25.6 / <G	10.7	13.7 / F-G	140.6	6.5	6.1
		27.9		16.7		137.5	6.1	
		26.8		13.7		141.9	6.1	
		22.6		14.4		144.9	6.1	
		33.3		12.9		141	5.7	
(5a) 4 in. Phoenix Slag	4.0	31.6	24.7 / <G	15.9	19.8 / F-G	164.7	3.6	3.6
		23.4		14.1		165	3.6	
		17.4		20.6		156.4	3.5	
		15.4		24		154	3.5	
		35.8		24.3		156.4	3.8	
(5b) 2 in. Phoenix Slag	4.2	44.8	34.1 / G	23	19.7 / F-G	157.8	4.5	5.7
		38.6		23.8		159	4.8	
		23.7		21		154.6	4.6	
		29.1		11.2		144.4	5.4	
(6) Control	4.3	30.3	23.6 / <G	15.2	10.6 / F-G	127.1	9.4	10.2
		26.3		15		130.3	9.9	
		20.5		10		129.3	10.2	
		13.9		5.1		131.4	10.4	
		26.9		7.6		133.2	10.1	

E=excellent, F-G=fair–good, G=good, P-G=poor–fair, VG=very good, VP=very poor

Table 16. Summary of Cherokee County test sections for DCP tests April 25, 2019

Section Name	Avg. Thickness (in.)	*DCP-CBR_{AGG}* (%)	Avg. *DCP-CBR_{AGG}* / Rating (%)	*DCP-CBR_{SG}* (%)	Avg. *DCP-CBR_{SG}* / Rating (%)	In Situ Dry Unit Weight (lb/ft^3)	In Situ Moisture Content	
							(%)	Avg.
(1) Aggregate Columns	5.3	13.8	24.2 / <G	7.8	7.4 / P-F	125.3	8.8	7.8
		27.7		8.4		129.7	7.6	
		32.4		5.5		125.6	6.8	
		21.7		9.8		133.5	6.5	
		25.2		5.5		119.8	9.4	
(2) Optimized Gradation w / Clay Slurry	4.4	13.5	21.2 / <G	5.2	10.1 / F-G	132.4	5.9	5.2
		30.6		10.0		135.0	4.1	
		21.8		9.5		131.5	6.5	
		18.3		15.2		137.8	4.7	
		21.9		10.5		134.1	4.9	
(3) RAP	5.8	14.6	12.0 / <G	19.0	10.9 / F-G	127.1	7.0	6.4
		15.4		11.6		127.4	6.3	
		7.9		6.1		128.0	6.5	
		15.2		14.0		127.5	6.3	
		6.9		3.9		125.8	6.1	
(4a) 2 in. Harsco Slag	5.3	9.8	16.3 / <G	5.5	7.8 / P-F	142.3	4.6	4.3
		18.0		14.5		143.2	4.5	
		18.8		8.9		144.8	4.3	
		19.3		5.4		153.5	4.2	
		15.7		4.8		151.2	3.8	
(4b) 4 in. Harsco Slag	5.0	10.1	13.2 / <G	3.4	4.6 / VP	153.2	3.7	3.9
		15.8		8.4		145.1	4.1	
		5.6		2.4		151.3	3.9	
		15.1		3.1		156.1	3.9	
		19.6		5.8		150.4	4.0	
(5a) 4 in. Phoenix Slag	7.4	15.5	23.9 / <G	3.5	6.0 / P-F	165.2	2.3	2.4
		15.9		5.0		168.2	2.2	
		32.9		7.2		175.5	2.1	
		25.1		9.4		167.3	2.5	
		30.3		5.1		162.5	3.1	
(5b) 2 in. Phoenix Slag	4.6	29.0	27.7 / <G	16.7	12.7 / F-G	144.7	5.0	3.6
		27.2		10.8		154.8	2.5	
		34.6		14.7		150.3	2.3	
		25.9		9.8		141.0	3.4	
		21.6		11.5		137.6	4.2	
(6) Control	5.3	3.5	5.2 / <G	9.7	7.1 / P-F	140.7	4.3	5.4
		1.5		11.2		128.1	4.7	
		6.3		5.6		133.4	5.2	
		7.9		5.1		132.4	5.2	
		6.7		4.2		124.1	6.6	

E=excellent, F-G=fair–good, G=good, P-G=poor–fair, VG=very good, VP=very poor

Table 17. Summary of Cherokee County test sections for DCP tests November 2, 2019

Section Name	**Avg. Thickness (in.)**	***DCP-CBR*$_{AGG}$ (%)**	**Avg. *DCP-CBR*$_{AGG}$ / Rating (%)**	***DCP-CBR*$_{SG}$ (%)**	**Avg. *DCP-CBR*$_{SG}$ / Rating (%)**	**In Situ Dry Unit Weight (lb/ft^3)**	**In Situ Moisture Content**	
							(%)	**Avg.**
(1) Aggregate Columns	3.7	30.7	41.9 / G	17.5	17.5 / F-G	126.2	9.3	7.5
		23.4		13.0		133.5	7.6	
		51.8		14.8		133.9	7.2	
		58.9		16.6		135.1	7.4	
		44.5		25.6		132.3	6.0	
(2) Optimized Gradation w / Clay Slurry	3.9	55.3	68.4 / VG	10.9	14.2 / F-G	125.9	7.2	5.7
		77.2		13.9		137.2	5.0	
		71.2		15.1		132.2	6.1	
		40.9		11.2		138.4	4.9	
		97.3		20.1		134.8	5.3	
(3) RAP	5.7	48.9	41.2 / G	14.9	12.3 / F-G	128.1	6.9	6.8
		33.6		10.9		119.4	6.5	
		50.6		16.3		123.6	6.6	
		65.8		11.9		123.7	7.4	
		7.0		7.2		125.5	6.7	
(4a) 2 in. Harsco Slag	6.5	54.2	44.8 / G	14.7	11.6 / F-G	152.0	4.5	4.6
		45.1		10.6		143.8	4.7	
		30.7		9.0		140.8	5.2	
		48.5		9.8		142.9	4.7	
		45.7		13.7		153.5	3.9	
(4b) 4 in. Harsco Slag	3.7	46.6	45.8 / G	21.3	10.6 / F-G	150.8	3.8	4.1
		46.2		7.7		146.0	4.1	
		52.2		6.1		144.3	4.1	
		34.1		9.6		151.1	4.3	
		49.7		8.1		147.9	4.0	
(5a) 4 in. Phoenix Slag	6.1	36.6	41.3 / G	11.4	9.3 / P-F	158.1	2.9	2.8
		40.6		14.9		159.9	2.6	
		47.9		8.3		139.2	3.1	
		40.9		6.4		163.2	2.6	
		40.4		5.4		162.3	2.8	
(5b) 2 in. Phoenix Slag	3.1	73.0	64.5 / VG	31.3	25.1 / VG	135.2	5.5	3.8
		61.5		30.9		149.7	3.3	
		68.2		26.5		150.7	2.2	
		29.5		10.9		140.0	2.8	
		90.1		26.0		146.7	5.1	
(6) Control	4.2	76.0	44.23 / G	10.3	17.2 / F-G	141.9	4.5	5.3
		40.1		13.8		140.4	4.6	
		61.3		15.4		138.2	5.1	
		27.3		29.9		128.7	5.9	
		16.5		16.7		128.7	6.5	

E=excellent, F-G=fair–good, G=good, P-G=poor–fair, VG=very good, VP=very poor

Table 18. Summary of Cherokee County test sections for DCP tests May 18, 2020

Section Name	Avg. Thickness (in.)	*DCP-*CBR_{AGG} (%)	Avg. *DCP-*CBR_{AGG} / Rating (%)	*DCP-*CBR_{SG} (%)	Avg. *DCP-*CBR_{SG} / Rating (%)	In Situ Dry Unit Weight (lb/ft^3)	In Situ Moisture Content	
							(%)	Avg.
(1) Aggregate Columns	4.9	36.0	36.4 / G	16.9	16.7 / F-G	126.9	9.6	7.6
		33.7		17.5		135.8	7.0	
		39.5		15.6		129.6	6.3	
(2) Optimized Gradation w / Clay Slurry	3.8	70.2	90.0 / E	11.3	17.0 / F-G	130.6	5.7	5.1
		53.0		11.0		137.0	4.4	
		146.8		28.9		138.1	5.1	
(3) RAP	4.4	41.5	40.2 / G	13.5	13.5 / F-G	127.1	6.2	5.9
		33.3		16.9		126.7	5.5	
		45.8		10.1		126.2	6.0	
(4a) 2 in. Harsco Slag	3.1	194.8	139.5 / E	30.9	30.4 / > VG	153.8	9.6	7.6
		153.1		32.8		149.0	7.0	
		70.7		27.4		153.0	6.3	
(4b) 4 in. Harsco Slag	4.3	156.0	177.9 / E	23.7	29.4 / VG	136.9	4.4	4.4
		92.0		41.5		142.9	4.6	
		285.6		22.9		149.7	4.1	
(5a) 4 in. Phoenix Slag	4.4	134.0	199.4 / E	44.0	36.9 / > VG	160.2	2.5	2.4
		166.6		37.8		156.1	2.4	
		297.6		28.9		162.7	2.2	
(5b) 2 in. Phoenix Slag	4.7	145.4	186.6 / E	37.0	37.5 / > VG	149.5	3.4	2.9
		235.7		51.1		155.3	2.9	
		178.8		24.2		142.3	2.4	
(6) Control	5.6	356.4	262.9 / E	43.5	47.3 / > VG	140.8	4.3	4.2
		192.6		63.8		137.5	4.1	
		239.7		34.5		134.4	4.3	

E=excellent, F-G=fair–good, G=good, P-G=poor–fair, VG=very good, VP=very poor

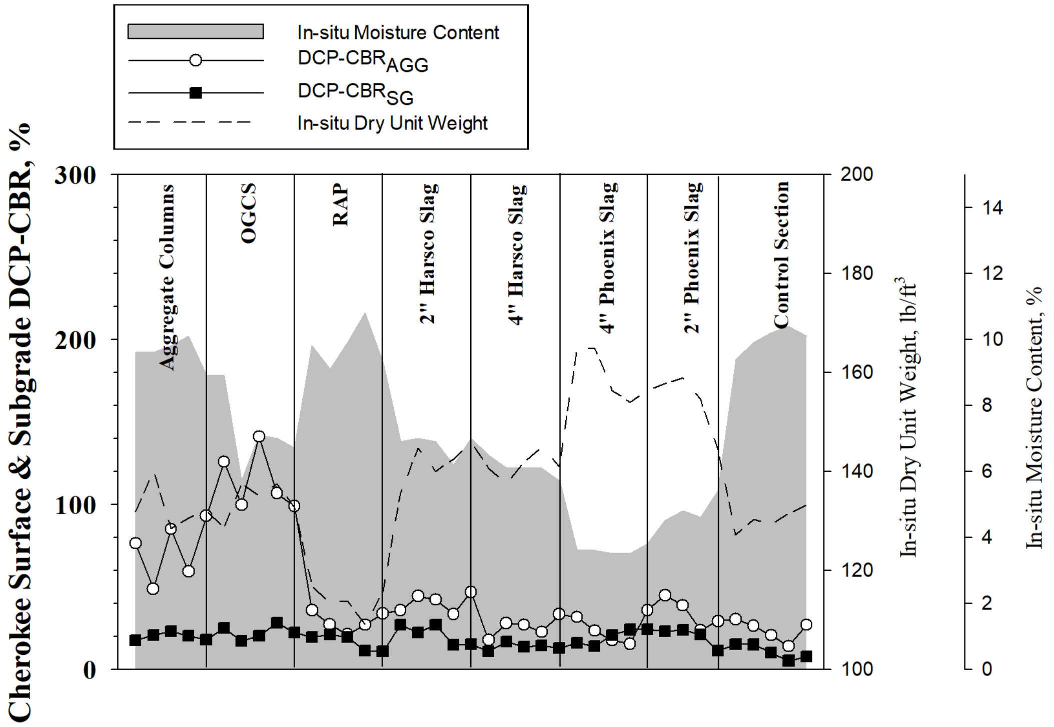


Figure 53. Graphical summary of Cherokee County test sections for DCP tests on November 8, 2018

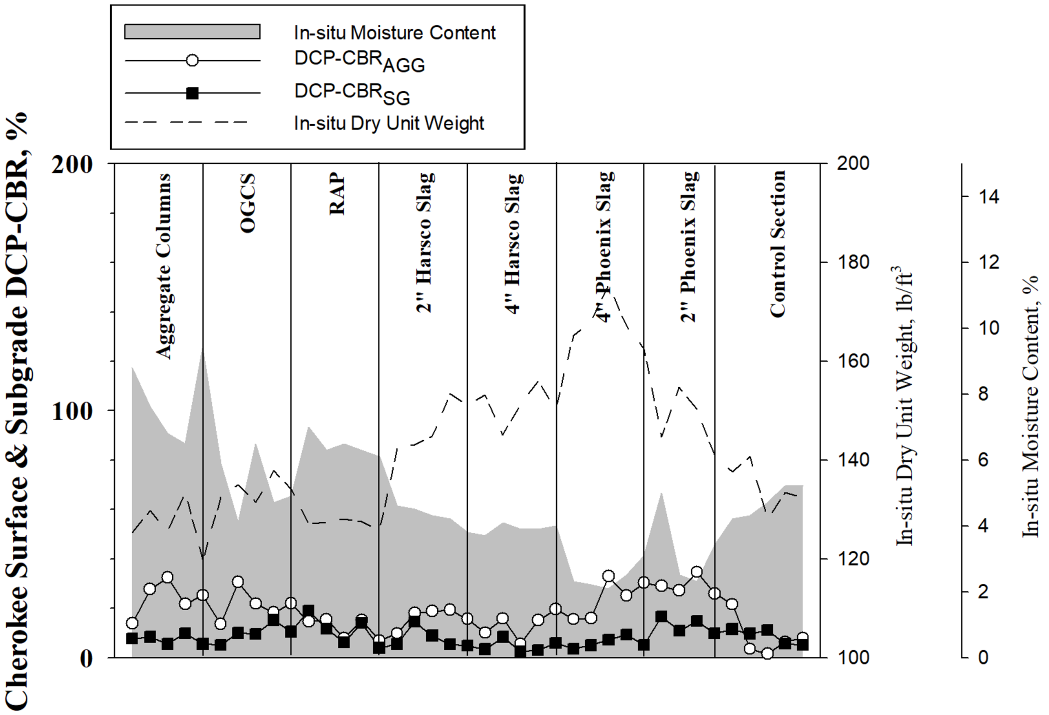


Figure 54. Graphical summary of Cherokee County test sections for DCP tests on April 25, 2019

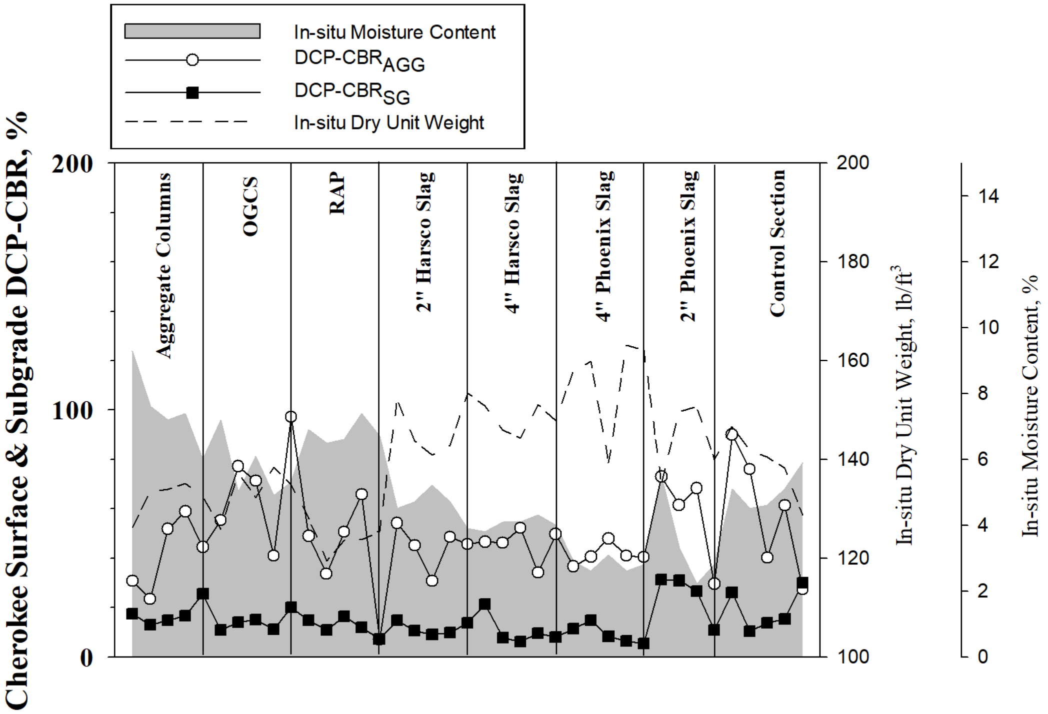


Figure 55. Graphical summary of Cherokee County test sections for DCP tests on November 2, 2019

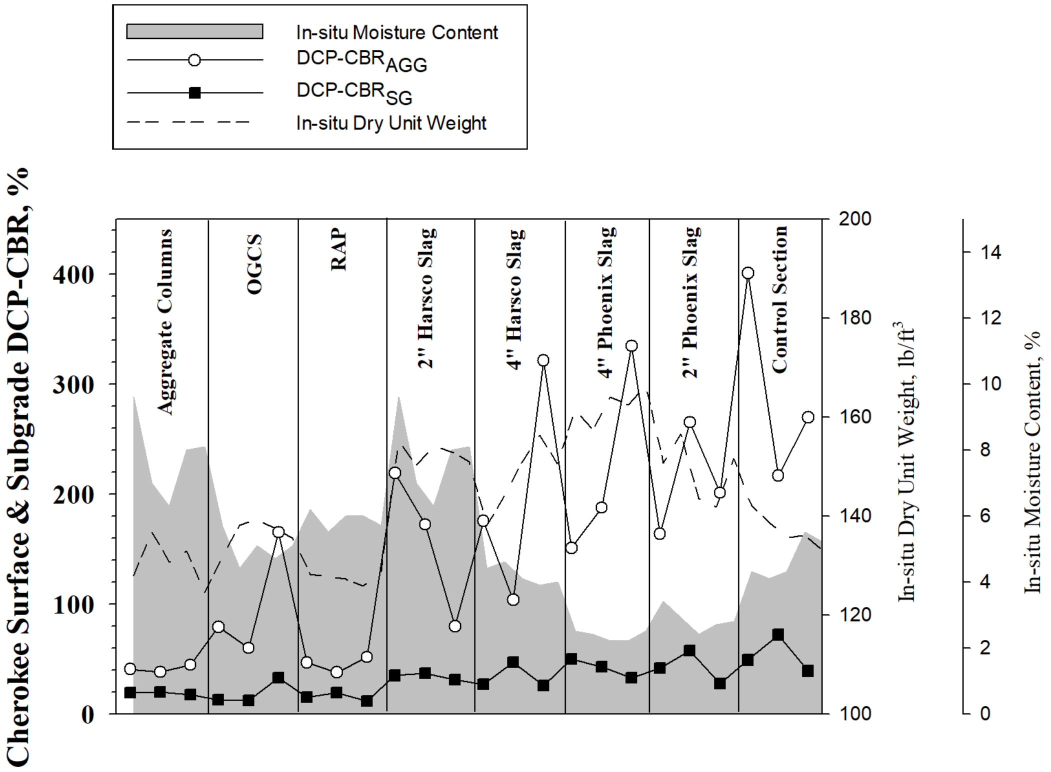
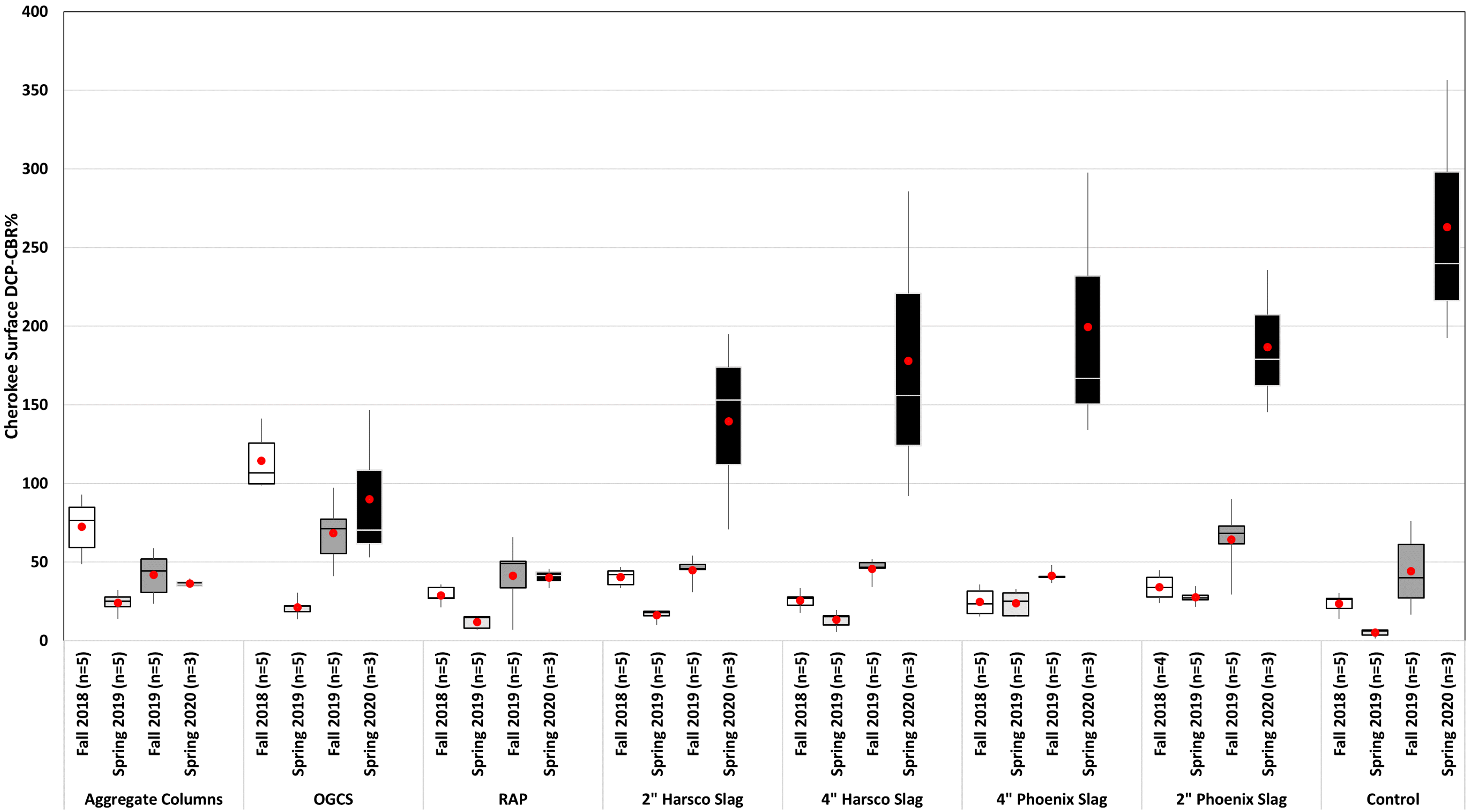


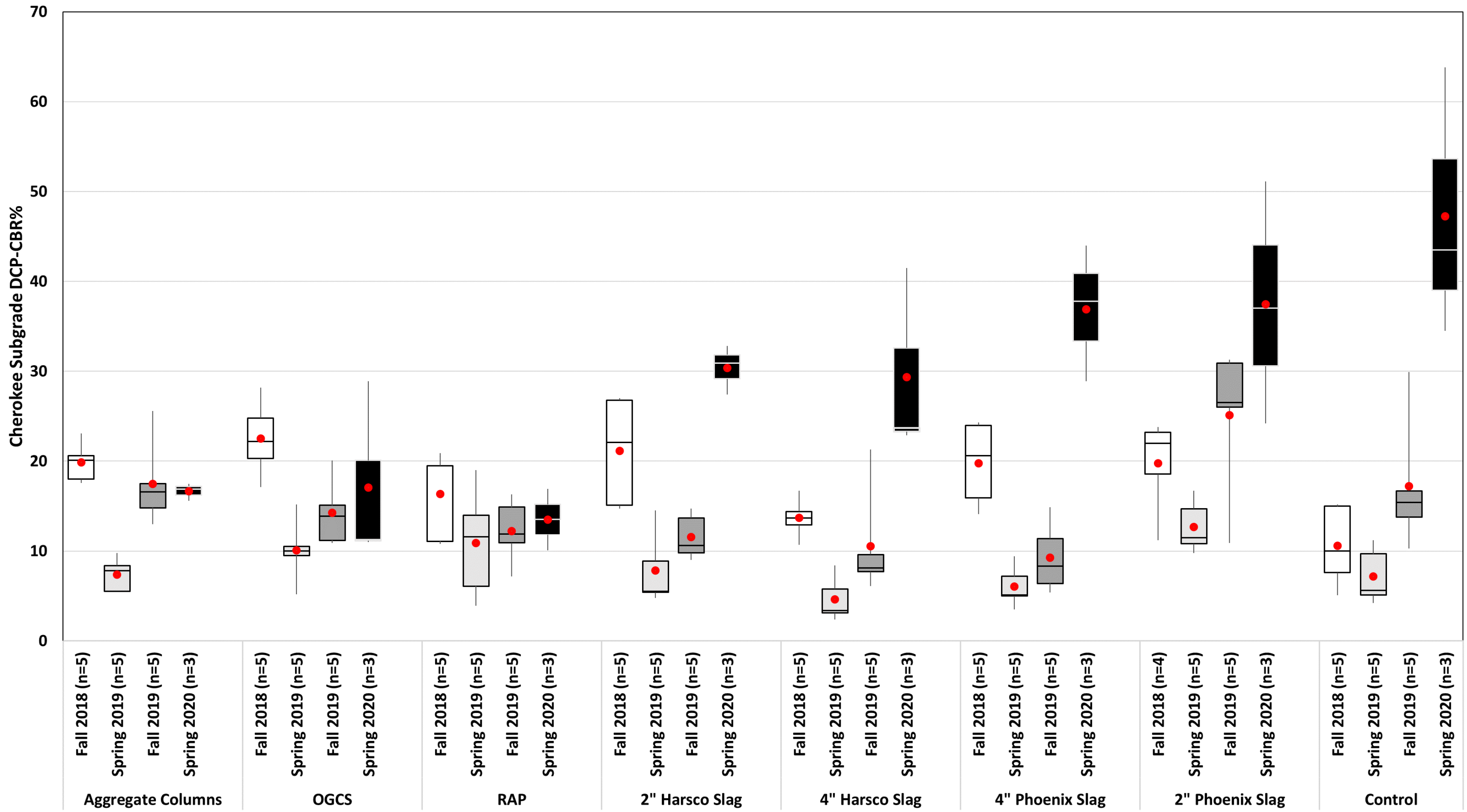
Figure 56. Graphical summary of Cherokee County test sections for DCP tests on May 18, 2020

Statistical boxplots of the DCP-CBR values over the fall 2018 through spring 2020 timeframe in Cherokee County are presented in Figure 57 to examine changes in the shear strength over time.

In this and all subsequent boxplots, the bottom and top of the box are the 25th and 75th percentiles, respectively; the central mark is the median; the whiskers extend to the most extreme values not considered to be outliers; and a red dot denotes the mean (average) value.


Cherokee Surface DCP-CBR%
400
350
300
250
200
150
100
50
0
Fall 2018 (n=5)
Spring 2019 (n=5)
Fall 2019 (n=5)
Spring 2020 (n=3)
Aggregate Columns
OGCS
RAP
2" Harsco Slag
4" Harsco Slag
4" Phoenix Slag
Fall 2018 (n=4)
2" Phoenix Slag
Control

(a)



(b)

Figure 57. Statistical boxplots of DCP-CBR over time for Cherokee County test sections: (a) $DCP\text{-}CBR_{AGG}$ and (b) $DCP\text{-}CBR_{SG}$

To calculate the average DCP-CBR values in the surface and subgrade layers, the thicknesses of the surface layers for most Cherokee County test sections were taken to be 4 in. in fall 2018 because there was no clear distinction between the surface courses and subgrade at that time. As previously explained, the granular surface course in Cherokee County gradually transitioned to finer sand-sized particles over the first few feet of depth, then gradually transitioned to silt.

As shown in Table 15 and Figure 57a, between construction in fall 2018 and the spring thaw of 2019, the average shear strength decreased for the surface courses of all test sections in Cherokee County, except for the 4 in. Phoenix slag section.

After construction, the OGCS section had the highest average surface course $DCP\text{-}CBR_{AGG}$ of 114%, corresponding to an Iowa SUDAS relative support rating of excellent. However, this value drastically decreased to 21% in spring 2019, corresponding to a less than good Iowa SUDAS rating.

The aggregate columns section had the next highest average $DCP\text{-}CBR_{AGG}$ value of 72% and a very good Iowa SUDAS relative rating after construction, but it also suffered from the effects of freeze-thaw cycles and decreased to a below good rating in spring 2019. In fact, all test sections other than the two Phoenix slag sections suffered significantly reduced $DCP\text{-}CBR_{AGG}$ values after their first winter. The aggregate columns and OGCS sections started with the highest initial strengths and therefore suffered the greatest percentage decreases in $DCP\text{-}CBR_{AGG}$ by spring 2019, but it should be noted that all stabilized sections had higher average $DCP\text{-}CBR_{AGG}$ values than the control section in spring 2019.

Between fall 2019 and spring 2020, the DCP-CBR values did not decrease; rather they increased drastically, especially in the slag sections and control section. Unfortunately, it was determined that this unusual behavior was a result of the application of additional surface aggregate on these sections, which was not communicated to the research team following a change in leadership at the Cherokee County Secondary Roads office.

For the subgrades below the test sections, Table 15 and Figure 57b show that the $DCP\text{-}CBR_{SG}$ values for all sections were higher than that of the control section after construction in fall 2018, but all sections suffered from frost damage and reduced $DCP\text{-}CBR_{SG}$ values in spring 2019.

As expected, the surface courses and subgrades of all test sections recovered strength through the summer months, as exhibited by increases in DCP-CBR values from spring 2019 to fall 2019. Comparing the aggregate surface layer results from fall 2018 and fall 2019, the average $DCP\text{-}CPR_{AGG}$ value for all but the aggregate columns and OGCS sections increased in the first year after construction, although they are also dependent on the moisture and temperature conditions on the particular test dates.

6.2.1.2 Howard County DCP Test Results

DCP tests were conducted in Howard County on October 23, 2018; May 4, 2019; October 27, 2019; and May 21, 2020. Detailed plots for all tests are provided in Appendix D. The DCP-CBR values and corresponding Iowa SUDAS ratings are summarized in Table 19 through Table 22, along with the in situ dry unit weight and moisture content values, and are shown graphically in Figure 58 through Figure 61.

Table 19. Summary of Howard County test sections for DCP tests October 23, 2018

Section Name	**Avg. Thickness (in.)**	***DCP-CBR*$_{AGG}$ (%)**	**Avg. *DCP-CBR*$_{AGG}$ / Rating (%)**	***DCP-CBR*$_{SG}$ (%)**	**Avg. *DCP-CBR*$_{SG}$ / Rating (%)**	**In Situ Dry Unit Weight (lb/ft^3)**	**In Situ Moisture Content**	
							(%)	**Avg.**
(1) Optimized Gradation w / Clay Slurry	4.1	56.0	66.6 / VG	9.1	12.0 / F-G	127.7	9.0	7.4
		73.5		12.4		125.5	7.7	
		62.9		10.0		124.8	6.8	
		69.1		15.4		124.7	6.7	
		71.6		13.0		126.5	6.6	
(2) Control	4.3	190.1	116.7 / E	15.8	14.8 / F-G	133.8	7.7	7.8
		105.1		15.6		135.4	7.2	
		102.0		15.0		137.3	7.1	
		81.6		16.2		136.4	7.3	
		104.7		11.4		119.1	9.6	
(4) RAP	4.0	51.3	39.0 / G	16.0	12.7 / F-G	116.8	10.5	9.2
		25.2		10.2		121.6	9.6	
		31.0		8.3		125.1	8.0	
		52.5		12.1		122.7	9.5	
		35.3		16.8		125.1	8.3	
(5a) 2 in. Harsco Slag	4.6	47.8	143.4 / E	8.6	27.6 / VG	146.4	6.9	6.3
		131.4		39.4		139.6	6.5	
		108.3		19.2		148.6	6.3	
		154.5		42.4		149.0	5.9	
		275.2		28.3		138.6	5.7	
(5b) 4 in. Harsco Slag	4.9	209.0	330.1 / E	28.5	25.1 / VG	150.8	3.8	5.3
		254.7		21.3		146.0	4.1	
		387.3		33.0		144.3	4.1	
		469.4		17.6		151.1	4.3	
		76.9		12.1		169.4	4.5	
(6a) 4 in. Phoenix Slag	4.3	131.8	77.1 / VG	13.8	14.3 / F-G	168.1	4.4	4.3
		63.1		16.2		163.5	4.0	
		48.3		14.1		168.2	4.4	
		65.5		15.2		170.4	4.2	
		87.8		10.2		165.2	6.3	
(6b) 2 in. Phoenix Slag	4.2	122.7	95.9 / E	17.5	16.3 / F-G	170.1	5.4	6.9
		138.9		15.3		161.2	4.5	
		41.3		10.8		172.5	6.0	
		89.0		28.0		167.0	7.0	
(7) Aggregate Columns	4.0	25.0	20.3 / <G	7.8	5.1 / P-F	121.1	12.2	12.2
		28.1		4.8		126.9	11.0	
		11.2		4.4		110.0	15.1	
		13.3		5.7		114.6	15.2	
		24.2		2.9		125.0	7.3	

E=excellent, F-G=fair–good, G=good, P-G=poor–fair, VG=very good, VP=very poor

Table 20. Summary of Howard County test sections for DCP tests May 4, 2019

Section Name	Avg. Thickness (in.)	*DCP-CBR_{AGG}* (%)	Avg. *DCP-CBR_{AGG}* / Rating (%)	*DCP-CBR_{SG}* (%)	Avg. *DCP-CBR_{SG}* / Rating (%)	In Situ Dry Unit Weight (lb/ft^3)	In Situ Moisture Content	
							(%)	Avg.
(1) Optimized Gradation w / Clay Slurry	4.5	26.9	44.0 / G	3.0	6.9 / P-F	123.8	6.2	6.3
		39.2		4.7		127.7	5.3	
		31.9		5.2		117.6	6.9	
		62.9		8.7		117.9	8.0	
		59.1		12.9		126.4	5.1	
(2) Control	4.2	38.3	39.7 / G	19.3	13.0 / F-G	125.6	6.3	6.7
		37.9		9.4		107.5	7.4	
		59.3		17.4		133.7	5.5	
		16.0		10.1		129.3	6.3	
		47.0		8.7		106.5	8.1	
(4) RAP	5.5	118.3	69.5 / VG	12.4	10.5 / F-G	121.8	6.3	7.1
		46.4		6.8		125.7	7.8	
		75.5		20.0		127.5	7.4	
		73.8		7.4		126.6	7.4	
		33.3		5.9		131.8	6.4	
(5a) 2 in. Harsco Slag	5.1	11.1	83.6 / E	2.3	9.9 / P-F	146.2	4.7	5.5
		48.9		8.0		110.5	7.5	
		47.7		6.6		145.9	5.4	
		139.4		18.8		158.3	5.2	
		171.1		13.8		159.7	4.6	
(5b) 4 in. Harsco Slag	4.1	100.5	138.2 / E	8.6	15.3 / F-G	160.8	3.9	4.1
		108.1		17.1		156.7	4.3	
		169.7		22.2		159.8	3.6	
		152.0		18.8		157.6	3.9	
		160.9		9.7		151.3	4.6	
(6a) 4 in. Phoenix Slag	3.9	71.0	43.4 / G	7.0	5.8 / P-F	153.1	4.3	3.5
		89.2		8.9		153.8	3.6	
		18.1		4.4		170.0	3.4	
		11.9		2.9		168.8	2.8	
		27.0		5.5		158.7	3.2	
(6b) 2 in. Phoenix Slag	3.6	38.0	46.4 / G	4.0	9.8 / P-F	146.8	4.3	6.1
		79.8		7.6		155.3	4.7	
		79.7		25.4		161.1	3.3	
		18.8		6.1		149.7	6.4	
		15.6		6.1		122.4	9.9	
(7) Aggregate Columns	5.2	12.6	30.8 / G	5.6	9.1 / P-F	131.0	7.9	12.0
		9.5		5.9		126.5	7.5	
		19.6		7.2		103.8	16.5	
		20.0		11.2		101.9	18.8	
		92.4		15.6		117.4	5.0	

E=excellent, F-G=fair–good, G=good, P-G=poor–fair, VG=very good, VP=very poor

Table 21. Summary of Howard County test sections for DCP tests October 27, 2019

Section Name	Avg. Thickness (in.)	$DCP\text{-}CBR_{AGG}$ (%)	Avg. $DCP\text{-}CBR_{AGG}$ / Rating (%)	$DCP\text{-}CBR_{SG}$ (%)	Avg. $DCP\text{-}CBR_{SG}$ / Rating (%)	In Situ Dry Unit Weight (lb/ft^3)	In Situ Moisture Content	
							(%)	Avg.
(1) Optimized Gradation w / Clay Slurry	4.9	75.3	65.4 / VG	19.9	13.6 / F-G	131.0	7.0	7.1
		99.7		14.7		131.7	6.7	
		72.8		19.7		134.0	6.6	
		52.0		7.7		128.6	7.1	
		27.0		5.9		129.8	7.9	
(2) Control	4.5	16.3	18.8 / F-G	9.2	8.2 / P-F	130.7	5.3	6.6
		14.6		7.5		123.7	7.2	
		41.4		12.4		127.6	6.9	
		9.8		5.7		131.0	6.2	
		11.7		6.2		126.9	7.5	
(4) RAP	3.8	50.4	28.7 / VG	19.1	8.3 / P-F	125.6	7.1	7.4
		12.1		5.0		120.7	8.1	
		13.5		6.5		124.9	7.1	
		44.5		6.7		126.9	8.0	
		23.2		4.0		135.3	6.6	
(5a) 2 in. Harsco Slag	2.9	6.0	49.0 / G	3.1	8.8 / P-F	142.7	5.5	5.5
		1.2		3.6		147.5	5.7	
		85.3		5.4		151.3	6.0	
		79.2		16.2		152.7	5.6	
		73.3		15.7		162.8	4.8	
(5b) 4 in. Harsco Slag	3.6	51.0	67.6 / VG	6.4	7.8 / P-F	155.9	4.5	4.7
		81.7		9.0		157.4	5.2	
		101.9		12.1		154.6	4.6	
		64.4		6.9		160.0	4.9	
		39.0		4.4		151.5	4.4	
(6a) 4 in. Phoenix Slag	3.9	76.9	76.1 / VG	12.1	13.4 / F-G	160.4	3.6	3.2
		125.0		11.0		171.8	3.1	
		64.2		14.4		164.5	3.6	
		46.2		14.0		163.2	3.1	
		68.2		15.7		172.2	2.8	
(6b) 2 in. Phoenix Slag	2.9	99.6	90.2 / E	6.6	11.4 / F-G	152.1	4.8	4.5
		113.1		9.7		161.3	3.7	
		109.7		7.6		163.8	3.2	
		54.1		6.1		149.2	5.5	
		74.5		26.8		156.9	5.3	
(7) Aggregate Columns	4.5	40.1	25.5 / <G	14.9	10.6 / F-G	139.6	6.8	9.2
		12.8		5.3		134.7	5.8	
		15.8		3.7		118.7	13.2	
		11.1		5.5		113.2	14.5	
		47.6		23.6		124.7	5.9	

E=excellent, F-G=fair–good, G=good, P-G=poor–fair, VG=very good, VP=very poor

Table 22. Summary of Howard County test sections for DCP tests May 21, 2020

Section Name	Avg. Thickness (in.)	*DCP-CBR*$_{AGG}$ (%)	Avg. *DCP-CBR*$_{AGG}$ / Rating (%)	*DCP-CBR*$_{SG}$ (%)	Avg. *DCP-CBR*$_{SG}$ / Rating (%)	In Situ Dry Unit Weight (lb/ft^3)	In Situ Moisture Content	
							(%)	Avg.
(1) Optimized Gradation w / Clay Slurry	4.3	35.8	77.3 / VG	7.4	14.3 / F-G	129.2	8.0	7.6
		91.8		19.2		130.1	7.7	
		104.1		16.3		131.8	7.1	
(2) Control	4.8	132.9	73.9 / VG	18.6	14.1 / F-G	139.8	5.8	5.9
		55.9		16.2		131.5	6.3	
		33.0		7.5		141.6	5.5	
(4) RAP	6.3	99.6	83.6 / E	11.2	11.0 / F-G	134.4	6.3	6.8
		72.2		11.8		129.7	7.8	
		79.1		9.9		136.8	6.3	
(5a) 2 in. Harsco Slag	5.0	99.8	80.2 / E	13.0	16.0 / F-G	148.6	5.3	6.3
		51.3		22.9		141.3	6.9	
		89.6		11.9		138.2	6.7	
(5b) 4 in. Harsco Slag	4.3	76.9	114.8 / E	12.2	14.2 / F-G	166.2	3.8	4.1
		95.9		12.5		164.4	4.0	
		171.7		18.1		164.1	4.4	
(6a) 2 in. Harsco Slag	2.6	30.5	73.3 / VG	6.7	10.7 / F-G	162.7	3.1	3.8
		54.6		12.5		166.4	4.3	
		134.8		12.8		167.8	4.0	
(6b) 2 in. Phoenix Slag	4.2	51.6	44.2 / G	6.3	7.8 / P-F	155.0	5.2	4.4
		57.3		7.5		161.8	4.3	
		23.8		9.7		163.4	3.6	
(7) Aggregate Columns	5.4	39.0	37.9 / G	9.0	11.9 / F-G	127.2	10.3	10.8
		50.3		10.9		130.9	9.1	
		24.4		15.9		120.9	12.9	

E=excellent, F-G=fair–good, G=good, P-G=poor–fair, VG=very good, VP=very poor

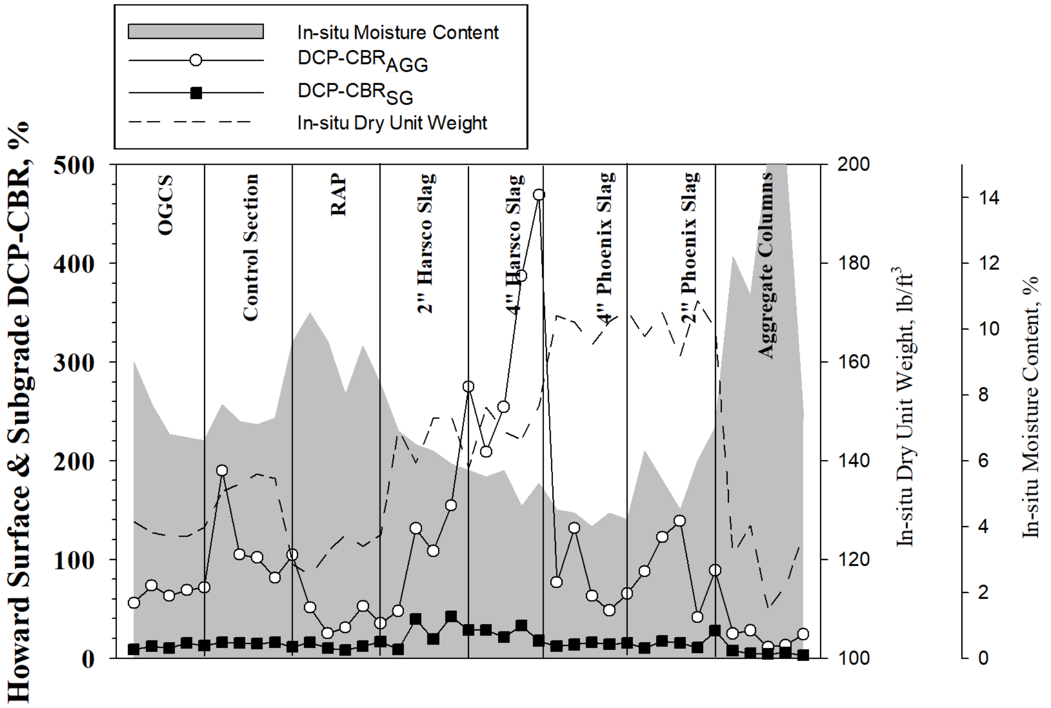


Figure 58. Graphical summary of Howard County test sections for DCP tests on October 23, 2018

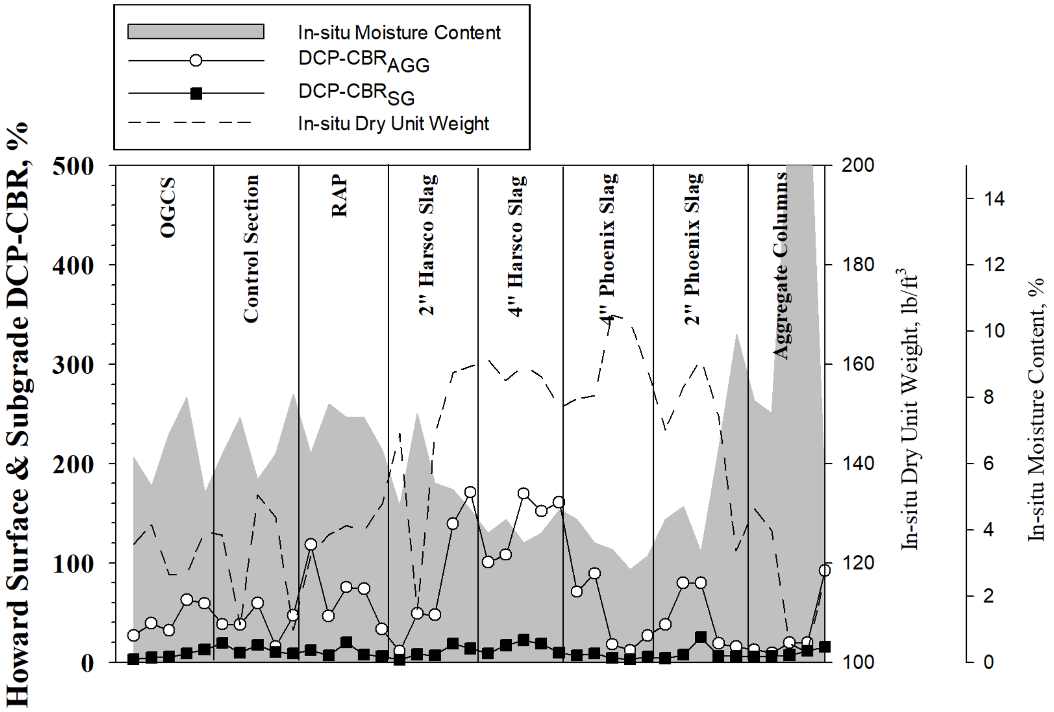


Figure 59. Graphical summary of Howard County test sections for DCP tests on May 4, 2019

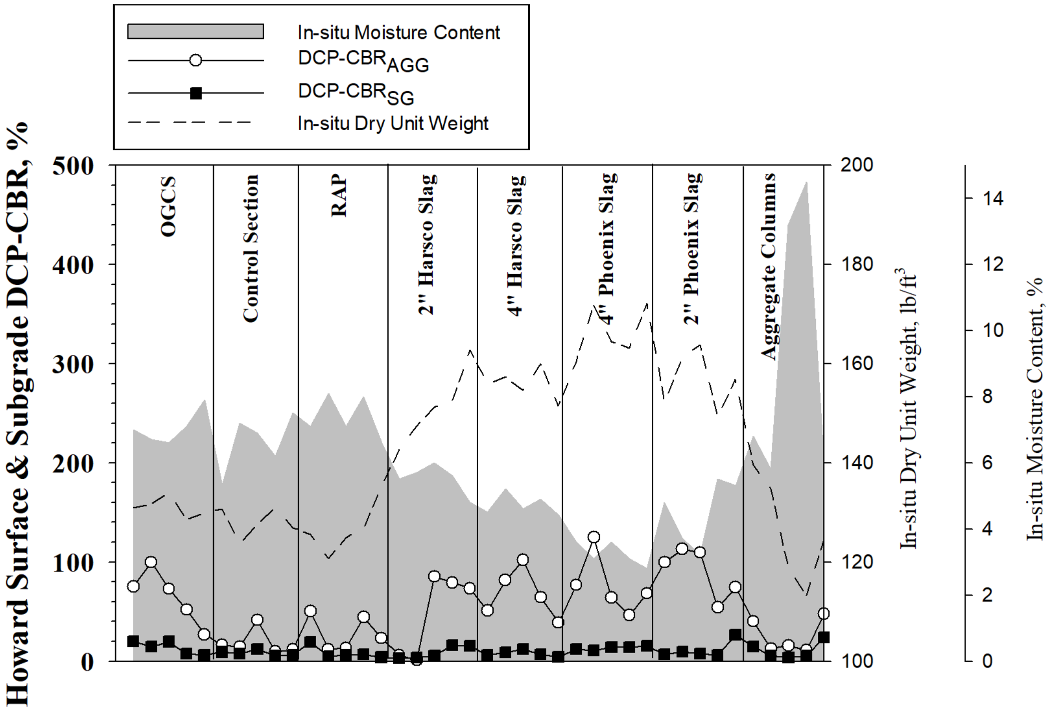


Figure 60. Graphical summary of Howard County test sections for DCP tests on October 27, 2019

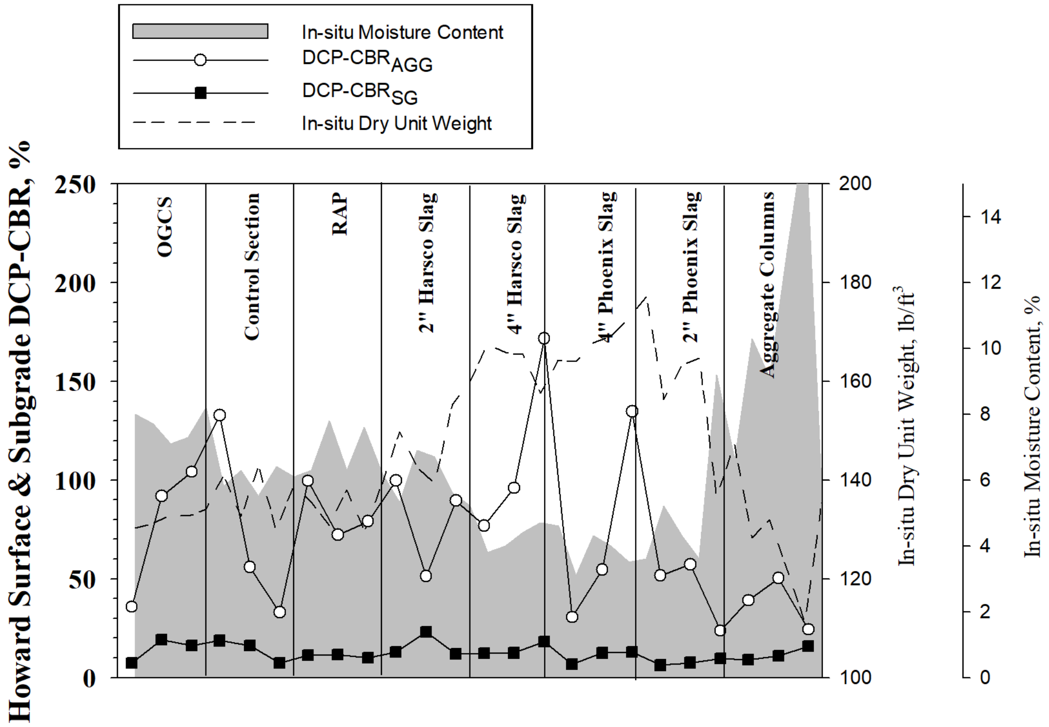
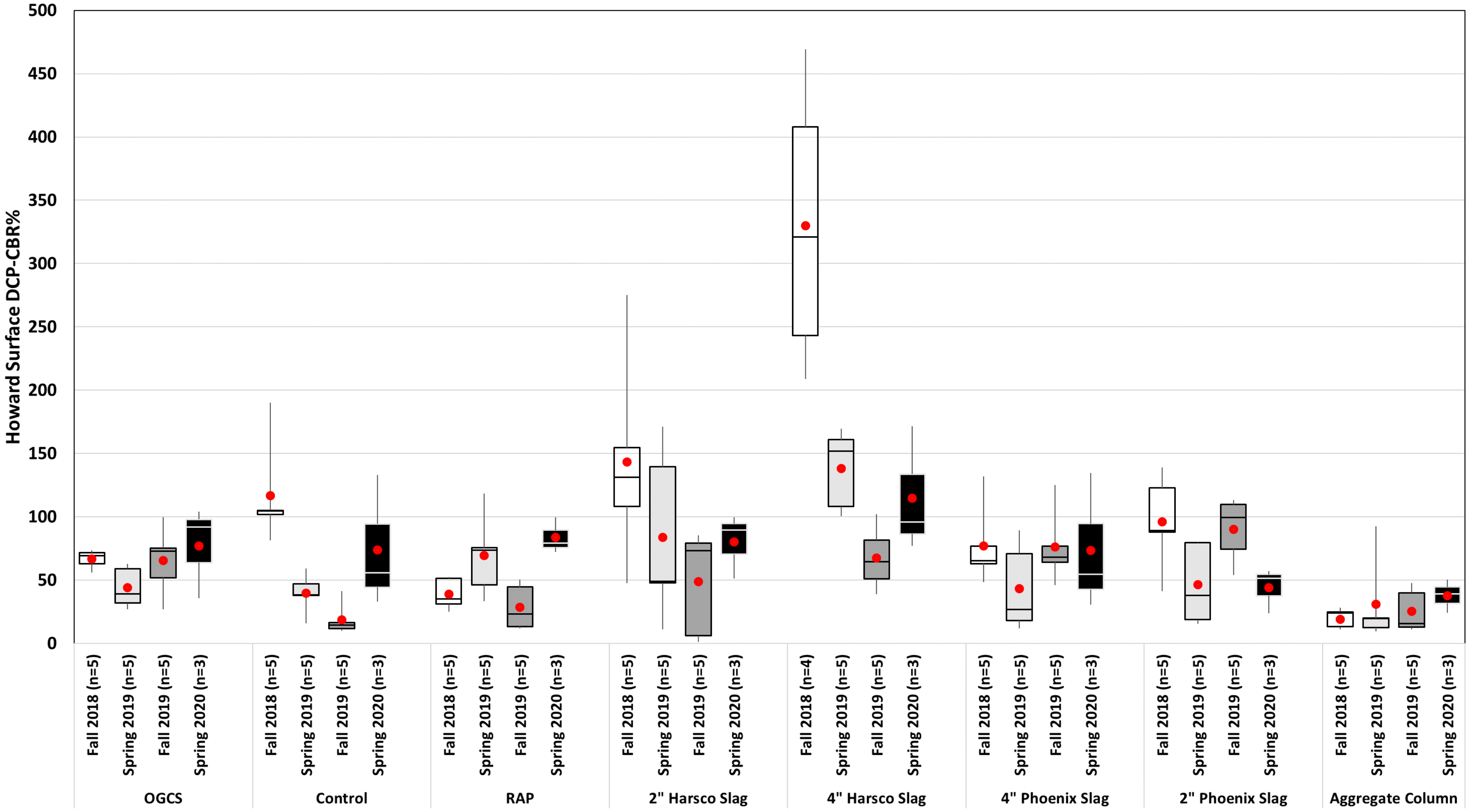


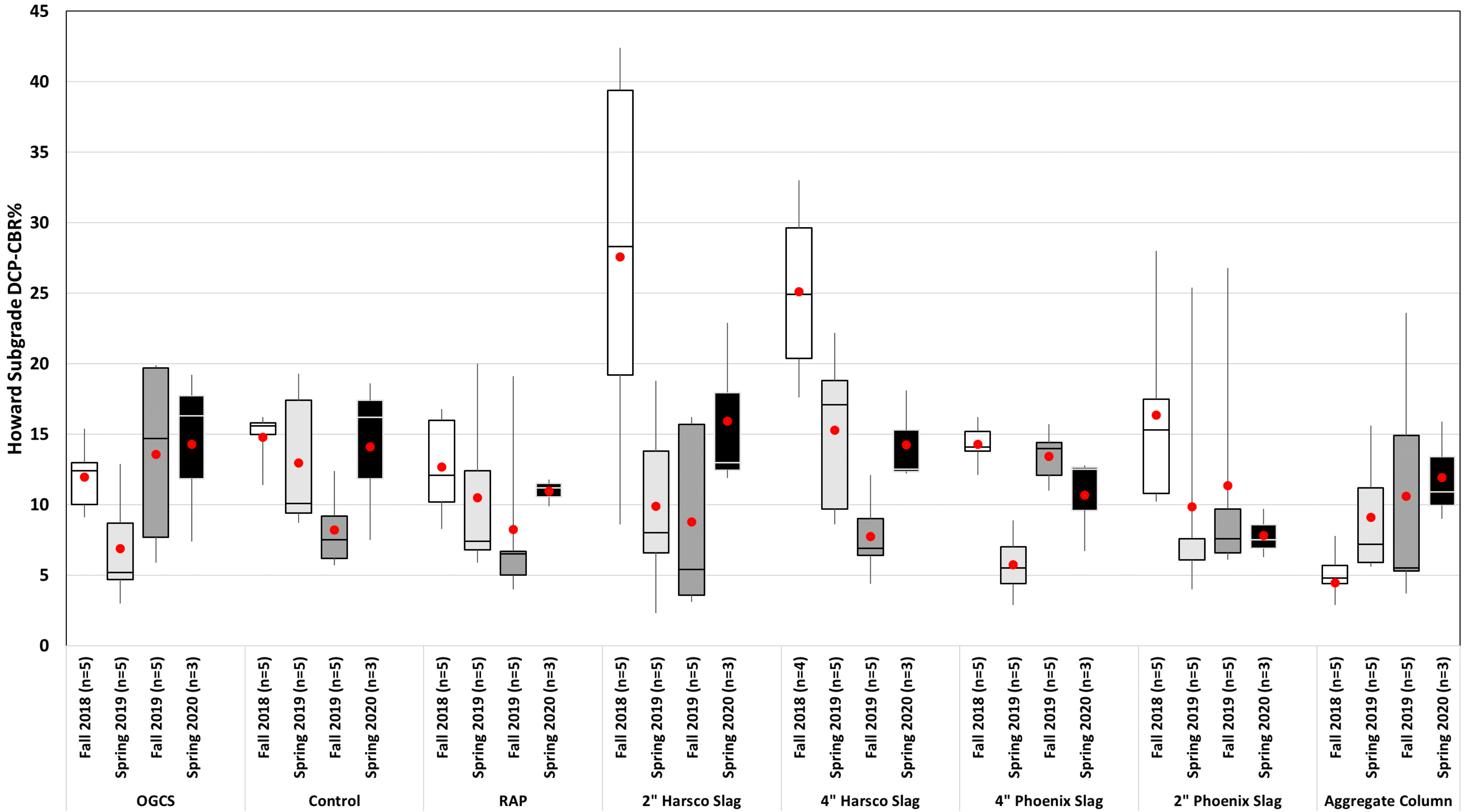
Figure 61. Graphical summary of Howard County test sections for DCP tests on May 21, 2020

Statistical boxplots of the DCP-CBR values for all four test series in Howard County are summarized in Figure 62.



Howard Surface DCP-CBR%
0
50
100
150
200
250
300
350
400
450
500
Fall 2018 (n=5)
Spring 2019 (n=5)
Fall 2019 (n=5)
Spring 2020 (n=3)
OGCS
Control
RAP
2" Harsco Slag
Fall 2018 (n=4)
4" Harsco Slag
4" Phoenix Slag
2" Phoenix Slag
Aggregate Column

(a)



(b)

Figure 62. Statistical boxplots of DCP-CBR over time for Howard County test sections: (a) *DCP-CBR$_{AGG}$* and (b) *DCP-CBR$_{SG}$*

Between construction in fall 2018 and the first spring thaw of 2019, all test sections experienced reductions in average DCP-CBR values in both the surface and subgrade layers, except for the RAP surface layer and the aggregate columns subgrade layer. In Cherokee County, 14 days elapsed between construction of the steel slag sections and performance of the fall 2018 DCP tests, while in Howard County 69 days elapsed between construction and testing.

The Harsco slag sections achieved significantly improved surface strength after construction in fall 2018. This is consistent with the findings of a study by Mathur et al. (1999), who concluded that slag mixtures initially behave like unbound material, then generally transform into bound material because of their self-stabilization characteristics.

The more coarsely graded Phoenix slag sections also achieved increased surface strength after construction in fall 2018, but experienced a strength decrease in spring 2019. From fall 2019 to spring 2020, the surface layers of the Harsco slag sections increased in strength, while those of the Phoenix slag sections decreased in strength. However, this behavior may be a result of an observed increase in subgrade strength beneath the Harsco slag sections, and a corresponding decrease in subgrade strength beneath the Phoenix slag sections, as detailed below.

The surface and subgrade layers of the two Harsco slag sections had the highest initial average DCP-CBR values in fall 2018, but by spring 2019 these values decreased to a lower range similar to those of the other sections. In fact, by spring 2019, the subgrades beneath all but the aggregate columns section exhibited decreases in shear strength (Figure 62b). The subgrade of the two Harsco slag sections showed the greatest percent decrease, and this may have been responsible for the strength decreases in the surface layers of the two Harsco sections in spring 2019 (Figure 62a).

In contrast to Cherokee County, the Iowa SUDAS support ratings for the surface courses in all Howard County test and control sections remained in the good to excellent range after the spring thaws of 2019 and 2020, despite the reductions in their subgrade strengths (previous Table 20 and Table 22).

Between fall 2019 and spring 2020, all surface and subgrade layers experienced an unexpected increase in shear strength, except for the Phoenix slag sections, which showed a strength decrease in both the subgrade and surface layers. The resulting spring 2020 surface and subgrade strengths for the OGCS and aggregate columns sections increased above their 2018 post-construction values. The same was true for the RAP surface course, despite a slight reduction in the strength of its subgrade.

6.2.1.3 Washington County DCP Test Results

DCP tests were conducted in Washington County on November 6, 2018; May 9, 2019; November 14, 2019; and May 18, 2020. Detailed plots for all tests are provided in Appendix D. The DCP-CBR values and corresponding Iowa SUDAS ratings are summarized in Table 23 through **Table** 26, along with the in situ dry unit weights and moisture contents, and are shown graphically in Figure 63 through Figure 66.

Table 23. Summary of Washington County test sections for DCP tests November 6, 2018

Section Name	**Avg. Thickness (in.)**	***DCP-CBR*$_{AGG}$ (%)**	**Avg. *DCP-CBR*$_{AGG}$ / Rating (%)**	***DCP-CBR*$_{SG}$ (%)**	**Avg. *DCP-CBR*$_{SG}$ / Rating (%)**	**In Situ Dry Unit Weight (lb/ft^3)**	**In Situ Moisture Content**	
							(%)	**Avg.**
(1) Optimized Gradation w / Clay Slurry	4.0	29.1	29.7 / <G	9.7	9.2 / P-F	136.1	3.7	6.0
		22.2		8.4		135.8	7.5	
		38.4		10.8		139.4	5.6	
		30.3		8.1		137.1	6.9	
		28.2		9.1		138.1	6.4	
(2) Control	4.0	29.5	33.9 / G	8.7	10.5 / F-G	130.0	9.8	7.9
		39.6		9.8		132.3	8.4	
		26.6		10.5		128.9	5.4	
		31.3		11.2		120.5	8.3	
		42.5		12.3		130.5	7.7	
(3) 12 in. Cement-Treated Subgrade	4.0	27.2	37.9 / G	39.5	34.4 / >VG	124.7	9.2	8.3
		21.1		36.9		126.7	7.2	
		38.1		25.9		125.9	9.6	
		63.0		37.9		130.8	8.3	
		39.9		32.1		125.4	7.2	
(4) 4 in. Cement-Treated Surface	4.0	166.6	169.9/ E	13.4	14.6 / F-G	129.1	9.3	9.2
		201.2		15.7		134.3	8.7	
		114.6		14.1		131.9	8.9	
		120.3		15.5		132.5	8.9	
		246.9		14.6		117.7	10.4	
(5) BASE ONE	4.0	28.6	37.0 / G	8.0	16.4 / F-G	122.5	8.7	8.4
		22.1		12.1		124.8	8.8	
		30.5		21.4		120.5	8.3	
		42.1		19.9		127.6	7.5	
		61.8		20.8		132.6	8.8	
(6) EMC SQUARED	4.0	36.7	34.2 / G	23.4	18.7 / F-G	121.4	10.4	10.5
		48.9		30.2		129.0	8.6	
		32.1		14.3		120.4	10.6	
		25.2		15.3		128.4	11.3	
		28.2		10.3		121.9	11.5	
(7) Claycrete	4.0	28.5	40.5 / G	11.8	22.7 / VG	125.7	9.3	9.0
		57.4		19.6		121.5	8.6	
		34.7		16.6		131.3	9.0	
		37.2		14.7		129.5	9.2	
		44.9		50.6		128.8	8.9	
(8) Aggregate Columns	4.0	38.3	37.4 / G	20.4	15.3 / F-G	122.8	9.2	9.0
		29.2		19.6		130.5	8.5	
		26.3		10.4		126.7	10.0	
		39.8		13.6		136.2	8.8	
		53.4		12.7		132.5	8.5	

E=excellent, F-G=fair–good, G=good, P-G=poor–fair, VG=very good, VP=very poor

Table 24. Summary of Washington County test sections for DCP tests May 9, 2019

Section Name	**Avg. Thickness (in.)**	***DCP-CBR*$_{AGG}$ (%)**	**Avg. *DCP-CBR*$_{AGG}$ / Rating (%)**	***DCP-CBR*$_{SG}$ (%)**	**Avg. *DCP-CBR*$_{SG}$ / Rating (%)**	**In Situ Dry Unit Weight (lb/ft^3)**	**In Situ Moisture Content**	
							(%)	**Avg.**
(1) Optimized Gradation w / Clay Slurry	3.3	139.5	114.9 / E	9.6	11.7 / F-G	140.3	4.9	5.8
		107.0		10.3		130.8	5.9	
		153.7		16.7		143.5	6.4	
		88.6		10.8		135.9	5.7	
		85.9		11.2		132.4	6.2	
(2) Control	3.4	39.9	70.9 / VG	9.5	10.6 / F-G	123.0	7.8	6.3
		62.3		7.2		125.0	7.9	
		113.9		14.6		136.5	4.1	
		62.6		10.7		129.0	6.3	
		75.9		10.7		138.8	5.6	
(3) 12 in. Cement-Treated Subgrade	6.0	94.2	69.3 / VG	30.4	27.6 / VG	127.1	7.3	7.0
		55.8		20.2		132.8	5.7	
		44.3		45.3		125.6	8.6	
		77.3		22.9		131.9	6.9	
		75.0		19.4		131.8	6.4	
(4) 4 in. Cement-Treated Surface	5.0	110.5	115.1 / E	7.3	10.4 / F-G	128.4	7.5	8.2
		41.5		5.4		134.5	6.7	
		217.4		6.4		129.9	8.3	
		51.4		15.9		130.1	8.3	
		154.7		17.1		112.2	10.4	
(5) BASE ONE	5.5	5.3	14.6 / <G	3.4	4.3 / VP	122.8	7.9	7.2
		9.8		3.7		126.0	8.4	
		23.7		6.3		136.8	6.1	
		18.1		4.0		132.8	6.9	
		16.3		4.1		131.0	6.9	
(6) EMC SQUARED	4.6	20.6	23.8 / <G	5.3	5.2 / P-F	128.2	7.4	8.8
		32.2		6.4		127.7	7.9	
		31.0		4.4		121.3	9.5	
		14.0		5.1		121.7	10.1	
		21.1		5.0		128.9	9.0	
(7) Claycrete	4.4	9.9	13.4 / <G	2.2	2.9 / VP	125.7	8.5	8.0
		11.4		2.4		134.1	6.9	
		12.8		3.2		126.2	8.4	
		16.9		2.6		131.6	8.0	
		16.0		4.2		129.7	7.7	
(8) Aggregate Columns	4.7	21.8	24.0 / <G	6.3	7.0 / P-F	122.8	8.3	8.7
		19.8		8.1		122.1	10.4	
		17.5		6.7		128.2	9.4	
		34.7		5.9		133.3	7.8	
		26.1		8.1		135.7	7.1	

E=excellent, F-G=fair–good, G=good, P-G=poor–fair, VG=very good, VP=very poor

Table 25. Summary of Washington County test sections for DCP tests November 14, 2019

Section Name	Avg. Thickness (in.)	DCP-CBR_{AGG} (%)	Avg. DCP-CBR_{AGG} / Rating (%)	DCP-CBR_{SG} (%)	Avg. DCP-CBR_{SG} / Rating (%)	In Situ Dry Unit Weight (lb/ft^3)	In Situ Moisture Content	
							(%)	Avg.
(1) Optimized Gradation w / Clay Slurry	4.6	245.6	139.5 / E	22.1	17.7 / F-G	139.9	3.9	5.2
		37.0		11.5		137.9	4.9	
		159.2		22.1		131.0	5.5	
		179.6		16.9		139.0	5.9	
		76.0		16.0		133.3	6.0	
(2) Control	4.8	70.7	98.4 / E	10.5	15.9 / F-G	128.7	8.8	7.2
		95.4		14.7		131.1	7.7	
		180.5		21.4		137.7	4.6	
		72.5		21.5		132.2	7.3	
		72.9		11.4		131.2	7.8	
(3) 12 in. Cement-Treated Subgrade	4.2	9.0	36.5 / G	39.2	33.5 / >VG	122.6	9.3	9.3
		21.3		36.8		130.9	6.9	
		39.9		24.4		121.7	11.0	
		68.2		36.7		122.4	9.3	
		44.0		30.6		121.6	9.8	
(4) 4 in. Cement-Treated Surface	4.0	171.6	174.1 / E	12.9	17.7 / F-G	122.4	8.4	7.8
		210.1		18.2		124.9	7.4	
		122.2		21.2		127.1	8.0	
		124.3		21.9		134.6	7.1	
		242.2		14.3		129.0	8.2	
(5) BASE ONE	6.1	45.4	63.8 / VG	8.1	11.2 / F-G	135.2	7.9	7.3
		60.9		9.1		133.4	8.2	
		53.9		12.5		129.2	6.7	
		48.6		12.9		130.9	6.8	
		110.4		13.4		133.6	6.8	
(6) EMC SQUARED	5.3	74.7	71.8 / VG	24.8	20.8 / VG	136.0	6.3	7.6
		100.3		27.7		134.4	7.0	
		74.6		11.5		129.7	8.0	
		55.9		29.3		129.0	7.8	
		53.4		10.8		127.6	8.9	
(7) Claycrete	4.4	63.5	52.7 / VG	8.0	10.5 / F-G	126.3	8.3	7.4
		60.6		10.6		134.4	7.2	
		56.5		12.9		133.7	7.5	
		41.6		10.1		138.7	6.8	
		41.4		10.9		132.4	7.3	
(8) Aggregate Columns	4.4	42.6	81.0 / E	11.3	16.0 / F-G	127.8	8.4	9.6
		38.7		11.4		125.7	9.6	
		41.3		18.0		121.4	10.3	
		47.6		27.3		117.4	11.8	
		234.9		11.9		130.6	7.8	

E=excellent, F-G=fair–good, G=good, P-G=poor–fair, VG=very good, VP=very poor

Table 26. Summary of Washington County test sections for DCP tests May 18, 2020

Section Name	Avg. Thickness (in.)	DCP-CBR_{AGG} (%)	Avg. DCP-CBR_{AGG} / Rating (%)	DCP-CBR_{SG} (%)	Avg. DCP-CBR_{SG} / Rating (%)	In Situ Dry Unit Weight (lb/ft^3)	In Situ Moisture Content	
							(%)	Avg.
(1) Optimized Gradation w / Clay Slurry	4.0	116.3	89.2/ E	22.2	19.3/ F-G	142.4	2.6	3.6
		71.9		13.8		146.5	4.2	
		79.5		21.8		138.2	4.1	
(2) Control	4.6	36.9	59.0/ VG	7.7	9.4/ P-F	133.0	8.0	5.8
		62.5		12.2		142.3	3.8	
		77.7		8.2		139.3	5.7	
(3) 12 in. Cement-Treated Subgrade	5.4	114.6	118.0/ E	32.4	32.5/ >G	128.8	7.3	8.0
		103.4		44.6		133.1	6.4	
		136.1		20.6		116.7	10.4	
(4) 4 in. Cement-Treated Surface	2.5	202.7	187.6/ E	23.0	20.7/ VG	129.5	6.2	6.1
		242.7		18.8		131.9	5.5	
		117.5		20.4		142.3	6.7	
(5) BASE ONE	2.5	26.3	41.7/ G	11.6	13.6/ F-G	128.4	5.5	5.4
		48.4		18.9		135.8	5.2	
		50.3		10.3		138.1	5.4	
(6) EMC SQUARED	4.0	35.0	49.3/ G	29.2	26.0/ VG	138.7	5.2	5.6
		46.5		31.5		136.5	4.9	
		66.4		17.2		133.6	6.6	
(7) Claycrete	3.6	36.1	39.5/ G	7.5	11.2/ F-G	133.8	5.5	5.4
		51.4		15.9		136.1	5.0	
		30.9		10.2		137.1	5.6	
(8) Aggregate Columns	5.1	21.5	30.4/ G	16.9	12.8/ F-G	127.1	7.8	7.8
		31.2		8.1		133.7	6.7	
		38.5		13.3		126.8	8.8	

E=excellent, F-G=fair–good, G=good, P-G=poor–fair, VG=very good, VP=very poor

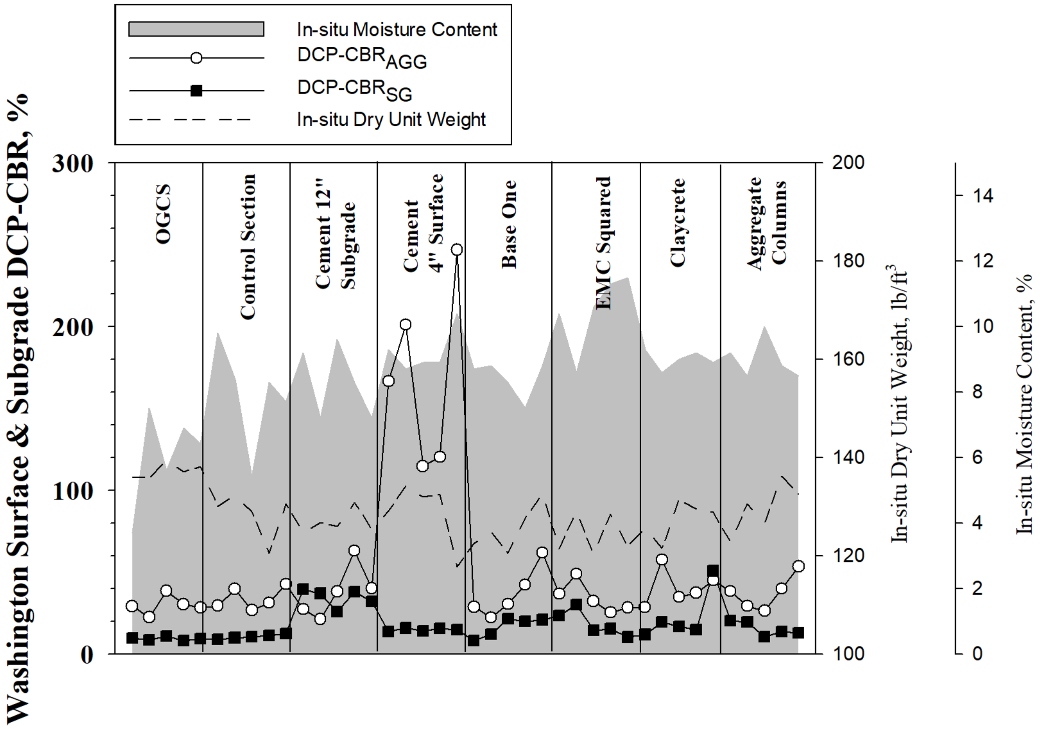


Figure 63. Graphical summary of Washington County test sections for DCP tests on November 6, 2018

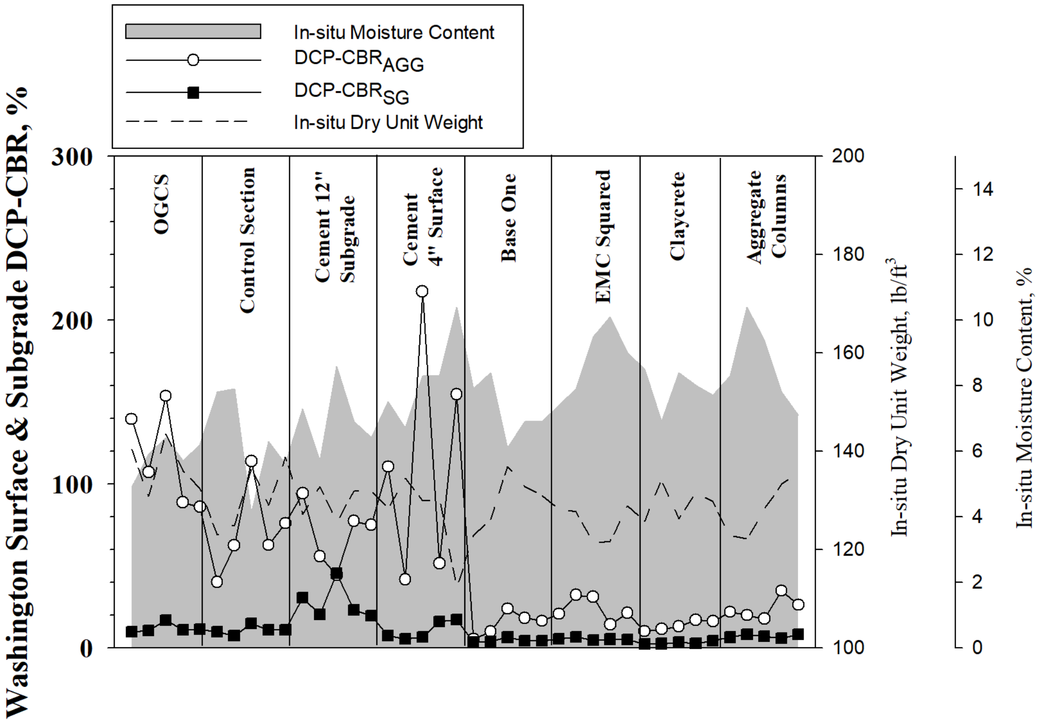


Figure 64. Graphical summary of Washington County test sections for DCP tests on May 9, 2019

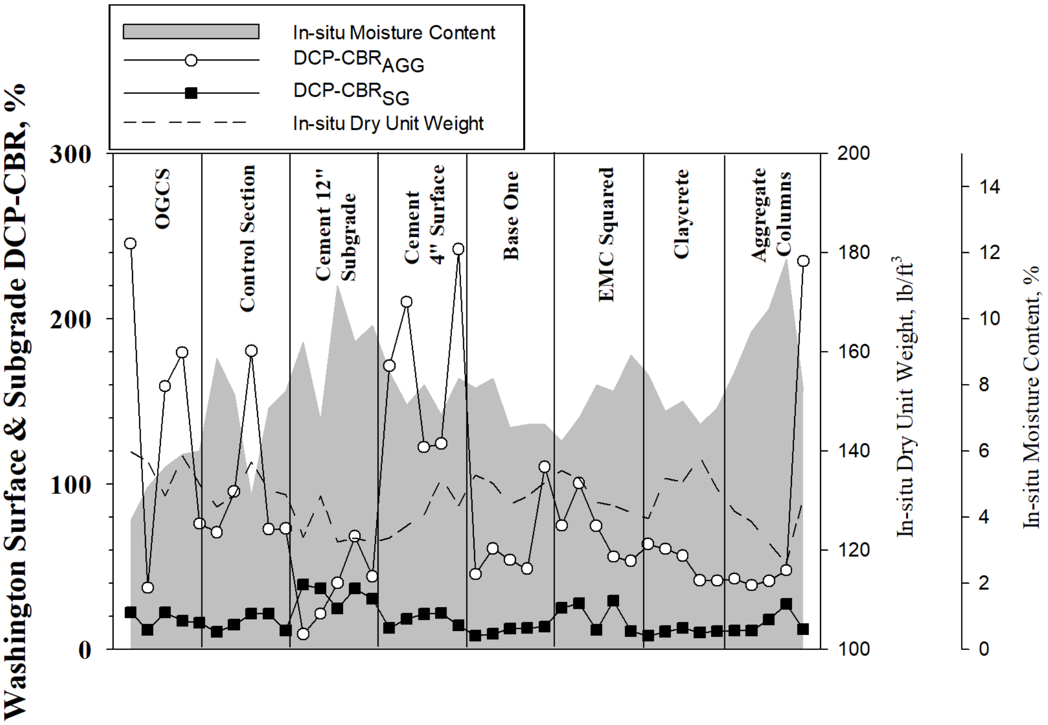


Figure 65. Graphical summary of Washington County test sections for DCP tests on November 14, 2019

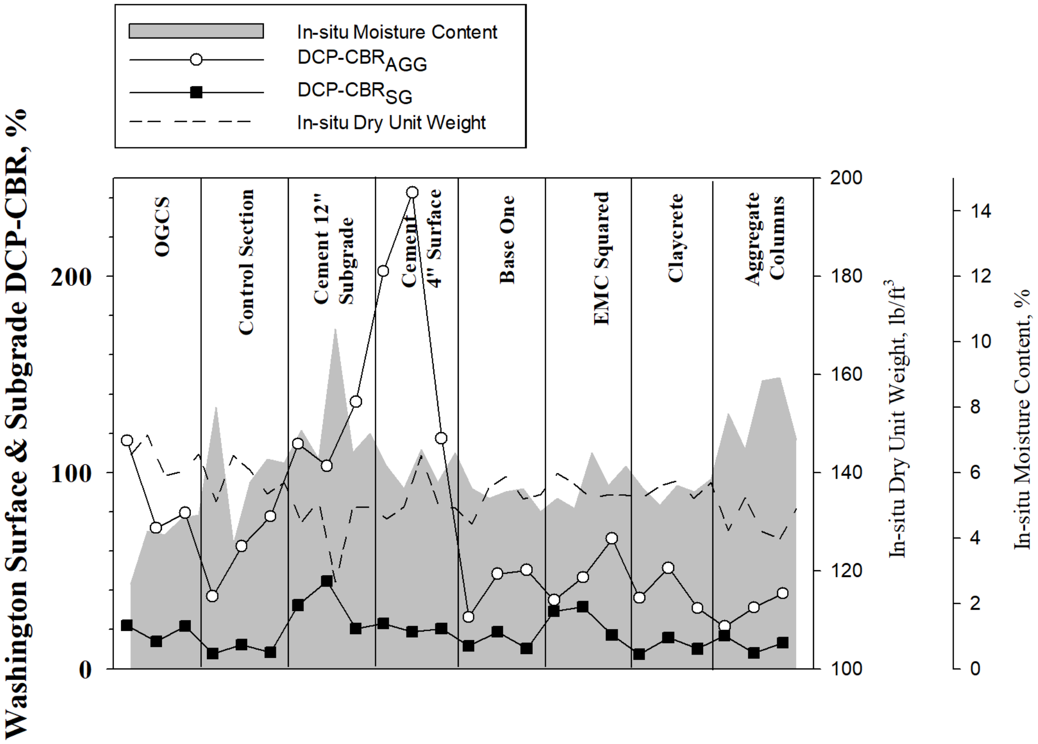
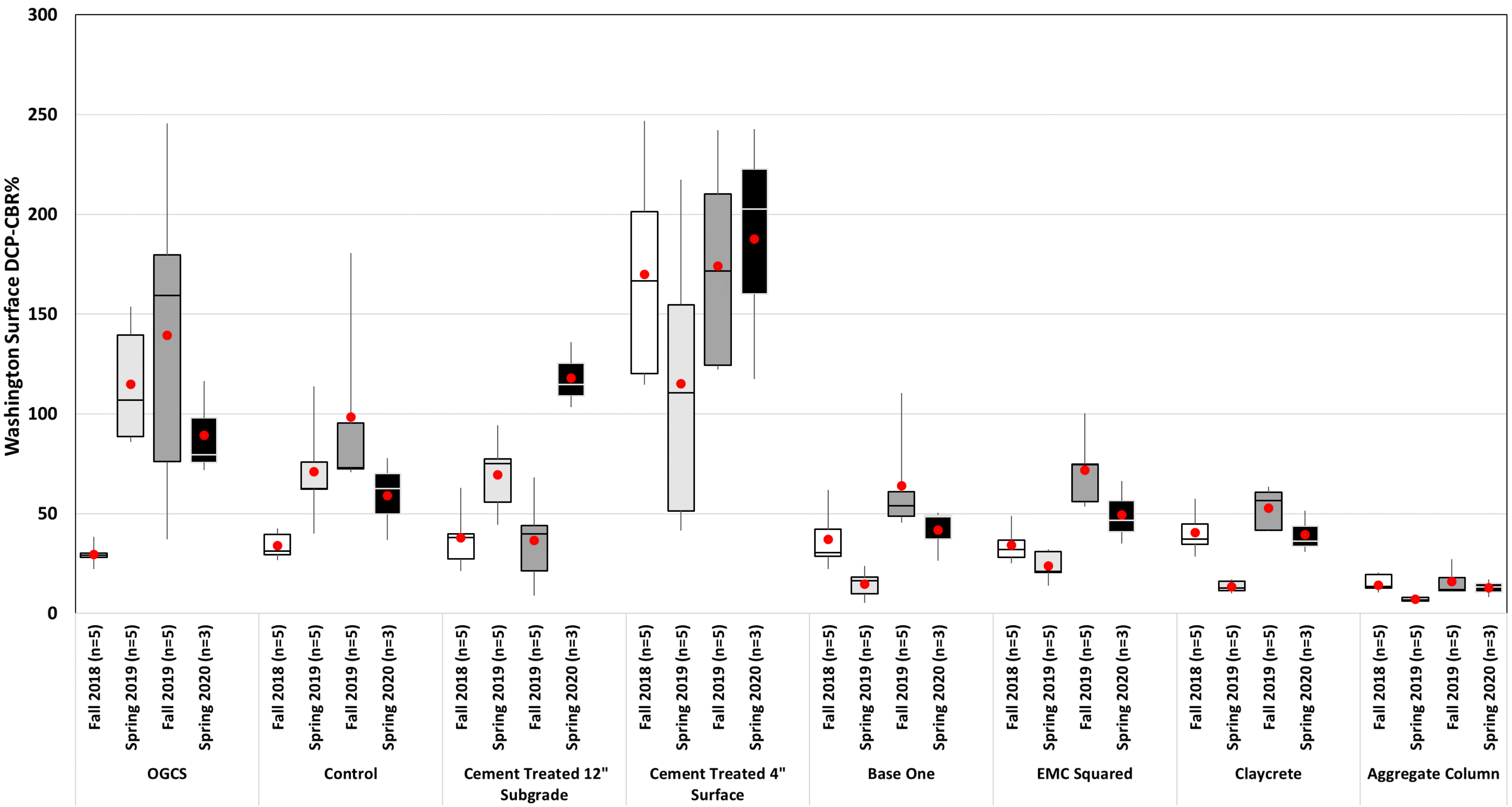
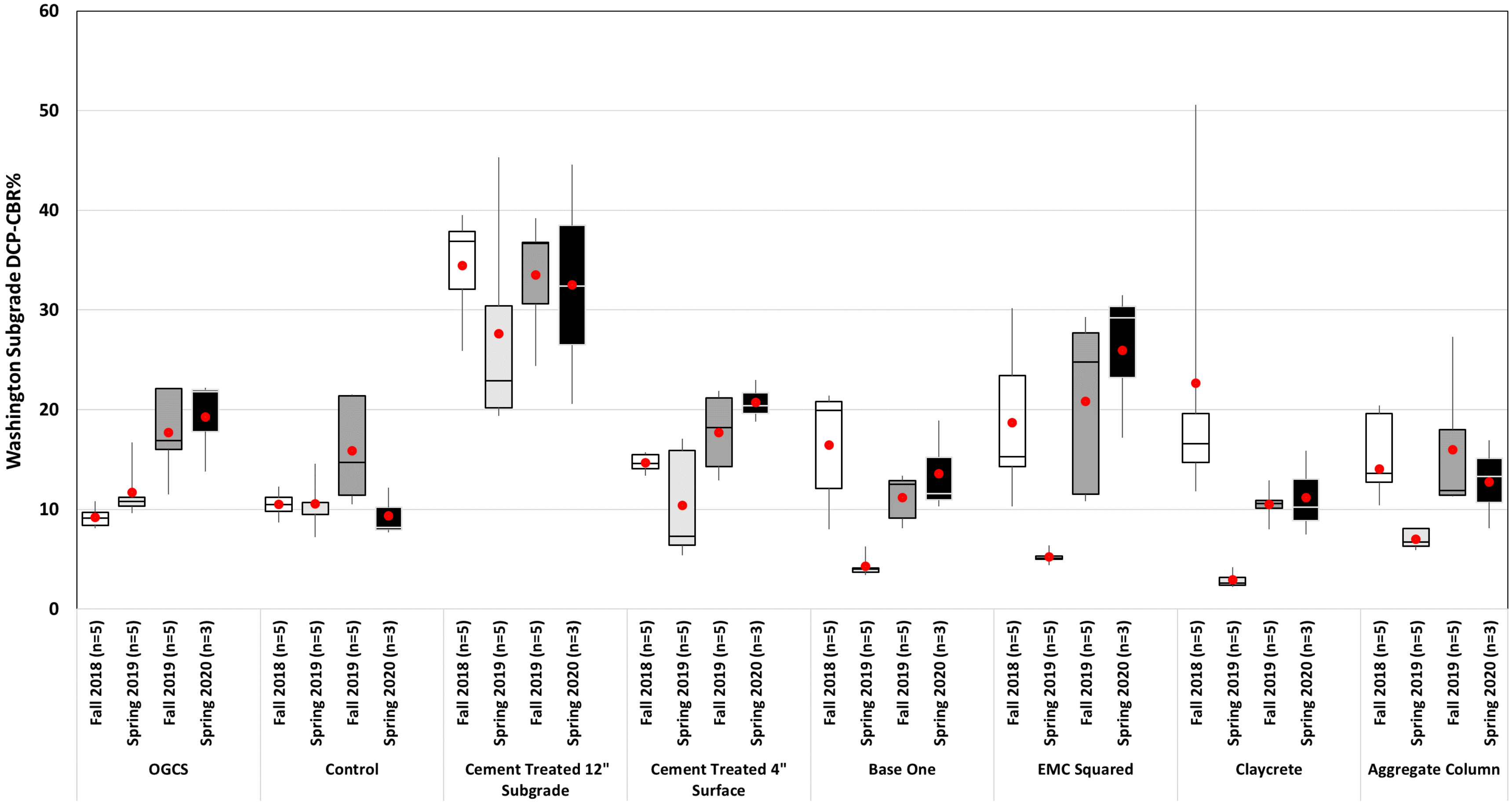


Figure 66. Graphical summary of Washington County test sections for DCP tests on May 18, 2020

Statistical boxplots of the DCP-CBR values for all four test series spanning fall 2018 through spring 2020 in Washington County are shown in Figure 67.


Washington Surface DCP-CBR%
300
250
200
150
100
50
0
Fall 2018 (n=5)
Spring 2019 (n=5)
Fall 2019 (n=5)
Spring 2020 (n=3)
OGCS
Control
Cement Treated 12" Subgrade
Cement Treated 4" Surface
Base One
EMC Squared
Claycrete
Aggregate Column

(a)



(b)

Figure 67. Statistical boxplots of DCP-CBR over time for Washington County test sections: (a) *DCP-CBR$_{AGG}$* and (b) *DCP-CBR$_{SG}$*

For the fall 2018 DCP tests, the surface thickness was taken to be 4 in. for calculating the average DCP-CBR values, because there was no clear trend in the data to indicate an interface between the surface and subgrade layers.

In fall 2018, the average DCP-CBR value of the OGCS section was about 4% lower than the control section, while the values for the other test sections were slightly higher than the control section by 0.3% to 6.6%. However, for spring 2019, fall 2019, and spring 2020, the strength of the clay slurry section increased significantly and remained two to four times higher than its 2018 post-construction value and also exceeded those of the other sections except for the 4 in. cement-treated surface and the spring 2020 12 in. cement-treated subgrade section (Figure 67a).

After construction in fall 2018, the 4 in. cement-treated surface section had the highest initial surface-layer strength, with $DCP\text{-}DCR_{AGG}$ values far exceeding 100%. The surface strength of this section decreased at a few of the test points in spring 2019 but increased again beyond the post-construction values in fall 2019 and spring 2020. Throughout the project duration, the surface of this section exhibited excellent performance in visual surveys except for some potholes in spring 2020, and the surface retained an average Iowa SUDAS support rating of excellent.

Outside of spring 2020, the 12 in. cement-treated subgrade section did not exhibit a high surface-layer strength (Figure 67a) but consistently had the highest subgrade strength of all sections, as expected (Figure 67b). This section's subgrade retained an average Iowa SUDAS support rating of very good or better throughout the project duration.

Based on the DCP results, both the cement-treated surface and cement-treated subgrade can improve the strength of the surface and subgrade layers and provide improved resistance through freeze-thaw cycles. However, the cement-treated subgrade requires specialized equipment that may be difficult to locate or schedule; whereas, the cement-treated surface can more easily be constructed using equipment owned or readily obtainable by secondary roads departments.

The three liquid stabilizer sections performed similarly, as all started with $DCP\text{-}CBR_{AGG}$ and $DCP\text{-}CBR_{SG}$ values slightly higher than the control section after construction in fall 2018. At that time, the Claycrete section had slightly higher DCP-CBR values than the BASE ONE and EMC SQUARED sections for both the surface and subgrade layers.

For spring 2019 and beyond, the EMC SQUARED section had somewhat higher surface and subgrade DCP-CBR values than the BASE ONE and Claycrete sections. Additionally, the surface layers of the BASE ONE, EMC SQUARED, and Claycrete sections, as well as the 4 in. cement-treated surface and aggregate columns sections, experienced a large decrease in average strength from fall 2018 to spring 2019, followed by a significant strength increase in fall 2019 and a slight decrease in 2020 for the last four sections (Figure 67a).

In each of these sections, the subgrade strength also decreased drastically in spring 2019, followed by significantly higher strengths for fall 2019 and spring 2020. Therefore, the subgrade moisture conditions below these sections may have been primarily responsible for the decreased surface-layer strengths observed in spring 2019.

Among the adjacent last four sections, the aggregate columns section (the only method to treat the subgrade to a depth of 7 ft) had the greatest subgrade strength in spring 2019. This result supports the hypothesis that the aggregate columns method can offer the anticipated improvements in subgrade strength, drainage, and water storage capacity. However, the overall performance of the aggregate columns in this study was not as good as the smaller diameter and shallower columns of the previous Phase II project. The strength of the surface course of the aggregate columns section was consistently below that of the control section and was lowest among all test sections in Washington County.

6.2.1.4 Hamilton County DCP Test Results

The DCP tests in Hamilton County were conducted on November 15, 2018; April 21, 2019; November 18, 2019; and May 22, 2020. Plots of the cumulative blows, DCPI, and DCP-CBR values versus depth for all eight Howard County sections and all four test series spanning fall 2018 through spring 2020 are provided in Appendix D.

The DCP-CBR values and corresponding Iowa SUDAS ratings, along with the in situ dry unit weights and moisture contents, are summarized in Table 27 through Table 30 and are shown graphically in Figure 68 through Figure 71.

Statistical boxplots of DCP-CBR values for all test series in Hamilton County are provided in Figure 72.

Table 27. Summary of Hamilton County test sections for DCP tests November 15, 2018

Section Name	**Avg. Thickness (in.)**	***DCP-CBR***$_{AGG}$ **(%)**	**Avg. *DCP-CBR***$_{AGG}$ **/ Rating (%)**	***DCP-CBR***$_{SG}$ **(%)**	**Avg. *DCP-CBR***$_{SG}$ **/ Rating (%)**	**In Situ Dry Unit Weight (lb/ft^3)**	**In Situ Moisture Content**	
							(%)	**Avg.**
(1) Optimized Gradation w / Clay Slurry	6.6	66.9	48.9 / G	39.4	18.1 / F-G	134.3	5.6	5.7
		62.1		15.6		126.4	5.1	
		49.3		9.2		129.0	5.2	
		32.9		12.6		131.9	6.2	
		33.		14.0		138.3	6.6	
(4) BASE ONE	5.0	35.1	23.1 / <G	9.3	7.3 / P-F	138.0	5.1	7.8
		30.7		7.6		127.7	9.0	
		16.1		5.8		133.5	8.9	
		25.8		6.6		130.7	10.4	
		7.6		7.3		140.5	5.5	
(5 EMC SQUARED	7.4	43.4	91.3 / E	9.0	15.0 / F-G	119.7	13.3	10.5
		23.1		7.9		115.0	15.3	
		103.6		15.6		130.1	10.7	
		63.4		13.2		134.4	6.4	
		222.8		29.4		136.9	6.7	
(6) Control	4.0	39.5	26.0 / <G	12.0	9.1 / P-F	132.9	6.6	9.5
		27.3		5.7		133.7	7.9	
		15.9		11.3		115.8	12.6	
		24.7		7.4		130.7	10.1	
		22.9		8.9		129.6	10.1	
(7) Claycrete	7.0	75.6	56.0 / VG	6.6	9.4 / P-F	140.0	5.0	6.2
		149.0		11.0		140.3	4.9	
		13.6		5.0		141.0	5.0	
		25.7		17.3		139.9	5.8	
		16.2		6.9		135.8	5.1	
(8) Aggregate Columns	4.9	18.9	25.6 / <G	6.3	7.0 / P-F	128.0	11.5	10.4
		29.8		9.5		124.0	12.6	
		24.4		5.0		106.4	15.7	
		33.4		7.2		134.1	7.5	
		21.4		7.1		135.9	5.9	

E=excellent, F-G=fair–good, G=good, P-G=poor–fair, VG=very good, VP=very poor

Table 28. Summary of Hamilton County test sections for DCP tests April 21, 2019

Section Name	**Avg. Thickness (in.)**	***DCP-CBR*$_{AGG}$ (%)**	**Avg. *DCP-CBR*$_{AGG}$ / Rating (%)**	***DCP-CBR*$_{SG}$ (%)**	**Avg. *DCP-CBR*$_{SG}$ / Rating (%)**	**In Situ Dry Unit Weight (lb/ft^3)**	**In Situ Moisture Content**	
							(%)	**Avg.**
(1) Optimized Gradation w / Clay Slurry	4.1	193.47	126.7 / E	18.4	11.7 / F-G	143.7	3.5	3.7
		231.71		28.4		145.3	3.3	
		54.79		4.2		145.3	3.5	
		57.58		2.6		141.5	4.2	
		96.08		4.9		127.2	4.1	
(4) BASE ONE	4.3	183.8	121.1 / E	14.1	6.9 / P-F	129.2	5.1	7.8
		31.6		6.8		128.1	9.0	
		83.8		2.6		123.1	8.9	
		68.1		3.8		122.5	10.4	
		238.4		7.3		134.6	5.5	
(5 EMC SQUARED	4.0	27.7	68.6 / VG	1.8	6.4 / P-F	113.0	12.6	9.3
		36.4		2.6		115.4	13.4	
		74.1		6.7		120.6	10.1	
		106.2		9.7		136.9	5.0	
		98.7		11.3		137.6	5.3	
(6) Control	4.5	68.2	29.5 / <G	9.3	5.4 / P-F	131.1	6.1	9.1
		38.6		3.5		134.0	7.2	
		30.9		4.8		116.8	13.4	
		7.6		7.3		120.1	11.5	
		2.2		2.1		134.1	7.2	
(7) Claycrete	4.2	204.7	109.9 / E	13.9	9.0 / P-F	140.5	3.6	5.8
		119.4		9.2		139.4	4.0	
		16.7		2.2		132.3	5.3	
		85.7		7.7		136.1	4.7	
		123.2		12.0		143.2	3.7	
(8) Aggregate Columns	4.1	2.7	23.4 / VG	3.0	5.2 / P-F	113.7	13.4	9.0
		14.3		4.6		123.3	10.2	
		10.9		3.7		115.2	13.7	
		10.5		4.6		130.8	7.8	
		78.9		10.4		144.9	4.1	

E=excellent, F-G=fair–good, G=good, P-G=poor–fair, VG=very good, VP=very poor

Table 29. Summary of Hamilton County test sections for DCP tests November 18, 2019

Section Name	Avg. Thickness (in.)	*DCP-CBR*$_{AGG}$ (%)	Avg. *DCP-CBR*$_{AGG}$/ Rating (%)	*DCP-CBR*$_{SG}$ (%)	Avg. *DCP-CBR*$_{SG}$ / Rating (%)	In Situ Dry Unit Weight (lb/ft^3)	In Situ Moisture Content	
							(%)	Avg.
(1) Optimized Gradation w / Clay Slurry	4.8	267.2	147.0 / E	15.1	11.7 / F-G	145.4	4.4	4.7
		252.6		15.4		138.4	4.2	
		61.5		8.1		137.0	4.9	
		50.6		5.1		141.6	6.0	
		103.3		14.7		143.6	4.2	
(4) BASE ONE	4.9	135.1	58.8 / VG	15.1	11.7 / F-G	137.2	3.9	6.4
		46.1		15.4		135.6	7.2	
		23.2		8.1		133.2	7.8	
		36.7		5.1		131.5	8.6	
		52.7		14.7		139.5	4.3	
(5 EMC SQUARED	3.3	17.0	60.3 / VG	6.5	13.4 / F-G	135.3	7.9	7.5
		30.4		9.4		123.9	11.5	
		37.0		7.1		132.6	7.9	
		111.9		19.8		140.7	5.1	
		105.3		24.1		139.8	5.1	
(6) Control	4.0	88.4	64.4 / VG	14.1	10.9 / F-G	135.8	6.0	12.1
		66.4		11.8		134.1	6.6	
		7.7		7.5		115.5	14.7	
		97.1		9.3		111.6	13.8	
		62.2		11.6		104.0	19.4	
(7) Claycrete	4.6	207.9	199.4 / E	17.9	18.7 / F-G	141.8	4.3	4.7
		227.5		30.3		145.6	3.8	
		191.5		14.2		131.2	7.3	
		87.5		14.2		145.1	4.6	
		282.5		17.1		143.5	3.4	
(8) Aggregate Columns	3.2	6.5	51.1 / G	4.2	8.8 / P-F	136.7	8.3	8.1
		62.4		11.3		139.4	8.0	
		17.2		8.7		121.5	13.6	
		21.3		5.9		137.0	6.5	
		148.0		13.8		138.7	4.3	

E=excellent, F-G=fair–good, G=good, P-G=poor–fair, VG=very good, VP=very poor

Table 30. Summary of Hamilton County test sections for DCP tests May 22, 2020

Section Name	Avg. Thickness (in.)	*DCP-CBR*$_{AGG}$ (%)	Avg. *DCP-CBR*$_{AGG}$/ Rating (%)	*DCP-CBR*$_{SG}$ (%)	Avg. *DCP-CBR*$_{SG}$ / Rating (%)	In Situ Dry Unit Weight (lb/ft^3)	In Situ Moisture Content	
							(%)	Avg.
(1) Optimized Gradation w / Clay Slurry	2.4	271.9	194.0 / E	53.7	31.9 / >VG	169.9	3.1	3.5
		159.6		15.9		144.6	3.5	
		150.4		25.9		147.5	3.9	
(4) BASE ONE	4.9	100.5	102.4 / E	3.9	5.6 / P-F	143.6	3.9	5.8
		60.8		6.7		135.6	6.6	
		146.0		6.3		136.5	6.9	
(5 EMC SQUARED	4.9	25.6	76.2 / VG	3.8	5.8 / P-F	120.8	11.6	9.5
		27.7		3.4		128.8	9.6	
		175.2		10.2		134.2	7.4	
(6) Control	3.4	42.2	24.5 / <G	4.7	6.6 / P-F	137.7	6.6	7.9
		15.2		7.3		140.3	4.8	
		16.2		7.8		120.6	12.4	
(7) Claycrete	6.8	270.4	163.1 / E	18.8	13.2 / F-G	143.3	3.6	4.3
		61.5		6.1		147.4	3.4	
		157.5		14.7		141.8	5.8	
(8) Aggregate Columns	4.1	26.4	24.9 / <G	4.8	4.6 / <VP	126.4	10.4	10.8
		31.1		4.7		122.5	11.2	
		17.3		4.4		138.9	10.9	

E=excellent, F-G=fair–good, G=good, P-G=poor–fair, VG=very good, VP=very poor

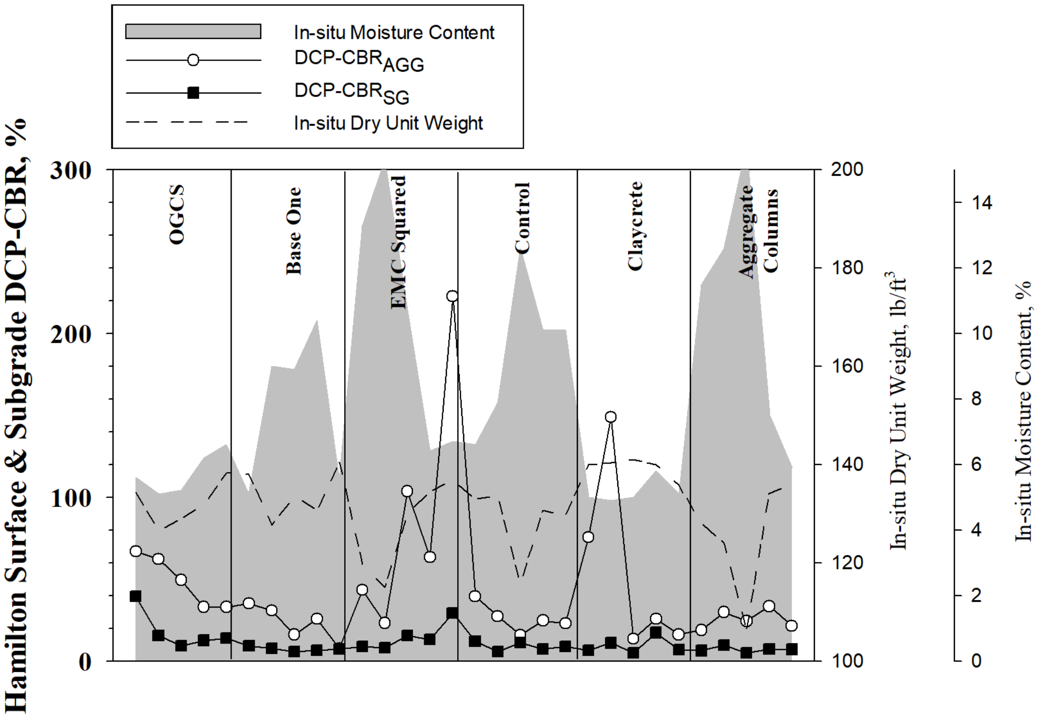


Figure 68. Graphical summary of Hamilton County test sections for DCP tests on November 15, 2018

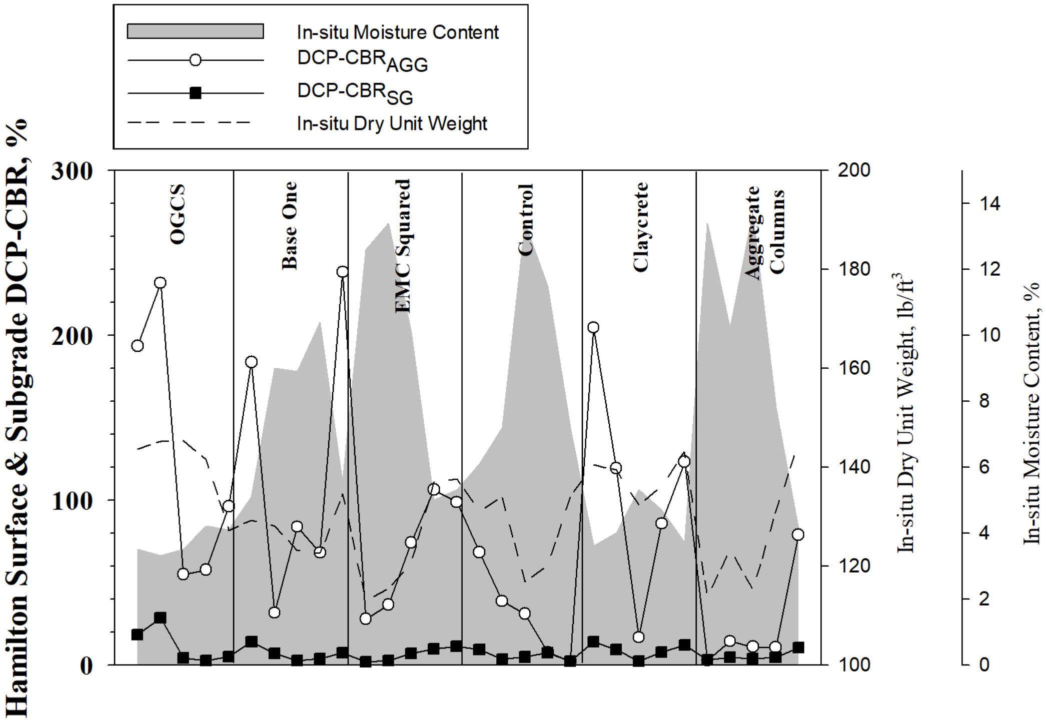


Figure 69. Graphical summary of Hamilton County test sections for DCP tests on April 21, 2019

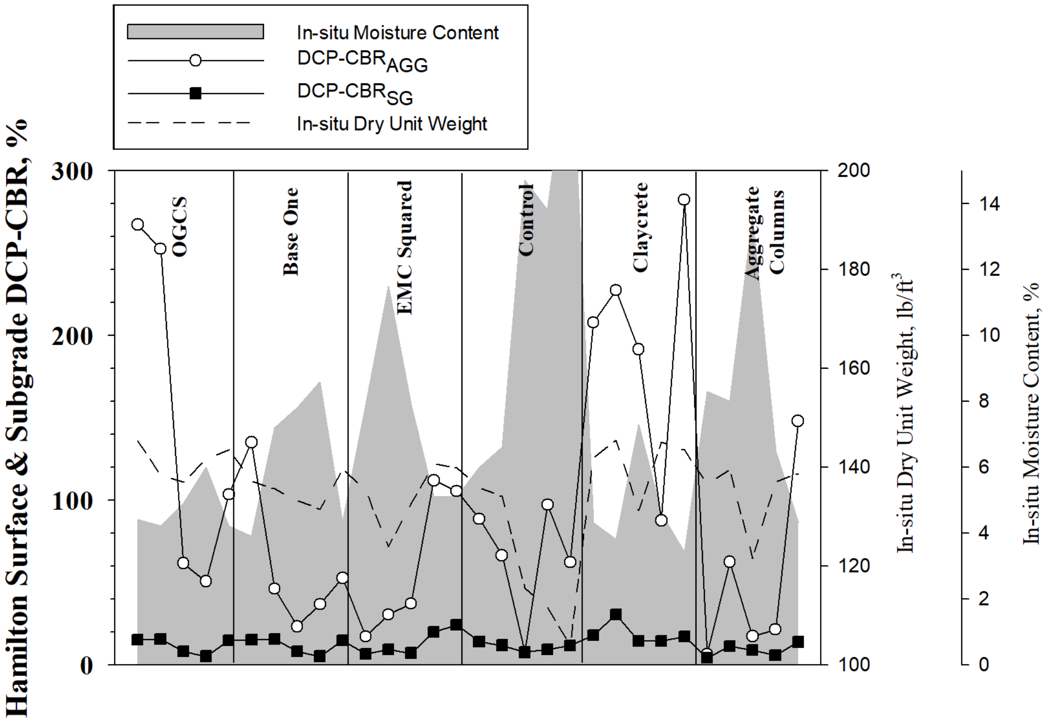


Figure 70. Graphical summary of Hamilton County test sections for DCP tests on November 18, 2019

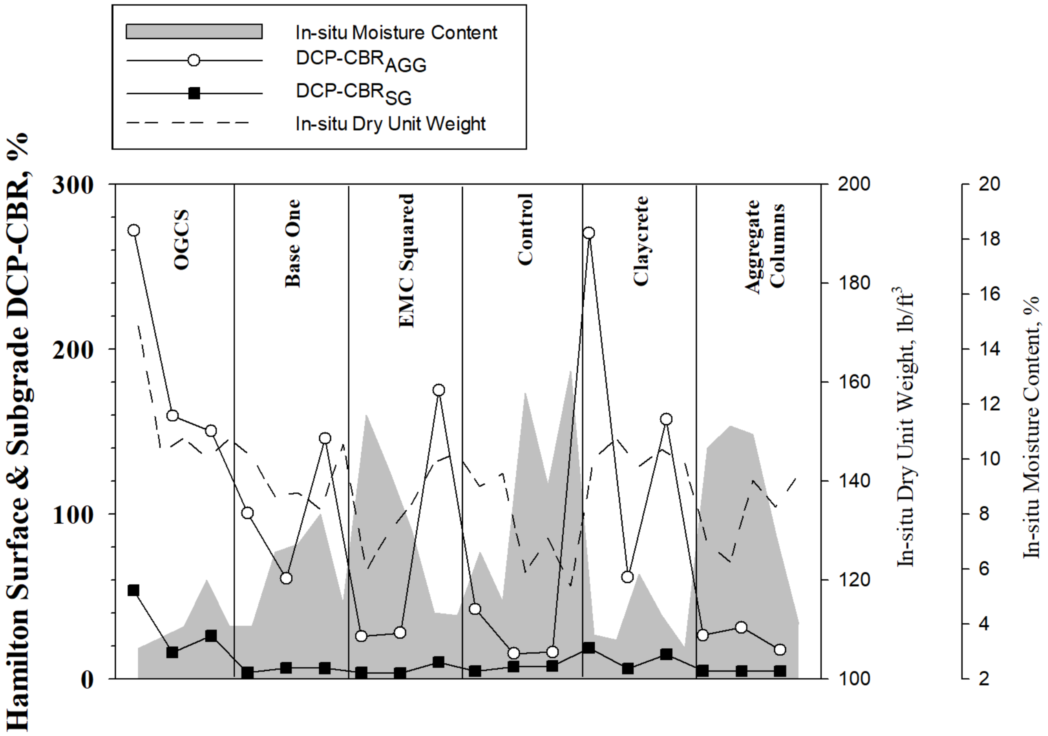
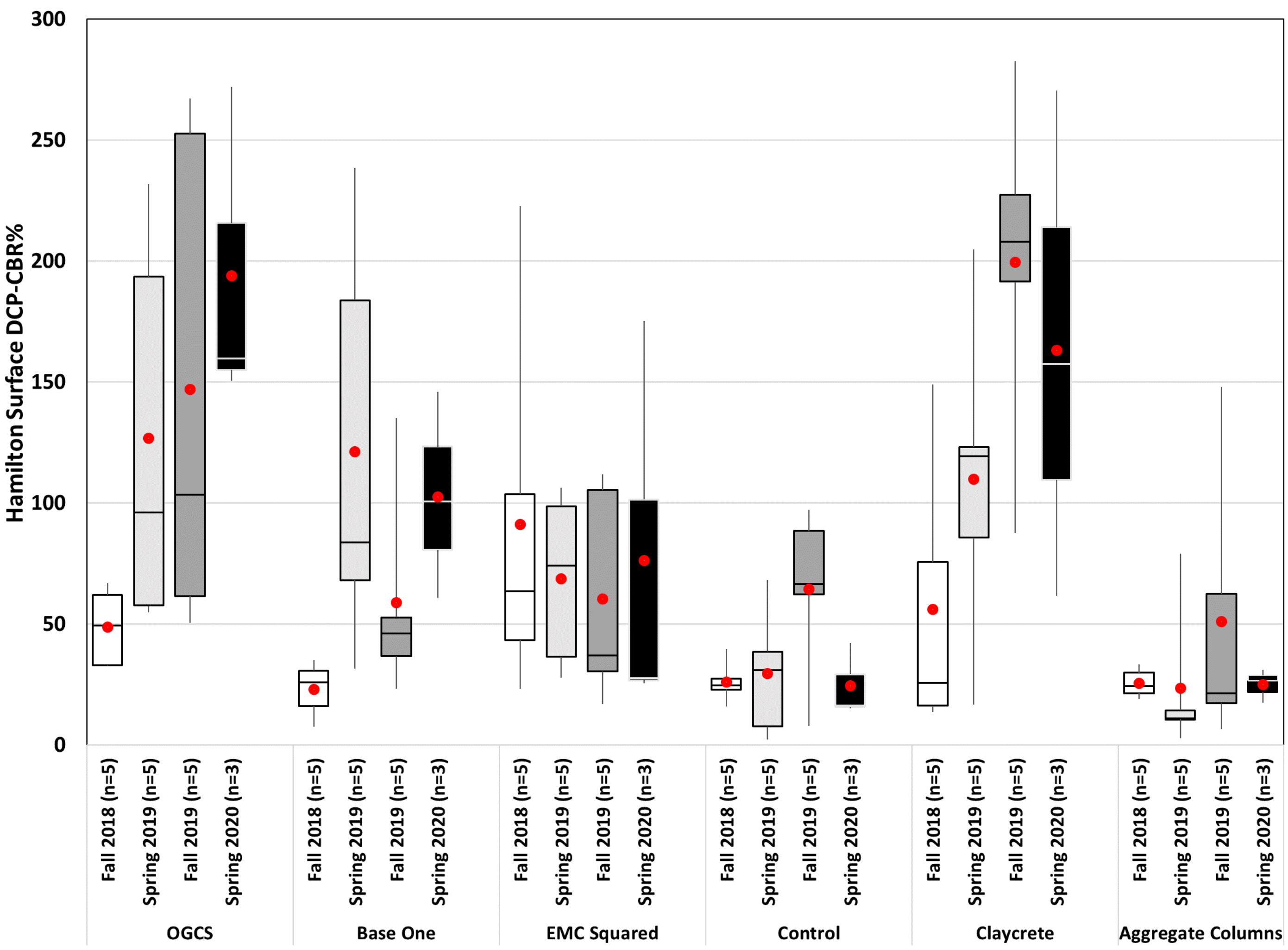
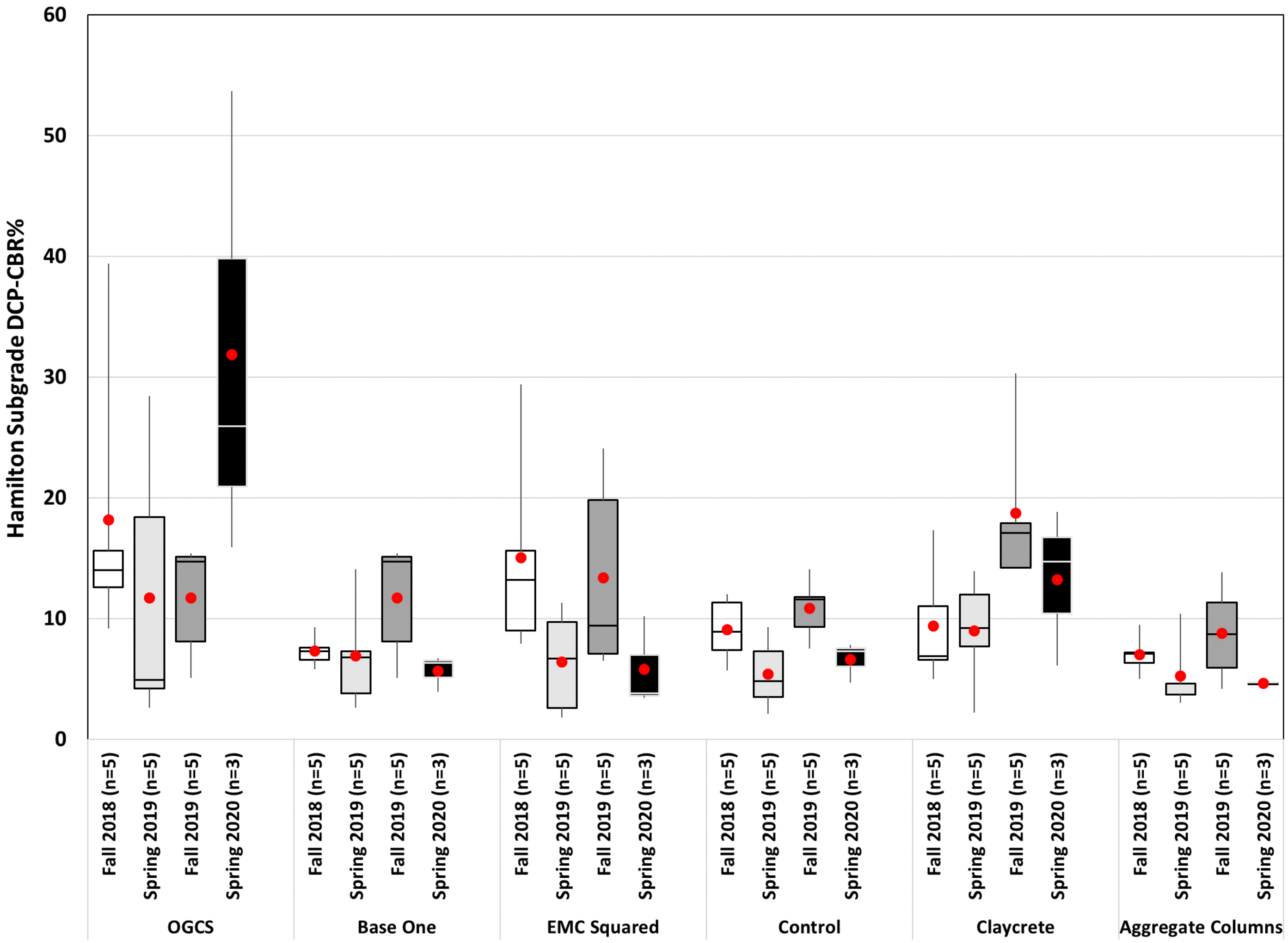


Figure 71. Graphical summary of Hamilton County test sections for DCP tests on May 22, 2020


Hamilton Surface DCP-CBR%
300
250
200
150
100
50
0
Fall 2018 (n=5)
Spring 2019 (n=5)
Fall 2019 (n=5)
Spring 2020 (n=3)
OGCS
Base One
EMC Squared
Control
Claycrete
Aggregate Columns

(a)



(b)

Figure 72. Statistical boxplots of DCP-CBR over time for Hamilton County test sections: (a) $DCP\text{-}CBR_{AGG}$ and (b) $DCP\text{-}CBR_{SG}$

Figure 72a reveals that none of the stabilized test sections exhibited a significant reduction in average strength of their surface layers over the two winter-spring cycles. On the contrary, from fall 2018 to spring 2020, the OGCS, BASE ONE, and Claycrete sections showed significant increases in average strength while the EMC SQUARED, control, and aggregate columns sections ended up with average strengths close to their starting values. Although the aggregate columns method was the only one to modify the subgrade to a significant depth of 7 ft, the results shown in Figure 72b indicate that the method was not successful at improving the subgrade strength for this specific site.

The surface layer of the OGCS section, in particular, exhibited a continuous and significant increase in strength over the duration of the project (Figure 72a), despite a large drop in its average subgrade strength in spring 2019 (Figure 72b). This section's surface layer started out with an Iowa SUDAS support rating of good in fall 2018 and subsequently improved to excellent for the remaining three test periods (Figure 72a).

From spring 2019 onward, the OGCS section's subgrade was also the only one to continually increase in strength with time over the reminder of the project (Figure 72b). The average subgrade strengths for all other sections remained in a similar range corresponding to Iowa SUDAS ratings of poor–fair and fair–good, except for the aggregate columns section, whose subgrade rated below very poor in spring 2020.

Despite these unfavorable subgrade conditions, the strengths of the surface layers for the three liquid stabilizer sections were typically greater than that of the control section with a few exceptions. Specifically, the control section surface had an average $DCP\text{-}CBR_{AGG}$ value of 26% in fall 2018, 30% in spring 2019, 64% in fall 2019, and 25% in spring 2020. In comparison, the BASE ONE section exhibited an overall trend of increasing strength with time, with average $DCP\text{-}CBR_{AGG}$ values of 23% in fall 2018, 121% in spring 2019, 59% in fall 2019, and 102% in spring 2020. The average strength of the BASE ONE section's surface layer was therefore approximately 0.9 times that of the control section in fall tests, and more than four times that of the control section in spring tests.

The EMC SQUARED section also maintained a relatively consistent range of average $DCP\text{-}CBR_{AGG}$ values, measuring 91% in fall 2018, 69% in spring 2019, 60% fall 2019, and 76% in spring 2020, which varied between 0.94 and 3.5 times that of the control section. Among the three chemical stabilization methods, EMC SQUARED had the highest initial strength after construction in 2018.

For the Claycrete section, the average $DCP\text{-}CBR_{AGG}$ values were 56% in fall 2018, 110% in spring 2019, 199% in fall 2019, and 163% in spring 2020. The Claycrete section's average surface strength was therefore consistently between 2.1 and 6.7 times that of the control section and was the highest among the three liquid stabilizer sections by spring 2020.

Another way to interpret these results is that the average strength of the stabilized surface layers exceeded that of the control section in two of the four testing periods for BASE ONE, three of the four testing periods for EMC SQUARED, and four of the four testing periods for Claycrete.

Most importantly, compared to the control section, all three of the liquid chemical stabilization methods examined provided benefits of significantly improved surface strength in the critical spring thaw periods of 2019 and 2020 despite the poor to fair ratings of their subgrades in all but one case (and specifically, the fair to good rating for the Claycrete subgrade in spring 2020).

6.2.1.5 Observations on DCP and Moisture Trends in Aggregate Columns Sections

Compared to the other test sections, the aggregate columns sections in all four counties did not show significant improvements in the strengths of their surface courses or subgrades through the two years of study. Based on the DCP data from all counties, the average surface strengths of the aggregate columns sections were between 0.1 and 4.7 times those of their corresponding control sections. However, this stabilization method only showed good surface strength performance in Cherokee County in fall 2018 (3.1 times that of the control section) and spring 2019 (4.7 times that of the control section) and did not increase the strength of the surface course in the other three counties.

In Howard, Washington, and Hamilton counties, the aggregate columns section's average surface strength was between 0.2 and 1.1 times that of their control section. The NDG data revealed that the aggregate columns sections consistently had the highest moisture contents, which may be a potential reason for their poor performance in terms of surface strength.

Theoretically, the aggregate columns sections should improve the water drainage of the surface course and subgrade while providing paths of greater hydraulic conductivity to accelerate the melting of frozen soil, but it appears they can also have the effect of retaining moisture at times when the other sections are able to dry more quickly.

6.2.2 LWD Test Results

To quantify the composite stiffness of the surface and subgrade layers, LWD tests were conducted on the same days as the DCP tests in fall 2018, spring 2019, and fall 2019. During spring 2020, LWD tests were performed on March 29 in Washington County, April 10 in Hamilton County, April 11 in Cherokee County, and April 18 in Howard County.

Statistical boxplots of the LWD test results for the four counties are shown in Figure 73 through Figure 76.

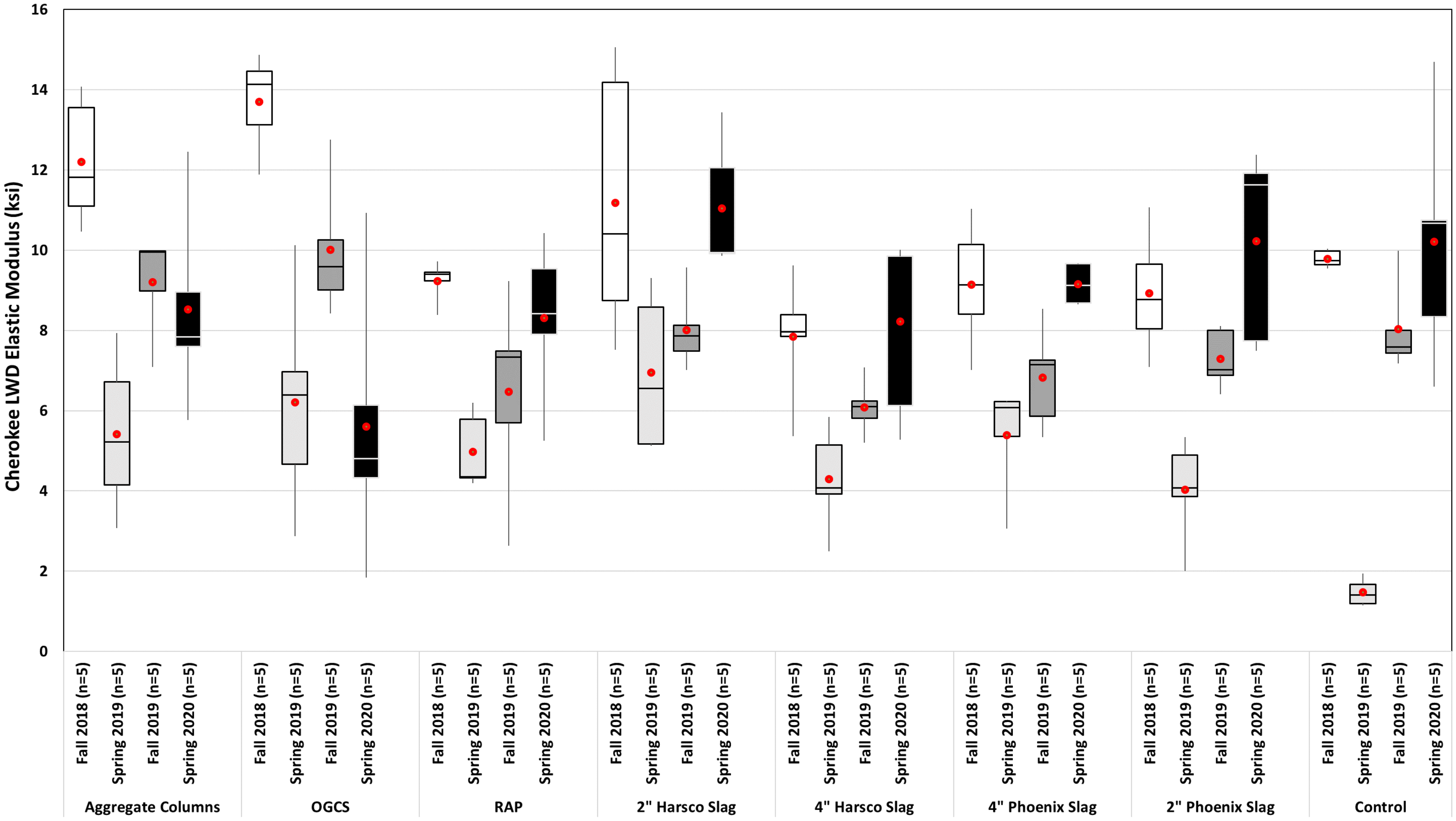


Figure 73. LWD test results over time for Cherokee County test sections

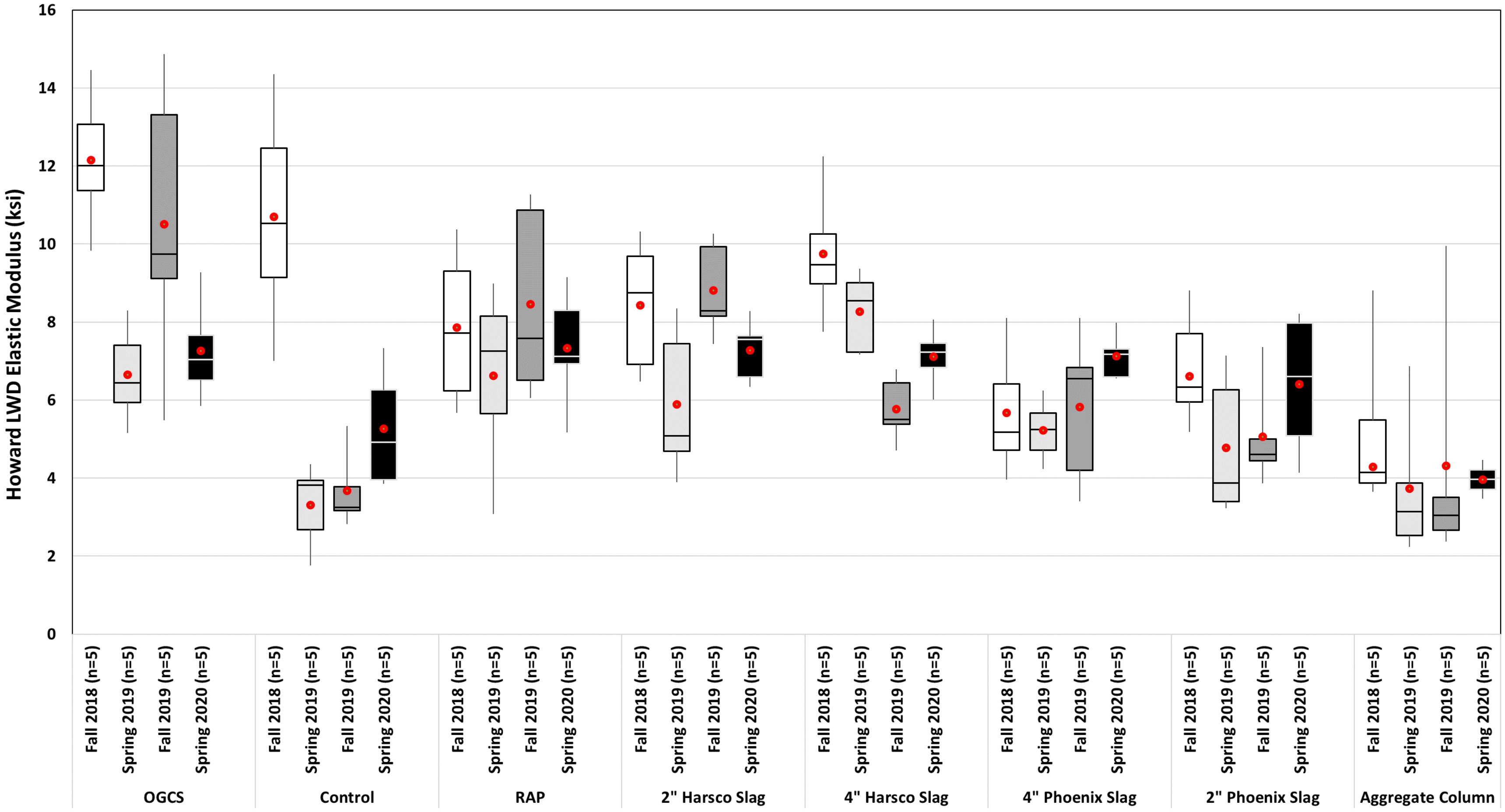


Figure 74. LWD test results over time for Howard County test sections

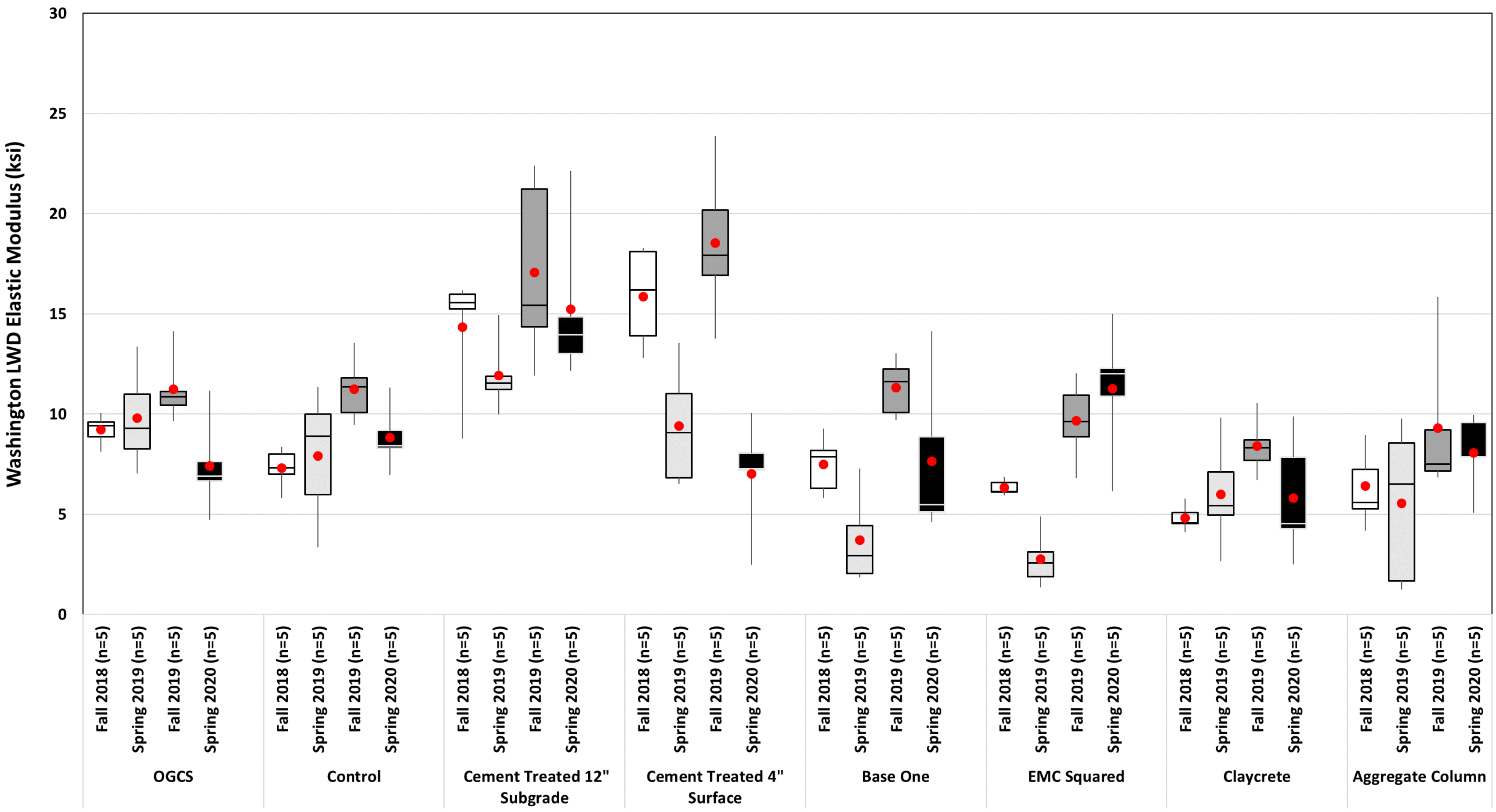


Figure 75. LWD test results over time for Washington County test sections

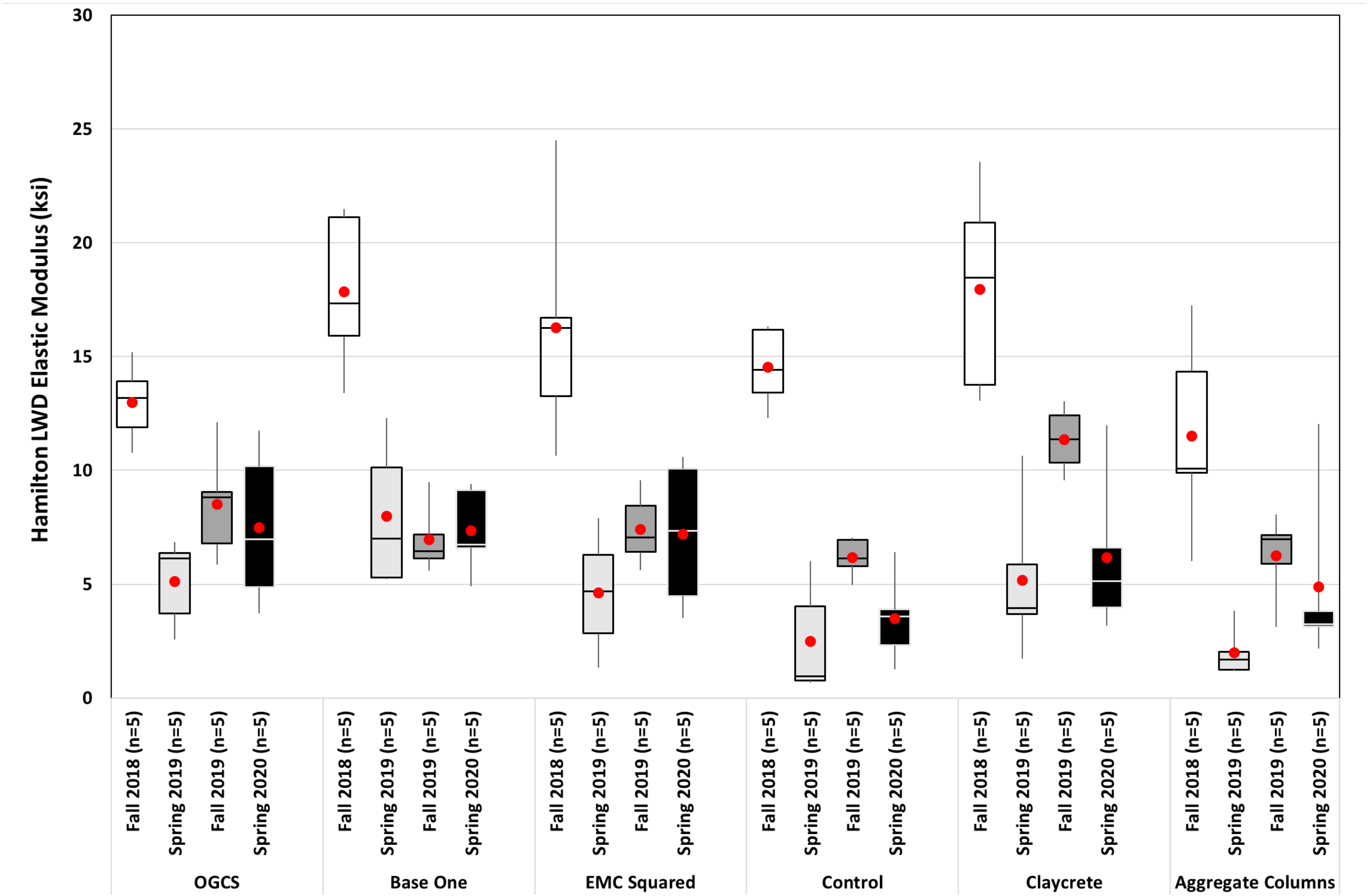


Figure 76. LWD test results over time for Hamilton County test sections

6.2.2.1 Cherokee County LWD Test Results

In Cherokee County, the composite elastic modulus values measured in the aggregate columns, OGCS, and 2 in. Harsco slag sections were higher than all other sections in fall 2018 (Figure 73). At that time, the average composite elastic modulus was 13.7 ksi for the OGCS section, 12.2 ksi for the aggregate columns section, and 11.2 ksi for the 2 in. Harsco slag section, compared to 9.8 ksi for the control section. At the same time, the RAP, 4 in. Harsco slag, and both Phoenix slag sections had average modulus values slightly below that of the control section.

The 2018–2019 winter freeze-thaw cycles caused severe reductions in elastic modulus for all sections, with the control section possessing the lowest modulus of all at 1.5 ksi in spring 2019. In contrast, all the stabilized sections maintained much higher modulus values between 4 and 7 ksi and therefore successfully improved stiffness during the spring thaw period of 2019.

From spring to fall of 2019, all sections exhibited an increase in modulus as expected.

For the final series of tests in spring 2020, the average composite elastic modulus was 8.5 ksi for the aggregate columns section and 5.6 ksi for the OGCS section, both of which represented decreases from their fall 2019 values. In contrast, the average modulus for the RAP section increased from 6.5 ksi to 8.3 ksi between fall 2019 and spring 2020. The composite elastic modulus values in spring 2020 for the control section and the four slag sections were artificially high due to unexpected maintenance operations as previously mentioned and are therefore not considered valid for evaluation of these sections.

6.2.2.2 Howard County LWD Test Results

In Howard County, the OGCS section exhibited the highest average modulus of 12.1 ksi compared to the other sections in fall 2018, at which time it was the only section stiffer than the control section (Figure 74). While the average modulus of all sections decreased through the first winter, the control section ended up with the lowest modulus in spring 2019, indicating that the stabilization methods were effective at increasing stiffness, although the aggregate columns section was only slightly stiffer than the control section. Specifically, the control section had an average modulus of 3.3 ksi in spring 2019, while all sections other than the aggregate columns section had values between 4.8 and 8.3 ksi with the highest value belonging to the 4 in. Harsco slag section.

Between spring and fall 2019, all sections exhibited slight to moderate increases in modulus, except for the 4 in. Harsco slag section, which showed a decrease of 30%. During the 2019–2020 winter-spring cycle, the average modulus values decreased for the OGCS, RAP, 2 in. Harsco slag, and aggregate columns sections but increased for the control and other three slag sections.

For the final tests in spring 2020, the average modulus for the control section was 5.3 ksi, while only that of the aggregate columns section was lower at 4.3 ksi. All other sections had average modulus values within a relatively narrow range of 6.4 to 7.3 ksi, which corresponds to modulus increases of 21% to 38% relative to the control section. Based on these results, the OGCS, RAP, both Harsco slag, and both Phoenix slag sections in Howard County exhibited higher composite elastic modulus values than the control section, exhibiting excellent resistance through both winter-spring freeze-thaw periods.

6.2.2.3 Washington County LWD Test Results

For the fall 2018 tests in Washington County, the two cement-treated sections had higher average composite elastic modulus values than those of all other test sections (Figure 75). The 12 in. cement-treated subgrade section had an average modulus of 14.3 ksi, while the 4 in. cement-treated surface section had an average value of 15.9 ksi, both of which were approximately twice the control section's modulus of 7.3 ksi. The average modulus of the OGCS section (9.2 ksi) and BASE ONE section (7.5 ksi) were also greater than that of the control section; whereas, the EMC SQUARED, Claycrete, and aggregate columns sections all had modulus values below that of the control section.

By the first spring thaw of 2019, the average modulus had increased slightly for the OGCS, control, and Claycrete sections; whereas, it decreased slightly for the aggregate columns section and decreased significantly for the other four sections. The significant modulus reductions for the cement-treated, BASE ONE, and EMC SQUARED sections in spring 2019 may be related to their low subgrade strengths discussed previously, although the Claycrete section exhibited a slight increase in modulus despite the weaker subgrade.

Between spring and fall 2019, the average modulus increased for all sections as expected. For the final round of tests in spring 2020, the average modulus of all sections exhibited decreases from their previous fall 2019 values, except for the EMC SQUARED section, which increased by 17%. Only the 12 in. cement-treated subgrade and EMC SQUARED sections had higher modulus values than the control section in spring 2020; whereas, the ratios of average modulus to that of the control section were 84% for the OGCS section, 78% for the 4 in. cement-treated surface, 85% for BASE ONE, 65% for Claycrete, and 92% for the aggregate columns section. Overall, the 12 in. cement-treated subgrade section exhibited the best elastic modulus resilience through both winter-spring freeze-thaw periods, while the modulus for the 4 in. cement-treated surface section decreased significantly after two years.

6.2.2.3 Hamilton County LWD Test Results

In Hamilton County, the surface layer was frozen during testing in fall 2018, resulting in much higher composite elastic modulus than would be measured under unfrozen conditions (Figure 76). Despite the frozen conditions, the three liquid chemical stabilizer sections exhibited modulus values above that of the control section, while the OGCS and aggregate columns sections were lower than the control section.

In spring 2019, all stabilized sections except for the aggregate columns section had higher modulus values than the control section. By the last round of tests in spring 2020, the average modulus values of all stabilized sections were greater than that of the control section. For the aggregate columns section, this was because of a few stiff test points, and the extents of the boxplot (i.e., the first and third quartiles) fall within the corresponding range of the control section's data. However, it should again be noted that the aggregate columns stabilization method focuses on improving the subgrade moisture transport rather than stiffening the surface course.

In spring 2020, the average elastic modulus was 7.4 ksi for the OGCS section, 7.3 ksi for the BASE ONE section, 7.2 ksi for the EMC SQUARED section, 6.2 ksi for the Claycrete section, and 4.9 ksi for the aggregate columns section, compared to only 3.5 ksi for the control section. All of the stabilization methods therefore exhibited improvements in the stiffness of the roadway.

6.2.3 FWD Test Results

FWD tests were performed at five equally distributed points in each test section by the Special Investigations section of the Iowa DOT Construction and Materials Bureau. The FWD test dates did not coincide with those of DCP or LWD tests because of scheduling logistics for the FWD equipment, as well as road firmness requirements for the FWD device not being met during spring thaws. All FWD test results for both the surface courses and subgrade layers are provided in Figure 77 through Figure 84.

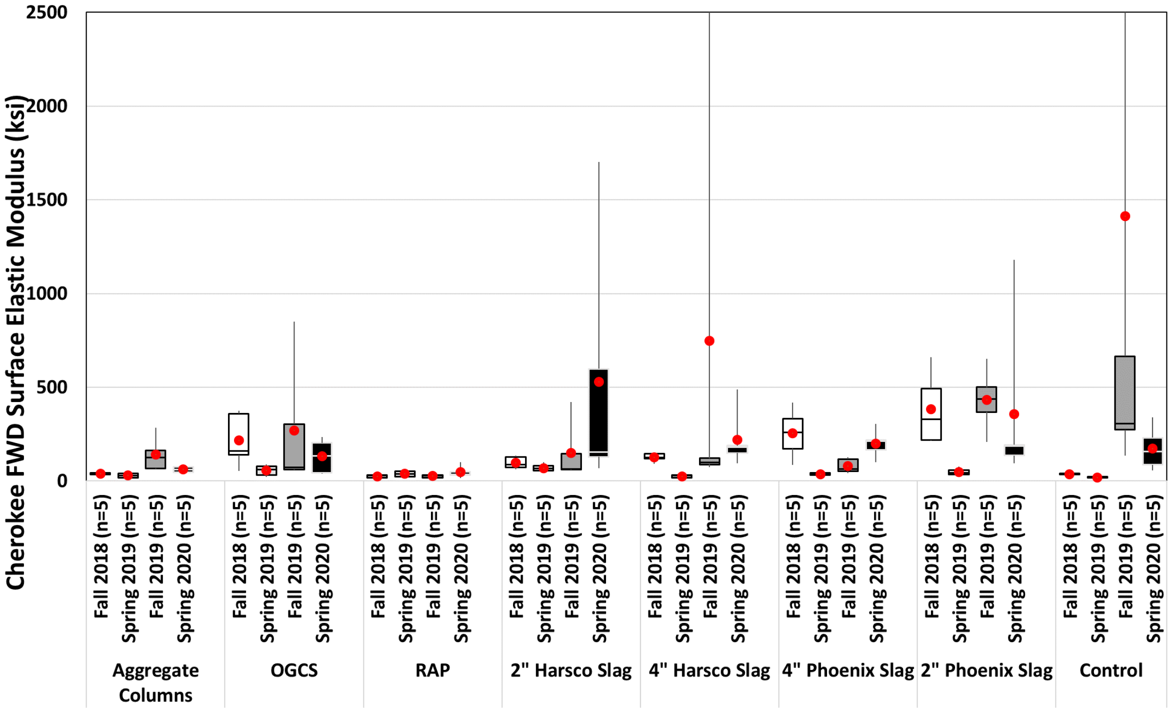


Figure 77. FWD test results over time for surface course of Cherokee County test sections

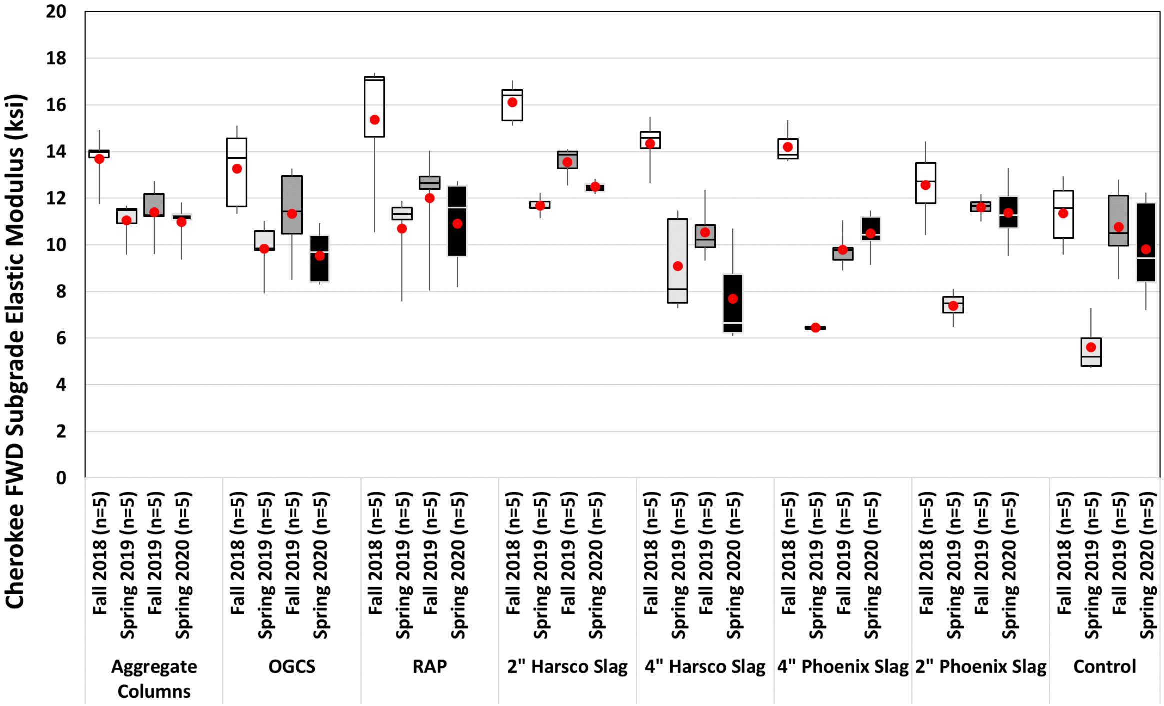


Figure 78. FWD test results over time for subgrade layer of Cherokee County test sections

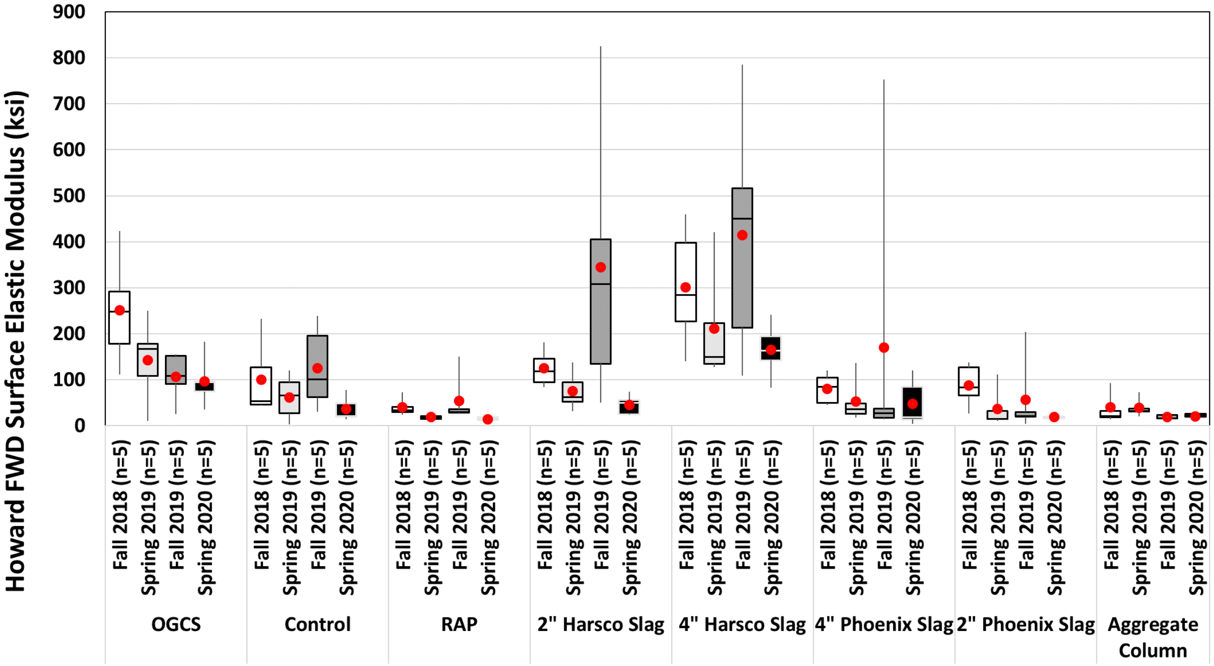


Figure 79. FWD test results over time for surface course of Howard County test sections

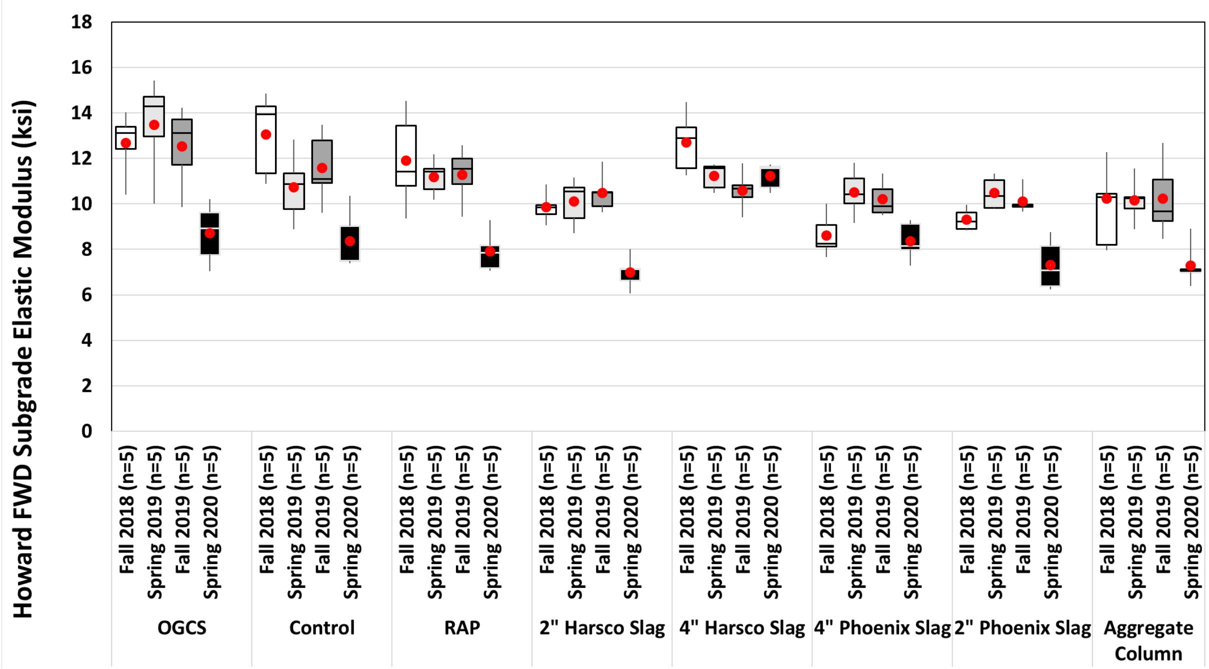


Figure 80. FWD test results over time for subgrade layer of Howard County test sections

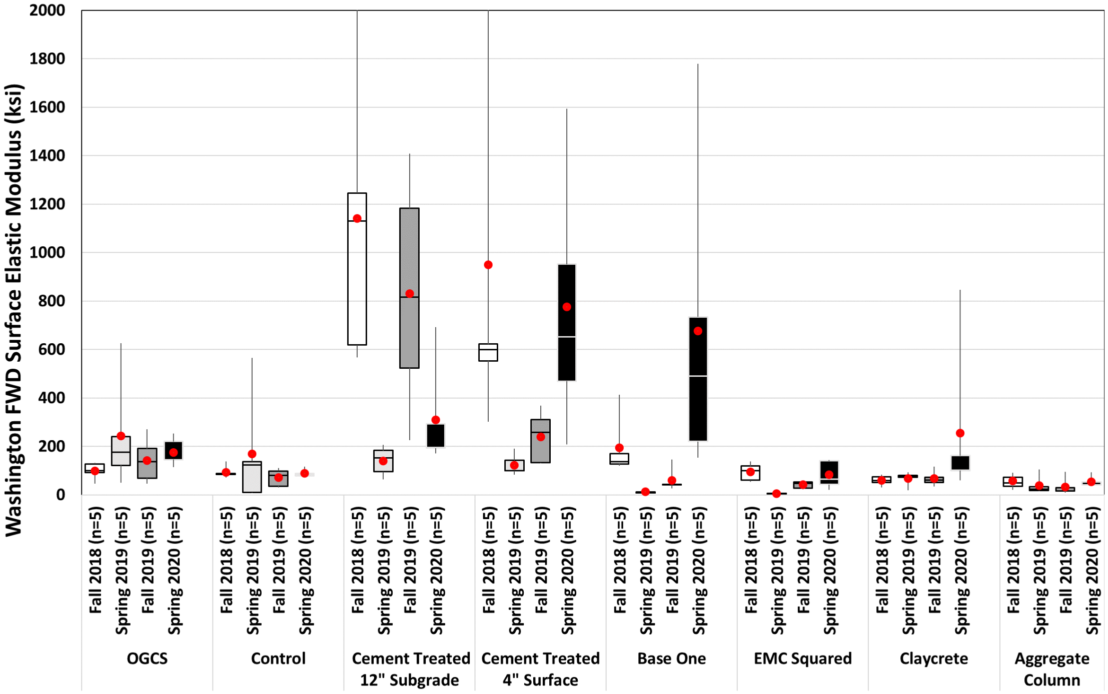


Figure 81. FWD test results over time for surface course of Washington County test sections

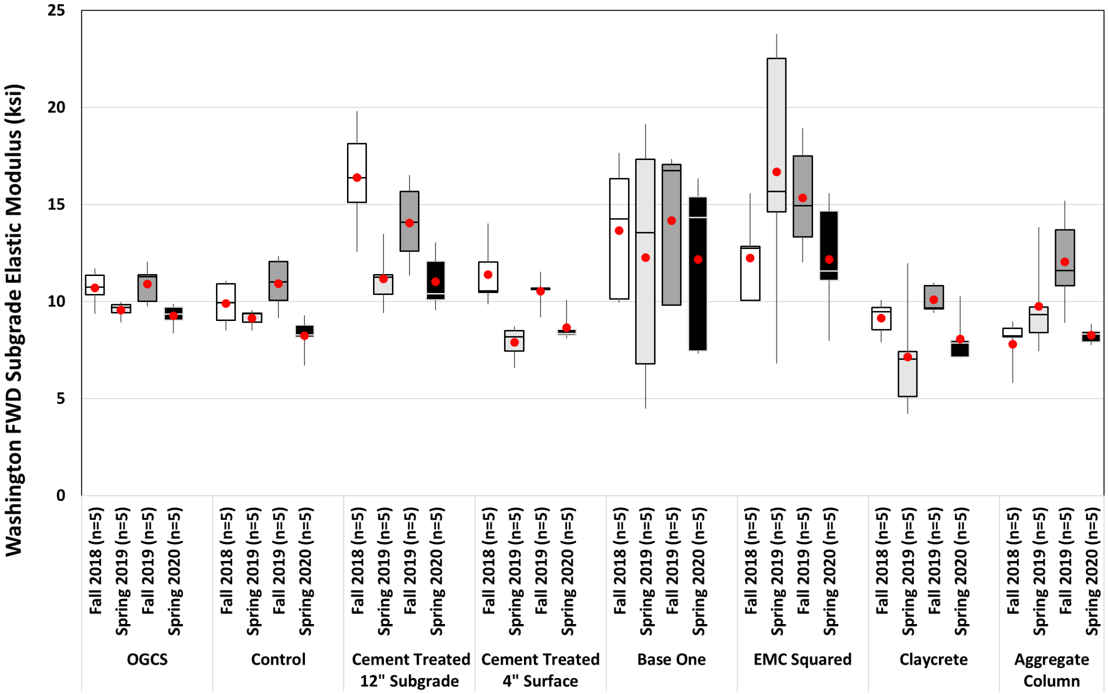


Figure 82. FWD test results over time for subgrade layer of Washington County test sections

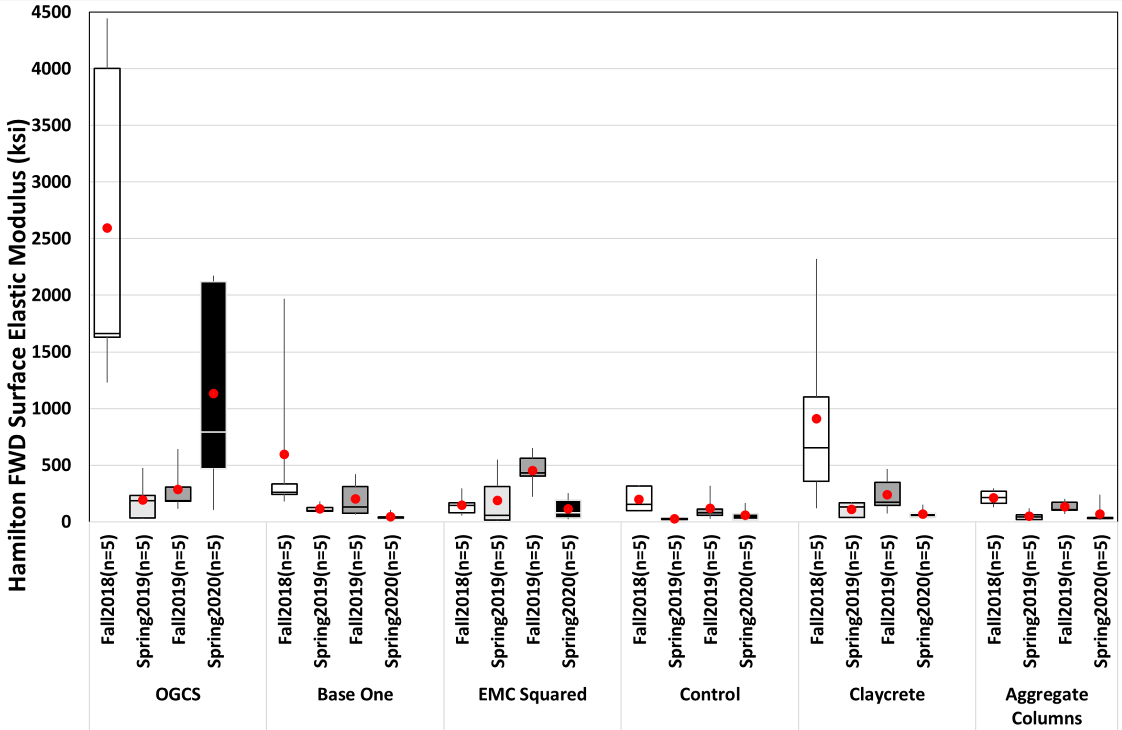


Figure 83. FWD test results over time for surface course of Hamilton County test sections

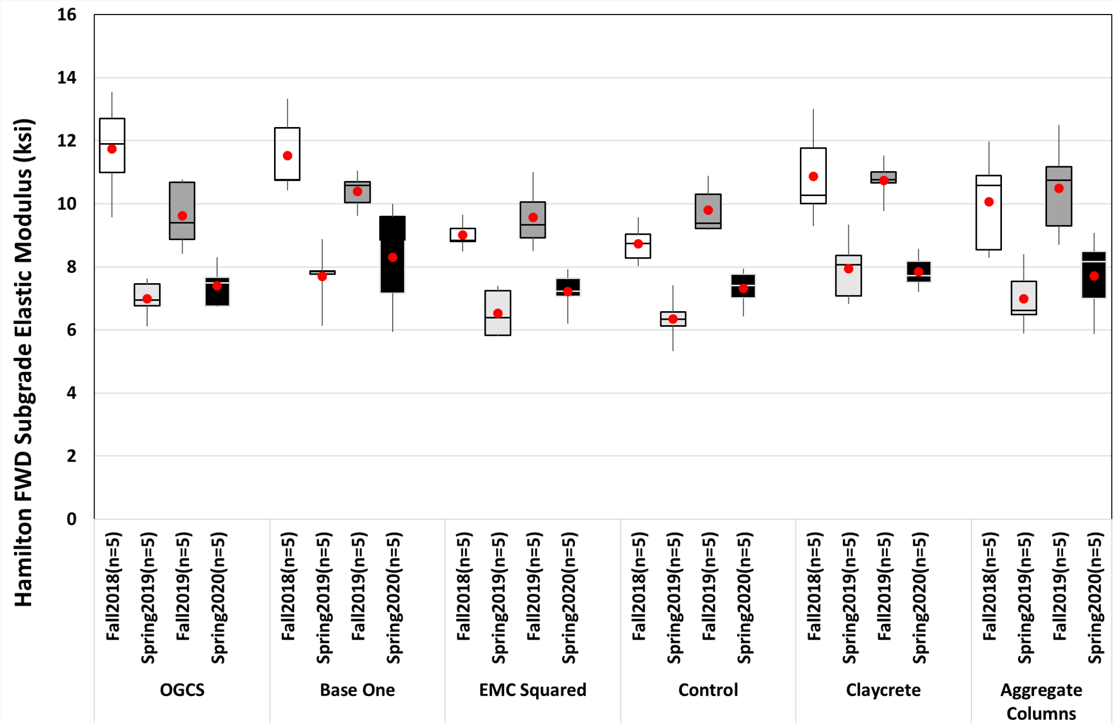


Figure 84. FWD test results over time for subgrade layer of Hamilton County test sections

The FWD elastic modulus values for each test point were calculated as the averages from three applied dynamic loads having target values of 4,000, 5,000 and 6,000 lb. This range was selected because 4,000 lb is the minimum load the equipment can apply, and 6,000 lb was typically the maximum load that could be applied on granular roads without over-ranging the velocity sensors used to determine the surface deflections.

6.2.3.1 Cherokee County FWD Test Results

The FWD tests in Cherokee County were conducted on October 31, 2018; April 16, 2019; September 17, 2019; and June 2, 2020. After construction in fall 2018, the average FWD surface course modulus of the OGCS section and all four slag sections were significantly improved relative to the control section (Figure 77). In contrast, the surface modulus of the aggregate columns section was approximately the same as that of the control section, while that of the RAP section was slightly lower.

For the subgrade layer, the fall 2018 average modulus values for all stabilized sections were greater than that of the control section (Figure 78).

Consistent with the DCP and LWD results, the FWD surface and subgrade modulus values exhibited noticeable decreases between fall 2018 and spring 2019 for nearly all test sections. The only exception was the RAP surface course, which experienced a slight increase in modulus for spring 2019. Despite the noticeable modulus decreases, the surface courses of all stabilized sections in spring 2019 retained slightly higher values than the control section, while those of the subgrade layer for all test sections were significantly higher than the control section.

Also consistent with the DCP and LWD results, the modulus values from spring to fall 2019 exhibited increases for both surface and subgrade layers of all sections, except for the surface of the RAP section. The most significant percentage increases in this timeframe occurred for the OGCS, 4 in. Harsco slag, 2 in. Phoenix slag, and control sections.

In spring 2020, the average surface course modulus for the aggregate columns, OGCS, and RAP sections were all higher than their values in the previous spring of 2019. Unfortunately, the spring 2020 results for the slag and control sections were not valid due to unplanned additional maintenance performed in those sections, as described previously.

6.2.3.2 Howard County FWD Test Results

The FWD tests in Howard County were conducted on October 30, 2018; August 19, 2019; October 8, 2019; and June 16, 2020. In Howard County, the 4 in. Harsco slag surface layer had significantly higher average modulus values than all other sections within each testing period, although the 2 in. Harsco slag section also had a very high modulus in fall 2019 (Figure 79).

After construction in fall 2018, the OGCS and 4 in. Harsco slag sections had average modulus values that were two and three times that of the control section, respectively, while that of the 2 in. Harsco slag section was slightly higher than the control section. The average modulus values for the Phoenix slag surfaces were slightly lower than the control section in fall 2018, while the RAP and aggregate columns sections were much lower.

As expected, all surface layers experienced a decrease in average modulus from fall 2018 to spring 2019, but the OGCS and both Harsco slag sections remained stiffer than the control section, while the RAP and 4 in. Phoenix slag sections were slightly softer than the control section (Figure 79).

From spring to fall 2019, the average surface modulus increased for all sections except for the OGCS and aggregate columns sections. The increase for the 4 in. Phoenix slag section in fall 2019 was due to only one or two stiff points, as the central box containing the 25th to 75th percentiles is below that of the control section for the same testing period.

From fall 2019 to spring 2020, all sections experienced significant decreases in average surface modulus, with those of the 4 in. Harsco slag and OGCS sections greatly exceeding that of the control section and those of the 4 in. Phoenix and 2 in. Harsco slag sections slightly exceeding that of the control section.

For the subgrade layer, the control section started out with the highest modulus of all sections in fall 2018, but it was surpassed in spring 2019 by the subgrade modulus of the OGCS, RAP, and 4 in. Harsco slag sections; whereas, the remaining sections were only slightly lower (Figure 80).

By fall 2019, the subgrade modulus of the control section increased beyond those of all but the OGCS section, with the RAP section only slightly lower.

By spring 2020, all sections experienced significant drops in subgrade modulus with only the 4 in. Harsco section having a modulus greatly exceeding that of the control section, while the OGCS section was marginally higher, the 4 in. Phoenix slag section was approximately the same, and the RAP section was slightly lower than the control section. The aggregate columns and 2 in. Harsco slag sections had the lowest subgrade modulus values in spring 2020.

6.2.3.3 Washington County FWD Test Results

The FWD tests in Washington County were conducted on October 31, 2018; April 9, 2019; October 2, 2019; and June 8, 2020. In fall 2018, the average surface modulus of the 12 in. cement-treated subgrade section was 12.2 times that of the control section, while the 4 in. cement-treated surface section had a similar ratio of 10.1 to 1 (Figure 81). The BASE ONE and OGCS sections also exceeded the control section's average surface modulus by factors of 2.1 and 1.1, respectively, while the EMC SQUARED, Claycrete, and aggregate columns sections had respective ratios of 1.0, 0.64, and 0.63.

Despite their initially high values, by spring 2019, the average surface modulus of both cement-treated sections decreased significantly to values close to that of the control section. At the same time, the OCGS section was the only one to have a greater average surface modulus than the control section. The spring 2019 surface modulus values of the Claycrete, aggregate columns, BASE ONE, and EMC SQUARED sections were all significantly lower than the control section despite the latter two sections having higher subgrade modulus values than the control section.

From spring to fall 2019, the average surface modulus increased appreciably in the BASE ONE, EMC SQUARED, and both cement-treated sections, while it decreased appreciably in the OGCS and control sections and decreased only slightly in the Claycrete and aggregate columns sections.

From fall 2019 to spring 2020, the average surface modulus increased in all sections except for the 12 in. cement-treated subgrade section, in which the modulus decreased by 63% yet remained greater than the control section. Over the same 2019–2020 winter-spring timeframe, the average surface modulus increased several fold in the 4 in. cement-treated surface, BASE ONE, and Claycrete sections, while it more than doubled in the EMC SQUARED section and increased by 24% in the OGCS section. The only section with an appreciably lower average modulus than the control section in spring 2020 was the aggregate columns section; whereas, that of the EMC SQUARED section was approximately the same and that of all other sections was greater.

For the subgrade layers (Figure 82), the average modulus of the 12 in. cement-treated subgrade, BASE ONE, and EMC SQUARED sections was consistently greater than the control section; whereas, the modulus of the Claycrete section was consistently less than the control section for all testing periods.

6.2.3.4 Hamilton County FWD Test Results

The FWD tests in Hamilton County were conducted on November 15, 2018; June 10, 2019; November 5, 2019; and June 10, 2020. After construction in fall 2018, the ratio of the average surface modulus of the OGCS section to that of the control section was the highest at 12.7, while the ratios for the other sections were 4.6 for Claycrete, 3.0 for BASE ONE, 1.09 for aggregate columns, and 0.75 for EMC SQUARED (Figure 83).

In spring 2019, the average surface modulus of the control section decreased to 17% of its fall 2018 value, yet the values for all other sections except for the aggregate columns section remained several times larger than the control section.

From spring 2019 to fall 2019, all sections exhibited an increase in average surface modulus as expected.

From fall 2019 to spring 2020, the average surface modulus of the OGCS section increased by a factor of 3.9, while the values for all other sections decreased. The resulting average modulus for the EMC SQUARED section was more than twice that of the control section; whereas, the values for the other three stabilized sections were not significantly different from the control section.

For the subgrade layer, all sections started out in fall 2018 with average subgrade modulus values higher than the control section, although that of the EMC SQUARED section was only slightly higher (Figure 84). All subgrade layers experienced significant modulus reductions in spring 2019 followed by significant gains in fall 2019, then significant reductions again in spring 2020.

By spring 2020, the average subgrade modulus of the OGCS and EMC SQUARED sections were approximately the same as the control section, while the modulus values of the other sections were slightly higher, with the highest modulus occurring under the BASE ONE section.

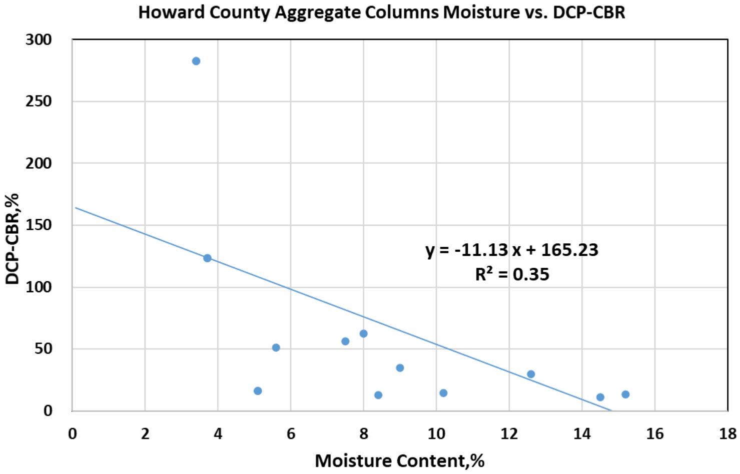
Overall, the FWD test results show that the OGCS, steel slag, and three liquid chemical stabilization methods examined have the potential to improve surface modulus during spring thaws compared to the control sections. The aggregate columns sections were not effective at increasing surface or subgrade modulus values due to the high moisture content.

It should be noted that increased modulus is not the only important measure of improvement, as some stabilization methods that reduce material loss by increasing binding properties can result in a trade-off of reduced stiffness. The performance of the different test sections toward reducing the effects of freeze-thaw and moisture-related damage should also be judged by visual surveys and the potential to reduce effects such as rutting, potholes, material loss, and associated maintenance costs. Those subjects are presented in the remaining sections of this chapter.

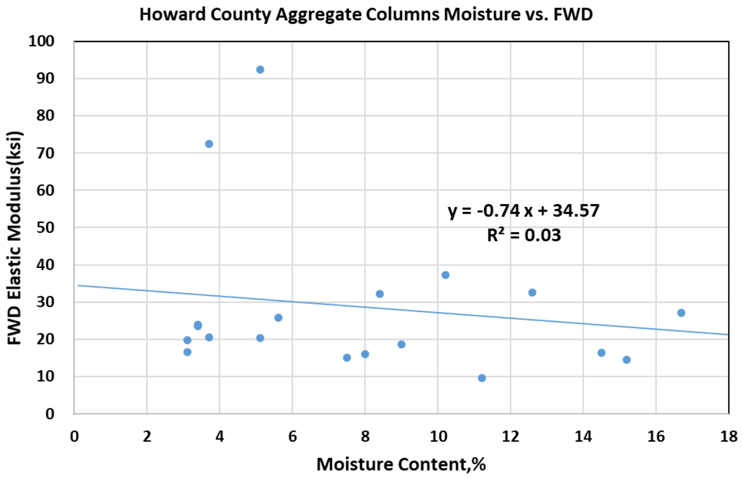
6.2.4 Influence of In Situ Moisture Content on Field Test Results

As previously mentioned, the moisture content of the surface and subgrade materials may influence the results of in situ field tests. The DCP-CBR strength values as well as the elastic modulus values from LWD and FWD tests are expected to decrease with increasing moisture content. This expected trend is evident in some of the previously presented data for the aggregate columns and three liquid stabilizer test sections. In the following, the results of the DCP, LWD, and FWD tests are examined against moisture content measurements from the NDG tests to investigate the sensitivity of the results to moisture content and determine whether any consistent trends can be established.

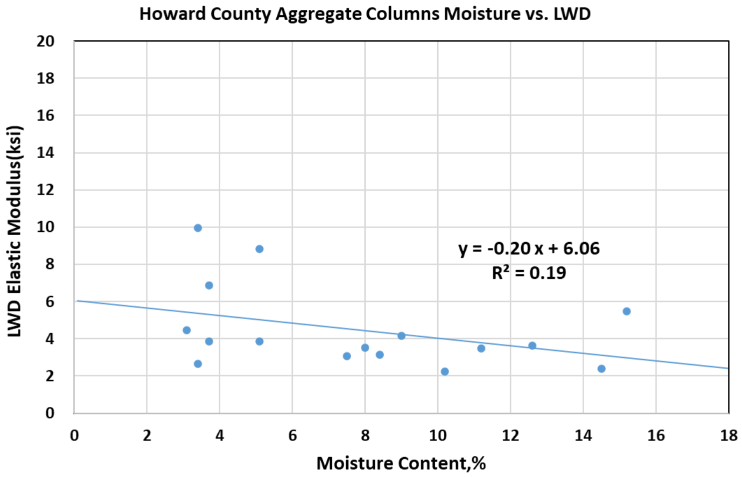
As shown in Section 6.2.1.5, the aggregate columns sections in all four counties consistently had high moisture contents relative to the other sections. To investigate the trends between in situ test results and moisture contents, the data for all DCP, LWD, and FWD tests over the two years of study for the aggregate columns sections were plotted against the moisture contents measured at the same test points. The results are shown in Figure 85 through Figure 88.



(a)

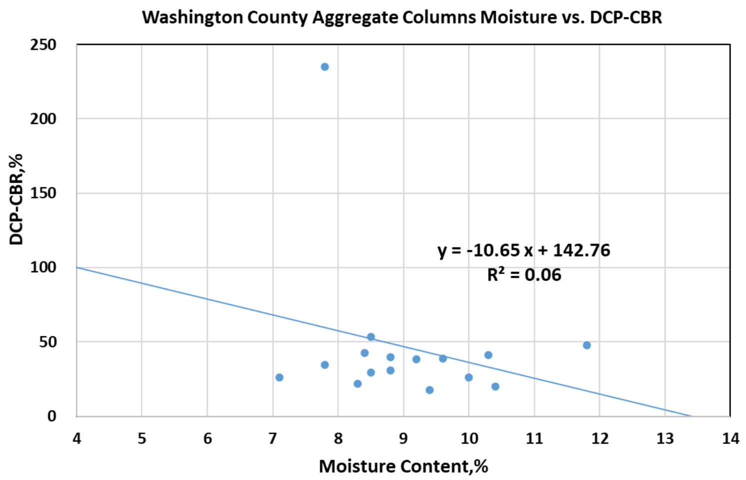


(b)

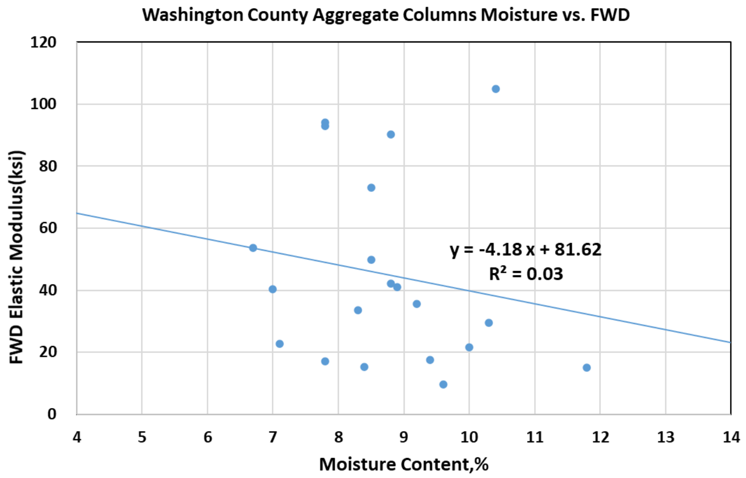


(c)

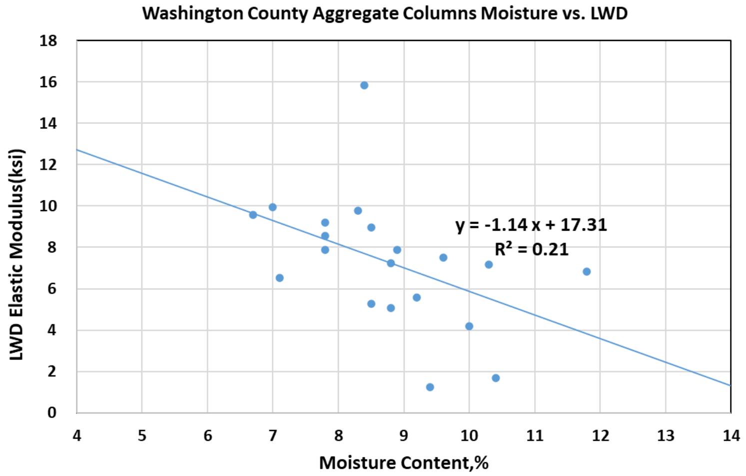
Figure 85. Howard County aggregate columns section moisture contents vs. (a) DCP-CBR, (b) FWD modulus, and (c) LWD modulus



(a)

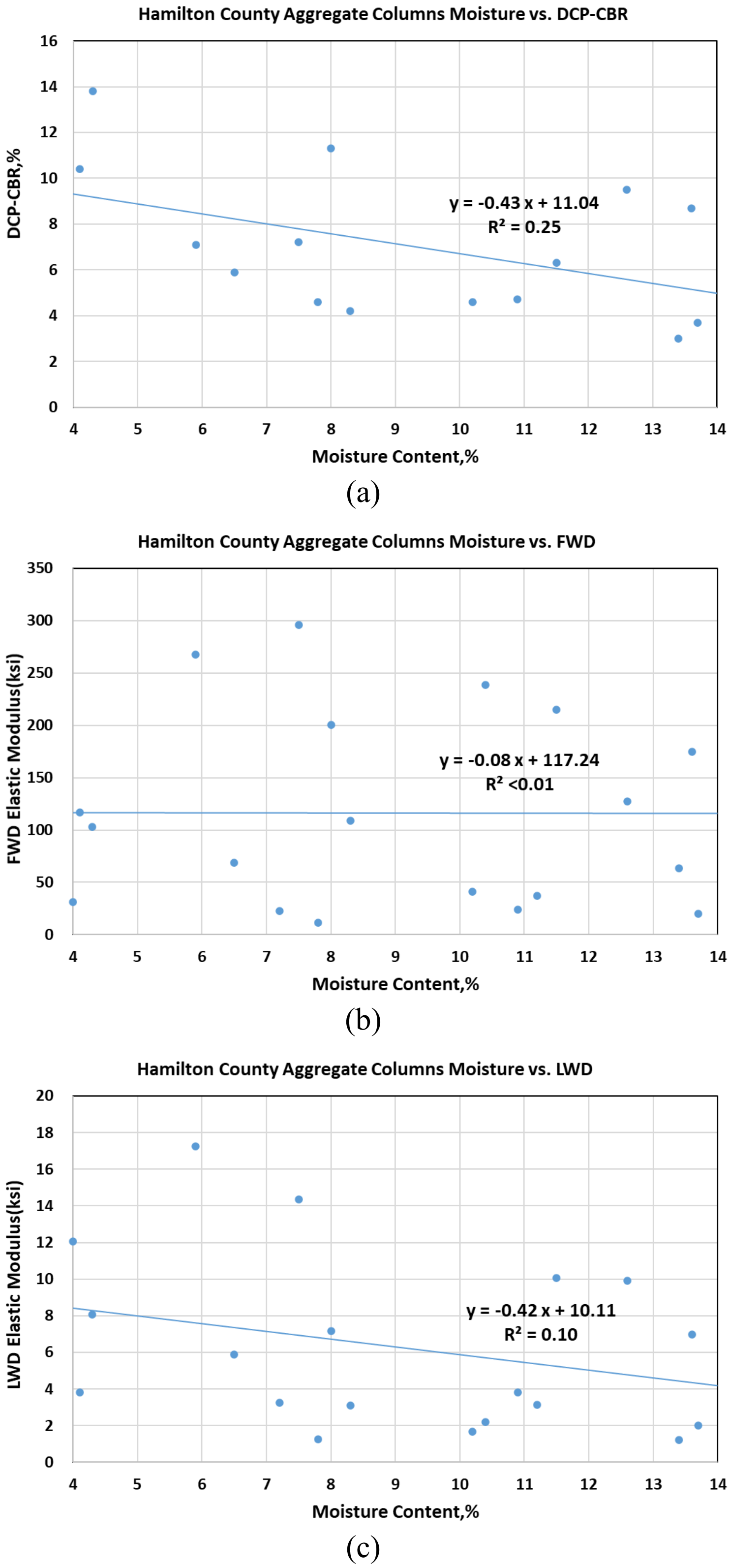


(b)



(c)

Figure 86. Washington County aggregate columns section moisture contents vs. (a) DCP-CBR, (b) FWD modulus, and (c) LWD modulus

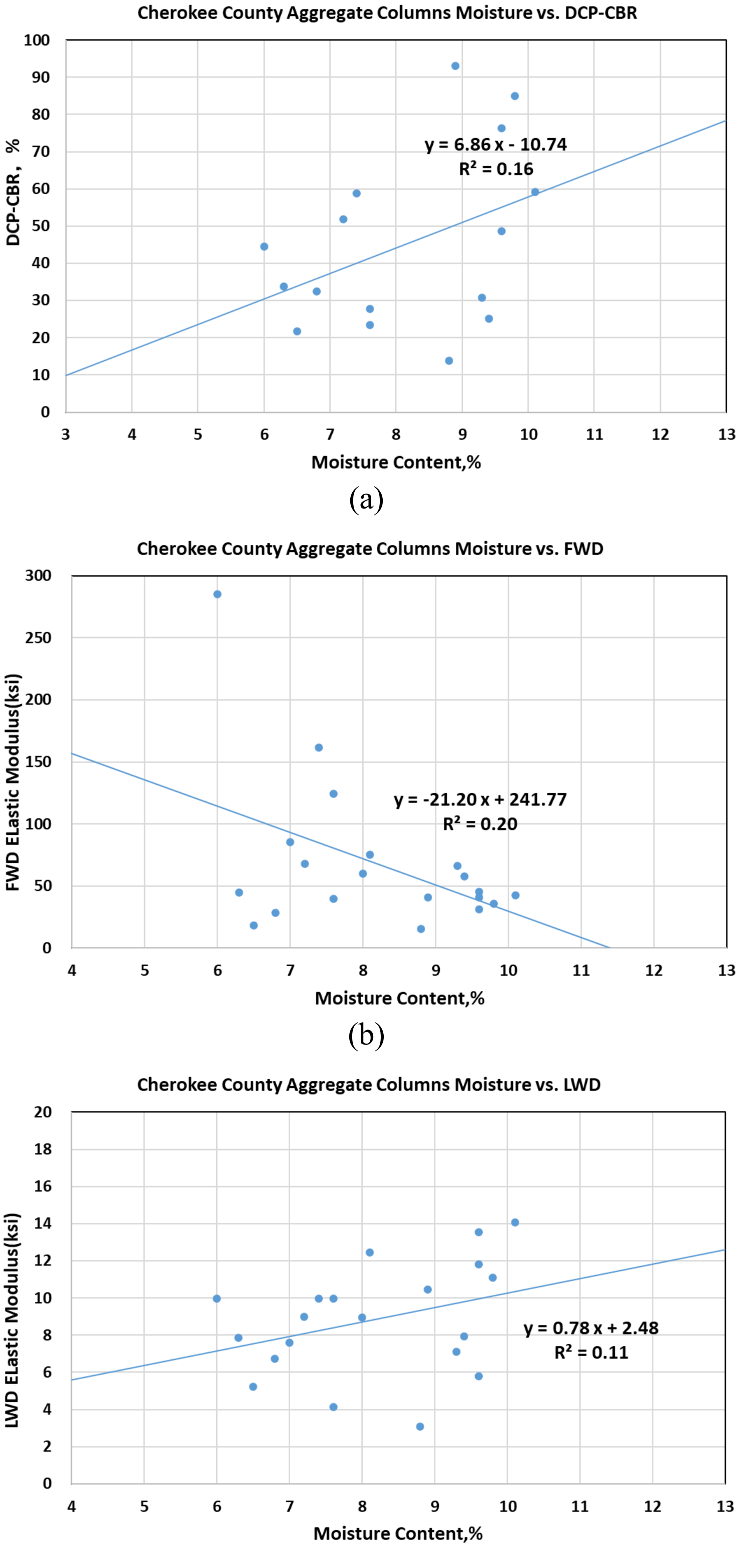


(a)

(b)

(c)

Figure 87. Hamilton County aggregate columns section moisture contents vs. (a) DCP-CBR, (b) FWD modulus, and (c) LWD modulus



(a)

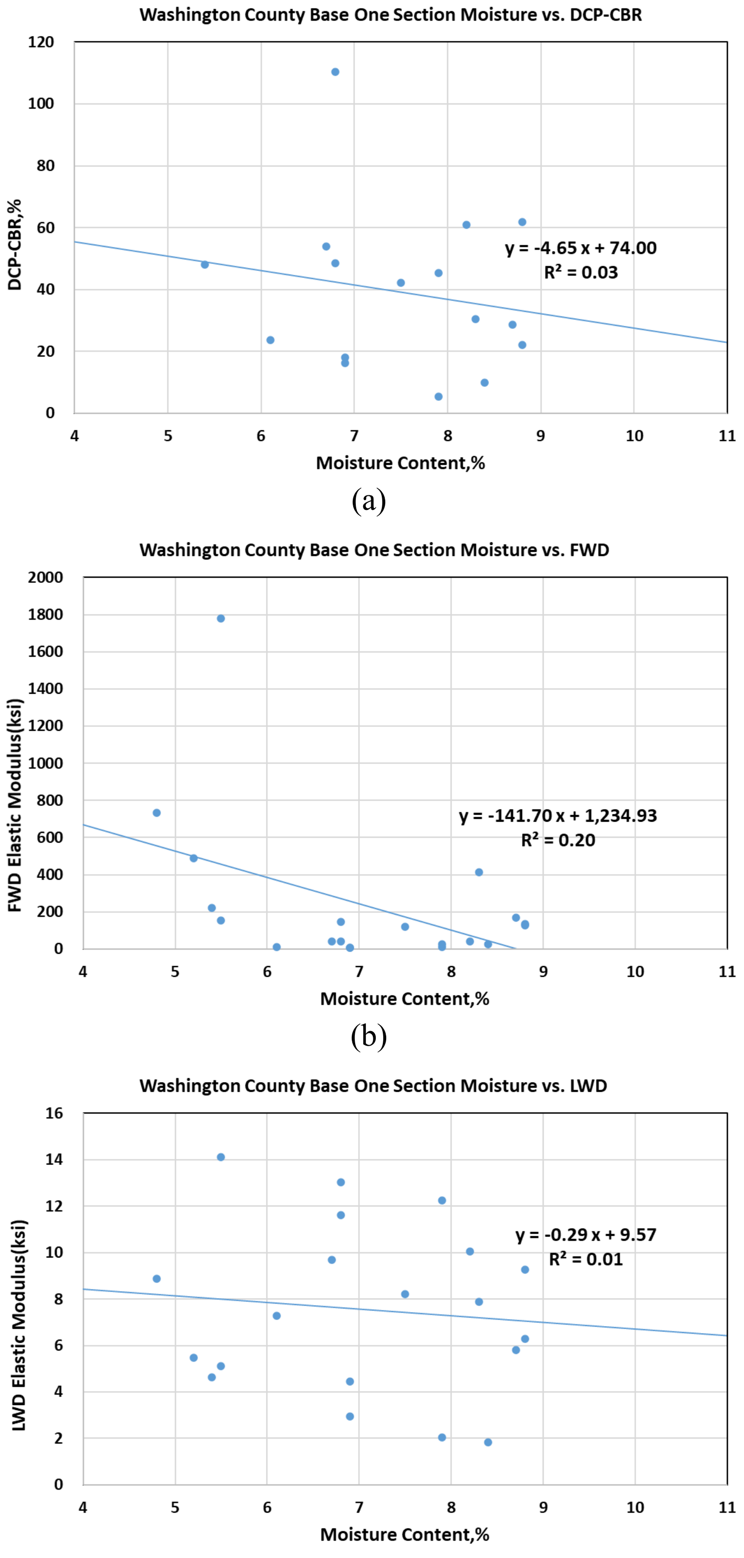
(b)

(c)

Figure 88. Cherokee County aggregate columns section moisture contents vs. (a) DCP-CBR, (b) FWD modulus, and (c) LWD modulus

In Howard County (Figure 85) and Washington County (Figure 86), all six trend lines for DCP-CBR, FWD modulus, and LWD modulus vs. moisture contents have negative slopes, indicating a decrease in strength and stiffness with increasing moisture content, as expected. However, the data also contain a significant amount of scatter and therefore exhibit low coefficients of determination (R^2 values). In Hamilton County (Figure 87), the DCP-CBR and LWD trend lines have negative slopes, while the FWD slope is essentially flat due to the relatively larger scatter. For Cherokee County (Figure 88), the trend lines for both DCP-CBR and LWD modulus show positive slopes against moisture contents, which is unusual. One possible explanation is that the moisture contents in the Cherokee County aggregate columns section varied over a smaller range (from 6% to 10%); whereas, the data from the other three counties had wider ranges of moisture contents (3% to 17% in Howard County, 6.5% to 12% in Washington County, and 4% to 14% in Hamilton County).

The field test data for the chemically stabilized sections (BASE ONE, EMC SQUARED, and Claycrete) in Washington and Hamilton counties are also plotted against moisture contents in Figure 89 through Figure 94.

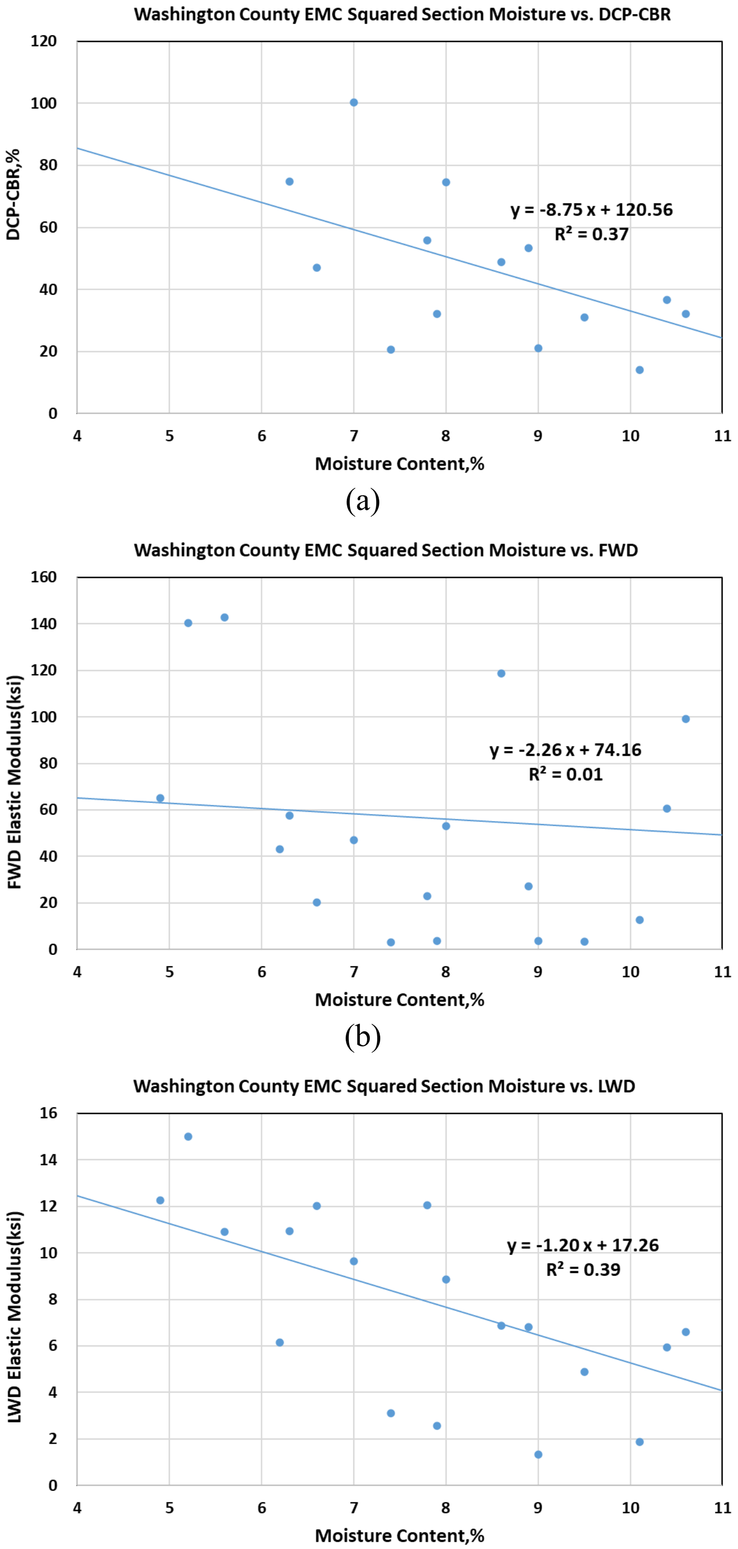


(a)

(b)

(c)

Figure 89. Washington County BASE ONE section moisture contents vs. (a) DCP-CBR, (b) FWD modulus, and (c) LWD modulus



(a)

(b)

(c)

Figure 90. Washington County EMC SQUARED section moisture contents vs. (a) DCP-CBR, (b) FWD modulus, and (c) LWD modulus

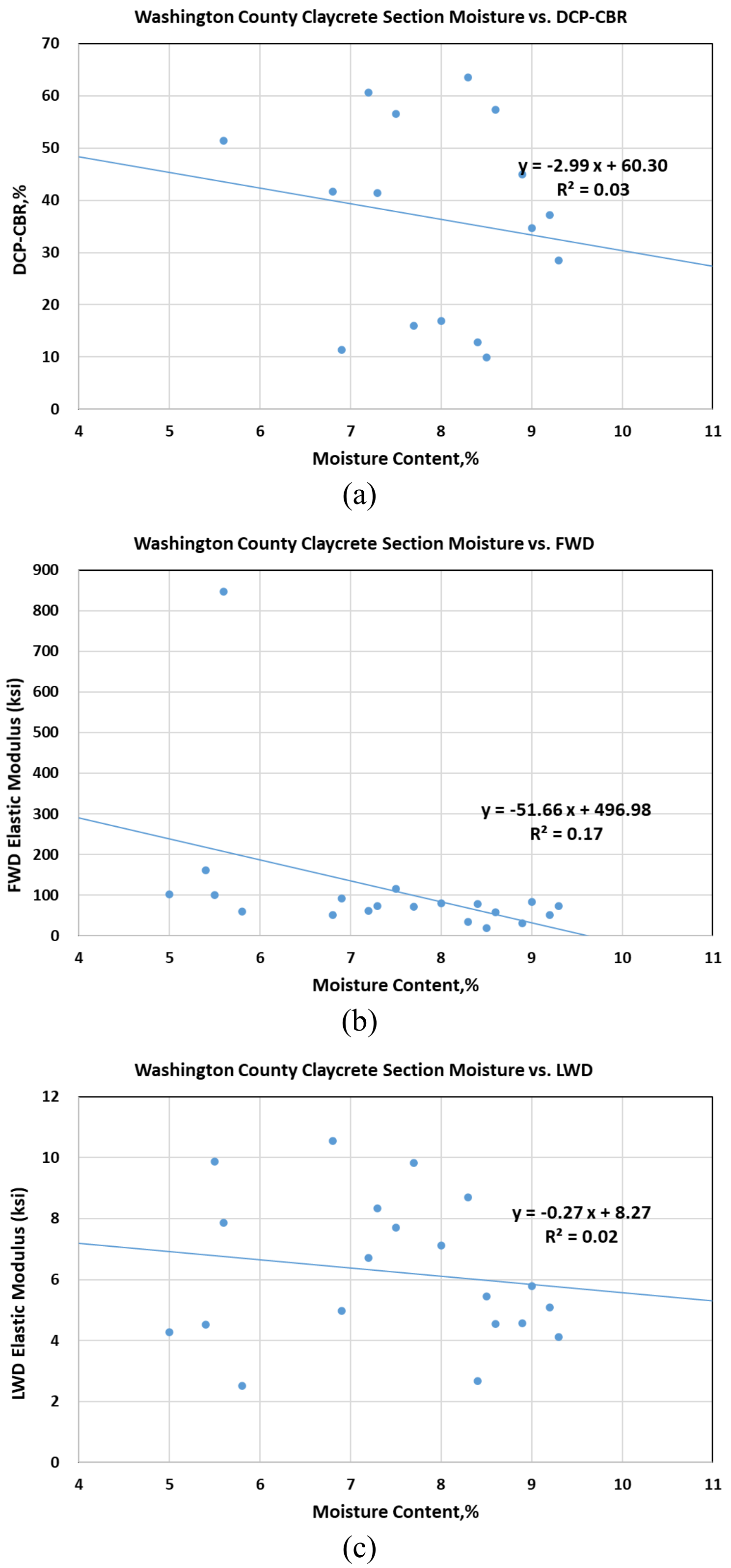
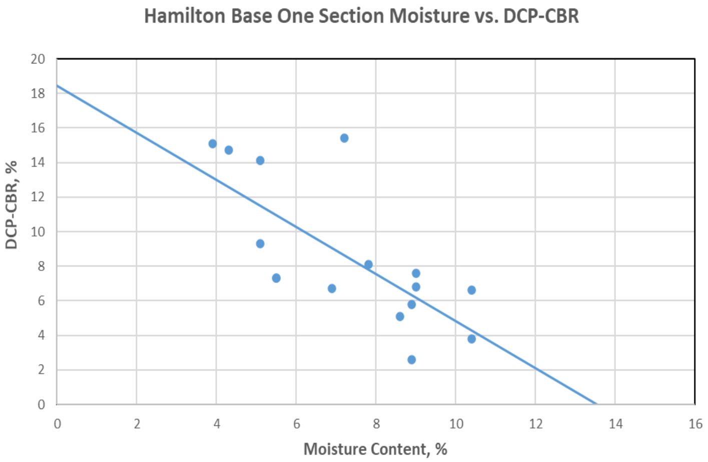
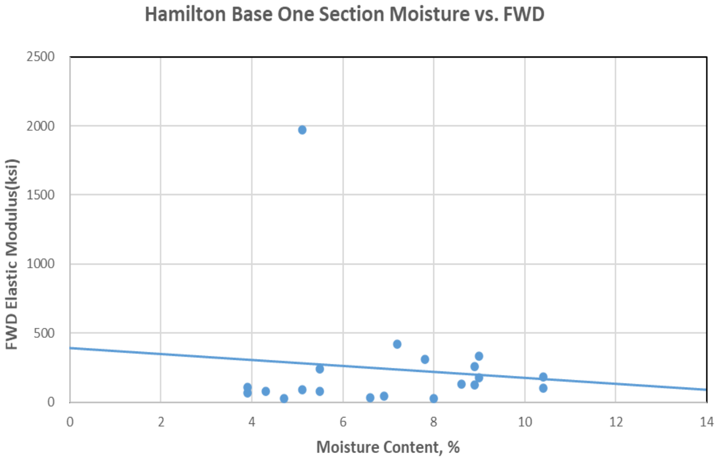


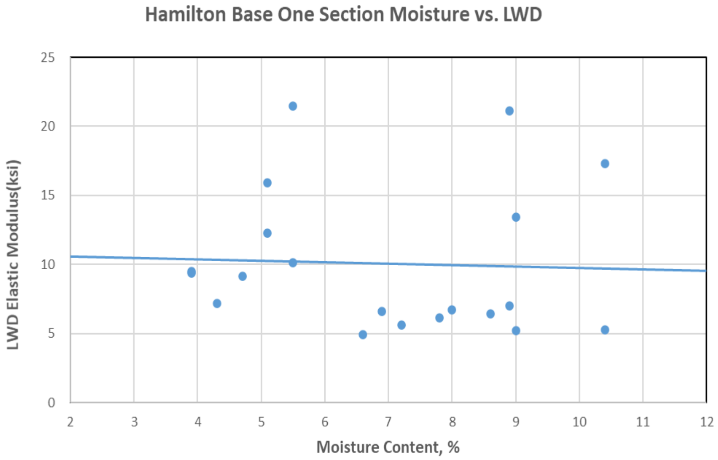
Figure 91. Washington County Claycrete section moisture contents vs. (a) DCP-CBR, (b) FWD modulus, and (c) LWD modulus



(a)

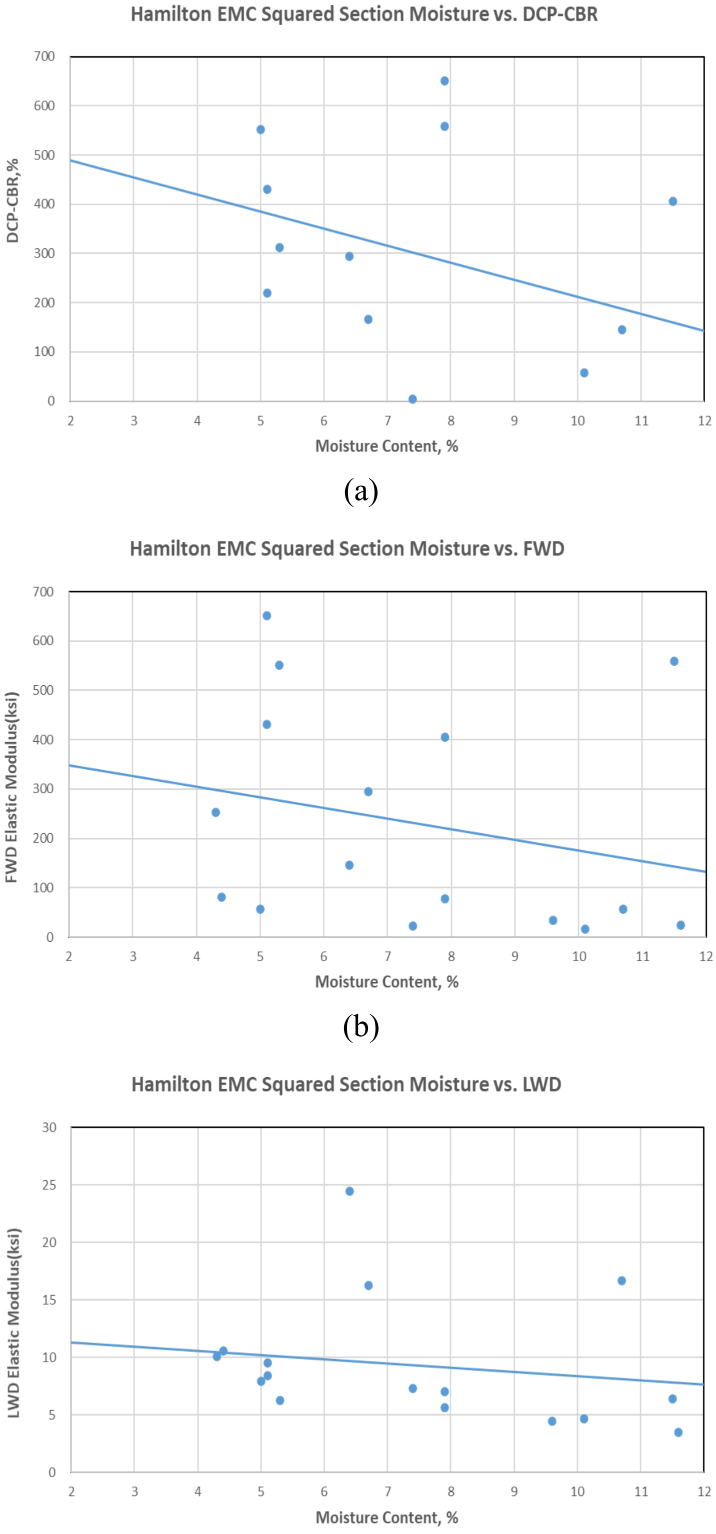


(b)



(c)

Figure 92. Hamilton County BASE ONE section moisture contents vs. (a) DCP-CBR, (b) FWD modulus, and (c) LWD modulus



(a)

(b)

(c)

Figure 93. Hamilton County EMC SQUARED section moisture contents vs. (a) DCP-CBR, (b)FWD modulus, and (c) LWD modulus

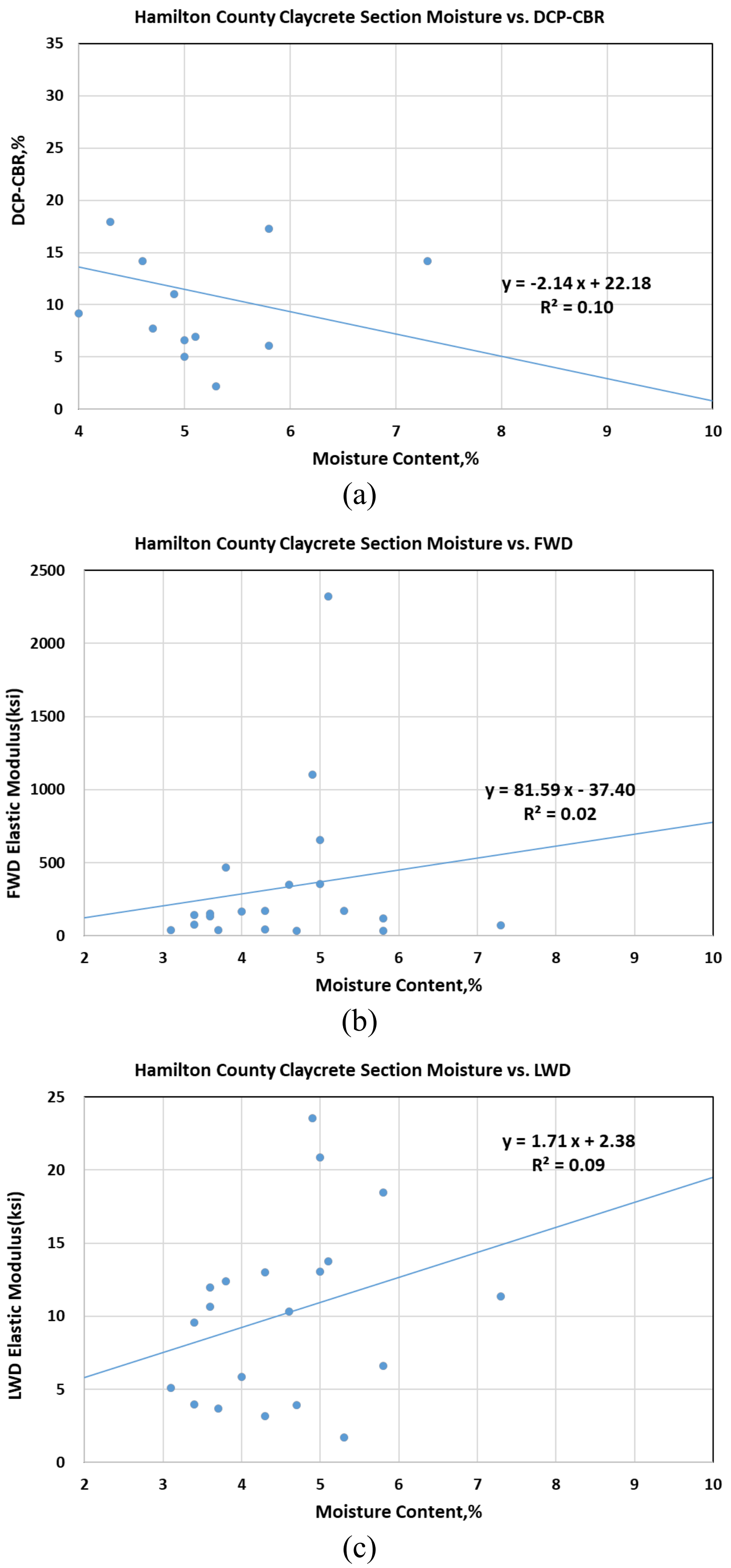


Figure 94. Hamilton County Claycrete section moisture contents vs. (a) DCP-CBR, (b) FWD modulus, and (c) LWD modulus

For Washington County, the trend lines for DCP-CBR, FWD, and LWD all show negative slopes as expected, although the R^2 values are quite low (Figure 89 through Figure 91). For Hamilton County, the BASE ONE and EMC SQUARED sections also show negative slopes for all three test methods (Figure 92 and Figure 93, respectively); whereas, the Claycrete section exhibits a negative slope for DCP-CBR but has positive slopes for both FWD and LWD modulus (Figure 94). The moisture contents values in the Claycrete section vary over a smaller range than the BASE ONE and EMC SQUARED sections, which again may partially explain the positive slopes.

Based on the data presented in this section, it appears that trends are discernable for the dependence of strength and stiffness of surface courses on moisture content. However, additional data covering a wider range of moisture contents are needed to develop reliable correlations that could be used to correct the test data for differences in moisture contents. Additionally, moisture contents is not the only factor that affects strength and stiffness. Other contributing factors should also be taken into consideration, such as traffic loads, subgrade material types and their drainage conditions, and other environmental factors.

6.2.5 Particle Size Distribution Test Results

To understand the relative changes in gradation caused by abrasion and material loss, samples were collected during and after construction, as well as during each round of fall and spring field tests. Sieve analyses were conducted on the samples, and the gradations were examined to assess their changes over time. The index properties of the stabilized surface course materials collected at the end of test section construction in all four counties are summarized in Table 31 through Table 34.

Table 31. Soil index properties of surface materials collected during construction in Cherokee County

Section Name	Aggregate Columns[a]	Optimized Gradation w/ Clay Slurry	RAP	Harsco Slag	Phoenix Slag
Particle Size Distribution Results (ASTM D6913)					
Gravel Content (%)	99.8	54.9	42.1	49.0	52.5
Sand Content (%)	0.2	31.8	53.4	43.1	44.6
Silt Content (%)	0.0	6.3	3.0	6.4	1.7
Clay Content (%)	0.0	7.0	1.5	1.5	1.2
D10 (mm)	10.16	0.02	0.45	0.16	0.61
D30 (mm)	12.47	1.01	1.52	1.87	2.51
D60 (mm)	15.56	9.23	5.18	6.38	6.97
Coefficient of Uniformity, c_u	1.53	563.39	11.43	39.50	11.41
Coefficient of Curvature, c_c	0.98	6.78	0.98	3.40	1.48
Atterberg Limits Test Results (Wasti 1987 and ASTM D4318-17e1)					
Liquid Limit (%)	NP	28	NP	NP	NP
Plastic Limit (%)		14			
AASHTO and USCS Soil Classification (ASTM D3282-15 and ASTM D2487-17)					
AASHTO Classification	A-1-a	A-2-6(0)	A-1-a	A-1-a	A-1-a
USCS Classification	GP	GC	GP	GP-GM	GW
Group Name	Poorly graded gravel	Clayey gravel with sand	Poorly graded sand with gravel	Poorly graded gravel with silt and sand	Well-graded gravel with sand

[a] Clean aggregate used to fill columns

Table 32. Soil index properties of surface materials collected during construction in Howard County

Section Name	**Optimized Gradation w/ Clay Slurry**	**RAP**	**Harsco Slag**	**Phoenix Slag**	**Aggregate Columns**[a]
Particle Size Distribution Results (ASTM D6913)					
Gravel Content (%)	71.6	52.6	56.3	77.6	97.8
Sand Content (%)	14.6	42.4	33.0	22.2	2.2
Silt Content (%)	10.6	4.6	9.4	0.0	0.0
Clay Content (%)	3.2	0.4	1.3	0.2	0.0
D10 (mm)	0.03	0.51	0.07	2.17	8.42
D30 (mm)	5.13	2.60	0.34	6.31	11.62
D60 (mm)	11.01	6.63	7.72	11.75	14.86
Coefficient of Uniformity, c_u	425.45	13.05	111.93	5.42	1.76
Coefficient of Curvature, c_c	92.39	2.01	12.89	1.57	1.08
Atterberg Limits Test Results (Wasti 1987 and ASTM D4318-17e1)					
Liquid Limit (%)	26	NP	NP	NP	NA
Plastic Limit (%)	17				
AASHTO and USCS Soil Classification (AASHTO M 145-91, ASTM D3282-15, and ASTM D2487-17)					
AASHTO Classification	A-2-4(0)	A-1-a	A-1-a	A-1-a	A-1-a
USCS Classification	GC	GW-GM	GP-GM	GW	GP
Group Name	Clayey gravel	Well-graded gravel with silt and sand	Poorly graded gravel with silt and sand	Well-graded gravel with sand	Poorly graded gravel

[a] Clean aggregate used to fill columns

Table 33. Soil index properties of surface materials collected during construction in Washington County

Section Name	Optimized Gradation w/ Clay Slurry	12 in. Cement-Treated Subgrade	4 in. Cement-Treated Surface	BASE ONE	EMC SQUARED	Claycrete	Aggregate Columns[a]
Particle Size Distribution Results (ASTM D6913)							
Gravel Content (%)	55.4	47.7	69.5	33.3	26.9	31.3	96.8
Sand Content (%)	24.5	34.1	27.3	25.3	25.7	31.0	3.2
Silt Content (%)	10.7	13.0	2.7	27.4	30.6	19.7	0.0
Clay Content (%)	9.4	5.2	0.5	14.0	16.8	18.0	0.0
D10 (mm)	0.01	0.04	2.31	0.002	–	–	9.25
D30 (mm)	1.37	1.06	4.69	0.03	0.02	0.02	13.18
D60 (mm)	8.60	6.17	9.36	2.41	0.37	1.18	17.91
Coefficient of Uniformity, c_u	1,535.78	163.09	4.06	1,318.91	–	–	1.94
Coefficient of Curvature, c_c	39.16	4.79	1.02	0.14	–	–	1.05
Atterberg Limits Test Results (Wasti 1987 and ASTM D4318-17e1)							
Liquid Limit (%)	27	NP	NP	27	31	28	NP
Plastic Limit (%)	14			11	15	14	
AASHTO and USCS Soil Classification (AASHTO M 145-91, ASTM D3282-15, and ASTM D2487-17)							
AASHTO Classification	A-2-6(0)	A-1-b	A-1-a	A-6(2)	A-6(4)	A-4(0)	A-a-a
USCS Classification	GC	GM	GP	GC	GC	GM	GP
Group Name	Clayey gravel with sand	Silty gravel with sand	Well-graded gravel with sand	Clayey gravel with sand	Clayey gravel with sand	Silty gravel with sand	Poorly graded gravel

[a] Clean aggregate used to fill columns

Table 34. Soil index properties of surface materials collected during construction in Hamilton County

Section Name	Optimized Gradation w/ Clay Slurry	BASE ONE	EMC SQUARED	Claycrete	Aggregate Columns[a]
Particle Size Distribution Results (ASTM D6913)					
Gravel Content (%)	60.5	35.4	43.1	30.6	94.4
Sand Content (%)	23.6	41.7	38.6	52.8	3.4
Silt Content (%)	9.2	11.8	10.0	5.8	2.2
Clay Content (%)	6.7	11.1	8.3	10.8	
D10 (mm)	0.02	0.004	0.01	0.004	5.95
D30 (mm)	1.66	0.24	0.56	0.34	10.08
D60 (mm)	10.27	3.50	5.48	2.42	15.83
Coefficient of Uniformity, c_u	685.23	880.73	608.52	609.39	2.66
Coefficient of Curvature, c_c	17.80	4.14	6.40	11.82	1.08
Atterberg Limits Test Results (Wasti 1987 and ASTM D4318-17e1)					
Liquid Limit (%)	23	20	26	17	NP
Plastic Limit (%)	13	11	17	9	
AASHTO and USCS Soil Classification (AASHTO M 145-91, ASTM D3282-15, and ASTM D2487-17)					
AASHTO Classification	A-2-4(0)	A-2-4(0)	A-2-4(0)	A-2-4(0)	A-1-a
USCS Classification	GC	SC	GC	SC	GP
Group Name	Clayey gravel with sand	Clayey gravel with sand	Clayey gravel with sand	Clayey sand with gravel	Poorly graded gravel

a Clean aggregate used to fill columns

For the aggregate columns sections, the gradations listed in the tables correspond to the clean aggregates used to fill the augured holes. After their construction, all aggregate columns sections were covered with each county's typical surfacing materials, which were the same ones used on the control sections.

The tables show that all stabilized surface courses classified as gravel immediately after construction, except for the BASE ONE and Claycrete sections in Hamilton County, which had greater sand than gravel fractions. The Harsco slag sections had 8% to 11% fines, while the Phoenix slag sections had approximately 3% fines in Cherokee County and 0% fines in Howard County. The index properties of the pre-existing surface and subgrade materials as well as all quarry products and stabilizers used in construction of the test sections were presented in Section 4.1.

Observations from selected test sections are presented in this section, and the complete gradation curves for all test sections are provided in Appendix E. For common points of reference, the Iowa DOT Class A and B specification for crushed stone (Iowa DOT 2020, Division 41 Construction Materials, Section 4120 Granular Surfacing and Granular Shoulder Aggregate) and a relevant target curve for the optimized gradation method are shown in all gradation plots.

For all test sections, if maintenance aggregates are not added, the continual material loss and abrasion with time typically results in an upward migration of the particle size distribution (PSD) curve (toward greater percent passing for any given sieve size) as the material becomes finer. Alternatively, the PSD migration can be thought of as a shift to the right (toward smaller particle size for a given percent passing), usually accompanied by a spreading out of the PSD as the material becomes more well-graded.

For granular road surfaces, this shift typically involves a decrease in the gravel content accompanied by increases in the sand and fines content and, therefore, a decrease in the gravel-to-sand (G:S) ratio. Adding fresh aggregate during maintenance moves the gradation curves of the resulting mixture downward back toward a coarser gradation. A loss of sand and fines due to dust or surface runoff and washboarding can also move the right portion of the gradation curve downward.

The PSD plots reveal that the granular surface materials in all control sections experienced significant abrasion and material loss, causing their gradations to become finer as their gradation curves migrated upward over time (Figure 95 through Figure 98).

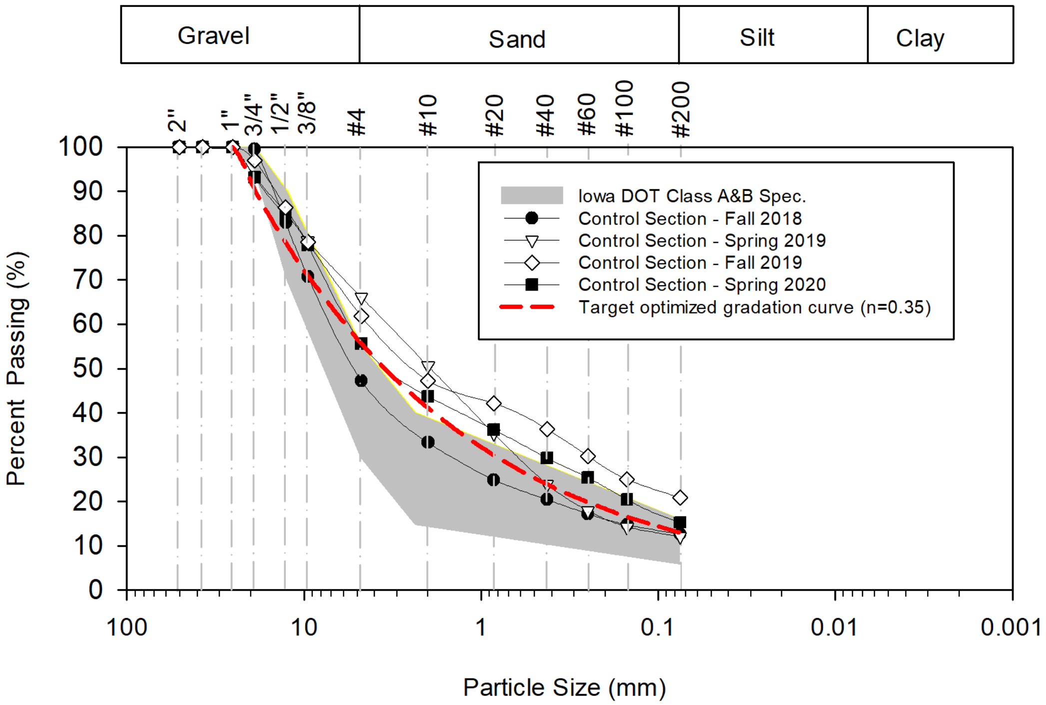


Figure 95. Particle size distribution curves for Cherokee County control section

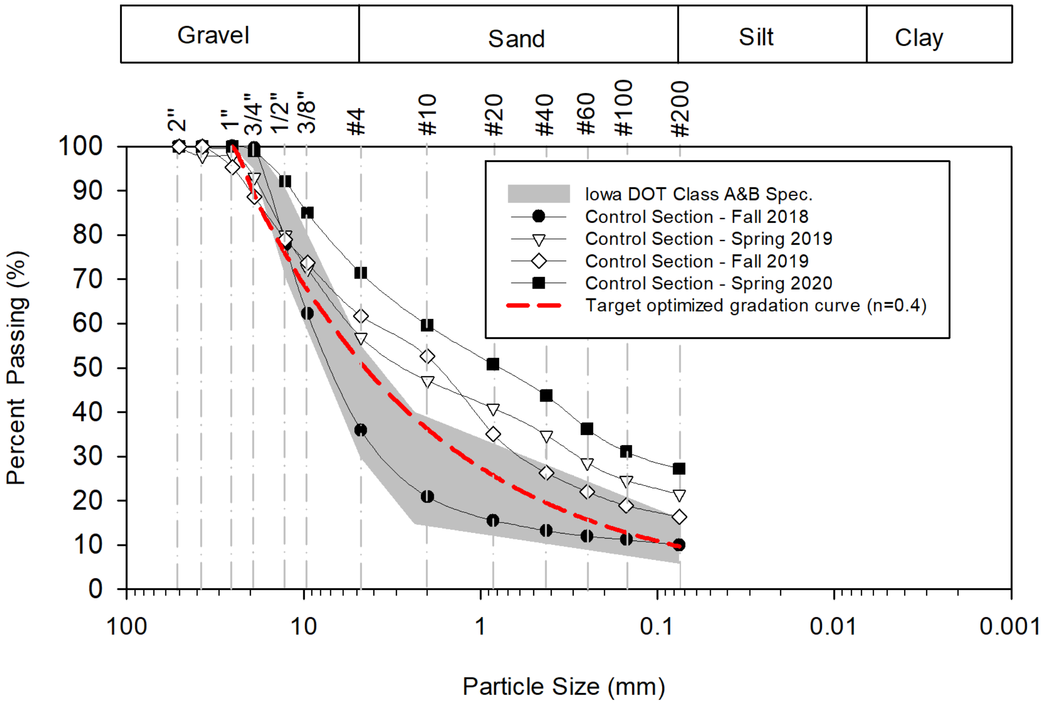


Figure 96. Particle size distribution curves for Howard County control section

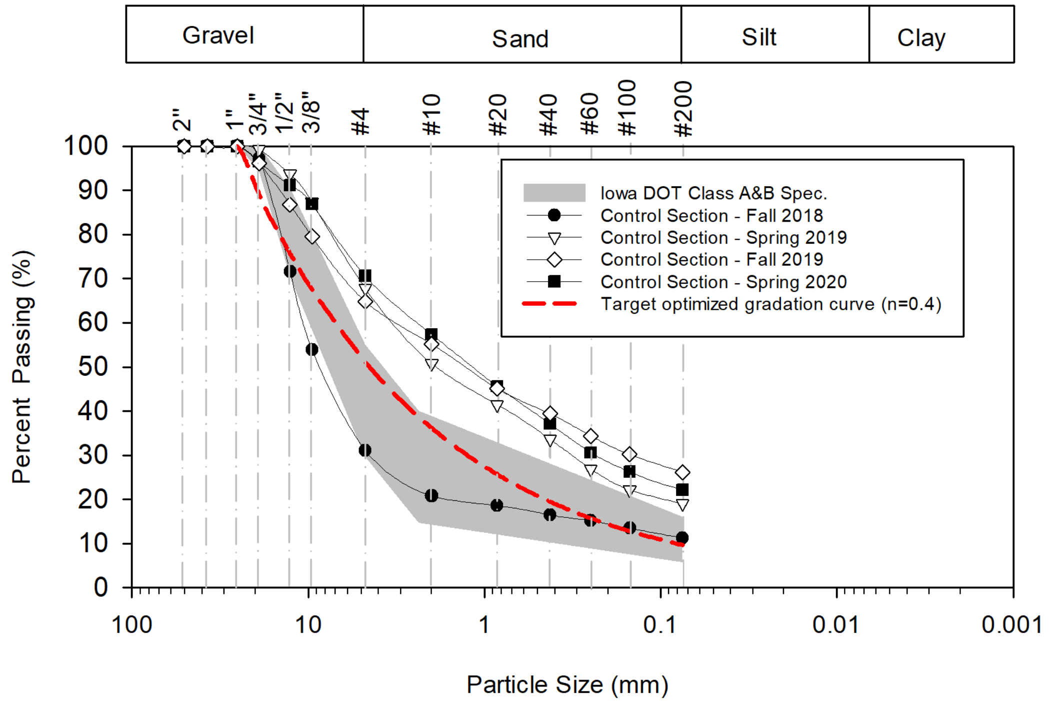


Figure 97. Particle size distribution curves for Washington County control section

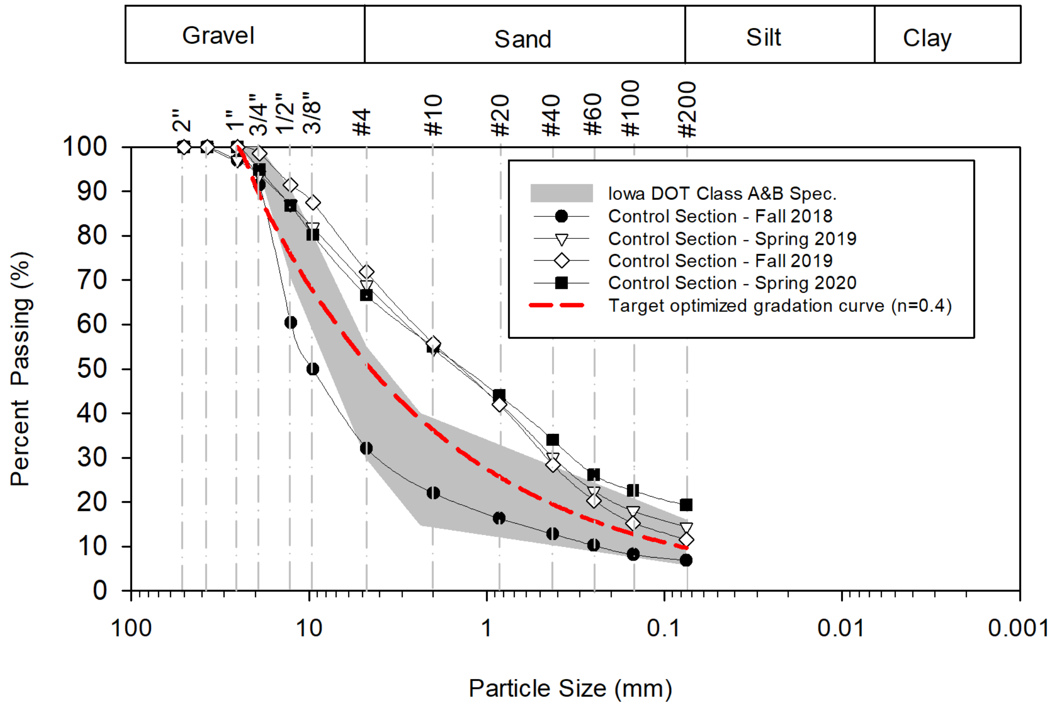


Figure 98. Particle size distribution curves for Hamilton County control section

In all four counties, the control section gradation curves migrated well above the Iowa DOT Class A and B specification band as the gradations became finer. In Howard County, 40 tons of fresh aggregate were spread over the surface of the control section prior to the fall 2019 tests, causing the spring 2019 gradation curve to shift to a smaller percentage of sand-sized particles and a greater percentage of gravel-sized particles in fall 2019 (previous Figure 96). Between fall 2019 and spring 2020, however, the gradation of this section had become much finer, with the gravel-sized fraction decreasing from 38% to 29% and the fines content increasing from 16% to 27%.

Compared to the control sections, the gradation curves for the OGCS sections stayed much closer to the initial target curve (and therefore the Class A and B specification band) for much of the project duration, as shown in Figure 99 through Figure 102, for the four counties.

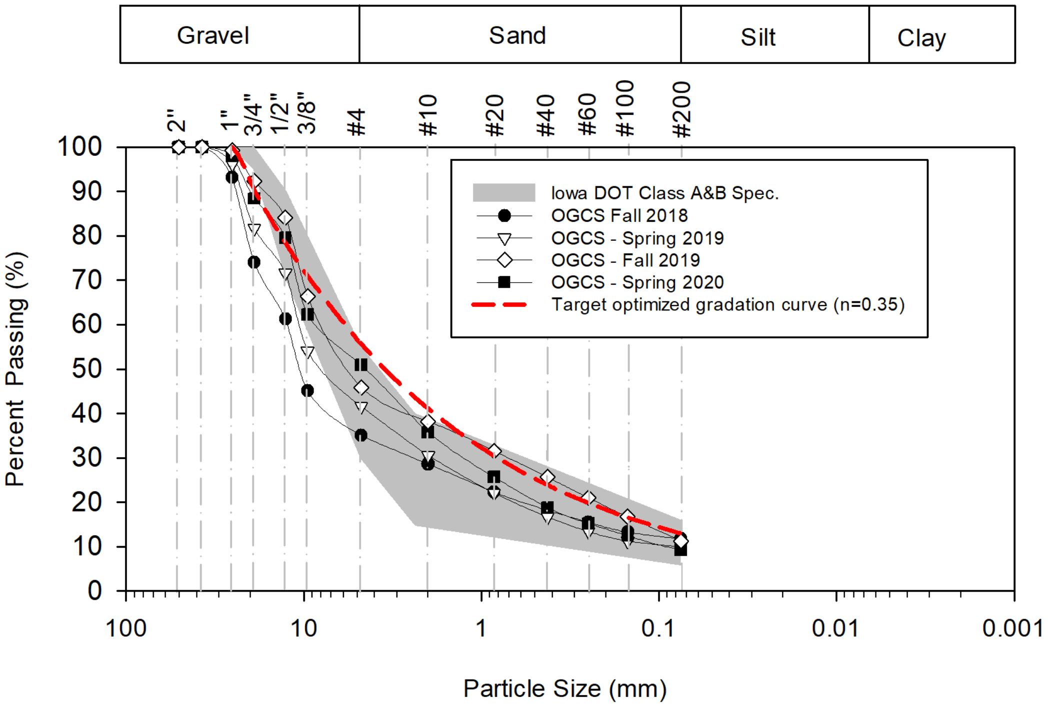


Figure 99. Particle size distribution curves for Cherokee County OGCS section

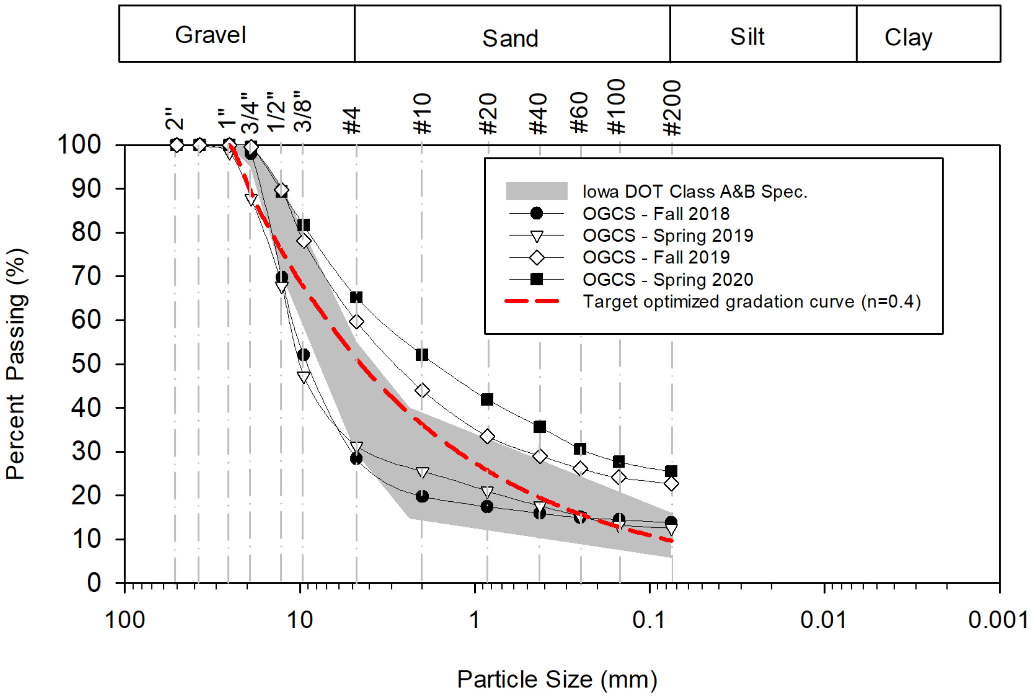


Figure 100. Particle size distribution curves for Howard County OGCS section

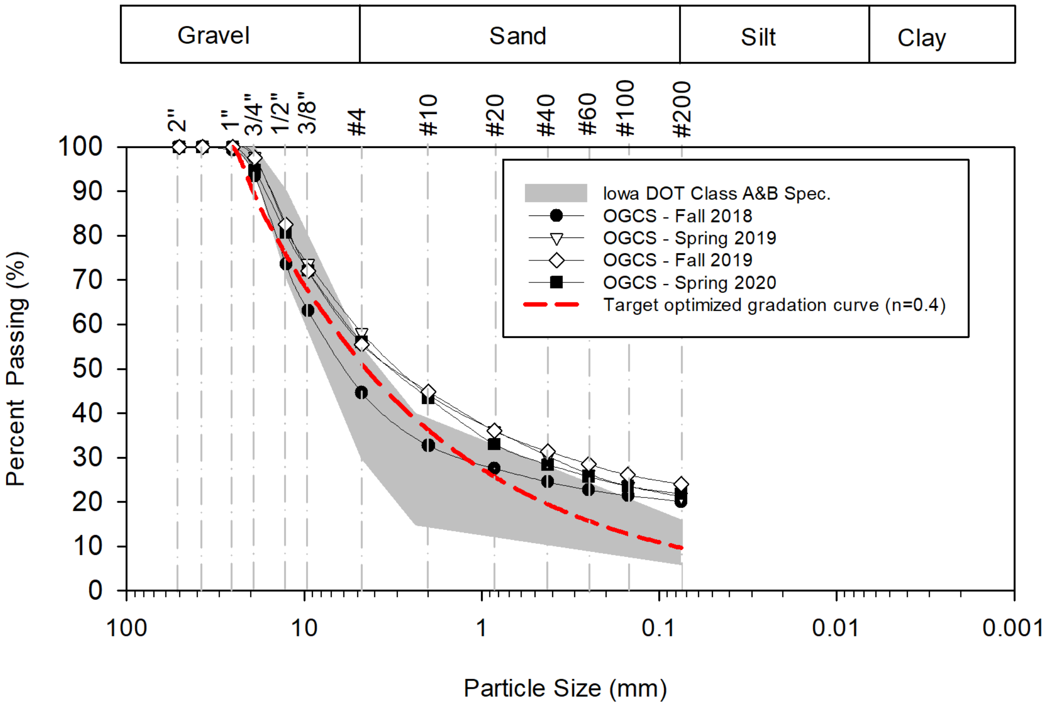


Figure 101. Particle size distribution curves for Washington County OGCS section

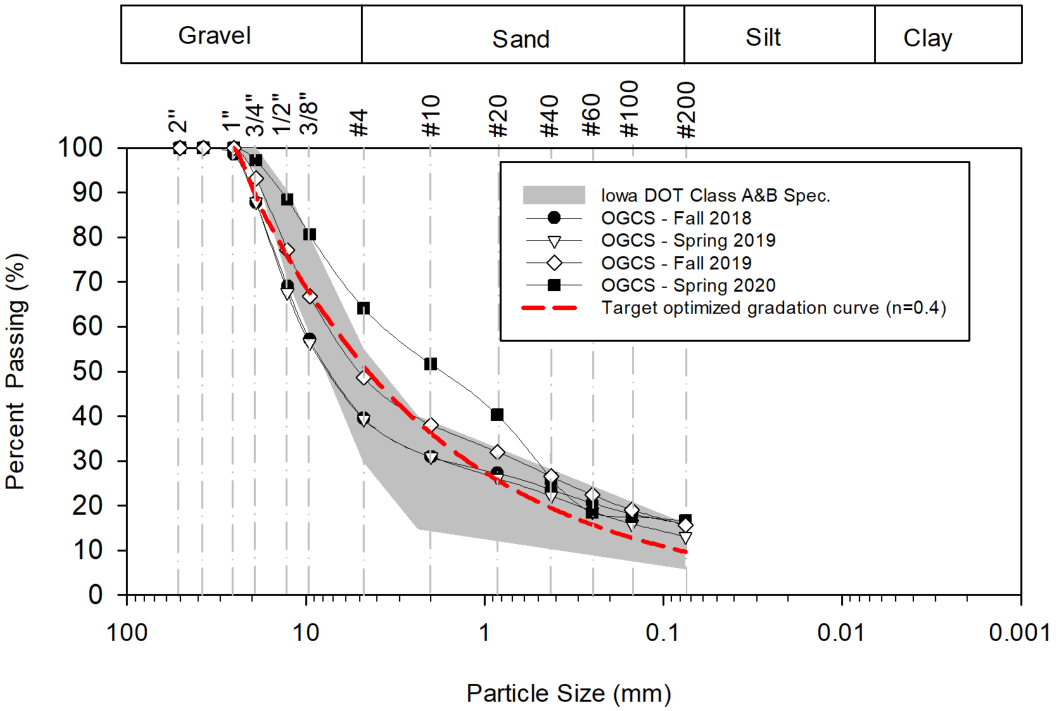


Figure 102. Particle size distribution curves for Hamilton County OGCS section

The OGCS sections therefore provided the benefits of reduced material loss and particle breakage relative to the control sections. This is likely a result of the increased binding capacity provided by the plastic clay particles, as well as the tighter particle packing achieved by the optimized gradation method.

The increased binding capacity reduces the loss of aggregate particles and helps form a crust that sheds water, while the optimized gradation improves stability by filling voids between larger particles with smaller particles. The resulting tighter particle packing increases the number of interparticle contacts, which reduces their contact stresses and therefore should lead to reduced abrasion and particle breakage.

By spring 2020, the OGCS gradations in Howard, Washington, and Hamilton counties had started to migrate above the Iowa DOT Class A and B specification band in some particle size ranges, indicating that the effectiveness of this method is reduced after two to three years. However, this performance represents an improvement over the use of powdered bentonite as a binding agent, which was found in the previous IHRB project to lose effectiveness after only one year.

The 2 in. and 4 in. Phoenix slag sections started out in 2018 with gradations generally coarser than the Iowa DOT Class A and B specification, as shown in Figure 103 through Figure 106.

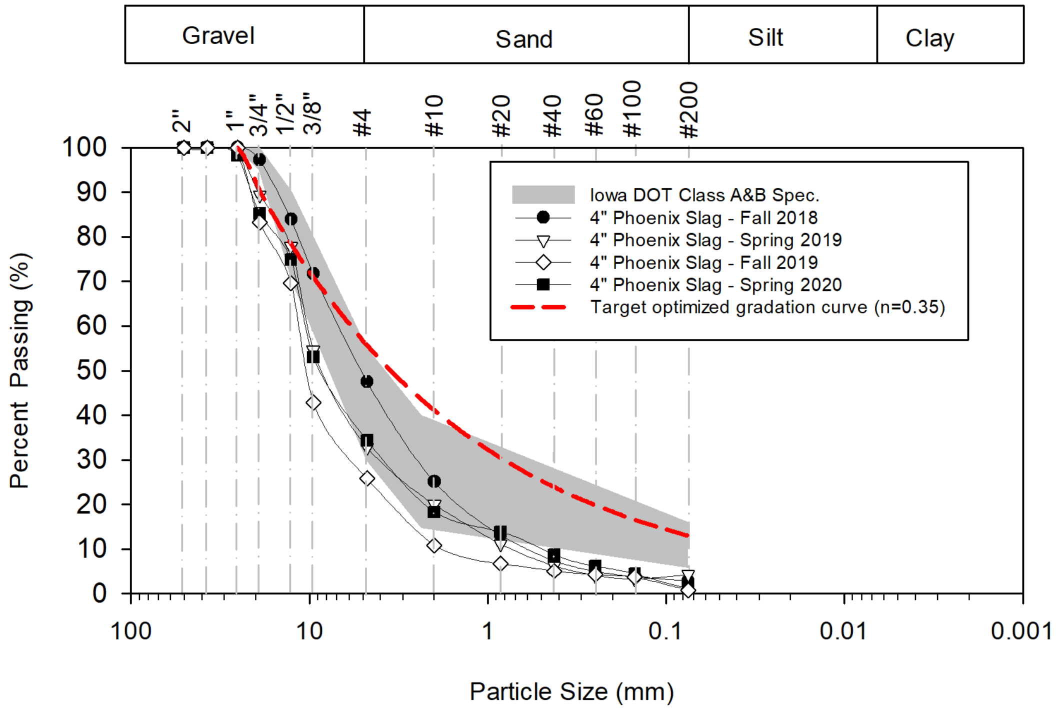


Figure 103. Particle size distribution curves for Cherokee County 4 in. Phoenix slag section

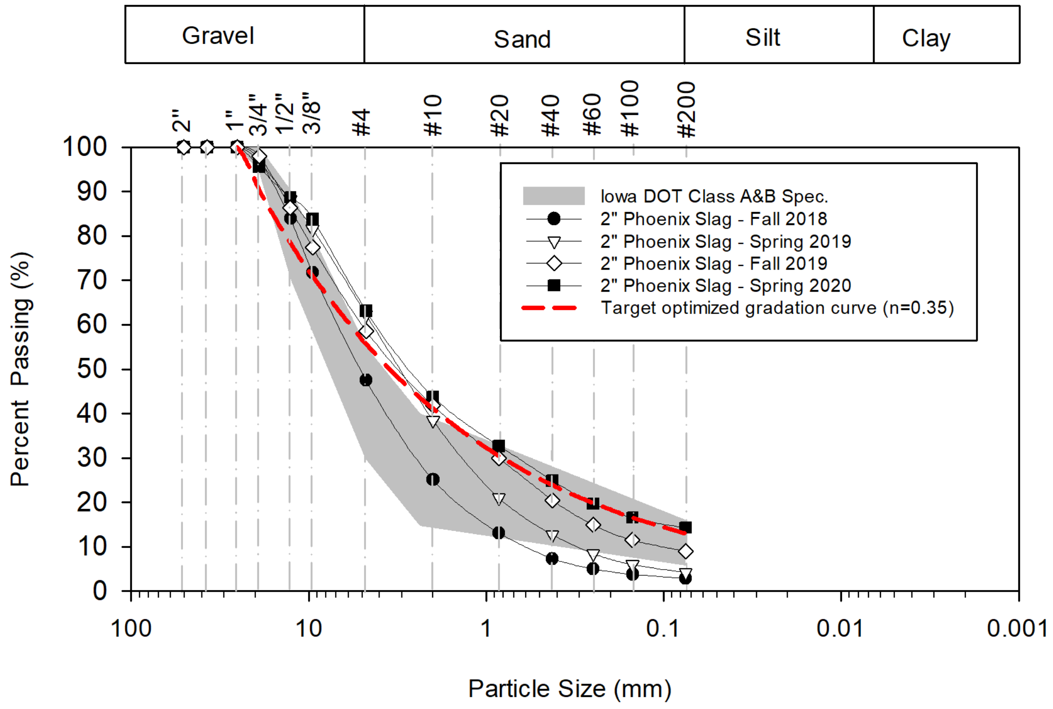


Figure 104. Particle size distribution curves for Cherokee County 2 in. Phoenix slag section

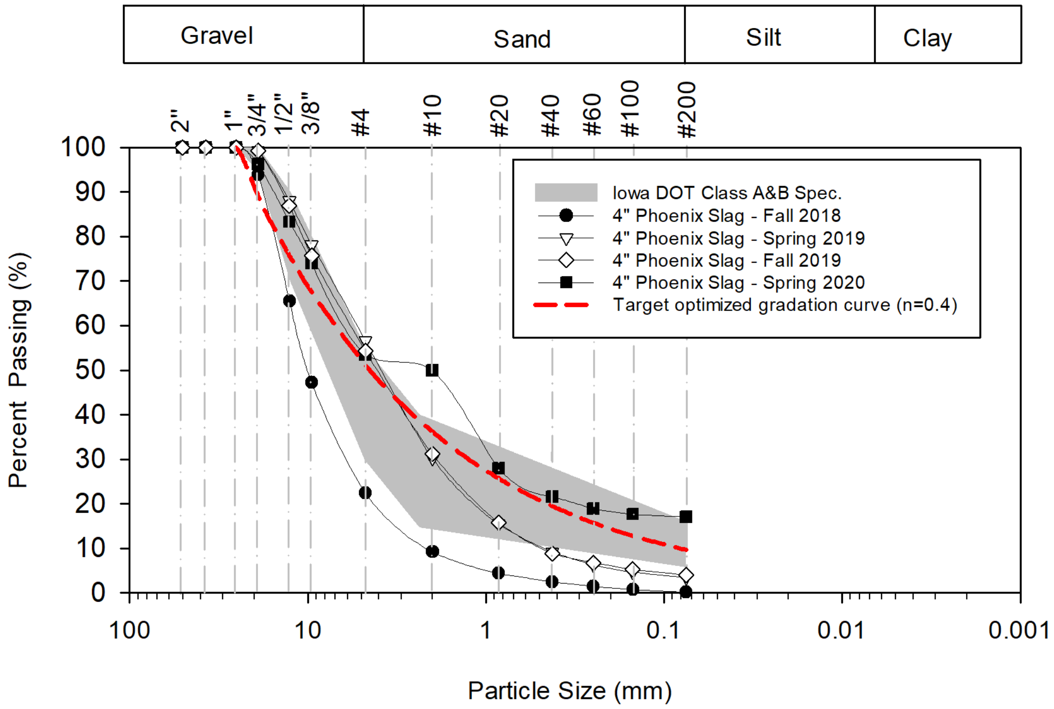


Figure 105. Particle size distribution curves for Howard County 4 in. Phoenix slag section

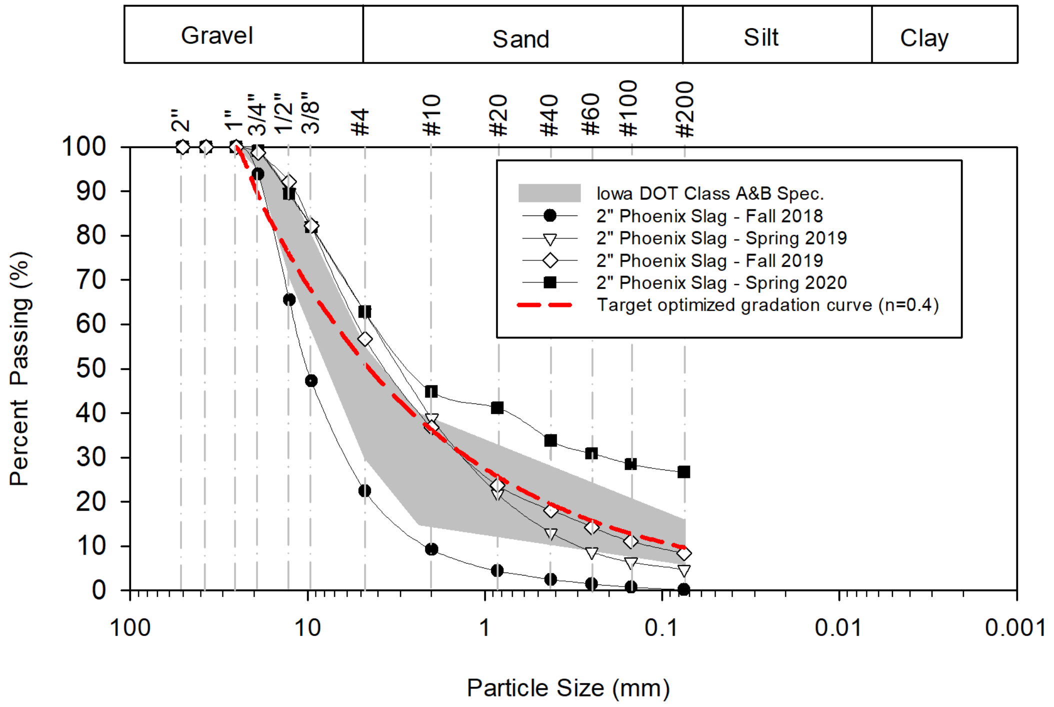


Figure 106. Particle size distribution curves for Howard County 2 in. Phoenix slag section

This was expected, because the processing method used to create the Phoenix slag results in a material that is practically free of fines; whereas, the Class A and B specification calls for between 6% and 16% fines.

From 2018 to 2020, the particle size distributions for the Phoenix slag sections became finer because of abrasion due to heavy traffic loading, along with material loss due to raveling. In Howard County, the fines content increased significantly from 0% to 17% in the 4 in. Phoenix slag section over the project duration and from 0% to 26% in the 2 in. Phoenix slag section. The latter section ended up with a gradation curve in spring 2020 that was almost entirely above the Class A and B specification band (previous Figure 106).

The two Phoenix slag sections in Howard County also became gap-graded by spring 2020, but this phenomenon was not observed for the Phoenix slag sections in Cherokee County, nor any other test sections. The Phoenix slag sections in Cherokee County fared better, showing much less change in gradation over time, with the 2 in. section becoming finer but remaining close to the Class A and B specification band (previous Figure 104) and the 4 in. section showing little gradation change in the fine sand range and only a slight increase in fines (previous Figure 103).

However, it should be noted that the spring 2020 slag gradations in Cherokee County include fresh crushed limestone surface aggregates that were placed without notice to the research team. An attempt was made to remove the limestone from the samples, but some particles remained and affected the spring 2020 gradation curves.

The Harsco slag is produced using a process aimed at creating a gradation with sufficient minus #200 sieve material to meet the Class A and B specifications. Consequently, the 2 in. and 4 in. Harsco slag sections started out in 2018 with gradations almost completely inside the Iowa DOT Class A and B specification band (Figure 107 through Figure 110).

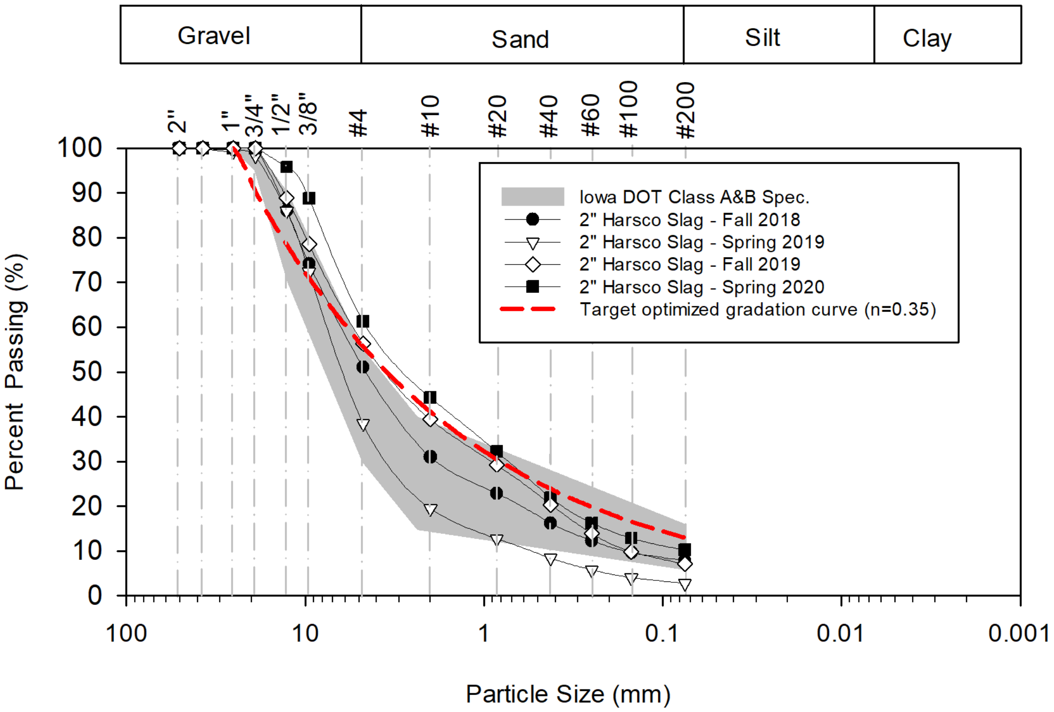


Figure 107. Particle size distribution curves for Cherokee County 2 in. Harsco slag section

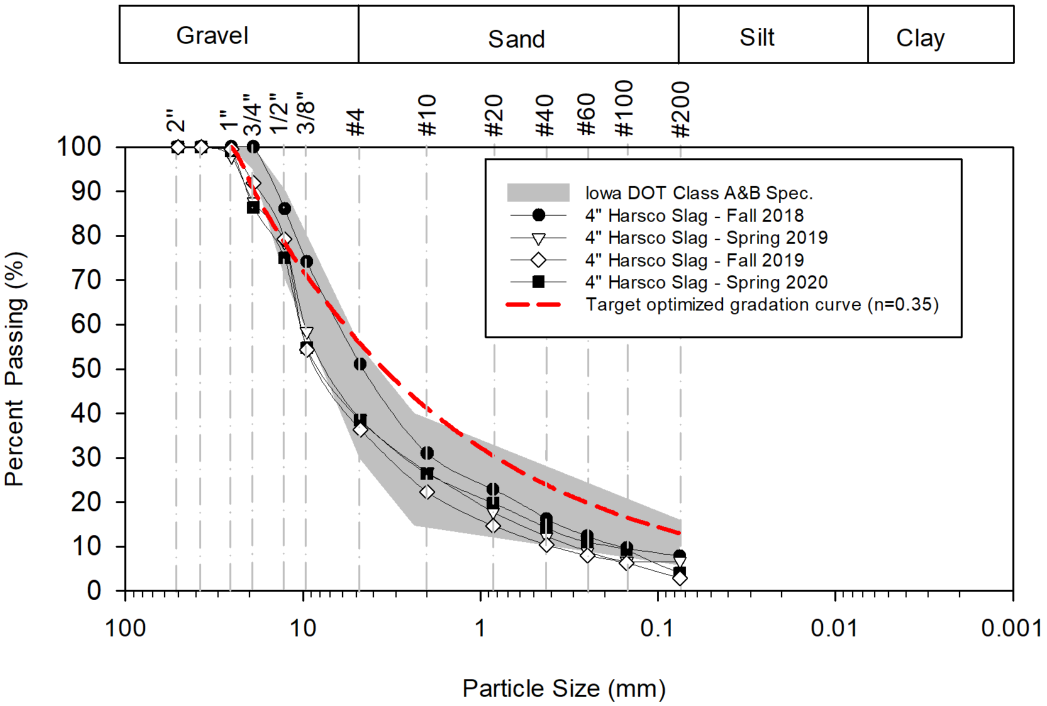


Figure 108. Particle size distribution curves for Cherokee County 4 in. Harsco slag section

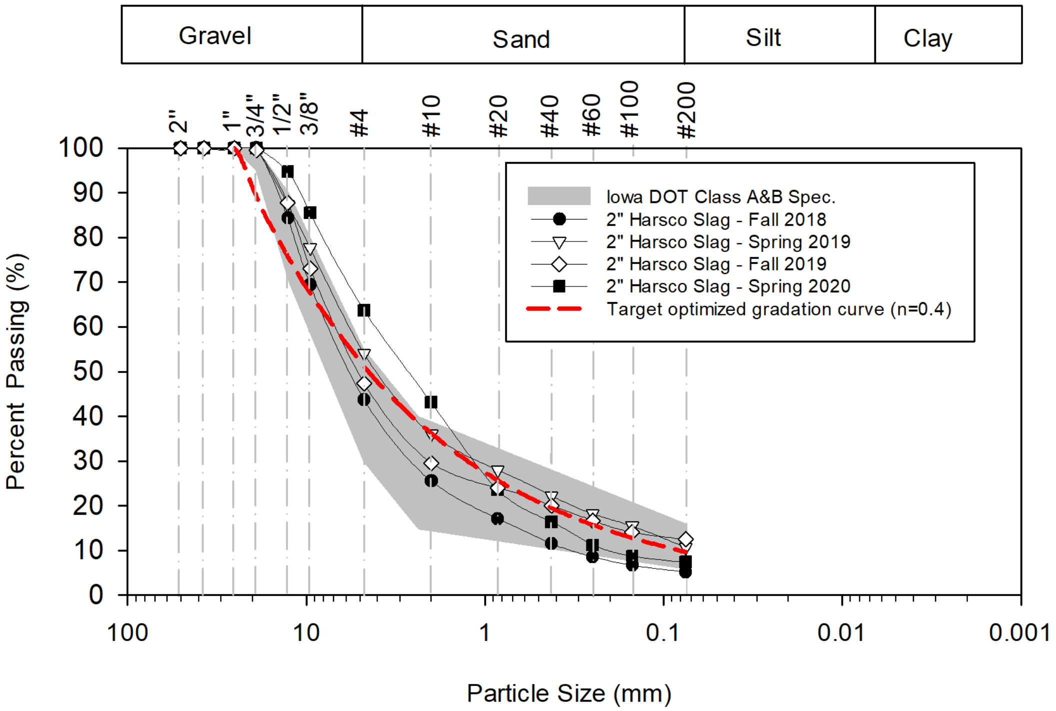


Figure 109. Particle size distribution curves for Howard County 2 in. Harsco slag section

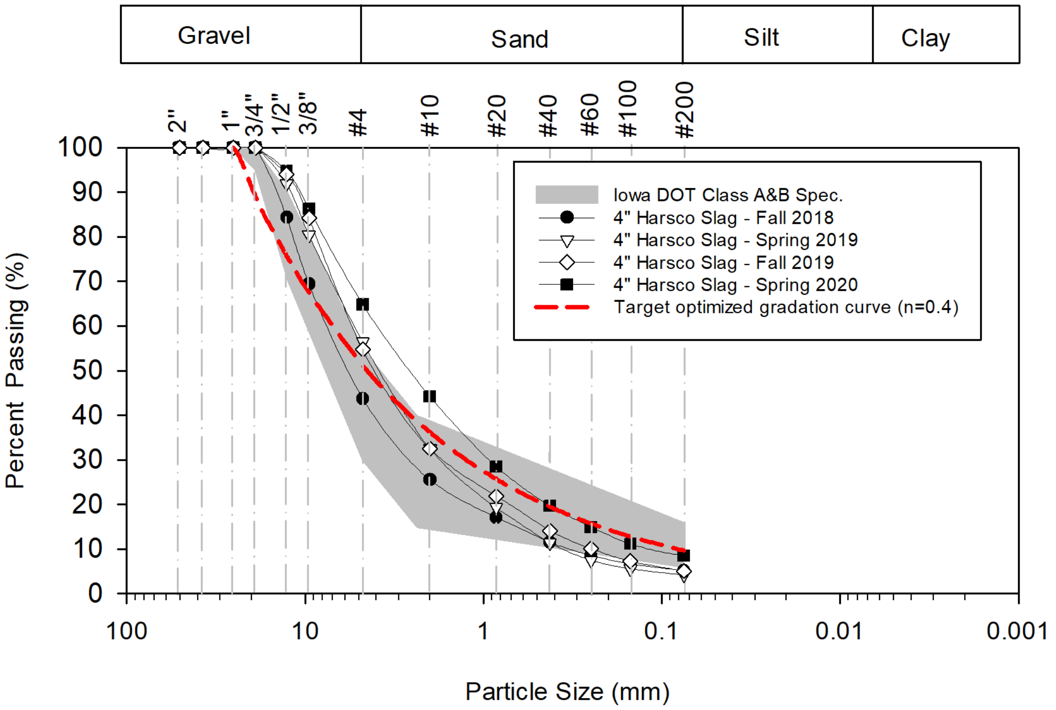


Figure 110. Particle size distribution curves for Howard County 4 in. Harsco slag section

The Harsco slag sections also exhibited some material degradation over the course of the project, but their gradation curves generally remained very close to the Class A and B specification band.

The gradation curves for both types of slag therefore demonstrated the potential for reduced particle breakage compared to the natural aggregates of the control sections. Using steel slag as a surfacing material could provide cost savings by reducing the frequency and amount of fresh maintenance materials needed, although the initial hauling costs for obtaining slag materials should be considered, as it can be high depending on hauling distance. The slag materials also resist pushing and spreading due to their high angularity, so they must be spread in thinner lifts and are more difficult to loosen and shape than natural aggregates.

For all aggregate columns sections, after filling the augured holes with clean aggregate fill, each county replaced the surface course with approximately 4 in. of their typical surfacing materials. In Hamilton County, the clean aggregate fill contained 2.2% fines, while the clean aggregate fill contained less than 1% fines in the other three counties. In Cherokee County, the gradation of the surface course of the aggregate columns section (Figure 111) experienced less change in gradation and stayed closer to the specification band compared to its nearby control section (previous Figure 95).

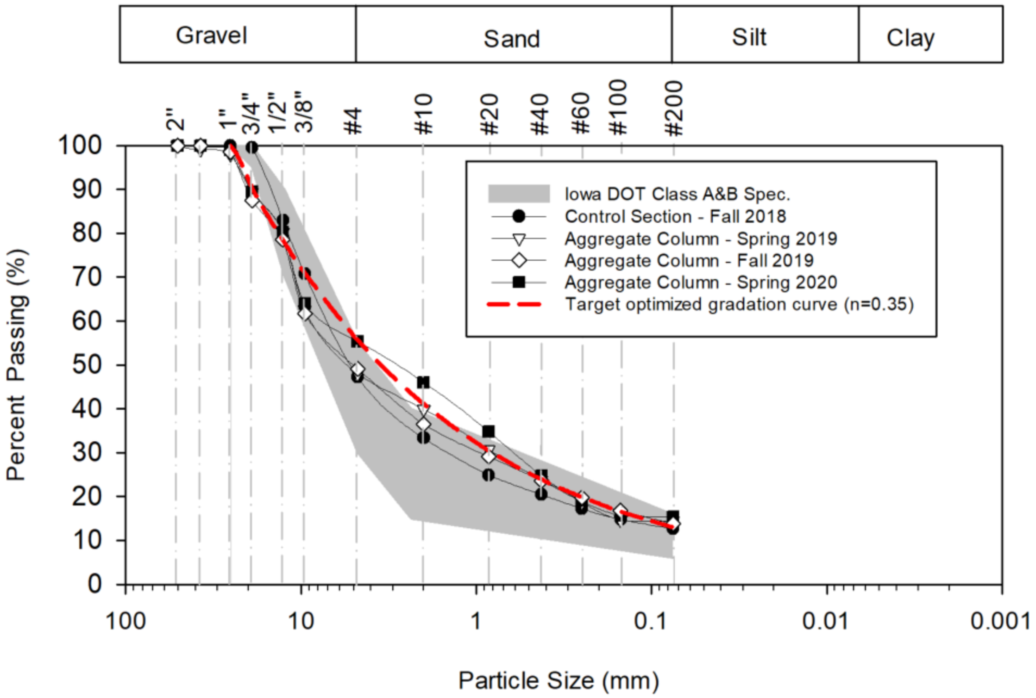


Figure 111. Particle size distribution curves for Cherokee County aggregate columns section

However, in Howard, Washington, and Hamilton counties (see Appendix E), the surface courses of the aggregate columns sections performed similar to their corresponding control sections. That is, their gradation curves indicated significant material loss and abrasion by migrating upwards well outside the Iowa DOT Class A and B specification band with time. As explained later in Section 6.3.2, an additional 1 in. of clean aggregate was spread over the Howard County aggregate columns section in fall 2019, which brought the gradation curve for the mixture of existing and fresh aggregate back down toward the upper bound of the Class A and B specification in spring 2020 (Figure 112).

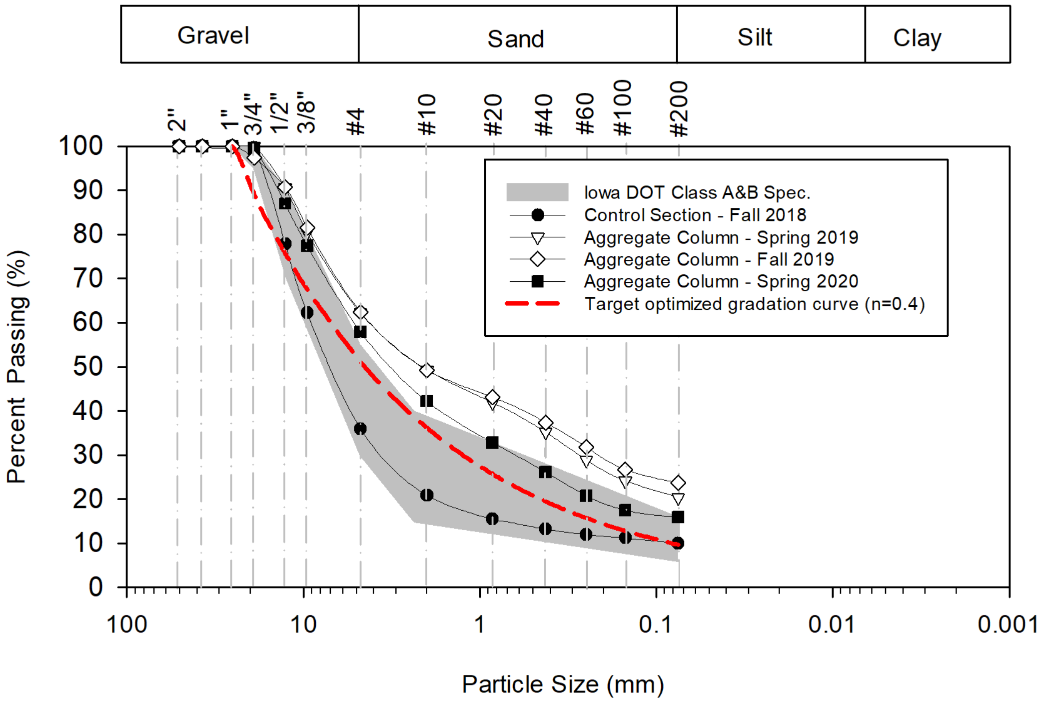


Figure 112. Particle size distribution curves for Howard County aggregate columns section

The RAP sections in Cherokee and Howard counties used locally sourced materials and both started out in fall 2018 with gradations that were inside the Iowa DOT Class A and B specification band for sieve #20 and larger and below the specification band for sieve #40 and smaller. The RAP section in Cherokee County underwent slight changes in gradation but remained almost entirely within the specification band (Figure 113).

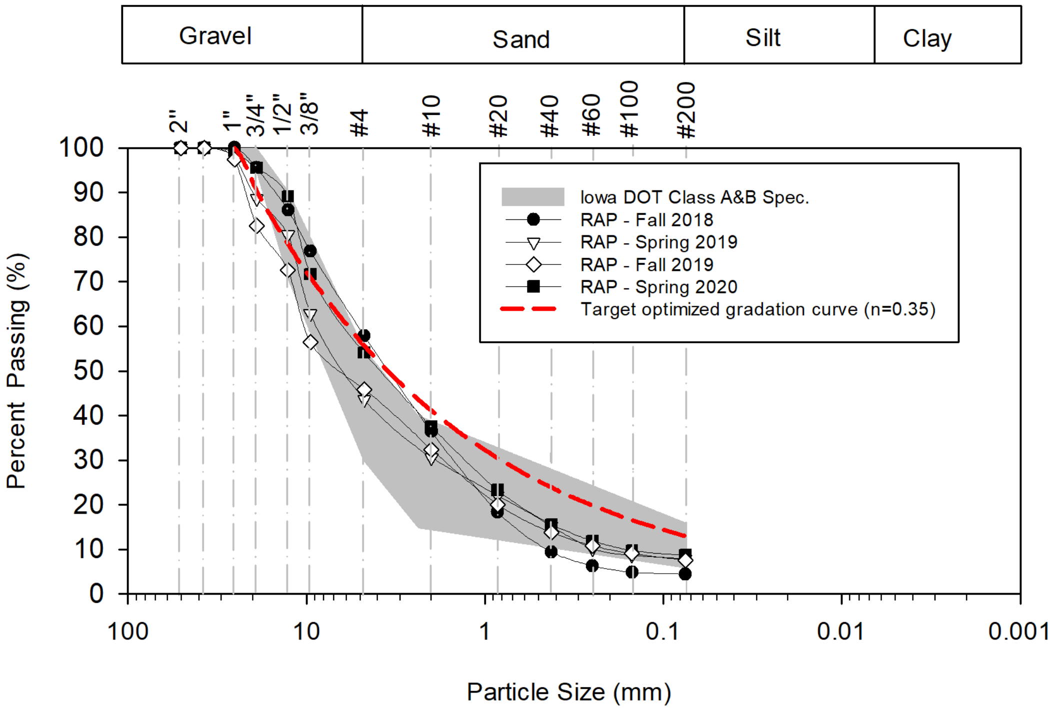


Figure 113. Particle size distribution curves for Cherokee County RAP section

In comparison, the RAP section in Howard County experienced more significant changes in gradation that ended up entirely above the specification band in fall 2019 (Figure 114).

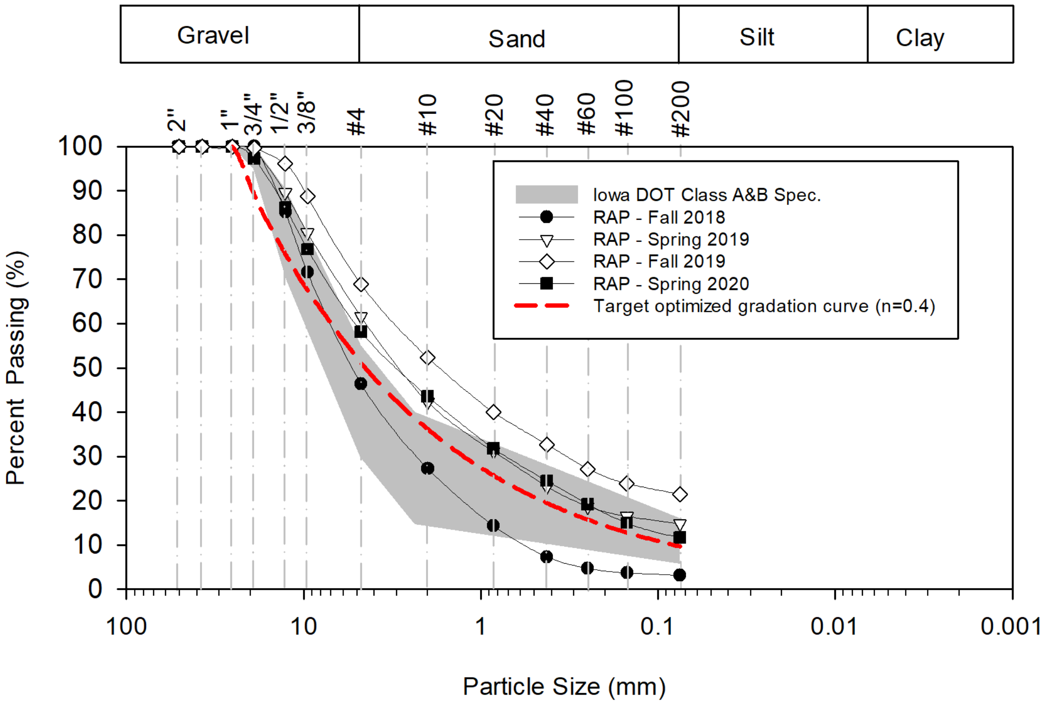


Figure 114. Particle size distribution curves for Howard County RAP section

In Washington County, the 4 in. cement-treated surface section initially had a coarser gradation curve below the Iowa DOT Class A and B specification; but with compaction and abrasion from traffic breaking up the aggregate over time, the gradation became finer and remained almost within the specification band from spring 2019 to spring 2020 (Figure 115).

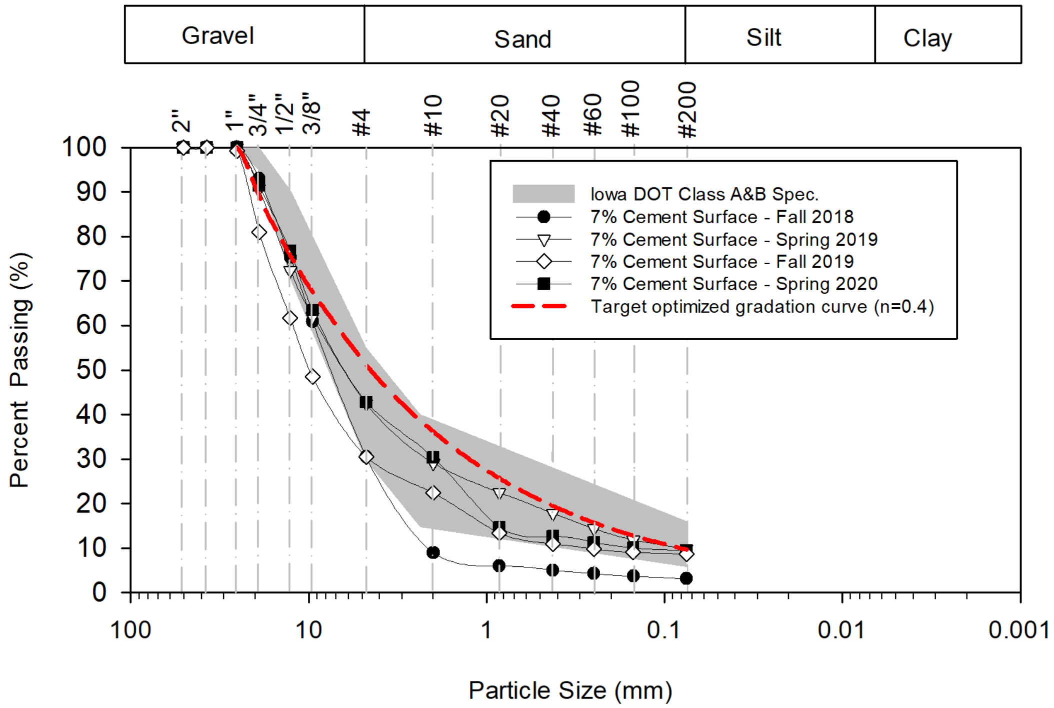


Figure 115. Particle size distribution curves for Washington County 4 in. cement-treated surface section

In spring 2020, an additional 26 tons of fresh aggregate were spread to cover potholes. In contrast, the initial gradation of the 12 in. cement-treated subgrade section in 2018 was almost entirely within the specification band, but migrated above the band in fall 2019 before decreasing by spring 2020 despite no fresh aggregate being placed on the section (Figure 116).

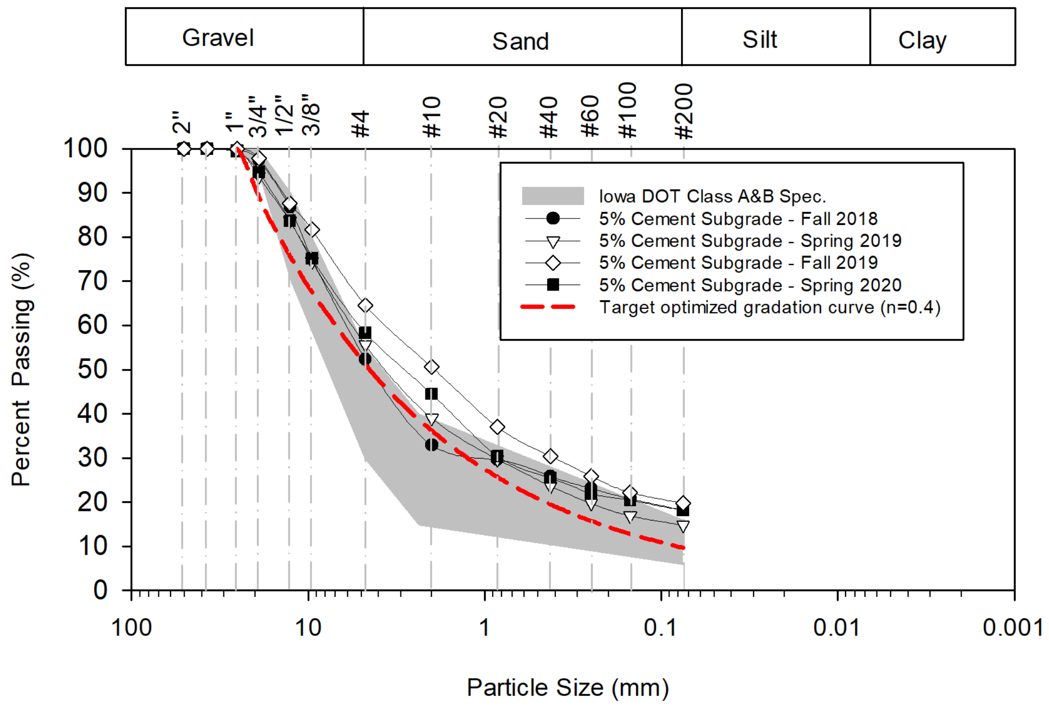


Figure 116. Particle size distribution curves for Washington County 12 in. cement-treated subgrade section

The decrease in the sand and fines fractions for this section in spring 2020 may be a result of dust generation in addition to abrasion from traffic loads creating sand-sized particles, which are then blown or washed off the relatively stiff surface by traffic and water.

The sections treated with liquid chemical stabilizers in Washington and Hamilton counties were constructed with subgrades mixed into their surface courses using a RoadHog, which resulted in finer initial gradations than any of the other types of test sections. Specifically, after construction in fall 2018, the surface courses of the BASE ONE, EMC SQUARED, and Claycrete sections in Washington County had respective fines contents of 40%, 47%, and 38% (Figure 117 through Figure 119); whereas, the corresponding sections in Hamilton County had much lower fines contents of 23%, 18%, and 17% (Figure 120 through Figure 122).

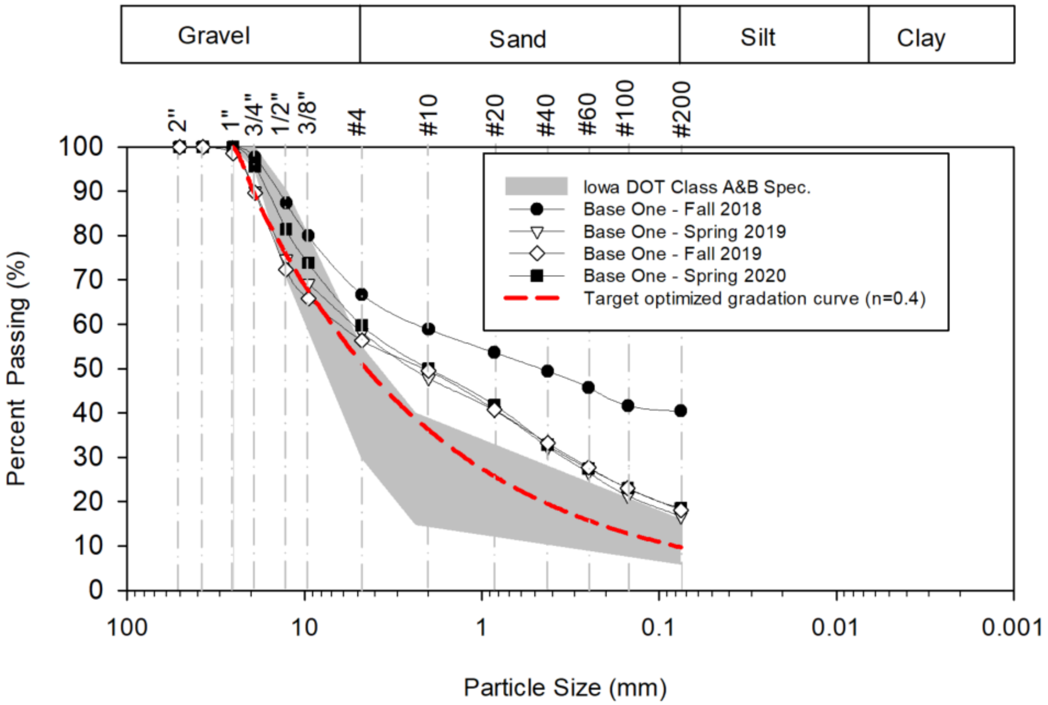


Figure 117. Particle size distribution curves for Washington County BASE ONE section

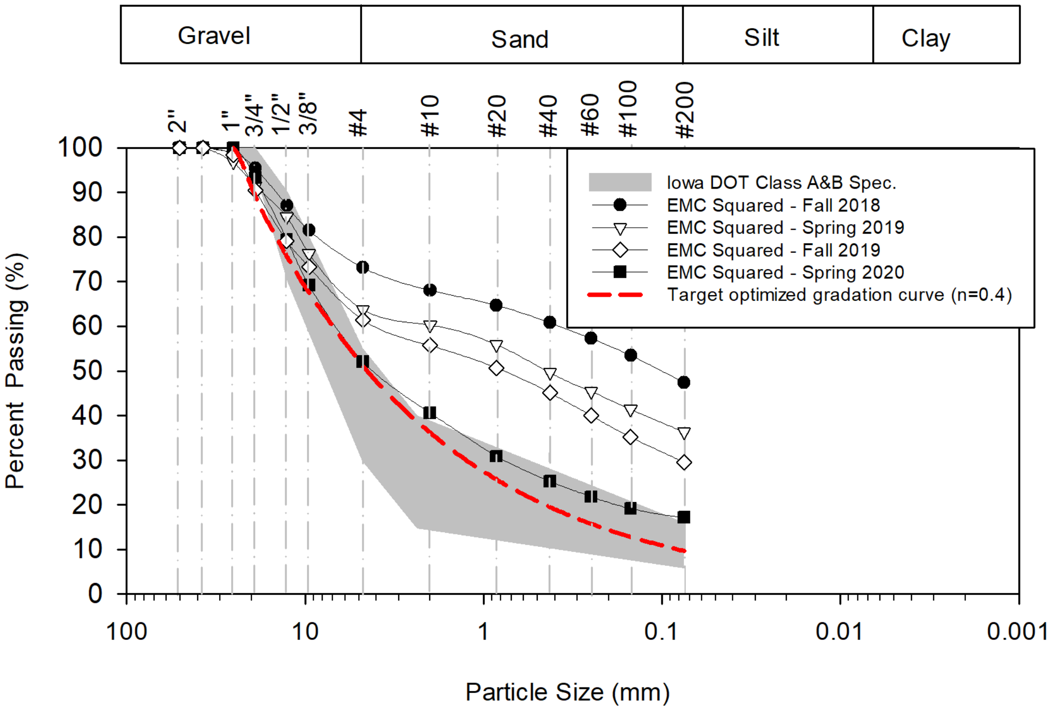


Figure 118. Particle size distribution curves for Washington County EMC SQUARED section

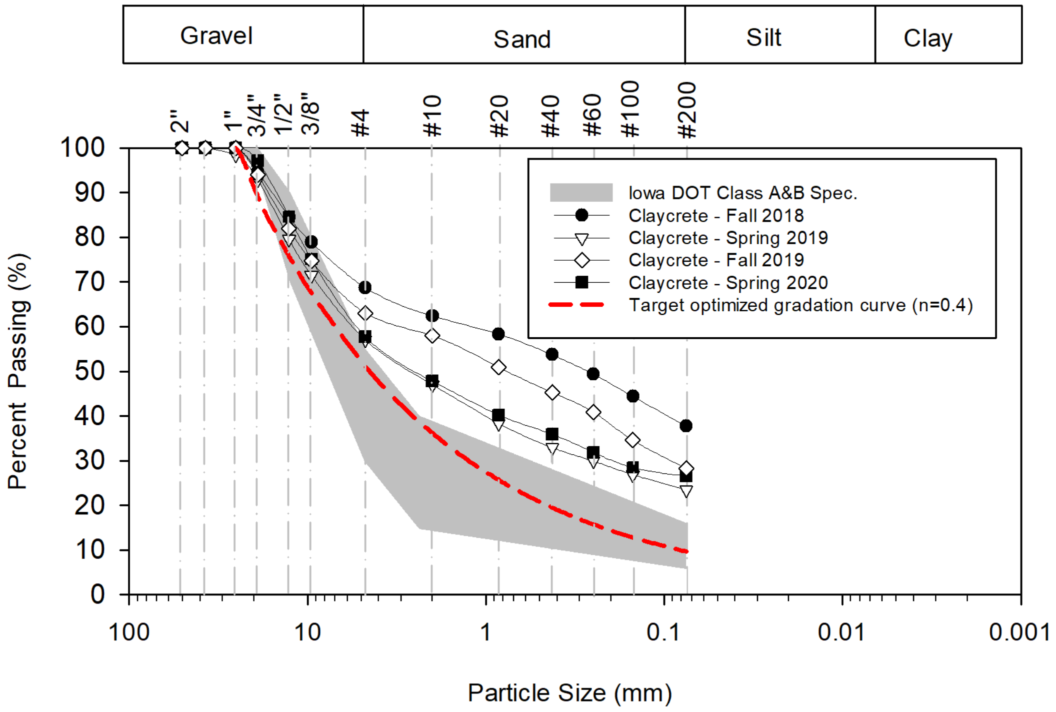


Figure 119. Particle size distribution curves for Washington County Claycrete section

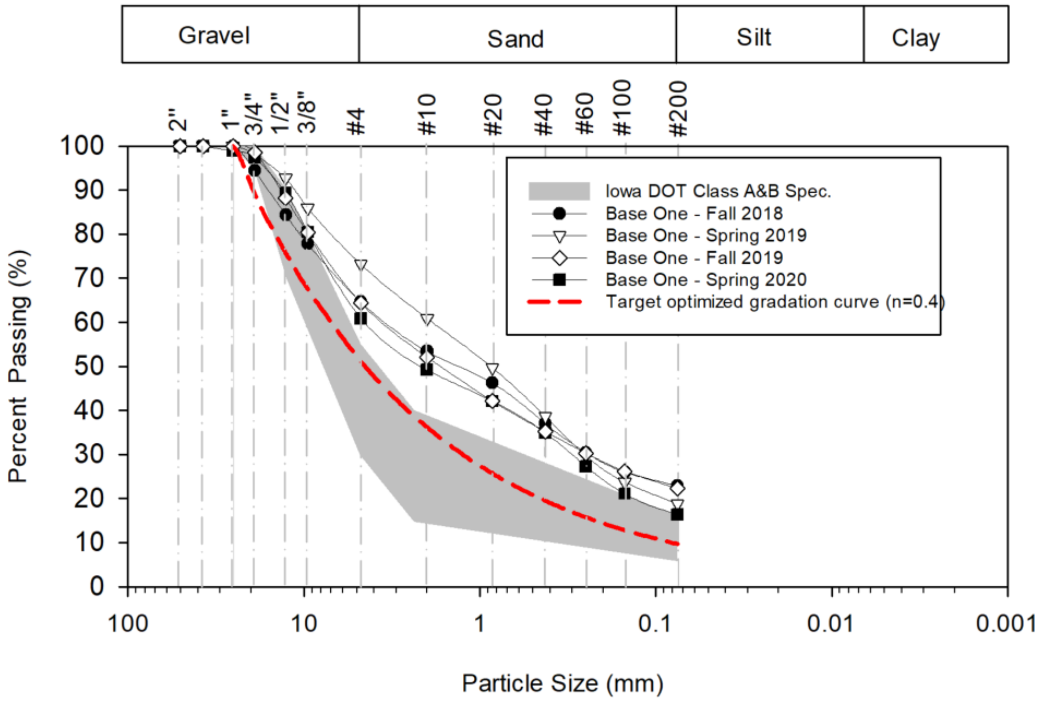


Figure 120. Particle size distribution curves for Hamilton County BASE ONE section

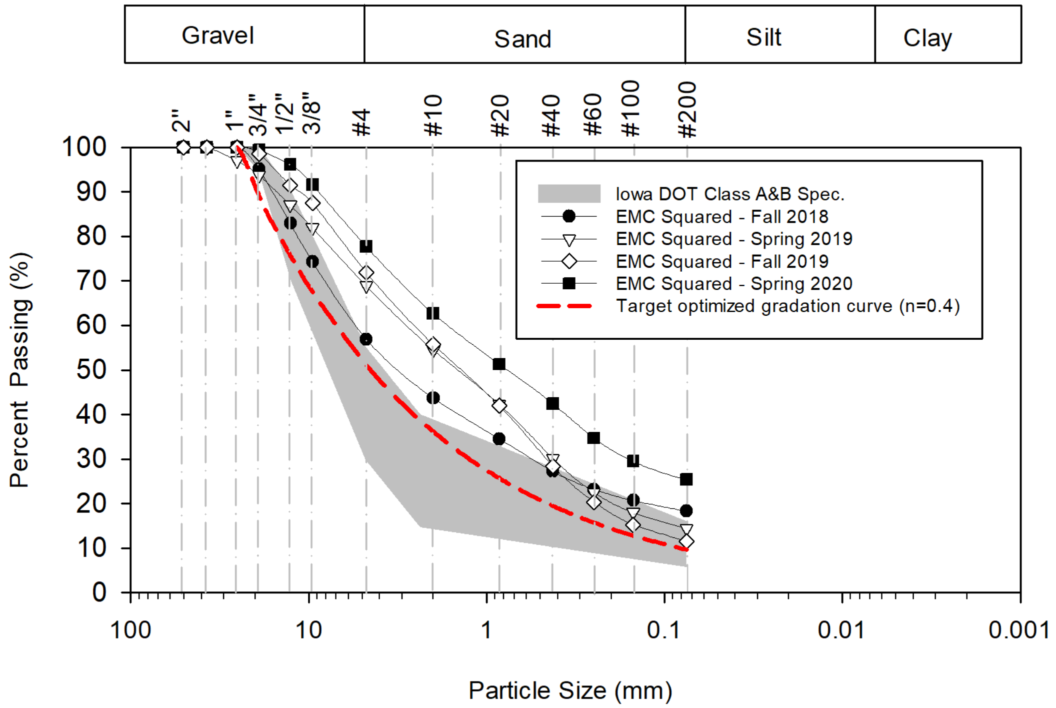


Figure 121. Particle size distribution curves for Hamilton County EMC SQUARED section

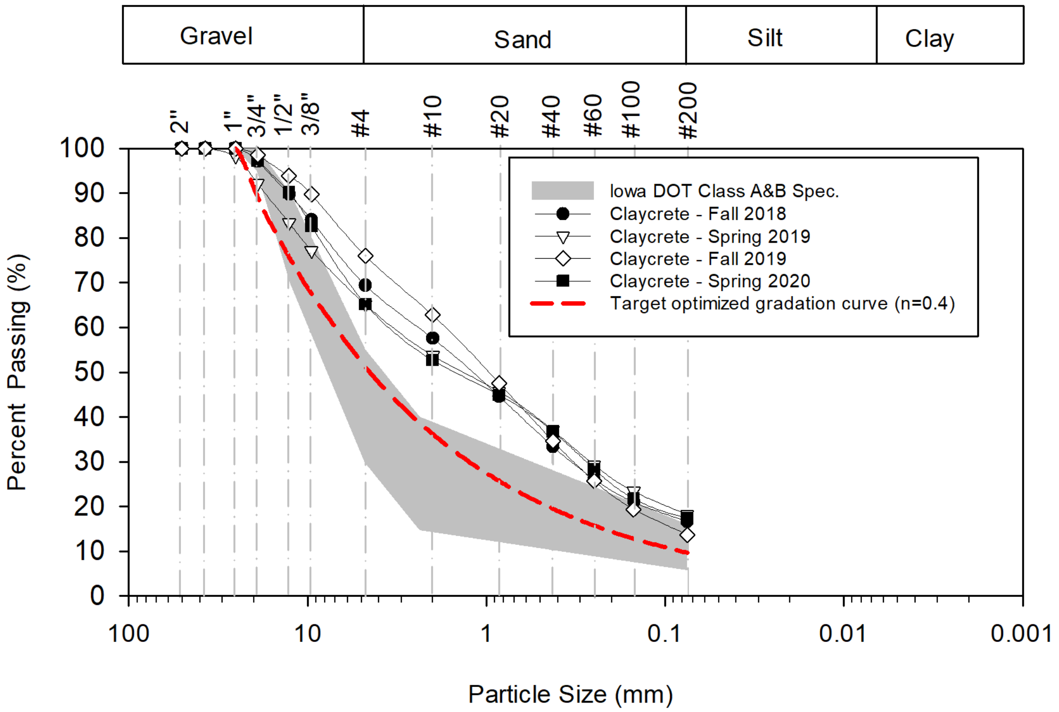


Figure 122. Particle size distribution curves for Hamilton County Claycrete section

The differences are partly due to the much higher fines content of 95% for the Washington County subgrade compared to only 53% for Hamilton County. However, by spring 2019, the fines contents in the three Washington County liquid-stabilized sections decreased significantly, after which the gradations remained closer to the upper bound of the Iowa DOT Class A and B specification band. As detailed later in Section 6.3.2, fresh aggregates were spread on the three liquid stabilizer sections in spring 2020 for maintenance.

The BASE ONE section in Hamilton County (see Figure 120) exhibited a smaller overall change in gradation than the one in Washington County (Figure 117), but the latter changed very little over the last three testing periods and retained more gravel-sized particles within the gradation band. Interestingly, the BASE ONE sections in both counties ended up with gradations very similar to their respective control sections in spring 2020.

The EMC SQUARED section in Washington County (Figure 118) started out in fall 2018 with a very fine gradation but continually became coarser over time, with its gradation curve ending up almost entirely inside the specification band after maintenance aggregate was added in spring 2020. In Hamilton County where no maintenance aggregate was added, the EMC SQUARED section showed the opposite trend (Figure 121), starting out with its coarsest gradation close to the top of the specification band in fall 2018 and ending with its finest gradation far above the band in spring 2020. Even before the maintenance aggregate was added in Washington County, the gravel-sized portion of the EMC SQUARED section's gradation stayed much closer to the specification band in Washington County than in Hamilton County.

The Claycrete section in Washington County (Figure 119) started out with its finest gradation in fall 2018 and generally moved toward a coarser one with time but remained above the specification band in the sand-sized range even after fresh aggregate was added in spring 2020.

In contrast, the gradation of the Hamilton County Claycrete section changed less over time but was further from the gravel-sized portion of the specification band than the Washington County gradation (Figure 122).

6.2.6 Dustometer Test Results

The results for all dustometer tests are shown in Figure 123 through Figure 126, along with the moisture contents from nuclear gauge measurements (see previous Table 15 through Table 30).

After construction in fall 2018, the measured dust generation was highest in Howard County and lowest in Washington County. In Cherokee County, the control section generated the most dust in fall 2018 while the slag sections generated the least, yet the slag sections were among the largest generators of dust in Howard County (Figure 123).

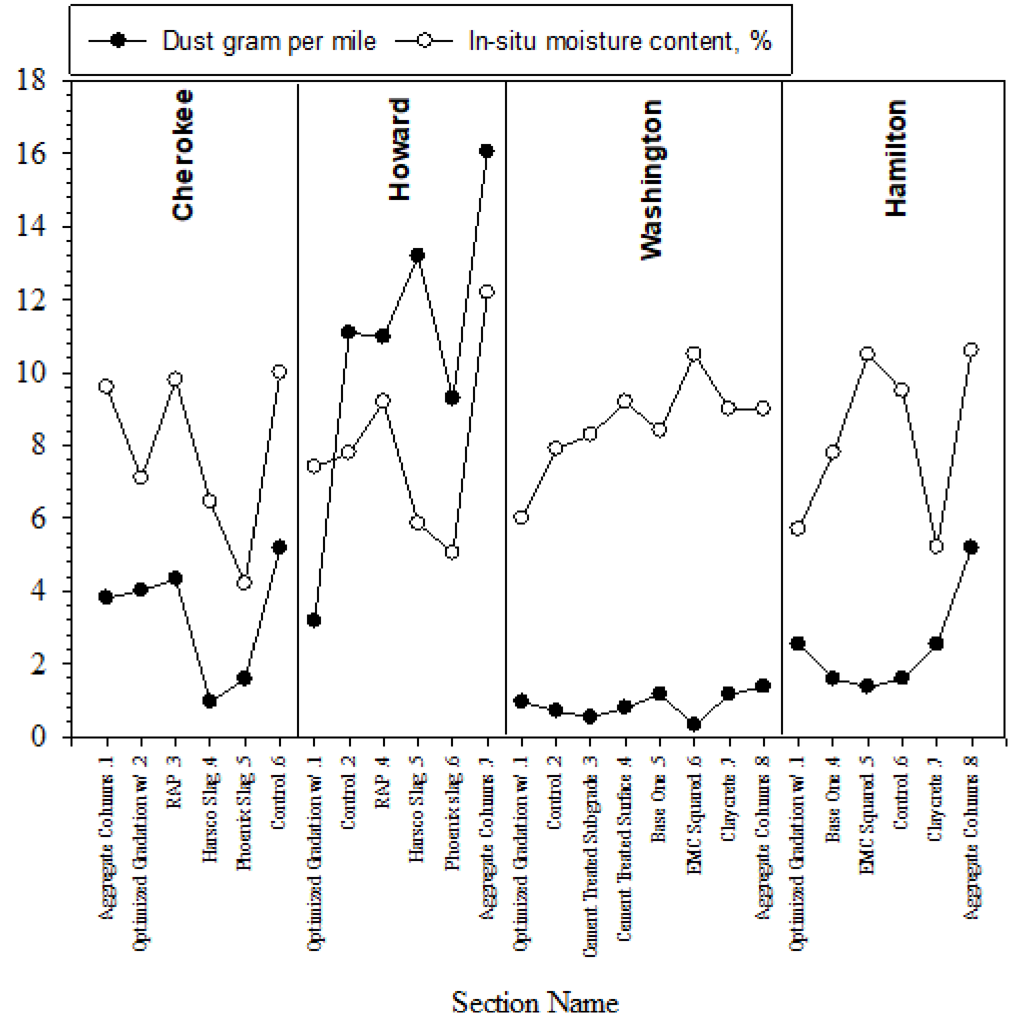


Figure 123. Dustometer results for fall 2018 tests

By spring 2019, dust production in the control section decreased more than all other sections in Cherokee County, while the BASE ONE section in Washington County and the control section in Hamilton County had the most dust (Figure 124). Note that dustometer results were not available in Howard County in spring 2019 due to prolonged rain.

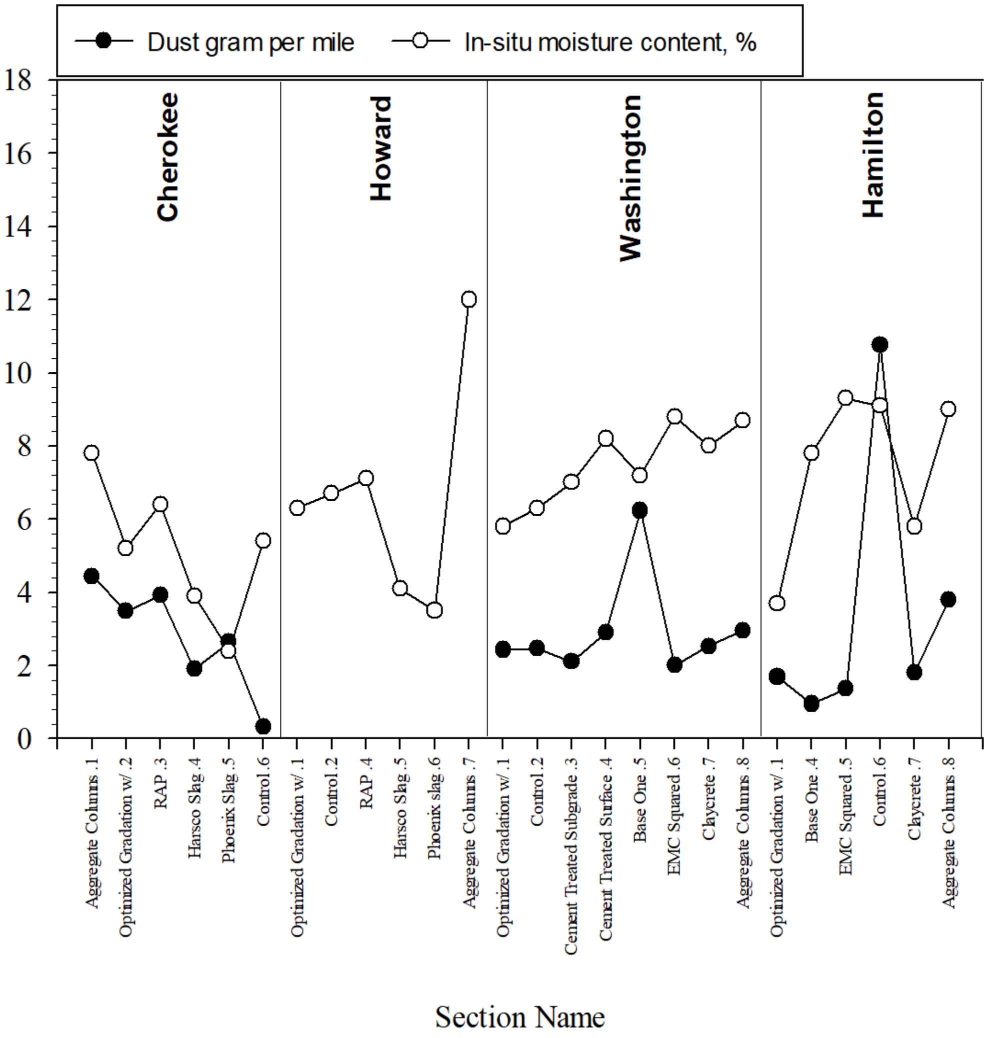


Figure 124. Dustometer results for spring 2019 tests

Figure 125 shows the dustometer test results for fall 2019.

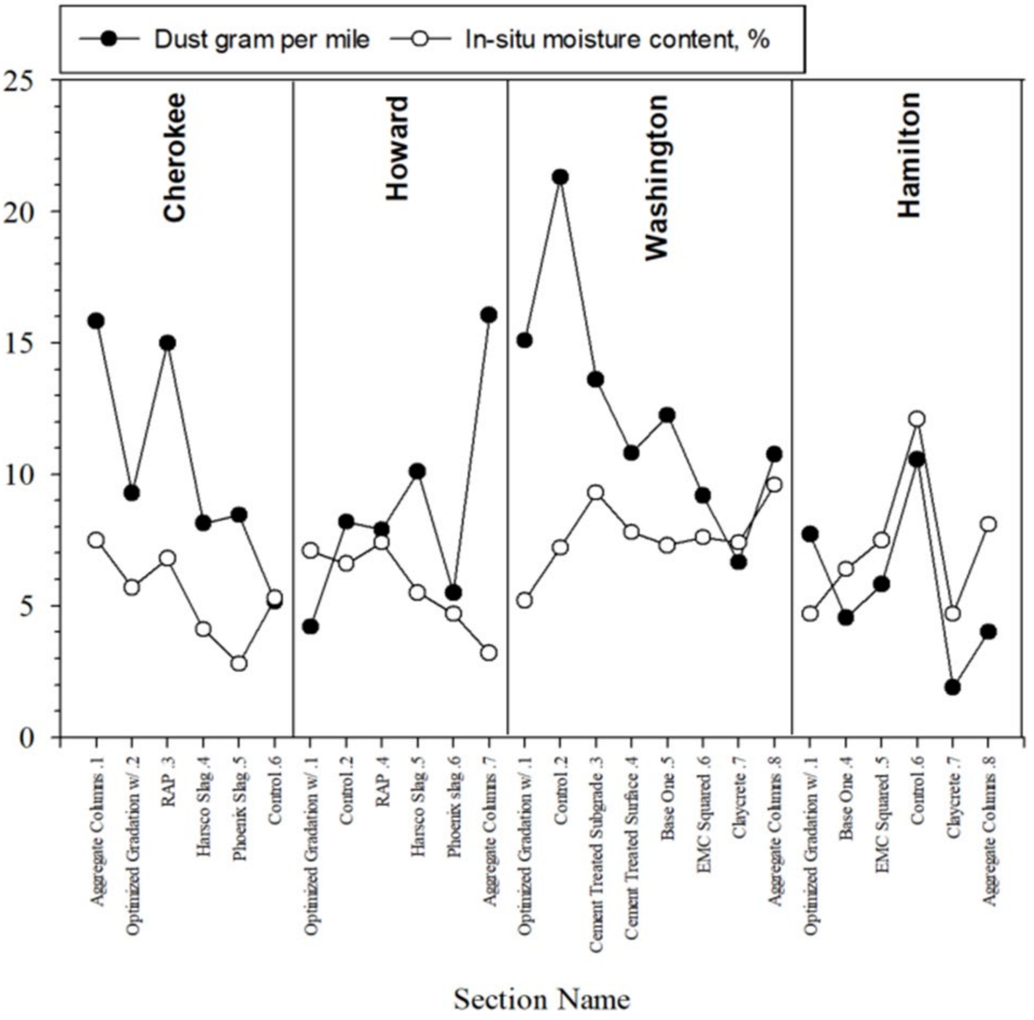


Figure 125. Dustometer results for fall 2019 tests

By spring 2020, all test sections exhibited lower dust emissions due to maintenance, but the control section and Phoenix slag sections in Howard County, as well as the aggregate columns section in Hamilton County, generated the most dust (Figure 126).

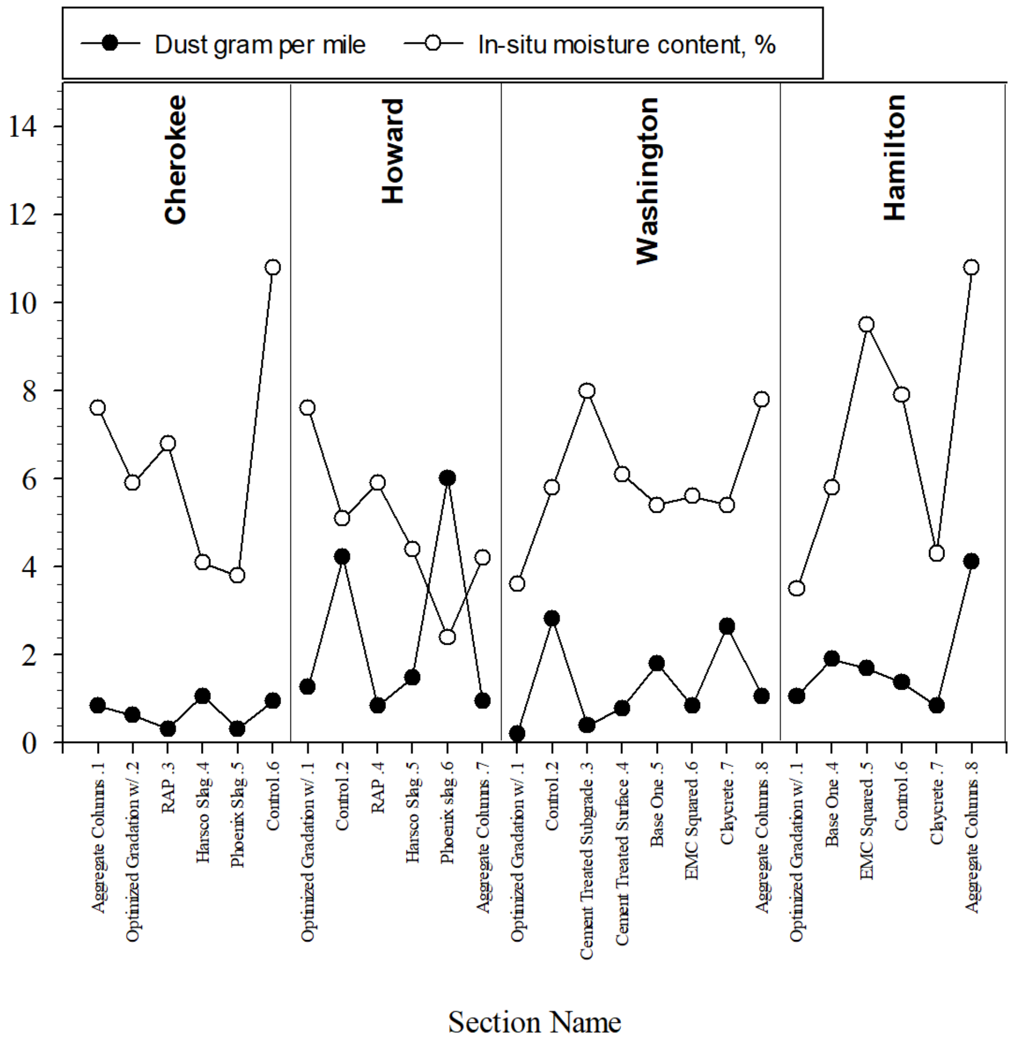


Figure 126. Dustometer results for spring 2020 tests

Weather information for the dustometer test dates is presented in Table 35.

Table 35. Weather information for dustometer test dates

Location	Test Date	Temperature (°F)	Humidity (%)	Wind Speed, (mph)	Precipitation Prior 3 days
Cherokee County	11/23/2018	26.6	68%	5.0	1 in. snow (11/11/2018)
Howard County	10/30/2018	44.6	70%	9.9	None
Washington County	11/14/2018	23	93%	5.0	None
Hamilton County	11/13/2018	19.4	80%	9.9	None
Cherokee County	4/25/2019	57.2	68%	10.6	None
Howard County	5/4/2019	55.4	73%	3.7	None
Washington County	4/9/2019	57.2	48%	7.5	None
Hamilton County	4/21/2019	68	50%	6.2	None
Cherokee County	10/24/2019	35.6	81%	4.3	None
Howard County	10/16/2019	42.8	84%	4.3	None
Washington County	11/14/2019	24.8	81%	6.8	None
Hamilton County	11/18/2019	39.2	94%	1.2	0.1 in. rain (11/17/2018)
Cherokee County	6/9/2020	73.4	76%	9.3	None
Howard County	6/8/2020	73.4	57%	8.1	None
Washington County	6/11/2020	69.8	60%	8.7	None
Hamilton County	6/8/2020	80.6	61%	4.3	None

Overall, the dustometer results are somewhat erratic and depend on the weather conditions leading up to the particular test date. However, they provide a snapshot of the relative dust production in the different test sections on the same day. While dust production in most test sections fluctuated up and down over time, the control, RAP, OGCS, and aggregate columns sections were generally among the highest generators of dust.

6.2.7 Visual Surveys with Images

Visual surveys were conducted during field testing each fall and spring, in which digital images were captured and surface distresses were documented to evaluate the performance of the different test sections. The images from all surveys in all four counties are included in Appendix B.

Throughout the study, the most common surface distress issues observed were rutting and potholes, with rutting caused by agricultural machinery on the road surface and shoulder being the most common issue in all counties. Examples of these conditions are shown in Figure 127 and Figure 128.

Figure 127. Rutting in EMC SQUARED section in Hamilton County during spring 2019

Figure 128. Rutting in Howard County OGCS section during spring 2020

Figure 129 shows a place in the OGCS section in Hamilton County where the clay binder migrated to the surface because of freeze-thaw cycles.

Figure 129. Clay on the surface in Hamilton County Claycrete section

The worst surface distresses were found in Washington County in spring 2020, as shown in Figure 130, where it should be noted that the 4 in. cement-treated surface section looks more favorable because it had just been covered with fresh aggregate five days prior to the survey.

Figure 130. Potholes in control section in Washington County during spring 2020

During the same survey, the cement-treated subgrade, BASE ONE, and Claycrete sections had the least amount of surface distress; the OGCS section was slightly better than the control section, while the cement-treated subgrade and aggregate columns sections were worse; and the

EMC SQUARED section had significant potholes. In general, most test sections held up well relative to the control sections over the course of the survey, except for spring 2020 in Washington County.

The stabilized Howard County sections also held up remarkably well in spring 2019 compared to both the control section and nearby roads that were recently resurfaced. At the time, some of the surrounding untreated roads were nearly impassable or closed due to significant damage and flooding from melting of snow followed by significant precipitation resulting in the worst road conditions seen in decades, while the test sections were in relatively good condition (see Figure 131).

OGCS
Control
RAP
Resurfaced nearby Rd.
Harsco Slag
Phoenix Slag
Aggregate Columns
Resurfaced Nearby

Figure 131. Test sections and recently resurfaced nearby roads in Howard County March 14, 2019

6.3 Cost Summary and Economic Analysis

To help assess the cost-effectiveness of the various stabilization methods examined for mitigating freeze-thaw damage, a summary of the construction and maintenance costs was prepared with the assistance of the county engineers.

6.3.1 Construction Costs

Figure 132 presents a summary of construction costs, the details of which are listed in Table 36.

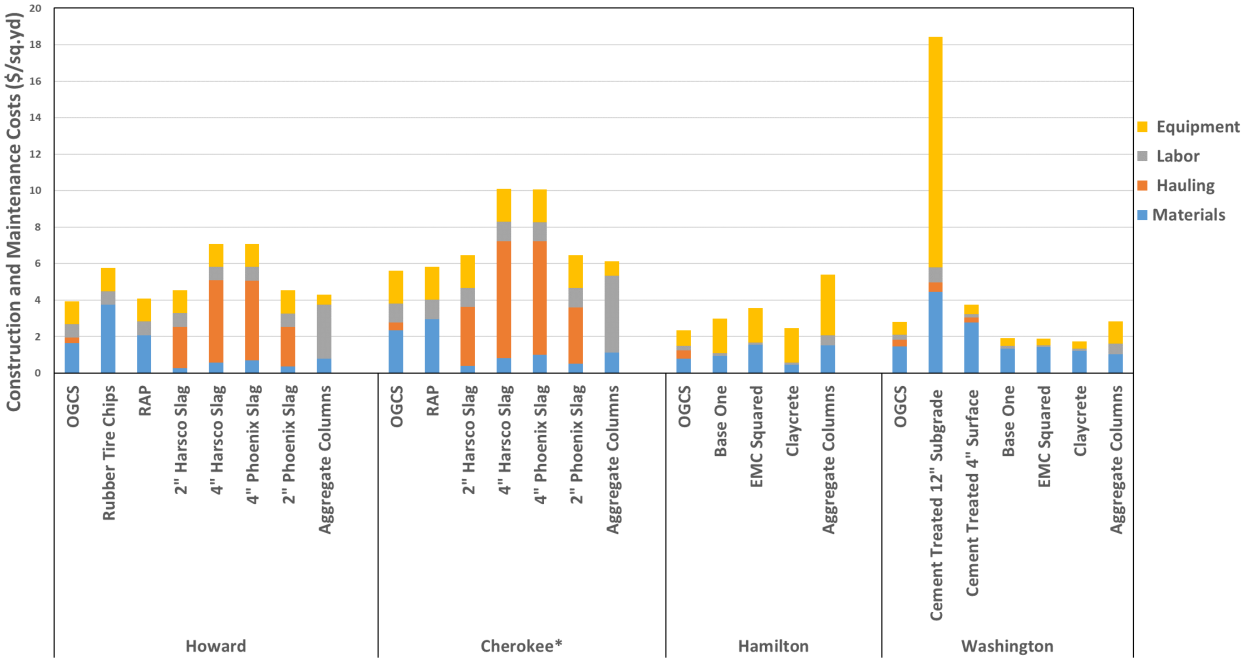


Figure 132. Construction costs ($/yd^2) for stabilized test sections in all four counties

Table 36. Breakdown of construction costs for test sections in all four counties ($\$/yd^2$)

County	Test Section	Materials	Hauling	Labor	Equipment	Total Cost
Howard	OGCS	1.65	0.29	0.74	1.27	3.95
	Rubber Tire Chips	3.76	0.00*	0.74	1.27	5.76
	RAP	2.09	0.00*	0.74	1.27	4.09
	2 in. Harsco Slag	0.28	2.26	0.74	1.27	4.55
	4 in. Harsco Slag	0.57	4.52	0.74	1.27	7.09
	4 in. Phoenix Slag	0.71	4.37	0.74	1.27	7.08
	2 in. Phoenix Slag	0.35	2.19	0.74	1.27	4.54
	Aggregate Columns	0.80	0.00*	2.95	0.56	4.30
Cherokee	OGCS	2.35	0.42	1.05	1.80	5.62
	Rubber Tire Chips	5.35	0.00*	1.05	1.80	8.20
	RAP	2.97	0.00*	1.05	1.80	5.82
	2 in. Harsco Slag	0.40	3.22	1.05	1.80	6.47
	4 in. Harsco Slag	0.81	6.43	1.05	1.80	10.09
	4 in. Phoenix Slag	1.01	6.22	1.05	1.80	10.08
	2 in. Phoenix Slag	0.50	3.11	1.05	1.80	6.46
	Aggregate Columns	1.14	0.00*	4.19	0.80	6.13
Hamilton	OGCS	0.78	0.46	0.26	0.85	2.35
	BASE ONE	0.95	0.00*	0.14	1.91	3.00
	EMC SQUARED	1.56	0.00*	0.10	1.91	3.57
	Claycrete	0.45	0.00*	0.13	1.91	2.48
	Aggregate Columns	1.53	0.00*	0.53	3.34	5.41
Washington	OGCS	1.48	0.35	0.27	0.72	2.82
	Control	1.16	0.00*	0.04	0.10	1.30
	12 in. Cement-Treated Subgrade	4.47	0.49*	0.85	12.63	18.44
	4 in. Cement-Treated Surface	2.76	0.30*	0.18	0.52	3.76
	BASE ONE	1.34	0.00*	0.15	0.44	1.93
	EMC SQUARED	1.42	0.00*	0.11	0.35	1.88
	Claycrete	1.21	0.00*	0.13	0.39	1.73
	Aggregate Columns	1.04	0.00*	0.57	1.21	2.83

* Portions of Hauling costs for some materials were included in Materials cost

The figure shows that the construction costs for the mechanically stabilized sections were higher than those for the chemically stabilized sections. Given that Howard County is in far northeast Iowa and Cherokee County is in far northwest Iowa, hauling costs were the most significant component of the construction costs for the steel slag sections. For use of steel slag to be cost-effective, a nearby source of material is needed.

For the RAP sections, the material costs were also relatively high despite the materials being locally obtained. This was because prices for RAP have been rising in recent years due to its increased usage in construction of recycled pavements.

For the 12 in. cement-treated subgrade section, the costs for materials and equipment were significant due to the specialized equipment and operators required (i.e., pneumatic tanker, spreader truck, rotary mixer, vibratory roller). Although this section performed well over the two-year project duration, the high initial cost needs to be weighed against the potential long-term reductions in maintenance costs.

The construction costs for the other stabilized sections were comparatively low. The four OGCS sections and the 4 in. cement-treated surface section provided good performance with low construction costs, making them two of the most cost-effective stabilization methods examined in this study.

The aggregate columns sections did not perform as well as in previous studies and, therefore, were not as cost-effective as the other methods examined.

The three liquid chemical stabilizer sections were among the least expensive to construct and exhibited some improvement over the control section in Hamilton County, as well as prior to the second year of spring tests in Washington County, at which time additional fresh maintenance aggregate was required on all three sections.

6.3.2 Maintenance Costs

After construction of the test sections was completed, the maintenance requirements for each section, including cost details, were recorded by the county engineering offices. A set of Surface Condition Rating Report sheets were given to the counties for grader operators to fill out each time they needed to perform maintenance on the test sections.

The reports requested a numerical score from 1 (most severe) to 9 (least severe) for rutting, washboarding, potholes, loose aggregate, dust, and crown conditions. The detailed reports are included in Appendix A.

Most of the reported maintenance costs resulted from blading the entire mile containing the test sections at once, in which case, the total cost of blading had to be evenly divided among the sections.

In Howard County in fall 2019, 40 tons of rock were applied on the control section surface, while 15 tons of 1 in. clean aggregate were applied on the aggregate columns section. The price for both materials was $12.44 per ton.

In Washington County in spring 2020, 3/4 in. rock was widely applied on the surfaces of the three liquid-stabilized sections as well as the aggregate columns section and the 4 in. cement-treated surface section.

Details of the maintenance costs are provided in Table 37.

Table 37. Breakdown of maintenance costs for all four counties

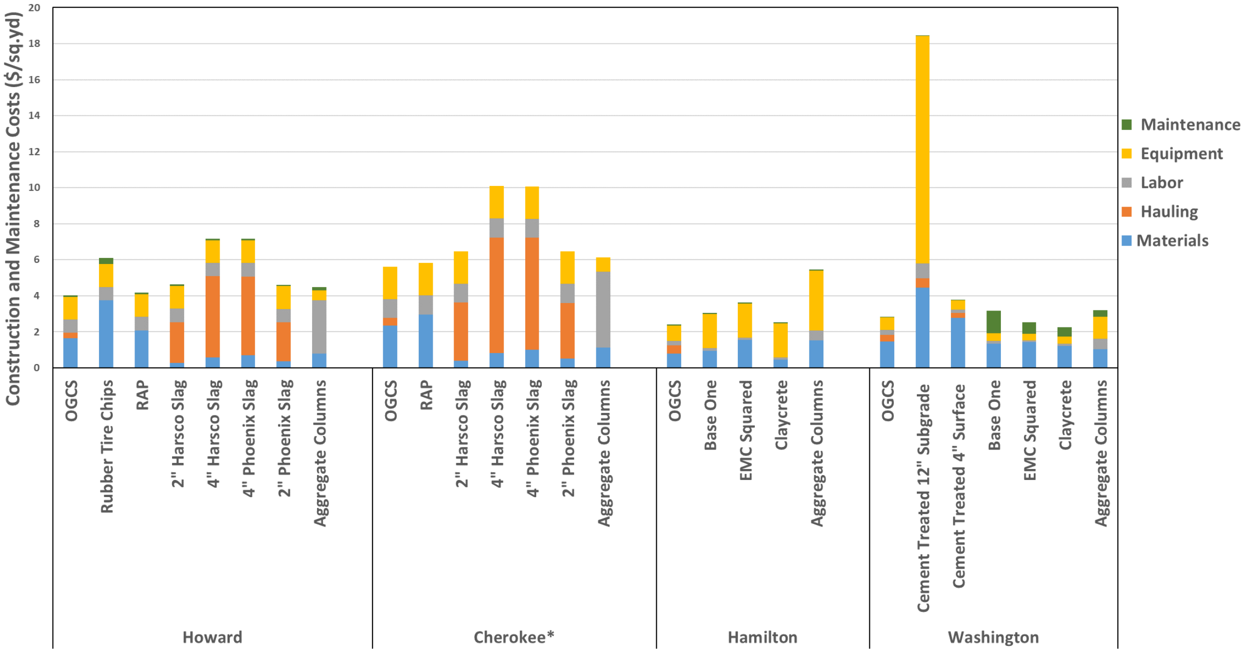
Date	County	Description	Section Name	Aggregate (tons)	Material Cost $	Equipment Cost $	Labor Cost $	Total Cost $	Cost ($/yd^2)
9/23/2019	Hamilton	8 hrs blading for all	OGCS	NA	NA	57.67	24.13	81.80	0.045
			BASE ONE	NA	NA	57.67	24.13	81.80	0.045
			EMC SQUARED	NA	NA	57.67	24.13	81.80	0.045
			Control	NA	NA	57.67	24.13	81.80	0.045
			Claycrete	NA	NA	57.67	24.13	81.80	0.045
			Aggregate Columns	NA	NA	57.67	24.13	81.80	0.045
3/25/2020	Hamilton	4 hrs blading for all	OGCS	NA	NA	9.58	4.02	13.60	0.007
			BASE ONE	NA	NA	9.58	4.02	13.60	0.007
			EMC SQUARED	NA	NA	9.58	4.02	13.60	0.007
			Control	NA	NA	9.58	4.02	13.60	0.007
			Claycrete	NA	NA	9.58	4.02	13.60	0.007
			Aggregate Columns	NA	NA	9.58	4.02	13.60	0.007
6/18/2020	Hamilton	2 hrs blading for all	OGCS	NA	NA	4.79	2.01	6.80	0.004
			BASE ONE	NA	NA	4.79	2.01	6.80	0.004
			EMC SQUARED	NA	NA	4.79	2.01	6.80	0.004
			Control	NA	NA	4.79	2.01	6.80	0.004
			Claycrete	NA	NA	4.79	2.01	6.80	0.004
			Aggregate Columns	NA	NA	4.79	2.01	6.80	0.004
fall 2019	Howard	1.42 hrs blading	OGCS	NA	NA	99.49	51.37	150.86	0.073
		1.9 hrs blading	Control	40	497.60	133.01	68.68	699.29	0.340
		1.54 hrs blading	RAP	NA	NA	108.28	55.91	164.19	0.080
		0.75 hrs blading	2 in. Harsco Slag	NA	NA	52.48	27.10	79.58	0.077
		0.75 hrs blading	4 in. Harsco Slag	NA	NA	52.48	27.10	79.58	0.077
		0.75 hrs blading	4 in. Phoenix Slag	NA	NA	52.48	27.10	79.58	0.077
		0.75 hrs blading	2 in. Phoenix Slag	NA	NA	52.48	27.10	79.58	0.077
		1.5 hrs blading	Aggregate Columns	15	186.60	104.96	54.20	345.76	0.168

Date	County	Description	Section Name	Aggregate (tons)	Material Cost $	Equipment Cost $	Labor Cost $	Total Cost $	Cost ($/yd^2)
fall 2019	Washington	3 hrs blading for all	OGCS	NA	NA	30.06	16.27	46.33	0.030
			Control	NA	NA	30.06	16.27	46.33	0.030
			12 in. Cement-Treated Subgrade	NA	NA	24.05	13.02	37.08	0.030
			4 in. Cement-Treated Surface	NA	NA	24.05	13.02	37.08	0.030
			BASE ONE	NA	NA	30.06	16.27	46.33	0.030
			EMC SQUARED	NA	NA	30.06	16.27	46.33	0.030
			Claycrete	NA	NA	30.06	16.27	46.33	0.030
			Aggregate Columns	NA	NA	30.06	16.27	46.33	0.030
2/4/2020	Washington	2 hrs blading for all	BASE ONE	4.63	48.52	67.85	39.74	156.11	0.090
			EMC SQUARED	4.63	48.52	67.85	39.74	156.11	0.090
3/24/2020	Washington	2.5 hrs blading for all	4 in. Cement-Treated Surface	26	272.48	165.48	95.91	533.87	0.390
3/31/2020	Washington	3.75 hrs blading for all	BASE ONE	7.09	74.36	136.56	133.57	344.49	0.170
			EMC SQUARED	7.09	74.36	136.56	133.57	344.49	0.170
5/19/2020	Washington	7.5 hrs blading for all	BASE ONE	67.02	702.37	341.60	212.34	762.06	0.730
			EMC SQUARED	34.06	356.95	173.60	107.91	762.06	0.370
			Claycrete	30.40	318.59	154.95	96.32	762.06	0.330
			Aggregate Columns	31.13	326.24	158.67	98.63	762.06	0.340

In Hamilton County, no additional surface aggregate was applied to the test sections over the duration of the project, and blading was done for the entire 1 mile test site, so no difference in maintenance costs could be determined between the test sections. The OGCS, slag, and RAP sections had the lowest maintenance costs per yd^2.

In Cherokee County, unfortunately, the detailed maintenance costs could not be located due to a change in leadership in that county engineering office during the project. However, the previous county engineer mentioned that 45 tons of Class A limestone was applied on the surfaces of both the 2 in. Phoenix slag section and the control section, because these two sections did not hold up to plowing.

The total cost summary, including the available data on both construction and maintenance costs, is presented in Figure 133.



* Cherokee County maintenance cost information was not provided

Figure 133. Construction and maintenance costs ($/yd^2) for all four counties

The three liquid stabilizers and the OGCS sections had the lowest total cost; whereas, that of the 4 in. cement-treated subgrade section was only slightly higher. The 12 in. cement-treated subgrade and 4 in. slag sections had the highest total costs, while that of the failed rubber tire chips section was comparable to that of the 2 in. slag sections.

To be cost-effective, a stabilization method should provide relatively good surface and subgrade strength after curing or an initial period of traffic loading, effective mitigation of moisture damage related to freeze-thaw cycles, improvements in surface strength and reductions in surface distresses over multiple years, and ideally require only conventional roadway construction methods using equipment and materials readily available to secondary roads departments. Since long-distance hauling can increase construction costs significantly, county engineers need to account for the distances to various material sources when considering different stabilization methods.

CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS

Over the two-year project duration, extensive field and laboratory tests were performed to study a selected set of chemical and mechanical stabilization methods for mitigating damage caused to granular-surfaced roads in Iowa by freeze-thaw cycles. This final chapter provides overall conclusions from the research, as well as recommendations for further research and practice in stabilization of granular-surfaced roads in Iowa.

7.1 Conclusions

Many of the test sections remained stabilized well after construction, but the ground tire rubber section was deemed to have failed. Other than the cement-stabilized subgrade method, which requires use of a large powder spreader and rotary mixer, the necessary materials and equipment for the various stabilization methods are readily obtainable by counties and utilize conventional granular roadway construction methods at relatively low cost.

The OGCS sections generally exhibited good strength (DCP-CBR) performance compared to the control sections, and the OGCS surface course elastic modulus from LWD tests and composite elastic modulus from FWD tests were also improved in all counties. Considering the improved performance and relatively low cost, the OGCS method is a relatively cost-effective stabilization technique.

For the RAP sections, the improvement in strength was marginal compared to the control sections, and no improvement was seen in modulus from LWD or FWD tests. Considering that the price for recycled asphalt has increased in recent years, blending aggregates with RAP does not appear to be a cost-effective method at this time.

For all four of the steel slag sections in Howard and Cherokee counties, the DCP-CBR, LWD elastic modulus, and FWD elastic modulus results were relatively good compared to that for the control sections initially in fall 2018 before the first of the two freeze-thaw cycles. However, over the next two years, the surface strength of the slag sections diminished significantly because of freeze-thaw damage. In addition, the hauling costs for the steel slag sections were significant due to the distances, which ranged from 165 to 317 miles, for the slag from their sources.

For the aggregate columns sections, the performance from fall 2018 to spring 2020 was unsatisfactory in all four counties, and the strengths of these sections were below those of their corresponding control sections. This may be due to the columns acting like retention basins and increasing the moisture content of the subgrade below these sections. Based on the test results, the aggregate columns method did not effectively mitigate damage from freeze-thaw cycles for the 12 in. diameter by 7 ft deep column size used in this Phase III study. However, this method performed better in the previous Phase II study, which employed smaller 8 in. diameter by 6 ft deep columns.

Both the cement-treated surface and cement-treated subgrade sections showed extraordinary improvements in DCP-CBR values (strength) and elastic modulus (stiffness). While the use of portland cement can obviously improve the strengths of both the surface and subgrade layers, the construction process for the 12 in. cement-treated subgrade section was more complicated and required more specialized equipment than the other test sections. The need for the large rotary mixer, pneumatic tanker, and powder spreader truck resulted in much higher mobilization and overall initial construction costs than the other sections. This method may be more financially justifiable if a county has a significant length of particularly bad roads to stabilize or can partner with a neighboring county to share mobilization costs.

On the other hand, the 4 in. cement-treated surface section was constructed at relatively low cost and requires only a way to spread the cement powder, a water truck and motor grader, and a RoadHog or similar milling attachment. Based on the observed excellent strength performance against freeze-thaw cycle damage, the 4 in. cement-treated surface was found to be a cost-effective method, but engineers must consider the material, equipment, and hauling costs when applying this method to any particular site. Additionally, the test surface did suffer from several potholes after two years of service, which required spreading 26 tons of maintenance aggregates over the 500 ft long roadway surface.

The sections treated with the Claycrete, BASE ONE, and EMC SQUARED liquid stabilizers in Washington County did not meet Iowa DOT gradation specifications right after construction, but this was anticipated as they each required incorporation of different thicknesses of subgrade soils during construction. Based on their resulting gradations and performance, these sections may have performed better in Washington County if less subgrade and perhaps less water were incorporated during construction. On the other hand, these three methods had gradations closer to the Iowa DOT specifications and good overall performance in Hamilton County.

7.2 Recommendations

Beneficial stabilization methods should provide good performance at acceptable costs. In this study, the steel slag test sections showed good performance in the beginning but exhibited reduced freeze-thaw resistance over time and had high hauling costs. The 12 in. cement-treated subgrade method performed well but does not meet the overall project goal, which was to identify economical and effective stabilization methods that counties can implement by themselves with readily available equipment.

Based on the test results and cost summary presented in this report, the most suitable stabilization methods meeting the project goals are the 4 in. cement-treated surface and OGCS methods, as well as the BASE ONE, EMC SQUARED, and Claycrete liquid stabilizers. For these concentrated liquid stabilizers, care should be taken to closely follow the manufacturer’s recommended construction methods, with particular attention to the amount and type of subgrade soils incorporated and the amount of compaction water added.

The 4 in. cement-treated surface method had a relatively low cost and provided good performance against freeze-thaw damage. Given this method was only applied in Washington

County, further study is recommended to determine whether it can be widely applied with similar success in other regions of Iowa.

The OGCS method improved the DCP-CBR strength values as well as the stiffnesses, and after the slurry was applied by the tanker trucks, the method was easily implemented by county secondary roads departments with existing equipment and crews. The company that processes the clay slurry now sells the product in the form of a pre-treated and dried aggregate containing the clay binder, which should reduce construction costs related to hauling the large amounts of water contained in the slurry. Additional studies are recommended to develop construction methods and measure the performance of such aggregates pre-treated with the clay binder.

The sections treated with the Claycrete, BASE ONE, and EMC SQUARED liquid stabilizers in Washington County did not perform as well as those in Hamilton County. Since these three chemical stabilization products showed good performance in Hamilton County at relatively low cost, further studies are recommended to examine how their effectiveness can be improved for the typical freeze-thaw conditions in Iowa.

The influence of the type and gradation of both surfacing aggregates and subgrade soils should also be studied to better understand why the three liquid stabilizers performed better in Hamilton County than in Washington County. When building new test sections, construction quality control measures should be used to ensure the best performance of liquid stabilizers on future research projects.

For example, field measurement of moisture content during construction would not only help ensure that the materials are compacted close to their OMC as determined by laboratory compaction tests but also indicate when materials are wet of optimum due to precipitation and therefore require aeration by blading or mixing. Additionally, field soil density tests, such as sand cone, rubber balloon, or nuclear gauge tests, could be performed during construction to help determine if compaction is adequate and to provide better information for making field adjustments.

Finally, the influence of moisture content on the thermo-hydro mechanics of the aggregate columns should be studied to understand their relatively poor performance in this project despite good performance of smaller columns in previous projects. The moisture content is related to the regional subgrade and weather conditions and should be carefully evaluated including consideration of the local topography as well as nearby creeks and other water sources such as culverts or drainage pipes beneath the sections. All of these factors may contribute to the moisture content and therefore the final performance of a test section.

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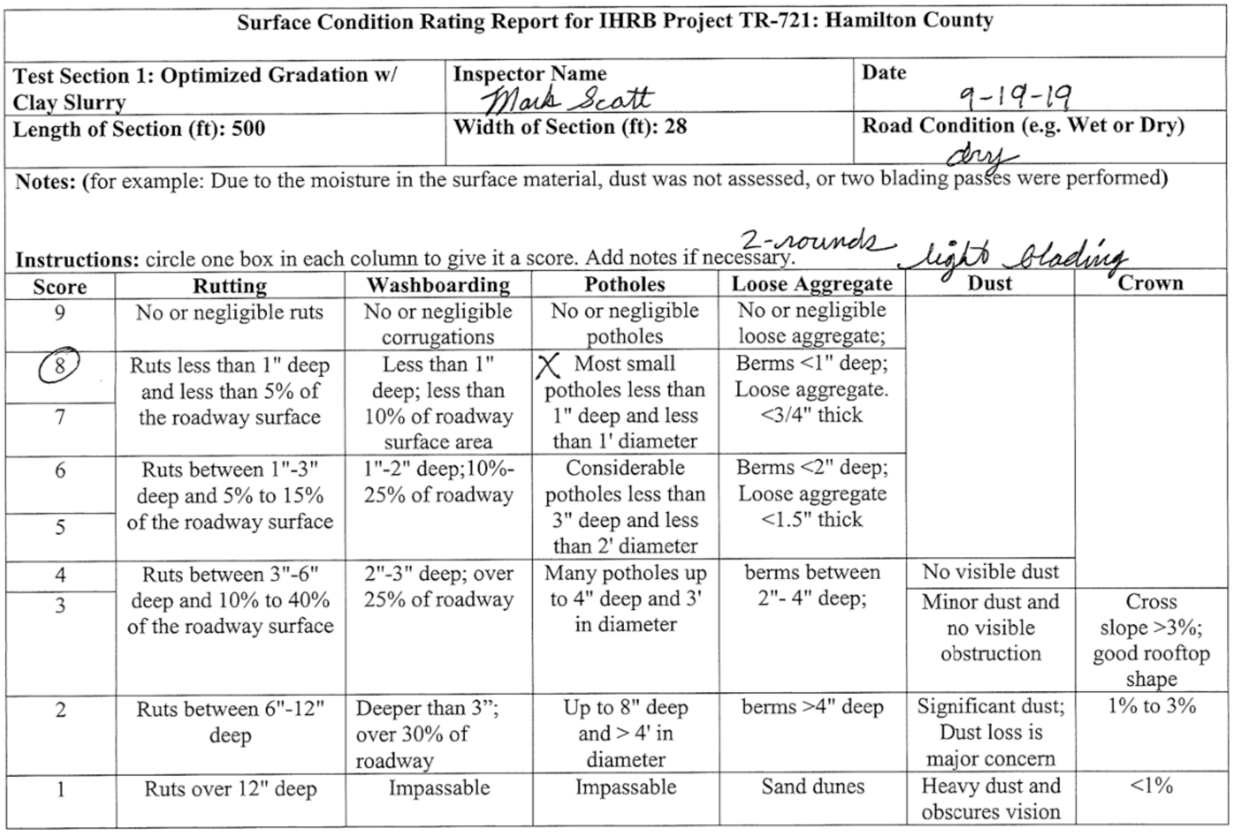
APPENDIX A. SURFACE CONDITION RATING REPORTS

Hamilton County Reports



Surface Condition Rating Report for IHRB Project TR-721: Hamilton County

Test Section 1: Optimized Gradation w/ Clay Slurry	**Inspector Name** Mark Scott	**Date** 9-19-19
Length of Section (ft): 500	**Width of Section (ft): 28**	**Road Condition (e.g. Wet or Dry)** dry

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

2-rounds light blading

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	No or negligible ruts	No or negligible corrugations	No or negligible potholes	No or negligible loose aggregate;		
[✓ 8]	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	X Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					Minor dust and no visible obstruction	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Hamilton County

Test Section 4: Base One
Inspector Name Mark Scott
Date 9-19-19
Length of Section (ft): 500
Width of Section (ft): 25
Road Condition (e.g. Wet or Dry) dry

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

Black spots - low material 2-rounds light blading

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	No or negligible ruts	No or negligible corrugations	No or negligible potholes	No or negligible loose aggregate;		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	[✓ Considerable potholes less than 3" deep and less than 2' diameter]	Berms <2" deep; Loose aggregate <1.5" thick		
[✓ 5]						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					Minor dust and no visible obstruction	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Hamilton County

Test Section 6: Control Section
Inspector Name Mark Scott
Date 9-19-19
Length of Section (ft): 500
Width of Section (ft): 28
Road Condition (e.g. Wet or Dry) dry

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

Black spots - low material 2-rounds light blading

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	No or negligible ruts	No or negligible corrugations	No or negligible potholes	No or negligible loose aggregate;		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
[✓ 5]						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					Minor dust and no visible obstruction	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Hamilton County

Test Section 7: Claycrete	**Inspector Name** Mark Scott	**Date** 9-19-19
Length of Section (ft): 500	**Width of Section (ft): 25**	**Road Condition (e.g. Wet or Dry)** dry

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

2-rounds light blading

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
[✓ 9]	No or negligible ruts	No or negligible corrugations	No or negligible potholes	No or negligible loose aggregate;		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					Minor dust and no visible obstruction	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Hamilton County

Test Section 8: Aggregate Columns	**Inspector Name** Mark Scott	**Date** 9-19-19
Length of Section (ft): 500	**Width of Section (ft): 28**	**Road Condition (e.g. Wet or Dry)** dry

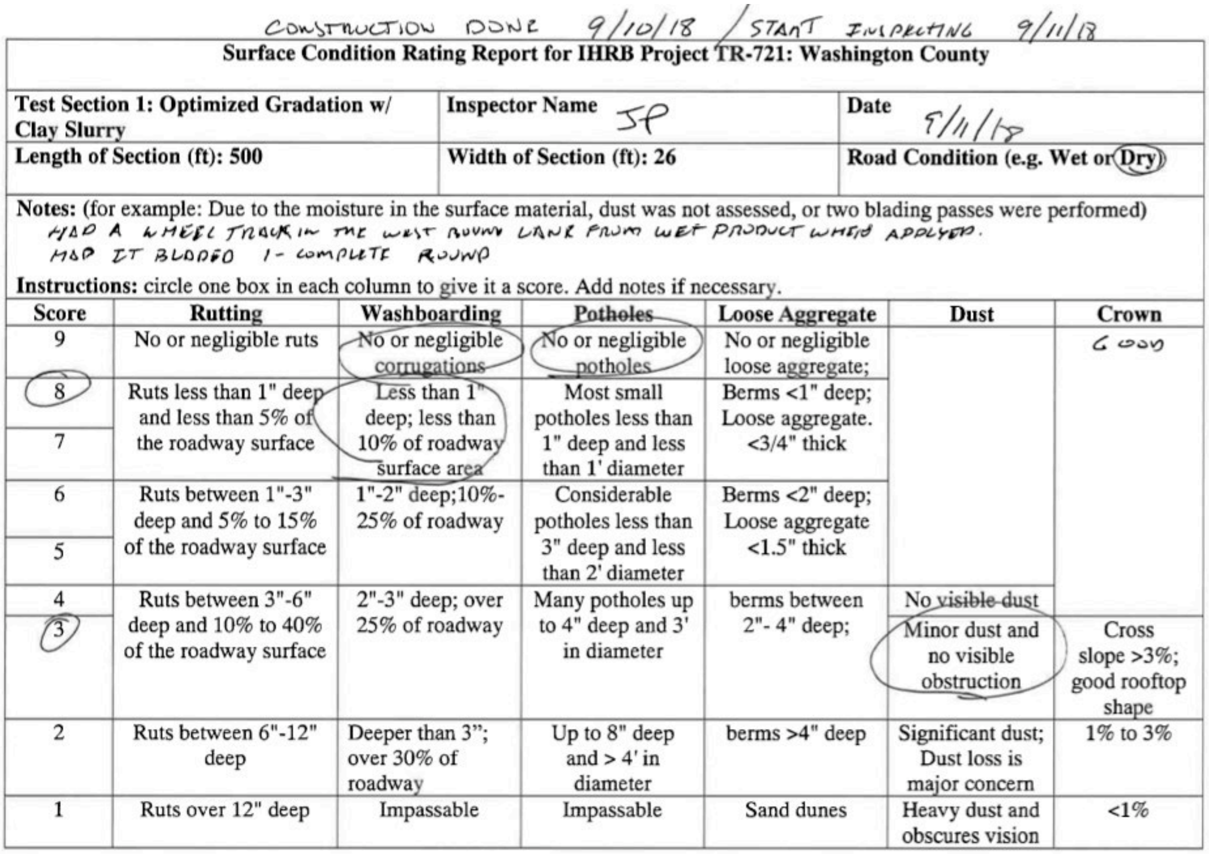
Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

2-rounds light blading

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
[✓ 9]	No or negligible ruts	No or negligible corrugations	No or negligible potholes	No or negligible loose aggregate;		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					Minor dust and no visible obstruction	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Reports for Washington County OGCS Section



CONSTRUCTION DONE 9/10/18 / START INSPECTING 9/11/18

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 1: Optimized Gradation w/ Clay Slurry	**Inspector Name** JP	**Date** 9/11/18
Length of Section (ft): 500	**Width of Section (ft): 26**	**Road Condition (e.g. Wet or [✓ Dry])**

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)
HAD A WHEEL TRACK IN THE WEST BOUND LANE FROM WET PRODUCT WHEN APPLYED.
HAD IT BLADED 1- COMPLETE ROUND

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	No or negligible ruts	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	No or negligible loose aggregate;		GOOD
[✓ 8]	Ruts less than 1" deep and less than 5% of the roadway surface	[✓ Less than 1" deep; less than 10% of roadway surface area]	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
[✓ 3]					[✓ Minor dust and no visible obstruction]	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 1: Optimized Gradation w/ Clay Slurry	**Inspector Name**	**Date** 10/8/18
Length of Section (ft): 500	**Width of Section (ft): 26**	**Road Condition (e.g. [✓ Wet] or Dry)**

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)
GOOD SHAPE NO POTHOLES RAIN - 4" FOR 3 DAYS
NO PICS

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	No or negligible ruts	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					Minor dust and no visible obstruction	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 1: Optimized Gradation w/ Clay Slurry	**Inspector Name**	**Date** 10/16/18
Length of Section (ft): 500	**Width of Section (ft): 26**	**Road Condition (e.g. Wet or [✓ Dry])**

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)
NO BLADING REQUIRED

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	[✓ No visible dust]	
3					Minor dust and no visible obstruction	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 1: Optimized Gradation w/ Clay Slurry
Inspector Name JB
Date 12/3/18
Length of Section (ft): 500
Width of Section (ft): 26
Road Condition (e.g. [✓ Wet] or Dry)

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)
HAD 12" SNOW A WEEK AGO AND RAIN LAST TWO DAYS – ROAD WAS NOT FROZE BEFORE + AFTER SNOW + RAIN
PICS TAKEN

Instructions: circle one box in each column to give it a score. Add notes if necessary. NEED WORD AL DESCR. ON COMPUTER

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	No or negligible ruts	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		GOOD
8	[✓ Ruts less than 1" deep and less than 5% of the roadway surface]	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	[✓ No visible dust]	
3					Minor dust and no visible obstruction	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

THIS SECTION OF ROAD IS UP ON FLAT WHERE MOST OF THE SNOW BLEW OFF

Surface Condition Rating Report for IHRB Project TR-721: Washington County

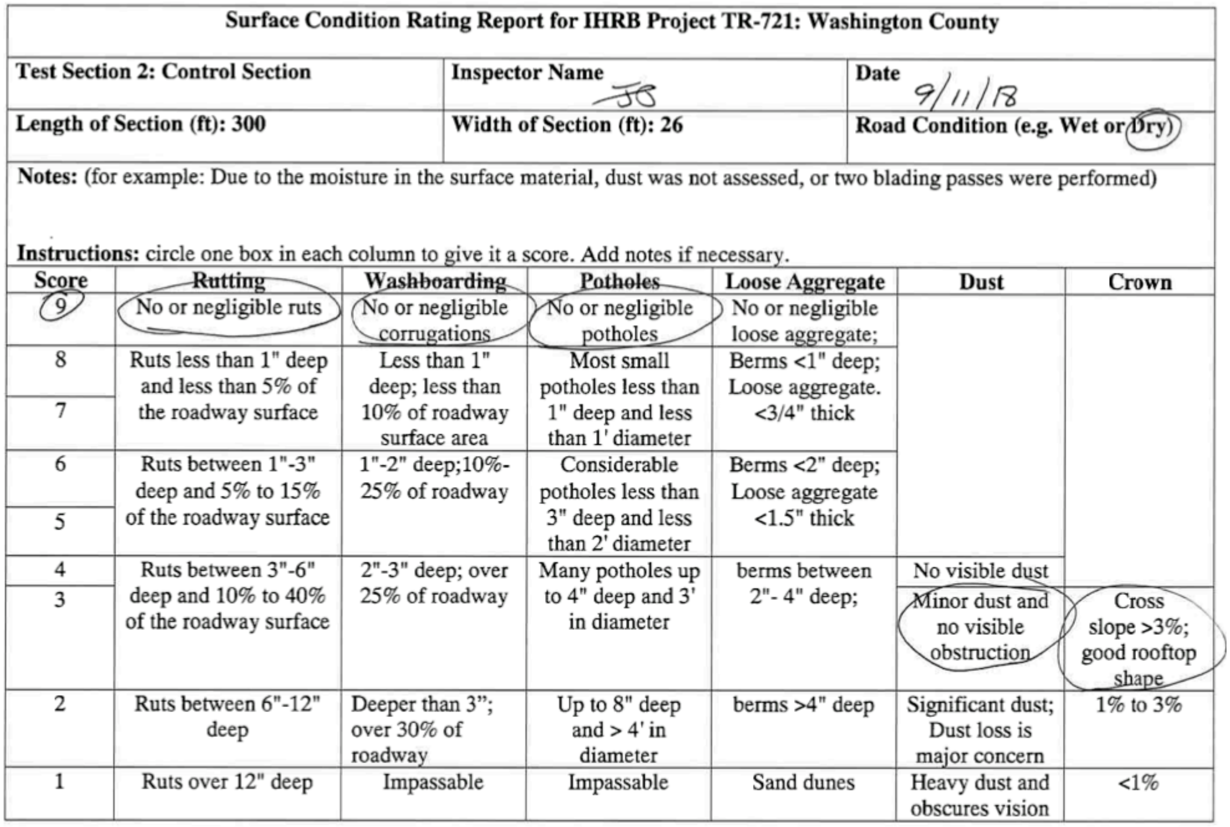
Test Section 1: Optimized Gradation w/ Clay Slurry
Inspector Name JB
Date 12/18/18
Length of Section (ft): 500
Width of Section (ft): 26
Road Condition (e.g. Wet or [✓ Dry])

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)
NO BLADING REQUIRED NO PICS

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					[✓ Minor dust and no visible obstruction]	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Washington County Control Section Reports



Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 2: Control Section

Inspector Name JG

Date 9/11/18

Length of Section (ft): 300

Width of Section (ft): 26

Road Condition (e.g. Wet or [✓ Dry])

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
[✓ 9]	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	No or negligible loose aggregate;		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					[✓ Minor dust and no visible obstruction]	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 2: Control Section	**Inspector Name**	**Date** 10/8/18
Length of Section (ft): 300	**Width of Section (ft): 26**	**Road Condition (e.g. [✓ Wet] or Dry)**

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

AFTR 30M' OF RAW 4"+   WILL BLADE THIS WEEK

NO PICS

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	No or negligible ruts	No or negligible corrugations	No or negligible potholes	No or negligible loose aggregate;		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	[✓ Considerable potholes less than 3" deep and less than 2' diameter]	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					Minor dust and no visible obstruction	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 2: Control Section	**Inspector Name**	**Date** 10/16/18
Length of Section (ft): 300	**Width of Section (ft): 26**	**Road Condition (e.g. Wet or [✓ Dry])**

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

BLADED 2.5 ROUNDS TO GET CROWN BACK IN ROAD   BLADING REQUIRED

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	No or negligible ruts	No or negligible corrugations	No or negligible potholes	No or negligible loose aggregate;		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	[✓ Berms <2" deep; Loose aggregate <1.5" thick] LOOSE ROCK ON BOTH EDGES OF ROAD		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	[✓ ~~Many~~ potholes up to 4" deep and 3' in diameter] A FEW POTHOLES IN CENTER OF ROAD	berms between 2"- 4" deep;	No visible dust	
3					[✓ Minor dust and no visible obstruction]	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	[✓ <1%] LOST CROWN

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 2: Control Section	**Inspector Name** JB	**Date** 12/3/18
Length of Section (ft): 300	**Width of Section (ft): 26**	**Road Condition (e.g. [✓ Wet] or Dry)**

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

HAD 12" SNOW 1 WEEK AGO SNOW WAS BLADED OFF, RAIN PAST TO DAYS ROAD WAS NOT FROZE BEFORE AND AFTER SNOW PICS TAKEN

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	No or negligible ruts	No or negligible corrugations	No or negligible potholes	[✓ No or negligible loose aggregate;]		
8	[✓ Ruts less than 1" deep and less than 5% of the roadway surface]	[✓ Less than 1" deep; less than 10% of roadway surface area]	[✓ Most small potholes less than 1" deep and less than 1' diameter]	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	[✓ No visible dust]	
3					Minor dust and no visible obstruction	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	[✓ 1% to 3%]
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

THIS SECTION OF ROAD IS UP ON THE FLAT WERE MOST OF THE SNOW BLEW OFF

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 2: Control Section	**Inspector Name** JB	**Date** 12/18/18
Length of Section (ft): 300	**Width of Section (ft): 26**	**Road Condition (e.g. Wet or [✓ Dry])**

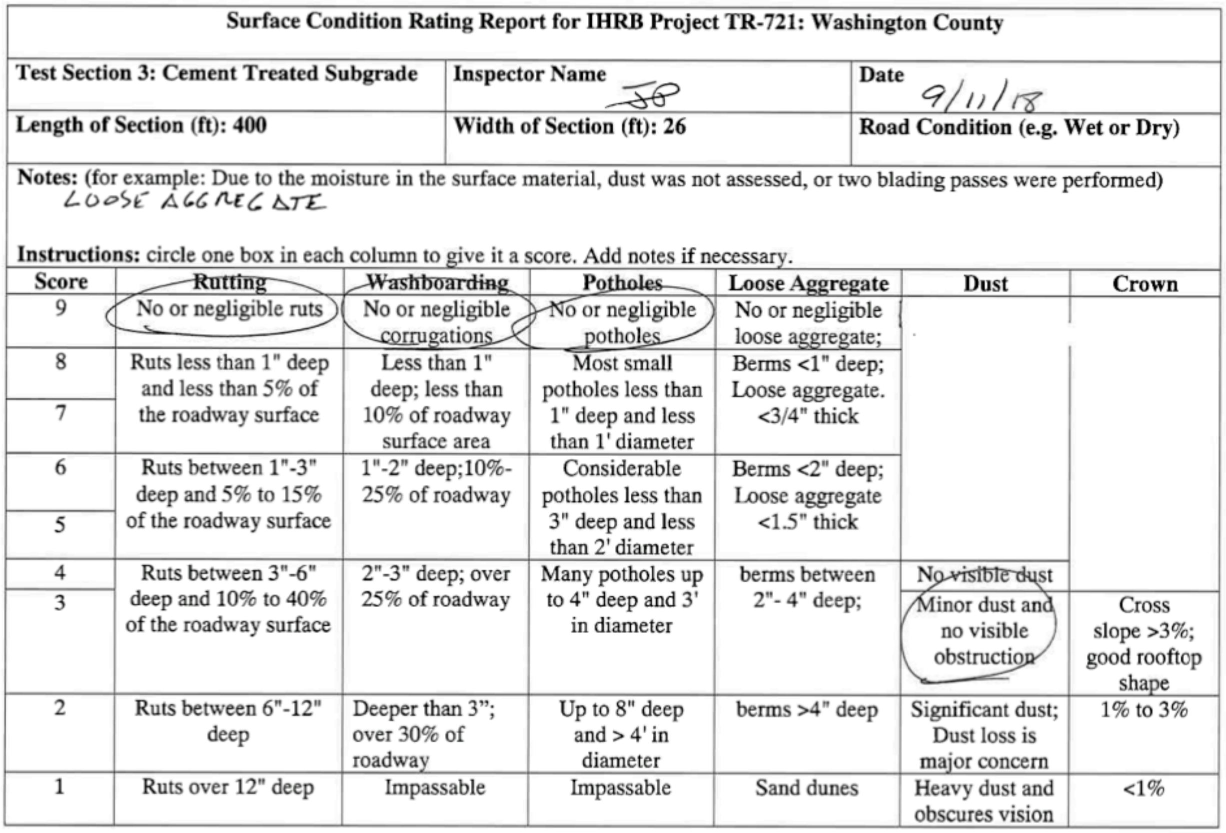
Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

NO BLADING REQUIRED NO PICS

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					[✓ Minor dust and no visible obstruction]	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	[✓ 1% to 3%]
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Washington County Cement-Treated Subgrade Section Reports



Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 3: Cement Treated Subgrade

Inspector Name JB

Date 9/11/18

Length of Section (ft): 400

Width of Section (ft): 26

Road Condition (e.g. Wet or Dry)

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

LOOSE AGGREGATE

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	No or negligible loose aggregate;		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					[✓ Minor dust and no visible obstruction]	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 3: Cement Treated Subgrade	**Inspector Name**	**Date** 10/8/18
Length of Section (ft): 400	**Width of Section (ft): 26**	**Road Condition (e.g. [✓ Wet] or Dry)**

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)
4" RAIN, 3 PAS)
NO PICS

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	No or negligible ruts	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					Minor dust and no visible obstruction	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 3: Cement Treated Subgrade	**Inspector Name**	**Date** 10/16/18
Length of Section (ft): 400	**Width of Section (ft): 26**	**Road Condition (e.g. Wet or [✓ Dry])**

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)
NO BLADING REQUIRED

LOOSE ROCK ON EDGES OF ROAD

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	[✓ No visible dust]	
3					Minor dust and no visible obstruction	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 3: Cement Treated Subgrade	**Inspector Name**	**Date** 12/3/18
Length of Section (ft): 400	**Width of Section (ft): 26**	**Road Condition (e.g. Wet or Dry)** WET 33°

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

12" SNOW ONE WEEK AGO SNOW WAS BLADED OFF LAST 2 DAYS HAVE HAD LIGHT RAIN ROAD WAS NOT FROZE BEFORE AND AFTER SNOW PIC TAKEN

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	[✓ No visible dust]	
3					Minor dust and no visible obstruction	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

THIS SECTION OF ROAD IS UP ON THE FLAT WHERE MOST OF THE SNOW BLEW OFF

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 3: Cement Treated Subgrade	**Inspector Name**	**Date** 12/18/18
Length of Section (ft): 400	**Width of Section (ft): 26**	**Road Condition (e.g. Wet or [✓ Dry])**

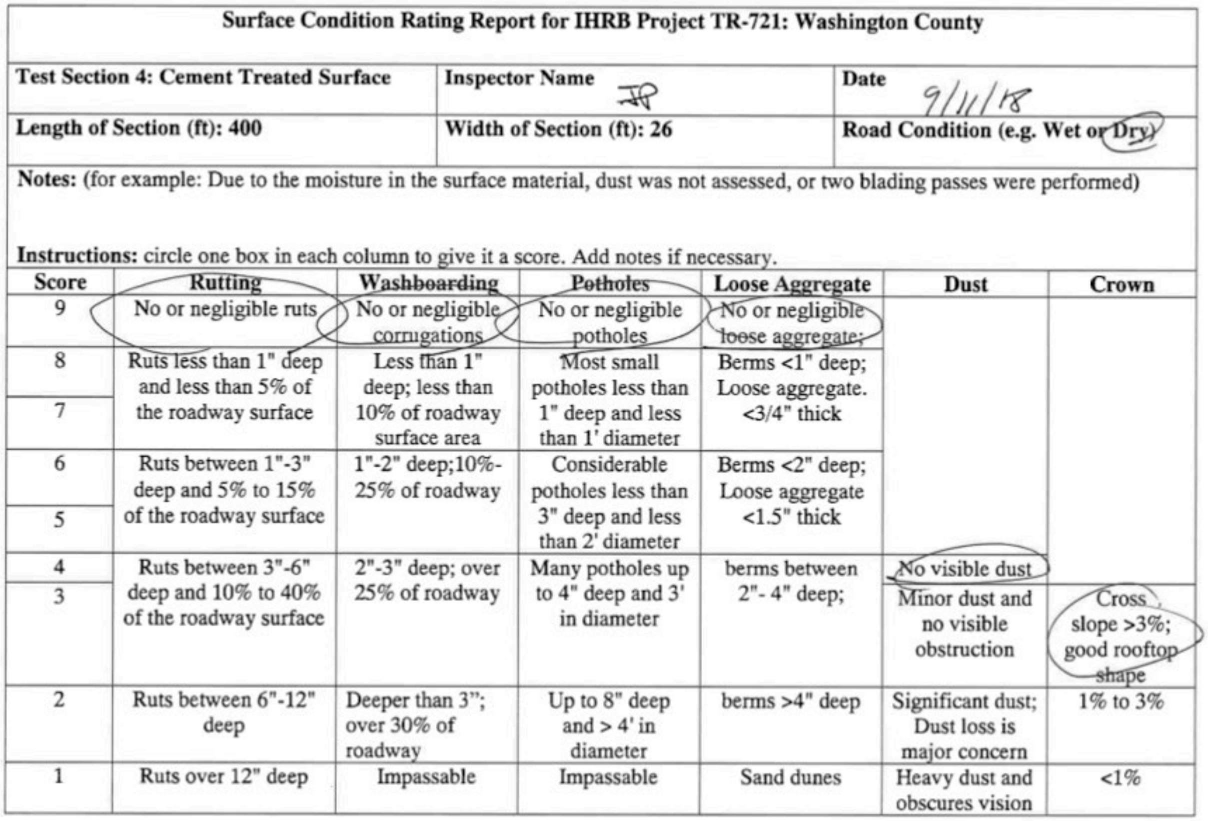
Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

NO BLADING REQUIRED NO PICS

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					[✓ Minor dust and no visible obstruction]	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Washington County Cement-Treated Surface Section Reports



Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 4: Cement Treated Surface

Inspector Name JP

Date 9/11/18

Length of Section (ft): 400

Width of Section (ft): 26

Road Condition (e.g. Wet or [✓ Dry])

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	[✓ No visible dust]	
3					Minor dust and no visible obstruction	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 4: Cement Treated Surface	**Inspector Name**	**Date** 10/8/18
Length of Section (ft): 400	**Width of Section (ft): 26**	**Road Condition** (e.g. [✓ Wet] or Dry)

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

AFTER 3 DAYS SAW 4" POTS

NO PICS

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	No or negligible ruts	[✓ No or negligible corrugations]	No or negligible potholes	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	[✓ Most small potholes less than 1" deep and less than 1' diameter]	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					Minor dust and no visible obstruction	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 4: Cement Treated Surface	**Inspector Name**	**Date** 10/16/18
Length of Section (ft): 400	**Width of Section (ft): 26**	**Road Condition** (e.g. Wet or [✓ Dry])

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

NO BLADING REQUIRED

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	No or negligible potholes	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	[✓ Most small potholes less than 1" deep and less than 1' diameter]	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	[✓ No visible dust]	
3					Minor dust and no visible obstruction	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 4: Cement Treated Surface	**Inspector Name** JB	**Date** 12/3/18
Length of Section (ft): 400	**Width of Section (ft): 26**	**Road Condition** (e.g. [✓ Wet] or Dry) 33°

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)
HAD 12" SNOW 1 WEEK AGO SNOW WAS BLADED OFF PAST 2 DAY HAVE HAD LIGHT RAIN
ROAD NOT FROZE BEFORE & AFTER SNOW
POT HOLEING IN WHEEL TRACKS PIC TAKEN

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	No or negligible ruts	No or negligible corrugations	No or negligible potholes	No or negligible loose aggregate;		
8	[✓ Ruts less than 1" deep and less than 5% of the roadway surface]	[✓ Less than 1" deep; less than 10% of roadway surface area]	[✓ Most small potholes less than 1" deep and less than 1' diameter]	[✓ Berms <1" deep; Loose aggregate. <3/4" thick]		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	[✓ No visible dust]	
3					~~Minor~~ dust and no visible obstruction	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

THIS SECTION OF ROAD IS UP ON THE FLAT WHERE MOST OF THE SNOW BLEW OFF

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 4: Cement Treated Surface	**Inspector Name**	**Date** 12/18/18
Length of Section (ft): 400	**Width of Section (ft): 26**	**Road Condition** (e.g. Wet or [✓ Dry])

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)
SEEMS THAT TOP 1/2 TO 1" CRUST IS BREAKING AWAY ON THE WEST BOUND LANE IN THE
WHEEL TRACK PICS TAKEN WILL BLADE NEXT TIME WE HAVE SOME MOISTURE PIC TAKEN

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	No or negligible ruts	No or negligible corrugations	No or negligible potholes	[✓ No or negligible loose aggregate;]		
8	[✓ Ruts less than 1" deep and less than 5% of the roadway surface]	Less than 1" deep; less than 10% of roadway surface area	[✓ Most small potholes less than 1" deep and less than 1' diameter]	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	[✓ 1"-2" deep;10%-25% of roadway]	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	[✓ No visible dust]	
3					Minor dust and no visible obstruction	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	[✓ 1% to 3%]
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County		
Test Section 4: Cement Treated Surface	**Inspector Name**	**Date** 12/21/18
Length of Section (ft): 400	**Width of Section (ft): 26**	**Road Condition (e.g. [✓ Wet] or Dry)** BUT FROZE LIGHTLY

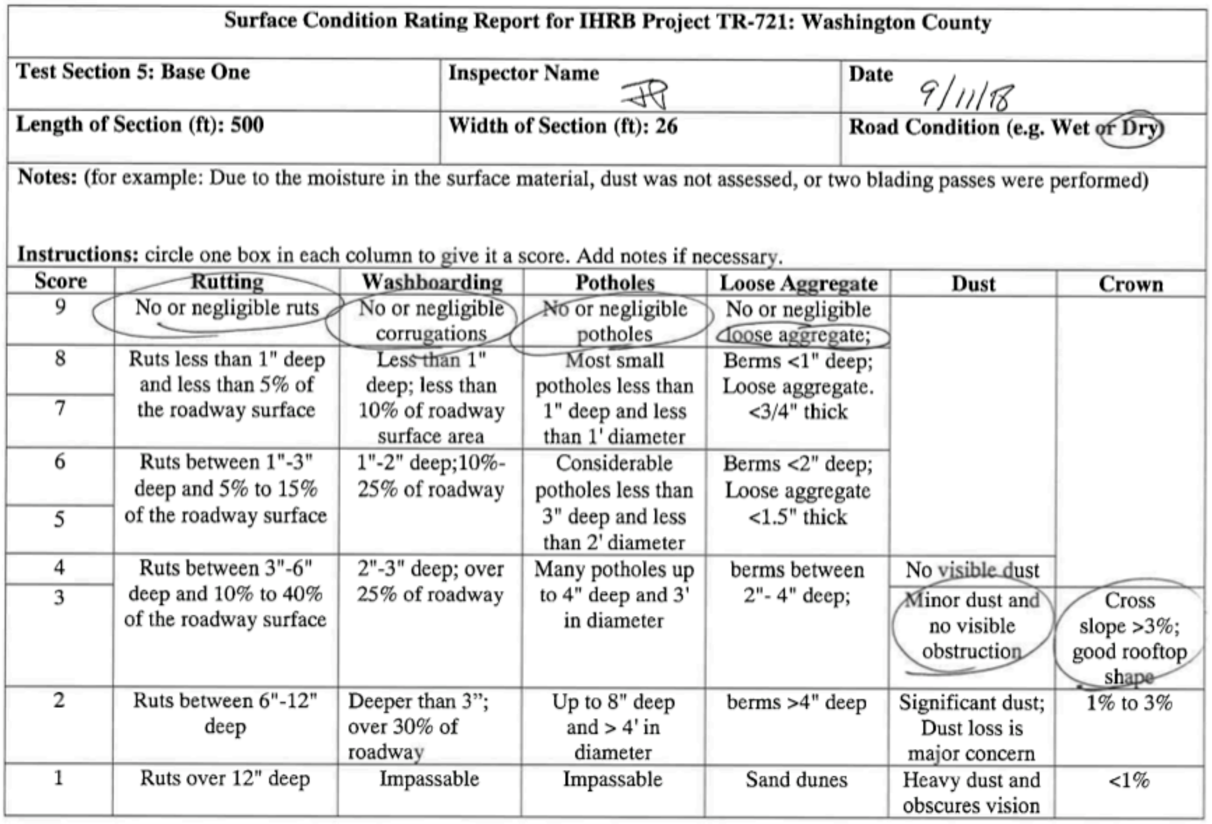
Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)
PIC TAKEN 1ST PIC BEFORE BLADING 2ND PICK OF WEST BOUND LANE AFTER 2-PASSES / 3RD PIC EAST BOUND 1 PASS
4TH PIC AFTER ROCK TAKEN TO NORTH SHOULDER NOTE: I THOUGHT WE HAD ENOUGH MOISTURE to FIX THIS SECTION BUT THERE WAS NOT

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	No or negligible ruts	No or negligible corrugations	No or negligible potholes	[✓ No or negligible loose aggregate;]		
8	[✓ Ruts less than 1" deep and less than 5% of the roadway surface]	[✓ Less than 1" deep; less than 10% of roadway surface area]	[✓ Most small potholes less than 1" deep and less than 1' diameter]	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	[✓ No visible dust]	
3					Minor dust and no visible obstruction	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	[✓ 1% to 3%]
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

SURFACE WAS HARD + DRY WE HAD LIGHT RAIN THE DAY BEFORE AND TEMP IN HIGH 30°

Washington County BASE ONE Section Reports



Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 5: Base One	**Inspector Name** JR	**Date** 9/11/18
Length of Section (ft): 500	**Width of Section (ft): 26**	**Road Condition (e.g. Wet or [✓ Dry])**

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					[✓ Minor dust and no visible obstruction]	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 5: Base One	**Inspector Name**	**Date** 10/8
Length of Section (ft): 500	**Width of Section (ft): 26**	**Road Condition** (e.g. [✓ Wet] or Dry)

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

3 cm OF RAIN 4"-1

NO PICS

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	No or negligible ruts	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					Minor dust and no visible obstruction	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 5: Base One	**Inspector Name** SD	**Date** 10/16/18
Length of Section (ft): 500	**Width of Section (ft): 26**	**Road Condition** (e.g. Wet or [✓ Dry]) DRY

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

NO BLADING REQUIRED

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	No or negligible loose aggregate;		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	[✓ Berms <1" deep; Loose aggregate. <3/4" thick] ON EDGES		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	[✓ No visible dust]	
3					Minor dust and no visible obstruction	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 5: Base One	**Inspector Name**	**Date** 12/3/18
Length of Section (ft): 500	**Width of Section (ft): 26**	**Road Condition** (e.g. [✓ Wet] or Dry) 330

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)
HAD 12" SNOW 1 WEEK BEFORE, LAST TWO DAYS HAD LIGHT RAIN ROAD NOT FROZE BEFORE + AFTER SNOW
SNOW WAS BLADED OFF
PICS TAKEN

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	No or negligible ruts	No or negligible corrugations	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	[✓ Ruts less than 1" deep and less than 5% of the roadway surface]	[✓ Less than 1" deep; less than 10% of roadway surface area]	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	[✓ No visible dust]	
3					Minor dust and no visible obstruction	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	[✓ 1% to 3%]
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

THIS SECTON OF ROAD IS DOWN HILL AND MOST OF THE SNOW STAYED ON THE ROAD

Surface Condition Rating Report for IHRB Project TR-721: Washington County

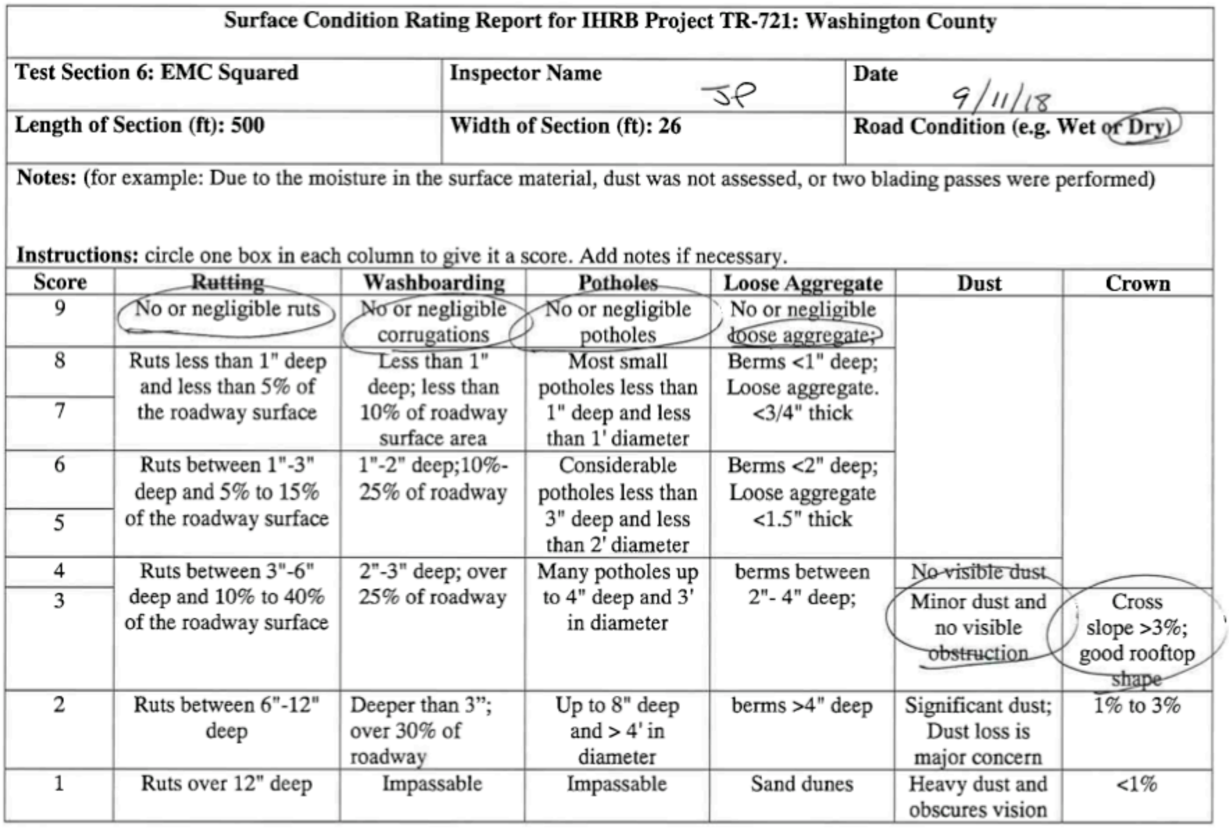
Test Section 5: Base One	**Inspector Name** JP	**Date** 12/18/18
Length of Section (ft): 500	**Width of Section (ft): 26**	**Road Condition** (e.g. Wet or [✓ Dry])

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)
NO BLADING REQURED NO PICS

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					[✓ Minor dust and no visible obstruction]	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Washington County EMC SQUARED Section Reports



Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 6: EMC Squared	**Inspector Name** JP	**Date** 9/11/18
Length of Section (ft): 500	**Width of Section (ft): 26**	**Road Condition (e.g. Wet or [✓ Dry])**

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					[✓ Minor dust and no visible obstruction]	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 6: EMC Squared	**Inspector Name**	**Date** 10/8/18
Length of Section (ft): 500	**Width of Section (ft): 26**	**Road Condition (e.g. [✓ Wet] or Dry)**

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

4" RAIN IN PAST 3 DAYS
OUTSIDE EDGES SOFT
NO PICS

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					Minor dust and no visible obstruction	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 6: EMC Squared	**Inspector Name**	**Date** 10/16/18
Length of Section (ft): 500	**Width of Section (ft): 26**	**Road Condition (e.g. Wet or [✓ Dry])**

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)
NO BLADING REQUIRED

TOOTHPICKS

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	[✓ No visible dust]	
3					Minor dust and no visible obstruction	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 6: EMC Squared	**Inspector Name**	**Date** 12/3/18
Length of Section (ft): 500	**Width of Section (ft): 26**	**Road Condition (e.g. [✓ Wet] or Dry)** 33°

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)
12" SNOW ONE WEEK AGO AND LIGHT RAIN PAST 2 DAYS SNOW WAS BLADED OFF, ROAD WAS NOT FROZE BEFORE AND AFTER SNOW
PICS TAKEN

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	No or negligible ruts	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	[✓ Ruts less than 1" deep and less than 5% of the roadway surface]	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	[✓ No visible dust]	
3					Minor dust and no visible obstruction	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	[✓ 1% to 3%]
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

THIS SECTION OF ROAD IS DOWN HILL SO MOST OF THE SNOW STAYED ON THE ROAD

Surface Condition Rating Report for IHRB Project TR-721: Washington County

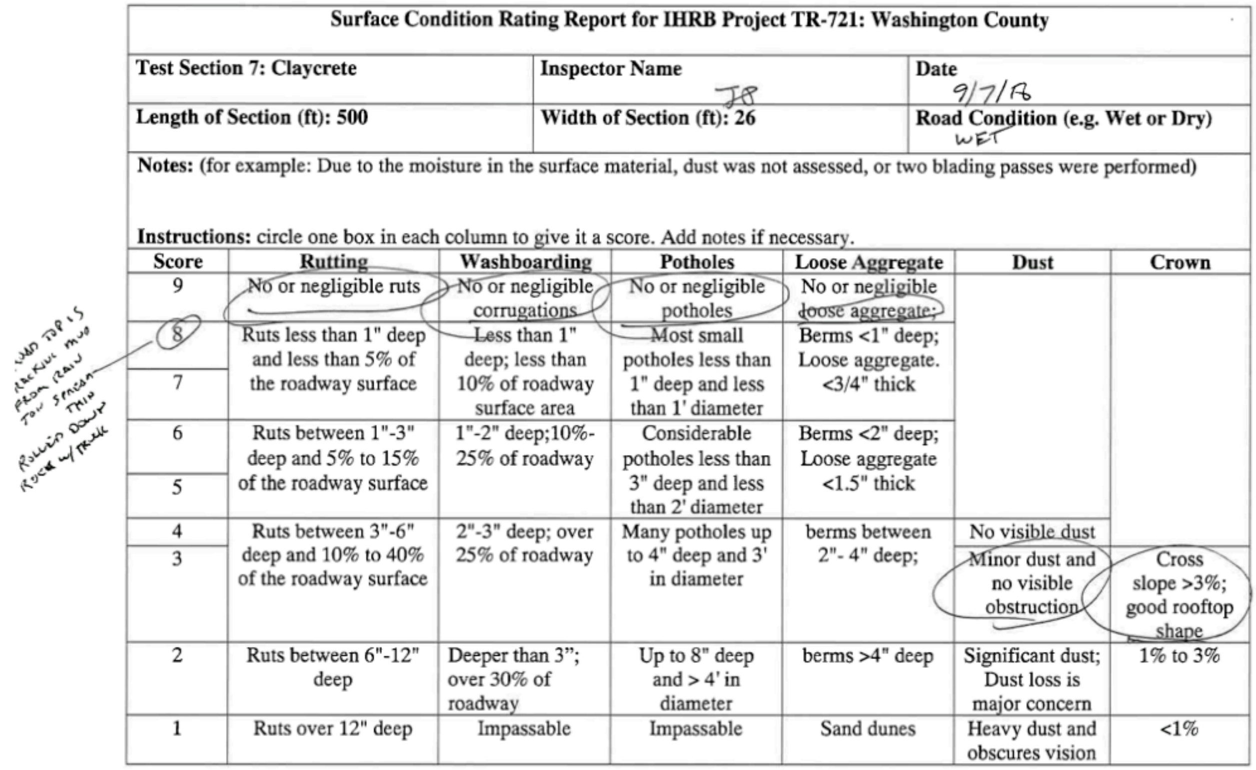
Test Section 6: EMC Squared	**Inspector Name**	**Date** 12/18/18
Length of Section (ft): 500	**Width of Section (ft): 26**	**Road Condition (e.g. Wet or [✓ Dry])**

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)
SOUTH SIDE WET FROM SNOW MELT
NO BLADING REQUIRED NO PICS

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					[✓ Minor dust and no visible obstruction]	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	[✓ 1% to 3%]
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Washington County Claycrete Section Reports



Surface Condition Rating Report for IHRB Project TR-721: Washington County

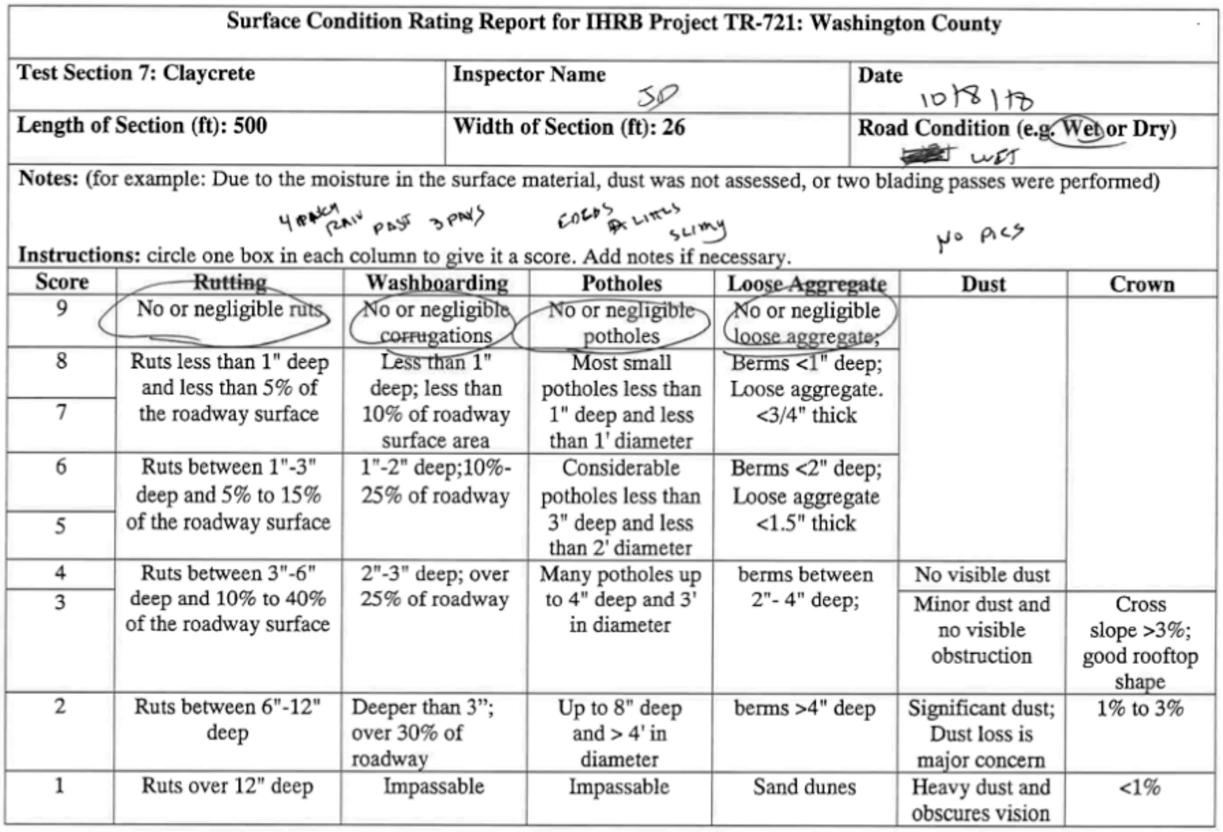
Test Section 7: Claycrete	**Inspector Name** JB	**Date** 9/7/18
Length of Section (ft): 500	**Width of Section (ft): 26**	**Road Condition (e.g. Wet or Dry)** WET

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
[✓ 8]	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					[✓ Minor dust and no visible obstruction]	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

WAS TOP IS TACKY MUD FROM RAIN TOO SPREAD THIN ROLLED DOWN ROCK w/ TRUCK



Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 7: Claycrete	**Inspector Name** JD	**Date** 10/8/18
Length of Section (ft): 500	**Width of Section (ft): 26**	**Road Condition (e.g. [✓ Wet] or Dry)** [illegible] WET

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

4 INCH RAIN PAST 3 DAYS LOOKS A LITTLE SLIMY NO PICS

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					Minor dust and no visible obstruction	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 7: Claycrete	**Inspector Name** JB	**Date** 10/16/18
Length of Section (ft): 500	**Width of Section (ft): 26**	**Road Condition (e.g. Wet or [✓ Dry])** DRY

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)
NO BLADING REQUIRED

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	[✓ No visible dust]	
3					Minor dust and no visible obstruction	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 7: Claycrete	**Inspector Name** JB	**Date** 12/3/18
Length of Section (ft): 500	**Width of Section (ft): 26**	**Road Condition (e.g. [✓ Wet] or Dry)** 33°

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)
HAD 12" SNOW ONE WEEK AGO AND LIGHT RAIN PAST 2 DAYS SNOW WAS BLOWN OFF ROAD WAS NOT FROZE BEFORE AND AFTER SNOW
PICS TAKEN

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	[✓ No visible dust]	
3					Minor dust and no visible obstruction	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

THIS SECTON OF ROAD IS DOWN HILL EXEPT FOR THE EAST END
HILL SIDE HELD SNOW EAST FLAT BLEW OFF

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 7: Claycrete	**Inspector Name** JB	**Date** 12/18/18
Length of Section (ft): 500	**Width of Section (ft): 26**	**Road Condition (e.g. ~~Wet or Dry~~)** DRY

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

NO BLADING REQUIRED

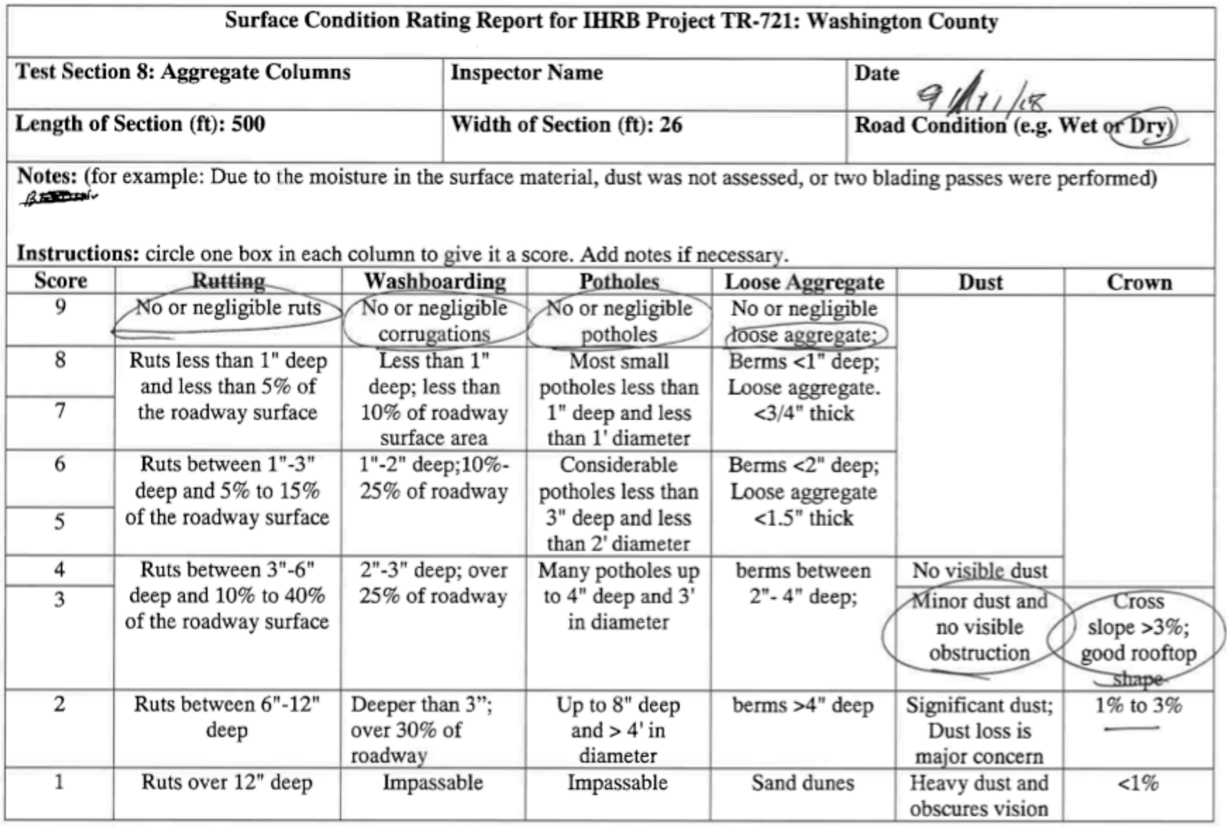
NO PICS

SOUTH SHOULDER WET FROM SNOW MELT

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					[✓ Minor dust and no visible obstruction]	Cross slope >3%; good rooftop shape
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	[✓ 1% to 3%]
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Washington County Aggregate Columns Section Reports



Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 8: Aggregate Columns

Inspector Name

Date 9/11/18

Length of Section (ft): 500

Width of Section (ft): 26

Road Condition (e.g. Wet or [✓ Dry])

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

[redacted]

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	[✓ No or negligible corrugations]	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					[✓ Minor dust and no visible obstruction]	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 8: Aggregate Columns

Inspector Name SI

Date 10/8/18

Length of Section (ft): 500

Width of Section (ft): 26

Road Condition (e.g. [✓ Wet] or Dry)

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

AFTER 4" RAIN DUST 3 DAYS

NO PICS

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	No or negligible ruts	No or negligible ~~corrugations~~	No or negligible ~~potholes~~	No or negligible loose aggregate;		
8	Ruts less than 1" deep and less than 5% of the roadway surface	[✓ Less than 1" deep; less than 10% of roadway ~~surface area~~]	[✓ Most small potholes less than 1" deep and less ~~than 1' diameter~~]	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	[✓ Berms <2" deep; Loose aggregate <1.5" thick]		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	[✓ No visible dust]	
3					~~Minor~~ dust and no visible obstruction	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	~~1% to 3%~~
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 8: Aggregate Columns

Inspector Name

Date 10/16/18

Length of Section (ft): 500

Width of Section (ft): 26

Road Condition (e.g. Wet or Dry)

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)

WASHBOARDING - LOOSE ROCK AT INTERSECTION TO 60FT IN BLADING REQUIRED

WILL BLADE IT TODAY BLADED 2 ROUNDS TO SPREAD OUT LOOSE ROCK + CUT WASHBOARDING

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	No or negligible ruts	No or negligible corrugations	No or negligible potholes	No or negligible ~~loose aggregate;~~		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway ~~surface area~~	[✓ ~~Most small~~ potholes less than 1" deep and less than 1' diameter]	[✓ Berms <1" deep; Loose aggregate. <3/4" thick]		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	[✓ 1"-2" deep;10%-25% of roadway] INTERSECTION	~~Considerable~~ potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					[✓ Minor dust and no visible obstruction]	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	~~1% to 3%~~
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 8: Aggregate Columns	**Inspector Name**	**Date** 12/3/18
Length of Section (ft): 500	**Width of Section (ft): 26**	**Road Condition** (e.g. [✓ Wet] or Dry)

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)
HAD 12" SNOW ONE WEEK AGO AND LIGHT RAIN PAST TWO DAYS SNOW WAS BLADED OFF ROAD WAS NOT FROZE BEFORE AND AFTER SNOW
PICS TAKEN

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	No or negligible corrugations	[✓ No or negligible potholes]	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	[✓ Less than 1" deep; less than 10% of roadway surface area]	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	[✓ No visible dust]	
3					Minor dust and no visible obstruction	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

WASHBOARDS
AT EAST END FROM
START + STOP TRAFFIC

THIS SECTION OF ROAD IS UP ON THE FLAT SO MOST OF THE
SNOW BLEW OFF

Surface Condition Rating Report for IHRB Project TR-721: Washington County

Test Section 8: Aggregate Columns	**Inspector Name**	**Date** 12/18/18
Length of Section (ft): 500	**Width of Section (ft): 26**	**Road Condition** (e.g. Wet [✓ or Dry])

Notes: (for example: Due to the moisture in the surface material, dust was not assessed, or two blading passes were performed)
NO BLADING REQUIRED TIL WE HAVE SOME MOISTURE
NO PICS
SOME WASH BOARDS AT EAST END
CAUSE OF INTERSECTION

Instructions: circle one box in each column to give it a score. Add notes if necessary.

Score	Rutting	Washboarding	Potholes	Loose Aggregate	Dust	Crown
9	[✓ No or negligible ruts]	No or negligible corrugations	No or negligible potholes	[✓ No or negligible loose aggregate;]		
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	[✓ Most small potholes less than 1" deep and less than 1' diameter]	Berms <1" deep; Loose aggregate. <3/4" thick		
7						
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick		
5						
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	berms between 2"- 4" deep;	No visible dust	
3					[✓ Minor dust and no visible obstruction]	[✓ Cross slope >3%; good rooftop shape]
2	Ruts between 6"-12" deep	Deeper than 3"; over 30% of roadway	Up to 8" deep and > 4' in diameter	berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%

APPENDIX B. IMAGE SURVEYS OF TEST SECTIONS

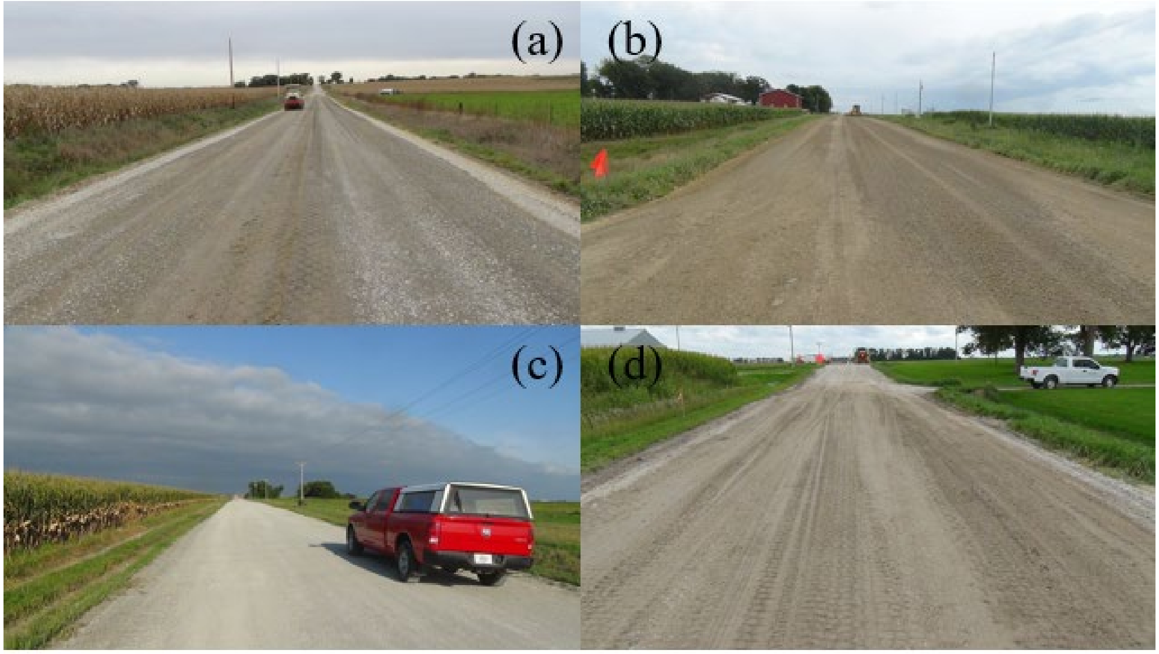


Figure 134. Optimized gradation sections at end of construction: (a) Cherokee, (b) Howard, (c) Washington, and (d) Hamilton County

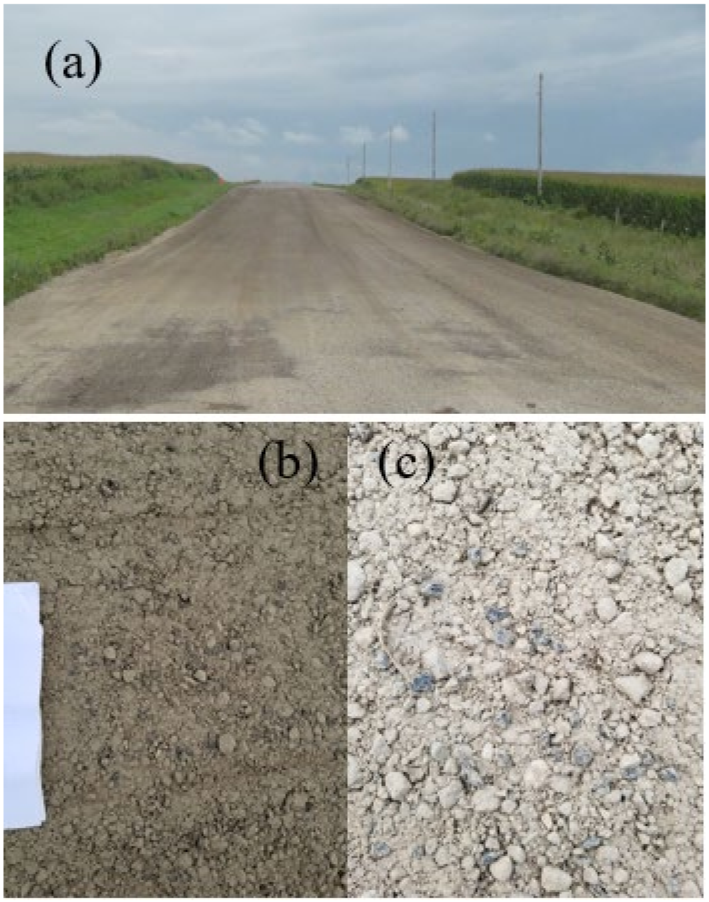


Figure 135. Ground tire rubber section at end of construction: (a) test section in Howard County and (b and c) Howard test section surface

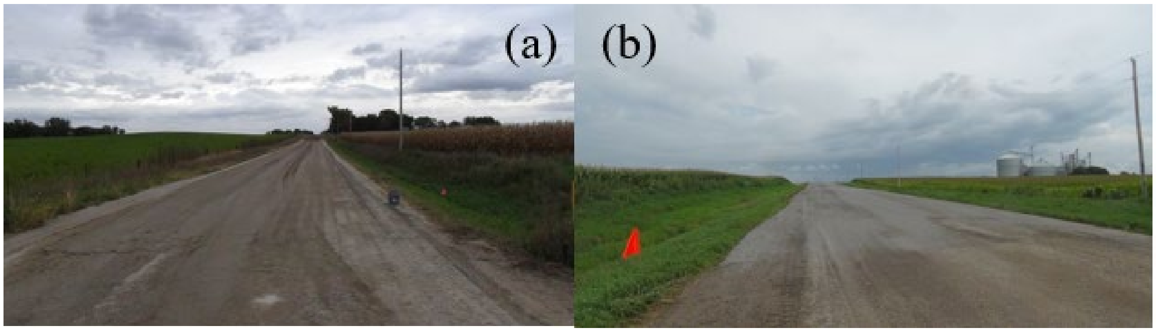


Figure 136. RAP sections at end of construction: (a) Cherokee and (b) Howard County

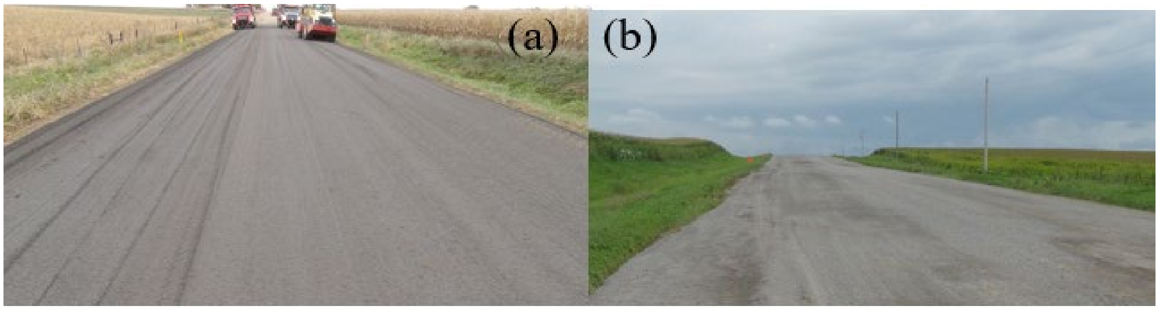


Figure 137. Harsco slag sections at end of construction: (a) Cherokee and (b) Howard County

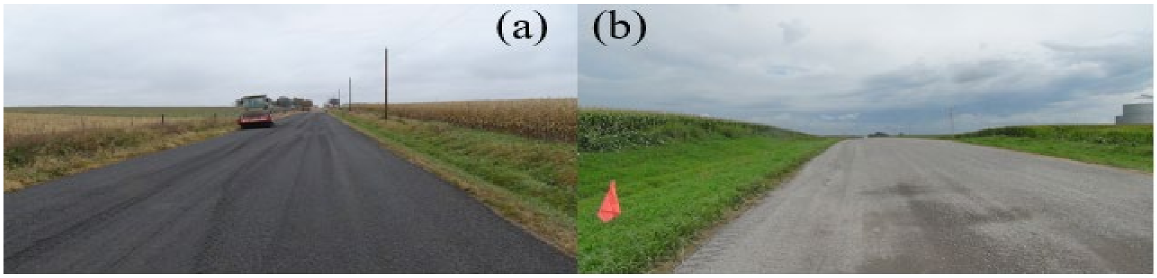


Figure 138. Phoenix slag sections at end of construction: (a) Cherokee and (b) Howard County

Figure 139. (a) Cement-treated surface section and (b) cement-treated subgrade section in Washington County at end of construction

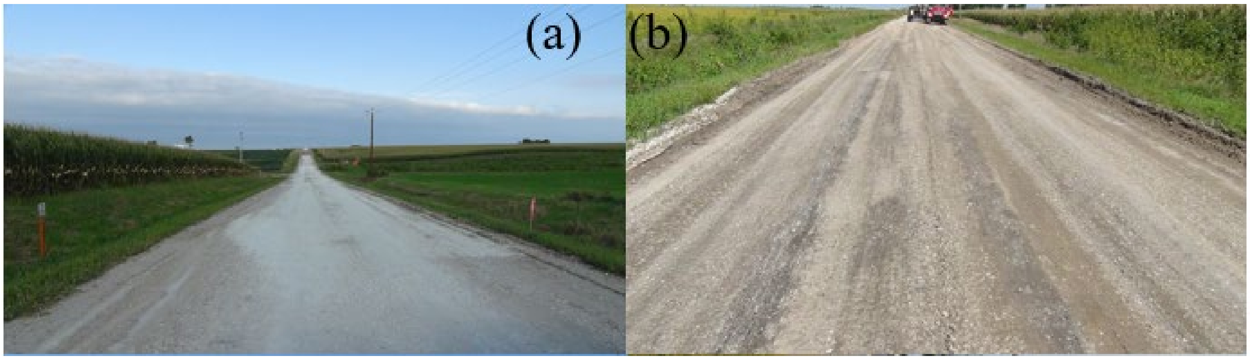


Figure 140. BASE ONE sections at end of construction: (a) Washington and (b) Hamilton County

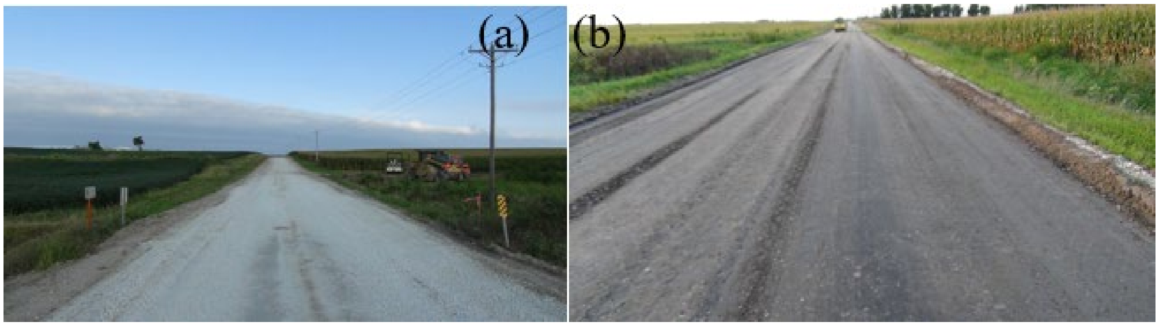


Figure 141. EMC SQUARED sections at end of construction: (a) Washington and (b) Hamilton County

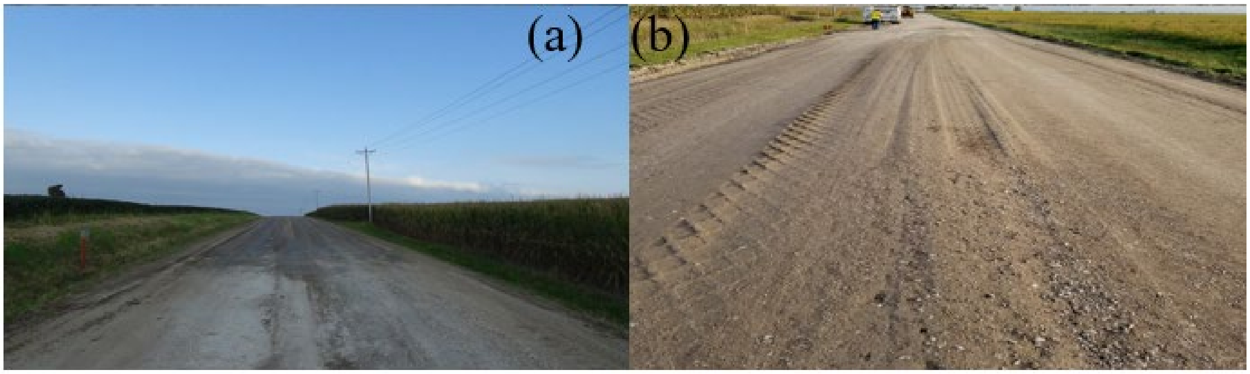


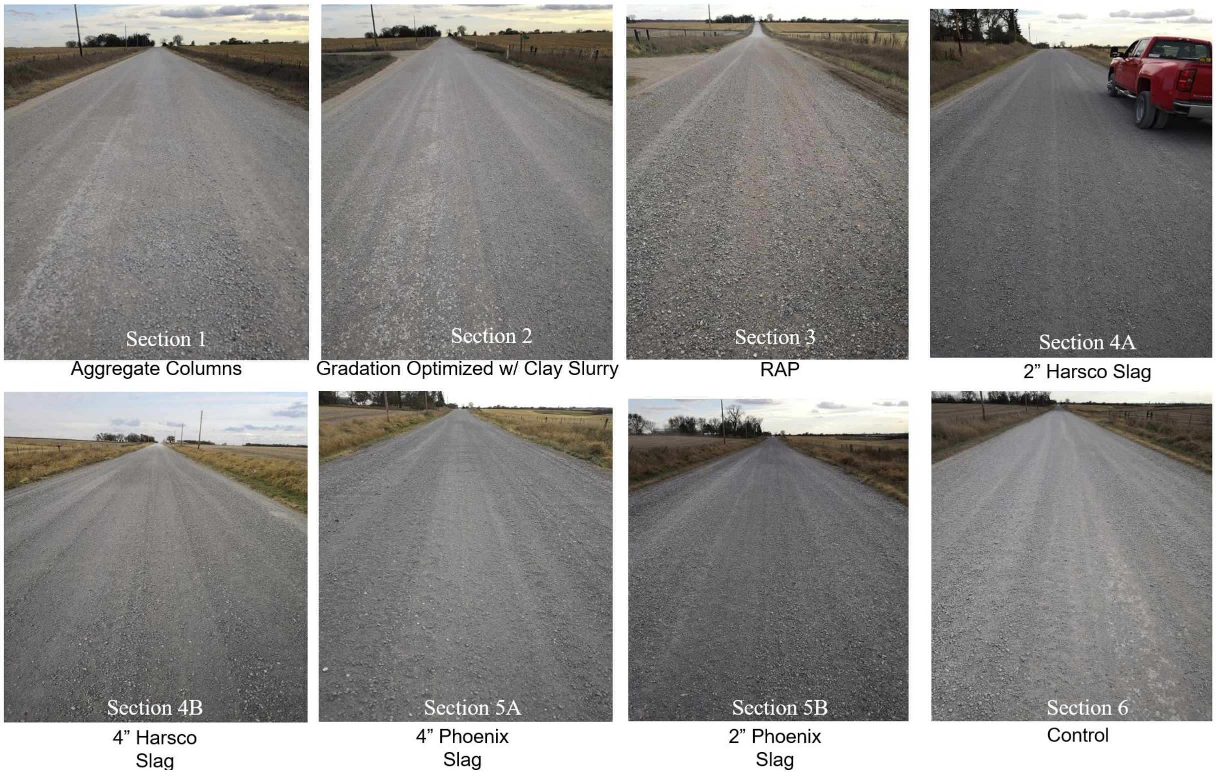
Figure 142. Claycrete sections at end of construction: (a) Washington and (b) Hamilton County

Aggregate Columns
Optimized Gradation w/ Clay Slurry
RAP
2" Harsco Slag
4" Harsco Slag
4" Phoenix Slag
2" Phoenix Slag
Control

Figure 143. Cherokee County survey November 8, 2018

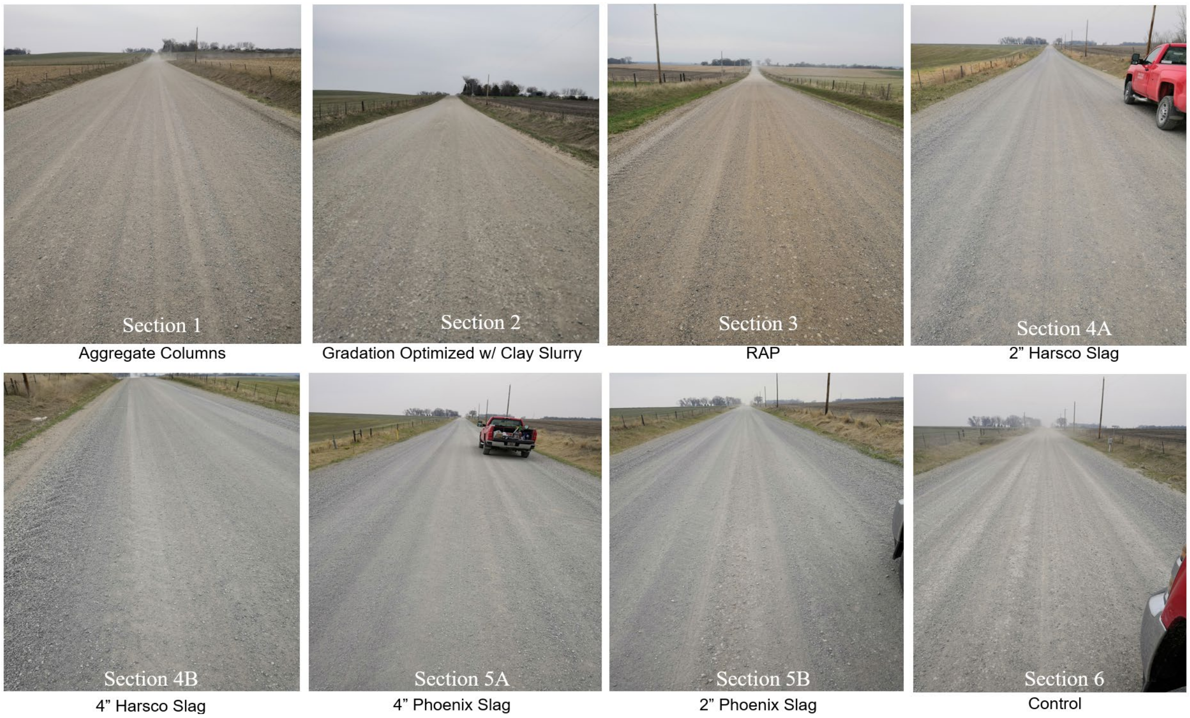
Aggregate Columns
Optimized Gradation w/ Clay Slurry
RAP
2" Harsco Slag
4" Harsco Slag
4" Phoenix Slag
2" Phoenix Slag
Control

Figure 144. Cherokee County survey April 25, 2019



Aggregate Columns
Gradation Optimized w/ Clay Slurry
RAP
2” Harsco Slag
4” Harsco Slag
4” Phoenix Slag
2” Phoenix Slag
Control

Figure 145. Cherokee County survey November 2, 2019



Aggregate Columns
Gradation Optimized w/ Clay Slurry
RAP
2” Harsco Slag
4” Harsco Slag
4” Phoenix Slag
2” Phoenix Slag
Control

Figure 146. Cherokee County survey April 11, 2020

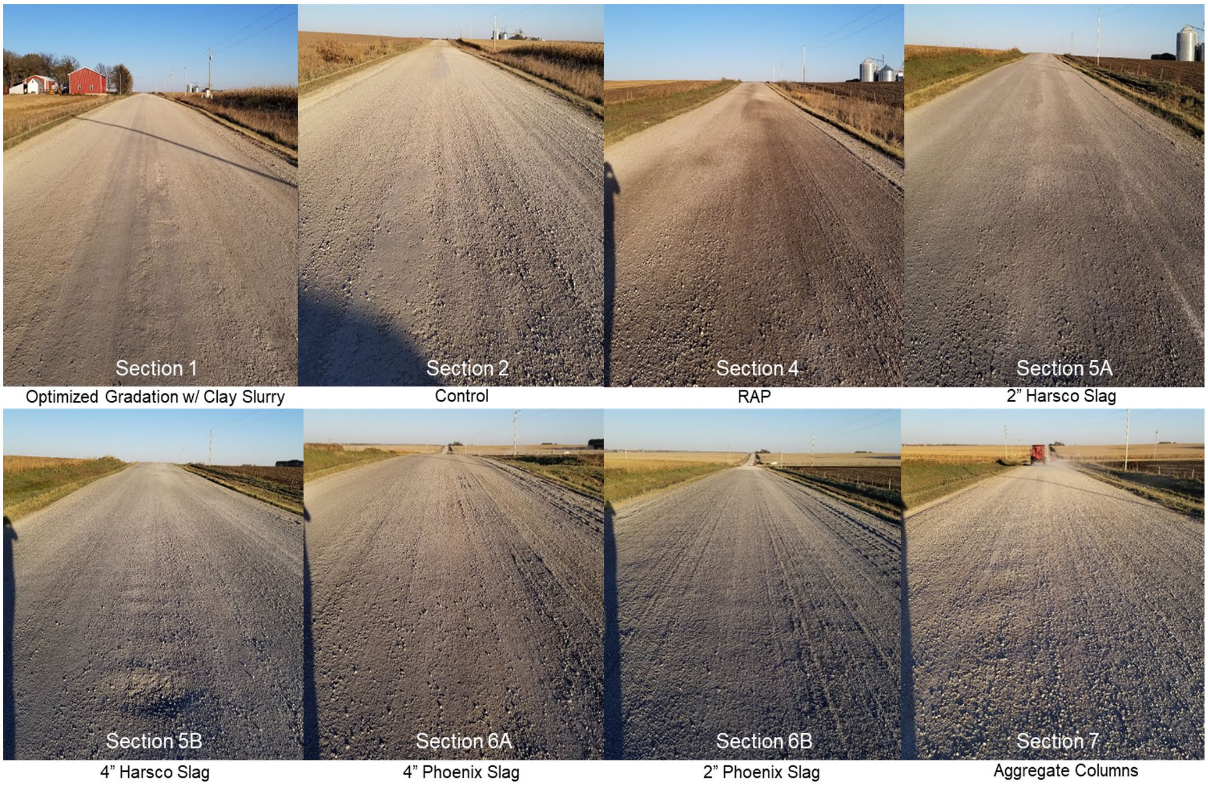


Figure 147. Howard County survey October 23, 2018

Figure 148. Howard County survey May 4, 2019

Gradation Optimized w/ Clay Slurry | Control | RAP | 2" Harsco Slag

4" Harsco Slag | 4" Phoenix Slag | 2" Phoenix Slag | Aggregate Columns

Figure 149. Howard County survey October 27, 2019

Gradation Optimized w/ Clay Slurry | Control | RAP | 2" Harsco Slag

4" Harsco Slag | 4" Phoenix Slag | 2" Phoenix Slag | Aggregate Columns

Figure 150. Howard County survey April 18, 2020

Figure 151. Washington County survey November 6, 2018

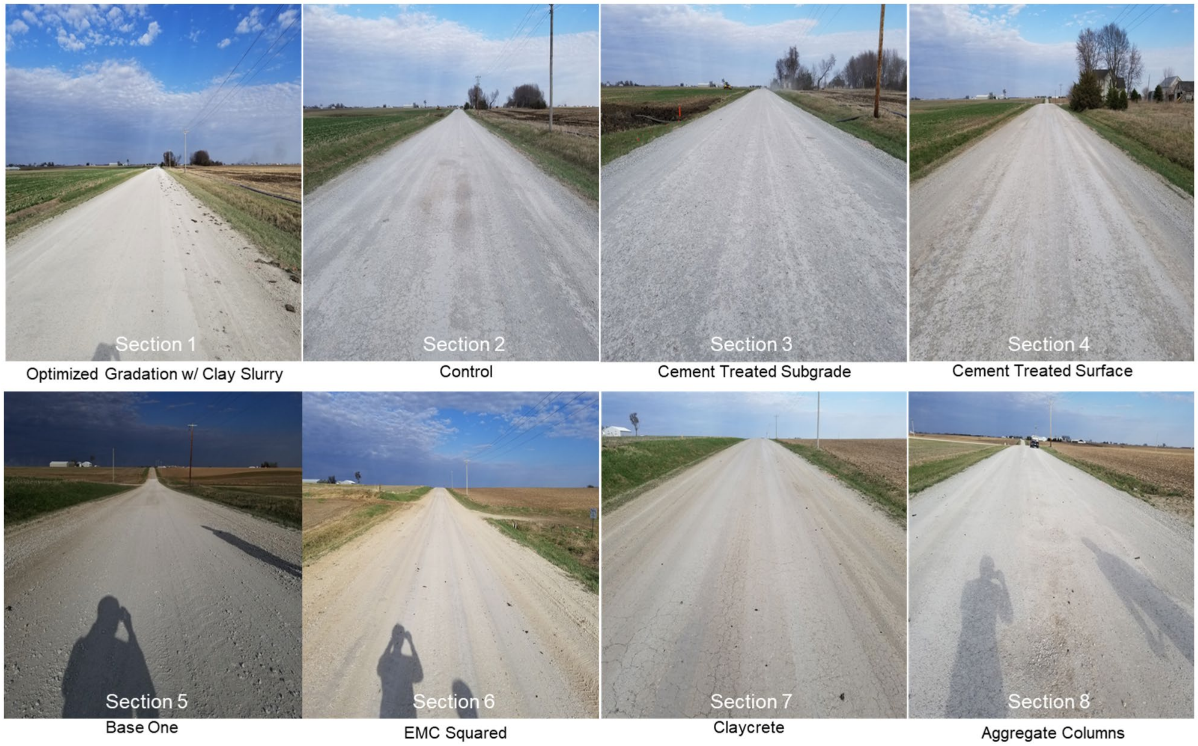


Figure 152. Washington County survey April 9, 2019

Base One

EMC Squared

Claycrete

Aggregate Columns

Figure 153. Washington County survey November 14, 2019

Base One

EMC Squared

Claycrete

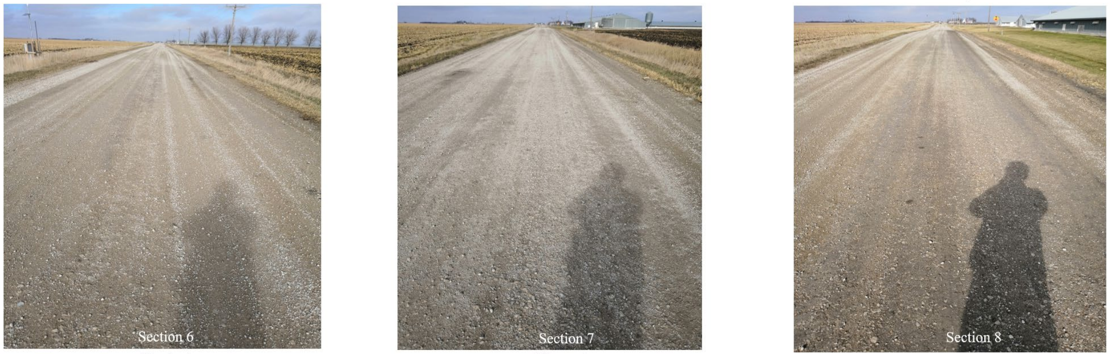
Aggregate Columns

Figure 154. Washington County survey March 29, 2020

Figure 155. Hamilton County survey November 14, 2018

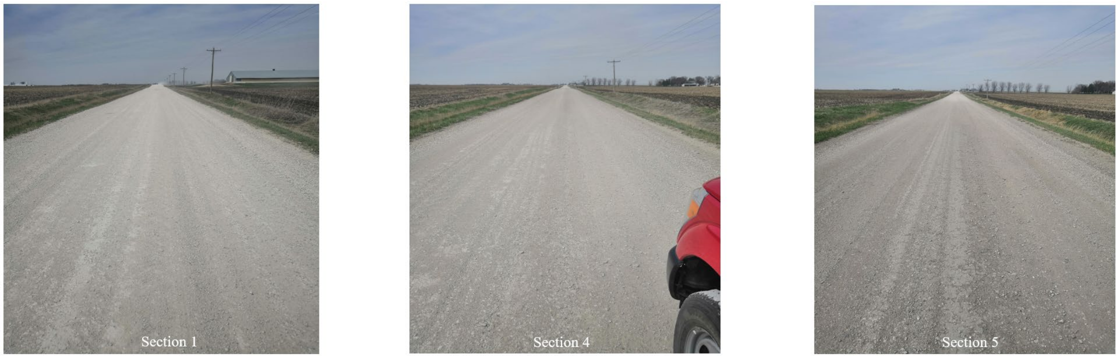
Figure 156. Hamilton County survey April 21, 2019

Gradation Optimized w/ Clay Slurry | Base One | EMC Squared



Control | Claycrete | Aggregate Columns

Figure 157. Hamilton County survey November 18, 2019



Gradation Optimized w/ Clay Slurry | Base One | EMC Squared

Control | Claycrete | Aggregate Columns

Figure 158. Hamilton County survey April 10, 2020

APPENDIX C. LAYOUT OF TEST SECTIONS

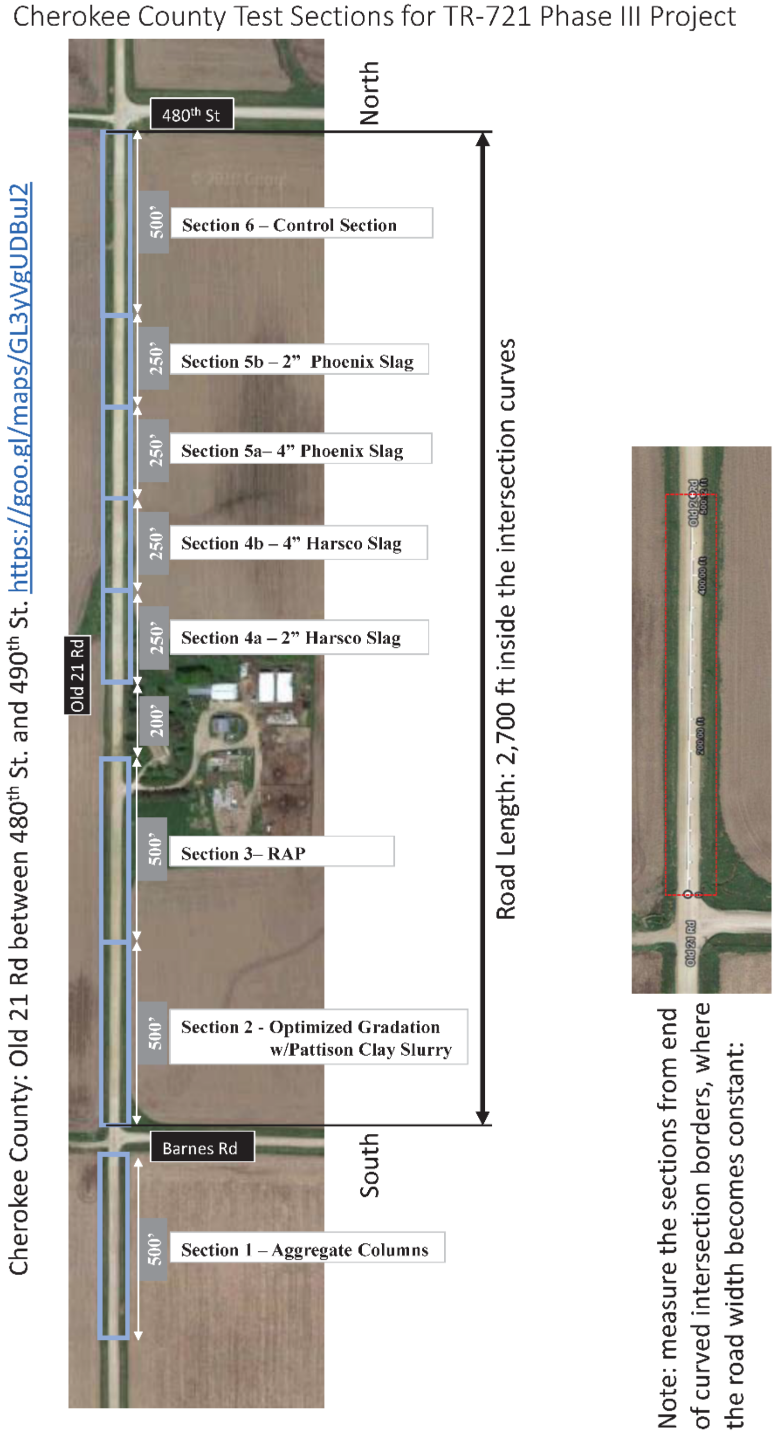


Figure 159. Cherokee County test section layout

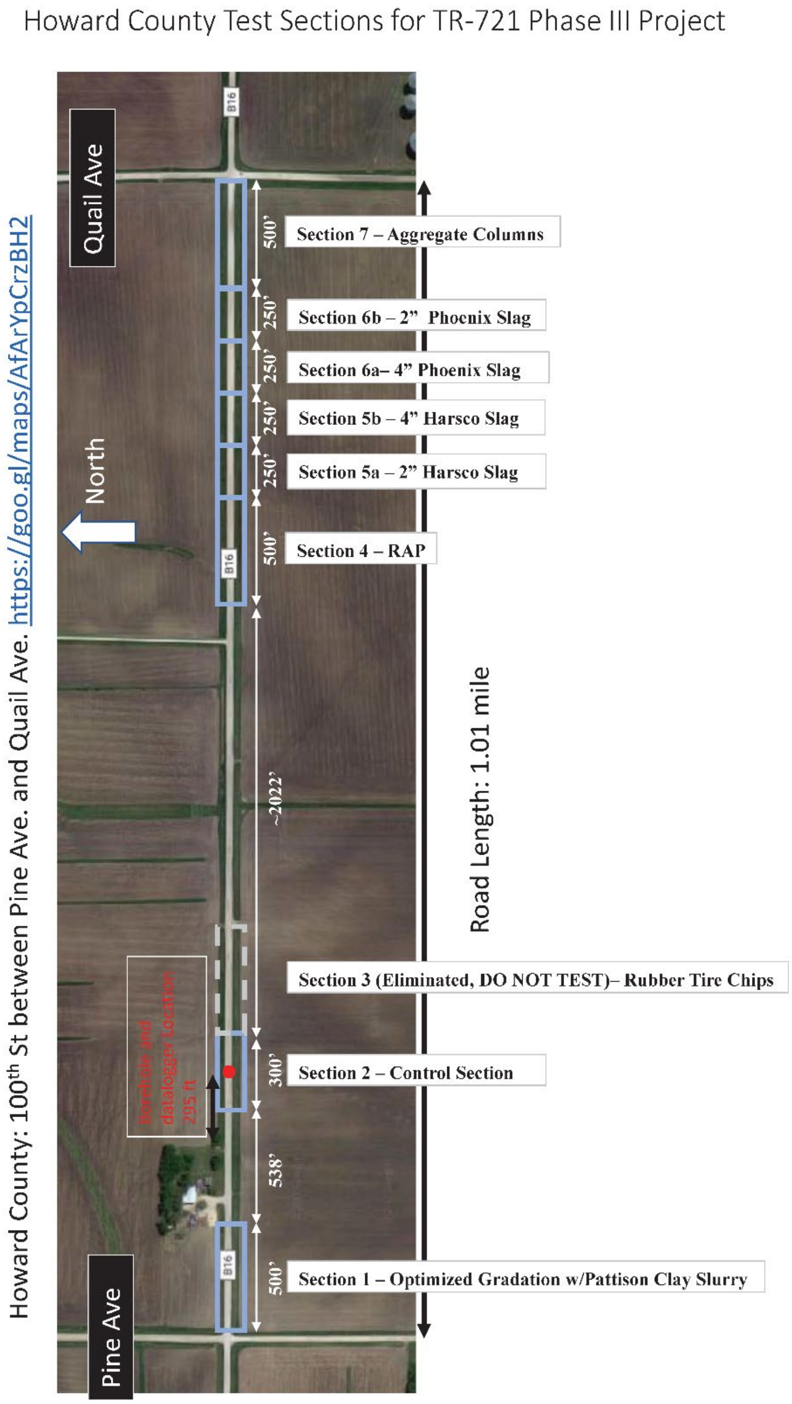
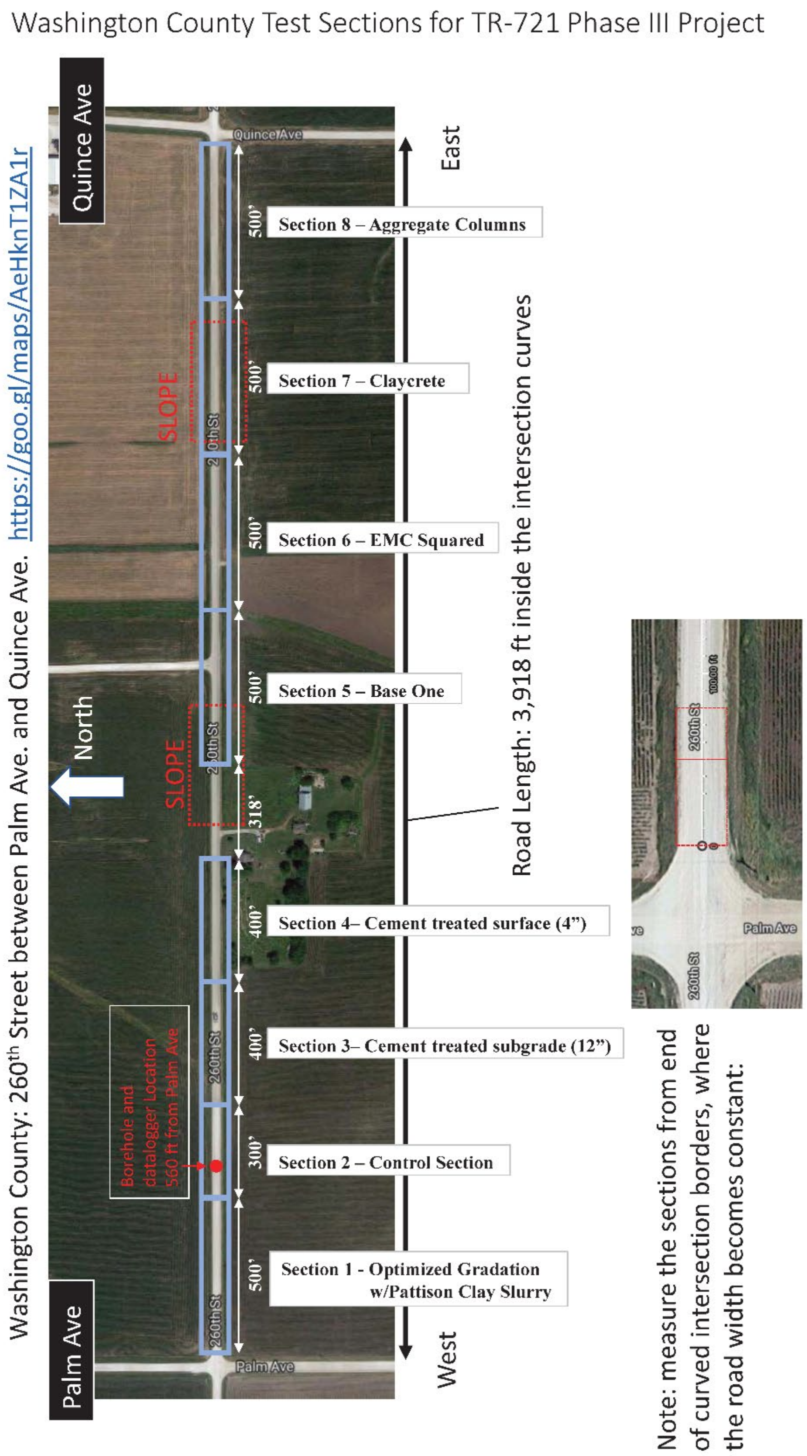


Figure 160. Howard County test section layout



Washington County Test Sections for TR-721 Phase III Project

Figure 161. Washington County test section layout

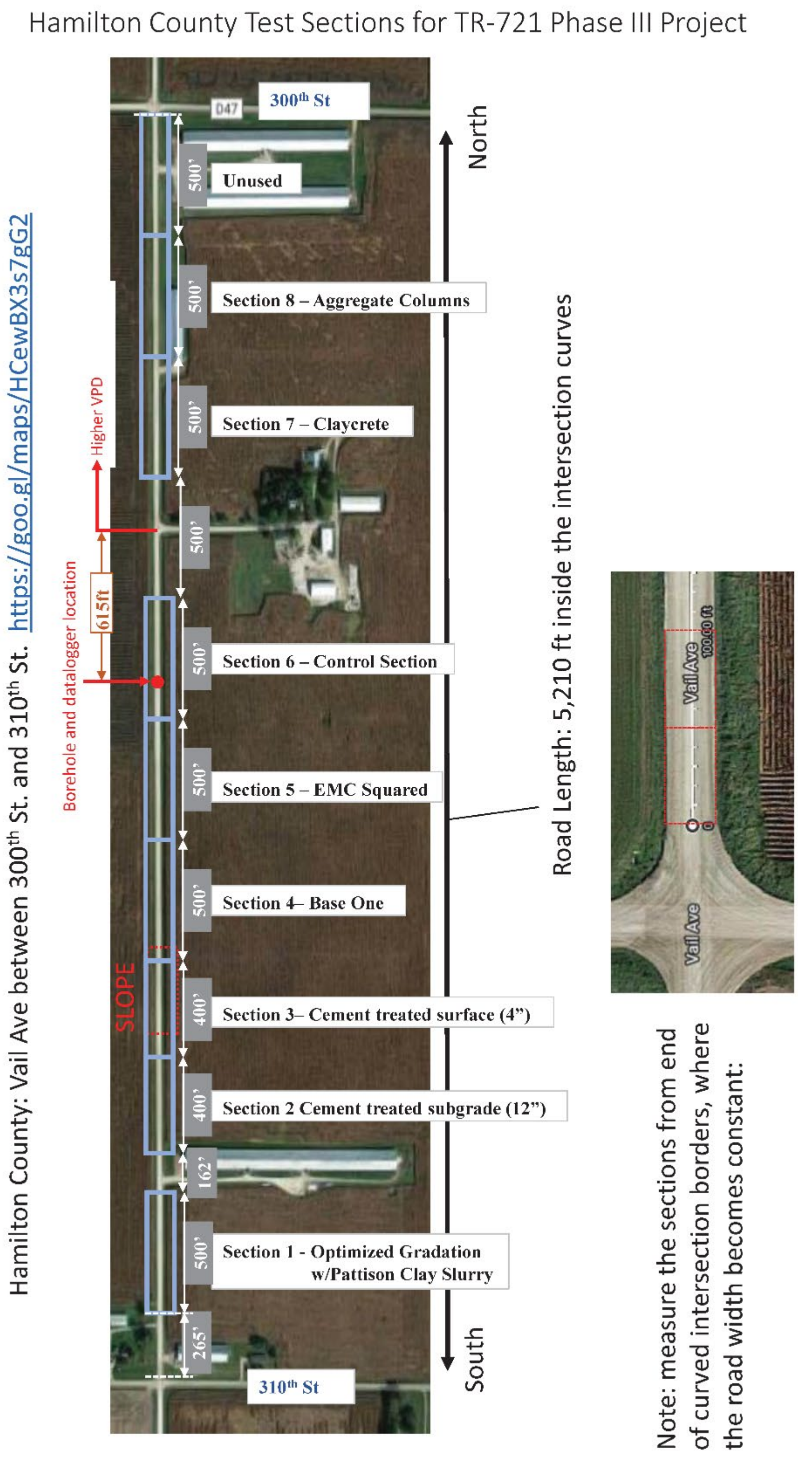
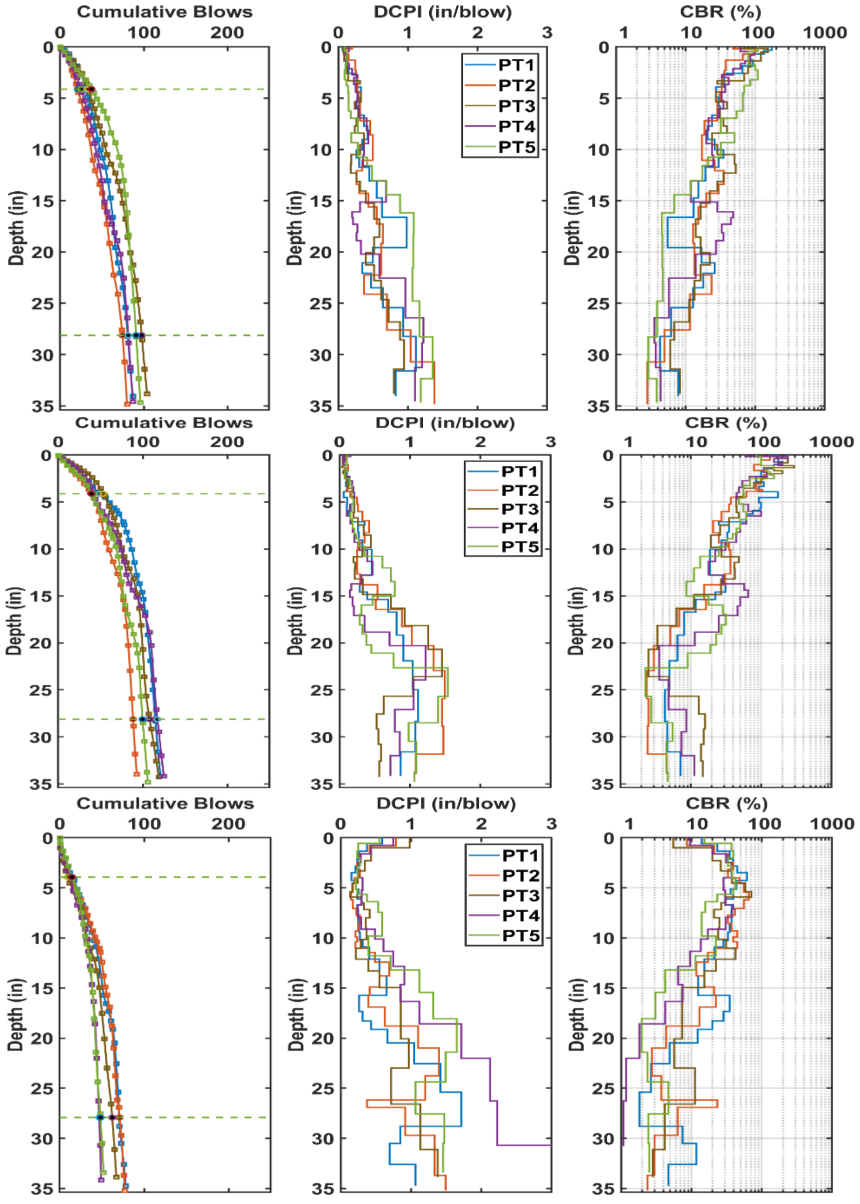


Figure 162. Hamilton County test section layout

APPENDIX D. DCP TEST RESULTS



(a) (b) (c)

Figure 163. Fall 2018 DCP results for Sections 1 (top row), 2 (middle row) and 3 (bottom row) in Cherokee County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR

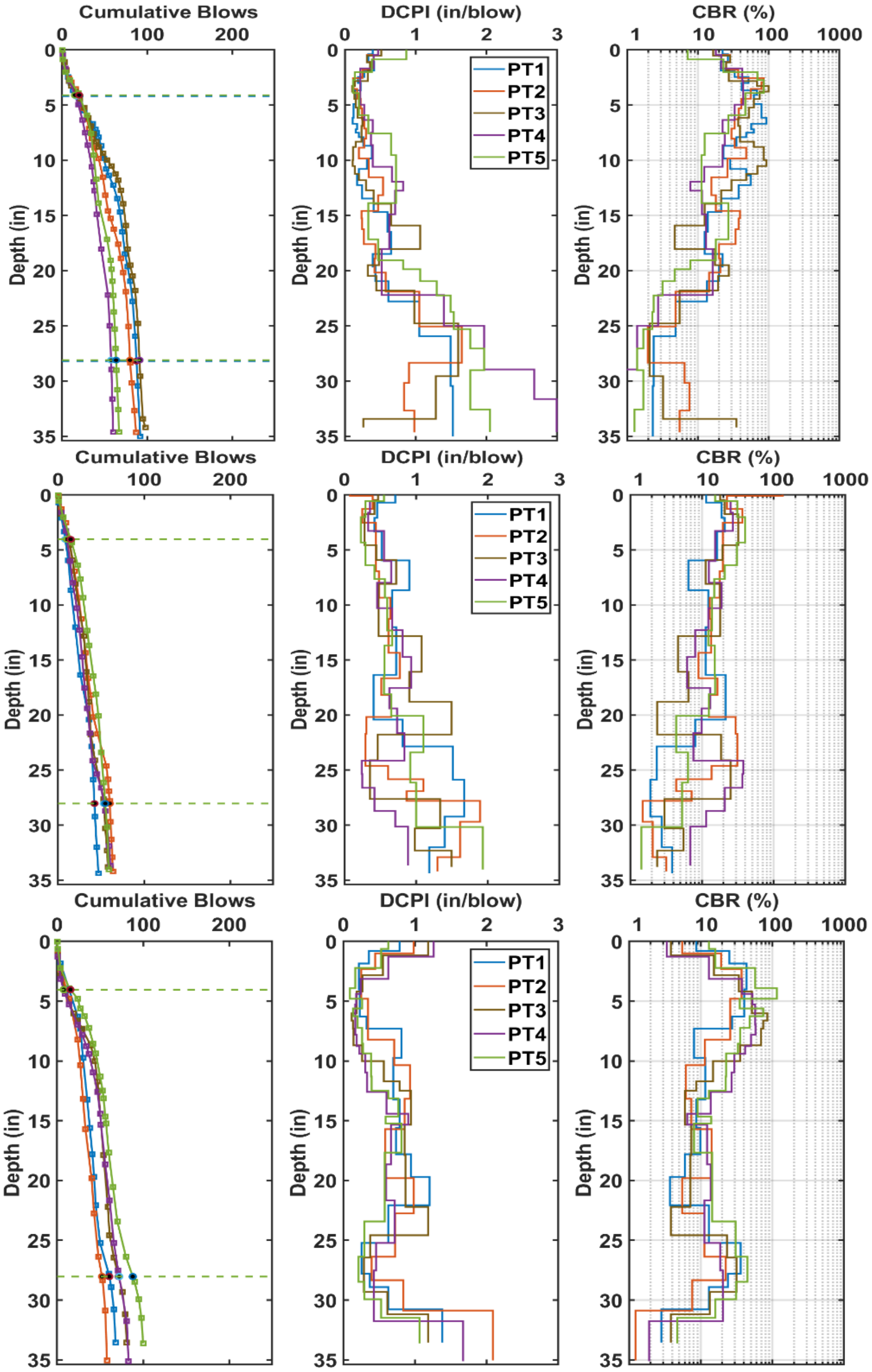
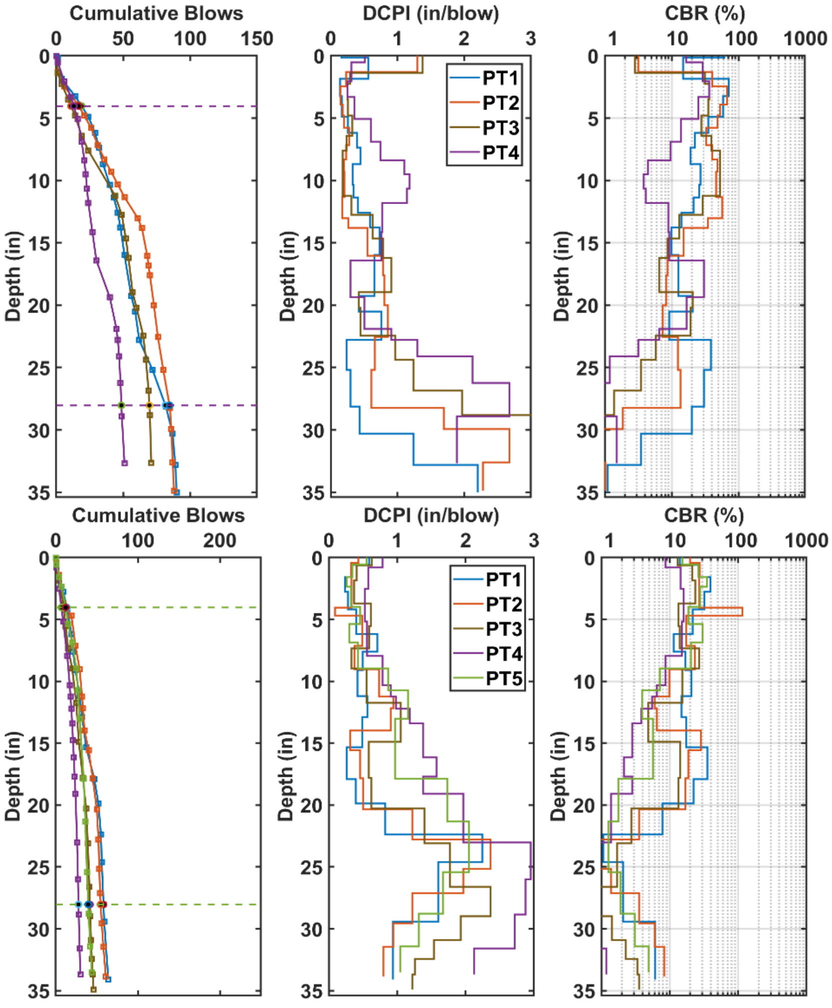
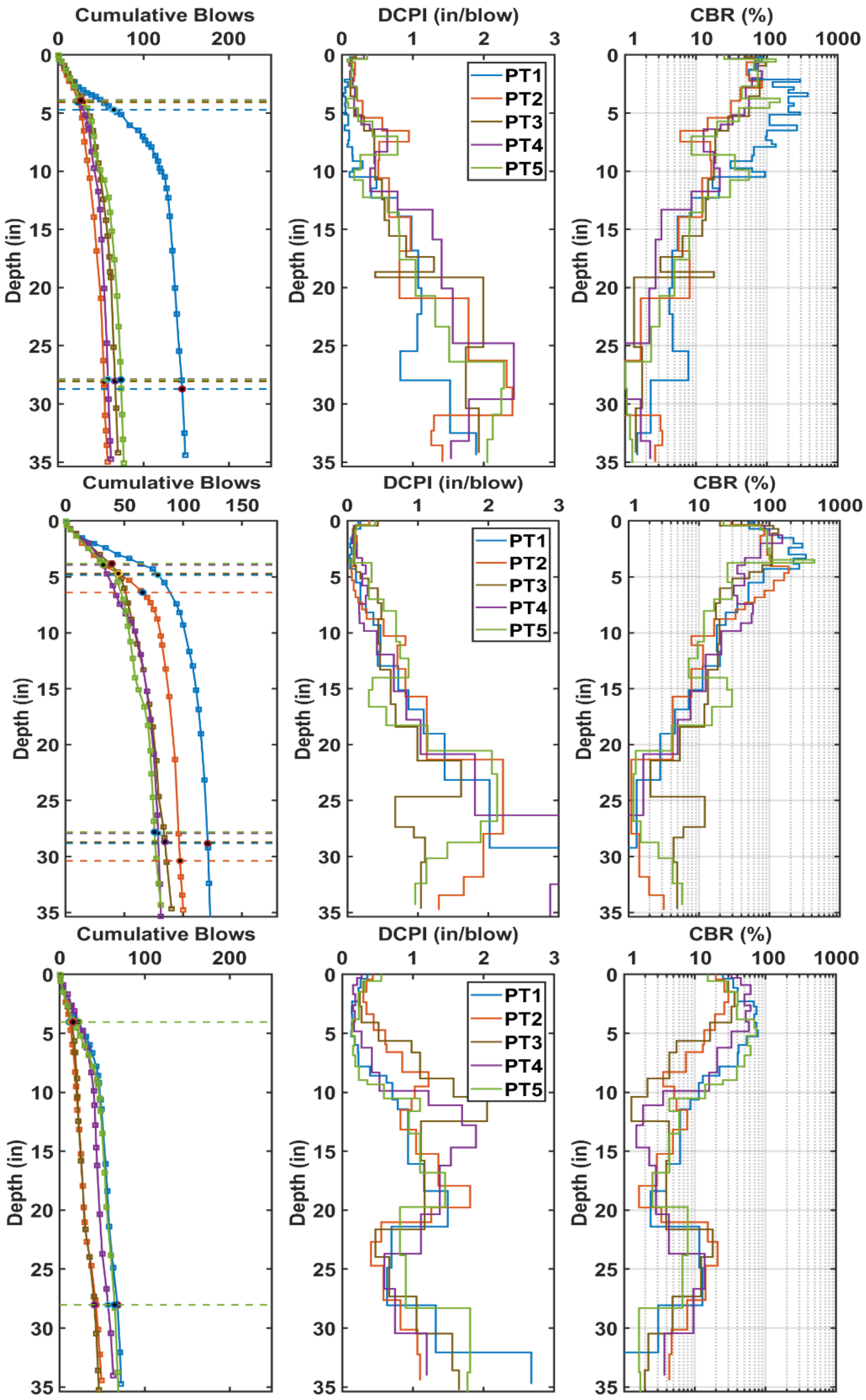


Figure 164. Fall 2018 DCP results for Section 4A (top row), 4B (middle row), and 5A (bottom row) in Cherokee County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



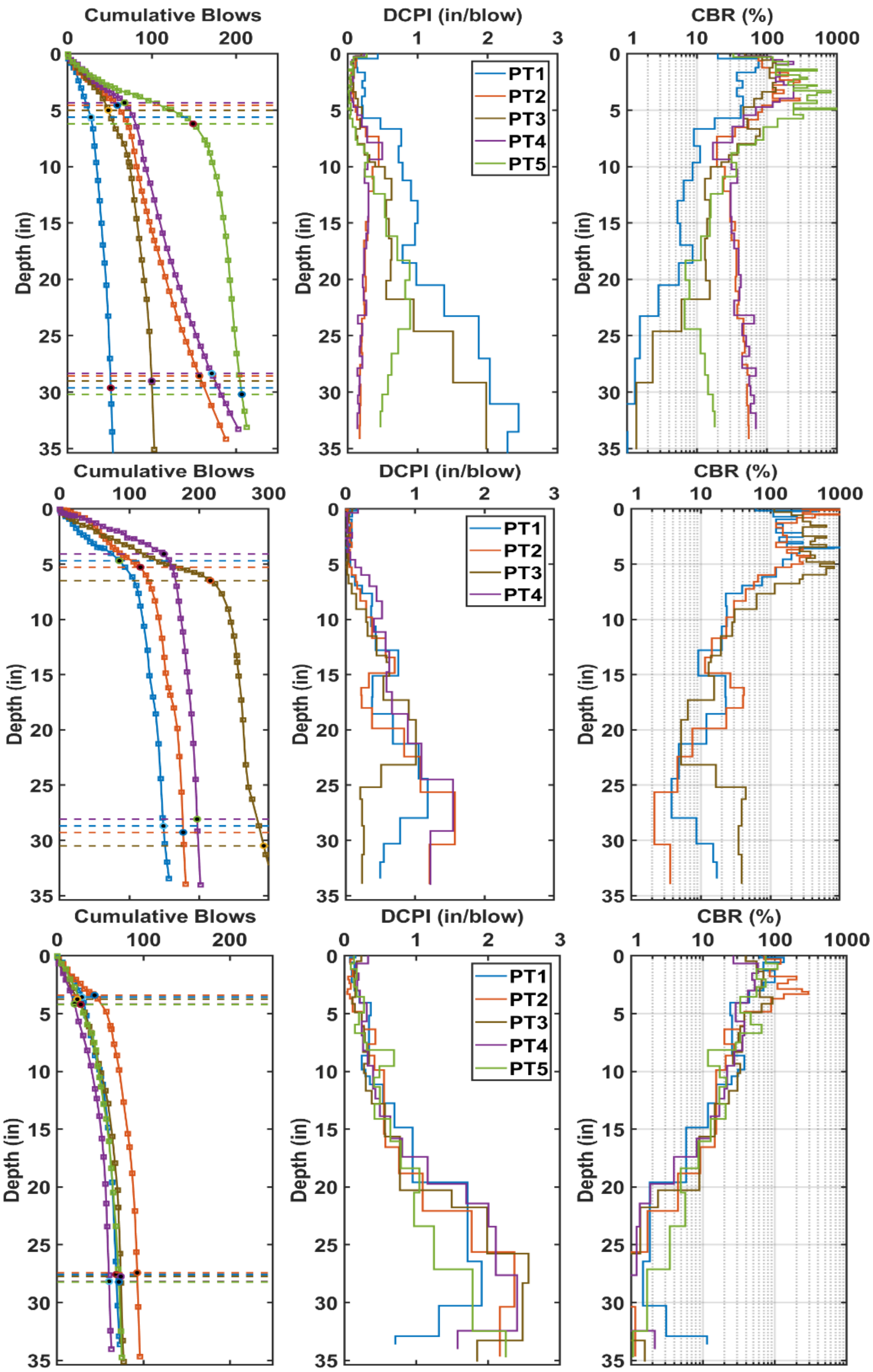
(a) (b) (c)

Figure 165. Fall 2018 DCP results for Section 5B (top row) and 6 (bottom row) in Cherokee County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



(a) (b) (c)

Figure 166. Fall 2018 DCP results for Section 1 (top row), 2 (middle row), and 4 (bottom row) in Howard County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



(a) (b) (c)

Figure 167. Fall 2018 DCP results for Section 5A (top row), 5B (middle row), and 6A (bottom row) in Howard County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR

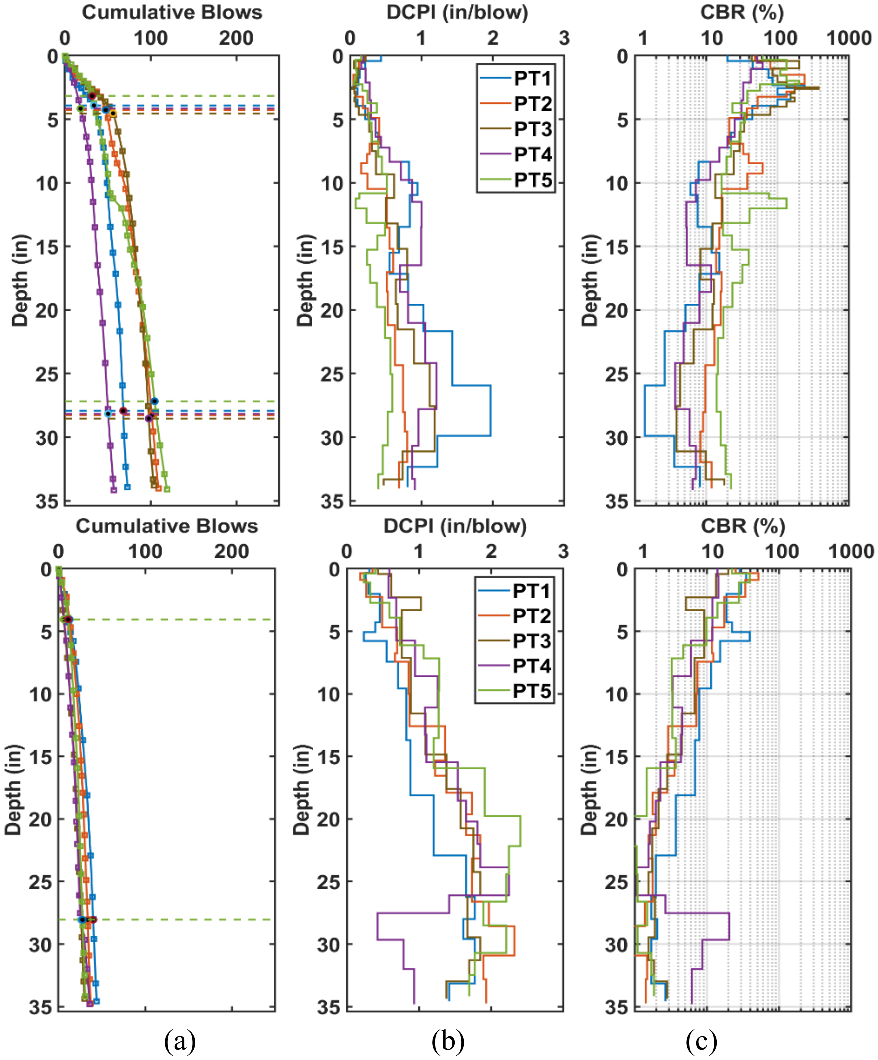
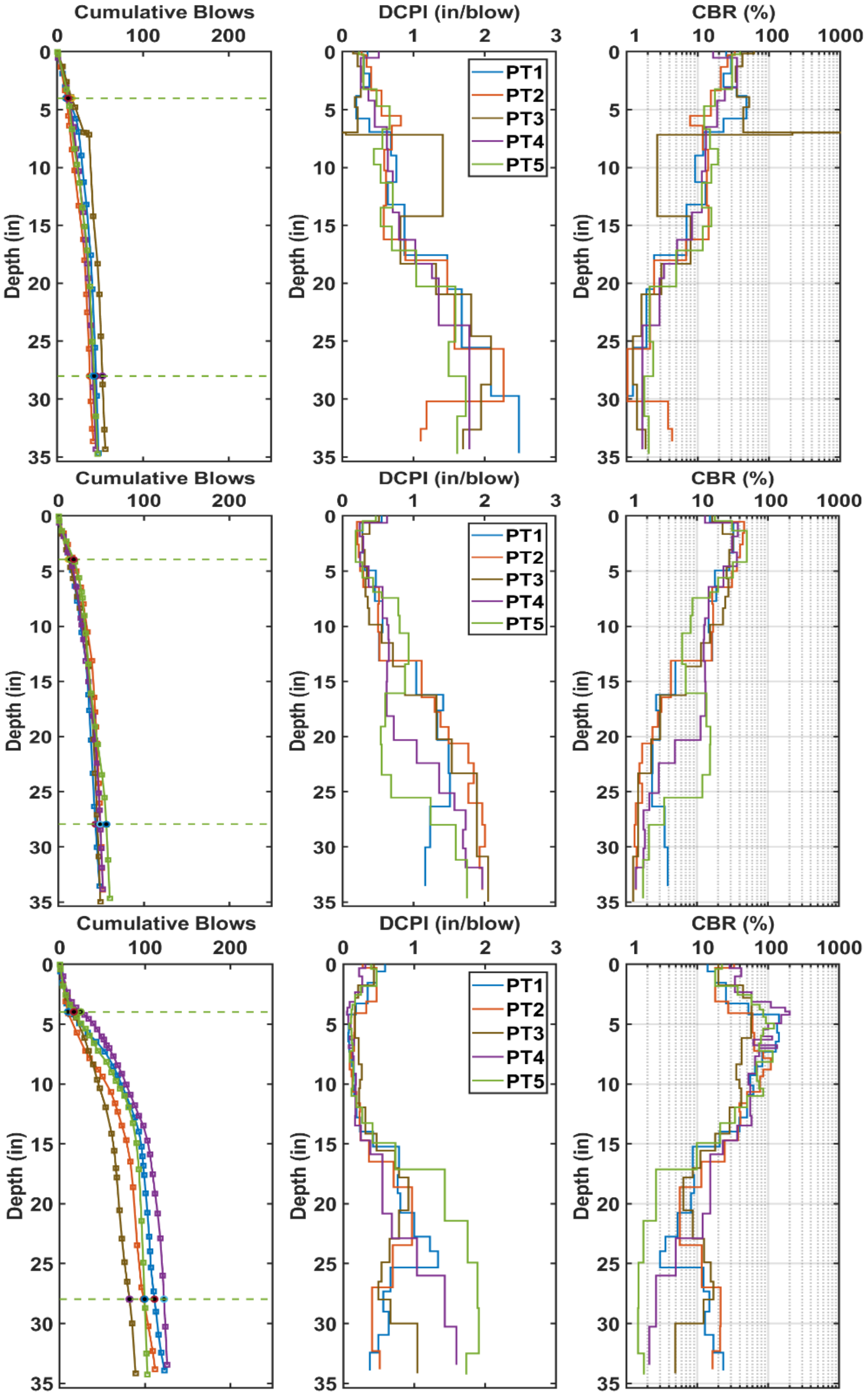
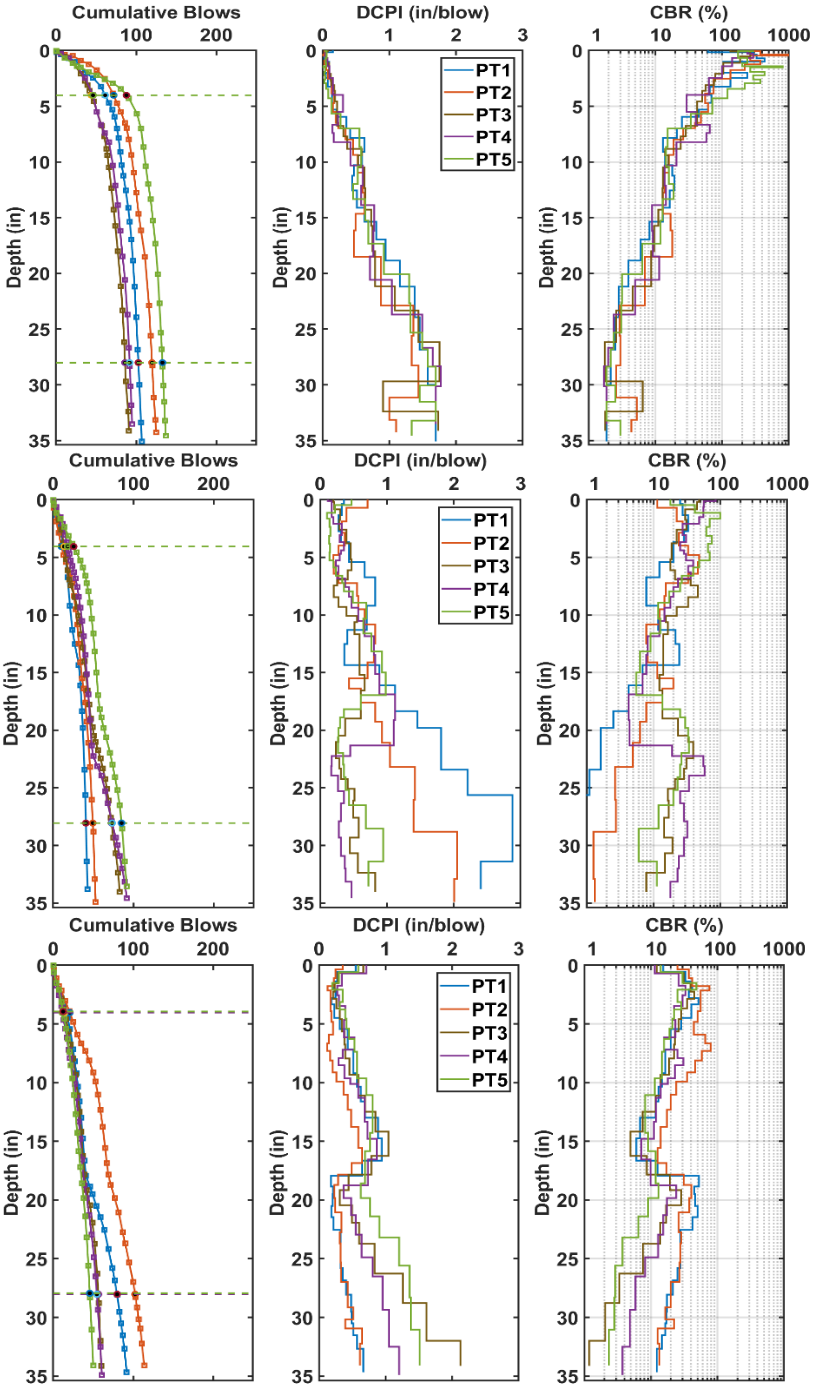


Figure 168. Fall 2018 DCP results for Section 6B (top row) and 7 (bottom row) in Howard County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



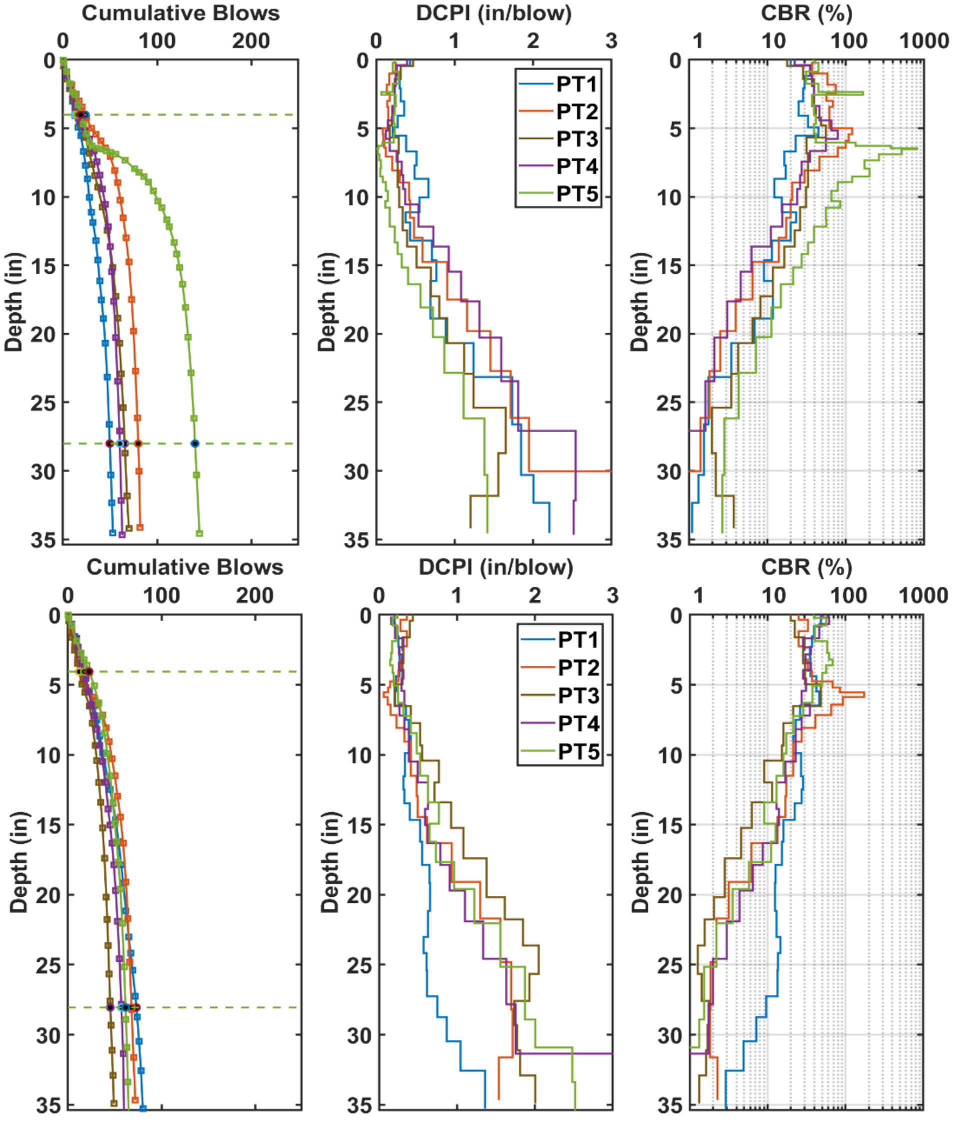
(a) (b) (c)

Figure 169. Fall 2018 DCP results for Section 1 (top row), 2 (middle row), and 3 (bottom row) in Washington County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



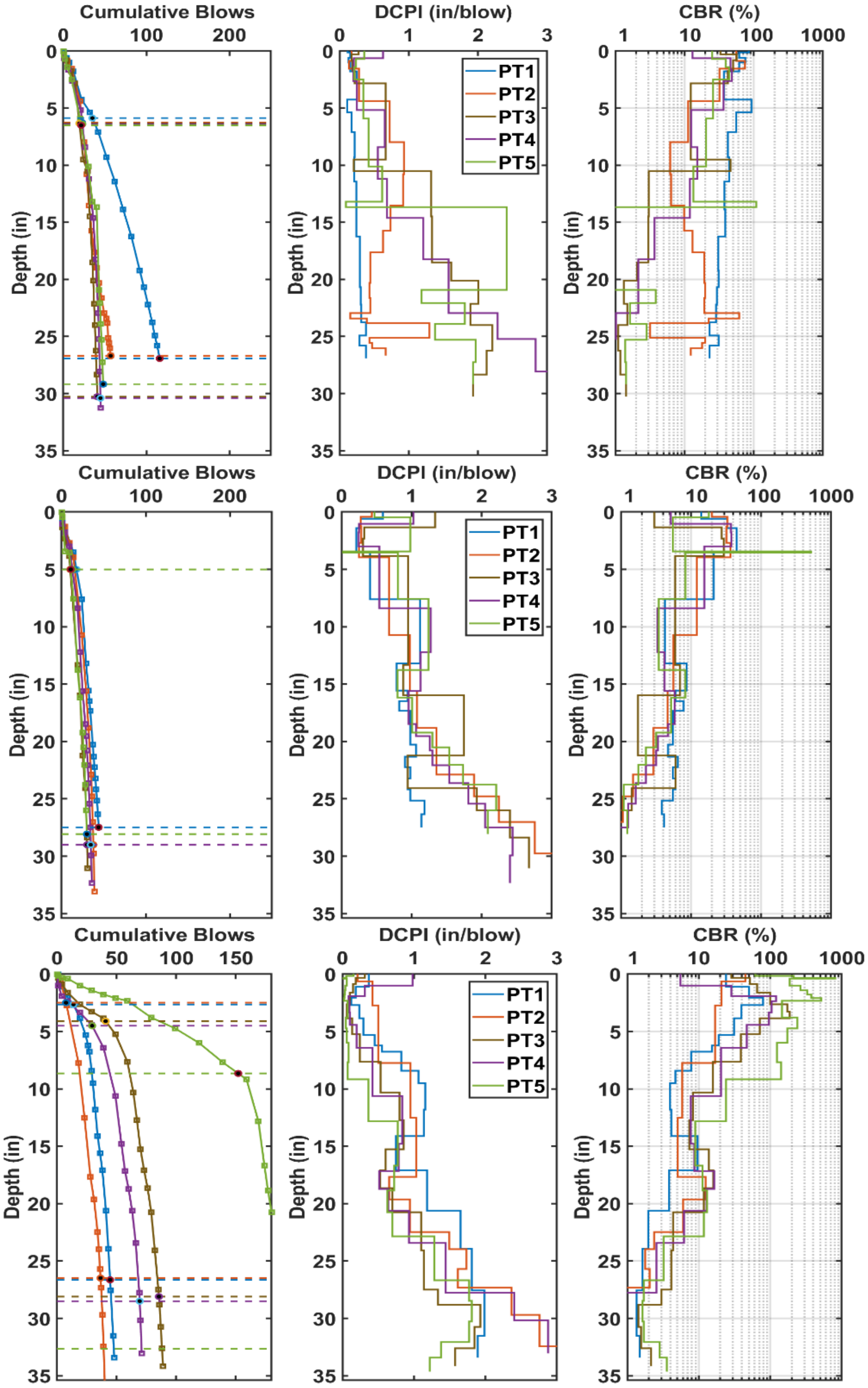
(a) (b) (c)

Figure 170. Fall 2018 DCP results for Section 4 (top row), 5 (middle row), and 6 (bottom row) in Washington County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



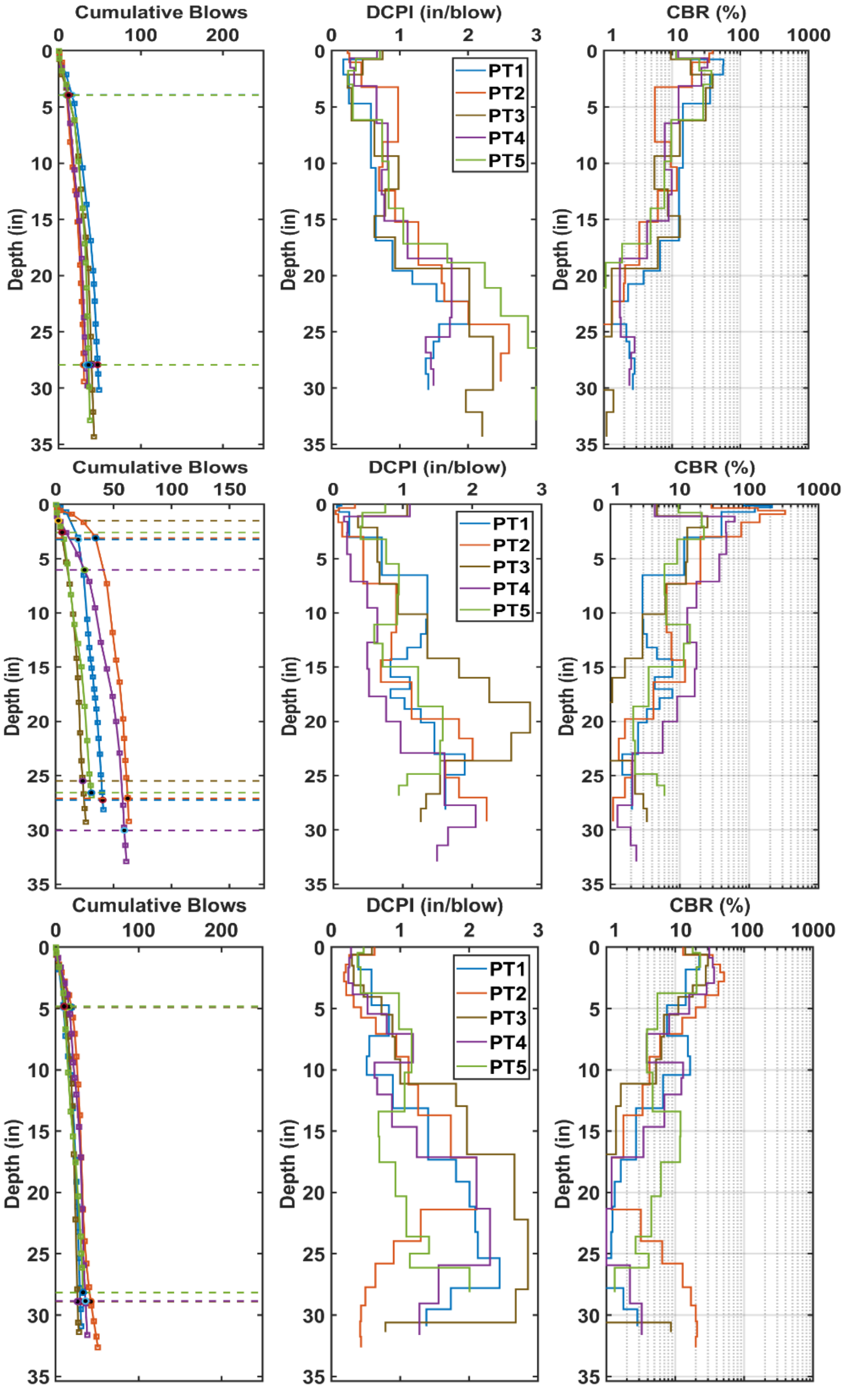
(a) (b) (c)

Figure 171. Fall 2018 DCP results for Section 7 (top row) and 8 (bottom row) in Washington County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



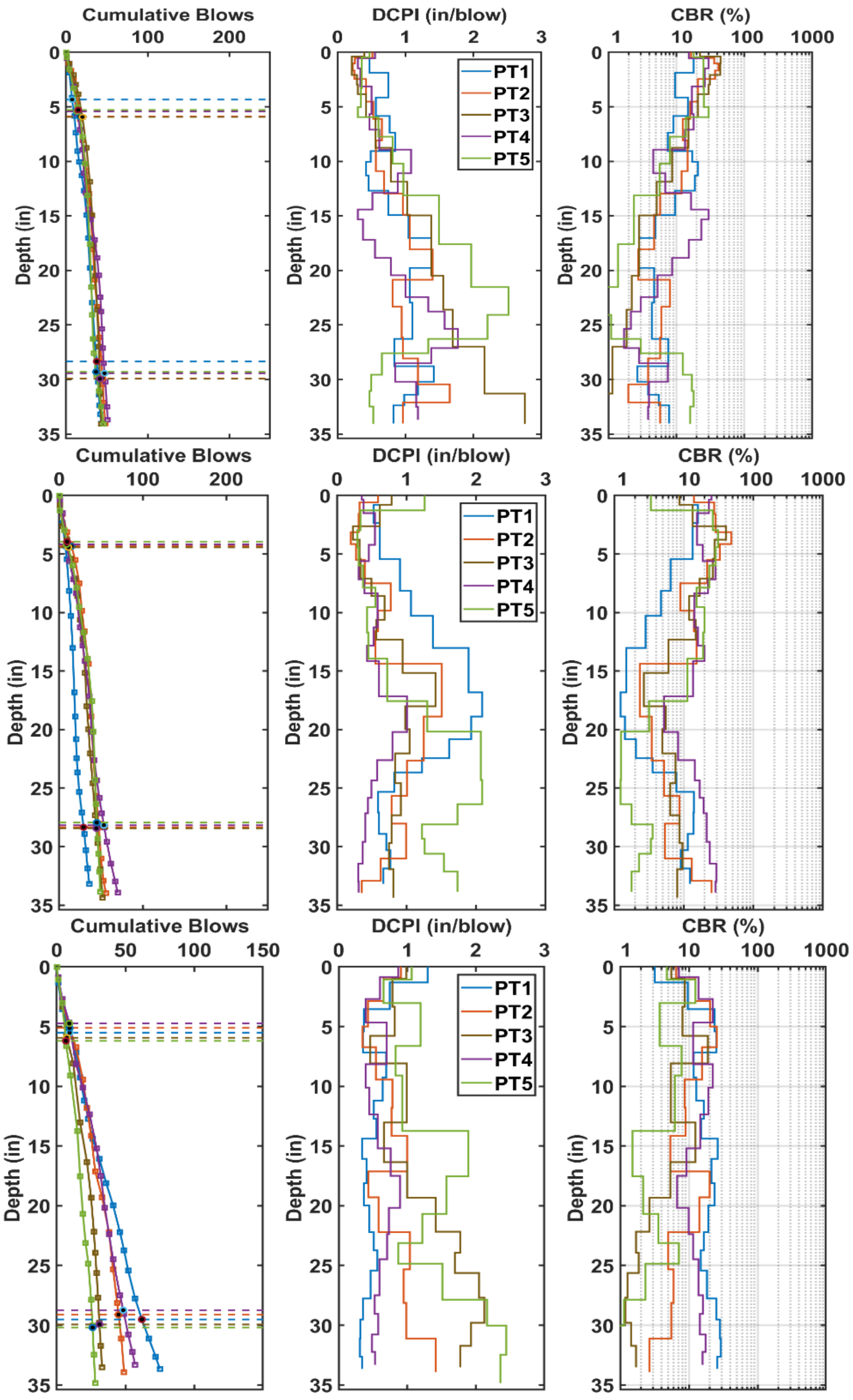
(a) (b) (c)

Figure 172. Fall 2018 DCP results for Section 1 (top row), 4 (middle row), and 5 (bottom row) in Hamilton County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



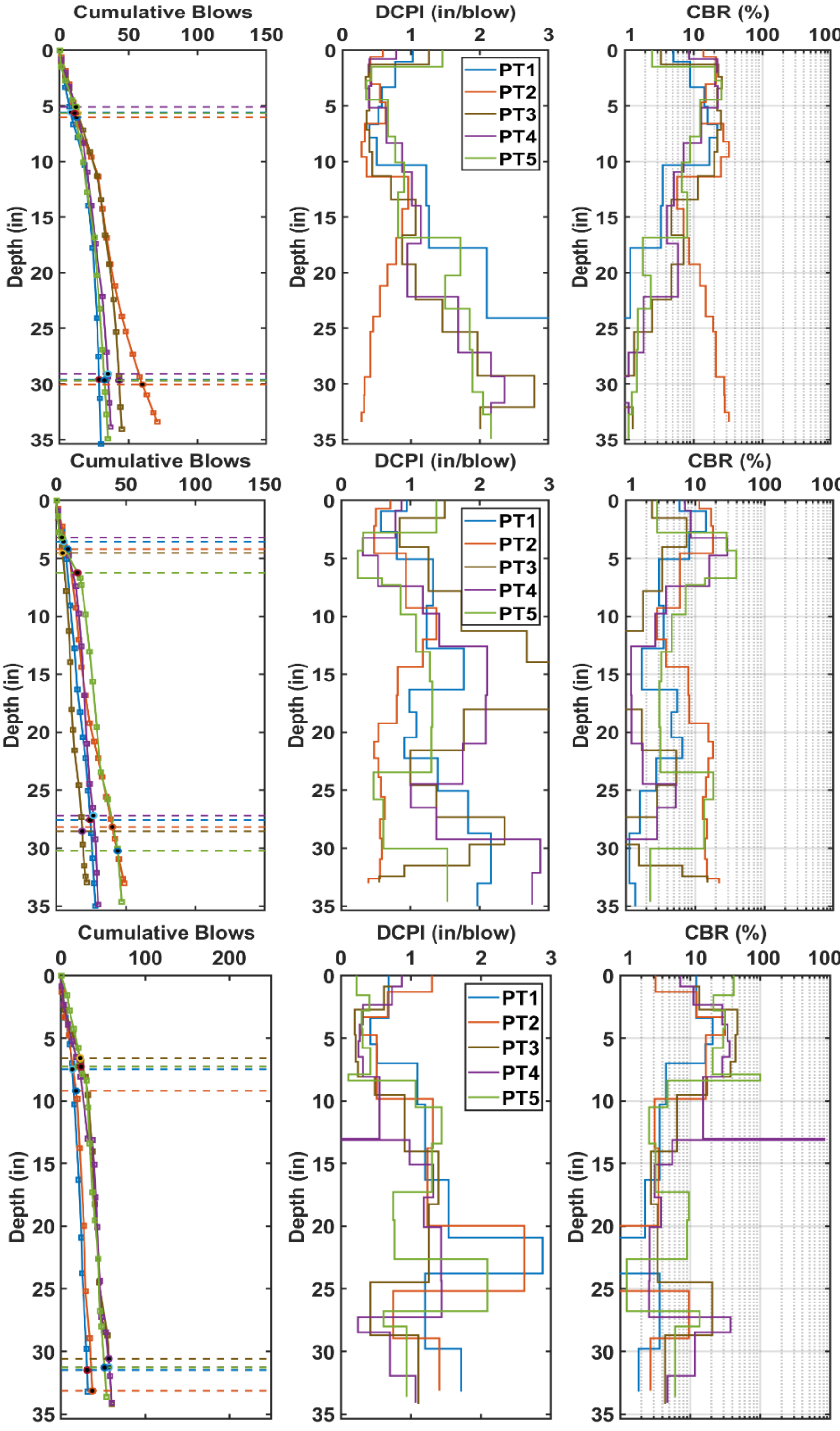
(a) (b) (c)

Figure 173. Fall 2018 DCP results for Section 6 (top row), 7 (middle row), and 8 (bottom row) in Hamilton County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



(a) (b) (c)

Figure 174. Spring 2019 DCP results for Section 1, (top row), 2 (middle row), and 3 (bottom row) in Cherokee County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



(a) (b) (c)

Figure 175. Spring 2019 DCP results for Section 4A (top row), 4B (middle row), and 5A (bottom row) in Cherokee County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR

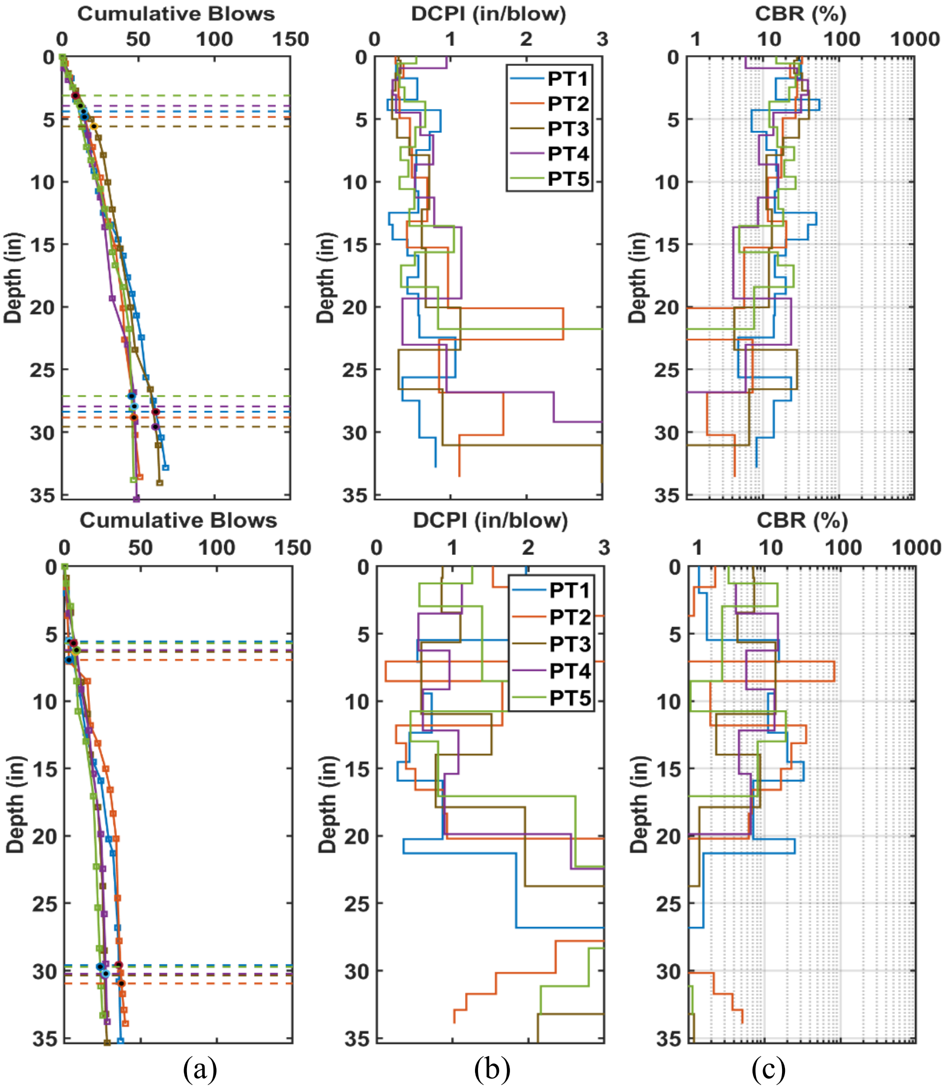
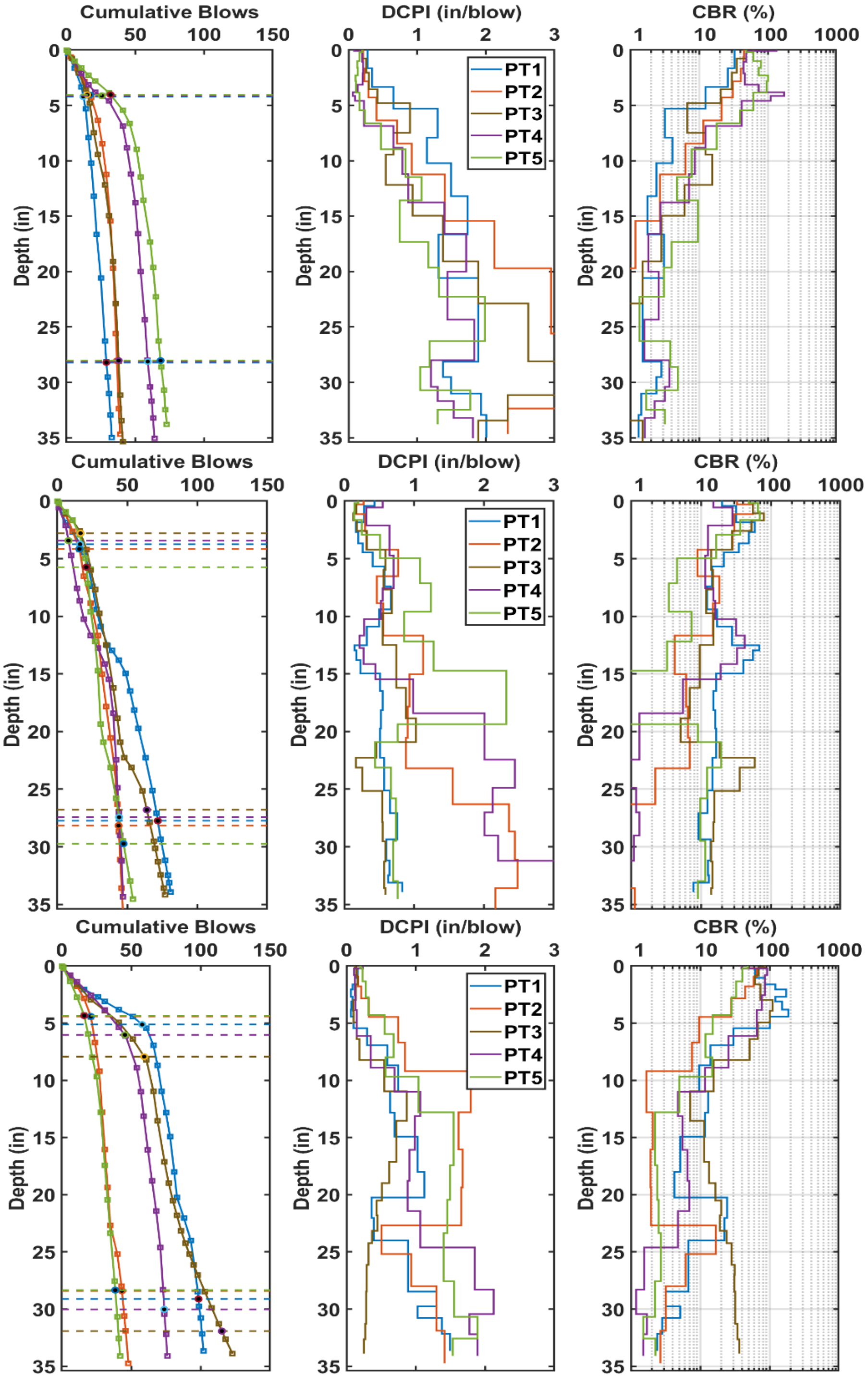


Figure 176. Spring 2019 DCP results for Section 5B (top row) and 6 (bottom row) in Cherokee County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



(a) (b) (c)

Figure 177. Spring 2019 DCP results for Section 1 (top row), 2 (middle row), and 4 (bottom row) in Howard County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR

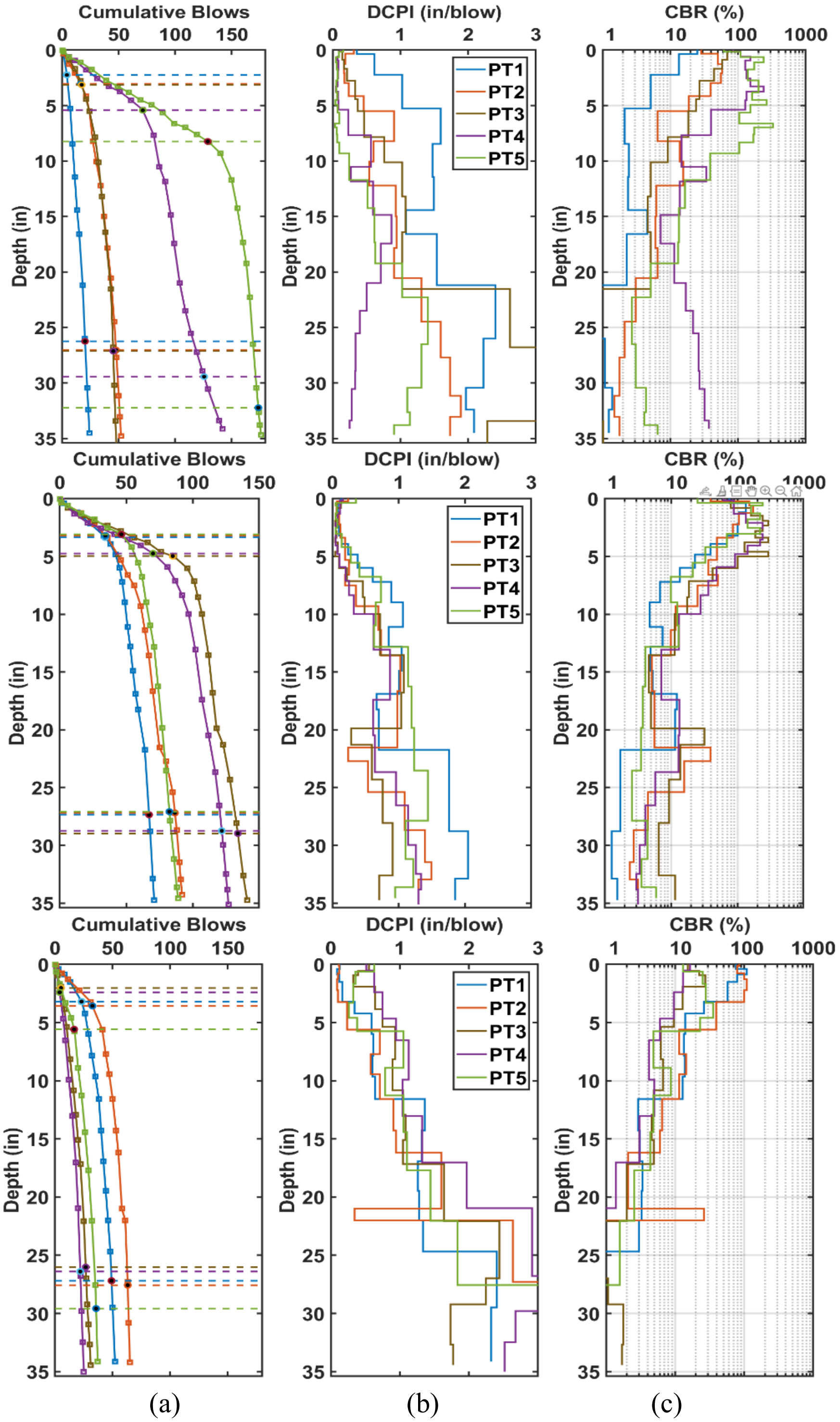


Figure 178. Spring 2019 DCP results for Section 5A (top row), 5B (middle row), and 6A (bottom row) in Howard County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR

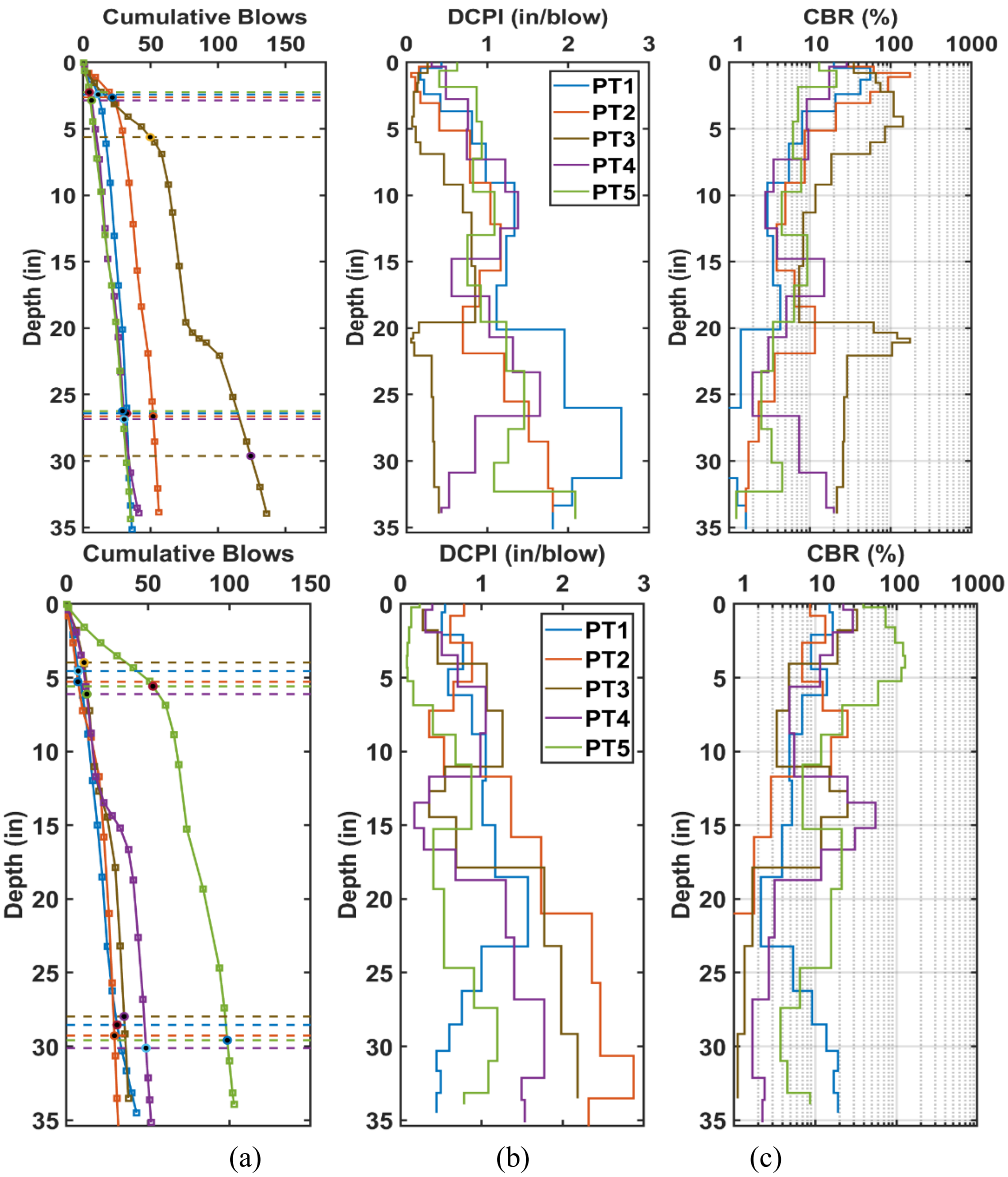
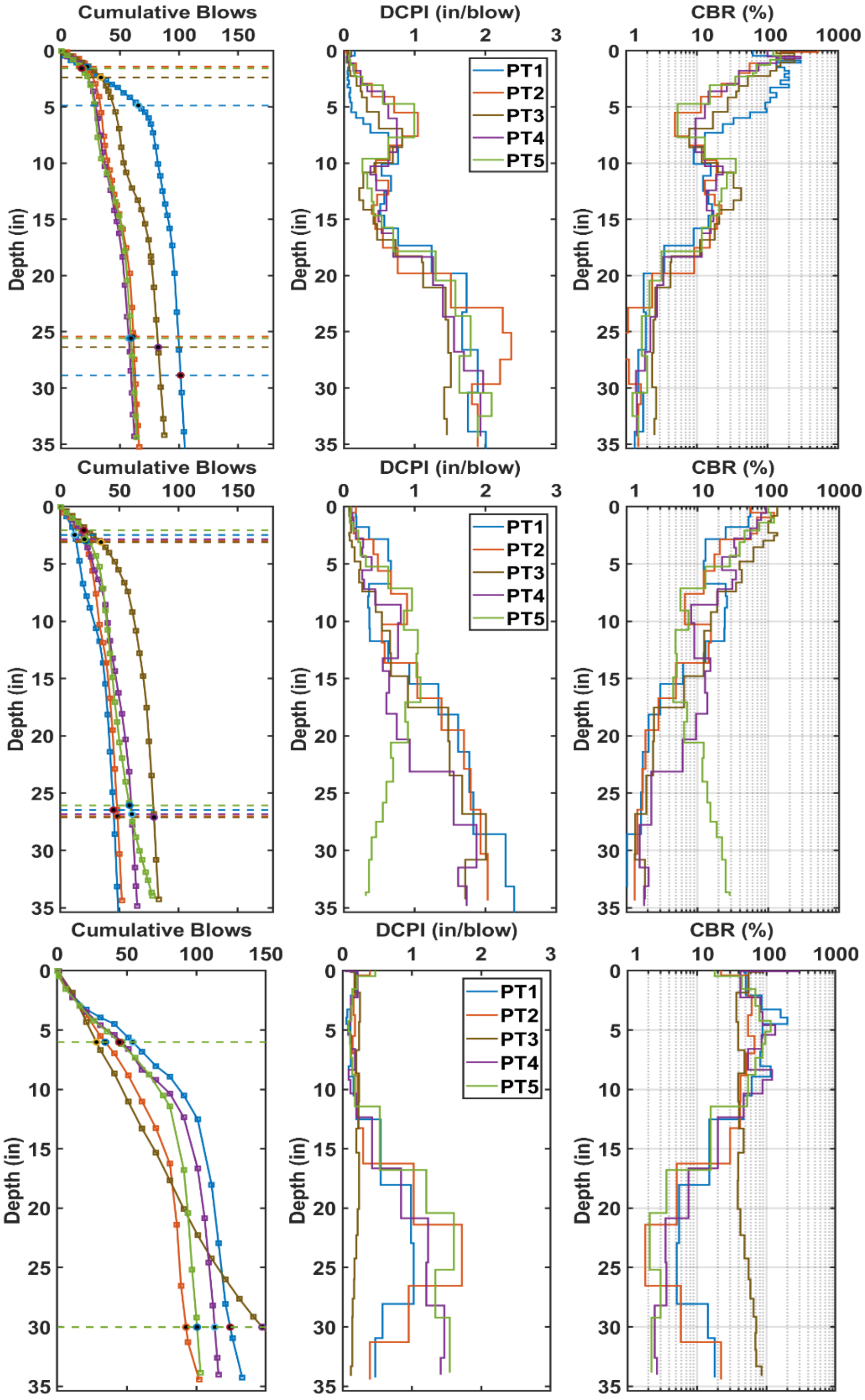
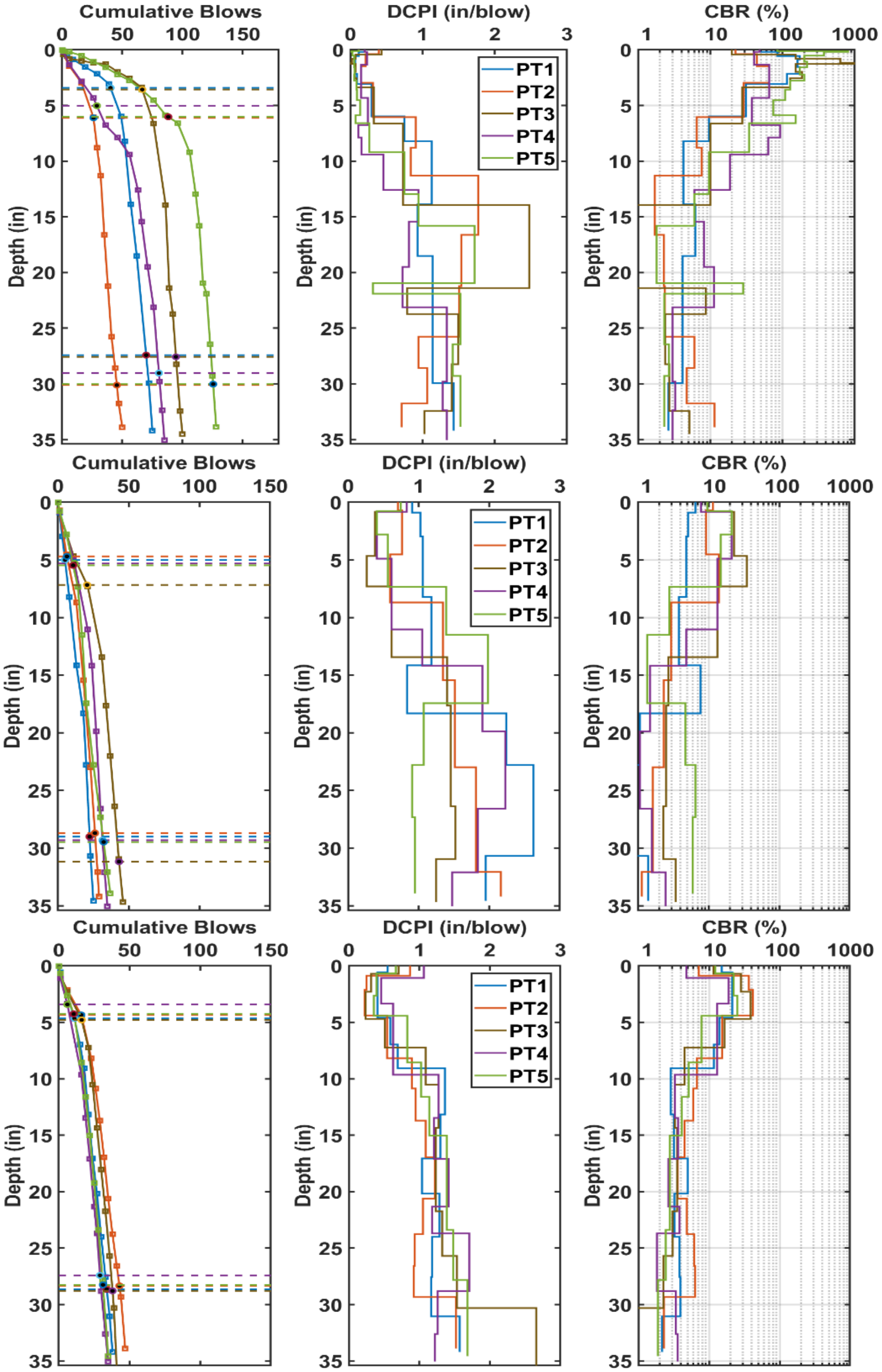


Figure 179. Spring 2019 DCP results for Section 6B (top row) and 7 (bottom row) in Howard County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



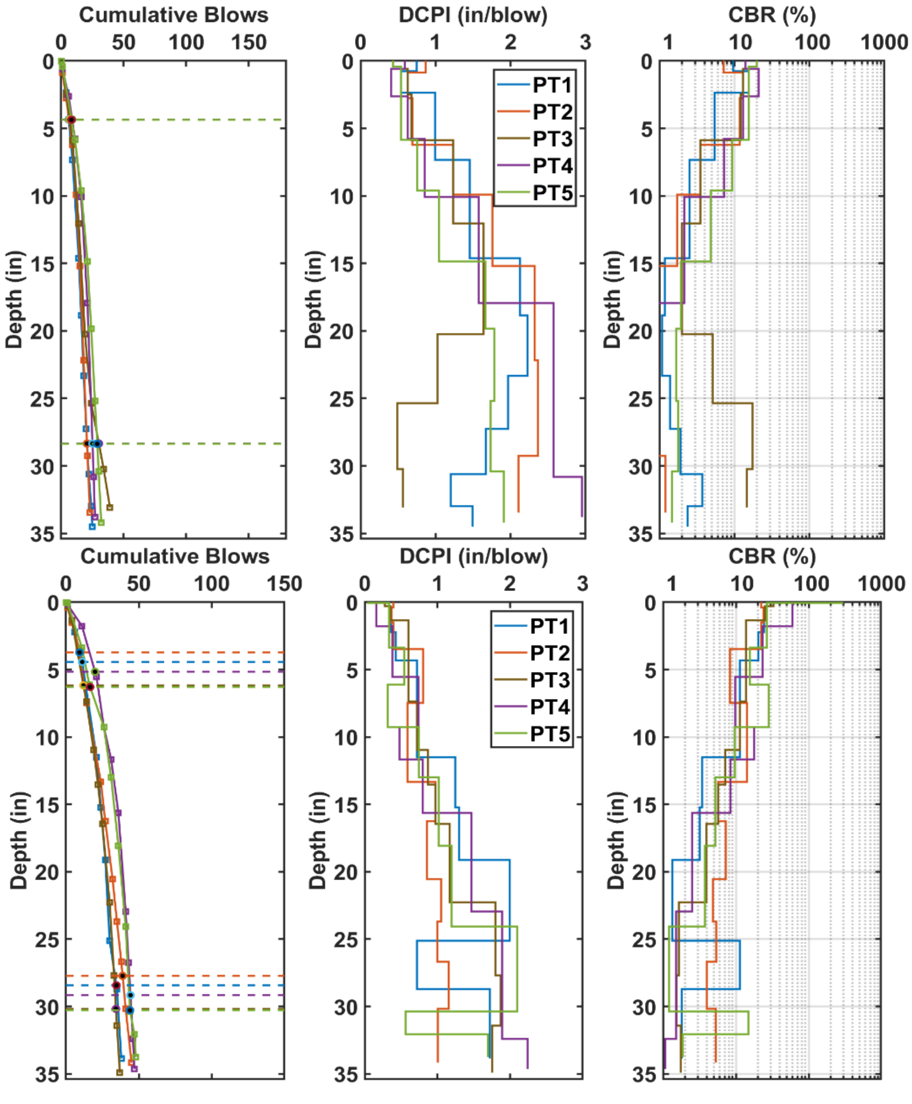
(a) (b) (c)

Figure 180. Spring 2019 DCP results for Section 1 (top row), 2 (middle row), and 3 (bottom row) in Washington County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



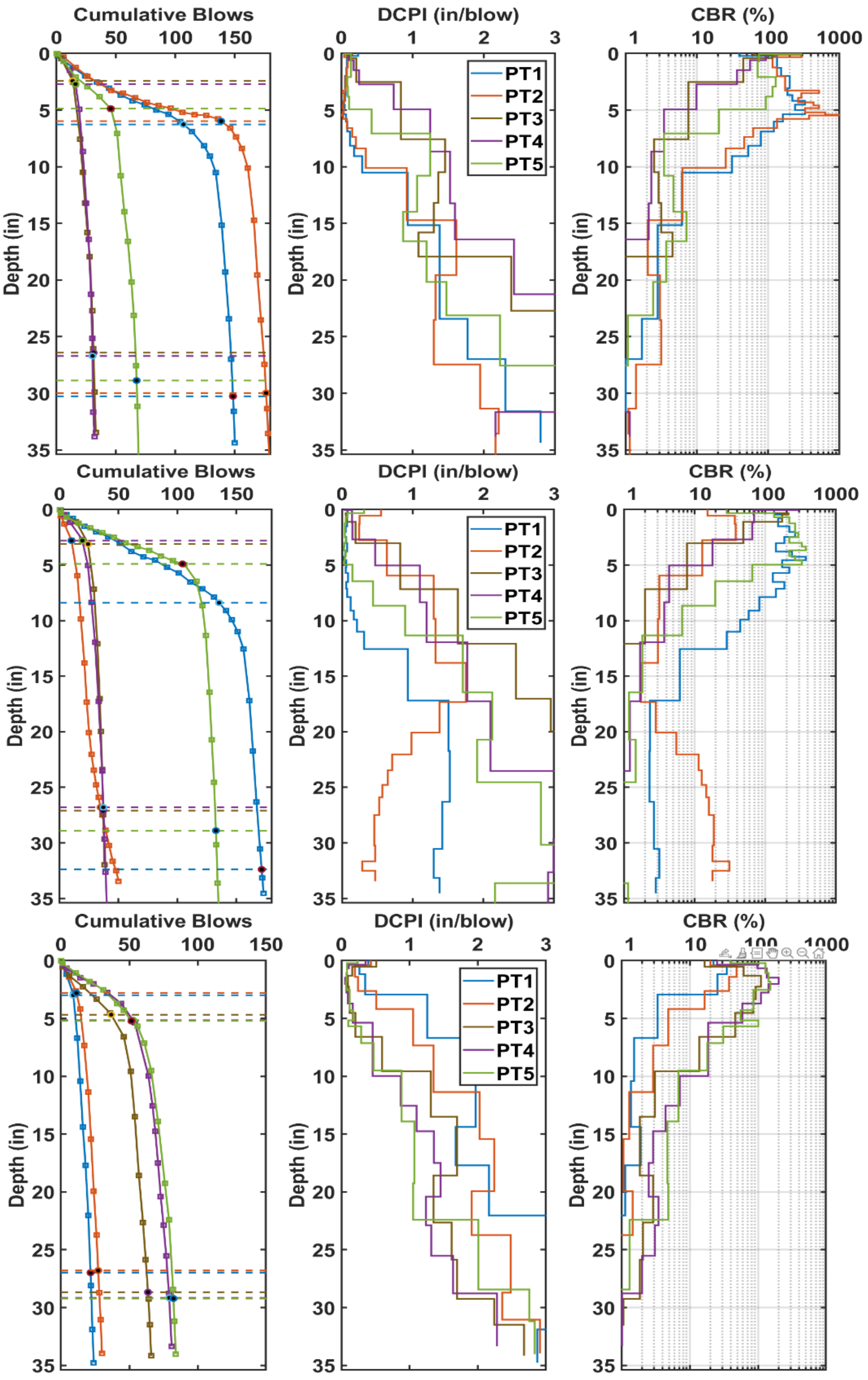
(a) (b) (c)

Figure 181. Spring 2019 DCP results for Section 4 (top row), 5 (middle row), and 6 (bottom row) in Washington County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



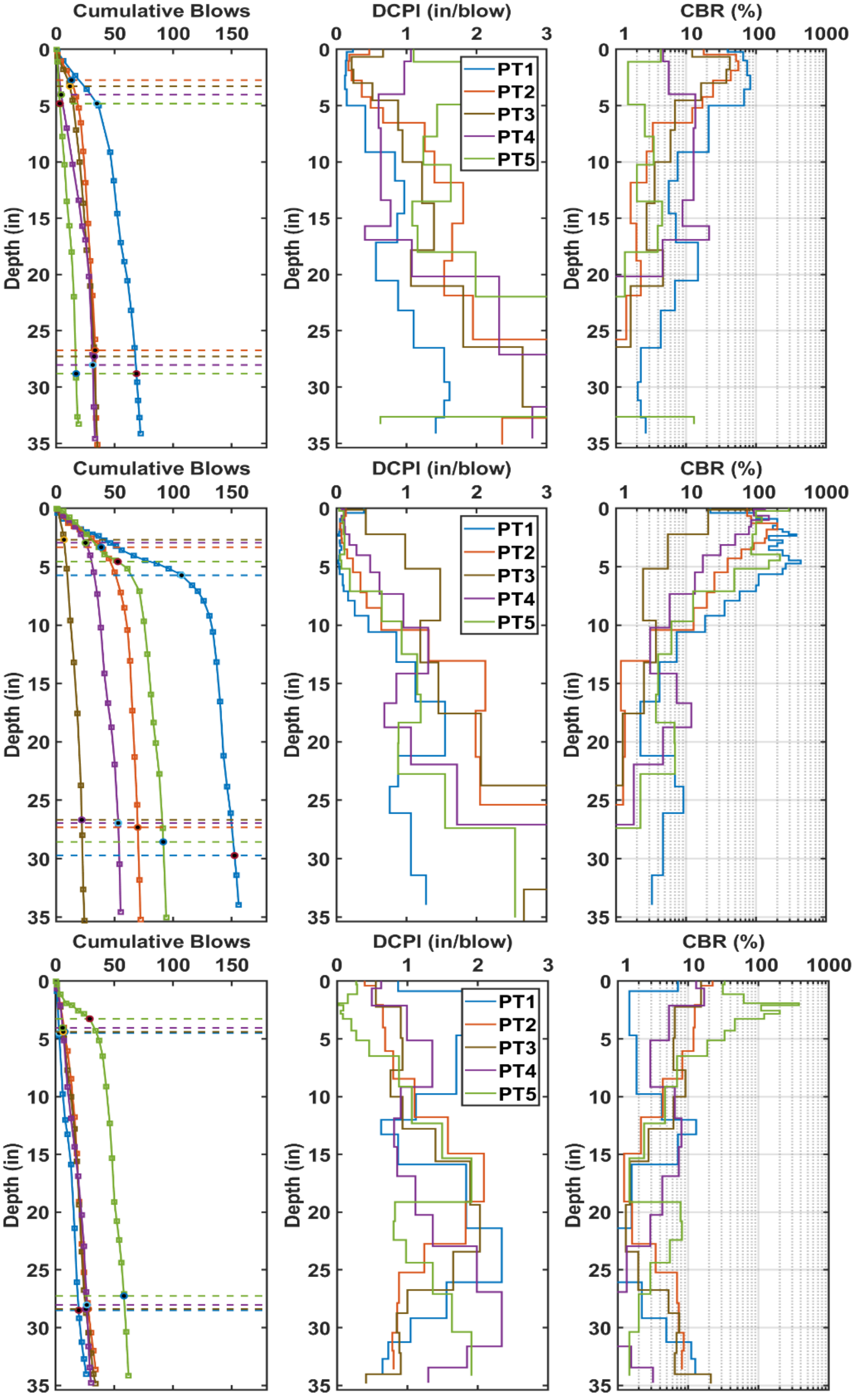
(a) (b) (c)

Figure 182. Spring 2019 DCP results for Section 7 (top row) and 8 (bottom row) in Washington County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



(a) (b) (c)

Figure 183. Spring 2019 DCP results for Section 1 (top row), 4 (middle row), and 5 (bottom row) in Hamilton County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



(a) (b) (c)

Figure 184. Spring 2019 DCP results for Section 6 (top row), 7 (middle row), and 8 (bottom row) in Hamilton County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR

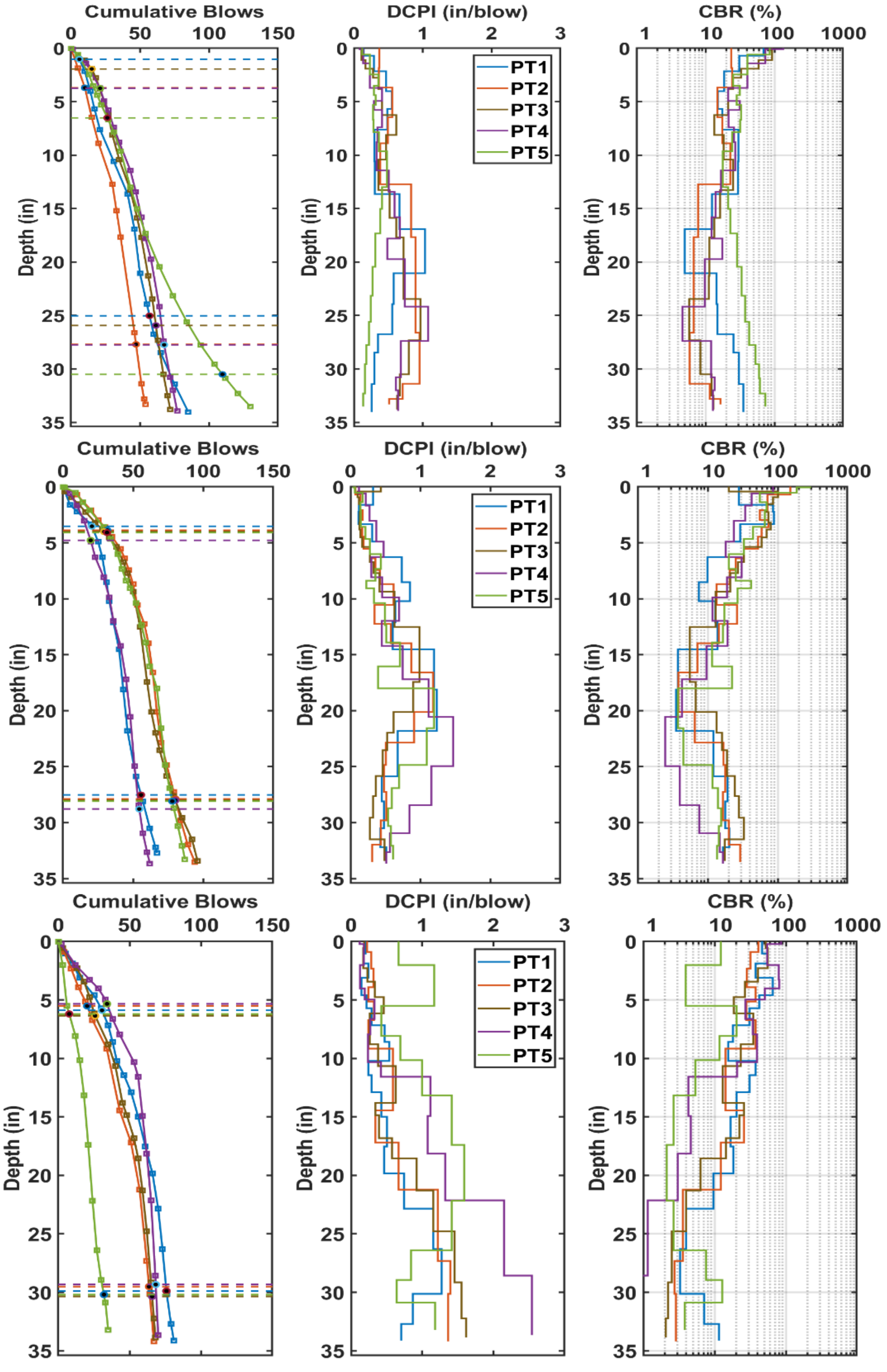
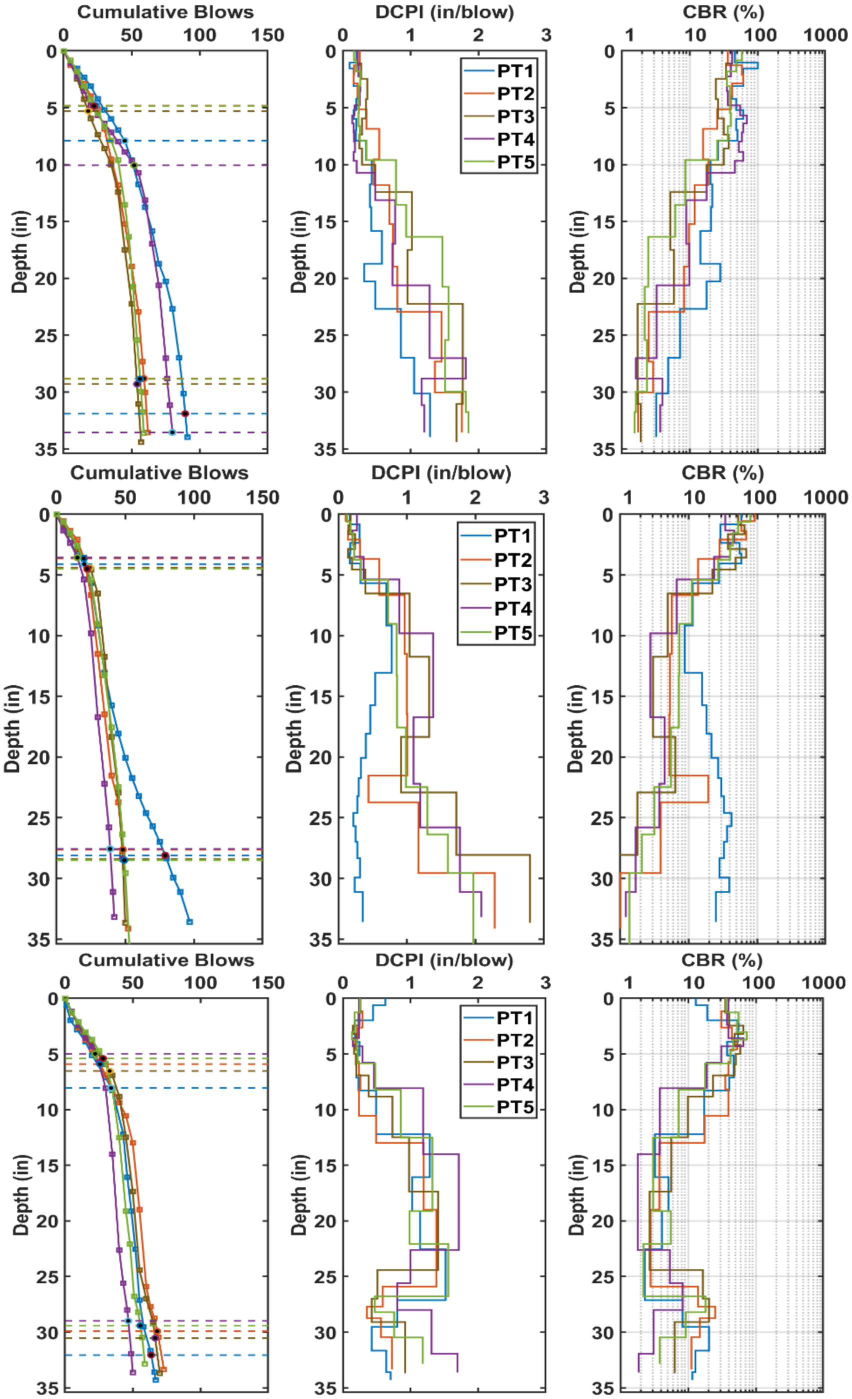


Figure 185. Fall 2019 DCP results for Section 1 (top row), 2 (middle row), and 3 (bottom row) in Cherokee County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



(a) (b) (c)

Figure 186. Fall 2019 DCP results for Section 4A (top row), 4B (middle row), and 5A (botom row) in Cherokee County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR

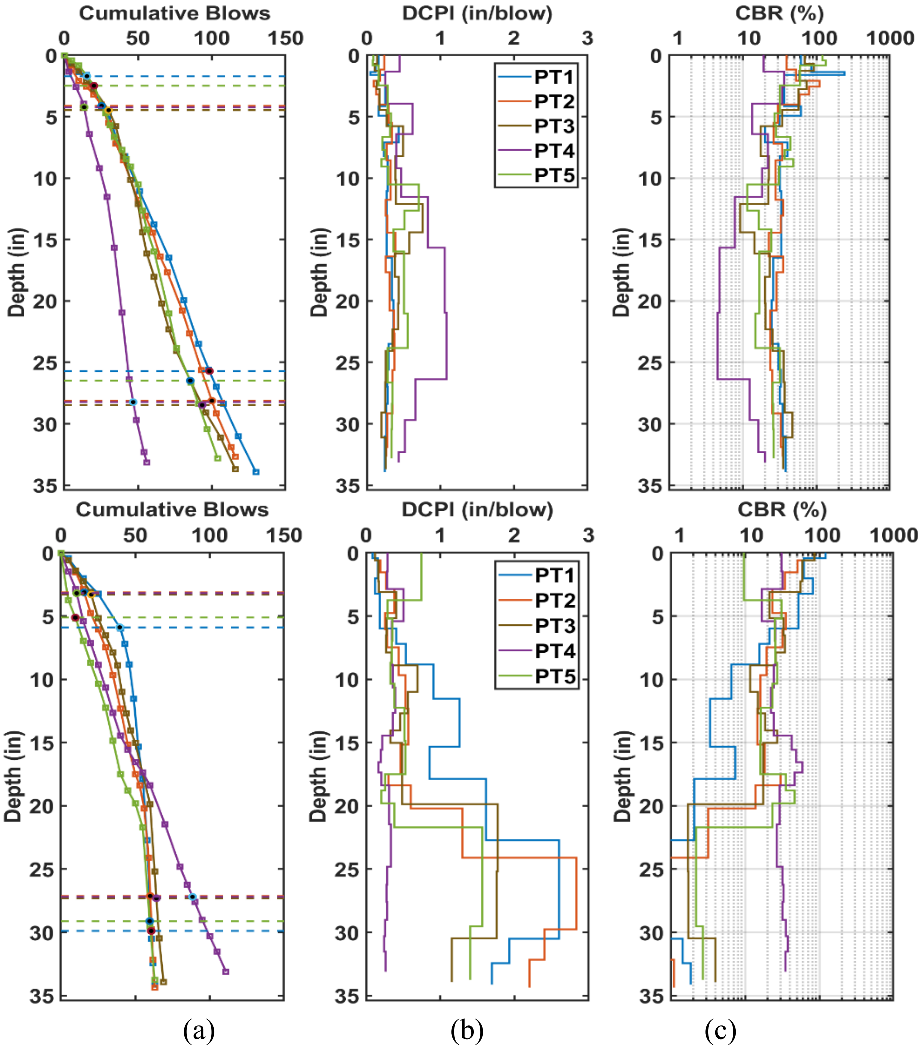
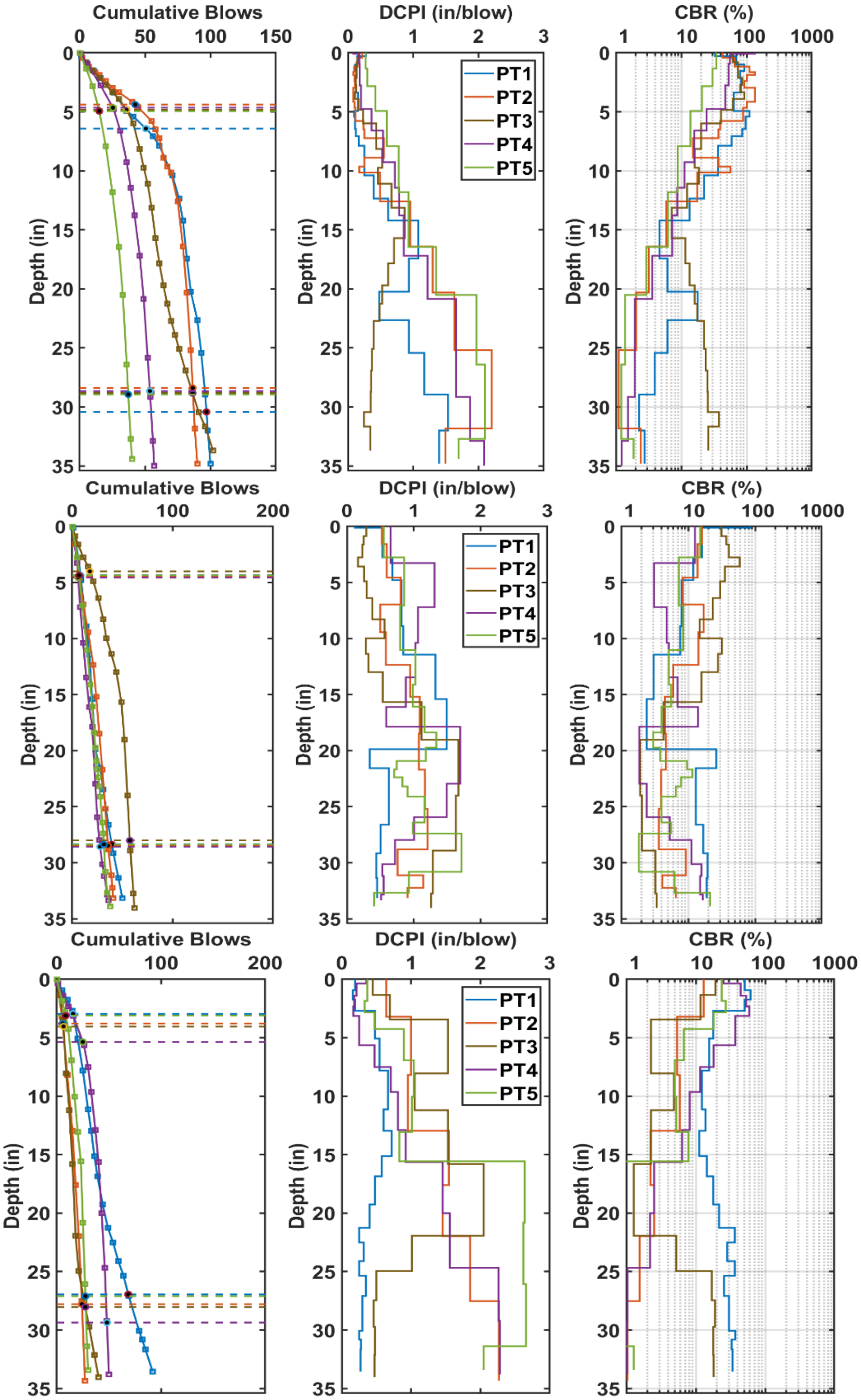
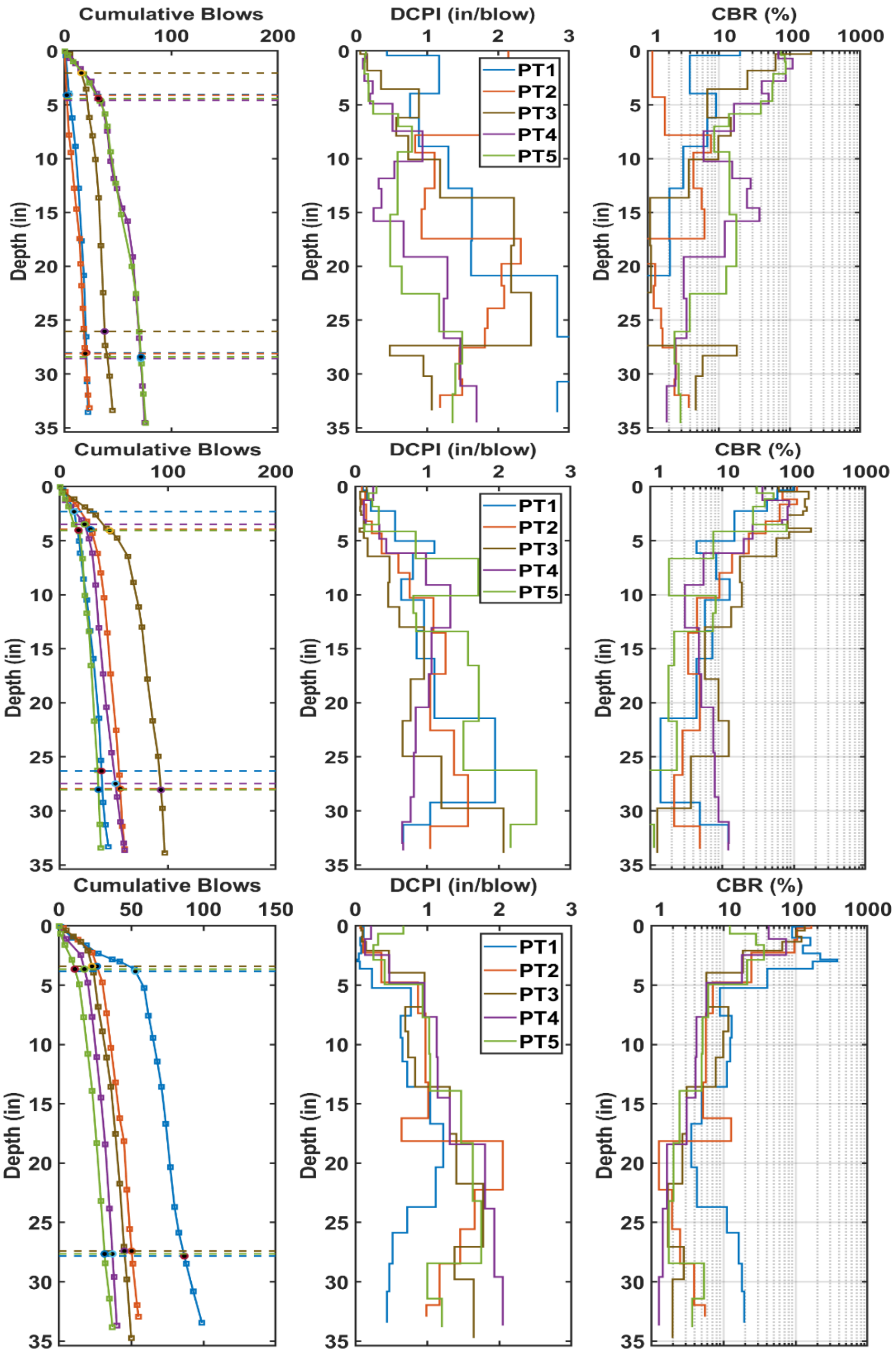


Figure 187. Fall 2019 DCP results for Section 5B (top row) and 6 (bottom row) in Cherokee County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



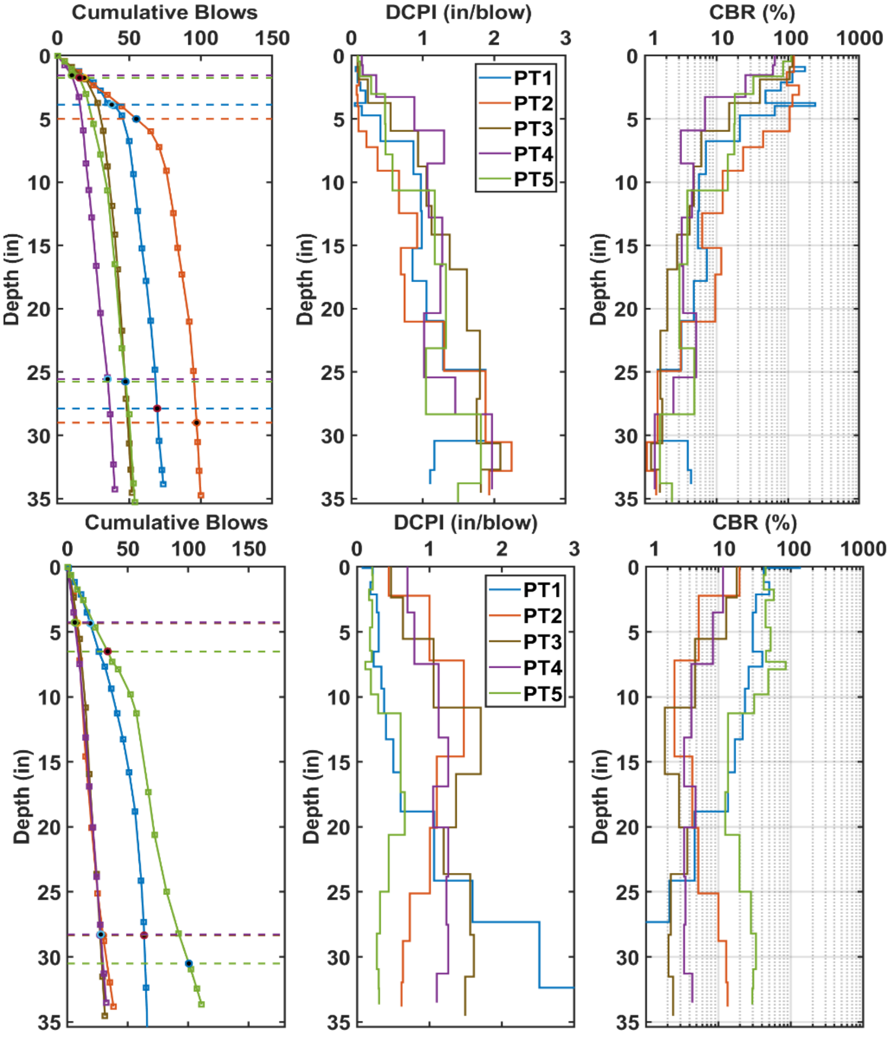
(a) (b) (c)

Figure 188. Fall 2019 DCP results for Section 1 (top row), 2 (middle row), and 4 (bottom row) in Howard County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



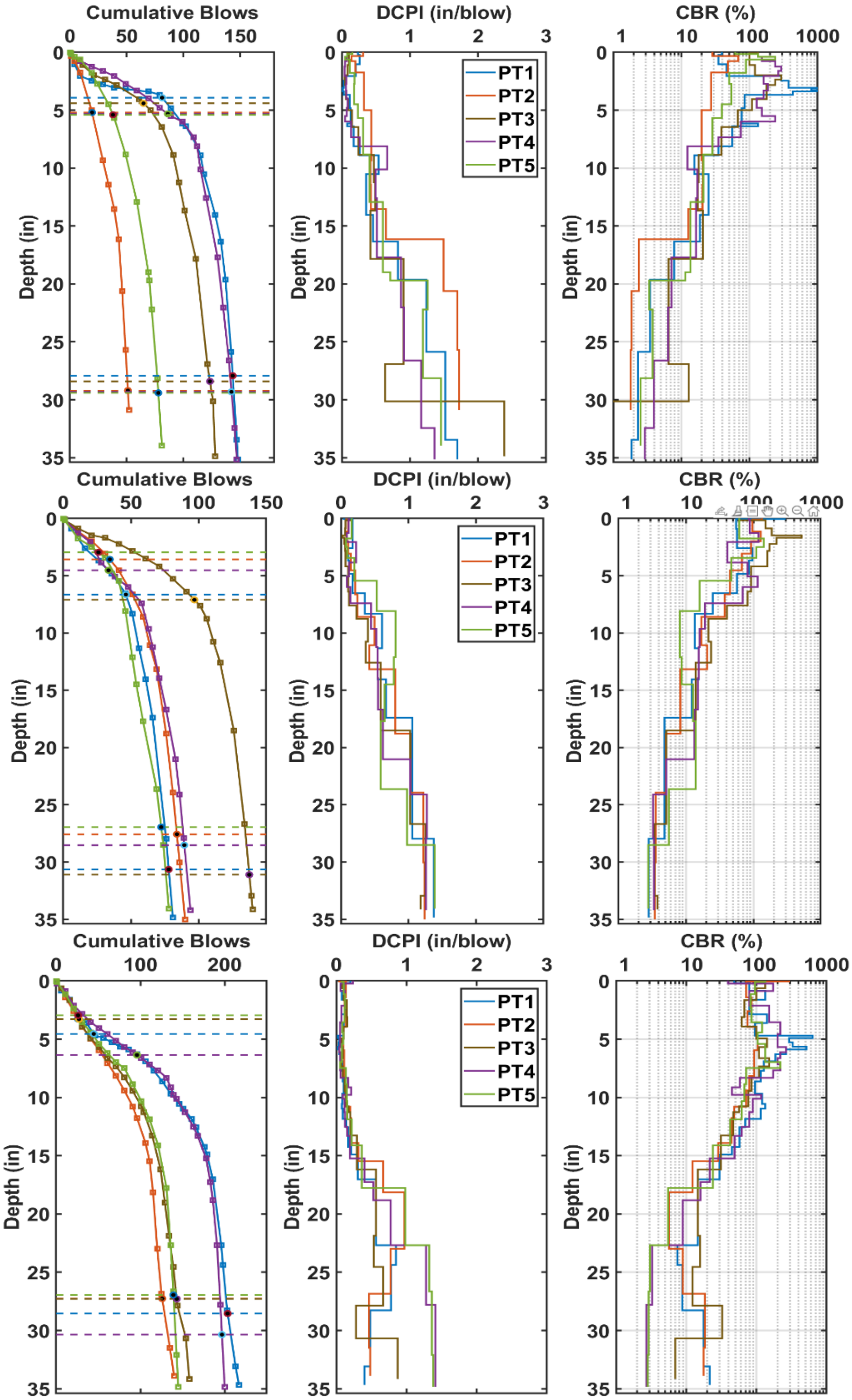
(a) (b) (c)

Figure 189. Fall 2019 DCP results for Section 5A (top row), 5B (middle row), and 6A (bottom row) in Howard County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



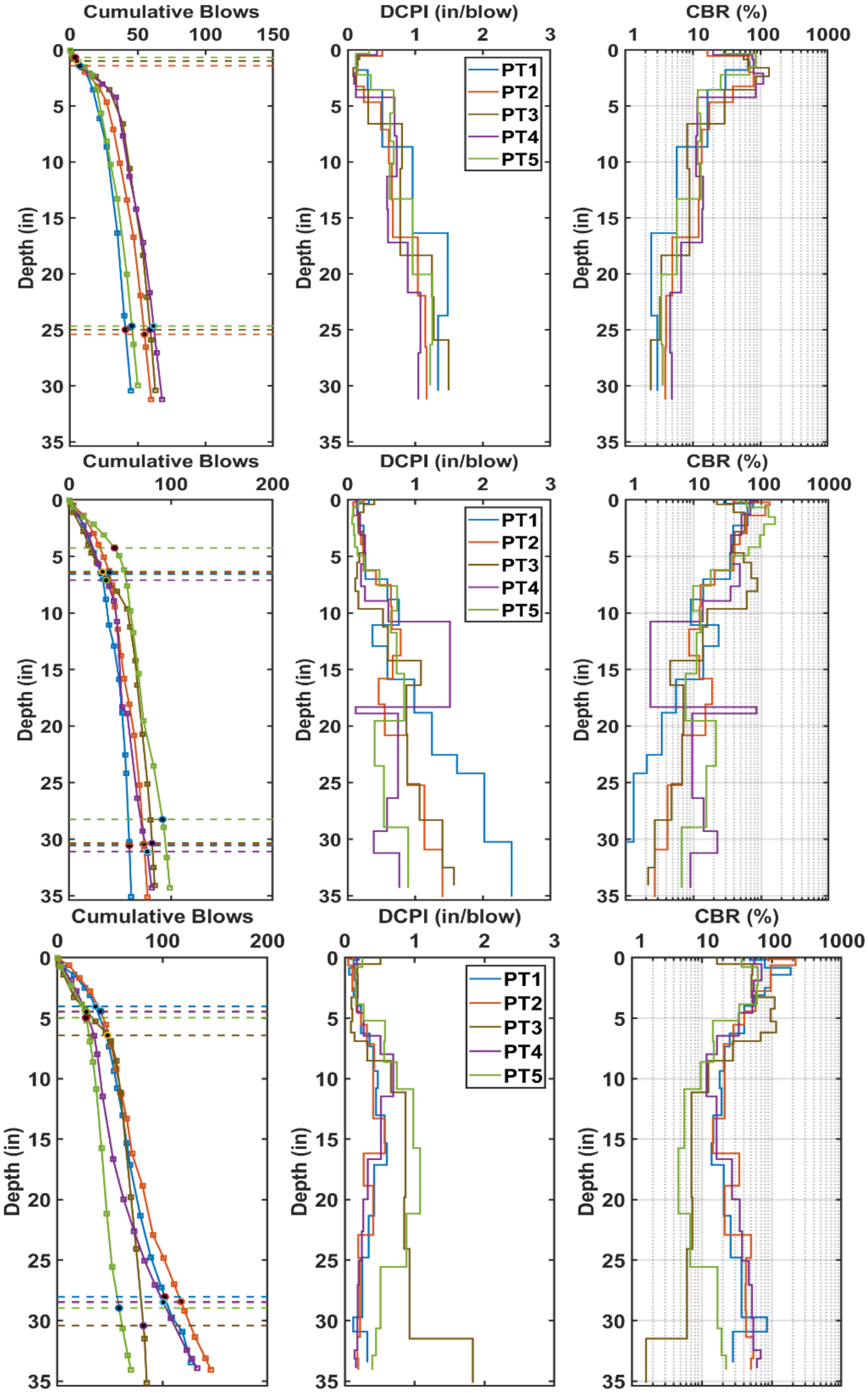
(a) (b) (c)

Figure 190. Fall 2019 DCP results for Section 6B (top row) and 7 (bottom row) in Howard County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



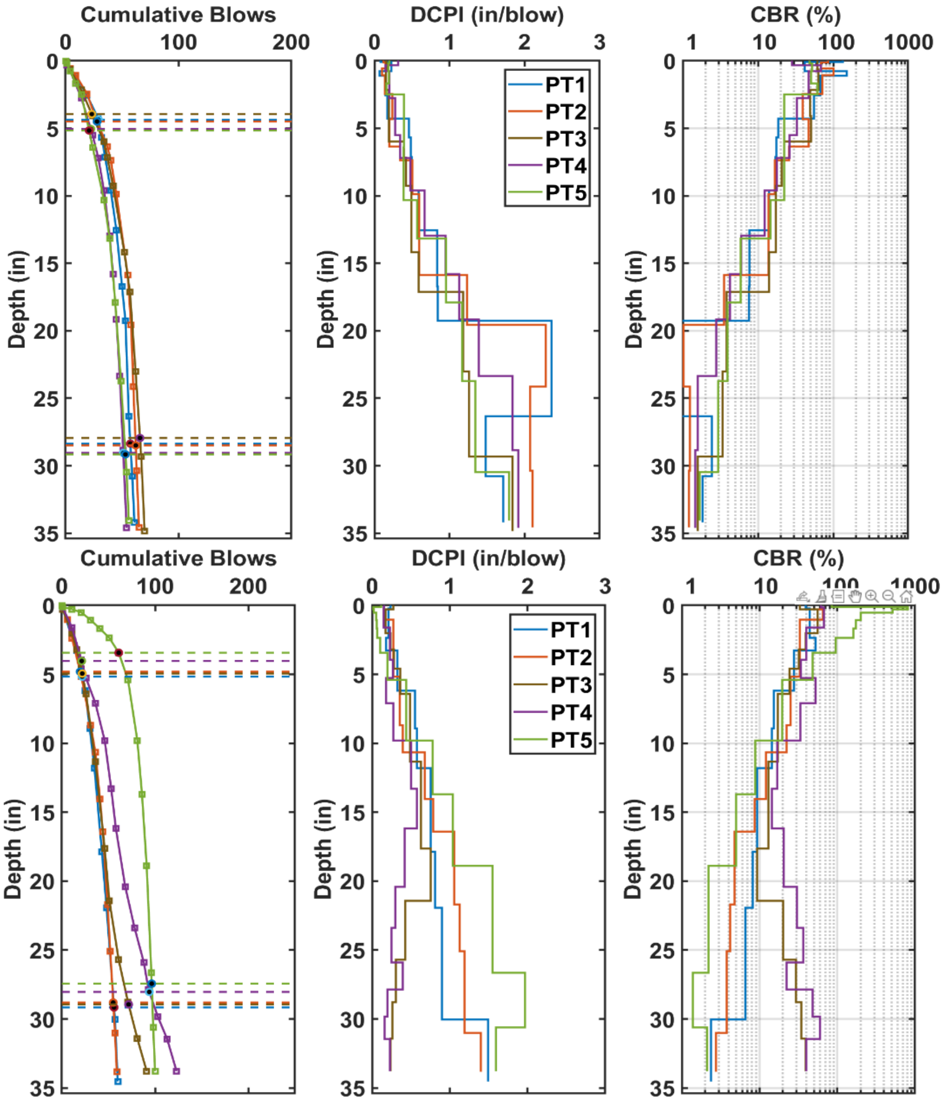
(a) (b) (c)

Figure 191. Fall 2019 DCP results for Section 1 (top row), 2 (middle row), and 3 (bottom row) in Washington County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



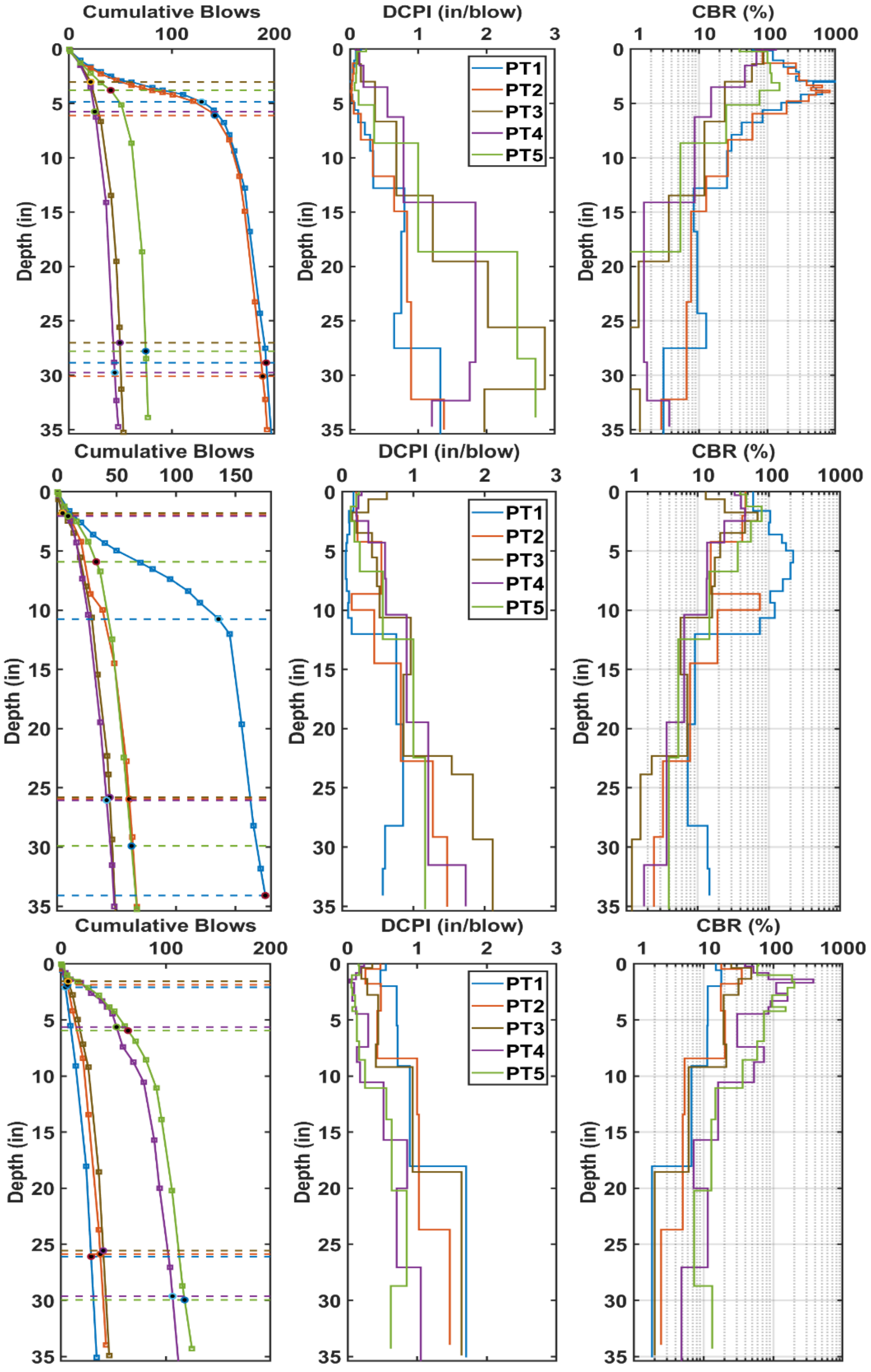
(a) (b) (c)

Figure 192. Fall 2019 DCP results for Section 4 (top row), 5 (middle row), and 6 (bottom row) in Washington County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



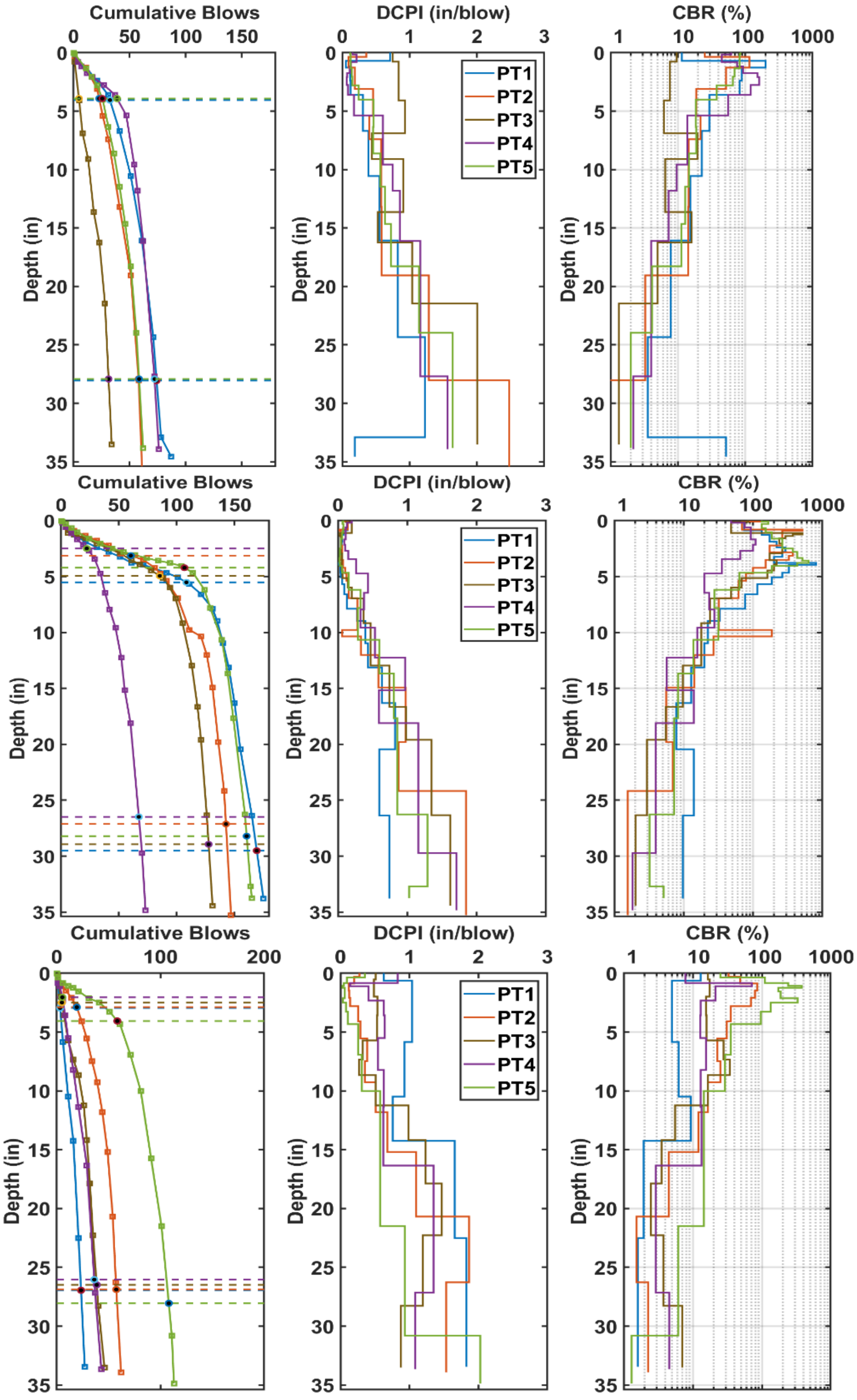
(a) (b) (c)

Figure 193. Fall 2019 DCP results for Section 7 (top row) and 8 (bottom row) in Washington County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



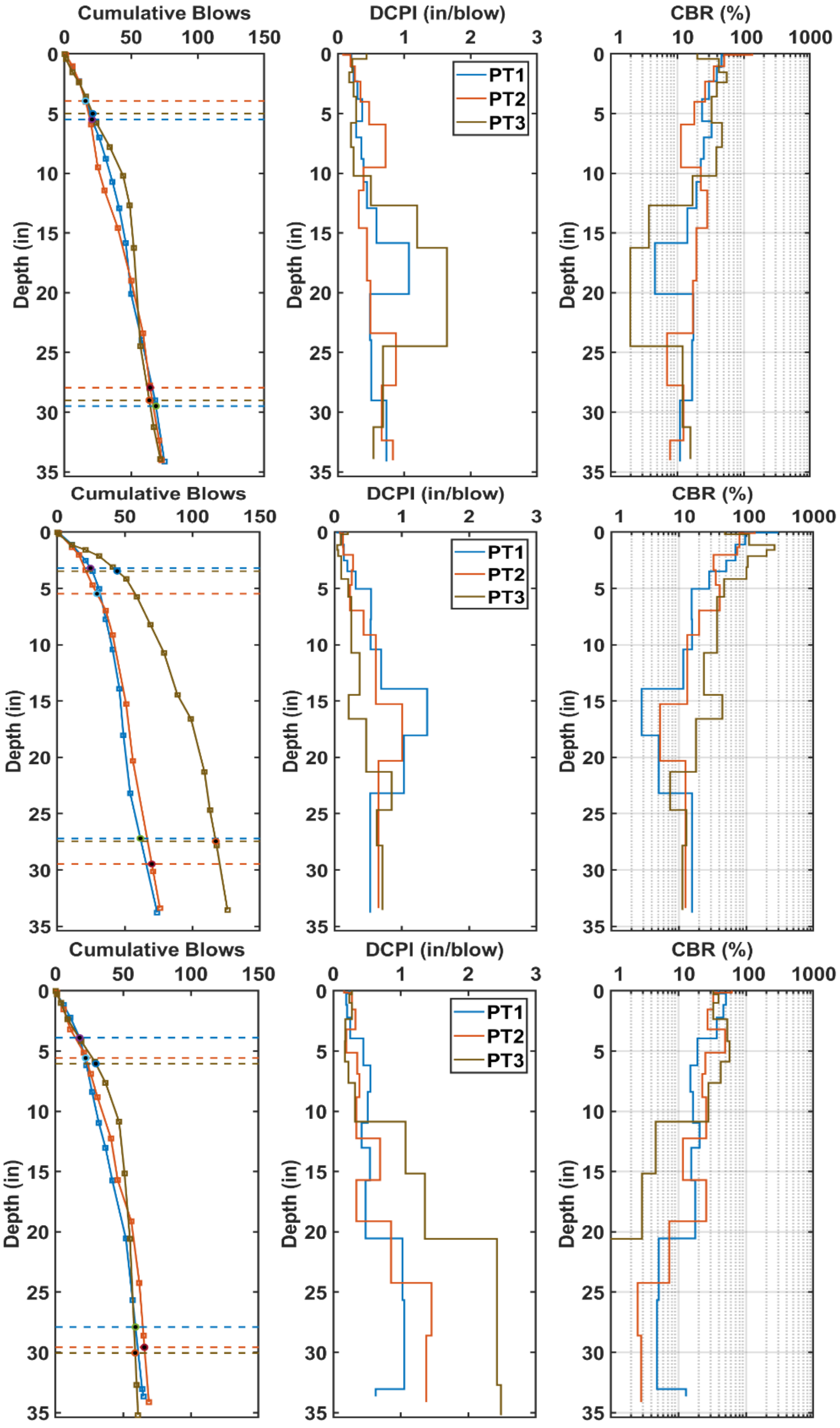
(a) (b) (c)

Figure 194. Fall 2019 DCP results for Section 1 (top row), 4 (middle row), and 5 (bottom row) in Hamilton County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



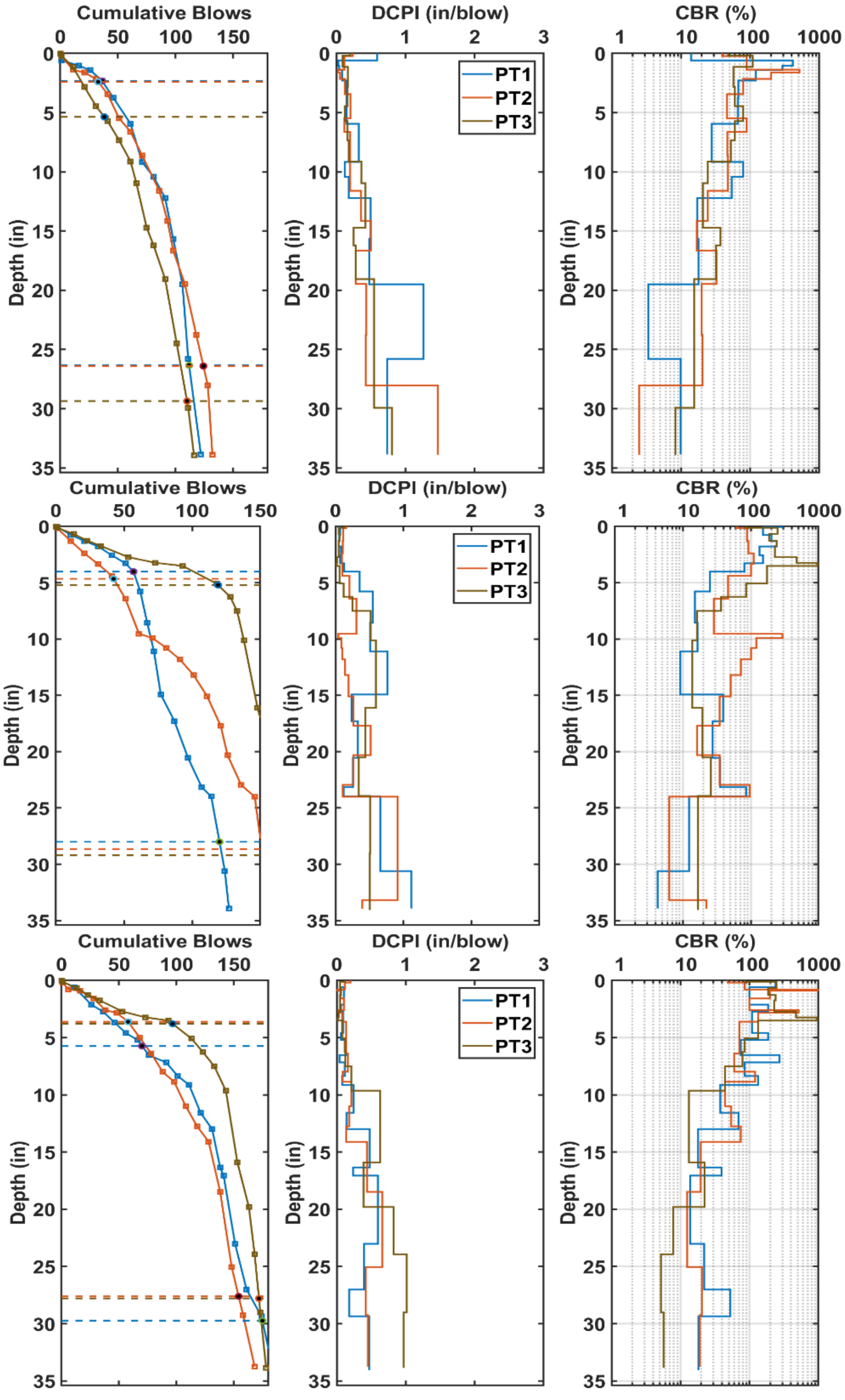
(a) (b) (c)

Figure 195. Fall 2019 DCP results for Section 6 (top row), 7 (middle row), and 8 (bottom row) in Hamilton County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



(a) (b) (c)

Figure 196. Spring 2020 DCP results for Section 1 (top row), 2 (middle row), and 3 (bottom row) in Cherokee County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



(a) (b) (c)

Figure 197. Spring 2020 DCP results for Section 4A, 4B, and 5A, Cherokee County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR

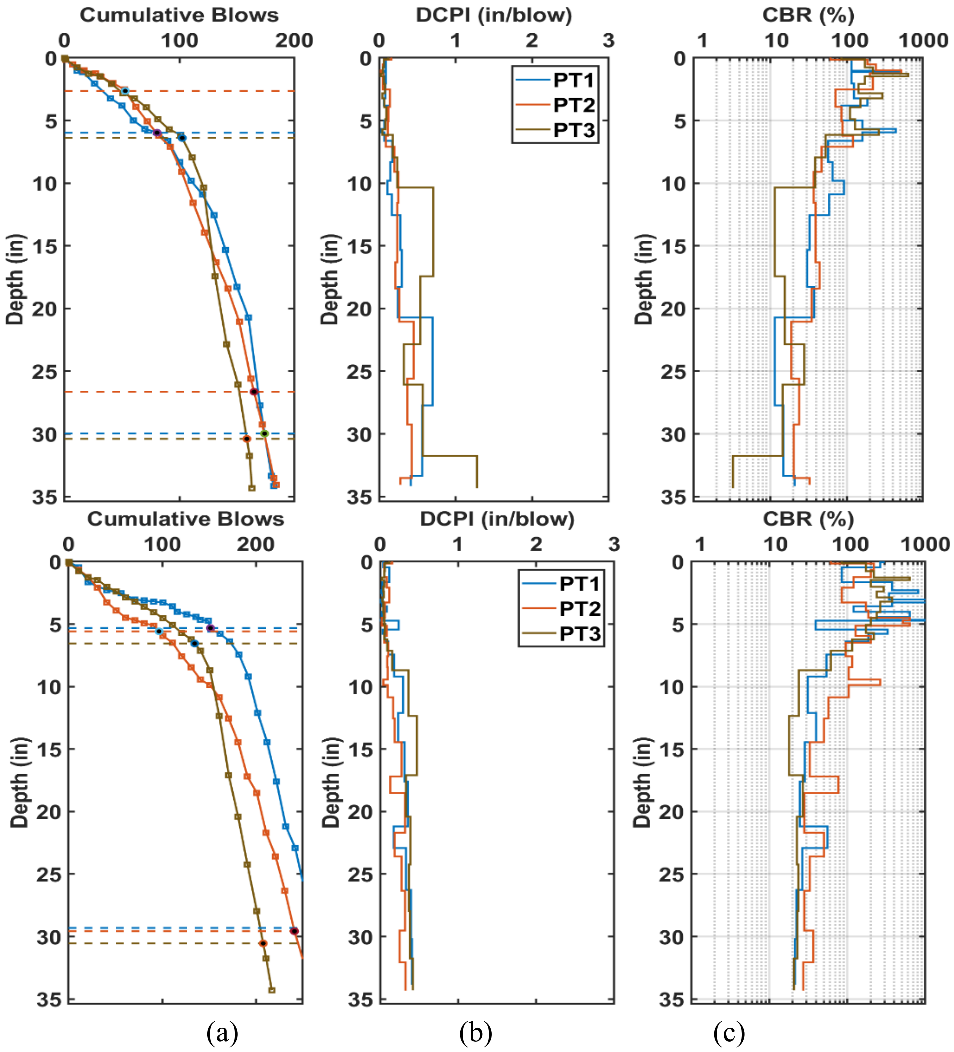
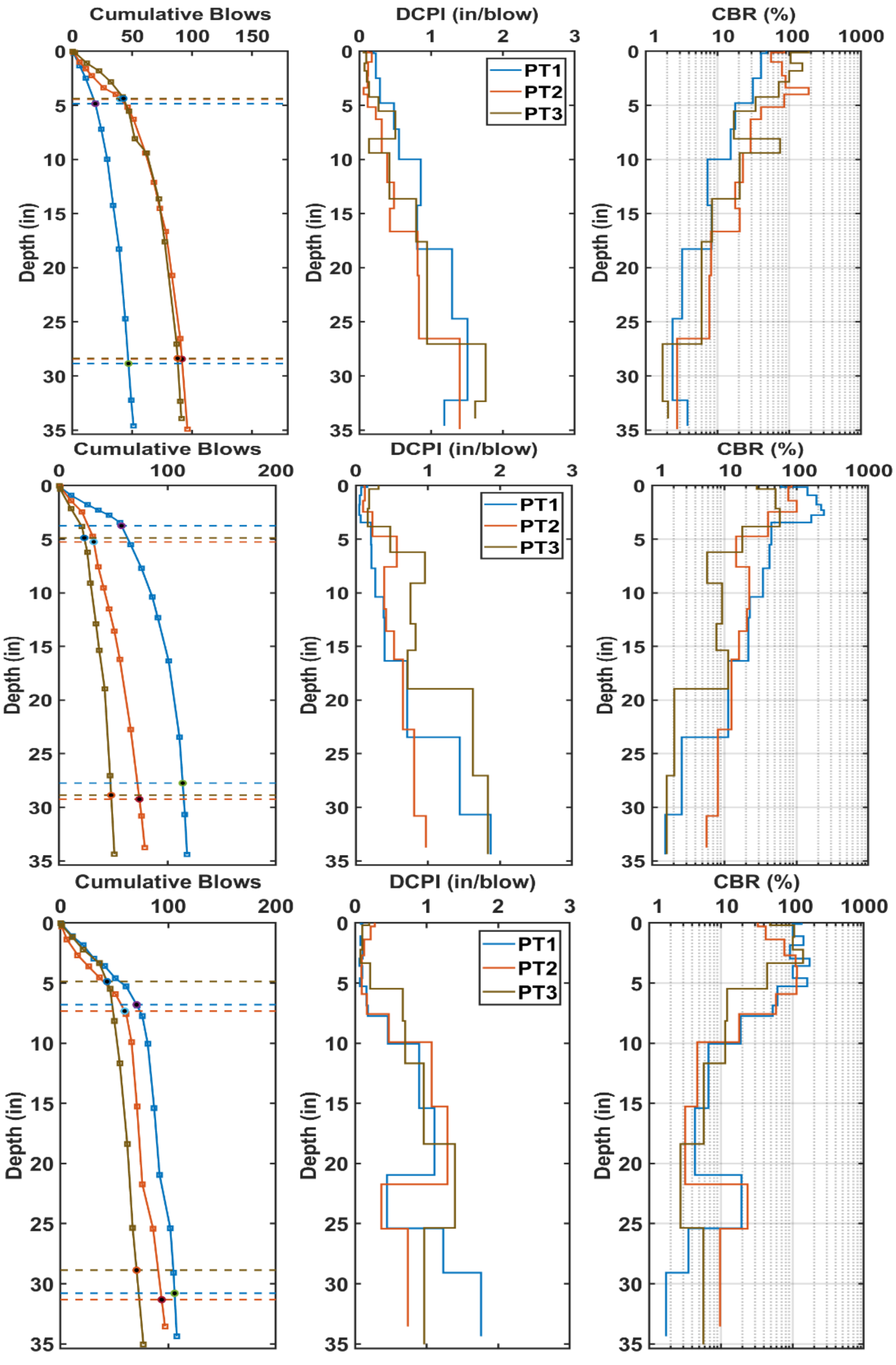
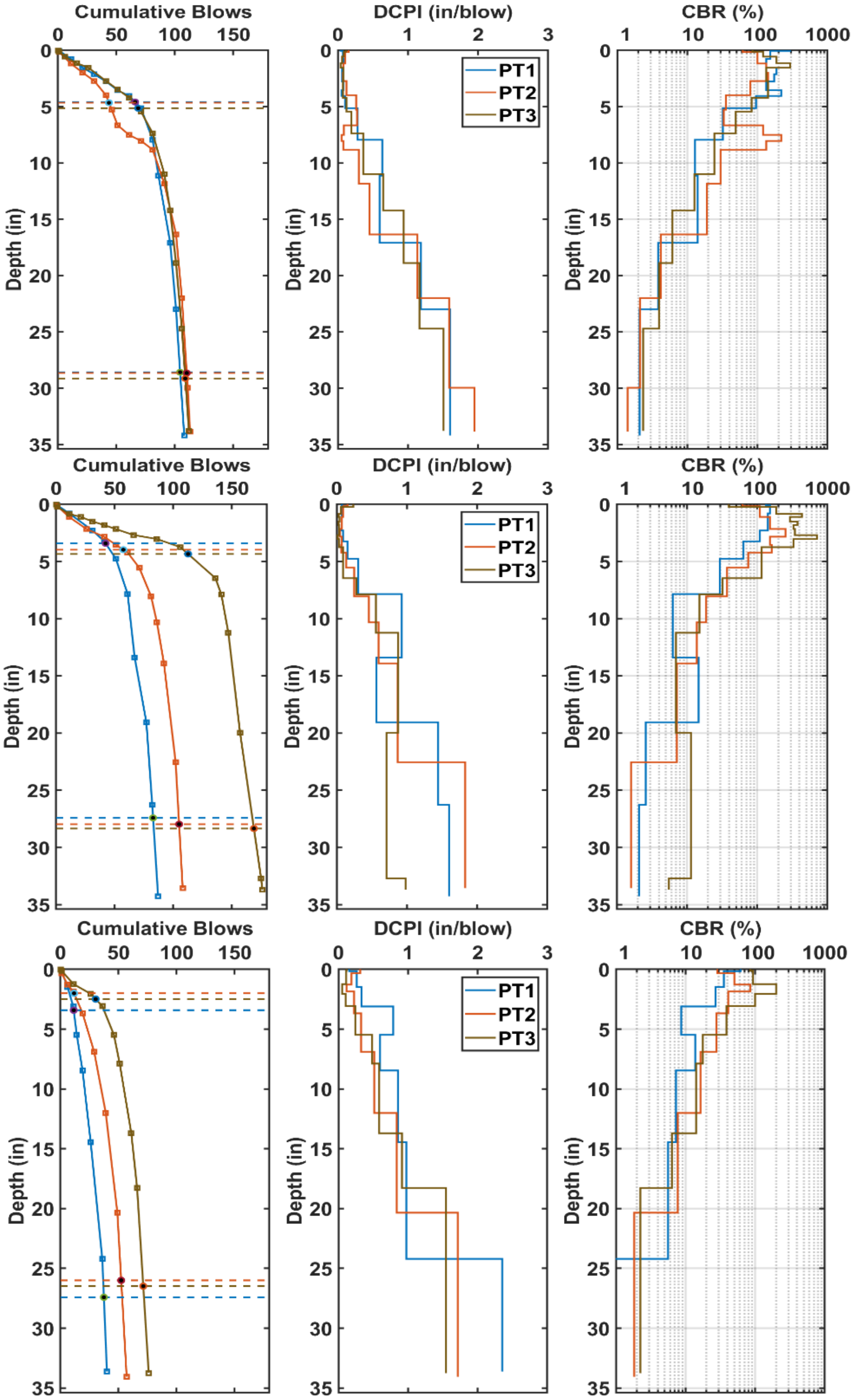


Figure 198. Spring 2020 DCP results for Section 5B and 6, Cherokee County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



(a) (b) (c)

Figure 199. Spring 2020 DCP results for Section 1, 2, and 4, Howard County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



(a) (b) (c)

Figure 200. Spring 2020 DCP results for Section 5A (top row), 5B (middle row), and 6A (bottom row) in Howard County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR

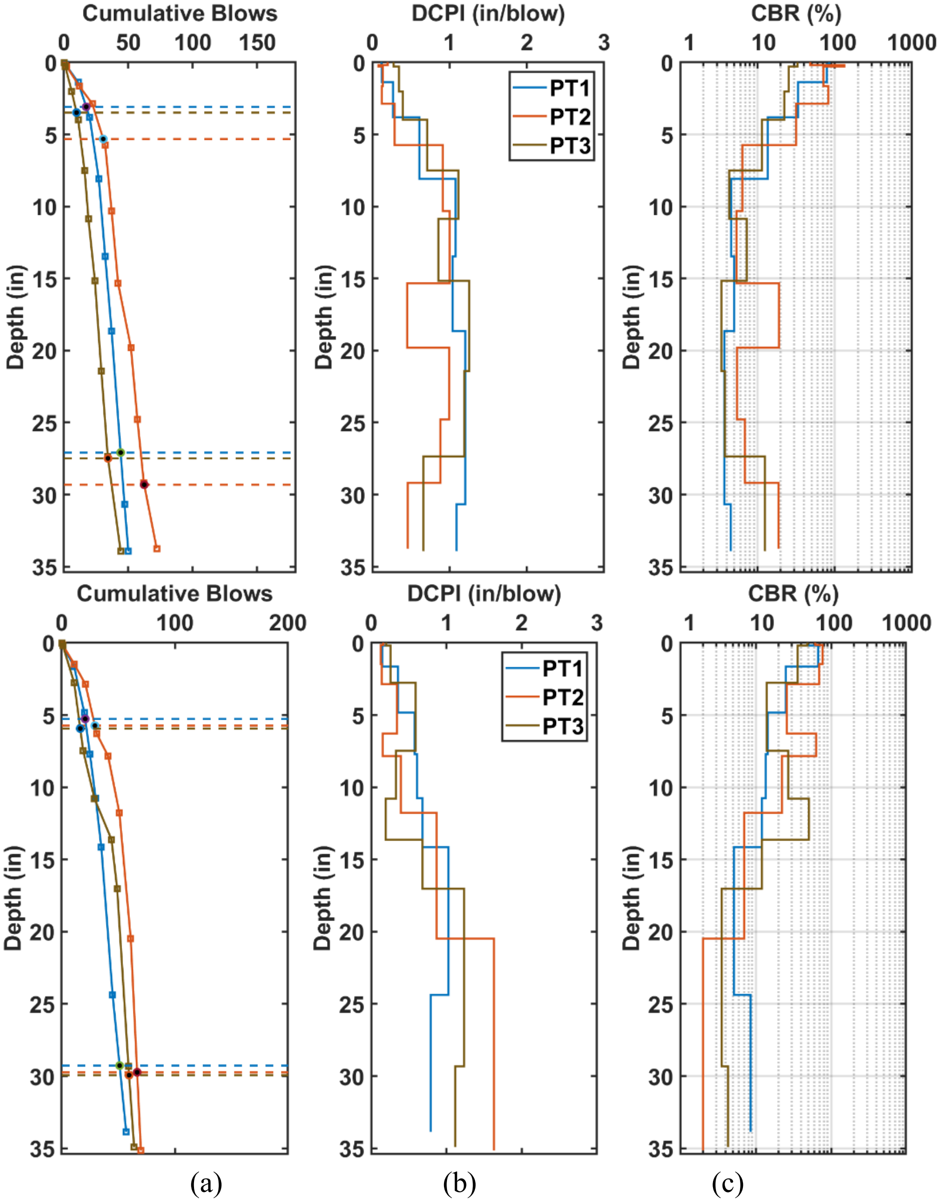
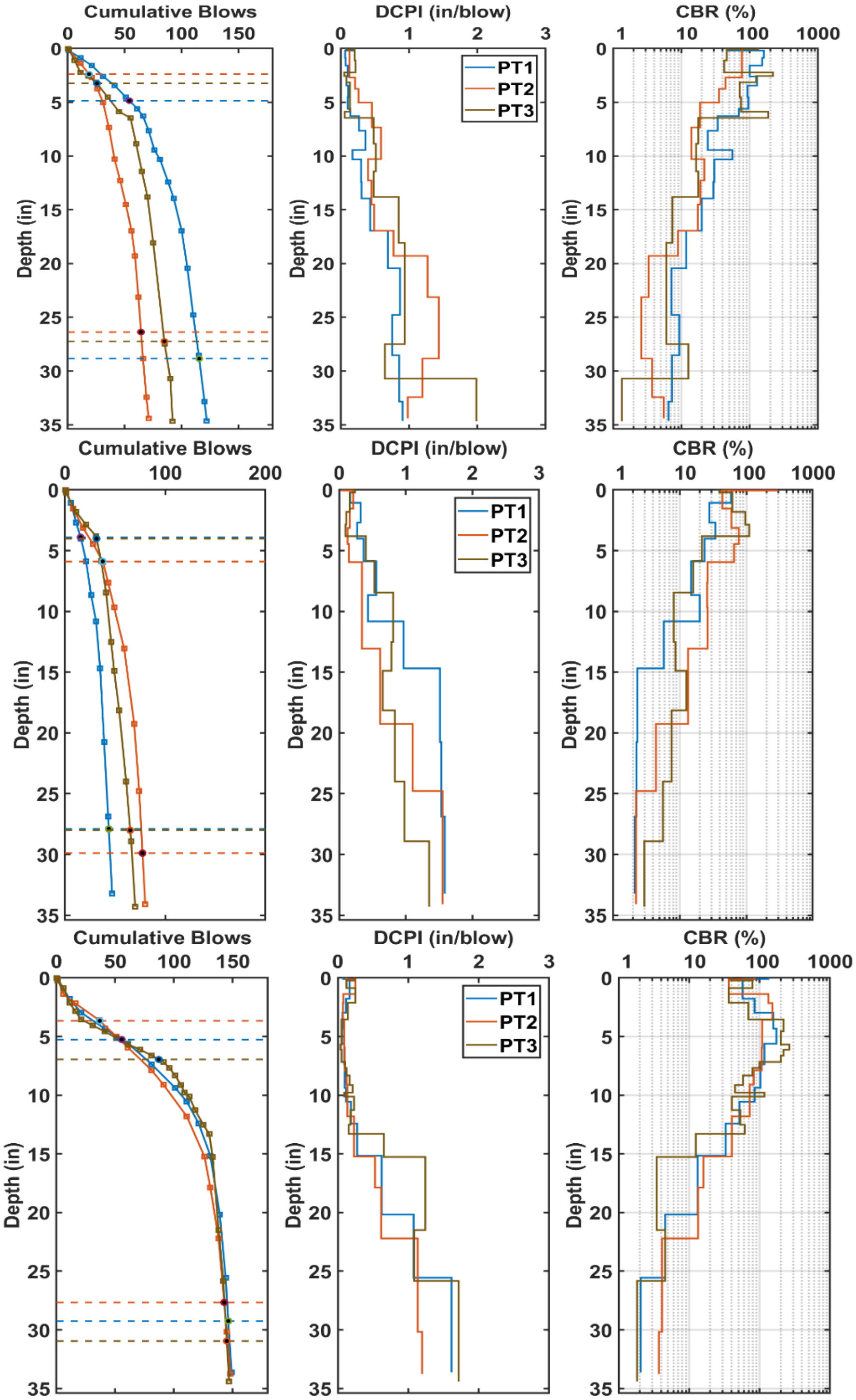
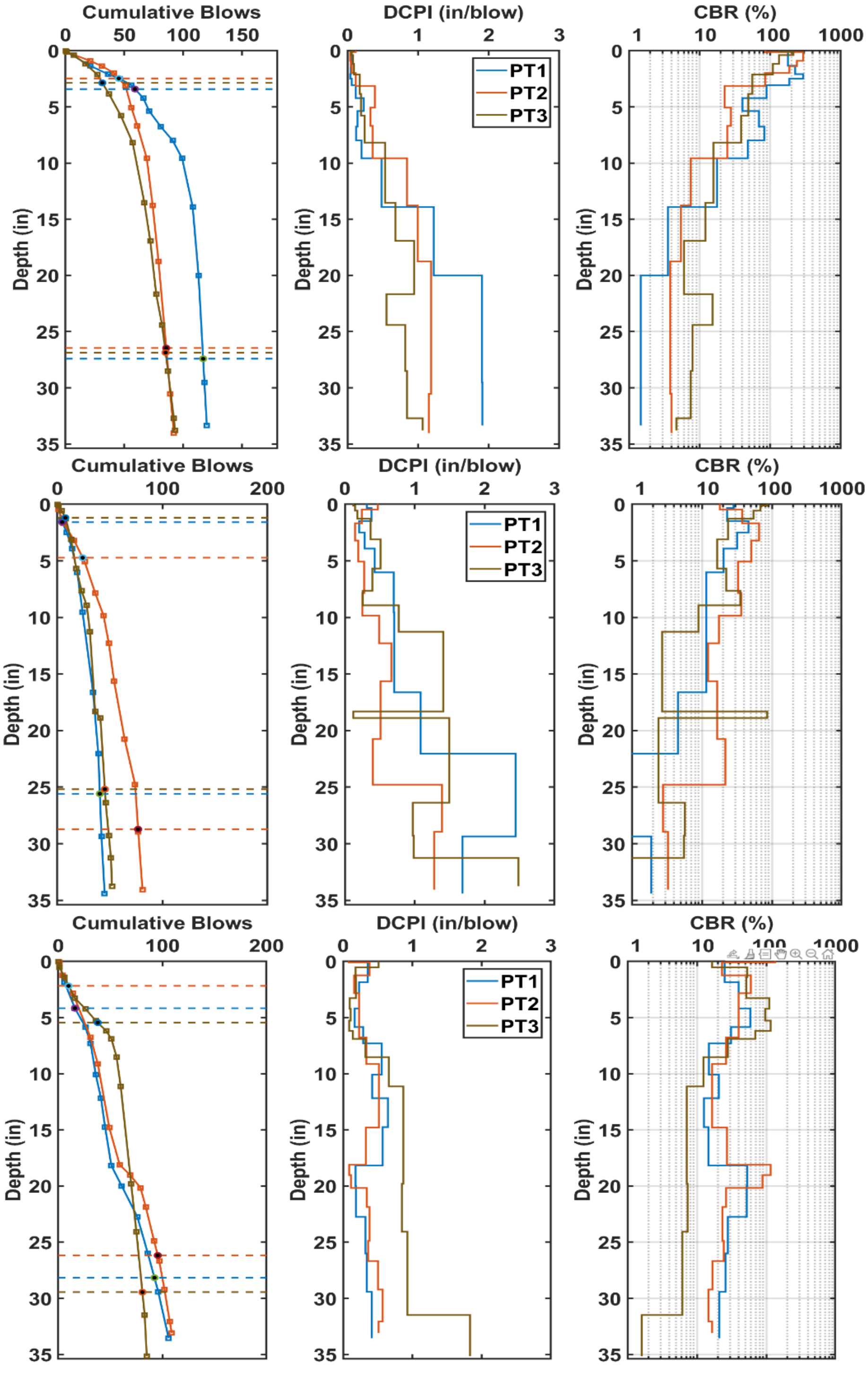


Figure 201. Spring 2020 DCP results for Section 6B (top row) and 7 (bottom row) in Howard County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



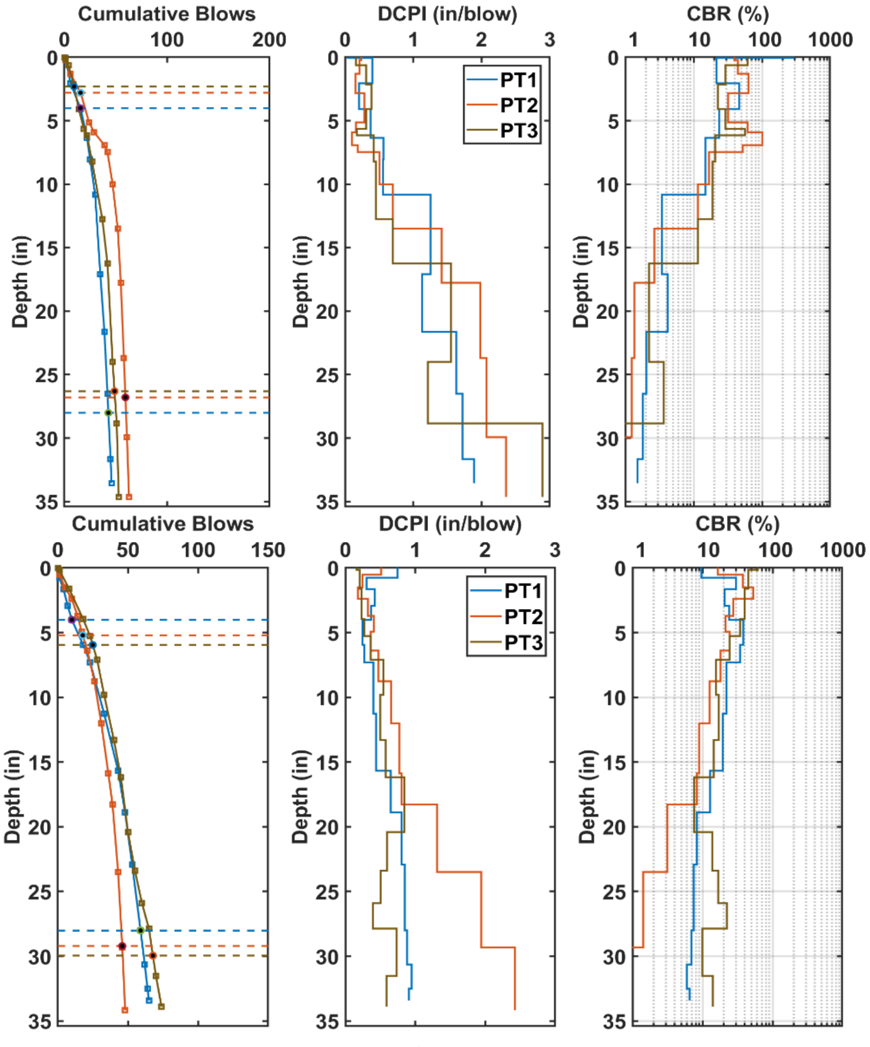
(a) (b) (c)

Figure 202. Spring 2020 DCP results for Section 1 (top row), 2 (middle row), and 3 (bottom row) in Washington County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



(a) (b) (c)

Figure 203. Spring 2020 DCP results for Section 4 (top row), 5 (middle row), and 6 (bottom row) in Washington County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



(a) (b) (c)

Figure 204. Spring 2020 DCP results for Section 7 (top row) and 8 (bottom row) in Washington County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR

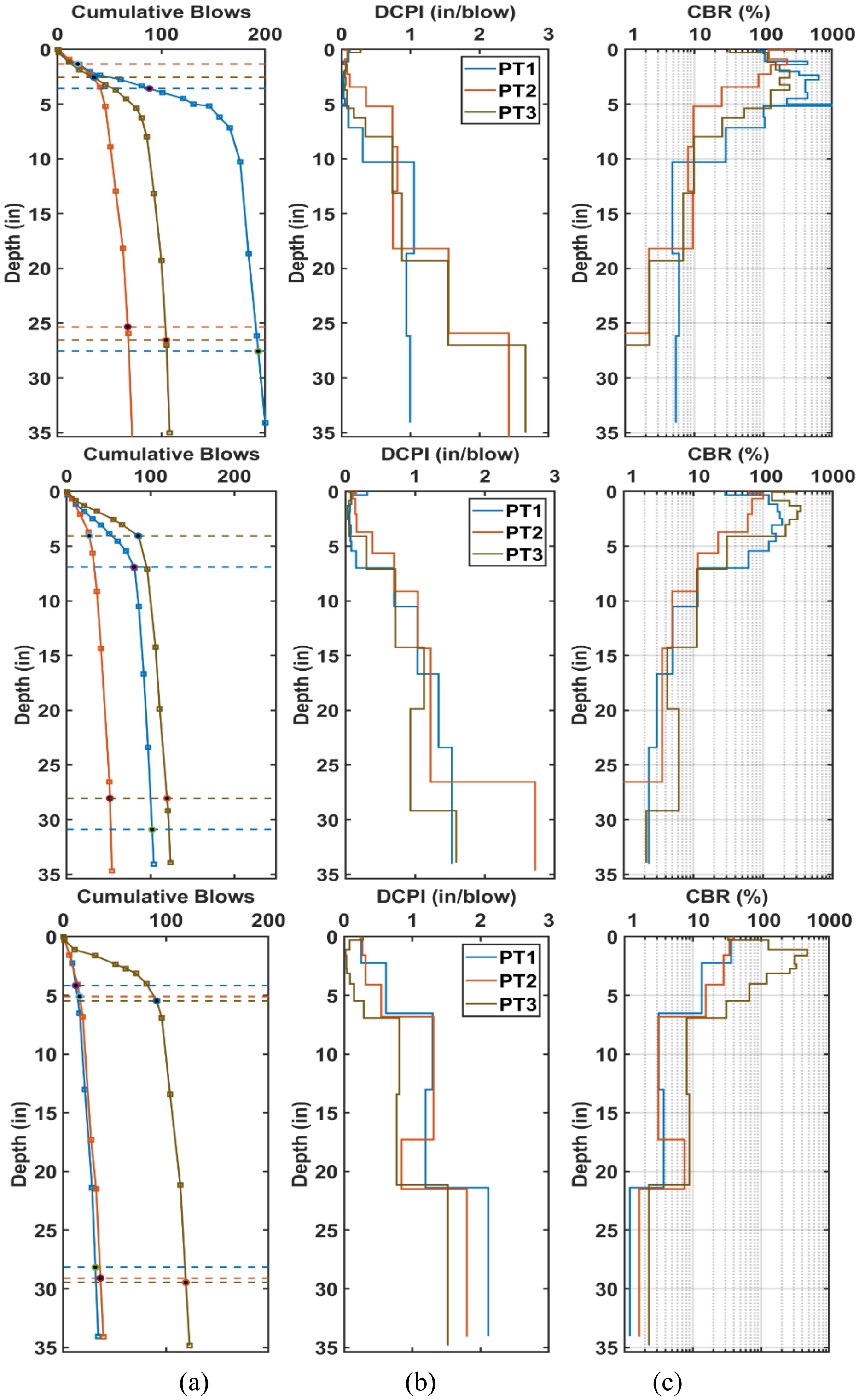
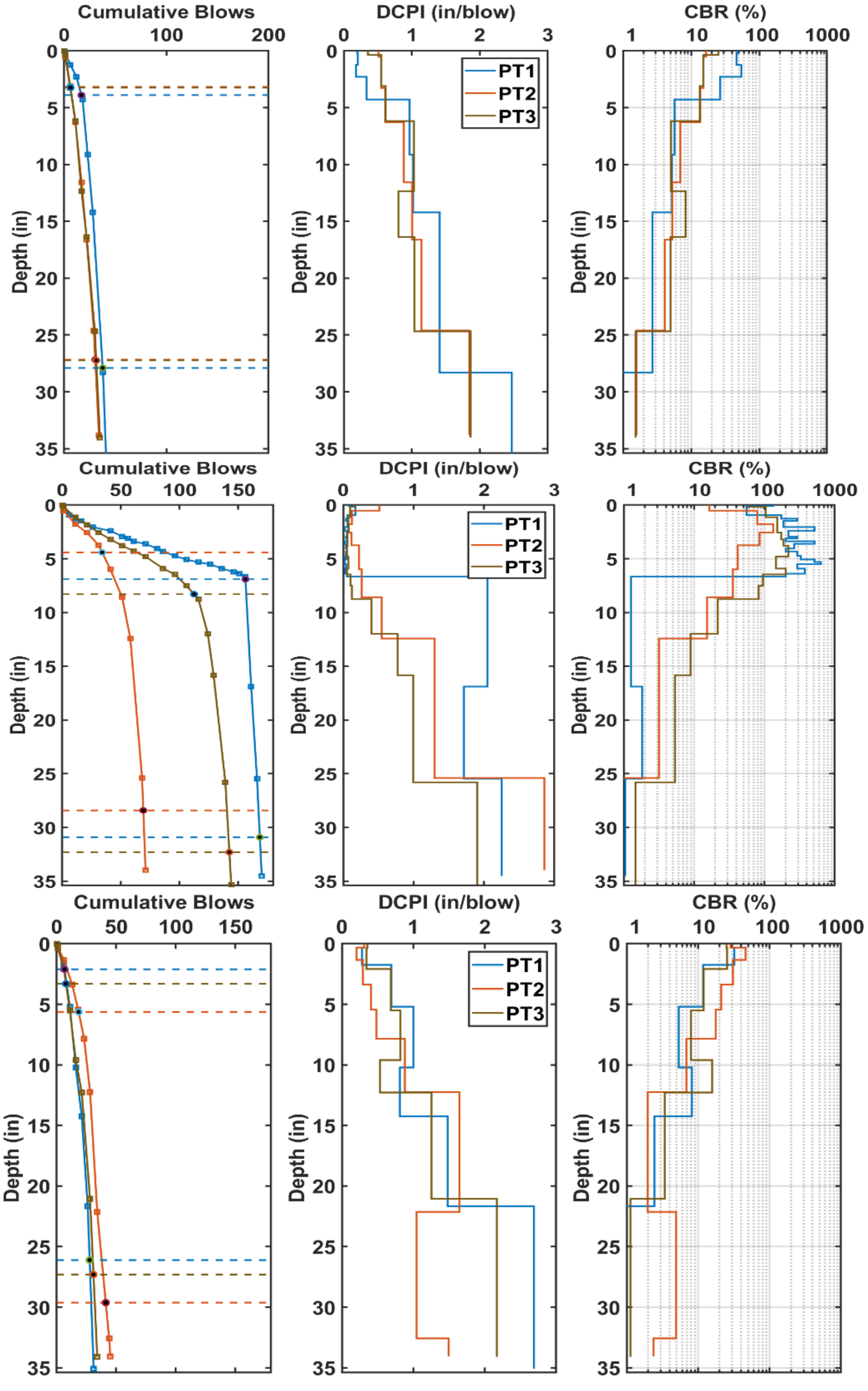


Figure 205. Spring 2020 DCP results for Section 1 (top row), 4 (middle row), and 5 (bottom row) in Hamilton County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR



(a) (b) (c)

Figure 206. Spring 2020 DCP results for Section 6 (top row), 7 (middle row), and 8 (bottom row) in Hamilton County: (a) cumulative blows, (b) DCPI, and (c) DCP-CBR

APPENDIX E. PARTICLE SIZE DISTRIBUTION CURVES

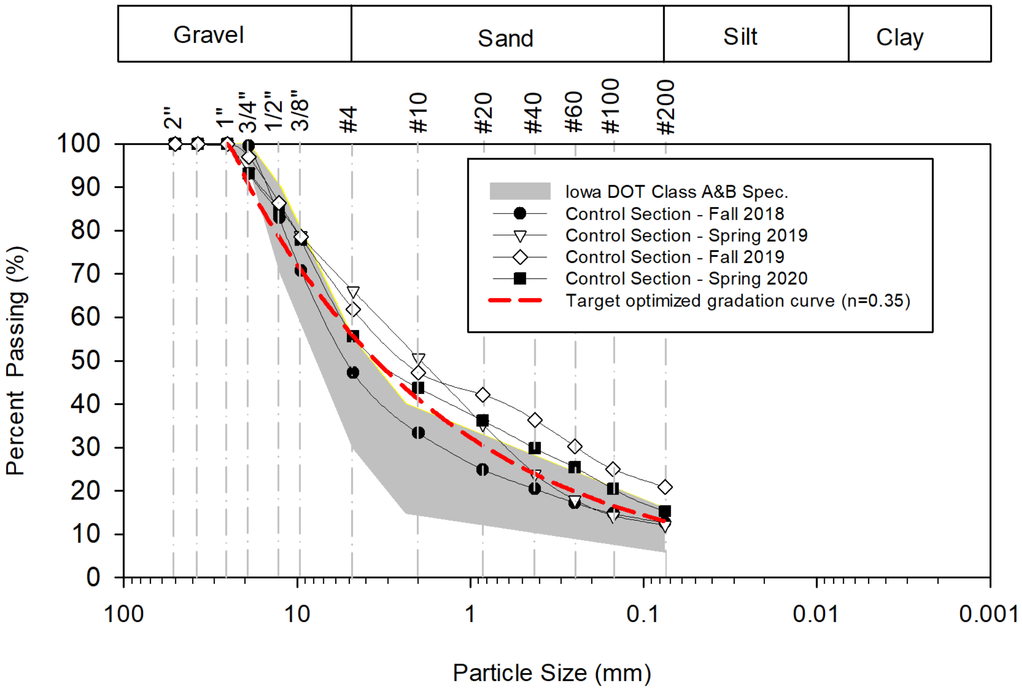


Figure 207. Particle size distribution curves for Cherokee County control section

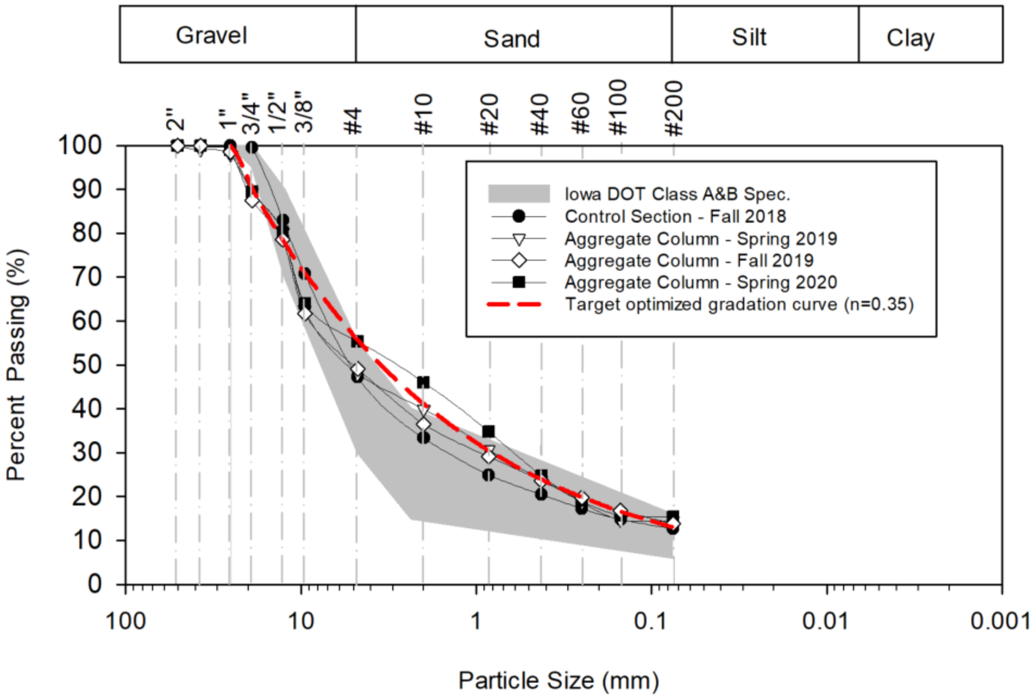


Figure 208. Particle size distribution curves for Cherokee County aggregate columns section

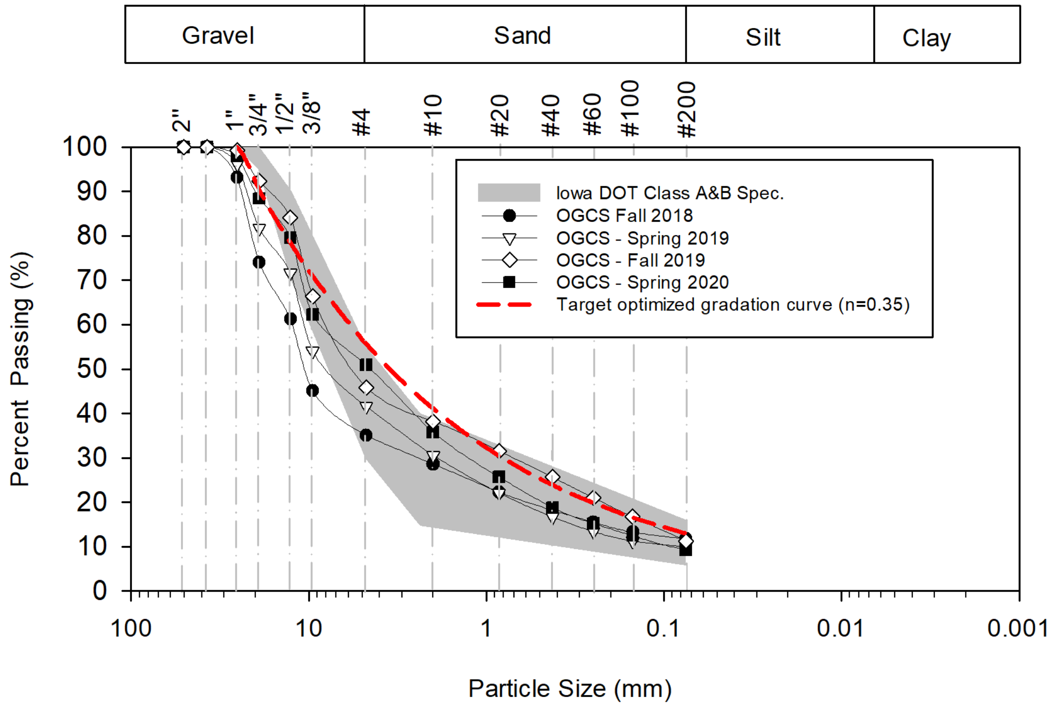


Figure 209. Particle size distribution curves for Cherokee County OGCS section

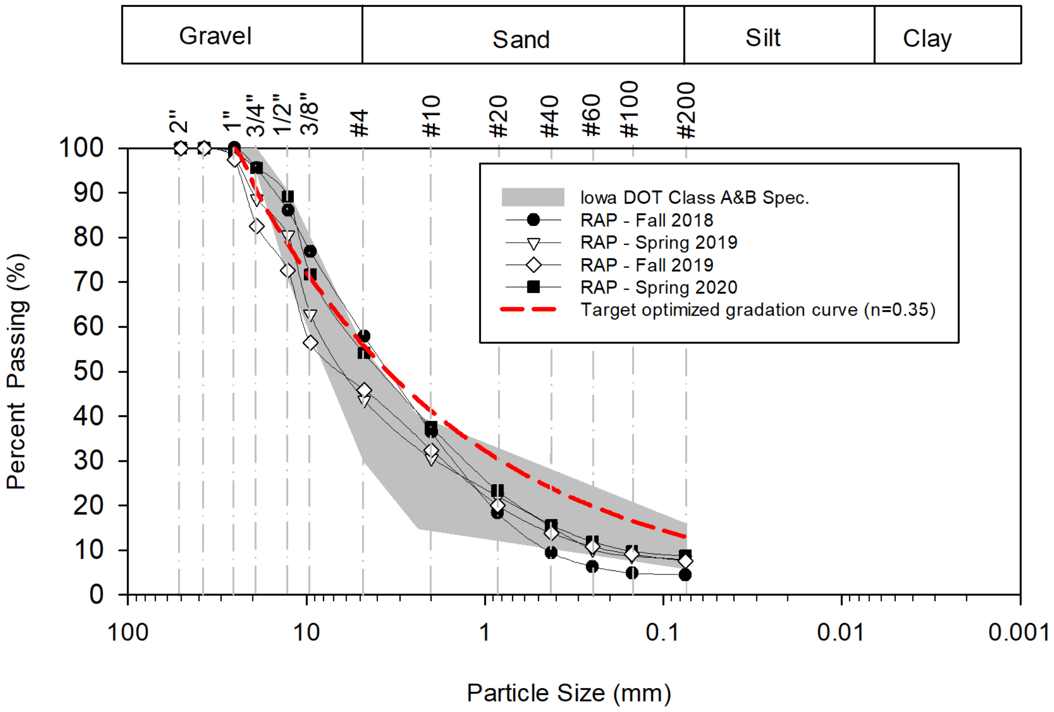


Figure 210. Particle size distribution curves for Cherokee County RAP section

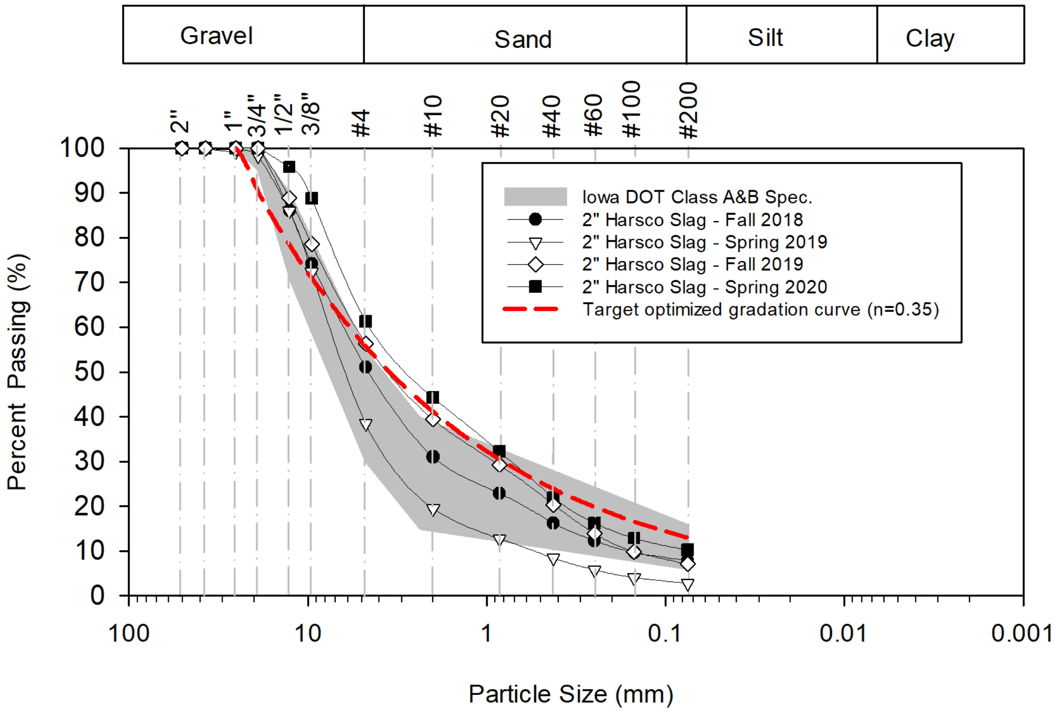


Figure 211. Particle size distribution curves for Cherokee County 2 in. Harsco slag section

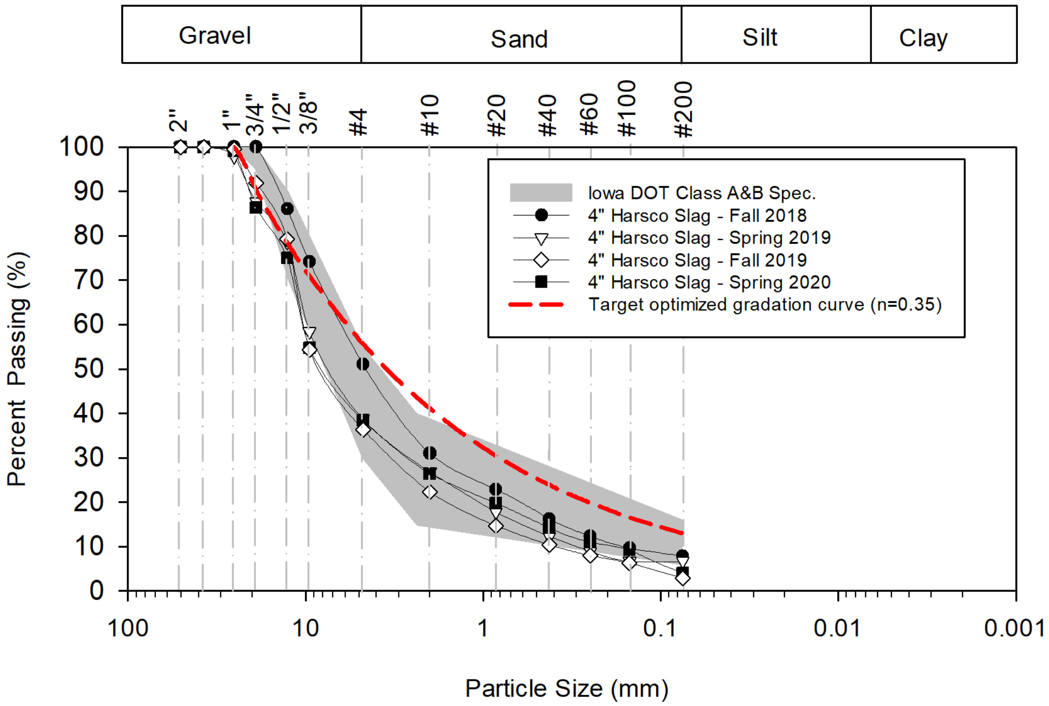


Figure 212. Particle size distribution curves for Cherokee County 4 in. Harsco slag section

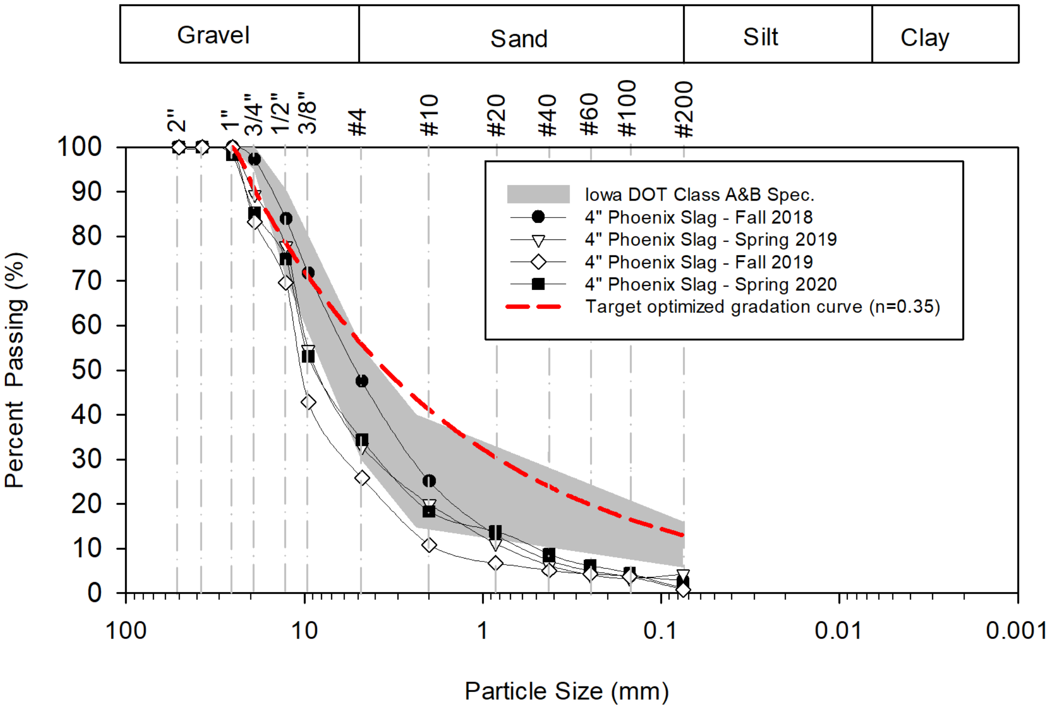


Figure 213. Particle size distribution curves for Cherokee County 4 in. Phoenix slag section

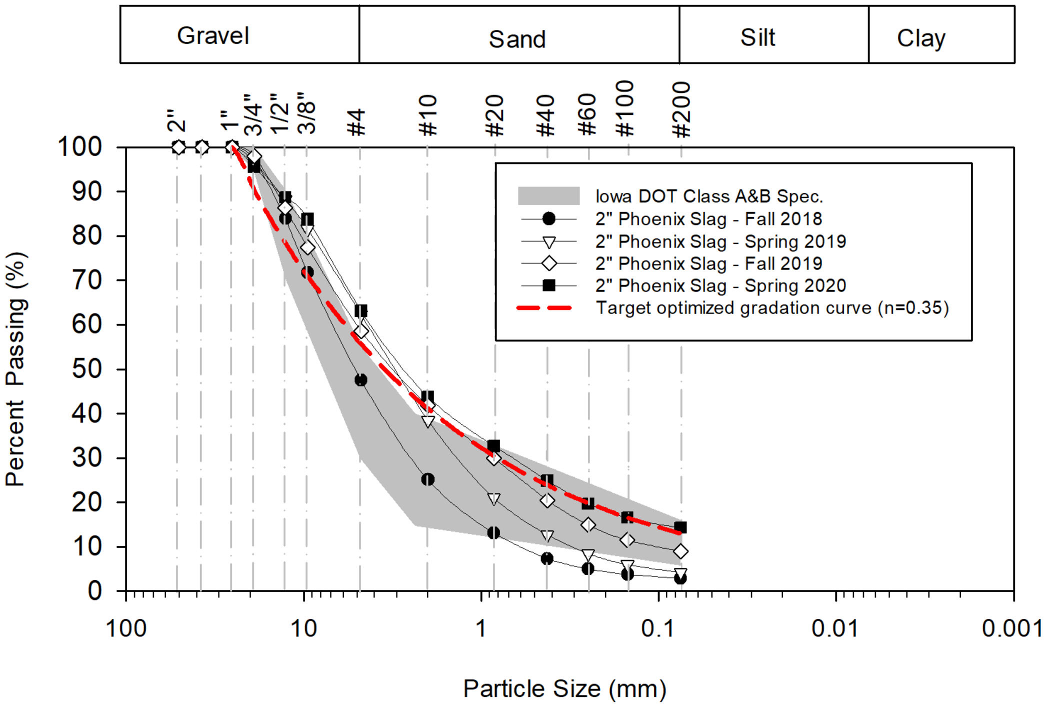


Figure 214. Particle size distribution curves for Cherokee County 2 in. Phoenix slag section

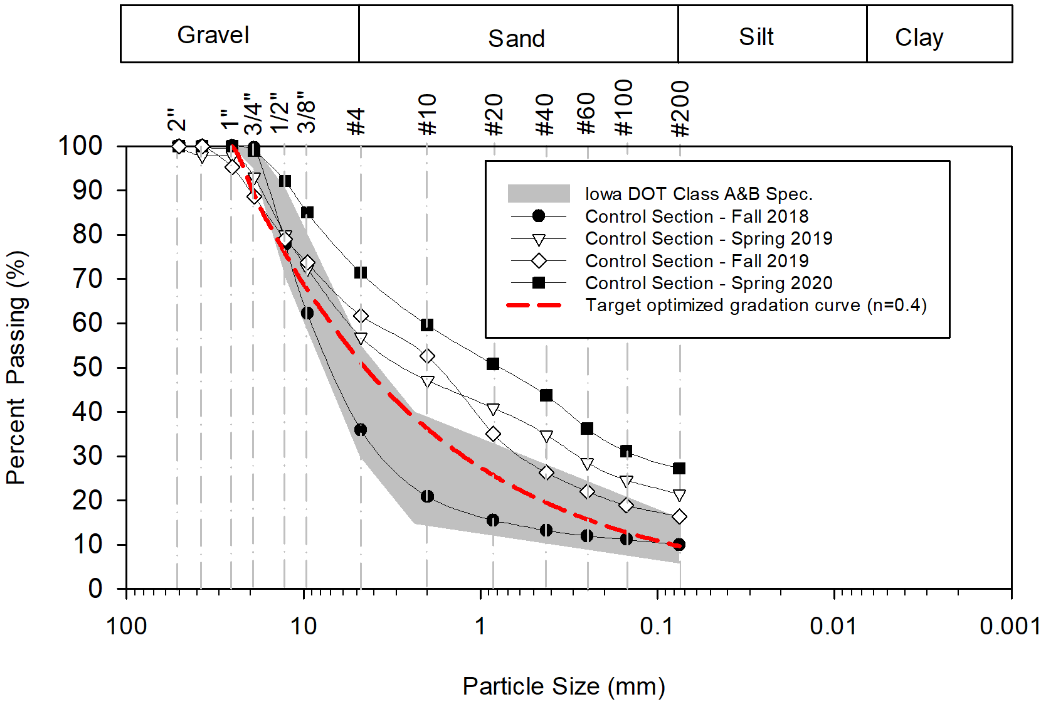


Figure 215. Particle size distribution curves for Howard County control section

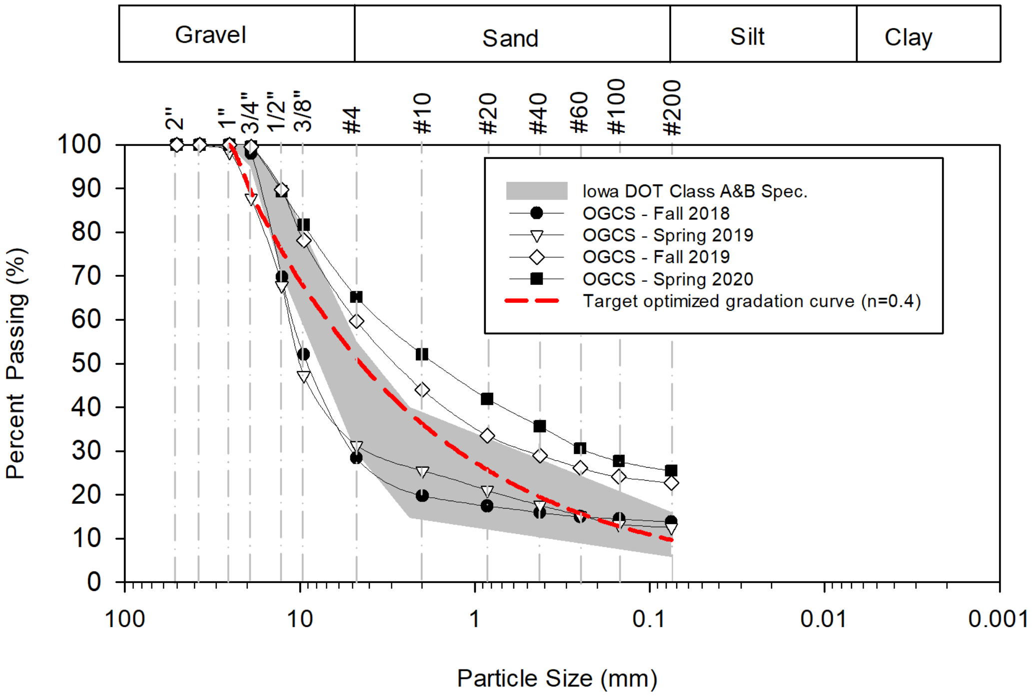


Figure 216. Particle size distribution curves for Howard County OGCS section

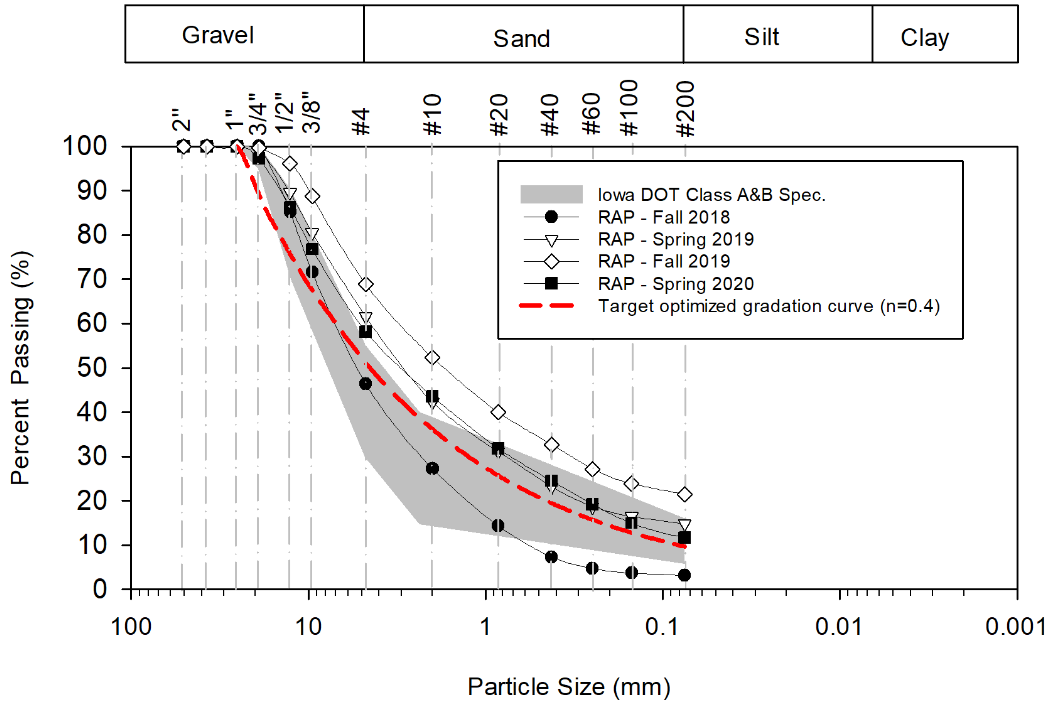


Figure 217. Particle size distribution curves for Howard County RAP section

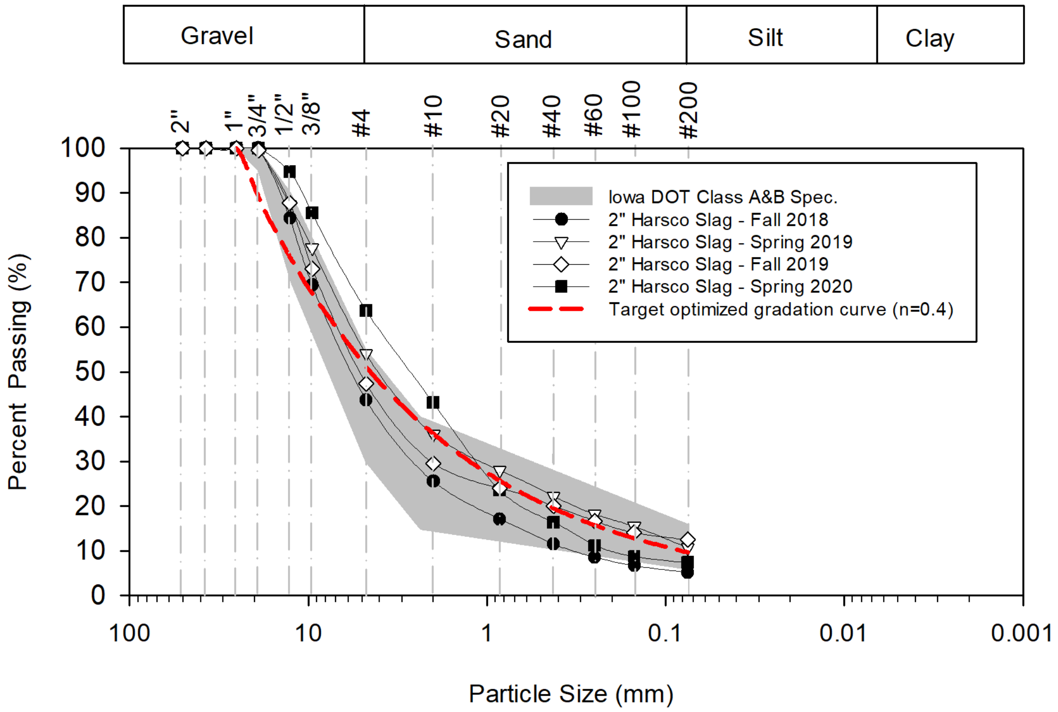


Figure 218. Particle size distribution curves for Howard County 2 in. Harsco slag section

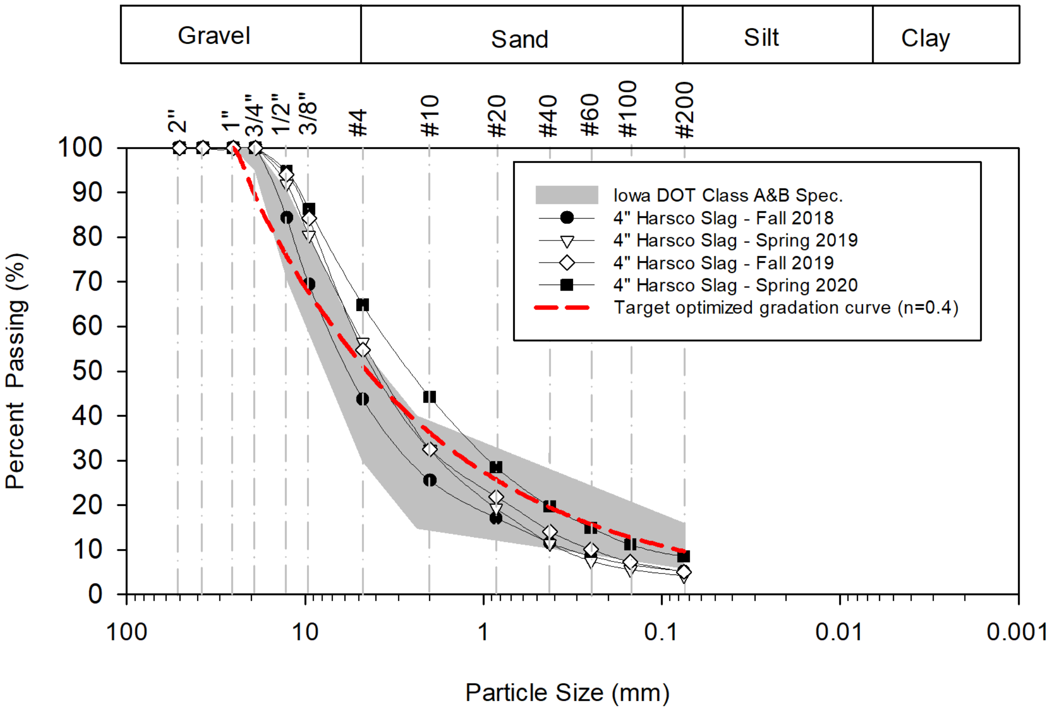


Figure 219. Particle size distribution curves for Howard County 4 in. Harsco slag section

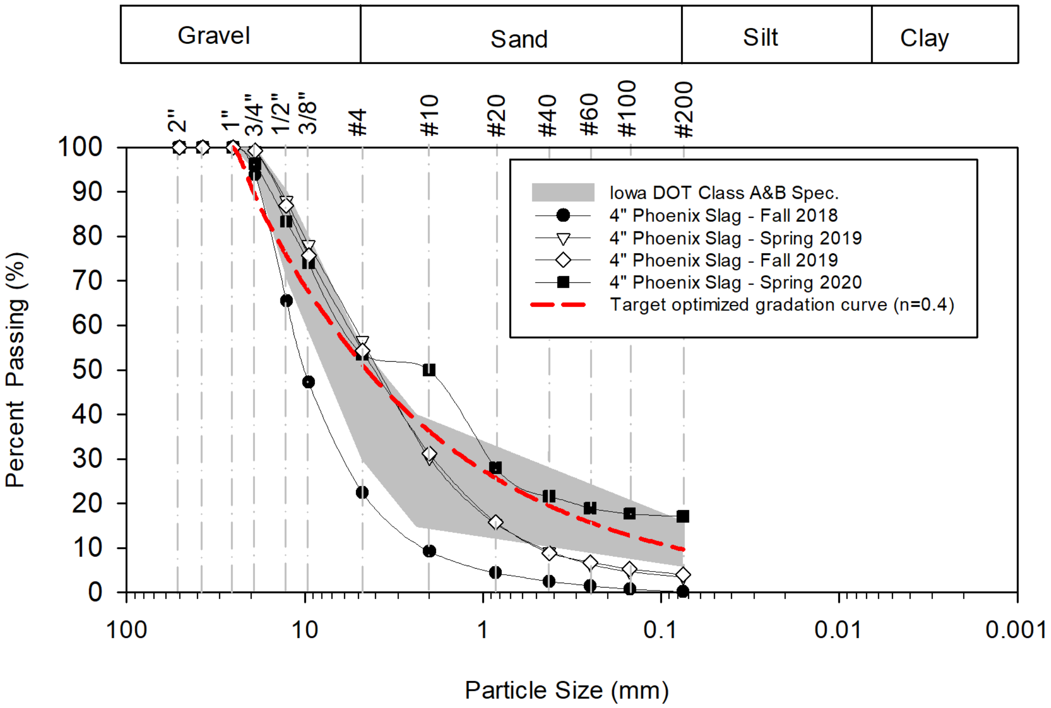


Figure 220. Particle size distribution curves for Howard County 4 in. Phoenix slag section

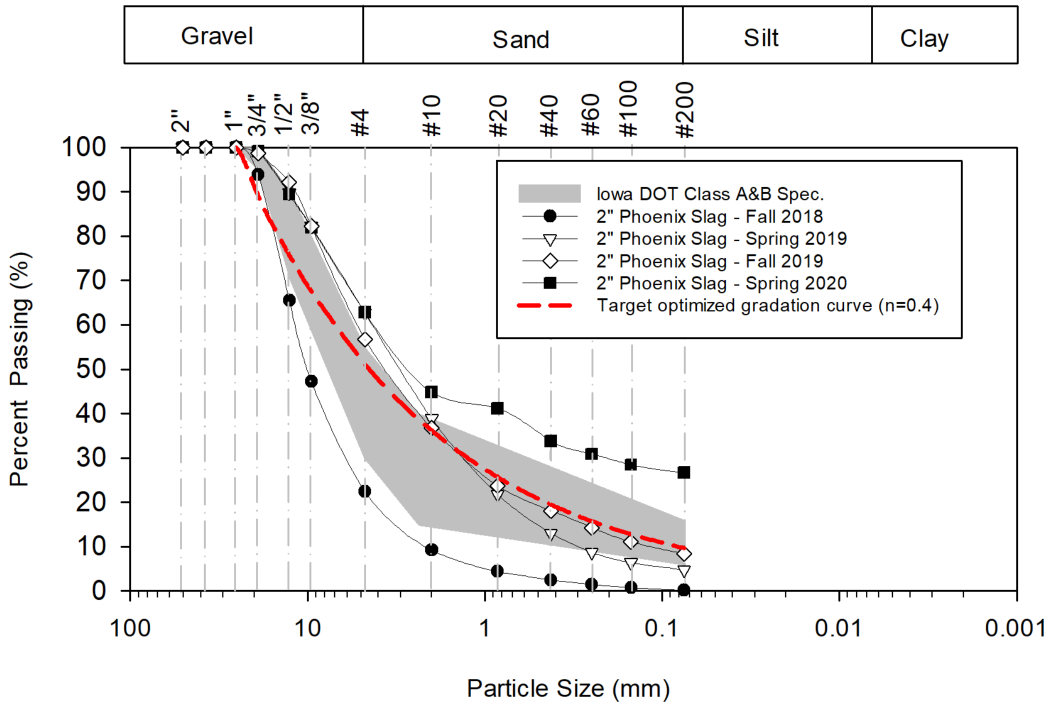


Figure 221. Particle size distribution curves for Howard County 2 in. Phoenix slag section

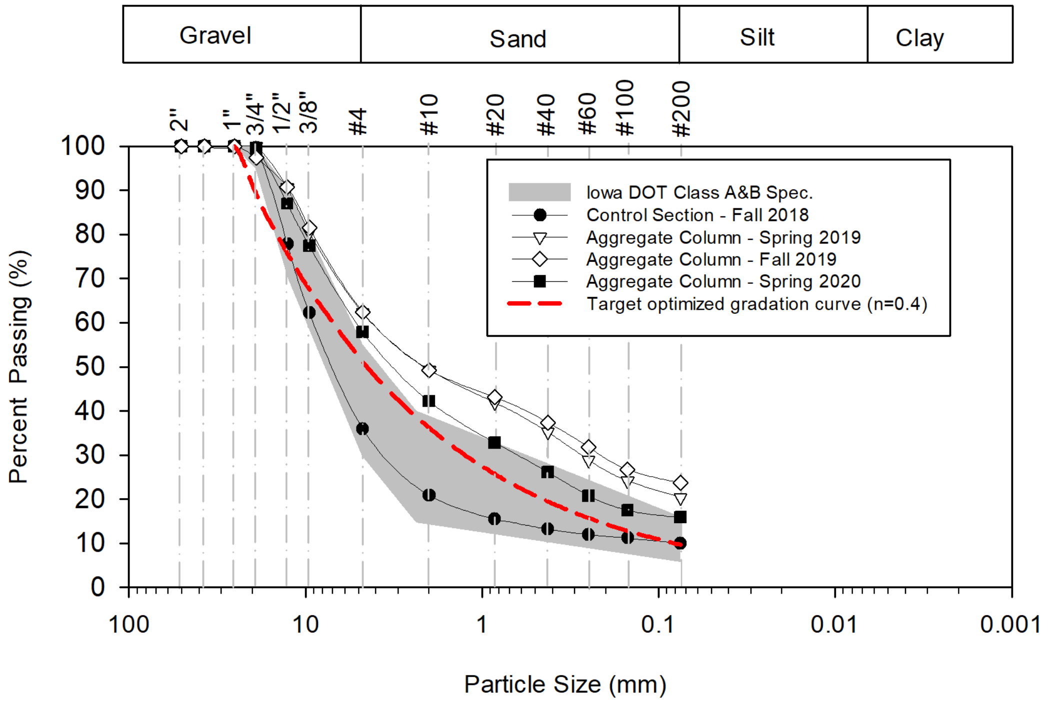


Figure 222. Particle size distribution curves for Howard County aggregate columns section

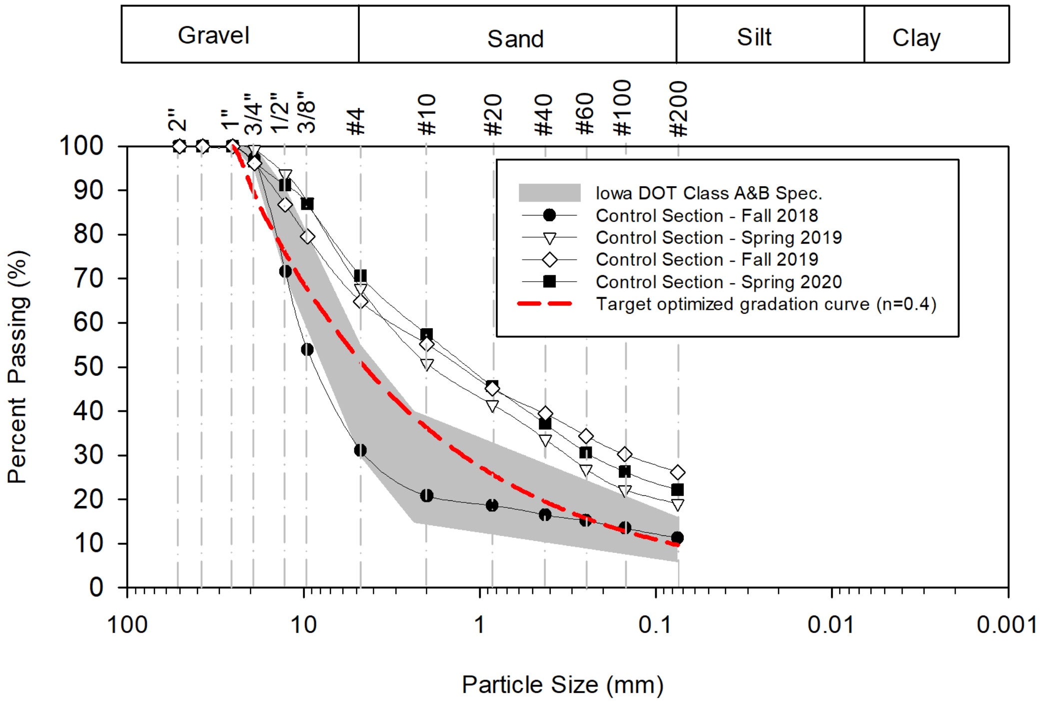


Figure 223. Particle size distribution curves for Washington County control section

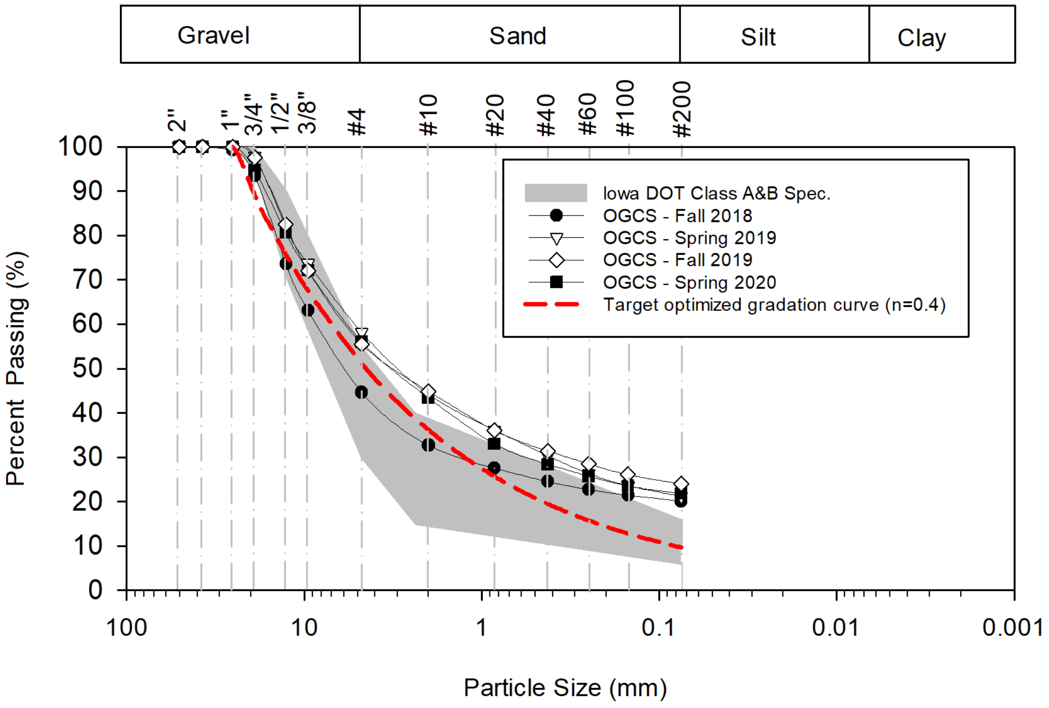


Figure 224. Particle size distribution curves for Washington County OGCS section

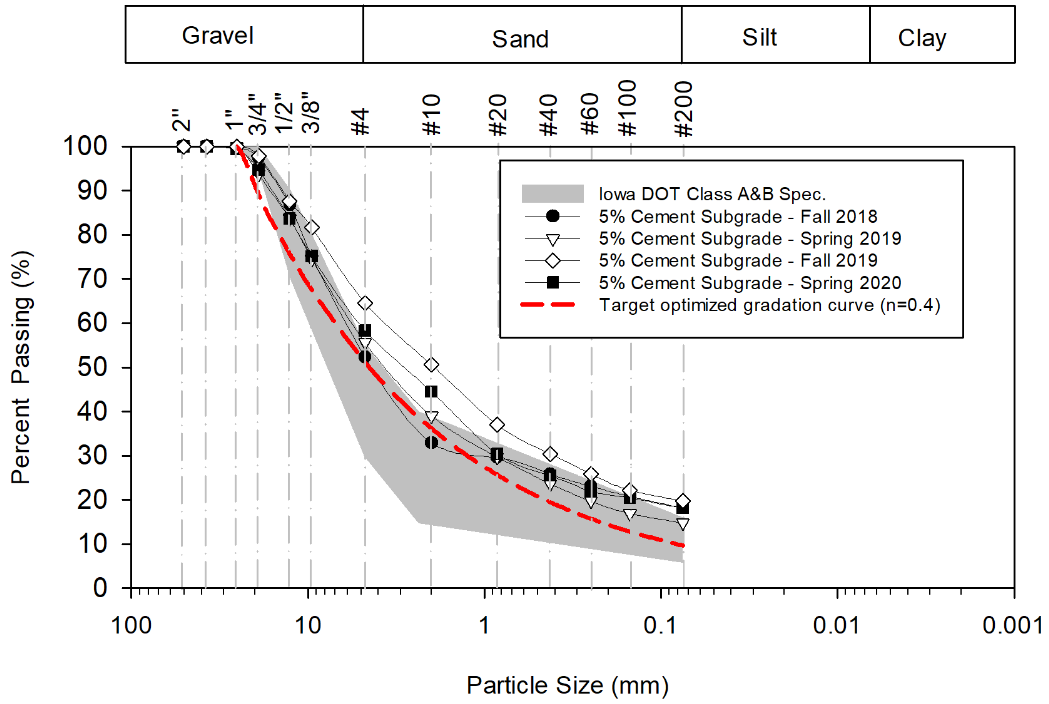


Figure 225. Particle size distribution curves for Washington County 12 in. cement subgrade section

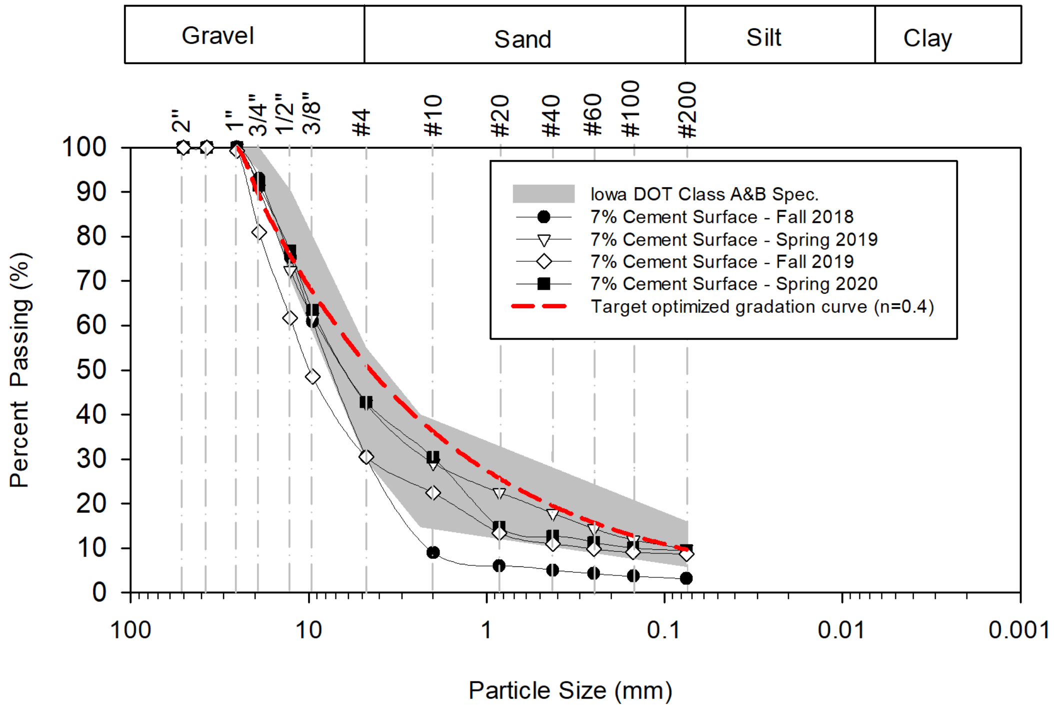


Figure 226. Particle size distribution curves for Washington County 4 in. cement surface section

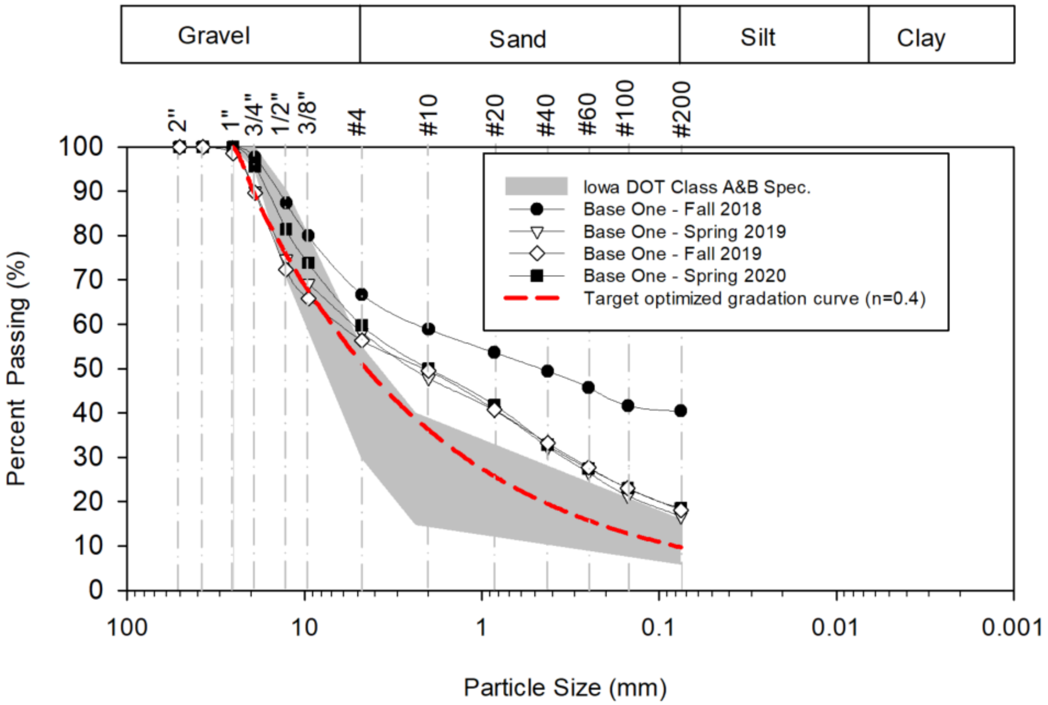


Figure 227. Particle size distribution curves for Washington County BASE ONE section

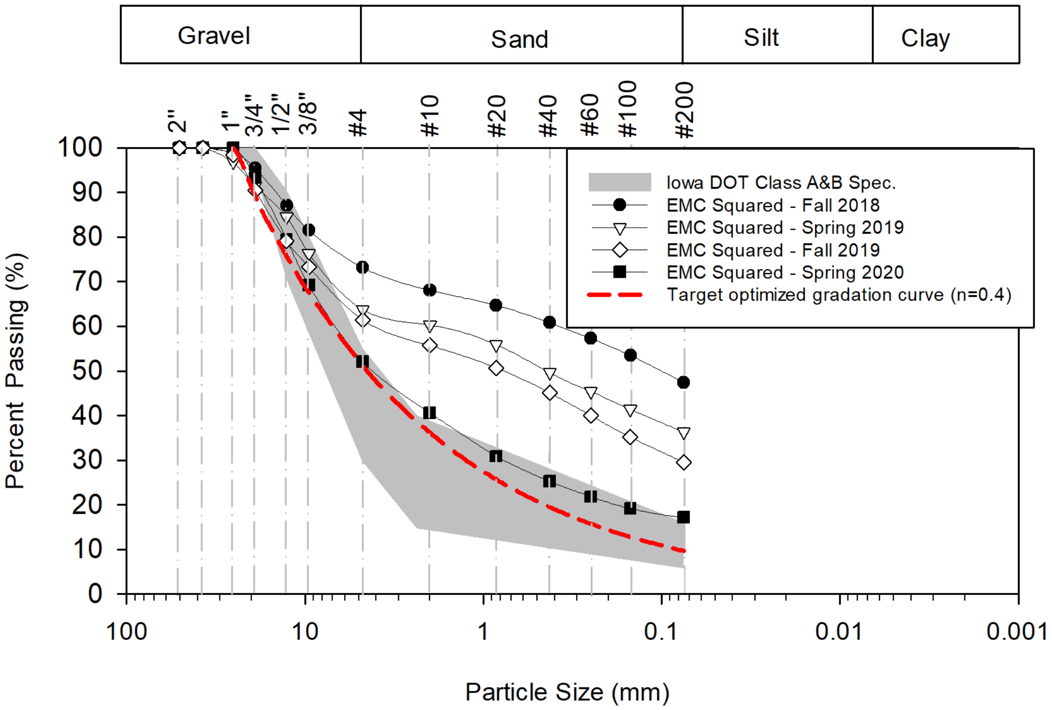


Figure 228. Particle size distribution curves for Washington County EMC SQUARED section

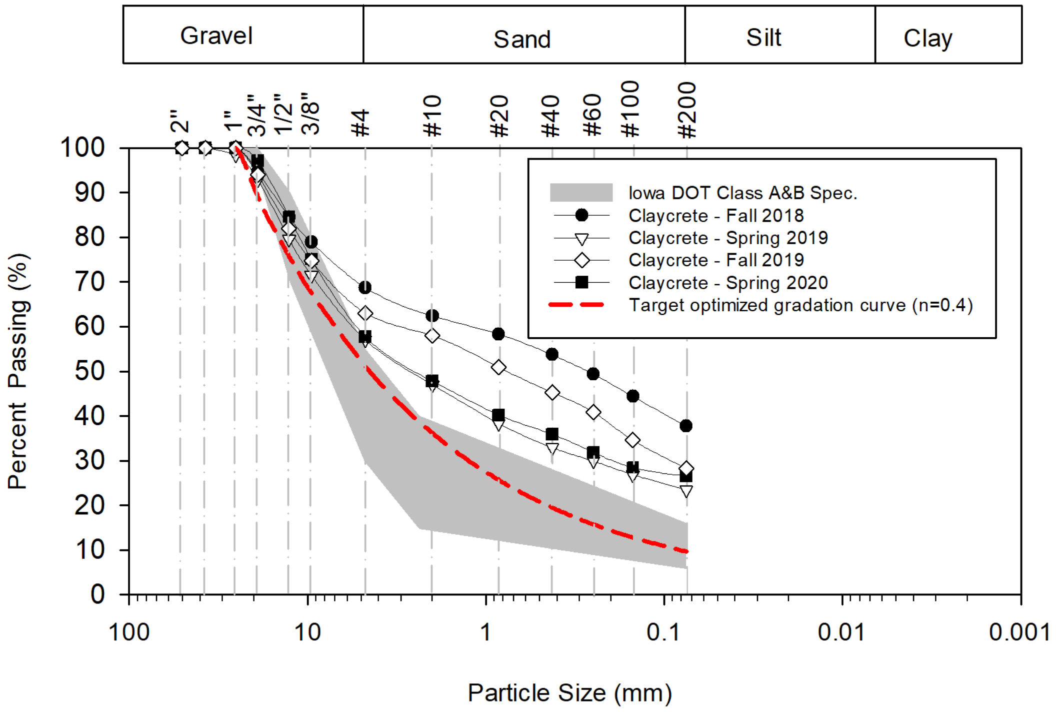


Figure 229. Particle size distribution curves for Washington County Claycrete section

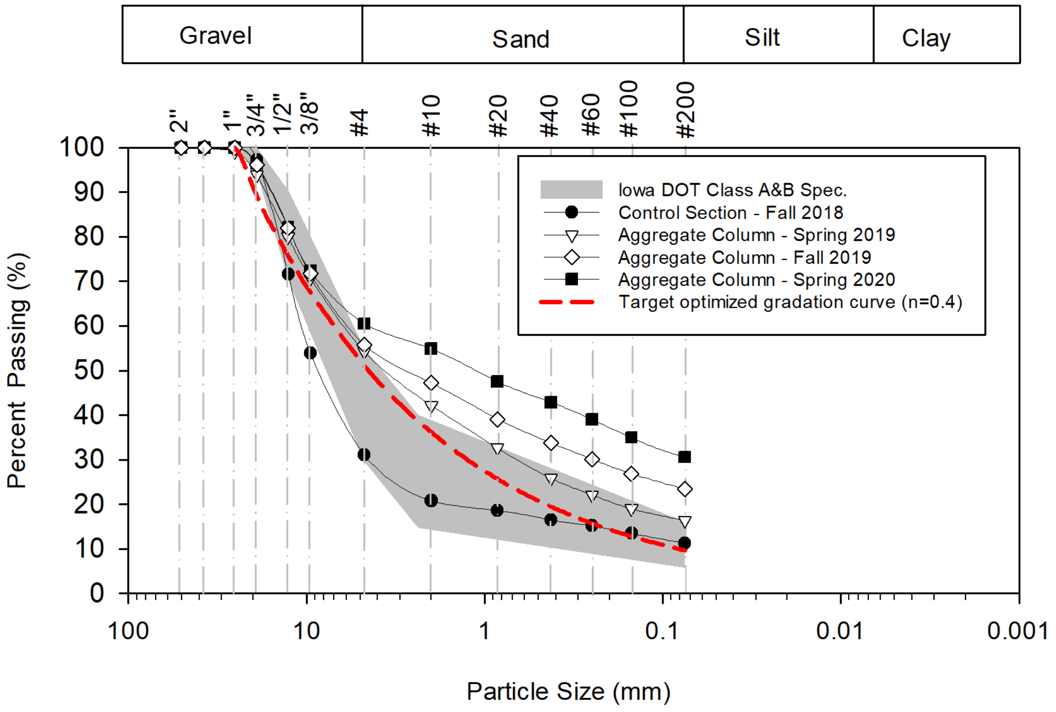


Figure 230. Particle size distribution curves for Washington County aggregate columns section

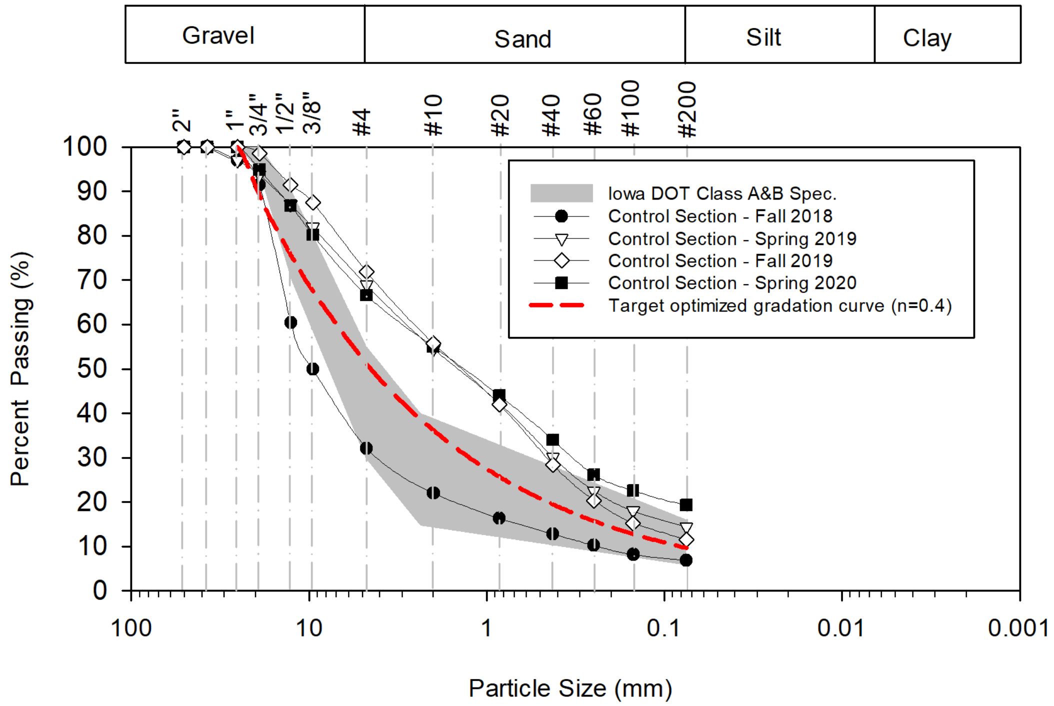


Figure 231. Particle size distribution curves for Hamilton County control section

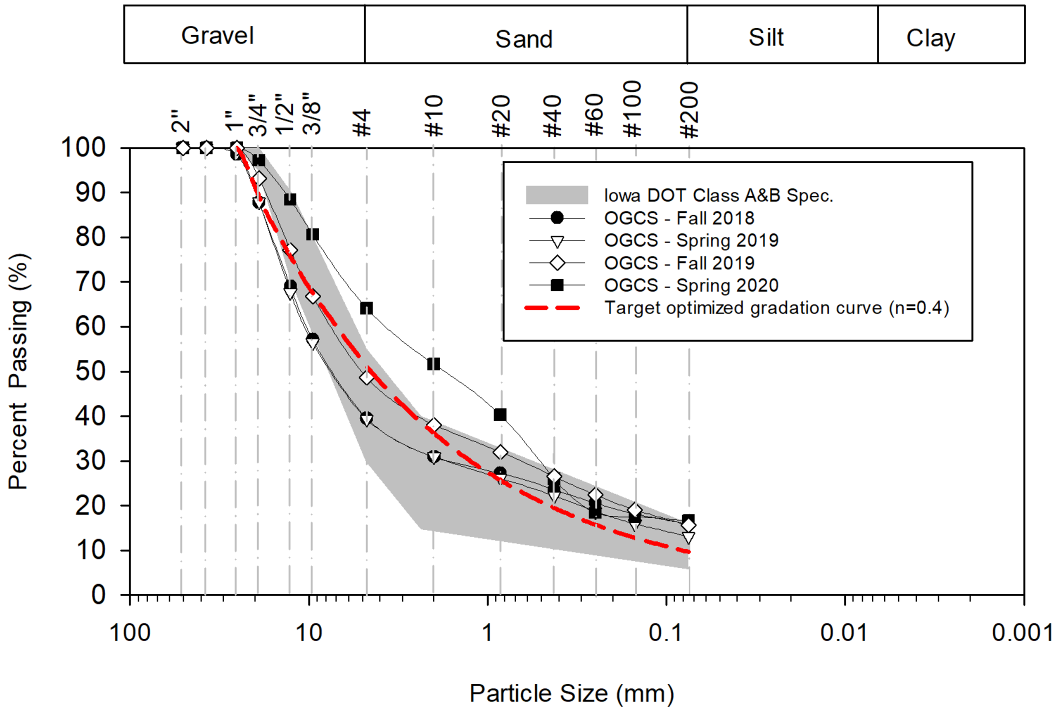


Figure 232. Particle size distribution curves for Hamilton County OGCS section

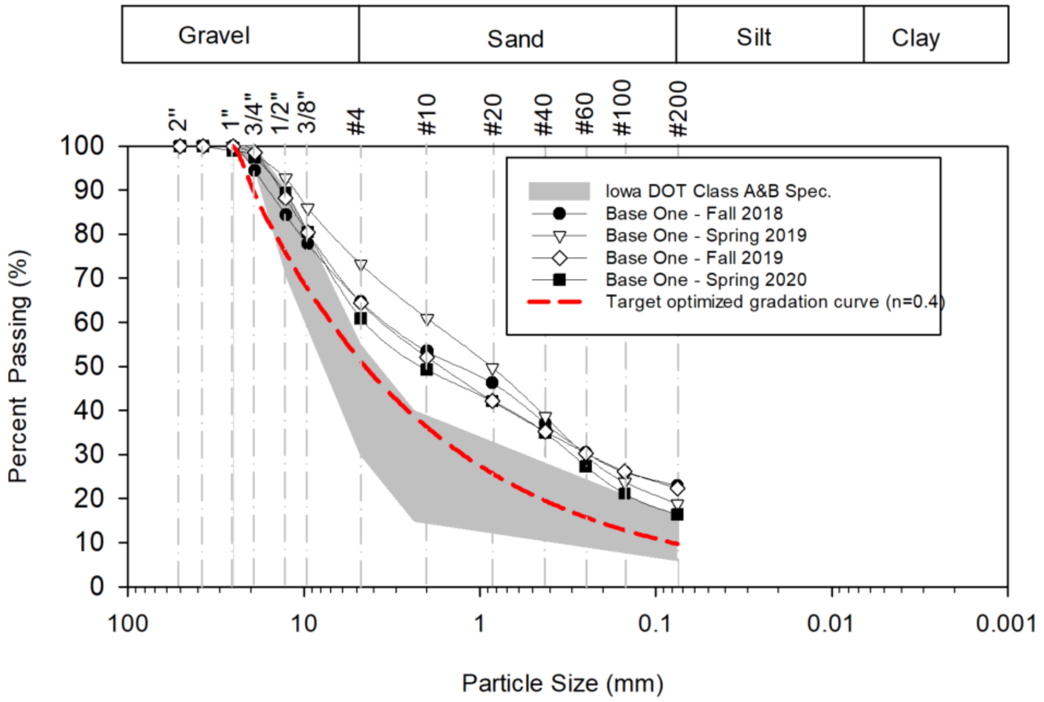


Figure 233. Particle size distribution curves for Hamilton County BASE ONE section

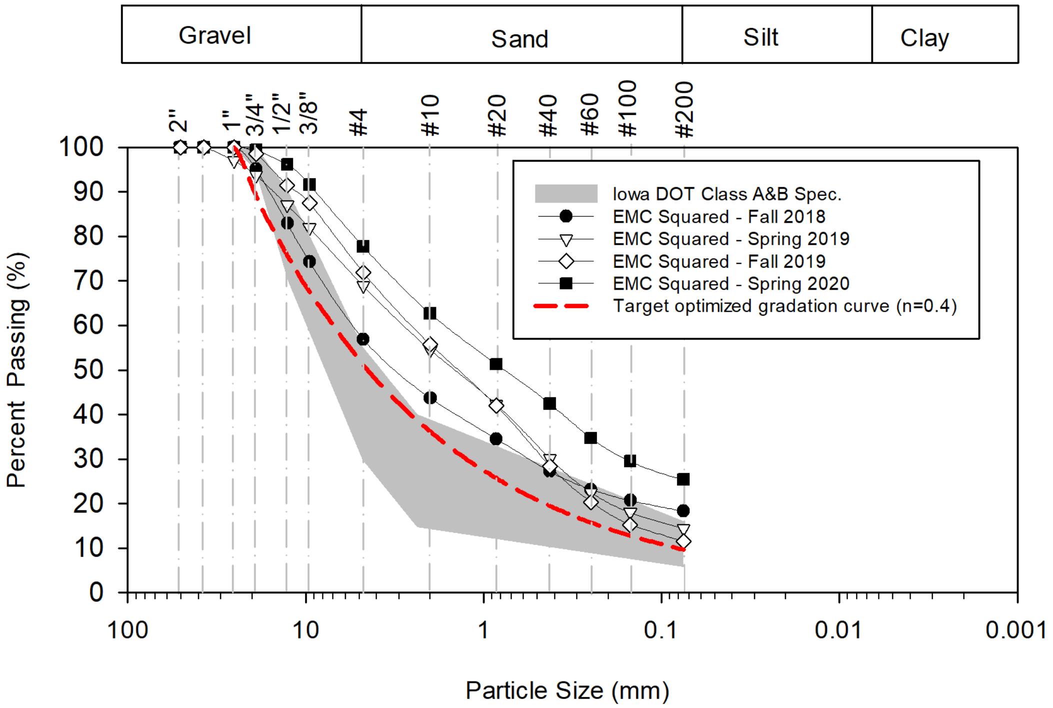


Figure 234. Particle size distribution curves for Hamilton County EMC SQUARED section

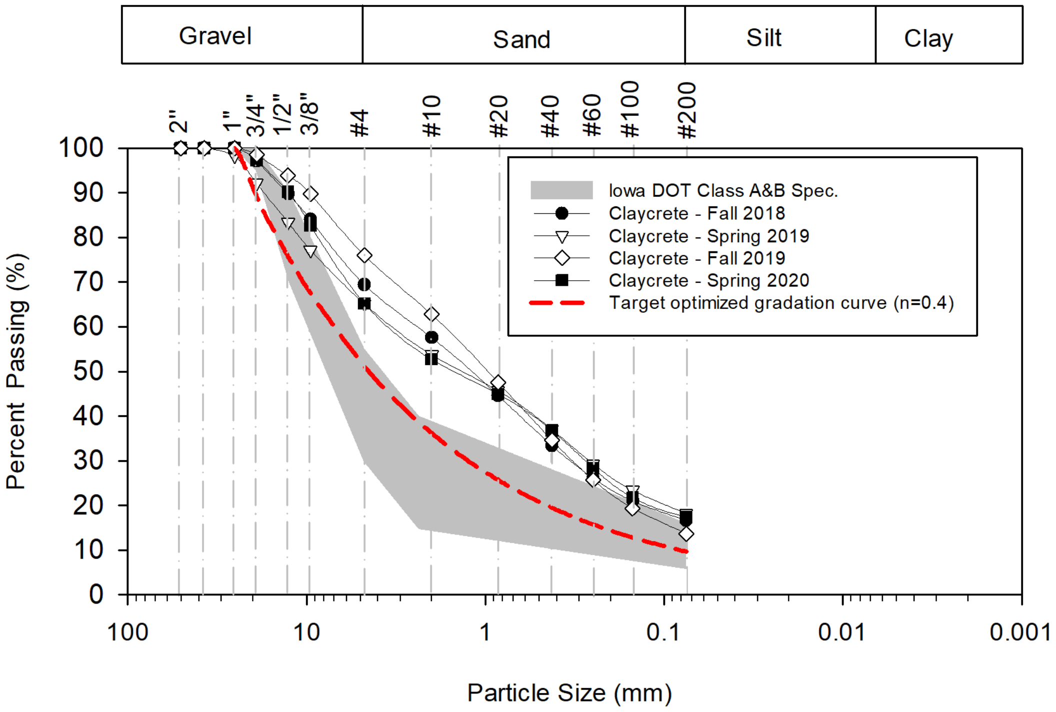


Figure 235. Particle size distribution curves for Hamilton County Claycrete section

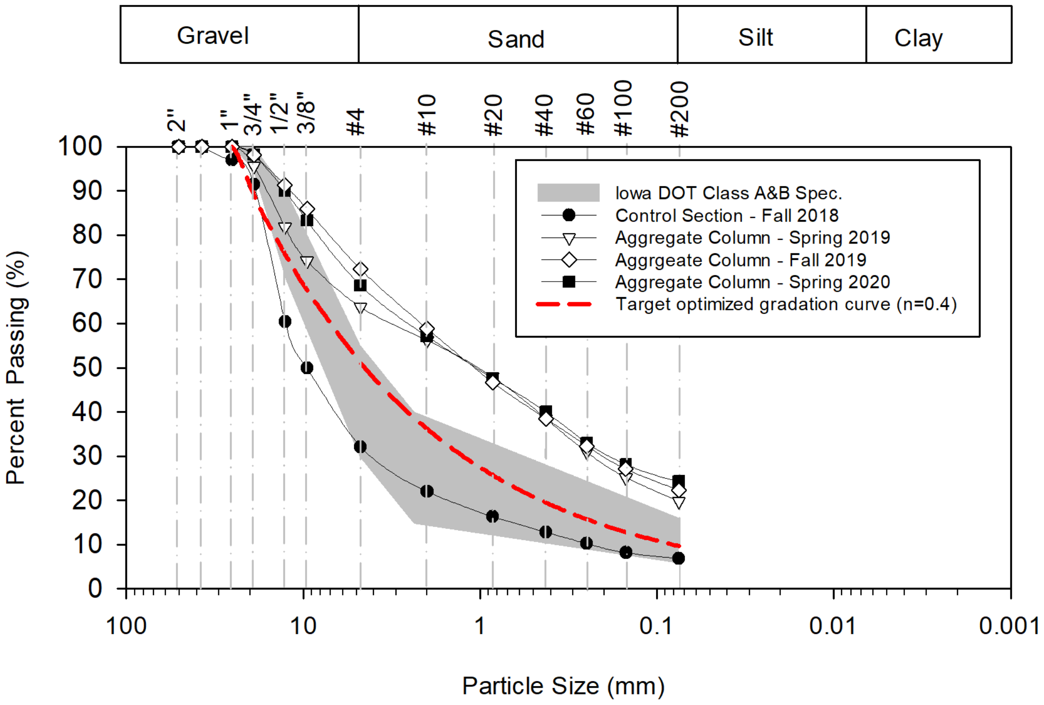


Figure 236. Particle size distribution curves for Hamilton County aggregate columns section

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