Demonstration of Innovative Technologies for Pavement Foundation Layer Construction: Pavement Foundation Mapping Projects

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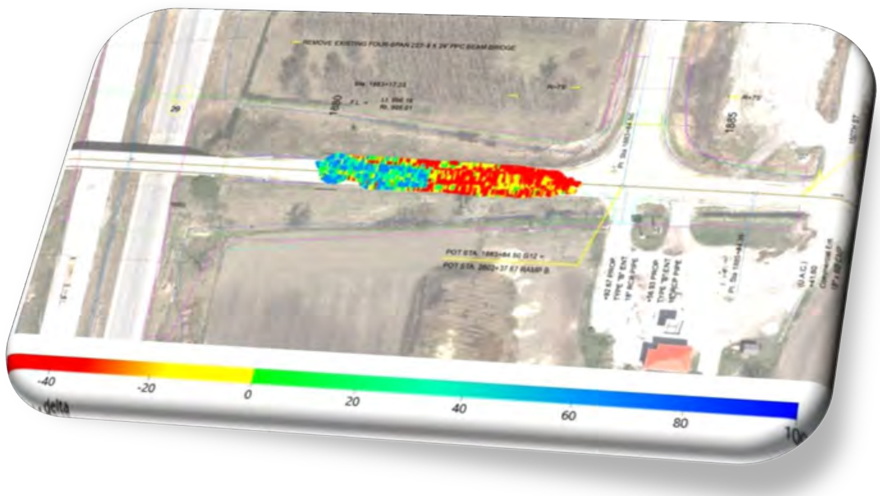

Interim Report

February 6, 2023

TPF-5(478) MP

Sponsored by the Iowa Department of Transportation and Federal Highway Administration

SUBMITTED BY
INGIOS GEOTECHNICS, INC

ingios GEOTECHNICS

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
TPF-5(478) MP (Interim)		

4. Title and Subtitle
Demonstration of Innovative Technologies for Pavement Foundation Layer Construction: Pavement Foundation Mapping Projects

5. Report Date
February 6, 2023

6. Performing Organization Code

7. Author(s)
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8. Performing Organization Report No.

9. Performing Organization Name and Address
Ingios Geotechnics, Inc.
P.O. Box 101
Northfield, MN 55057

10. Work Unit No.

11. Contract or Grant No.
TPF-5(478); 2301C

12. Sponsoring Agency Name and Address
Iowa Department of Transportation
800 Lincoln Way
Ames, IA 50010

Federal Highway Administration
1200 New Jersey Avenue, SE
Washington, DC 20590

13. Type of Report and Period Covered
Interim Report (06/08/2022 to 03/31/2023)

14. Sponsoring Agency Code
TPF-5(478); CFDA/ALN 20.205

15. Supplementary Notes
Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract
The Iowa Department of Transportation has recognized that the current level of performance from their pavements is not financially sustainable which has motivated the Iowa DOT to develop practical steps that will result in a lower ownership cost for their pavement infrastructure and increase their level of service to the public. The Iowa Department of Transportation believes that the next step forward in pavement foundation construction quality as well as optimized pavement designs will be realized by implementing design-value, modulus-based assessment and ensuring that the pavement design assumptions are met during construction. The FHWA has also recognized the need to improve the quality of pavement foundations nationally and has identified this need as a focus area in their 2019/2020 annual report to Congress on the Accelerated Implementation and Deployment of Pavement Technologies, AID-PT program. In recognition of this need the FHWA established Transportation Pooled Fund Project TPF-5(478) entitled: Demonstration to Advance New Pavement Technologies Pooled Fund. In 2022, The Iowa DOT joined the study and submitted a proposed project "Support for Pavement Foundation Design Modulus Verification and Construction Quality Monitoring" which was accepted to provide support for piloting and implementing modulus-based pavement foundation construction. To meet the project objectives, modulus-based verification technology was used on five (5) Iowa DOT projects during the 2022 construction season. The focus of the study was to collect material-specific pavement foundation support values to advance Iowa's mechanistic pavement design process. This report summarizes data and lessons learned from these mapping projects.

17. Key Words
performance specifications—modulus mapping—pavement foundation—resilient modulus—modulus of subgrade reaction

18. Distribution Statement
No restrictions.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	62	NA

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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Sponsored by the Iowa Department of Transportation and Federal Highway Administration TPF -5(478)

Submitted by Ingios Geotechnics, Inc.

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ACKNOWLEDGEMENTS

This project was sponsored by the Federal Highway Administration (FHWA) and the Iowa Department of Transportation (Iowa DOT) through the FHWA pooled fund study TPF-5(478).

Chris Brakke and Melissa Serio at the Iowa DOT provided guidance with the project selection and review of results. All their efforts are greatly appreciated.

Sincere thanks to the following for coordinating access to projects:

- Adrian Simonson and Cedric Wilkinson; Davenport RCE
- John Lamping and Robert Otto, Cedar Rapids RCE
- Dustin Skogerboe and Todd Eichhorst, Marshalltown RCE
- Kenneth Howe and Craig Greer, Mason City RCE
- David Dorsett and Mike Lynch, Council Bluffs RCE

Dr. David White, P.E. of Ingios Geotechnics served as the Principal Investigator for the project. Dr. Pavana Vennapusa, P.E. assisted with COMP-Score RT setup, analysis of field data and report generation. Mr. Tom Cackler, P.E. of Ingios Geotechnics assisted with project planning. Mr. Craig Swanson of Ingios Geotechnics assisted with COMP-Score RT and COMP-Score CONNECT setup. Mr. James Colby VanNimwegen and Mr. Heath Gieselman of Ingios Geotechnics assisted with roller mobilization, roller mapping, and field testing. Mr. John Puls, P.E. of Ingios Geotechnics assisted with roller mapping and report generation. Ms. Sue Ann Peters, P.E. of Ingios Geotechnics assisted with map summaries. Ms. Kera Gieselman of Ingios Geotechnics assisted with project planning, setup, coordination, and report generation.

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EXECUTIVE SUMMARY

Overview

In 2022, the Iowa Department of Transportation (DOT) joined the Federal Highway Administration (FHWA) pooled fund study TPF-5(478): Demonstration to Advance New Pavement Technologies. The DOT entered the study with the project titled "*Support for Pavement Foundation Design Modulus Verification and Construction Quality Monitoring*". The tasks identified in the DOT project were:

1) Generate modulus maps on five selected projects in addition to IA DOT pilot projects.
2) Develop training programs for Engineers, inspectors, and contractors and assist the DOT with integrating them into the current web-based training classes.
3) Develop model specifications to be used on future projects.
4) Develop workflow process and contractual documents for transitioning QC/QA processes from methods to performance specifications.
5) Field open house (For Iowa public agencies, contractors, and other DOTs with interest in technology partnerships)
6) Develop educational and technology transfer materials.
7) Develop a technology brief on the value proposition of improving pavement foundation performance using data from 2022 projects and cost modeling completed using 2021 pilot project data

Task 1 was completed in October 2022. This report summarizes the methods used to generate e-Compaction maps, project details, and data collected at each project as part of Task 1. The purpose of the study was to collect pavement foundation parameters in multiple material types to inform Iowa DOT's mechanistic-empirical pavement design process.

Key Findings

- A total of 1,046,519 square feet of pavement foundation area was mapped across the five sites.
- 13 hours of mapping was completed.
- 43 e-Compaction reports were generated.
- Six different material layers were mapped.
- Seven different material types were mapped.
- Average k-values for pavement foundations ranged from 37 to 180 psi/in.
- 3 of 43 maps had areas greater than 80% meeting or exceeding the target k-value.
- From a special compaction curve effort completed on the Linn County, IA project no significant increase in k-value after 16 roller passes was generated on Subgrade (Sand) and Modified Subbase Recycled Composite materials.
- COMP-Score INSPECTOR was successfully utilized on the Pottawattamie County project to improve communication regarding compaction operations and pavement foundation performance.

INTRODUCTION

Background

The Iowa Department of Transportation has recognized that the current level of performance from their pavements is not financially sustainable. Disinvestment in the lower end of the roadway network has been occurring for many years to address needs on the higher traffic routes. Current and anticipated future funding levels will require pavements to perform two- or three-times their current service life to maintain their system at an acceptable level of service. This disparity has motivated the Iowa DOT to develop practical steps that will result in a lower ownership cost for their pavement infrastructure and increase their level of service to the public.

The Iowa DOT is in the 3rd year of an implementation plan to move from their current method specifications to modulus-based requirements and field processes that will ensure the intended foundation support values assumed during pavement design are achieved. Also being evaluated are workflow processes to ensure design, material selection, and construction requirements are harmonized to achieve organization efficiency and maximum value.

The Iowa Department of Transportation believes that the next step forward in pavement foundation construction quality as well as optimized pavement designs will be realized by implementing design-value, modulus-based assessment and ensuring that the pavement design assumptions are met during construction. Field measurements of foundation support values obtained by plate load testing from a variety of foundation treatments across the state, indicate that the results of current design and construction requirements has resulted in only 30% of the locations tested meeting the support values assumed in design. This data set was generated from automated plate load testing (APLT) at over 130 locations under FHWA and Iowa DOT projects during 2017 – 2022 and is summarized in Figure 1.

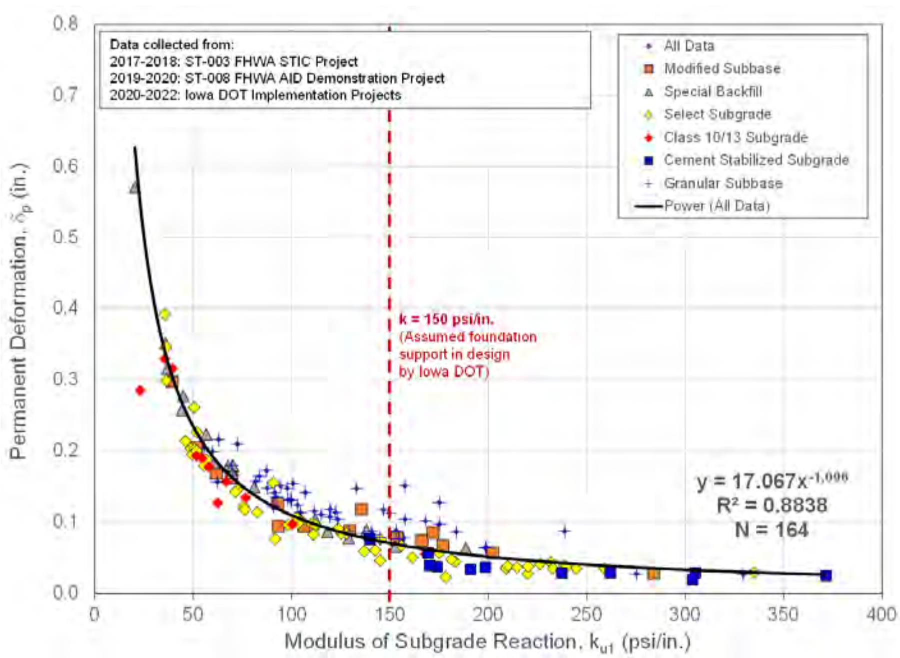

Figure 1: Modulus of subgrade reaction (k-value) versus permanent deformation at the end of test from field static plate load test measurements (164 tests from multiple project sites across Iowa from 2017 to 2022).

This realization was the culmination of a focused effort by the Iowa DOT to understand overall pavement performance and develop strategies that can achieve longer-life pavements with less required maintenance and built-in defects. A particularly helpful project that the Iowa DOT led was TPF-5(183) *Improving the Foundation Layers for Concrete Pavements; Lessons Learned and a Framework for Mechanistic Assessment of Pavement Foundations.* The Iowa DOT's current implementation plan builds upon the key findings and lessons learned from the detailed pavement foundation test programs in the participating states of California, Iowa, Michigan, Pennsylvania, and Wisconsin. Through this study, it was determined that current practices for pavement foundation quality inspection, specifically mechanistic characterization, are limited by the methods of measurement and frequency of testing. Ultimately, important pavement foundation parameters are not being measured in practice or controlled in situ, and therefore their impact on pavement performance is not well understood or accounted for in modern pavement design.

The key challenges regarding current practices were documented as follows:

- The geomaterials used in pavement foundations construction are variable and complex.
- No field verification of the engineering parameters used in the mechanistic design of pavement foundations is being used for quality acceptance during construction.
- While parametric studies of pavement design have shown that pavement performance has a low sensitivity to the support provided by the foundation materials, poor support conditions are well documented as affecting the long-term field performance of pavements.
- Substantial spatial variability (nonuniformity) exists in newly constructed pavement foundations for the range of materials tested.
- If the subgrade layer is nonuniform, the overlying aggregate base layer will be nonuniform.
- Uniformity of support is an important characteristic of pavement foundation systems. New finite element analyses quantify the effects of this characteristic on pavement performance.
- Loss of support due to irreversible plastic deformation in the foundation layer can significantly decrease the fatigue life of the pavement.
- Permanent (irreversible) deformation of the pavement foundation layers is not considered in modern pavement design or measured as part of the construction verification process.
- Limited geotechnical testing (covering less than 1% of a given work area) is used to accept the engineering support values of pavement foundations, resulting in low reliability.
- Constructed pavement foundation layers often show isolated areas of poor quality that contribute to localized pavement performance issues.
- Limited technology is available to help earthwork and paving contractors improve the field control of pavement foundation layers during construction.
- Modern laboratory testing to determine the stress-dependent resilient moduli of foundation materials does not accurately represent/replicate field boundary conditions.
- More frost heave and thaw testing is needed to characterize complex pavement foundation geomaterials, especially stabilized materials. In addition, the impact of wetting and drying cycles on these materials should be evaluated and characterized in terms of changes in volume, stiffness, and strength.
- Characterizing the soil water characteristics curves (SWCCs) of foundation layer materials is important, especially if the new mechanistic-empirical design procedure used in AASHTOWare Pavement ME Design is followed, because SWCCs have a direct impact on modeling the post-construction variations in the resilient moduli of these materials over the design life of the pavement.
- The current practice for selecting design input parameters for pavement foundation geomaterials (e.g., modulus, post-construction changes in modulus) is still largely empirical.
- Most methods for quality inspection testing do not qualify as direct mechanistic measurements.

Further the report identified the following key features of a performance-based construction specification.

- Measurement technologies that provide near 100% sampling coverage

- Acceptance and verification testing procedures that measure the performance-related parameters that are relevant to the mechanistic design inputs
- Protocols for establishing target values for acceptance based on design
- Quality statements that require achievement of spatial uniformity
- Protocols for data analysis and reporting that ensure that the construction process is field controlled in an efficient manner

The FHWA has also recognized the need to improve the quality of pavement foundations nationally and has identified this need as a focus area in their 2019/2020 annual report to Congress on the Accelerated Implementation and Deployment of Pavement Technologies, AID-PT program: *"Improving pavement foundation design is a focus area for FHWA. A pavement foundation that does not degrade over time does not need to be replaced, which may translate to significant sustainability benefits in environmental impact and costs. In congested areas, eliminating the need to replace the foundation could be highly advantageous by expediting pavement rehabilitation."*

In recognition of this need the FHWA established Transportation Pooled Fund Project TPF-5(478) entitled: Demonstration to Advance New Pavement Technologies Pooled Fund. The objective of this study is to support and showcase the implementation of innovative pavement technologies, products, and processes by State DOTs by leveraging of Federal investments with State DOT partnerships. DOTs were encouraged to submit topics of interest.

In 2022, The Iowa DOT joined the study and submitted a proposed project "*Support for Pavement Foundation Design Modulus Verification and Construction Quality Monitoring"* which was accepted and had the following objectives identified:

- Begin to develop a state specific library of the pavement foundation material properties for use as input values in Pavement ME Design (PMED).
- Provide direct support to interested states for piloting and implementing modulus-based pavement foundation construction.

To meet these objectives, the following tasks were identified:

1) Generate modulus maps on five selected projects in addition to IA DOT pilot projects.
2) Develop training programs for Engineers, inspectors, and contractors and assist the DOT with integrating them into the current web-based training classes.
3) Develop model specifications to be used on future projects.
4) Develop workflow process and contractual documents for transitioning QC/QA processes from methods to performance specifications.
5) Field open house (For Iowa public agencies, contractors, and other DOTs with interest in technology partnerships)
6) Develop educational and technology transfer materials.
7) Develop a technology brief on the value proposition of improving pavement foundation performance using data from 2022 projects and cost modeling completed using 2021 pilot project data

Task 1 was mapping began on 08/09/2022 with the Johnson County I-80 project, continued with Linn County I-380, Tama County US 30, Floyd County US 18, and was completed on 10/26/2022 with the Pottawattamie I-29 project.

Task 5 was completed on October 28, 2022, with the *Iowa DOT Open House: Demonstration of Innovative Technologies for Pavement Foundation Layer Construction*. The open house was hosted jointly by The Iowa Department of Transportation, Ingios Geotechnics, Inc. (Ingios), and The Federal Highway Administration.

Task 1- Pavement Foundation Mapping Projects

This interim report represents completion of TPF-5(478) Task 1. Modulus-verification mapping was completed on each of the five projects during the 2022 construction season. All mapping was performed by Ingios personnel using Ingios equipment, in coordination with Iowa DOT staff and construction partners.

Selection of the five mapping projects was completed in coordination with Iowa DOT management. Selection criteria consisted of the following:

- Projects located in different areas around the state in order to map subgrade soils in different geologic conditions.
- Projects located in DOT Districts which were not already part of 2021 or 2022 pilot projects to provide DOT District staff exposure to the technology.
- Pavement foundations with different profiles or subbase materials to provide stiffness values for the mechanistic-empirical database.

Table 1 is a summary of the projects, dates, project locations, materials mapped, layers mapped, and road segments mapped. Project locations are depicted as yellow stars on the map in Figure 2.

Table 1. Summary of project locations, materials, layers and segments mapped.

Project No.	Mapping Date	Location/ RCE	Materials Mapped	Layers Mapped	Segment Mapped	Notes
DOT Project Number: IM-NHS-080-7(174)248--03-52; Letting 02/15/2022						
1	08/09/22 and 08/10/22	I-80 Johnson County; RCE Davenport	Select Cohesive Class 10 Clay	Subgrade Treatment 24”	I-80	Geogrid
			Granular Subbase Recycled PCC	Subbase 6”		
			Special Backfill (RAP)	Subgrade Treatment 6”		
				Subgrade Treatment 12”		
DOT Project Number: IM-380-6(200)25--13-57; Letting 08/17/2021						
2	08/25/22 and 08/26/22	I-380 Linn County; RCE Cedar Rapids	Subgrade Class 10 (Sand)	Subgrade Top	Ramp C	
			Modified Subbase Recycled Composite	Subbase 12”	Tower Terrace Road	
DOT Project Number: NHSX-030-6(240)--3H-86; Letting 10/19/2021						
3	09/09/22	US 30 Tama County; RCE Marshalltown	Select Cohesive Class 10 Clay	Subgrade Treatment 24”	US 30 WB	
DOT Project Number: NHSX-018-6(95)--3H-34; 07/20/2021						
4	09/13/22	US 218 Floyd County; RCE Mason City	Modified Subbase Recycled PCC	Subbase 12”	US 18 EB	
				Subbase 6”	Ramp A	
				Subbase 6”	Ramp C	
			Subgrade Class 10 (Clay)	Subgrade Top	County Road T44	
					Ramp A	
DOT Project Number: IMX-029-4(112)72--02-78; Letting 12/21/2021						
5	10/26/22	I-29 Pottawatt-amie County; RCE Council Bluffs	Subgrade Class 10 (Clay)	Subgrade Top	County Road G12	

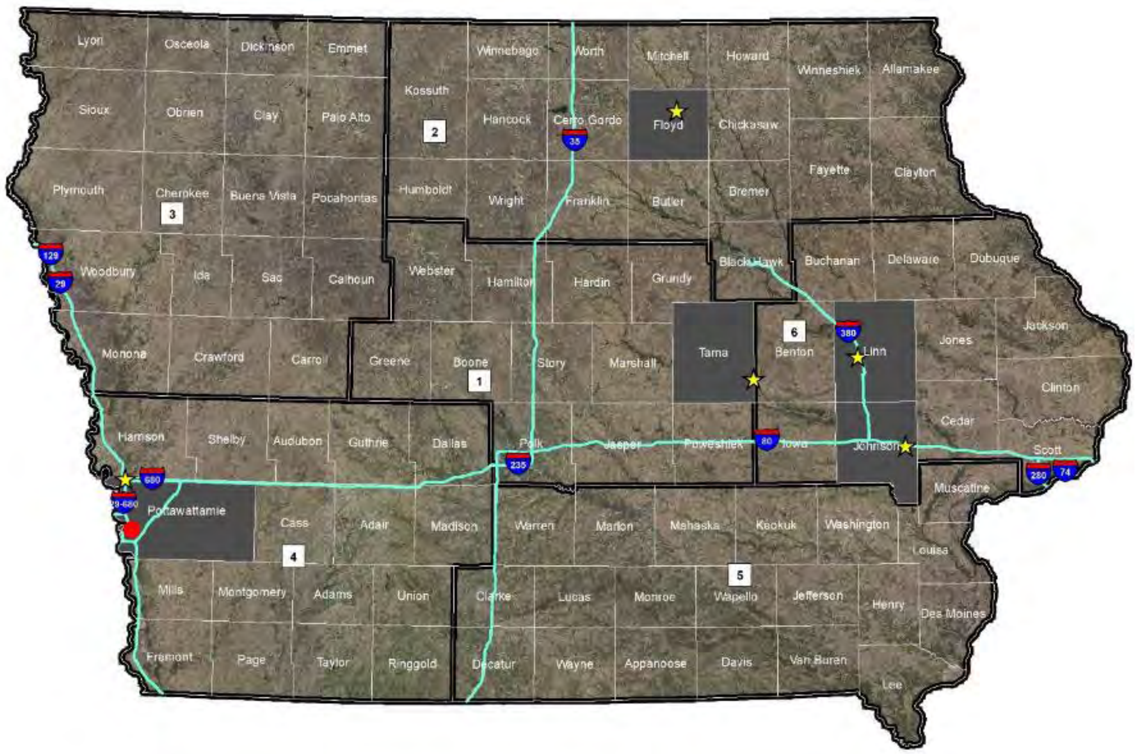

Figure 2. Project locations – TPF-5(478) Task 1 Sites 2022

At each of the five sites, an CAT CS56B smooth drum vibratory roller with modulus-verification technology was mobilized to the site in advance of mapping (Figure 3). Modulus verification roller mapping was completed using the Ingios CS56 vibratory smooth drum roller outfitted with the Ingios COMP-Score RT kit. The kit includes a real-time display monitor in the roller cab, a sensor kit mounted to the roller drum, computer to capture and process the sensor measurements, real-time kinematic (RTK) global positioning system (GPS) hardware, and the necessary hardware and software.

Once on site, mapping was completed by a trained Ingios roller operator on the materials, layers, and areas available at that phase of construction. Mapped areas were identified prior to mobilization and ultimately selected on-site after conversations with the Iowa DOT and contractor.

After maps were completed with the COMP-Score RT system, reports were generated and shared in near real-time to Iowa DOT users via the COMP-Score CONNECT web application. Additional details are described in the methods section of this report.

This report summarizes the results of modulus-based verification mapping on each of the five projects. Project information is detailed in the following sections:

- Materials: Description of materials mapped at each project with photographs
- Methods: Explanation of equipment and procedures
- Project summaries: Project details, key findings, typical cross sections for areas mapped, project photos, box plots of k-values, and sample e-Compaction reports
- Appendices A to E: e-Compaction reports

Figure 3. Instrumented roller mobilized to project sites.

MATERIALS

The materials mapped on each project are listed in Table 1. The material naming convention is based on a database of 26 materials identified for Iowa DOT projects per DOT standard specifications. Photos of materials and layers compacted and mapped on each project site are shown below in Figure 4 through Figure 12.

Figure 4. I-80, Subbase 6 inches, Granular Subbase Recycled PCC.

Figure 5. I-80, Subgrade Treatment 12 inches, Special Backfill RAP.

Figure 6. I-80, Subgrade Treatment 24 inches, Subgrade_Treatment Select Cohesive.

Figure 7. I-380, Subbase 12 inches, Modified Subbase Recycled Composite.

Figure 8. I-380, Subgrade Top, Subgrade Class 10 (Sand).

Figure 9. US30, Subgrade Treatment 24 inches, Subgrade_Treatment Select Cohesive.

Figure 10. US18, Subbase 12 inches, Modified Subbase Recycled PCC.

Figure 11. US18, Subgrade Top, Subgrade Class 10 (Clay).

Figure 12. I-29, Subgrade Top, Subgrade Class 10 (Clay).

METHODS

COMP-Score RT Mapping Technology

Ingios Geotechnics Comp-Score RT was used on all five mapping projects. The Comp-Score RT system uses instrumentation on the compaction machine to directly measure pavement foundation engineering parameters (stiffness/modulus) during compaction, as shown in Figure 13. Real-time kinematics (RTK) and GPS instruments provide geo-location of roller measurements. This information is synthesized by an on-board computer and is viewable to the machine operator from the screen display in the cab, as shown in Figure 14. The operator monitors the machine measurements in real-time to adjust the operation, as needed, to achieve the desired target value for stiffness or modulus.

Figure 13. COMP-Score RT roller setup on Floyd County project.

Figure 14. Machine operator interacting with on-board Comp-Score RT display.

COMP-Score CONNECT Web Application

Comp-Score CONNECT was used to view mapping results on all five mapping projects. e-Compaction reports are viewed using the Comp-Score CONNECT software platform; a web-based interface that is viewable from the desktop or mobile device, shown in Figure 15. The machine measurements taken via Comp-Score RT are transmitted to a cloud-based database where e-Compaction reports are generated within minutes of the completion of mapping. These reports provide users such as agency inspectors or engineers ability to assess the performance of the pavement foundation.

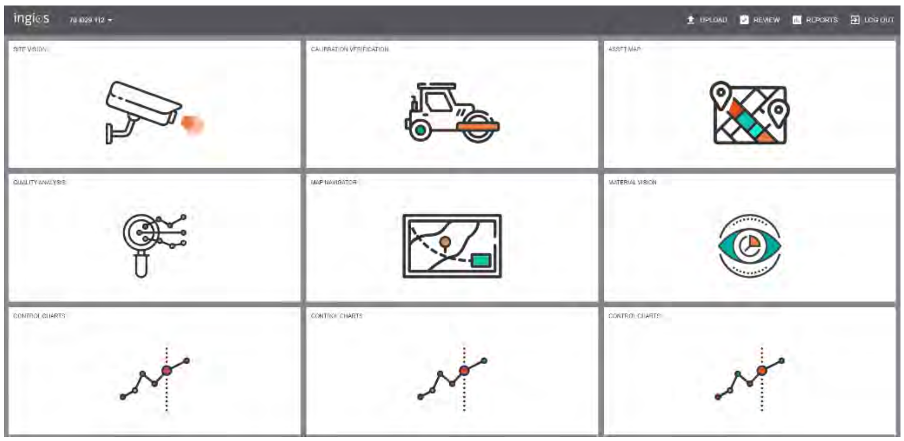

Figure 15. Comp-Score CONNECT web interface.

Approval of the pavement foundations can be documented via e-Compaction report as part of the quality assurance process. Corrective actions can be taken to produce a pavement foundation that meets the stiffness/modulus criteria specified in the design of the pavement system. Once corrective action is complete, additional mapping can be performed to document the effectiveness of the action.

e-Compaction reports are presented for each of the five projects in this report. Multiple map types are presented in each e-Compaction report which show the spatial measurements of each of the following parameters:

- k-value: Presents the material stiffness (units are psi/in) as measured by the compaction machine (using pre-calibrated results from full-scale plate load test).
- k-value-delta: Presents the difference between measured k-value and the target k-value. Negative values indicate areas that are below the target value while positive values indicate areas that exceed the target value. For this project, a target value of 100 psi/in. was used for subgrade, and all other materials had a target value of 150 psi/in.
- k-value-delta-iscore: Presents contiguous areas where k-value measurements fall below the target value. This map provides the user the ability to define areas of the pavement foundation which may require corrective action.
- Blobs: k-value-delta-iscore – Presents the difference between target k-value and actual k-value in contiguous areas large enough to exceed the minimum area, as defined (1000 ft^2 for these projects). Minimum blob size requirements are defined at the beginning of the project, prior to mapping.

COMP-Score INSPECTOR

COMP-Score INSPECTOR is a mobile platform supplement to the COMP-Score system. COMP-Score INSPECTOR allows users to visualize e-Compaction reports on-site within minutes of machine mapping.

A completed map is uploaded to a GPS-enabled mobile device where users can open the map and identify their location on the map via a mobile icon as seen in Figure 16 and Figure 17. Users combine the e-Compaction data with visual observations to assess moisture conditions, identify materials, and define areas for remediation in the field. This application further empowers field personnel to identify and demark areas for remediation. Discussions between agency inspectors, engineers, and contractors are enhanced by having e-Compaction data and GPS location viewable in real-time.

COMP-Score INSPECTOR was used on the Pottawattamie County project during field mapping. Refer to the Pottawattamie County project summary for additional information.

Figure 16. Inspector viewing Comp-Score(R) e-Compaction report using INSPECTOR application.

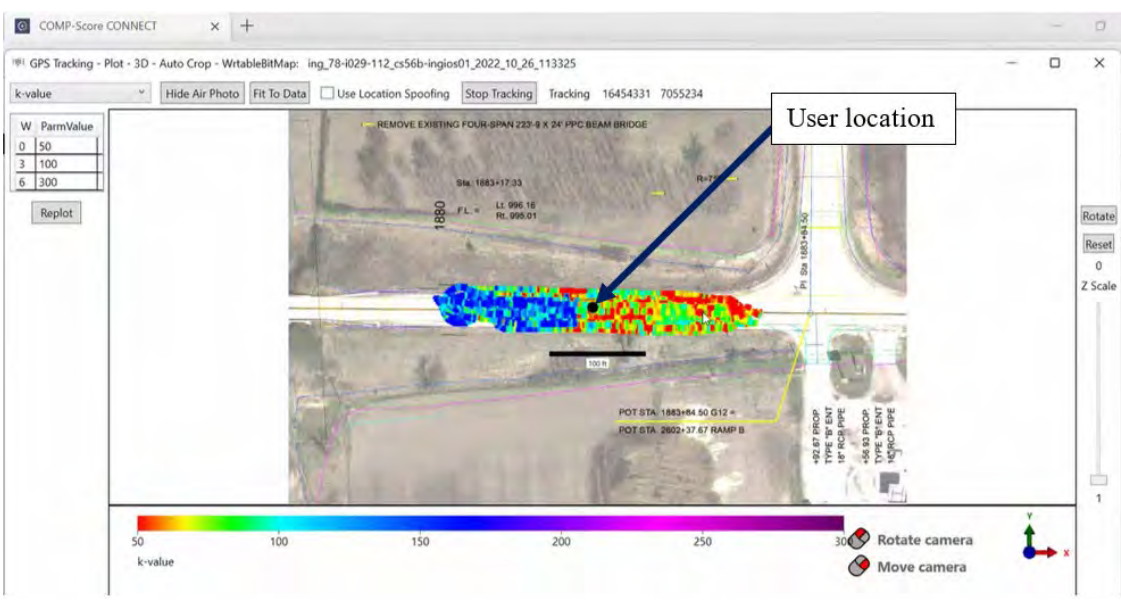

Figure 17. e-Compaction map as viewed on Comp-Score INSPECTOR application showing user location within e-Compaction map.

Project Data Analysis

Box plots of k-values for all map runs by project and material are reported in the project summary section of the report. Left and right ends of the box represent the 1st and 3rd quartile. Solid black line within the box represents the Median. Blue line represents the Mean. The left and right end of the whiskers represent the Minimum and Maximum.

Compaction Curve Analysis

A compaction curve was completed at the Linn County project on two materials: top of subgrade and subbase 12 inches. A compaction curve is developed through repeated passes of the machine over a defined area. By capturing data for all passes, average k-values can be obtained and plotted against machine pass, creating the compaction curve. Compaction curves provide an assessment of the effects of additional compaction effort on k-values. Additionally, Dynamic Cone Penetration (DCP) testing (ASTM D6951) test points are spaced evenly along the length of the compaction curve area. DCP testing is performed at 5 points prior to repeated compaction and 5 points after repeated compaction as an additional measurement of ground response to compaction effort. DCP plots are presented with the compaction curves in Appendix B.

PROJECT SUMMARIES

Five projects in five separate Iowa counties were mapped between the dates of 08/09/2022 and 10/26/2022. The projects were I-80 Johnson County, I-380 Linn County, US 30 Tama County, US 18 Floyd County, and I-29 Pottawattamie County. Ingios Geotechnics personnel coordinated with the Resident Construction Engineer (RCE) prior to scheduling mapping dates to determine which materials and layers would be available for mapping. Table 1 in the introduction of this report summarizes the projects, dates, project locations, materials mapped, layers mapped, and road segments mapped. The following sections include project details, key findings, typical cross sections for areas mapped, project photos, box plots of k-values, and sample e-Compaction reports for each project.

I-80 Johnson County

This project consisted of reconstruction and a lane addition on mainline Interstate 80 from 1.5 miles east of IA-1 to 0.5 miles east of Wapsi Ave. in Johnson County, Iowa. Mapping was performed on the east-bound lanes of I-80 on 8/9/22 and 8/10/22. A total of 17 e-Compaction reports were generated, as summarized in Table 2. Project materials mapped included 24 inches of select soil subgrade treatment (typical cross section in Figure 18), 12 inches of special backfill subgrade treatment (typical cross section in Figure 19), and 6 inches of granular subbase material (typical cross section in Figure 20). The top of the 24 inch select soil subgrade treatment was mapped intermittently from approximate station 1223+00 to 1274+00. The first 6-inch lift of special backfill subgrade treatment was mapped from station 1109+00 to 1120+50. The top of the 12-inch special backfill subgrade treatment was mapped intermittently from approximate station 1216+00 to 1223+00 and 1121+00 to 1150+00. The top of 6-inch granular subbase was mapped intermittently from approximate station 1216+00 to 1254+00. Polymer grid stabilizing material was placed by the contractor on this project below the special backfill or above the select soil subgrade treatment materials prior to mapping. Site conditions on the days of mapping can be seen in the photos in Figure 21, Figure 22, and Figure 23. Box plots of k-values for all project materials are displayed in Figure 24. Example e-Compaction map results can be seen in Figure 25 and Figure 26. Refer to Appendix A for all e-Compaction reports generated on this project.

Key findings from the e-Compaction reports completed at the Johnson County project include:

- A total of 384,696 SF of pavement foundation area was mapped in approximately 4 hours.
- 17 e-Compaction reports were generated.
- Four different material layers were mapped.
- Three different material types were mapped.
- Average k-values for pavement foundations ranged from 52.1 to 156.2 psi/in.
- 2 of 17 maps had areas greater than 80% meeting or exceeding the target k-value

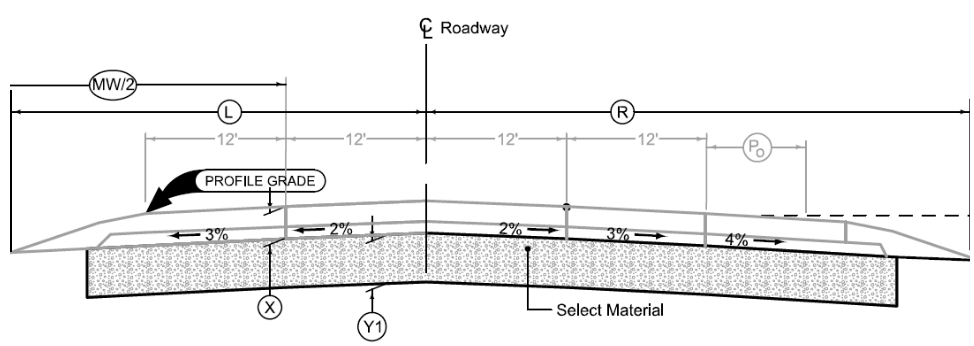

Figure 18. I-80 Grading Typical Cross Section: 24" Select Soil Subgrade Treatment Option.

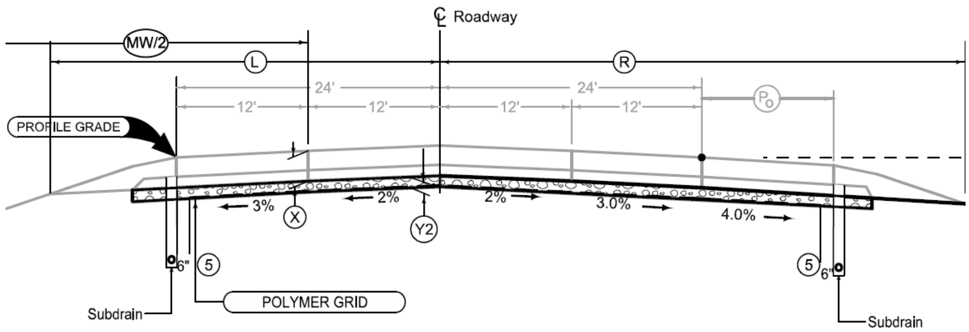

Figure 19. I-80 Grading Typical Cross Section: 12” Special Backfill Subgrade Treatment Option.

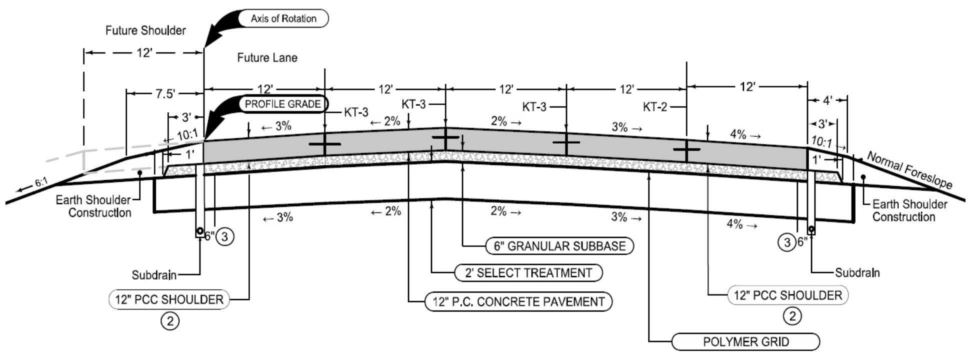

Figure 20. I-80 Paving Typical Cross Section.

Table 2. Summary of e-Compaction Reports, I-80 Johnson County, IA.

Johnson County, IA (52-I080-174)

Map Start Date	Map ID	Mapping Duration (hrs)	Area Mapped (sq. ft.)	Layer	Material Type	Average k-value	% Passing	COV %	# of Blobs	Total Blob Area (sq. ft.)
8/9/2022	ing_52-i080-174_cs56b-ingios01_2022_08_09_170036	0.11	7,089	Subbase 6 Inches	Granular Subbase Recycled PCC_IADOT	141.00	72.70	22.00	1	1,427
8/9/2022	ing_52-i080-174_cs56b-ingios01_2022_08_09_171152	0.06	3,129	Subgrade Treatment 12 Inches	Subgrade_Treatment Special Backfill RAP_IADOT	143.70	81.10	21.00	0	-
8/9/2022	ing_52-i080-174_cs56b-ingios01_2022_08_09_173544	0.14	11,120	Subbase 6 Inches	Granular Subbase Recycled PCC_IADOT	156.20	96.70	3.20	0	-
8/9/2022	ing_52-i080-174_cs56b-ingios01_2022_08_09_175350	0.21	24,679	Subbase 6 Inches	Granular Subbase Recycled PCC_IADOT	83.70	5.30	35.60	2	24,265
8/9/2022	ing_52-i080-174_cs56b-ingios01_2022_08_09_180902	0.11	8,314	Subgrade Treatment 12 Inches	Subgrade_Treatment Special Backfill RAP_IADOT	109.00	8.20	39.20	2	8,183
8/9/2022	ing_52-i080-174_cs56b-ingios01_2022_08_09_181750	0.09	5,762	Subgrade Treatment 12 Inches	Subgrade_Treatment Special Backfill RAP_IADOT	103.40	9.70	36.90	2	5,366
8/9/2022	ing_52-i080-174_cs56b-ingios01_2022_08_09_182712	0.23	25,779	Subgrade Treatment 24 Inches	Subgrade_Treatment Select Cohesive_IADOT	52.10	0.00	33.30	2	25,779
8/9/2022	ing_52-i080-174_cs56b-ingios01_2022_08_09_190557	0.37	47,038	Subgrade Treatment 24 Inches	Subgrade_Treatment Select Cohesive_IADOT	54.60	0.00	32.90	1	47,038
8/9/2022	ing_52-i080-174_cs56b-ingios01_2022_08_09_192938	0.22	20,841	Subbase 6 Inches	Granular Subbase Recycled PCC_IADOT	76.20	2.90	34.70	2	20,703
8/9/2022	ing_52-i080-174_cs56b-ingios01_2022_08_09_194641	0.06	7,098	Subbase 6 Inches	Granular Subbase Recycled PCC_IADOT	87.40	10.30	38.50	2	5,229
8/9/2022	ing_52-i080-174_cs56b-ingios01_2022_08_09_195429	0.46	43,288	Subbase 6 Inches	Granular Subbase Recycled PCC_IADOT	66.60	0.40	23.80	1	43,288
8/10/2022	ing_52-i080-174_cs56b-ingios01_2022_08_10_125633	0.22	19,531	Subgrade Treatment 6 Inches	Subgrade_Treatment Special Backfill RAP_IADOT	66.50	0.50	53.00	1	19,531
8/10/2022	ing_52-i080-174_cs56b-ingios01_2022_08_10_131843	0.26	22,612	Subgrade Treatment 12 Inches	Subgrade_Treatment Special Backfill RAP_IADOT	135.40	32.30	20.30	6	12,060
8/10/2022	ing_52-i080-174_cs56b-ingios01_2022_08_10_134821	0.38	32,340	Subgrade Treatment 12 Inches	Subgrade_Treatment Special Backfill RAP_IADOT	69.50	1.70	50.40	1	32,321
8/10/2022	ing_52-i080-174_cs56b-ingios01_2022_08_10_142134	0.19	17,827	Subgrade Treatment 12 Inches	Subgrade_Treatment Special Backfill RAP_IADOT	75.40	3.70	52.50	1	17,717
8/10/2022	ing_52-i080-174_cs56b-ingios01_2022_08_10_162950	0.52	53,500	Subgrade Treatment 12 Inches	Subgrade_Treatment Special Backfill RAP_IADOT	97.20	10.50	41.50	1	52,041
8/10/2022	ing_52-i080-174_cs56b-ingios01_2022_08_10_172102	0.35	34,749	Subgrade Treatment 12 Inches	Subgrade_Treatment Special Backfill RAP_IADOT	117.90	22.50	32.40	2	29,293

Figure 21. Photo I-80 Top of 24 Inch Select Soil Subgrade Treatment.

Figure 22. Photo I-80 Top of 12 Inch Special Backfill RAP Subgrade Treatment.

Figure 23. Photo Top of 6 Inch Granular Subbase Recycled PCC.

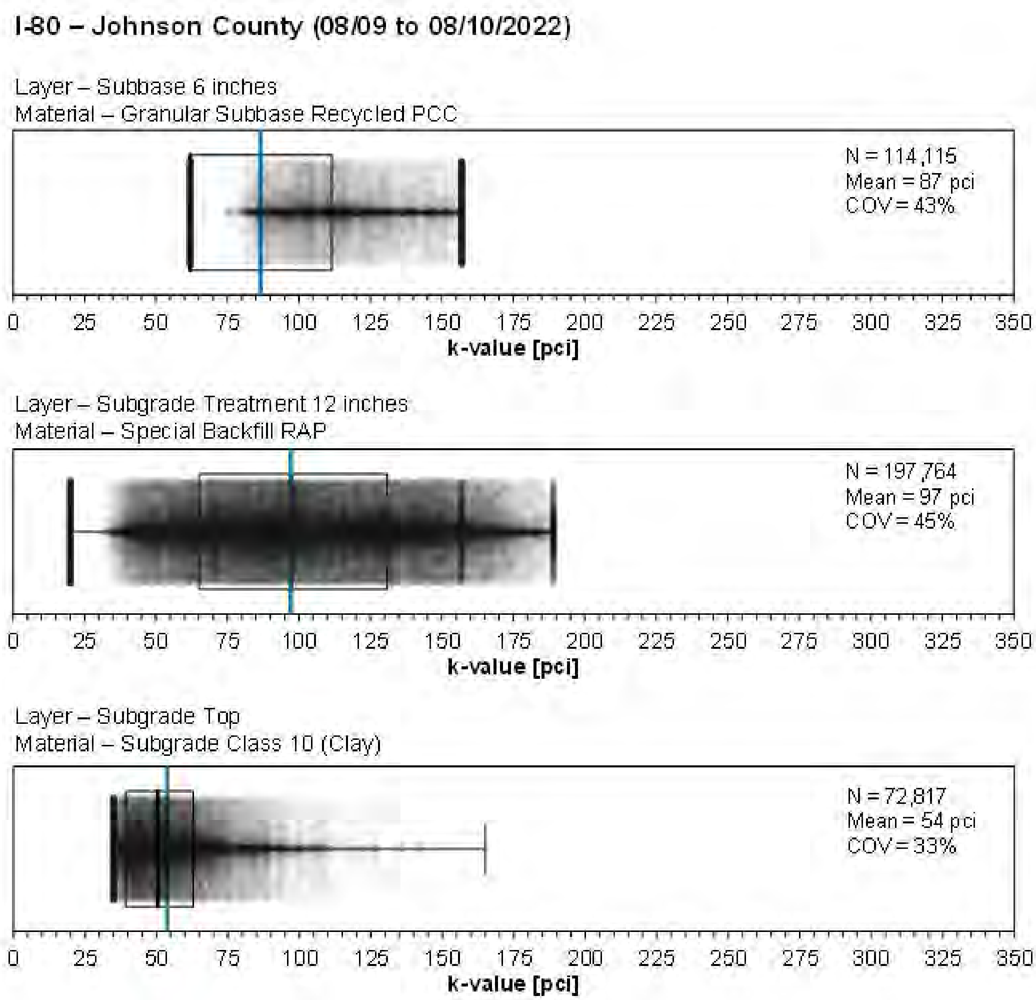

Figure 24. Box plots of k-value for the project materials (I-80 – Johnson County).

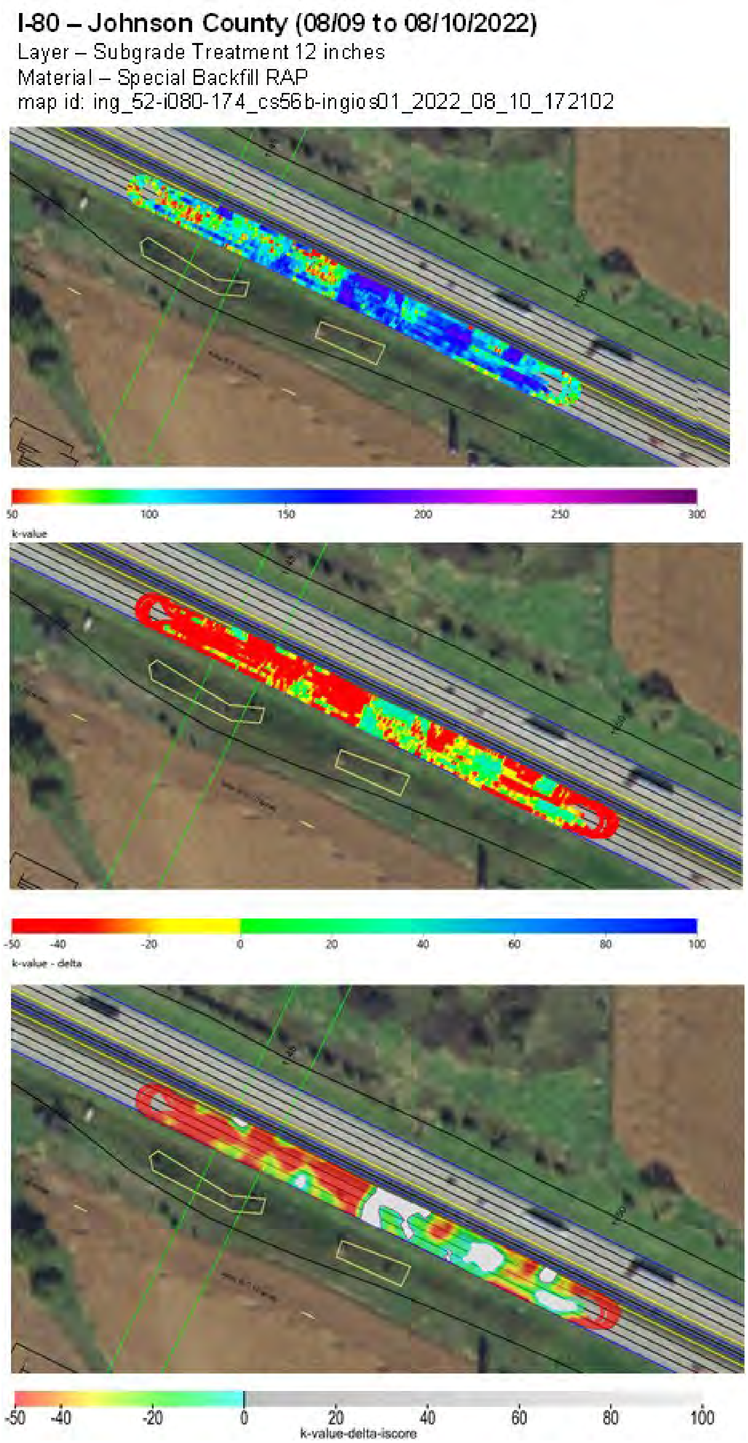

Figure 25. e-Compaction Map Results Showing Areas Meeting or Exceeding Target k-values.

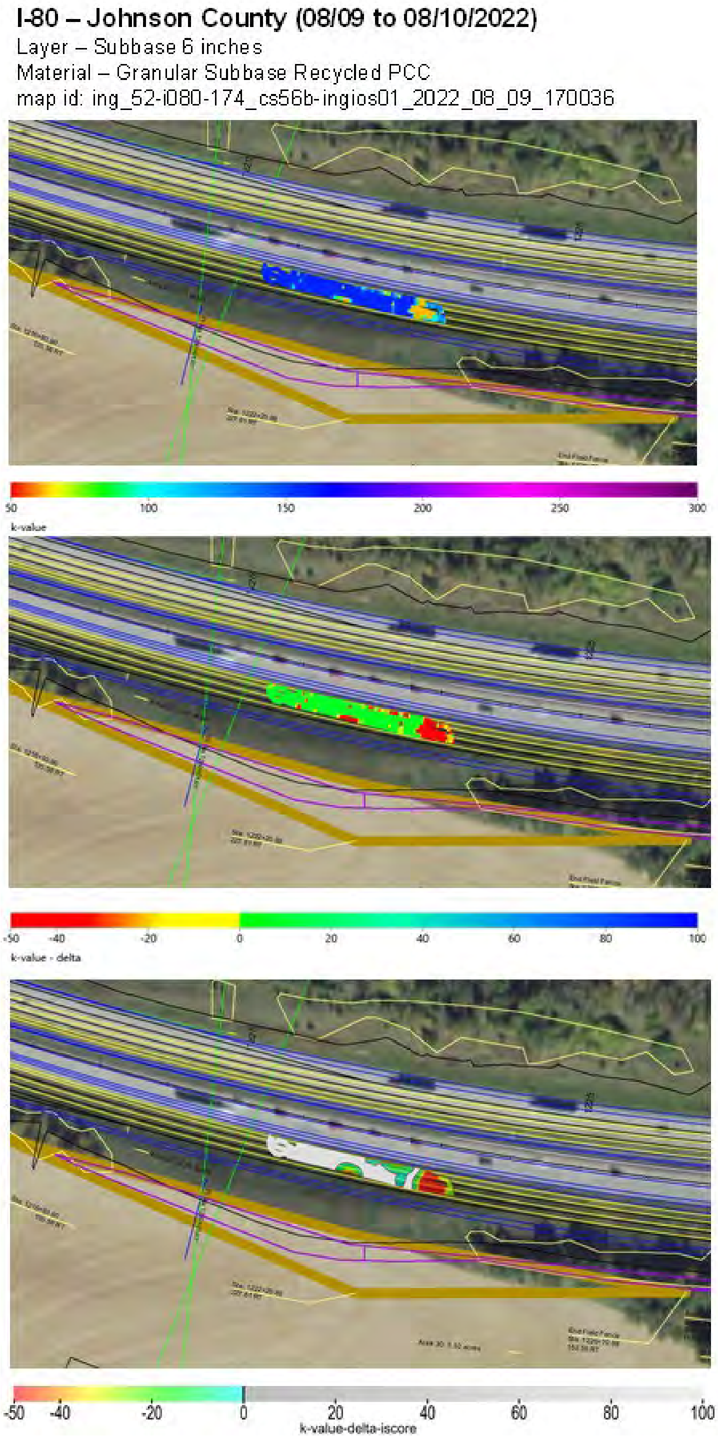

Figure 26. e-Compaction Map Results Showing Areas Meeting or Exceeding Target k-values.

I-380 Linn County

This project consisted of constructing a new interchange at Tower Terrace Road and Interstate 380. Mapping was performed on Tower Terrace Road and Ramp C on 8/25/22 and 8/26/22. A total of nine e-Compaction reports were generated, as summarized in Table 3. Project materials mapped included modified subbase recycled composite on Tower Terrace Road (typical cross section in Figure 27) and subgrade class 10 (sand) on Ramp C (typical cross section in Figure 18). The top of the 12-inch modified subbase on Tower Terrace Road and the top of subgrade was mapped on Ramp C. Site conditions on Ramp C during the days of mapping can be seen in the photo in Figure 29. Box plots of k-values for all project materials are displayed in Figure 30. Example e-Compaction map results on Tower Terrace Road can be seen in Figure 31. Refer to Appendix B for all e-Compaction reports generated on this project.

Additionally, compaction curve mapping was completed on this project on both Tower Terrace Road and Ramp C. This mapping consisted of an additional 16 passes with the smooth drum vibratory roller to evaluate the influence of additional compaction on k-value. Figure 32 and Figure 34 present the compaction curves for Ramp C top of subgrade and Tower Terrace Road top of subbase 12 inches, respectively. Each plot indicates no significant increase in k-value with additional passes. Site conditions during compaction curve mapping are shown in the photos in Figure 33 and Figure 35.

Key findings from the e-Compaction reports and compaction curve analysis completed at the Linn County project include:

- A total of 255,792 SF of pavement foundation area was mapped in approximately 4 hours.
- Nine e-Compaction reports were generated.
- Two different material layers were mapped.
- Two different material types were mapped.
- Average k-values for pavement foundations ranged from 37.7 to 130.4 psi/in.
- None of the maps had areas greater than 80% meeting or exceeding the target k-value
- No increase in k-value was seen with additional compaction passes

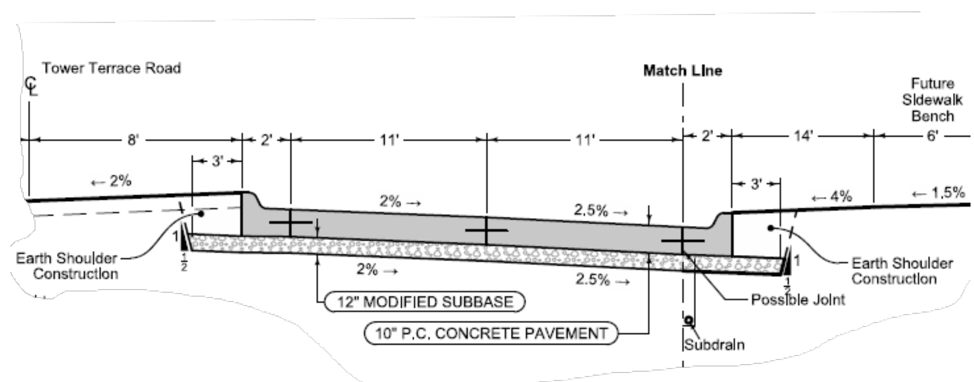

Figure 27. Tower Terrace Road Typical Cross Section.

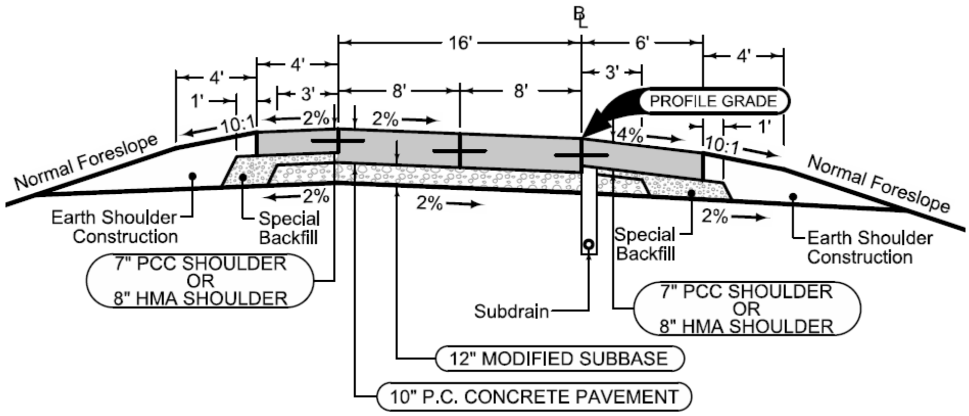

Figure 28. Ramp C Typical Cross Section.

Table 3. Summary of e-Compaction Reports, I-380 Linn County, IA.

Linn County, IA (57-I380-200)

Map Start Date	Map ID	Mapping Duration (hrs)	Area Mapped (sq. ft.)	Layer	Material Type	Average k-value	% Passing	COV %	# of Blobs	Total Blob Area (sq. ft.)
8/25/2022	ing_57-i380-200_cs56b-ingios01_2022_08_25_174134	0.03	4,067	Subgrade Top	Subgrade_Class 10 (Sand)_IADOT	37.70	0.00	11.90	1	4,067
8/26/2022	ing_57-i380-200_cs56b-ingios01_2022_08_26_073228	0.43	33,005	Subgrade Top	Subgrade_Class 10 (Sand)_IADOT	54.20	4.20	37.30	1	32,578
8/26/2022	ing_57-i380-200_cs56b-ingios01_2022_08_26_080109	0.53	46,071	Subgrade Top	Subgrade_Class 10 (Sand)_IADOT	43.50	0.30	25.60	1	46,071
8/26/2022	ing_57-i380-200_cs56b-ingios01_2022_08_26_085116	0.43	40,861	Subbase 12 Inches	Modified Subbase Recycled Composite_IADOT	130.40	33.90	29.10	3	28,960
8/26/2022	ing_57-i380-200_cs56b-ingios01_2022_08_26_092036	0.75	63,616	Subbase 12 Inches	Modified Subbase Recycled Composite_IADOT	111.70	18.60	37.00	1	55,871
8/26/2022	ing_57-i380-200_cs56b-ingios01_2022_08_26_100736	1.19	63,400	Subbase 12 Inches	Modified Subbase Recycled Composite_IADOT	124.70	29.50	31.40	3	50,197
8/26/2022	ing_57-i380-200_cs56b-ingios01_2022_08_26_120258	0.03	1,539	Subgrade Top	Subgrade_Class 10 (Sand)_IADOT	59.00	6.90	43.50	1	1,124
8/26/2022	ing_57-i380-200_cs56b-ingios01_2022_08_26_120728	0.23	1,785	Subgrade Top	Subgrade_Class 10 (Sand)_IADOT	58.10	8.80	40.40	1	1,764
8/26/2022	ing_57-i380-200_cs56b-ingios01_2022_08_26_133014	0.17	1,448	Subbase 12 Inches	Modified Subbase Recycled Composite_IADOT	87.90	0.00	34.40	1	1,448

Figure 29. Photo of mapping on Subgrade (Sand) on I-380 Ramp C.

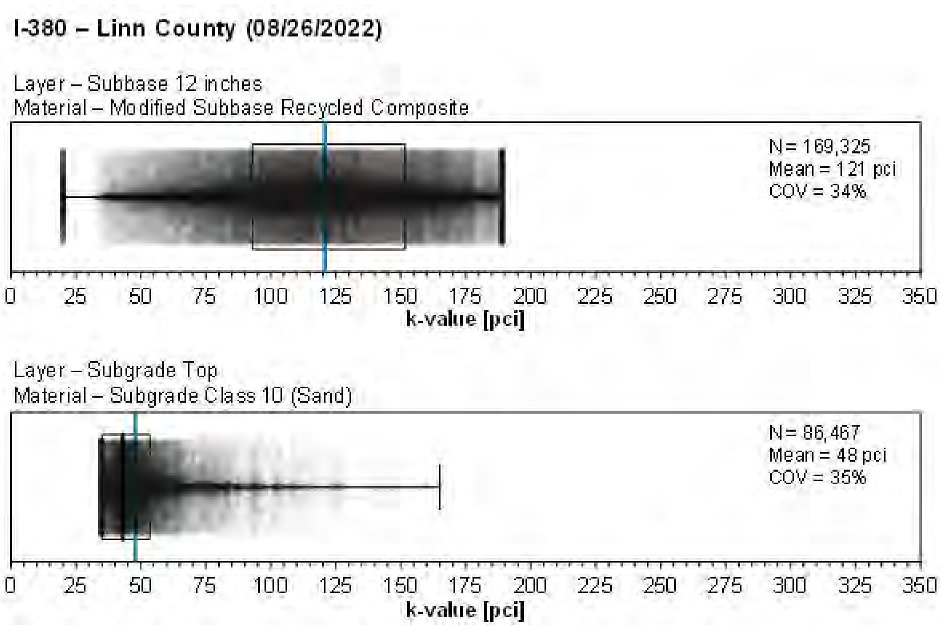

Figure 30. Box plots of k-value for the project materials (I-380 – Linn County)

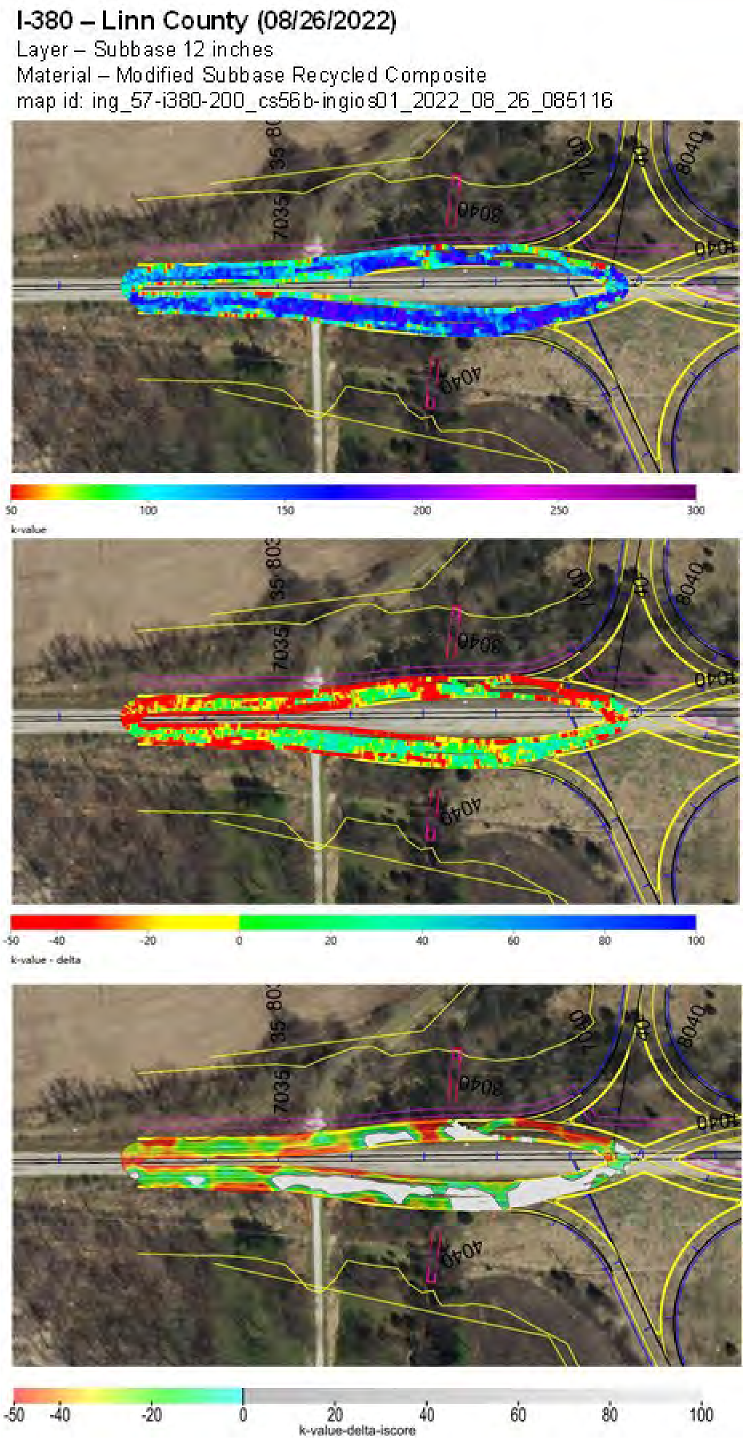

Figure 31. e-Compaction Map Results on Tower Terrace Road.

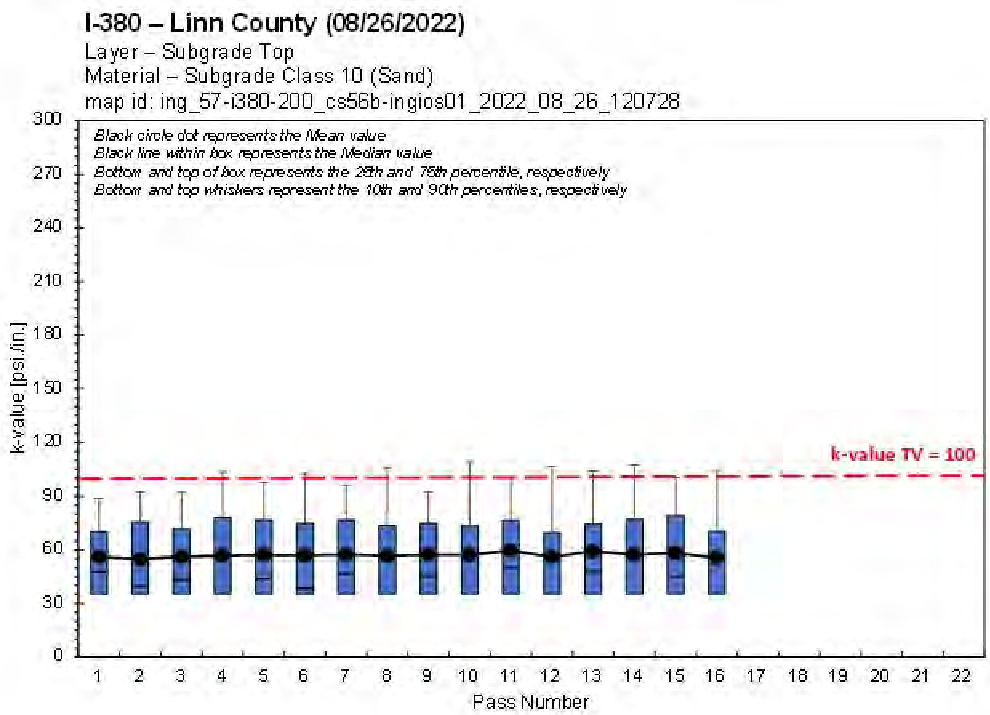

Figure 32. Compaction curve for top of subgrade on Ramp C.

Figure 33. Photo of Subgrade (Sand) on I-380 Ramp C at location of compaction curve mapping.

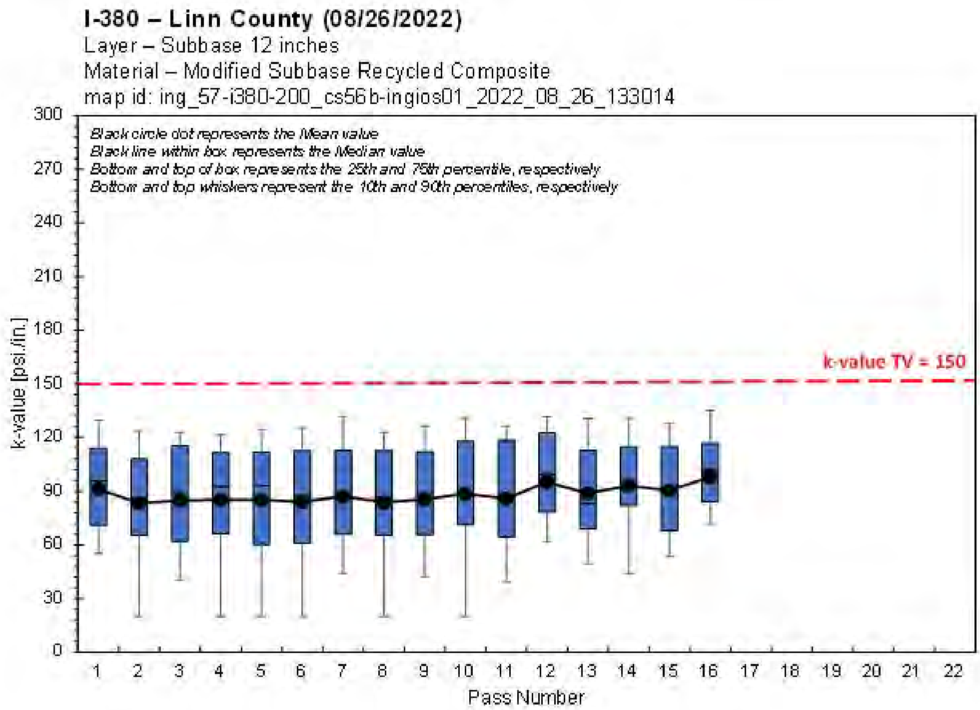

Figure 34. Compaction curve for Modified Subbase Recycled Composite on Tower Terrace Road.

Figure 35. Photo showing Modified Subbase Recycled Composite material on Tower Terrace Road at location of compaction curve mapping.

US 30 Tama County

This project consisted of new construction of two lanes on US 30 from west of IA 21 to 11th Avenue Drive in Tama County, Iowa. Mapping was performed on US 30 WB on 09/09/22 from approximate station 707+00 to 739+50. A total of six e-Compaction reports were generated, as summarized in Table 4. The material mapped was select soil subgrade treatment class 10 as shown in the typical cross section in Figure 36. Site conditions during mapping on the top of the select soil subgrade treatment can be seen in the photo in Figure 37. Box plots of k-values are displayed in Figure 38. Example e-Compaction map results on US 30 can be seen in Figure 39. Refer to Appendix C for all e-Compaction reports generated on this project.

Key findings from the e-Compaction reports completed at the Tama County project include:

- A total of 148,217 SF of pavement foundation area was mapped in approximately 2.2 hours.
- Six e-Compaction reports were generated.
- One material layer was mapped.
- One material type was mapped.
- Average k-values for pavement foundations ranged from 55.6 to 69.2 psi/in.
- None of the maps had areas greater than 80% meeting or exceeding the target k-value

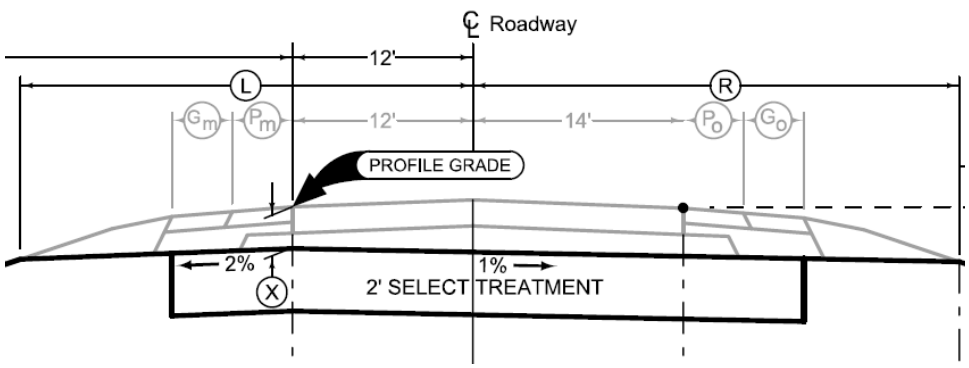

Figure 36. US-30 Grading Typical Cross Section.

Table 4. Summary of e-Compaction Reports, US 30 Tama County, IA.

Tama County, IA (86-US030-240)

Map Start Date	Map ID	Mapping Duration (hrs)	Area Mapped (sq. ft.)	Layer	Material Type	Average k-value	% Passing	COV %	# of Blobs	Total Blob Area (sq. ft.)
9/9/2022	ing_86-us030-240_cs56b-ingios01_2022_09_09_091716	0.12	13,336	Subgrade Treatment 24 inches	Subgrade_Treatment Select Cohesive_IADOT	69.20	0.60	27.20	2	13,336
9/9/2022	ing_86-us030-240_cs56b-ingios01_2022_09_09_114151	0.43	29,449	Subgrade Treatment 24 inches	Subgrade_Treatment Select Cohesive_IADOT	55.60	0.10	28.60	1	29,449
9/9/2022	ing_86-us030-240_cs56b-ingios01_2022_09_09_121304	0.43	28,955	Subgrade Treatment 24 inches	Subgrade_Treatment Select Cohesive_IADOT	64.70	0.30	35.30	1	28,955
9/9/2022	ing_86-us030-240_cs56b-ingios01_2022_09_09_124411	0.43	28,456	Subgrade Treatment 24 inches	Subgrade_Treatment Select Cohesive_IADOT	64.50	0.00	29.30	1	28,456
9/9/2022	ing_86-us030-240_cs56b-ingios01_2022_09_09_131333	0.50	27,752	Subgrade Treatment 24 inches	Subgrade_Treatment Select Cohesive_IADOT	58.50	0.00	30.60	1	27,738
9/9/2022	ing_86-us030-240_cs56b-ingios01_2022_09_09_135130	0.31	20,269	Subgrade Treatment 24 inches	Subgrade_Treatment Select Cohesive_IADOT	57.10	0.00	30.00	1	20,269

Figure 37. Photo of US 30 Top of 24 Inch Select Soil Subgrade Treatment.

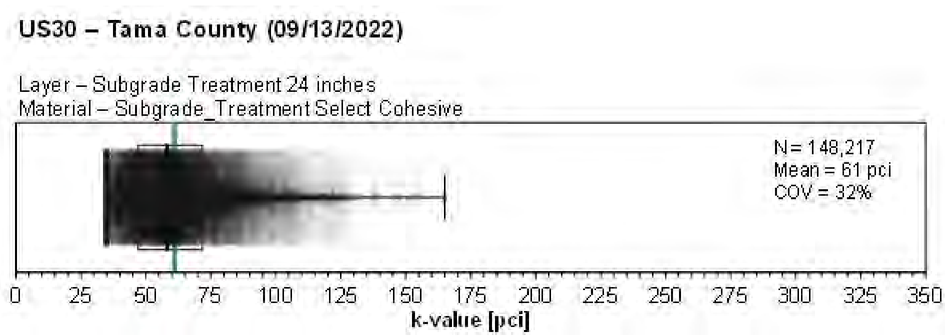

Figure 38. Box plots of k-value for the project materials (US30 – Tama County).

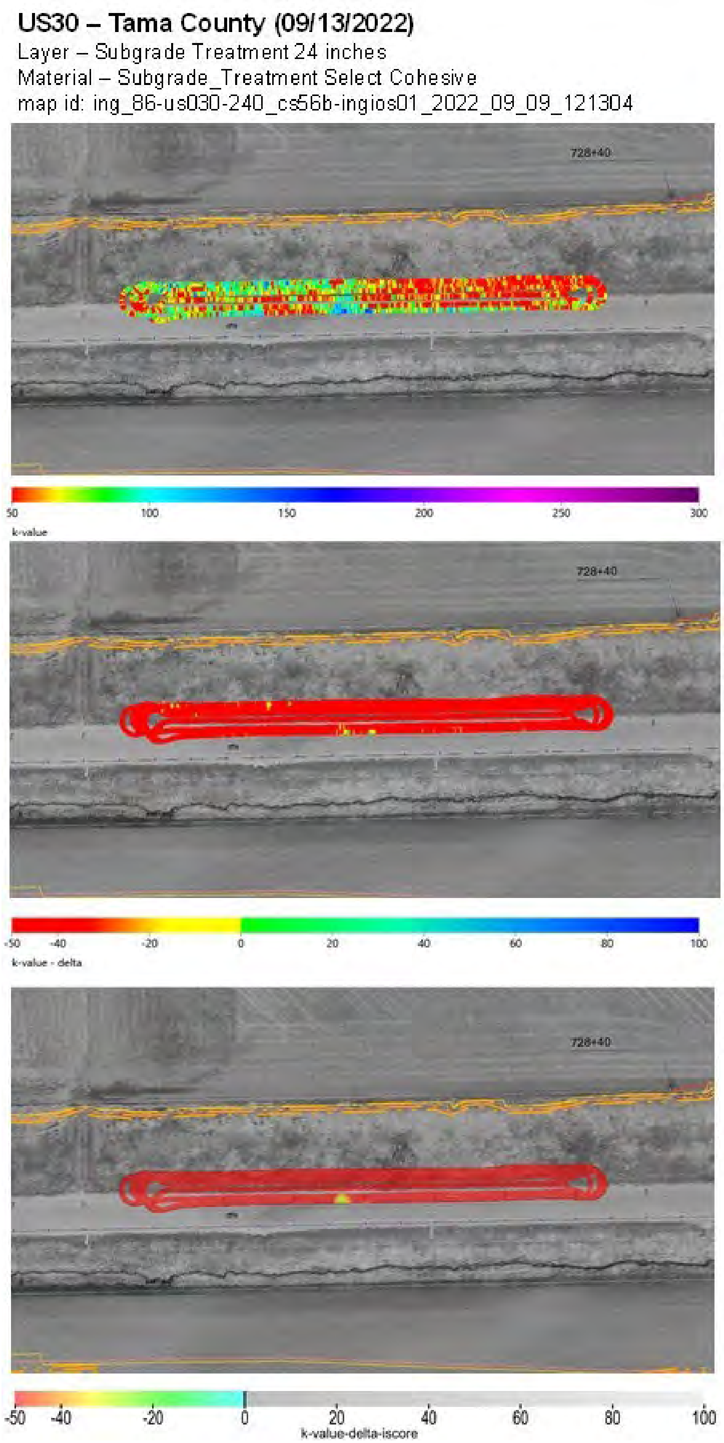

Figure 39. e-Compaction Map Results on US 30.

US 218 Floyd County

This project consisted of reconstruction of US 18 and constructing a new interchange at US 18 and County Road T-44 in Floyd County, Iowa. Mapping was performed on US 18 EB, Ramp A, Ramp C and county road T-44 on 09/13/22. A total of nine e-Compaction reports were generated, as summarized in Table 5. Project materials mapped included modified subbase recycled PCC on US 18 from approximate station 13390+50 to 13457+00 (typical cross section in Figure 40), modified subbase recycled PCC on Ramp A and Ramp C (typical cross section in Figure 41), subgrade class 10 clay on Ramp A, and subgrade class 10 clay on T-44 (typical cross section in Figure 42). Site conditions on Ramp C during mapping can be seen in the photo in Figure 43. Site conditions during mapping on US 18 can be seen in Figure 44. Box plots of k-values for all project materials are displayed in Figure 45. Example e-Compaction map results on County Road T-44 can be seen in Figure 46. Refer to Appendix D for all e-Compaction reports generated on this project.

Key findings from the e-Compaction reports completed at the Floyd County project include:

- A total of 230,612 SF of pavement foundation area was mapped in approximately 2.6 hours.
- Nine e-Compaction reports were generated.
- Three different material layers were mapped.
- Two different material types were mapped.
- Average k-values for pavement foundations ranged from 72.3 to 180.0 psi/in.
- 1 of 9 maps had areas greater than 80% meeting or exceeding the target k-value

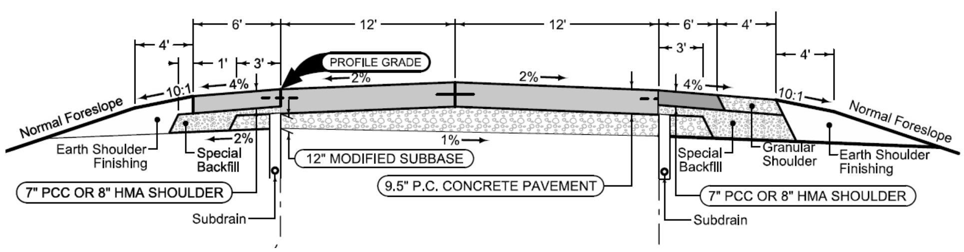

Figure 40. US 18 EB Paving Typical Cross Section

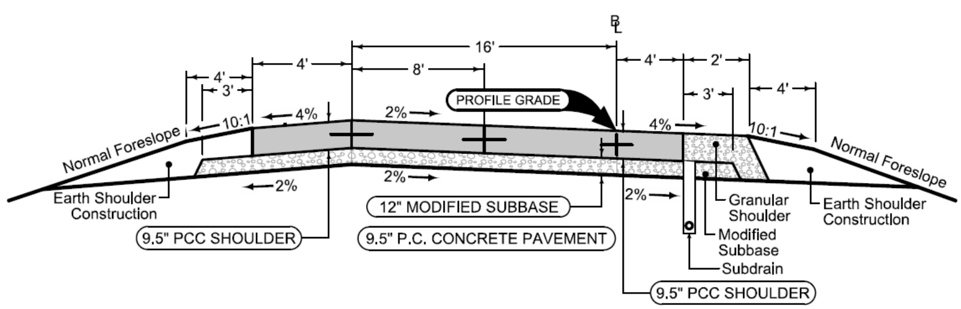

Figure 41. Ramp A and C Paving Typical Cross Section

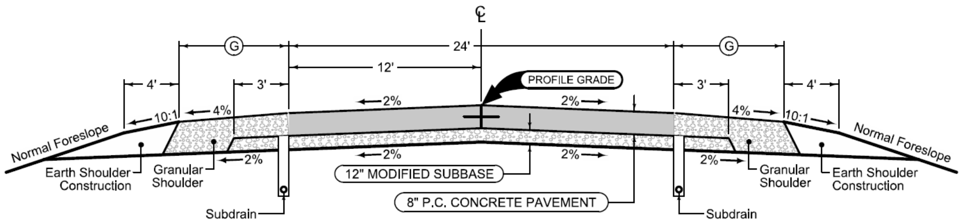

Figure 42. County Rd T-44 Paving Typical Cross Section

Table 5. Summary of e-Compaction Reports, US 218 Floyd County, IA.

Floyd County, IA (34-US018-95)

Map Start Date	Map ID	Mapping Duration (hrs)	Area Mapped (sq. ft.)	Layer	Material Type	Average k-value	% Passing	COV %	# of Blobs	Total Blob Area (sq. ft.)
9/13/2022	ing_34-us018-95_cs56b-ingios01_2022_09_13_171447	0.47	26,741	Subgrade Top	Subgrade_Class 10 (Clay)_IADOT	77.20	24.10	45.80	2	21,471
9/13/2022	ing_34-us018-95_cs56b-ingios01_2022_09_13_174743	0.14	15,649	Subbase 6 Inches	Modified Subbase Recycled PCC_IADOT	106.90	14.30	34.60	1	14,462
9/13/2022	ing_34-us018-95_cs56b-ingios01_2022_09_13_175636	0.16	16,607	Subbase 6 Inches	Modified Subbase Recycled PCC_IADOT	128.80	21.90	23.10	2	15,038
9/13/2022	ing_34-us018-95_cs56b-ingios01_2022_09_13_181358	0.28	24,582	Subbase 12 Inches	Modified Subbase Recycled PCC_IADOT	152.50	60.60	21.00	1	5,918
9/13/2022	ing_34-us018-95_cs56b-ingios01_2022_09_13_183704	0.33	34,058	Subbase 12 Inches	Modified Subbase Recycled PCC_IADOT	180.00	91.90	10.10	0	-
9/13/2022	ing_34-us018-95_cs56b-ingios01_2022_09_13_185855	0.57	59,877	Subbase 12 Inches	Modified Subbase Recycled PCC_IADOT	152.30	55.00	17.60	5	20,825
9/13/2022	ing_34-us018-95_cs56b-ingios01_2022_09_13_193920	0.14	10,494	Subgrade Top	Subgrade_Class 10 (Clay)_IADOT	72.30	19.20	48.30	2	9,054
9/13/2022	ing_34-us018-95_cs56b-ingios01_2022_09_13_195606	0.23	18,468	Subbase 6 Inches	Modified Subbase Recycled PCC_IADOT	111.60	14.10	30.50	3	16,356
9/13/2022	ing_34-us018-95_cs56b-ingios01_2022_09_13_201226	0.25	24,136	Subbase 12 Inches	Modified Subbase Recycled PCC_IADOT	134.20	26.20	16.50	3	18,903

Figure 43. Photo showing mapping of Subgrade Class 10 (Clay) on Ramp C.

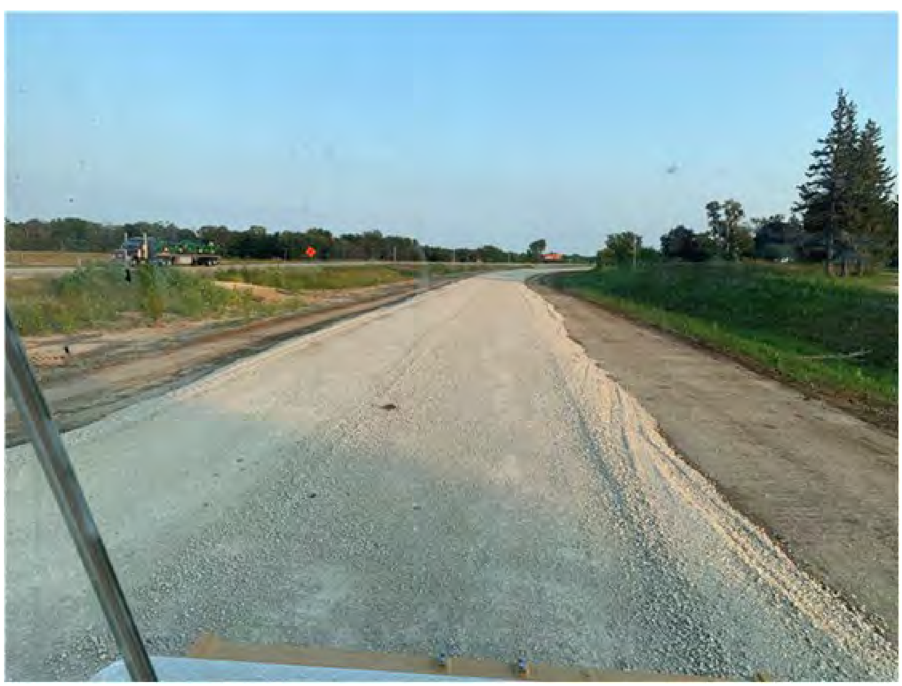

Figure 44. Photo showing mapping of Modified Subbase Recycled PCC on Eastbound Mainline.

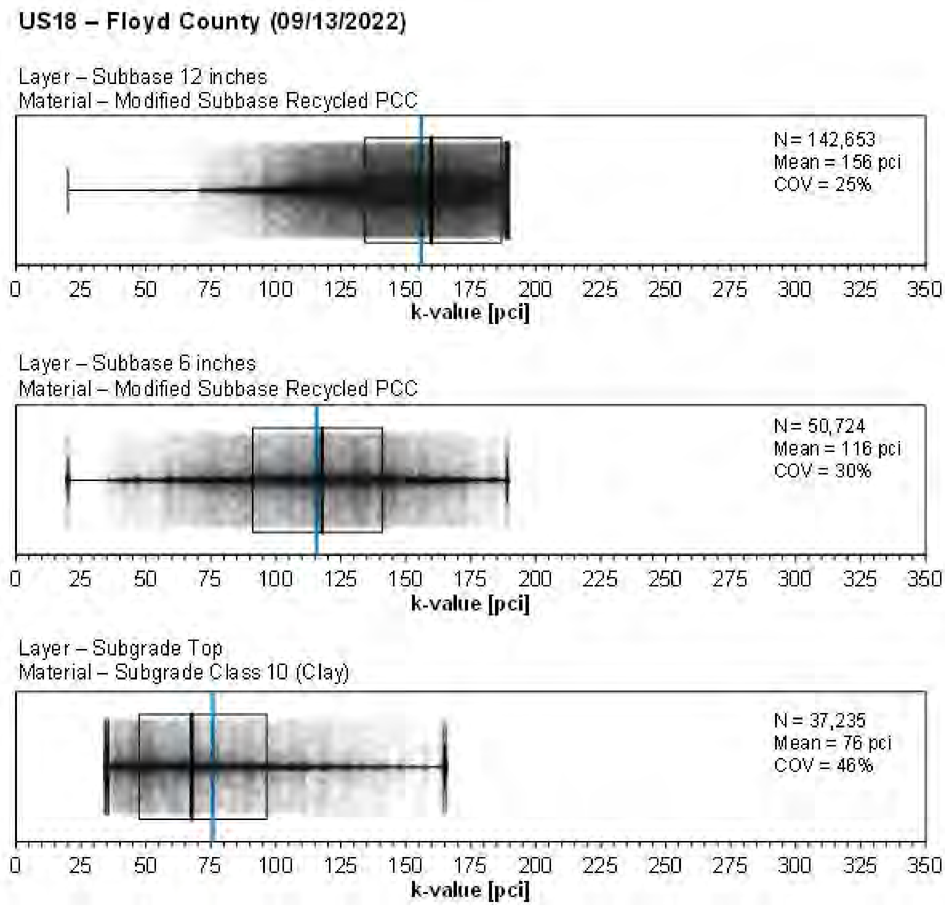

Figure 45. Box plots of k-value for the project materials (US18 – Floyd County).

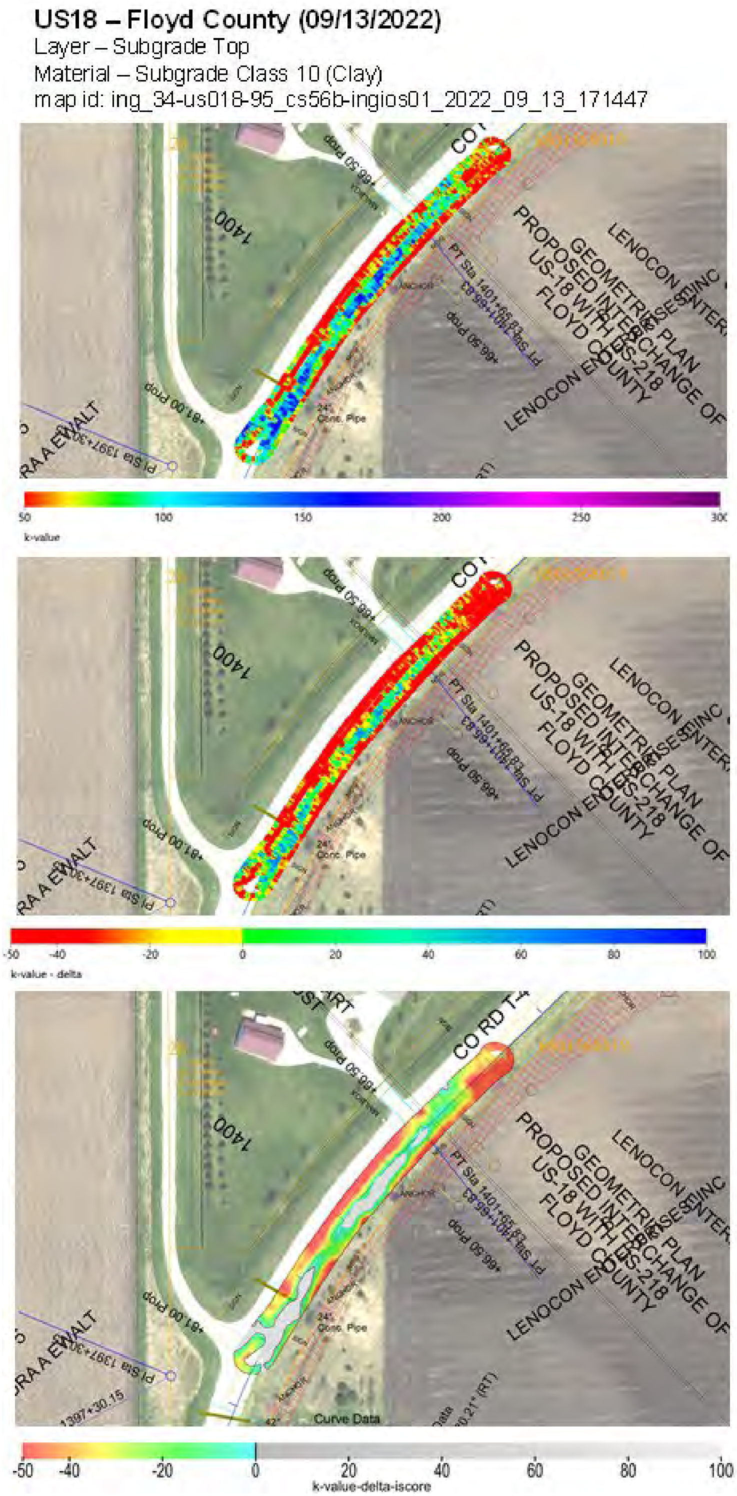

Figure 46. e-Compaction Map Results on County Road T-44.

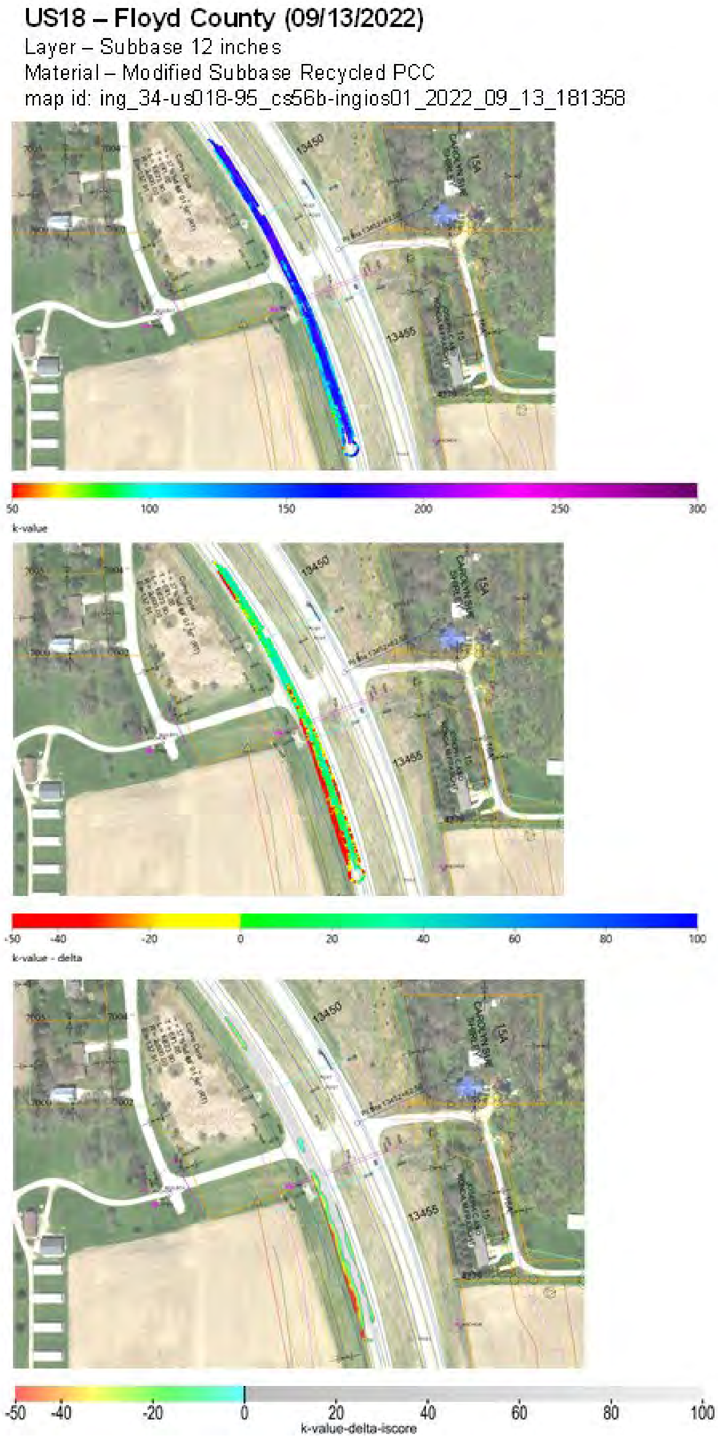

Figure 47. e-Compaction Map Results on US 18.

I-29 Pottawattamie County

This project consisted of reconstruction of County Road G12 at the interchange with I-29 in Pottawattamie County, Iowa. Mapping was performed on County Road G12 on 10/26/22. The east bridge approach embankment was available on the day of mapping. The same area was mapped twice to evaluate consistency in the map data. Two e-Compaction reports were generated, as summarized in Table 6. The project material mapped was the top of subgrade class 10 clay (typical cross section is shown in Figure 48). Site conditions on county road G12 during mapping can be seen in the photo in Figure 49 and Figure 50. Box plots of k-values are displayed in Figure 51. Example e-Compaction map results on County Road G12 can be seen in Figure 52. Refer to Appendix E for all e-Compaction reports generated on this project.

Key findings from the e-Compaction reports completed at the Pottawattamie County project include:

- A total of 27,202 SF of pavement foundation area was mapped in approximately 0.5 hours.
- Two e-Compaction reports were generated.
- One material layer was mapped.
- One material type was mapped.
- Average k-values for pavement foundations ranged from 90.0 to 94.1 psi/in. Indicating consistency and repeatability in the k-value measurements
- None of the maps had areas greater than 80% meeting or exceeding the target k-value

Comp-Score® INSPECTOR was utilized on this project to solicit feedback from the Iowa DOT inspector on the project. After mapping was complete, the map was uploaded to the tablet and shared with the inspector. After review of the map and geo-location, a clear boundary could be seen in the map (See Figure 52): the west side of the approach embankment exhibited higher k-values than the east side. Discussion with the inspector while viewing Comp-Score® INSPECTOR (Figure 53) revealed that moisture content of the borrow materials was different between these two areas. The east end of the fill was within specification for moisture content when it was placed. Therefore, it was placed, compacted, and approved after the minimum number of passes. The materials for the west end of the approach embankment were higher than specified when placed. Multiple rounds of scarification, drying, and re-compacting were required before this area was within the moisture content specification.

The e-Compaction map data reflected the additional compaction effort placed into the west end of the approach embankment vs those on the east end. For the material on this project, this indicated that proper moisture conditioning, combined with additional compaction, could achieve the required k-value of 150 psi/in.

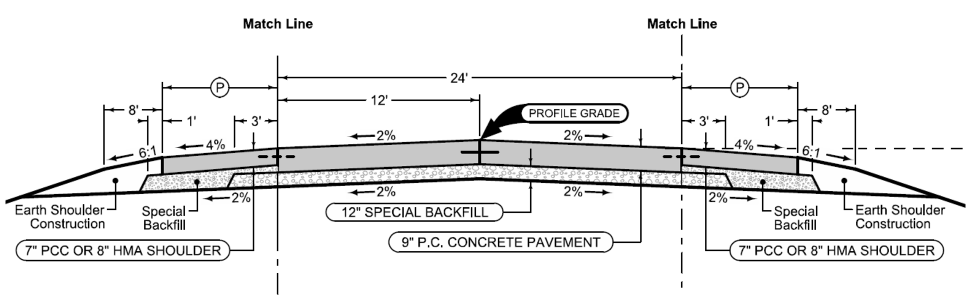

Figure 48. County Rd G12 Paving Typical Cross Section

Table 6. Summary of e-Compaction Reports, I-29 Pottawattamie County, IA.

Pottawattamie County, IA (78-I029-112)

Map Start Date	Map ID	Mapping Duration (hrs)	Area Mapped (sq. ft.)	Layer	Material Type	Average k-value	% Passing	COV %	# of Blobs	Total Blob Area (sq. ft.)
10/26/2022	ing_78-i029-112_cs56b-ingios01_2022_10_26_111637	0.19	13,281	Subgrade Top	Subgrade_Class 10 (Clay)_IADOT	90.00	32.20	41.60	1	8,278
10/26/2022	ing_78-i029-112_cs56b-ingios01_2022_10_26_113325	0.27	13,921	Subgrade Top	Subgrade_Class 10 (Clay)_IADOT	94.10	37.30	43.90	1	8,196

Figure 49. Photo showing east side approach embankment on G12.

Figure 50. Photo showing east side approach embankment on G12.

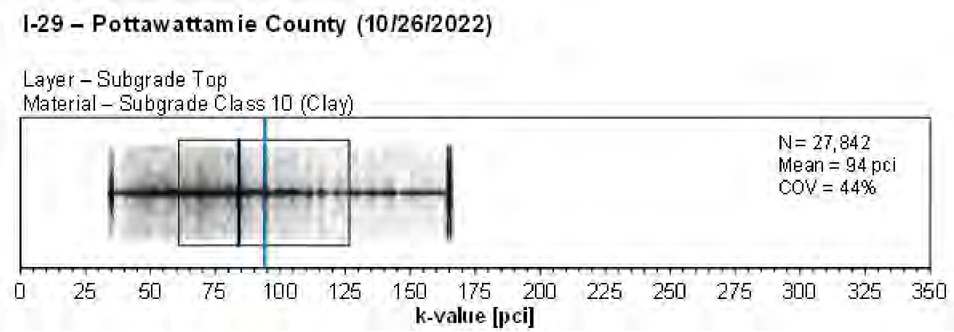

Figure 51. Box plots of k-value for the project materials (I-29 – Pottawattamie County).

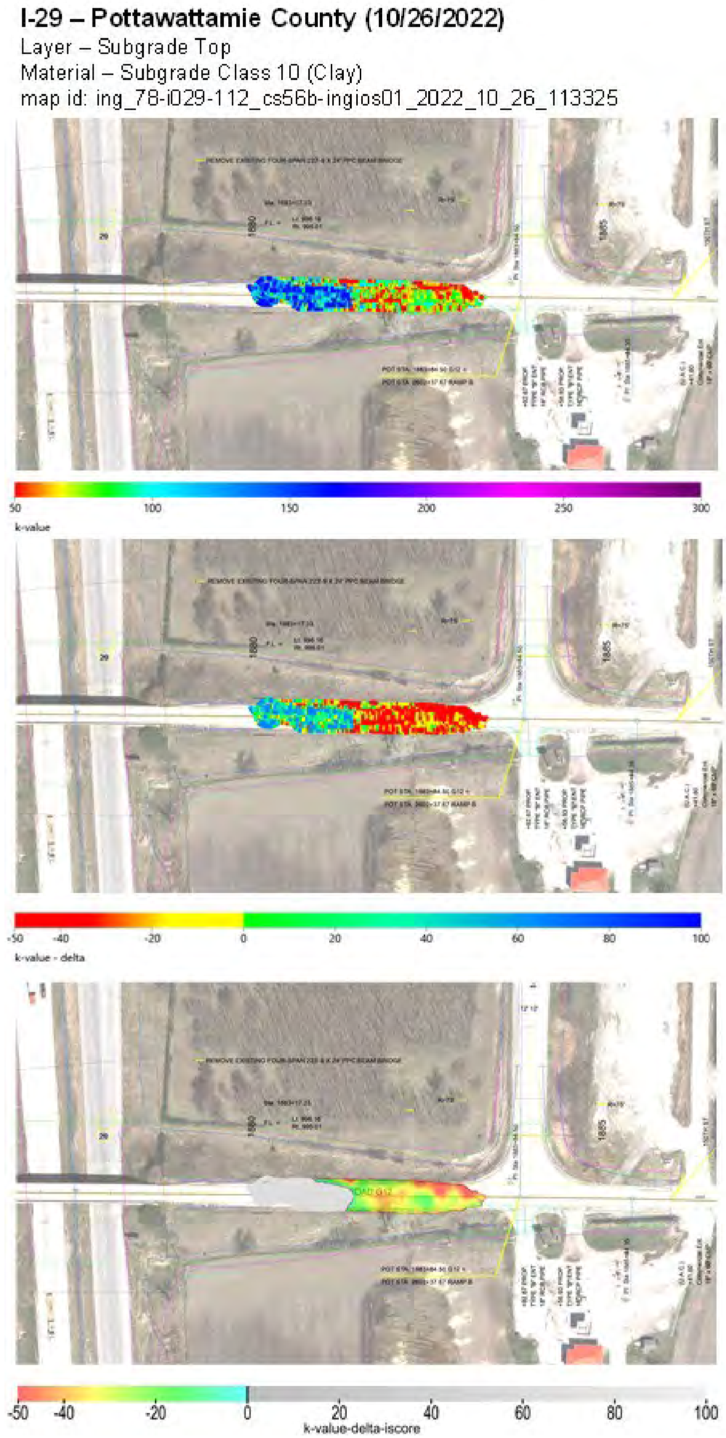

Figure 52. e-Compaction Map Results on County Road G12.

Figure 53. Photo showing Iowa DOT inspector moving around to viewing map data using Comp-Score INSPECTOR.

APPENDICES (A TO E)

Appendix A: Johnson County, IA (52-I080-174)

Appendix B: Linn County, IA (57-I380-200)

Appendix C: Tama County, IA (86-US030-240)

Appendix D: Floyd County, IA (34-US018-95)

Appendix E: Pottawattamie County, IA (78-I029-112)

Appendix A: Johnson County, IA (52-I080-174)

- ing_52-i080-174_cs56b-ingios01_2022_08_09_170036
- ing_52-i080-174_cs56b-ingios01_2022_08_09_171152
- ing_52-i080-174_cs56b-ingios01_2022_08_09_173544
- ing_52-i080-174_cs56b-ingios01_2022_08_09_175350
- ing_52-i080-174_cs56b-ingios01_2022_08_09_180902
- ing_52-i080-174_cs56b-ingios01_2022_08_09_181750
- ing_52-i080-174_cs56b-ingios01_2022_08_09_182712
- ing_52-i080-174_cs56b-ingios01_2022_08_09_190557
- ing_52-i080-174_cs56b-ingios01_2022_08_09_192938
- ing_52-i080-174_cs56b-ingios01_2022_08_09_194641
- ing_52-i080-174_cs56b-ingios01_2022_08_09_195429
- ing_52-i080-174_cs56b-ingios01_2022_08_10_125633
- ing_52-i080-174_cs56b-ingios01_2022_08_10_131843
- ing_52-i080-174_cs56b-ingios01_2022_08_10_134821
- ing_52-i080-174_cs56b-ingios01_2022_08_10_142134
- ing_52-i080-174_cs56b-ingios01_2022_08_10_162950
- ing_52-i080-174_cs56b-ingios01_2022_08_10_172102