Concrete Overlay Performance on Iowa's Roadways

Field Data Report
July 2017

National Concrete Pavement Technology Center




IOWA STATE UNIVERSITY
Institute for Transportation

Sponsored by
Iowa Highway Research Board
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Iowa Department of Transportation
(InTrans Project 15-559)

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16. Abstract

Pavement preservation and rehabilitation have been growing in importance nationwide, which has led to increased interest in concrete overlays. The objective of this study was to develop a report on the performance of concrete overlays in Iowa.

Pavement condition data such as the international roughness index (IRI), transverse cracking, longitudinal cracking, D-cracking, spalled joints, and faulting has been collected on Iowa roadways since 2002. From this data, a determination of the pavement condition index (PCI) is made.

By comparing key concrete overlay parameters, such as overlay type, thickness, age, and joint spacing, with IRI and PCI performance data, long-term performance trends can be established to complete the first major concrete overlay performance study of its kind.

A summary of results showed that Iowa's overlays performed very well, with service life trends exceeding previously defined expectations for concrete overlays. Further investigation of outlying data from poorly performing projects showed distress tended to be based on a combination of project-specific material- and construction-related issues rather than inherent overlay design issues. Addressing the causes of these issues may further improve the performance life of concrete overlays.

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CONCRETE OVERLAY PERFORMANCE ON IOWA'S ROADWAYS

Field Data Report
July 2017

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This project was sponsored by the Iowa Highway Research Board and the Iowa Department of Transportation (DOT). The Iowa Concrete Paving Association partnered with the National Concrete Pavement Technology Center on this project.

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EXECUTIVE SUMMARY

Problem Statement

Concrete overlays are a cost-effective, low-maintenance preservation technique used to extend pavement life. However, there have been few comprehensive studies of long-term performance of concrete overlays.

Project Objective

The objective of this project was to determine the performance of concrete overlays on Iowa's roadways. The long history of concrete overlay construction in Iowa coupled with the availability of performance data presents the opportunity for a comprehensive, long-term performance study of concrete overlays.

Background

Pavement preservation and rehabilitation have been growing in importance nationwide, leading to increased interest in concrete overlays. This study was necessary to evaluate the performance of concrete overlays as well as understand lessons learned and determine reasons for success.

Research Description and Methodology

The National Concrete Pavement Technology (CP Tech) Center partnered with the Iowa Concrete Paving Association (ICPA) and the Iowa Department of Transportation (DOT) on this project.

The Iowa DOT collects pavement condition data including international roughness index (IRI), transverse cracking, longitudinal cracking, D-cracking, spalled joints, and faulting. Data collection on all paved secondary roads began in 2002; since 2013, data collection has occurred on every paved public roadway in Iowa.

The Institute for Transportation (InTrans) at Iowa State University manages the pavement condition data as part of the Iowa Pavement Management Program (IPMP). The ICPA has an extensive database of historical information for overlays constructed within Iowa.

Four overlay types were studied: unbonded and bonded concrete overlays on concrete and on asphalt (UBCOC, BCOC, UBCOA, and BCOA, respectively). Concrete overlays on composite pavements were included in the BCOA and UBCOA categories.

A majority (94%) of Iowa's overlays were constructed on secondary roads. A majority (87%) of these overlays are traveled by 2,000 or fewer vehicles per day.

For this study, the researchers analyzed concrete overlay performance using the pavement condition index (PCI) from the IPMP and the IRI. The research included PCI and IRI performance data from 384 concrete overlays on 1,493 miles of roadway and encompassing 14 years of data collection.

Key Findings

In the early years of development and implementation of concrete overlays, expected service life was approximately 20 years (McGhee 1994). The results of this study developed by a review of the performance data showed that concrete overlays in Iowa exceed this service life. Key findings include the following:

- 89% of all concrete overlays had a PCI of 60+ (good to excellent)
- Overlays on asphalt generally performed better than overlays on concrete
- 93% of all concrete overlays had an IRI of 170 in/mi (the Federal Highway Administration upper threshold limit for acceptable ride quality) and below
- Among overlays on concrete, UBCOCs performed better than BCOCs (90% of UBCOCs were in good to excellent condition while 72% of BCOCs were in good to excellent condition)
- Among overlays on asphalt, UBCOAs performed slightly better than BCOAs (94% of UBCOAs were in good to excellent condition while 88% of BCOAs were in good to excellent condition)
- With respect to PCI values, analysis of the complete concrete overlay data set showed that a majority of projects were on track to achieve good performance (PCI=60) or better during the first 35 years of service life
- With respect to IRI values, analysis of the complete concrete overlay data set showed that most projects were on track to maintain adequate ride quality (IRI=170 in/mi) or better during the first 37 years of service life
- UBCOCs with short joint spacing (i.e., 12- and 15-ft) perform better than those with longer joint spacing (i.e., 20-ft) in terms of IRI
- BCOAs with shorter transverse joint spacing (5.5- and 6-ft) have shown better performance compared to 12-, 15-, and 20-ft joint spacings

- Overlays on asphalt (BCOA and UBCOA) showed PCI trends for 12-ft joint spacing with lower performance than 15- and 20-ft joint spacing

    - Field reviews of a number of Iowa overlays did not find any inherent issue with 12-ft joint spacing that caused those overlays to perform poorer than other joint spacing designs; the reviews discovered the underlying causes of poorer performance to include material-related distresses, deficient thickness, and inadequate system drainage

Implementation Readiness and Benefits

The majority of concrete overlays in Iowa have service life trends exceeding the expectations listed in the National Cooperative Highway Research Program (NCHRP) Synthesis of Highway Practice 204 (McGhee 1994). A majority of projects in the complete overlay data set were on track to achieve a PCI rating of good (PCI=60) or better and a ride quality rating of adequate (IRI=70 in/mi) or better during the first 35 years of service life.

The results of this study are beneficial to the Iowa DOT and local agencies. The results provide definite evidence on a large scale that concrete overlays are a successful preservation technique that can provide extended service lives to roadways in need of rehabilitation.

Future Research

To provide further benefit to the Iowa DOT and local agencies, concrete overlay jointing for thin (4 to 6 in.) overlays can be studied to determine optimum spacing. This will help to determine the most optimum and efficient joint spacing for varying thicknesses and traffic counts, both with and without macro-synthetic fiber reinforcement.

By optimizing the spacing, concrete overlays will be more cost effective and may lead to increased service life. As part of the Iowa Highway Research Board’s IHRB TR-698, Phase 2A and 2B will study optimum joint spacing with emphasis on both analytical investigation and field demonstration.

1. OVERVIEW

Pavement preservation and rehabilitation have been growing in importance nationwide, leading to increased interest in concrete overlays. Concrete overlays are a cost-effective, low-maintenance preservation technique used to extend pavement life. Iowa can be considered a national leader in the use of concrete overlays. Figure 1 shows locations of concrete overlays from the American Concrete Pavement Association (ACPA) Overlay Explorer with an emphasis of projects located in Iowa.

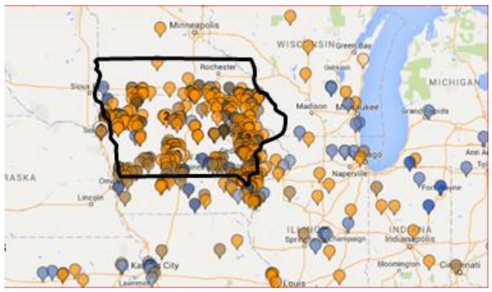


Figure 1. ACPA Overlay Explorer

The types of concrete overlays constructed in Iowa include bonded concrete overlays on asphalt (BCOAs), bonded concrete overlays on concrete (BCOCs), unbonded concrete overlays on asphalt (UBCOAs), and unbonded concrete overlays on concrete (UBCOCs).

There have been few comprehensive studies of long-term performance of all types of concrete overlays. The long history of concrete overlay construction in Iowa, coupled with the availability of performance data, presents the opportunity for the first comprehensive, long-term performance study of concrete overlays.

This study, Concrete Overlay Performance on Iowa's Roadways, provides this evaluation. The Iowa Department of Transportation (DOT) collects pavement condition data such as the international roughness index (IRI), transverse cracking, longitudinal cracking, D-cracking, spalled joints, and faulting. Data collection on all paved secondary roads began in 2002, and since 2013, data collection has occurred on every paved public roadway in Iowa. The Institute for Transportation (InTrans) at Iowa State University manages the pavement condition data as part of the Iowa Pavement Management Program (IPMP). In this study, concrete overlay performance was measured by analyzing the pavement condition index (PCI) and the IRI.

1.1. Concrete Overlay Performance

In the early years of development and implementation of concrete overlays, expected service life was approximately 20 years (McGhee 1994). The results of this study developed by a review of the performance data showed that concrete overlays in Iowa exceed this service life. Results from the study show the following conclusions support the overall good performance of concrete overlays in Iowa:

- 89% of all concrete overlays had a PCI of 60+ (good to excellent). See Figure 2.

- 93% of all concrete overlays had an IRI of 170 in/mi and below. (170 in/mi is the Federal Highway Administration [FHWA] upper threshold limit for acceptable ride quality.) See Figure 3.

- Among overlays on concrete, UBCOCs performed better than BCOCs. (90% of UBCOCs were in good to excellent condition, whereas 72% of BCOCs were in good to excellent condition.) Refer to Table 9.

- Among overlays on asphalt, UBCOAs performed slightly better than BCOAs. (94% of UBCOAs were in good to excellent condition, whereas 88% of BCOAs were in good to excellent condition.) Refer to Table 9.

- With respect to PCI values, analysis of the complete concrete overlay data set showed that a majority of projects were on track to achieve good performance (PCI = 60) or better during the first 35 years of service life. Refer to Figure 12.

- With respect to IRI values, analysis of the complete concrete overlay data set showed that most projects were on track to maintain adequate ride quality (IRI = 170 in/mi) or better during the first 37 years of service life. Refer to Figure 13.

- Higher overlay thickness leads to increased overlay service life in terms of PCI values. This is more evident in UBCOCs. Refer to Figure 48.

- UBCOCs with short joint spacing (i.e., 12 ft and 15 ft) perform better than those with longer joint spacing (i.e., 20 ft.) in terms of IRI values. Refer to Figures 50 and 51.

- Although only in existence since about 2004, BCOAs with shorter transverse joint spacing (5.5 and 6 ft) have shown better performance with respect to PCI and IRI compared to 12-, 15-, and 20-ft spacings. Refer to Figures 54 and 55.

- The PCI values trend line for UBCOAs with 7-in. and 8-in. thicknesses maintained at or above 60 during the first 35 years of service life. Refer to Figure 56.

- Overlays on asphalt (BCOA and UBCOA) show PCI trends for 12-ft joint spacing with lower performance than 15-ft and 20-ft joint spacing. Refer to Figures 54 and 58.

  - Field reviews of a number of Iowa overlays did not find any inherent issue with 12-ft joint spacing that caused those overlays to perform poorer than other joint spacing designs. The field reviews discovered the underlying causes of poorer performance to include material-related distresses (MRDs), deficient thickness, and inadequate system drainage.

Figures 2 and 3 show the PCI and IRI performance results for the complete study.

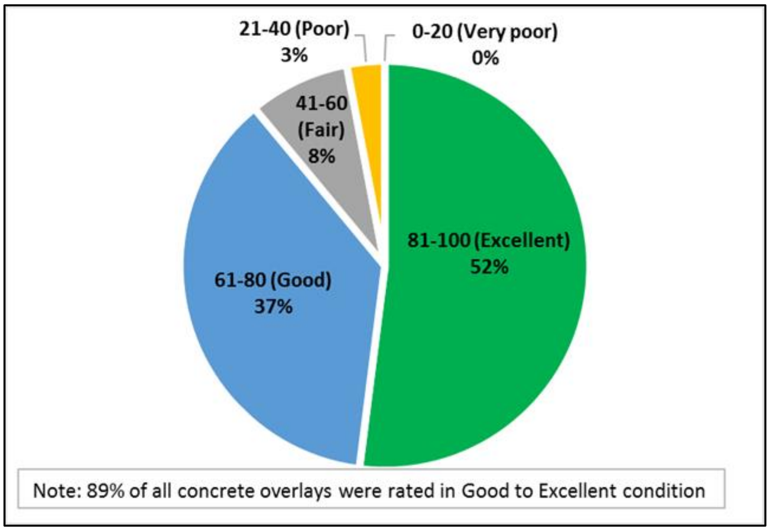


Figure 2. PCI performance

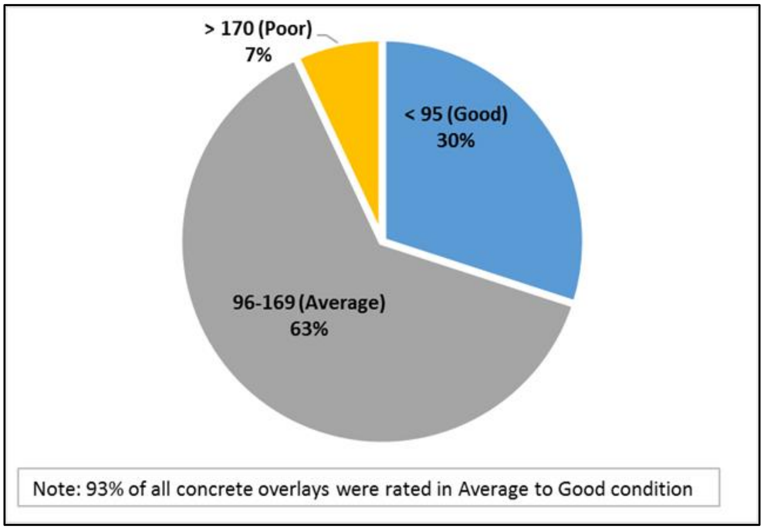


Figure 3. IRI performance

Figures 4 through 7 show the PCI performance with age. Figures 8 through 11 show the IRI performance with age.

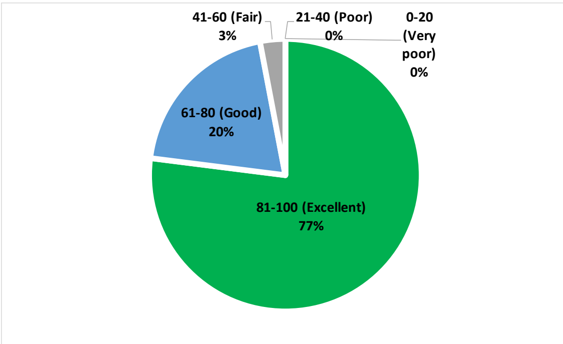


Figure 4. PCI ages 0–10 years

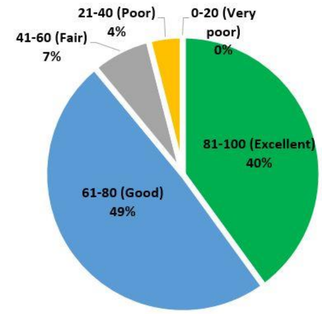


Figure 5. PCI ages 11–20 years

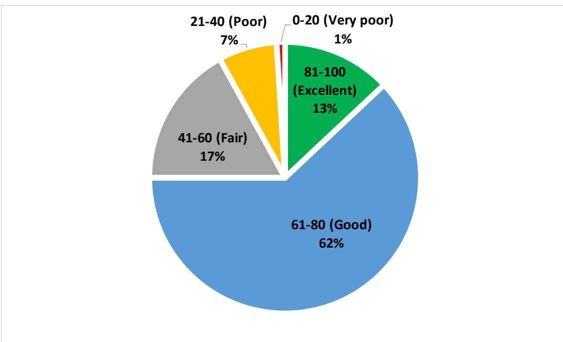


Figure 6. PCI ages 21–30 years

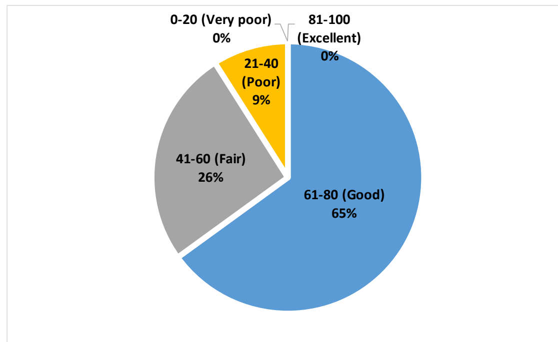


Figure 7. PCI ages greater than 30 years

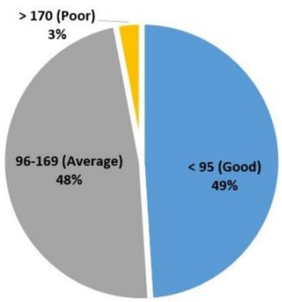


Figure 8. IRI ages 0–10 years

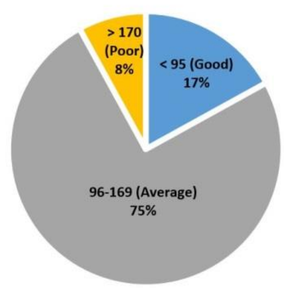


Figure 9. IRI ages 11–20 years

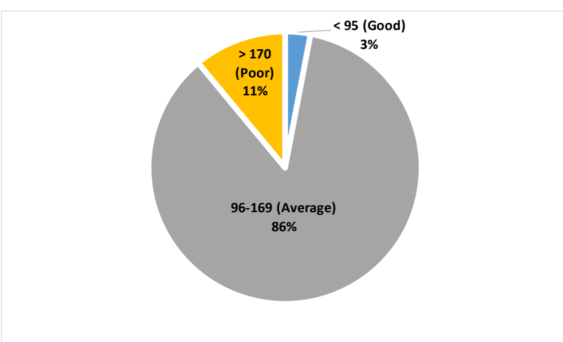


Figure 10. IRI ages 21–30 years

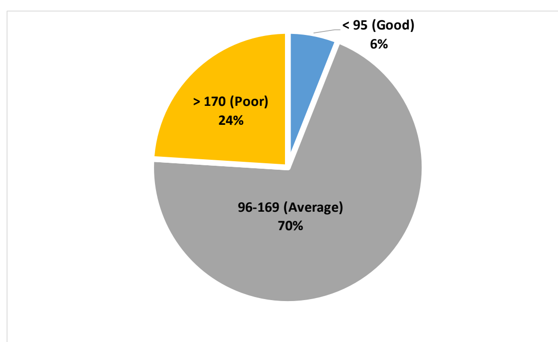


Figure 11. IRI ages greater than 30 years

To further evaluate the performance of the individual concrete overlay types, plots of the trend line value at Year 20 were developed. Refer to Figures 60 through 67. Table 1 summarizes the PCI and IRI performance values based on the trend line at Year 20.

Table 1. Trend line value of concrete overlay types at Year 20

Type	BCOC	UBCOC	BCOA	UBCOA
PCI	47	63	74	76
IRI	138	150	125	128

Figure 12 shows a trend line correlating a PCI of 60 (lower bound of good) with an age of 35 years.

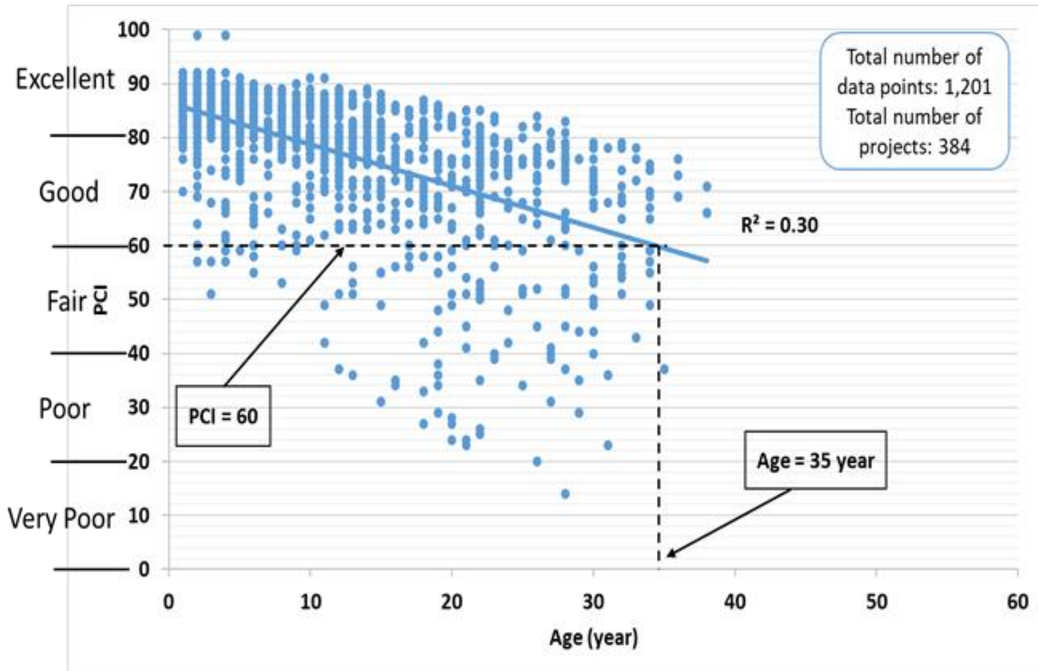


Figure 12. Performance of concrete overlays based on the total database PCI and age

Figure 13 shows the performance of concrete overlays based on IRI and age.

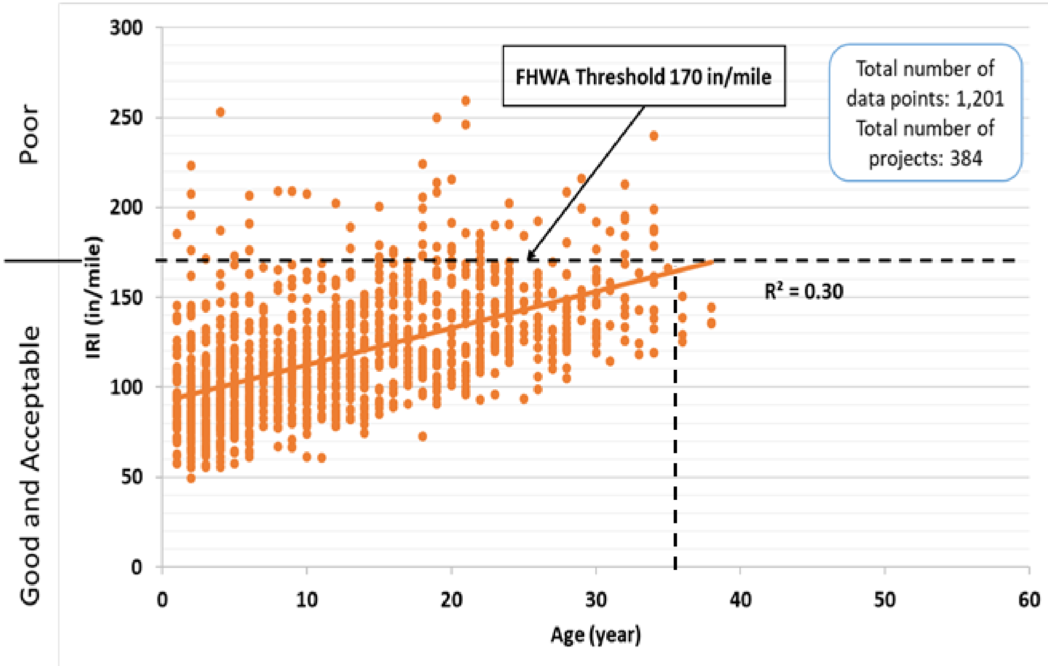


Figure 13. Performance of concrete overlays based on the total database IRI and age

Based on the FHWA and Federal Transit Administration (FHWA and FTA 2006) threshold of 170 in/mi (upper limit of acceptable condition), the trend line shows an age of 40 years. At age 35, the IRI is approximately 160, still within the acceptable category.

1.2. Performance Measurement

1.2.1. Pavement Condition Index

The PCI is a widely accepted method used to measure pavement performance. The PCI is based on a rating scale from 0 to 100 with 100 representing a new pavement with no distress and 0 representing a failed pavement. See Figure 14.

Figure 14. IPMP PCI rating scale

In this study, the PCI is calculated based on the amount of transverse cracking, D-cracking, joint spalling, and the IRI per Equation 1-1.

$$PCI = 100 - 35\left(\frac{IRI}{253}\right) - 25\left(\frac{\#\ of\ D\text{-}crack\ joints\ per\ 528\ ft}{8}\right) - 15\left(\frac{\#\ of\ spalled\ joints\ per\ 528\ ft}{9}\right) - 25\left(\frac{\#\ of\ transverse\ cracks\ per\ 528\ ft}{14}\right) \quad \textbf{(1-1)}$$

1.2.2. International Roughness Index

The IRI is a property of the pavement profile and is the most widely used statistic to describe roughness (Smith et al. 2014). The FHWA classifies the IRI in Table 2 for good, acceptable, and not acceptable ranges. Lower values are smoother, whereas higher values are rougher.

Table 2. Relationship between IRI and pavement condition

Ride Quality Terms	IRI Rating (in/mi)
Good	< 95
Acceptable	95 to 170
Not Acceptable	> 170

Source: FHWA and FTA 2006

1.3. Development of the Database

1.3.1. Historical Data

A historical database was provided by the Iowa Concrete Paving Association (ICPA) that included 521 concrete overlays totaling more than 1,900 centerline miles. The overlays were identified as bonded overlay (BOL), unbonded overlay (UBOL), and whitetopping (WT). Bonded overlay referred to BCOCs, while UBOL referred to UBCOCs.

Historically, WT projects referred to all concrete overlays on asphalt. For the purposes of this study, WT projects have been divided into BCOAs and UBCOAs. Overlays 6 in. thick and less were designated as BCOA and overlays more than 6 in. thick were designated as UBCOA. It is critical to note that a majority of the 6-in.-thick overlays were not specifically designed as bonded overlays. This study designates BCOA and UBCOA to match the current Iowa DOT designation.

1.3.2. Linking the Database

A critical step was necessary to enable performance evaluation. The ICPA historical data and the IPMP condition data were linked together by assigning longitude and latitude coordinates for the beginning and end of each project location as well as assigning a unique project identifier (ROADID) to each set of data attributed to a single project. The ICPA historical data were then linked to the IPMP condition data using the ROAD_ID identifier and the project coordinates to create a single database.

1.3.3. Filtering the Data

After compiling the concrete overlay performance data, some instances of irrelevant, inaccurate, or incomplete records were discovered. Some of the incomplete information was provided by the Iowa DOT, cities, and counties, and the remaining incomplete projects were removed from the database.

1.3.4. Final Database

After filtering the performance data, the final concrete overlay database included 384 concrete overlay projects totaling 1,493 miles.

Based on the total number of projects and their total length, the most common types of overlays are BCOA and UBCOC. Figure 15 shows the distribution of overlay types by number of projects, and Figure 16 shows the distribution of overlay types by length of projects.

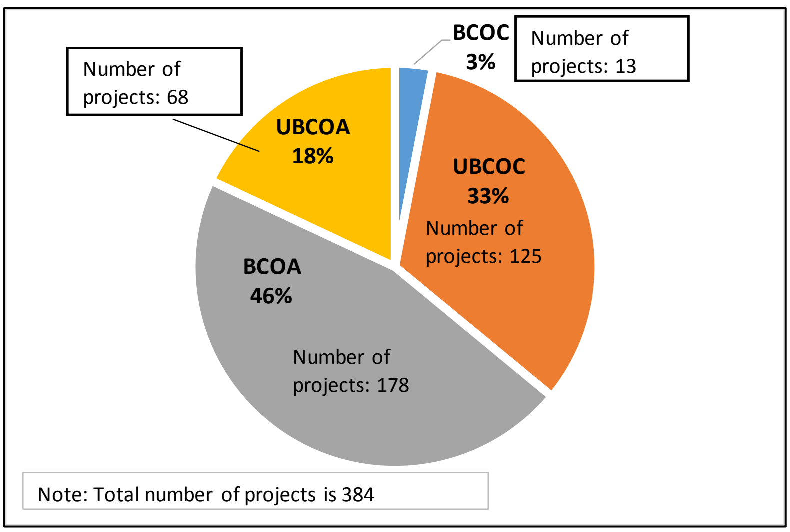


Figure 15. Overlays based on number of projects

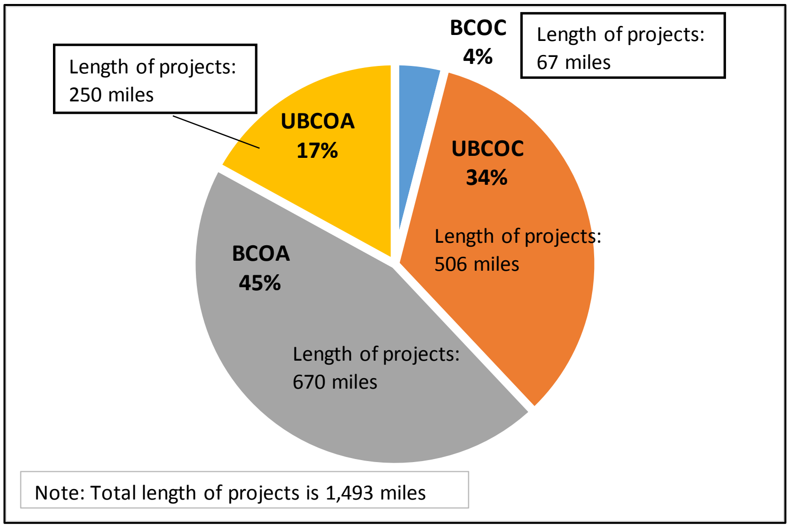


Figure 16. Overlays based on project length

Figures 17, 18, and 19 show the distribution of overlay projects by thickness, transverse joint spacing, and traffic, respectively.

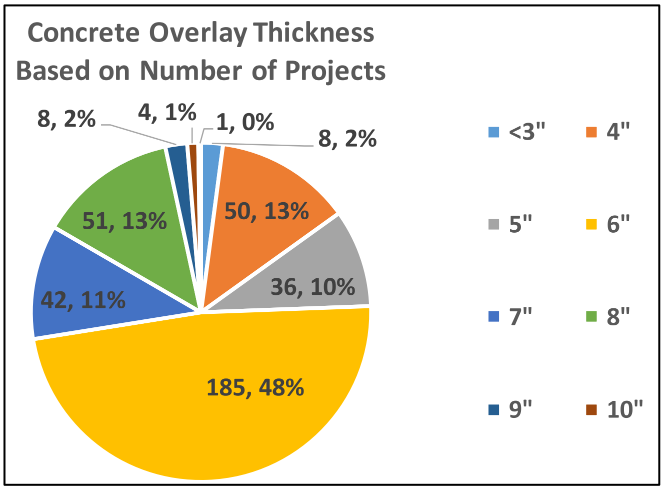


Figure 17. Concrete overlay thickness based on number of projects

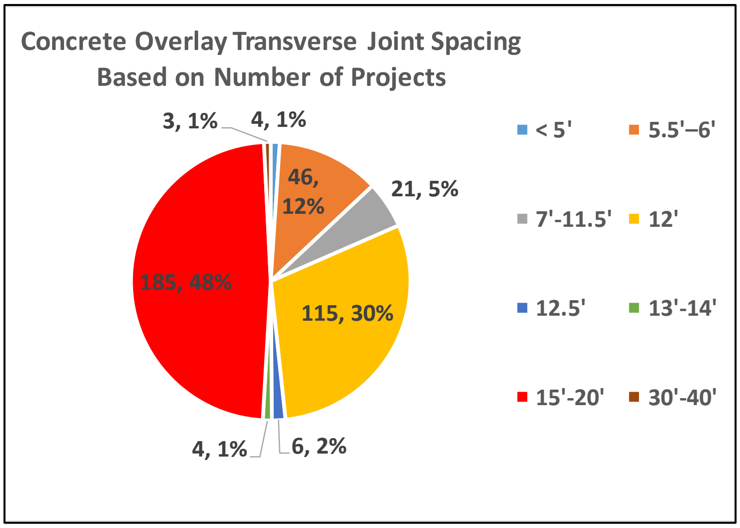


Figure 18. Concrete overlay transverse joint spacing based on number of projects

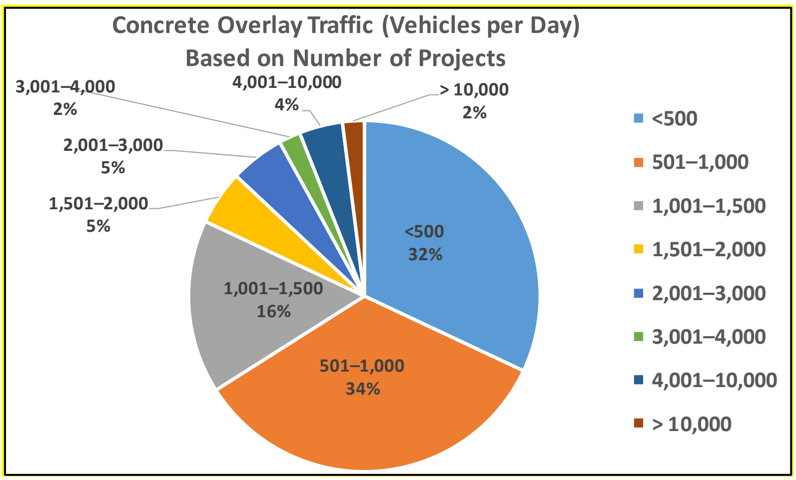


Figure 19. Concrete overlay traffic based on number of projects

1.4. Data Analysis

To determine the performance of the concrete overlays, a careful analysis of the data was completed based on reviewing the relationships between PCI, IRI, and the following parameters:

- Overlay type (BCOA, BCOC, UBCOA, UBCOC)
- Overlay age
- Overlay thickness
- Transverse joint spacing
- Traffic

Although traffic was included as a parameter of the study, it ultimately was not a significant factor in the determination of performance because the majority of overlays had relatively low traffic volumes. Among all overlays, 87% carried 2,000 vehicles per day or less. The majority (94%) of the overlays within the database represented secondary roads (360 total projects). Primary roads accounted for 4% of the projects (16 total projects). Overlays located within municipalities accounted for 3% of the projects (12 total projects). Figure 20 illustrates the market types of Iowa concrete overlays.

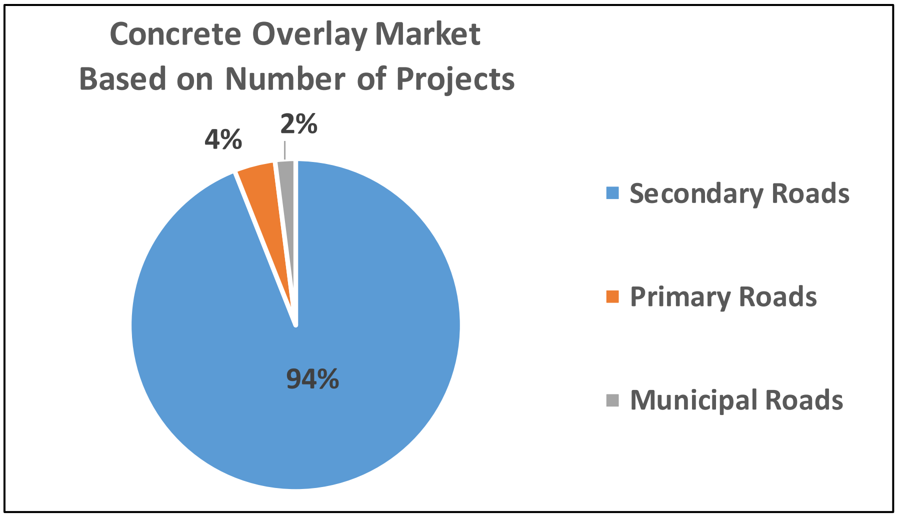


Figure 20. Iowa's concrete overlay market

The data analysis was performed in two steps:

- Step 1 included a performance analysis of the total database (384 projects, 1,493 miles).
- Step 2 included a separate performance analysis of the four overlay types (BCOA, UBCOA, BCOC, and UBCOC).

For each of the two steps, the performance was analyzed by comparing PCI against age and IRI against age for various overlay thicknesses and various overlay joint spacings.

1.5. BCOA Faulting

A separate analysis was performed to investigate faulting of BCOA pavements. Faulting was defined as the vertical displacement between adjacent slabs and was only measured in the IPMP condition data when individual joints were found to have faulted greater than a threshold of 0.12 in. and the number of faulted joints per project was counted and classified according to severity.

The data showed that a low percentage of joints overall exhibited faulting, and the majority of faulted joints were of low severity (0.12 to 0.24 in.). Of the low severity faulting, 91% of the 110 BCOA projects dating back to 1977 have less than 40 faulted joints per mile. It is concluded that faulting of BCOA pavements is minimal and has not been perceived as a problem in Iowa. It is understood that data collection beginning in 2017 will measure maximum, minimum, and average faulting dimensions for each roadway section.

1.6. Lessons Learned

Table 3 lists the lessons learned after reviewing performance trends in the overlay database of 384 projects and 1,493 miles.

Table 3. Lessons learned

Lessons Learned
Concrete overlays are performing very well, with service life trends exceeding the expectations listed in the *NCHRP Synthesis of Highway Practice 204* (McGhee 1994). A majority of projects in the complete overlay data set were on track to achieve a PCI rating of good (PCI = 60) or better and a ride quality rating of adequate (IRI = 170 in/mi) or better during the first 35 years of service life.
UBCOAs performed better than the other three overlay types.
In general, concrete overlays on asphalt performed better than concrete overlays on concrete.
UBCOCs with shorter joint spacings (i.e., 12- and 15-ft) perform better than those with longer joint spacing (i.e., 20 ft) in terms of IRI values.
Although only in existence since about 2004, BCOAs with shorter transverse joint spacing (5.5 and 6 ft) have performed as well or better than 12-, 15-, and 20-ft joint spacings with respect to PCI and IRI.
Traffic count was not a significant parameter in the performance of the overlays because of the overall low volumes. 87% of the data were for traffic counts of fewer than 2,000 vehicles per day.
Higher overlay thickness leads to increased overlay service life in terms of PCI values.

To further determine lessons learned from the performance of the concrete overlays, a selection of the poorer-performing overlays (data outliers) was studied in detail. It is important to note that the poorer-performing overlays accounted for less than 5% of the total database. The investigation showed four different causes for poorer performance, the most common being related to structural failure and MRD. Table 4 lists the four conditions as well as recommendations for improvement.

Table 4. Causes of poorer performance and recommendations for improvement

Cause of Poorer Performance (Data Outlier)	Recommendations for Improvement
Material-related distress	Use high-quality materials Use water/cement ratio 0.40 to 0.43 Use proper air entrainment system
Structural failure	Plan for future truck traffic Use overlay design software: (ACPA StreetPave, BCOA-ME, ACPA BCOA, AASHTO Pavement ME)
Inadequate drainage system	Properly drain existing pavement and new overlays (BCOA, UBCOA, and UBCOC) Consider surface and joints
Excessive joint spacing	Refer to *Guide to Concrete Overlays*, Third Edition (Harrington and Fick 2014)

Table 5 lists best practices for evaluation and design of concrete overlays (Harrington and Fick 2014).

Table 5. Best practices for evaluation and design of concrete overlays

Project Phase	Recommendations
Project Evaluation and Overlay Selection	• Investigate existing layer conditions by coring, falling weight deflectometer (FWD) measurements, and as-built drawings. • Core to determine available pavement thickness if milling (3- to 4-in. minimum remaining). • For overlays on asphalt with heavy truck traffic, check existing asphalt layers for evidence of stripping. • Because of freeze-thaw conditions and/or areas with expansive soils, evaluate existing pavement in spring and summer to identify critical pavement distress to be accounted for in design.
Concrete Overlay Design	• For UBCOC, provide positive drainage paths for surface moisture to exit from separation layer to prevent erosion (stripping) under heavy-traffic loadings. Consider a geotextile separation layer for feasibility with respect to construction time and performance. • For BCOA, ensure adequacy of the asphalt layer after milling to avoid structure failure. • Seal pavement joints. • Review construction sequence and traffic control in conjunction with joint layout. Tied longitudinal construction joints can interfere with traffic during construction. • Design transitions and bridge approach pavement sections to minimize hand placement areas. • For BOLs, understand the challenges and pay attention to details. • Improve joint performance by using proper sawing dimensions and depths, adequate air entrainment, and maximization of durability by lowering water-to-cement (w/c) ratio.
Construction	• Require use of vibrator frequency monitor recorders on the paver to ensure adequate and non-excessive consolidation. • Use standard concrete mixes and maturity measurements to control openings of intersections and access points. Use accelerated concrete mixes only where necessary. • When existing surface milling is required, clearly define vertical and cross-slope limits and required existing surface survey accuracy.

Source: Chapter 1 of the *Guide to Concrete Overlays*, Third Edition, National CP Tech Center (Harrington and Fick [2014])

1.7. Potential for Improved Performance

Even though concrete overlays are performing very well, the analysis showed that performance can be improved and service life can be extended. This can be accomplished by addressing the conditions listed in Table 4 and following the best practices listed in Table 5. To design a concrete overlay properly, use the *Guide to Concrete Overlays, Third Edition* (Harrington and Fick 2014) and *Guide Specifications for Concrete Overlays* (Fick and Harrington 2015). Some of the data sets show clear division of data points. For example, Figure 21 shows PCI versus age for a sample data set of concrete overlays with 12-ft joint spacing less than 20 years old.

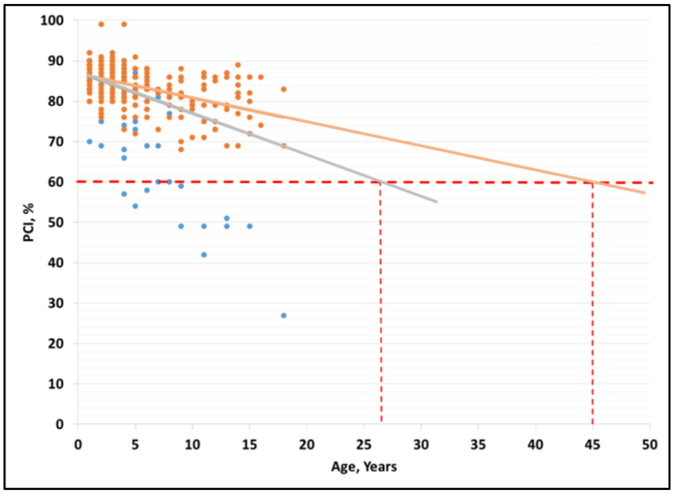


Figure 21. PCI improved performance all overlays 12-ft joint spacing (less than 20 years)

The orange points refer to well-performing pavements, whereas the blue data points refer to pavements that have deteriorated more quickly than normal. In this study, the reasons for the quicker decrease in performance are related to many factors, including joint performance, inadequate drainage, selection of the wrong overlay type, thickness design, and MRD.

In Figure 21, the gray line indicates the linear trend line for the complete data set, showing a pavement age of approximately 27 years at a PCI of 60. Although this is considered good performance because it exceeds service life based on existing guidelines from the National Cooperative Highway Research Program (NCHRP) (McGhee 1994), it can be greatly improved by taking steps to ensure that good quality pavement is placed. This is accomplished by verifying the use of quality materials, providing proper drainage, selecting the correct overlay type, providing adequate air entrainment, and insuring proper joint construction.

If the pavement quality and construction is improved, service life expectations for concrete overlays may be increased further. Among the well-performing projects, the slope of the linear trend line (in orange) becomes flattened and a PCI of 60 is achieved at year 45, representing an extension of pavement life by nearly 20 years compared to the subset of projects exhibiting premature deterioration.

1.8. Conclusions

The results of the performance analysis concluded that concrete overlays in Iowa are performing very well, with service life trends far exceeding expectations listed in the *NCHRP Synthesis of*

Highway Practice 204 (McGhee 1994). In addition, 89% of the database has a PCI rating of good to excellent and 93% of the IRI database is below the acceptable threshold of 170 in/mi. Finally, the poorer-performing pavements chosen for field reviews and additional study were representative of fewer than 5% of the complete project database entries. The field reviews showed that deterioration of poorer-performing pavements was based on MRD resulting from use of substandard materials or material incompatibilities, structural failure, and poor drainage. All causes for the distress found in the poorer-performing pavements are correctable.

Based on an analysis of the faulting data on BCOA pavements, it is concluded that faulting on Iowa overlays did not occur to a significant extent, with only 9% of the projects containing more than 40 faulted joints per mile. Where faulted joints existed, the vast majority were of low severity. Further study would be needed to determine exact fault dimensions. It is understood that the data collection system beginning in 2017 will have the capability of collecting maximum, minimum, and average faulting dimensions for each roadway section.

1.9. Further Study

One way to optimize performance and optimize life cycle costs for concrete overlays is to study joint spacing designs. Proper joint spacing and joint construction is essential to maximize concrete overlay performance. Minimizing the number of joints has become a topic of discussion related to the economy of pavement construction and maintenance. Field observations have documented that some joints may not be working effectively, particularly on low-volume roadways. A sawed contraction joint in which a crack does not deploy may increase the cost of the project and subject the pavement to potential distress over the years. In such situations, determination of minimum joint spacing is advisable, particularly for thin BCOA slabs.

The use of structural macrofibers in concrete overlays increases fatigue capacity and fracture toughness. Fibers also reduce overlay design thickness, help control differential slab movement caused by curling and warping, and will hold cracks tightly together.

Phases 2A and 2B of this study, TR-698 Concrete Overlay Performance on Iowa’s Roadways, will follow this report with the objective of optimizing joint spacing for concrete overlays. Phase 2A will concentrate on studying performance of concrete overlays through using design software Pavement ME and BCOA-ME. This software will be used to simulate several concrete overlay designs both with and without structural fibers to determine the optimum joint spacing for different types of overlays. Phase 2A will also include field evaluation of concrete overlays in Iowa and Illinois to determine locations of contraction joints where cracks have not deployed. Illinois overlays were chosen for the study based on the availability of overlays constructed with fibers.

Phase 2B is a two-year study that will use the information developed in Phase 2A. In this phase, test sections for new concrete overlays will be developed and constructed in 2017 and 2018, after which they will be monitored over a period of time to determine locations of crack deployment and to better understand the optimum joint spacing for a given overlay. Test sections will include overlays with varying thicknesses, varying joint spacings, concrete mixes both with and without structural fibers, and varying fiber concentrations.

2. INTRODUCTION

2.1. Background

Pavement preservation and rehabilitation have been growing in importance nationwide, leading to increased interest in concrete overlays. Concrete overlays are a cost-effective, low-maintenance preservation technique used to extend pavement life. Iowa can be considered a national leader in the use of concrete overlays. Early experimentation with concrete overlays accelerated in the 1970s and, by the end of the decade, concrete overlays began to be constructed regularly in Iowa.

There have been few comprehensive studies of long-term performance of all types of concrete overlays. The long history of concrete overlay construction in Iowa, coupled with the availability of performance data, allows for the first comprehensive, long-term performance study of all types of concrete overlays.

The ICPA maintains a history database of all concrete overlay projects that have been constructed in Iowa. The ICPA historical database has project information on more than 500 overlay projects (as of 2016), encompassing more than 2,000 centerline miles. Figure 22 identifies the locations for all Iowa concrete overlays within the ICPA database.

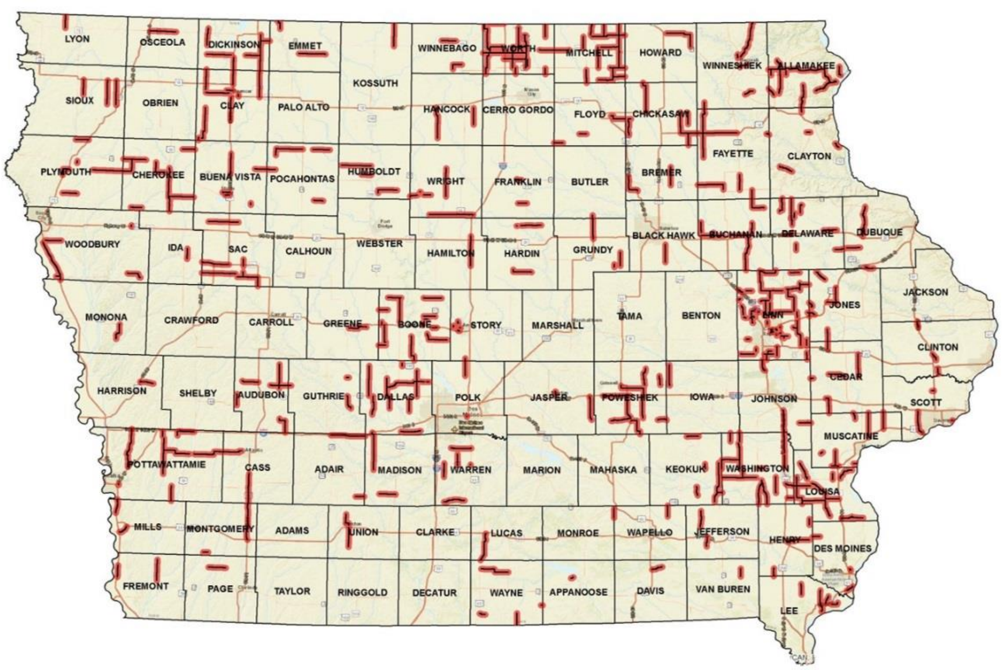


Figure 22. Iowa concrete overlay map

Concrete overlays are not new to Iowa and have undergone some changes over the years, during which time joint spacing, basic design thickness parameters, separation layers, and construction details have evolved. Events conducted by the IPMP have also evolved over the years. In Iowa, collection of pavement condition data for the secondary (county) road system started in 2002, and since 2013, pavement condition data have been collected on all public pavements in Iowa.

Figure 23 shows a timeline of events for concrete overlays as well as events for the IPMP.

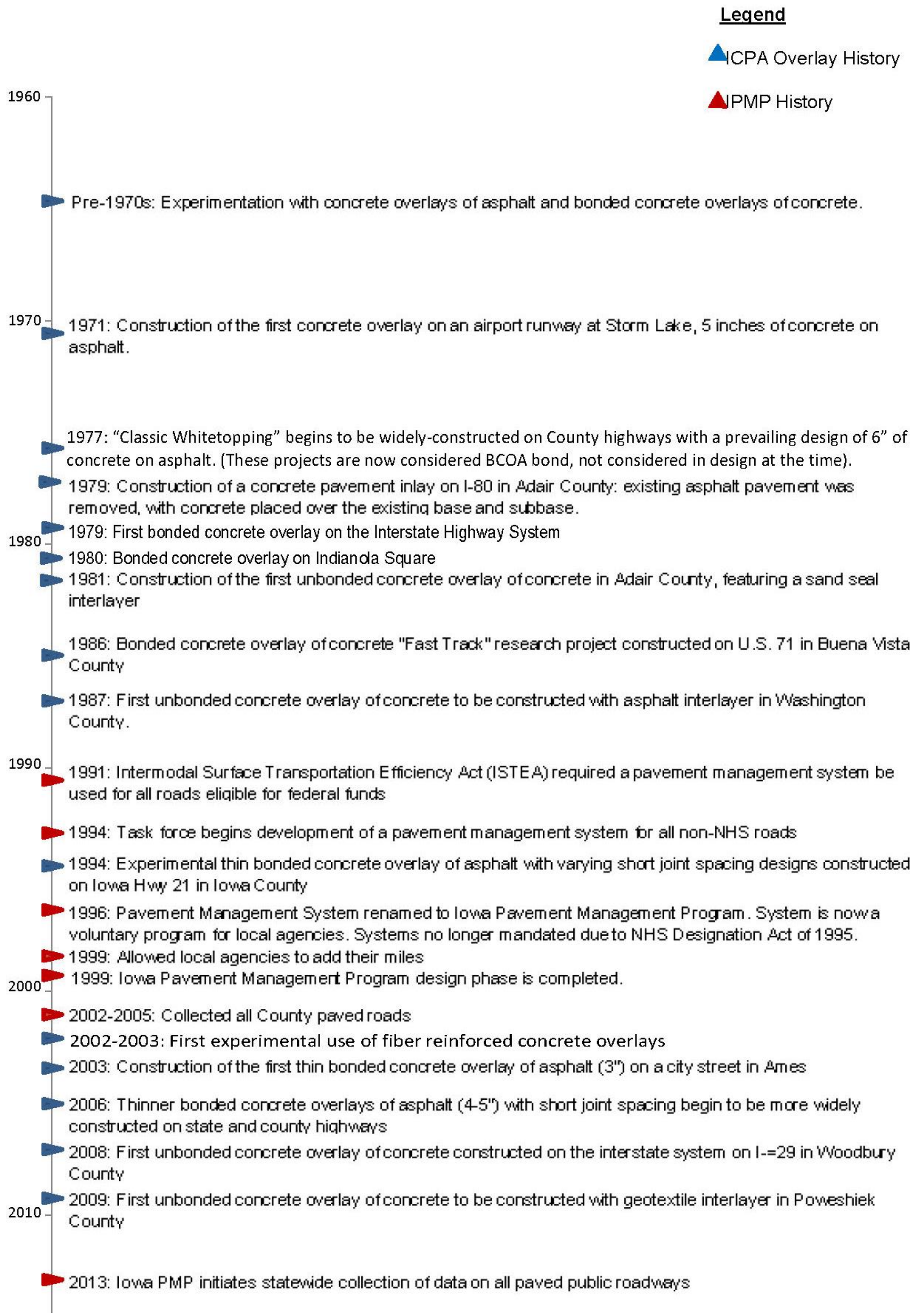


Figure 23. ICPA history and IPMP events timeline

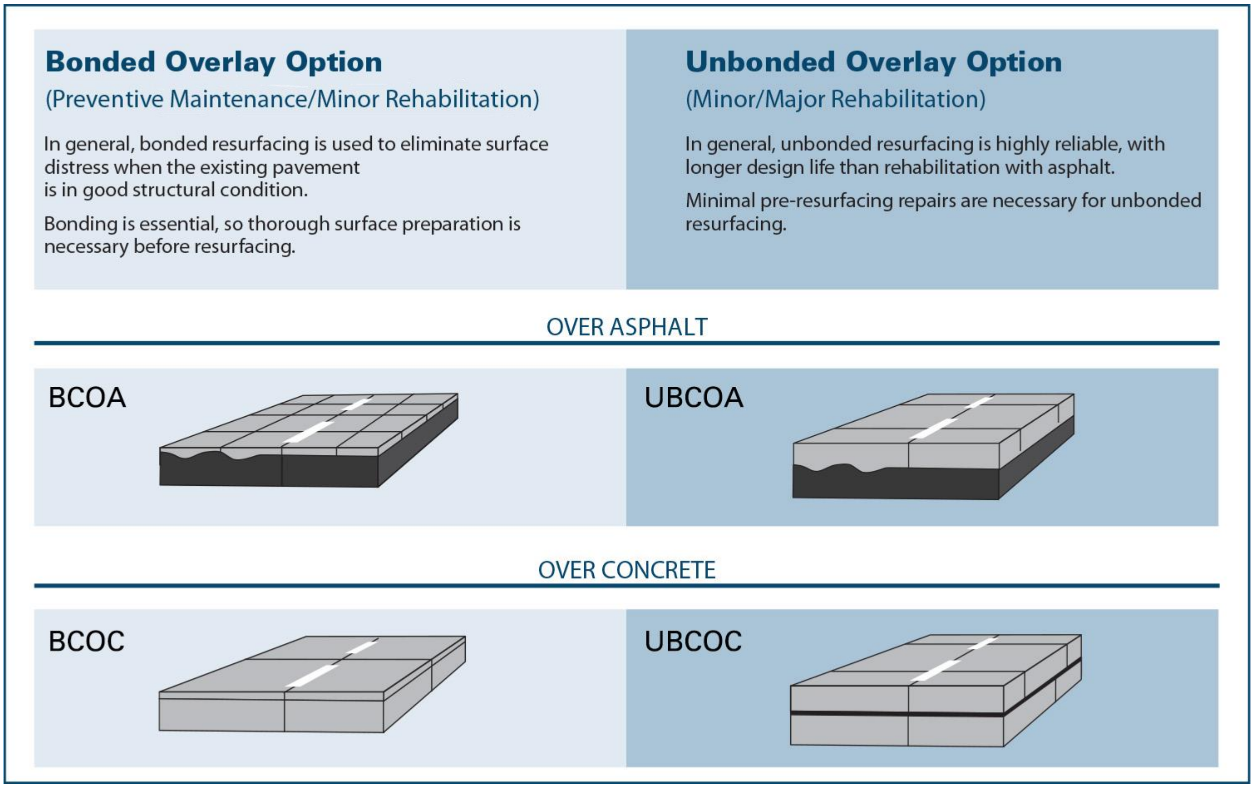
2.1.1. Concrete Overlay Types

Although the *Guide to Concrete Overlays*, Third Edition (Harrington and Fick 2014) defines six different types of concrete overlays, the database originally developed by the ICPA did not differentiate between asphalt pavements and composite pavements when concrete overlays were placed onto them, considering them all to be overlays on asphalt. Further, concrete overlays on asphalt pavements were identified using the term whitetopping. Therefore, at the beginning of the study, the concrete overlay database included only three overlay categories: BCOCs, UBCOCs, and WT.

To follow more conventional categorizing of the overlay types, it was decided to separate the WT category into BCOAs and UBCOAs with the distinguishing factor being the thickness of the overlay. The Iowa DOT was consulted for their definition of the overlay categories and it was decided that, for the purposes of this study, concrete overlays on asphalt that were 6 in. thick or less were considered bonded, whereas concrete overlays on asphalt that were more than 6 in. were considered unbonded. This division is equivalent to the Iowa DOT designation.

It is important to note that despite their designation as BCOAs, the majority of 6-in. concrete overlays on asphalt were not designed with anticipation of bonding.

Figure 24 illustrates the four categories of concrete overlays included in this study. Overlays on composite pavements are included in BCOAs and UBCOAs.



Adapted from *Guide to Concrete Overlays*, Third Edition, National CP Tech Center (Harrington and Fick 2014)

Figure 24. Concrete overlay categories

2.1.2. ICPA History Database

The ICPA history database includes the following information for each overlay project:

- Overlay type (bonded/unbonded on concrete/asphalt)
- Location (county/city)
- Project number
- Road name and description
- Length
- Latitude and longitude of project limits
- Overlay construction year
- Overlay thickness
- Transverse joint spacing
- Traffic count

When possible, the year of construction and thickness of the original pavement were also noted along with overlay features, including truck traffic and the presence of integral widening and dowel bars.

2.1.3. IPMP Condition Database

As part of the IPMP, automated collection of condition data for secondary roads began in 2002. By 2005, all secondary roads had their pavement conditions collected for the first time. The program continued and, since 2013, all paved public roads in Iowa have had their pavement conditions recorded every other year. A number of different performance metrics are collected by the IPMP that can be utilized to evaluate concrete overlays. These performance metrics include the following:

- IRI
- Transverse cracking
- Longitudinal cracking
- Transverse joint faulting
- D-cracking
- Transverse joint spalling
- Patching

Each of the above performance metrics are further defined in terms of amount and/or severity of distress. For example, cracking is classified into levels of low, medium, and high severity; faulting is classified into four severity levels depending on the fault depth; patching is classified as good, bad, and by quantity; and joint spalling and D-cracking are classified as medium or high severity.

2.2. Objective of Research

Although interest in the use of concrete overlays as a pavement preservation method has been growing, little information is available on long-term concrete overlay performance. The studies of field concrete overlay performance have generally encompassed a limited number of projects and/or limited performance periods (Cable et al. 2001, Winkelman 2005, Roesler et al. 2008, Vandenbossche et al. 2011, Fick and Harrington 2014, King and Roesler 2014). To date, there has not been a truly comprehensive study with a large data set containing all types of concrete overlays spanning several decades of service life. The long history of concrete overlays in Iowa coupled with the availability of performance data presents a unique opportunity to undertake such a comprehensive, long-term study.

The objective of this project was to determine the performance of concrete overlays on Iowa’s roadways. By studying the PCI and IRI performance in terms of key overlay parameters such as overlay type, thickness, transverse joint spacing, and traffic, performance trends can be established, be attributed to overlays with good performance, and provide lessons learned for pavements with poorer performance. This research provides the results of a comprehensive study on long-term concrete overlay performance.

3. RESEARCH APPROACH

3.1. Joining the Data

Each project record in the ICPA database contained a description of the location and route of each overlay but lacked detailed project coordinates or geometric information compatible with the IPMP. Therefore, before project records and performance data could be merged, geographic coordinates (latitude and longitude) corresponding to the beginning and end of each overlay project were identified and added to the ICPA project records.

From there, the overlay project coordinates were imported into ArcGIS and mapped on roadway segment geometries provided by the IPMP. The ICPA project records were then linked to the objects corresponding to each overlay segment in the IPMP database, allowing a full merger of overlay project information and performance data. The resulting database of overlay projects contained the full spectrum of project information and historical IPMP performance data. The ICPA provided the project coordinates and InTrans linked the data sets.

Joining the ICPA historical database with the IPMP condition database made it possible to analyze the performance of concrete overlays based on a number of parameters, including overlay type, thickness, age, and traffic.

3.2. How Is Performance Measured?

The performance measures used in the data analysis are the PCI and IRI.

The PCI is a widely accepted method used to measure pavement performance. The PCI is based on a rating scale ranging from 0 to 100, with 100 representing a new pavement with no distress and 0 representing a failed pavement, as shown in Figure 25.

Figure 25. IPMP PCI rating scale

In this study, the PCI was calculated based on the amount of transverse cracking, D-cracking, joint spalling, and the IRI given by Equation 3-1 as defined per the IPMP.

$$PCI = 100 - 35\left(\frac{IRI}{253}\right) - 25\left(\frac{\#\ of\ D - crack\ joints\ per\ 528\ ft}{8}\right) -$$

$$15\left(\frac{\#\ of\ spalled\ joints\ per\ 528\ ft}{9}\right) - 25\left(\frac{\#\ of\ transverse\ cracks\ per\ 528\ ft}{14}\right) \quad \textbf{(3-1)}$$

The Iowa DOT calculates the PCI differently from the IPMP. The Iowa DOT also has a different rating scale. Equation 3-2 shows the Iowa DOT PCI equation for Portland cement concrete (PCC) pavements, which is based on cracking (longitudinal, transverse, and wheel path), ride, and faulting.

$$\text{PCI-2}_{\text{(PCC)}} = 0.40 \times (\text{Cracking Index}) + 0.40 \times (\text{Riding Index}) + 0.20 \times (\text{Faulting Index}) \quad \textbf{(3-2)}$$

The method of calculating the PCI using Equation 3-1 has been in use statewide as part of the IPMP since its implementation in 1996. Because distress data for the statewide paved network became available beginning in 2002 with secondary roads, and since 2013 across all public paved roadways in Iowa, it was decided to use this equation to determine the PCI for evaluation of pavement performance.

The IRI is a property of the pavement profile and is the most widely used statistic to describe roughness (Smith et al. 2014). The FHWA classifies IRI ratings shown in Table 6 into good, acceptable, and nonacceptable ranges. Lower values are smoother, whereas higher values are rougher.

Table 6. Relationship between IRI and pavement condition

Ride Quality Terms	IRI Rating (in/mi)
Good	< 95
Acceptable	95 to 170
Not Acceptable	> 170

Source: FHWA and FTA 2006

3.3. Resolution of Partial Historical Data

Missing information from the ICPA historical database (e.g., project location, thickness, joint spacing) was obtained from the DOT, cities, and counties as much as possible. For some of the older overlay projects, some of the information could not be found. Projects for which key information was lacking were removed from the database.

3.4. Data Analysis Approach

A detailed data analysis was conducted in two steps. In the first step, performance for the complete database was studied. In the second step, performance was studied for each overlay category: BCOA, UBCOA, BCOC, and UBCOC.

Performance graphs were developed to plot PCI vs. age and IRI vs. age. Trend lines were plotted using linear best fit lines. From each of the performance graphs developed in step one and step two, conclusions were drawn based on the data and trend lines. Performance measures were plotted using a PCI of 60 (lower end of the good rating) and an IRI of 170 (upper end of the acceptable level) to correlate to overlay age. This correlation provided an estimate of service life and performance for each of the projects. It can be noted that each data point plotted in the graphs represents one pavement condition collection year for a particular project. Older projects have multiple data points, while newer projects have fewer data points.

From the performance analysis, lower-performing overlays were further studied by analyzing specific conditions of distress in the database and also by investigating overlays in the field. The field reviews and database investigation provided particular insight into the poorer-performing overlays by visually observing distress types and severity. At the conclusion of this investigation, the causes of poorer performance were identified and lessons learned could be quantified.

An additional study of faulting was completed for BCOA pavements. The collected data was reviewed and graphing relationships were completed to relate faulting (severity level and quantity) to overlay thickness, age, and traffic. This faulting study provides another level of concrete overlay performance analysis.

4. DATA ANALYSIS AND RESULTS

4.1. Pavement Condition Data Collection and Analysis

Iowa concrete overlay performance data were obtained from a pavement distress data set maintained by the IPMP.

A number of different performance metrics for evaluating concrete pavements, including concrete overlays, are collected by the IPMP. These performance metrics include the IRI, transverse cracking, longitudinal cracking, transverse joint faulting, D-cracking, transverse joint spalling, and patching. The IPMP also calculates a PCI for all concrete pavements that incorporates IRI, D-cracking, transverse joint spalling, and transverse cracking, which was calculated using Equation 4-1:

$$PCI = 100 - 35\left(\frac{IRI}{253}\right) - 25\left(\frac{\#\ of\ D-crack\ joints\ per\ 528\ ft}{8}\right) - 15\left(\frac{\#\ of\ spalled\ joints\ per\ 528\ ft}{9}\right) - 25\left(\frac{\#\ of\ transverse\ cracks\ per\ 528\ ft}{14}\right) \qquad \textbf{(4-1)}$$

After compiling the concrete overlay performance data from the IPMP, some instances of irrelevant, inaccurate, or incomplete records were discovered. To ensure accurate and reliable data analysis, the overlay performance data were filtered according to the following six criteria:

- Removal of data corresponding to overlay projects with age less than one year (i.e., age = 0 years).
  - This step eliminated instances in which data were collected just prior to construction of the overlay, eliminating circumstances with erroneous data.
  - This criterion led to the removal of approximately 41 projects from the data set and was the most common reason for project removal.

- Removal of data corresponding to research projects.
  - Three research projects had been constructed with varying overlay parameters, including joint spacing and thickness, and could not be similarly compared to other overlay categories.

- Removal of data for which the PCI was less than 70 with age equal to 1.
  - Pavements with low PCI at age 1 were likely to have experienced erroneous data collection.

- Removal of erroneous data.
  - There were a few data points that were clearly erroneous—for example, when an IRI of 999 in/mi was reported. An IRI of 999 in/mi is the default value given when the

IRI was not able to be collected in the automated distress survey. Removal of this and other similar data avoided inaccurate calculation of the PCI.

- Removal of data for overlays no longer in service and whose timeline of removal was unclear, i.e., the concrete overlay had been reconstructed or rehabilitated and the project team could not distinguish whether data points corresponded to performance of the original concrete overlay or subsequent pavement.
    - A total of 35 projects were removed for this reason, half being BCOC projects constructed prior to 2002 with only minimal data points. Performance data corresponding to overlays that were no longer in service but for which the date of removal was confirmed remained in the data set.

- Removal of data after maintenance or rehabilitation altered the performance trend of the overlay.
    - For example, if an observed PCI value jumped from 50 to 80 at an advanced pavement age, this jump was attributed to either maintenance or rehabilitation. Data collected before the jump were included in the data set, whereas data collected after the jump were eliminated from the data set.

After filtering the performance data in accordance with the above criteria, and after removing instances in which basic project information (e.g., thickness, joint spacing, project location) had been missing from the ICPA database, the final performance data set included 384 concrete overlay projects with 1,201 data points constructed in Iowa through 2015. This data set was analyzed to study the distribution of Iowa concrete overlay projects through identification of the following parameters:

- Overlay type (BCOA, BCOC, UBCOA, UBCOC)
- Overlay age
- Overlay thickness
- Transverse joint spacing
- Traffic
- PCI
- IRI

Table 7 shows the distribution of total traffic for the concrete overlays. Because reliable truck traffic data were not available and overall traffic levels were uniformly low, they did not correlate very strongly with performance metrics (IRI, PCI) and thus were not further analyzed.

Table 7. Traffic count distribution

Average Daily Traffic (vehicles per day)	Percent of Data Based on Number of Projects
<500	32
501–1,000	34
1,001–1,500	16
1,501–2,000	5
2,001–3,000	5
3,001–4,000	2
4,001–10,000	4
> 10,000	2

Historical IRI and PCI records were then analyzed to achieve a better understanding of long-term performance behavior of concrete overlays in Iowa.

Concrete overlay data shown in Figures 26 and 27 summarize the different types of concrete overlays used in Iowa roadways.

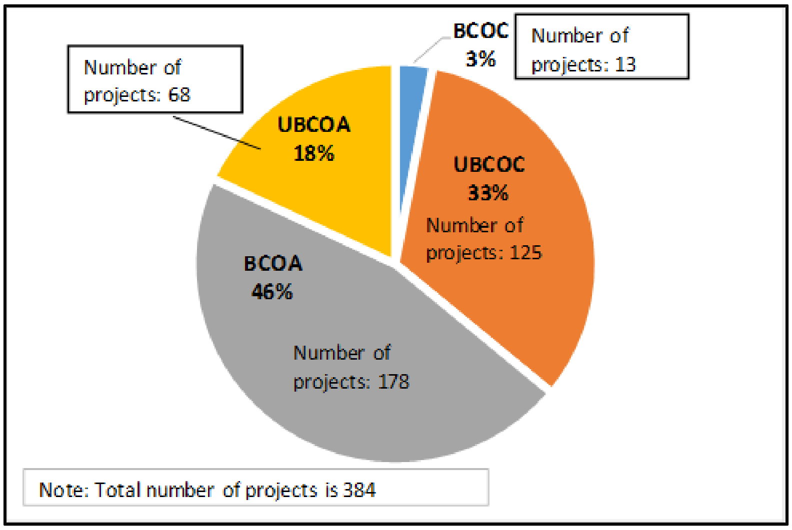


Figure 26. Distribution of overlay types based on number of projects

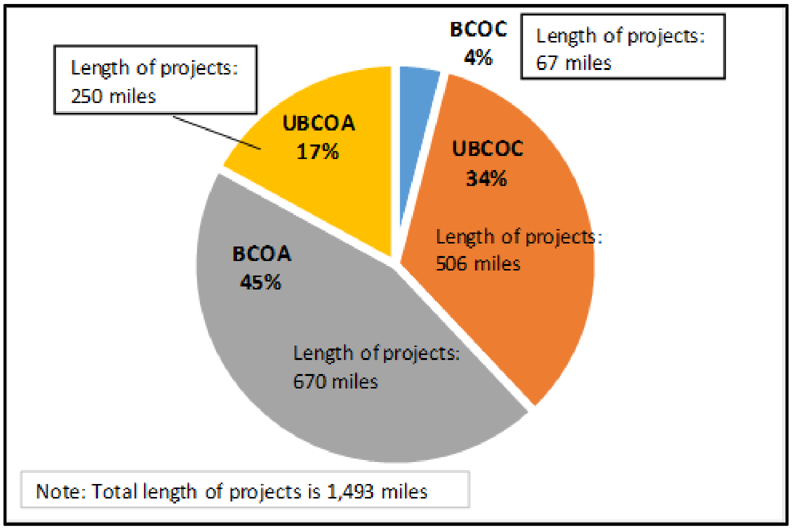


Figure 27. Distribution of overlay types based on length of projects

As shown in Table 8, 384 projects and 1,493 centerline miles of concrete overlay roads were in use and included in this study.

Table 8. Distribution of concrete overlay types

Type of Overlay	Total Number of Projects	Percent of Data Based on Number of Projects (%)	Project Length (mi)	Percent of Data Based on Length of Projects (%)
Bonded concrete on concrete (BCOC)	13	3	67	4
Unbonded concrete on concrete (UBCOC)	125	33	506	34
Bonded concrete on asphalt (BCOA)	178	46	670	45
Unbonded concrete on asphalt (UBCOA)	68	18	250	17
Total	**384**	**100**	**1,493**	**100**

It can be seen that 45% of all concrete overlay projects were BCOAs, 34% were UBCOCs, 17% were UBCOAs, and only 4% were BCOCs. Similar distributions could be observed in terms of concrete overlay project lengths.

Table 9 summarizes the different thicknesses of concrete overlays used in Iowa roadways.

Table 9. Distribution of concrete overlay thickness

PCC Slab Thickness (in.)	Total Number of Projects	Percent of Data Based on Number of Projects (%)	Project Length (mile)	Percent of Data Based on Length of Projects (%)
>3	8	2	20	1
4	50	13	283	19
5	36	9	178	11
6	185	48	626	42
7	42	11	177	12
8	51	13	159	11
9	8	2	45	3
10	3	1	4	1
12	1	0	1	0
Total	**384**	**100**	**1,493**	**100**

Of these projects, 95% reflect design thicknesses ranging from 4 to 8 in. Almost half (48%) of Iowa concrete overlay projects were 6 in. thick, 22% of the projects were 4 to 5 in. thick, and 24% of the projects were 7 to 8 in. thick. Similar distributions were observed with respect to concrete overlay project lengths.

Table 10 summarizes the various joint spacings in concrete overlays used in Iowa roadways.

Table 10. Distribution of concrete overlay joint spacing

Joint Spacing (ft)	Total Number of Projects	Percent of Data Based on Number of Projects (%)	Project Length (mile)	Percent of Data Based on Length of Projects (%)
< 5	4	1	39	3
5.5–6	46	12	238	16
7–11.5	21	5	77	5
12	115	30	291	19
12.5	6	2	14	1
13–14	4	1	38	3
15–20	185	48	786	53
30–40	3	0	10	0
Total	**384**	**100**	**1,493**	**100**

As shown in Table 10, although transverse joint spacing ranged from 3 to 40 ft, 90% of Iowa concrete overlay projects had joint spacings of 5.5 to 6, 12, or 15 to 20 ft. As shown in the table, 48% had joint spacings of 15 to 20 ft, 30% had joint spacing of 12 ft, and 12% had joint spacings of 5.5 to 6 ft.

However, the 12-ft transverse joint spacing data distribution was 19% based on project length, which is a 10% decrease compared to the distribution in terms of the number of projects. For5.5 to 6 ft and 15 to 20 ft transverse joint spacing, data distributions were 16% and 53% in terms of length of projects, respectively—a 9% increase compared to the distribution in terms of the number of projects.

Table 11 and Figures 28 through 32 summarize the PCI values of concrete overlays used on Iowa roadways.

Table 11. PCI rating for concrete overlay projects

PCI	Concrete Overlay: Percent of Data Based on Number of Projects (%)	BCOC: Percent of Data Based on Number of Projects (%)	UBCOC: Percent of Data Based on Number of Projects (%)	BCOA: Percent of Data Based on Number of Projects (%)	UBCOA: Percent of Data Based on Number of Projects (%)
81–100 (Excellent)	52	21	51	54	58
61–80 (Good)	37	51	39	34	36
41–60 (Fair)	8	21	6	9	6
21–40 (Poor)	3	7	4	3	0
0–20 (Very poor)	0	0	0	0	0
Total	**100**	**100**	**100**	**100**	**100**

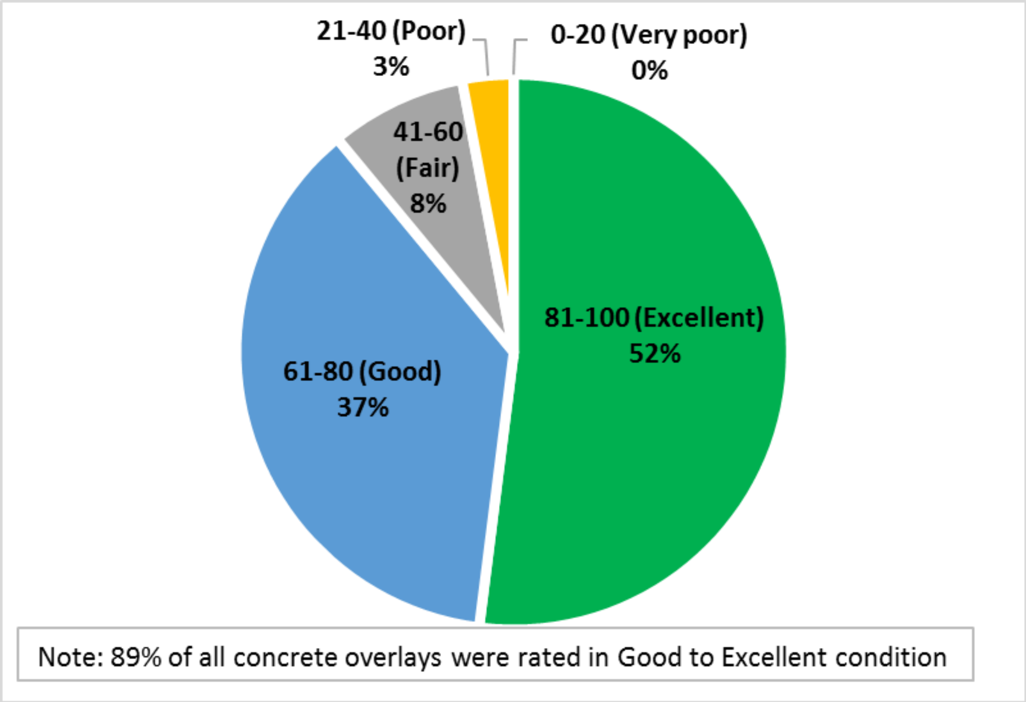


Figure 28. PCI rating of all concrete overlays

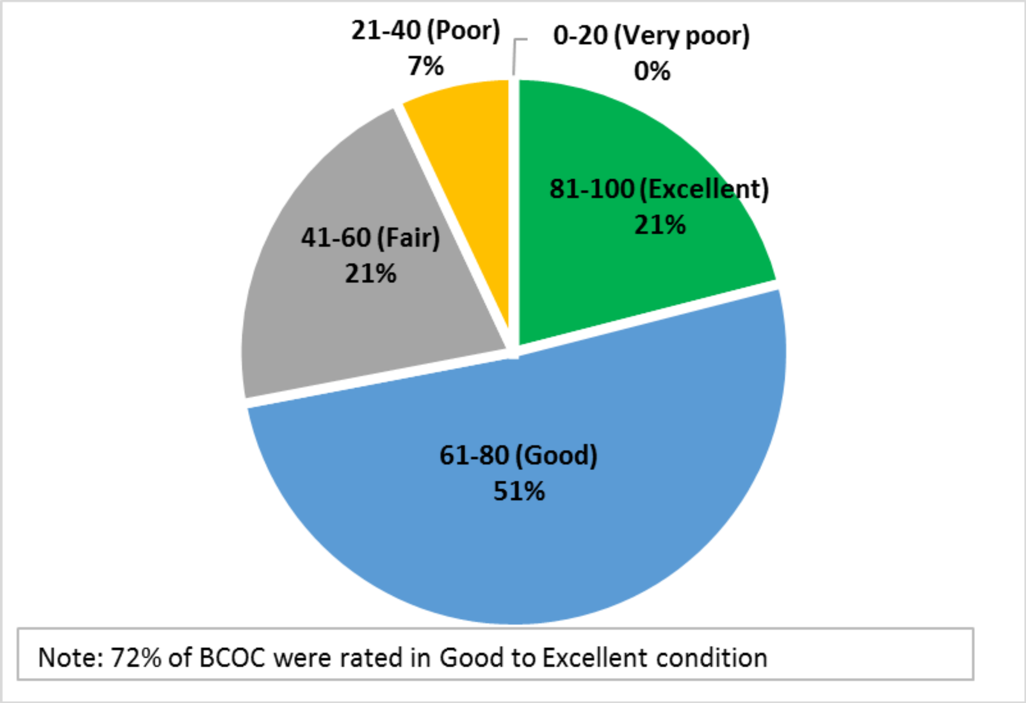


Figure 29. PCI rating of BCOC projects

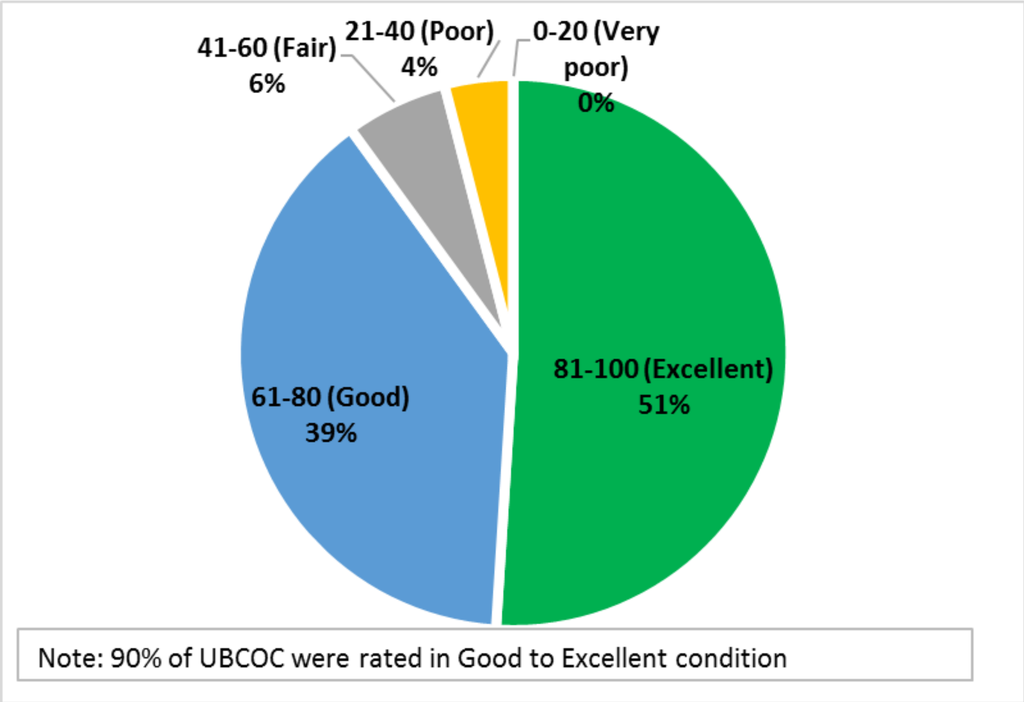


Figure 30. PCI rating of UBCOC projects

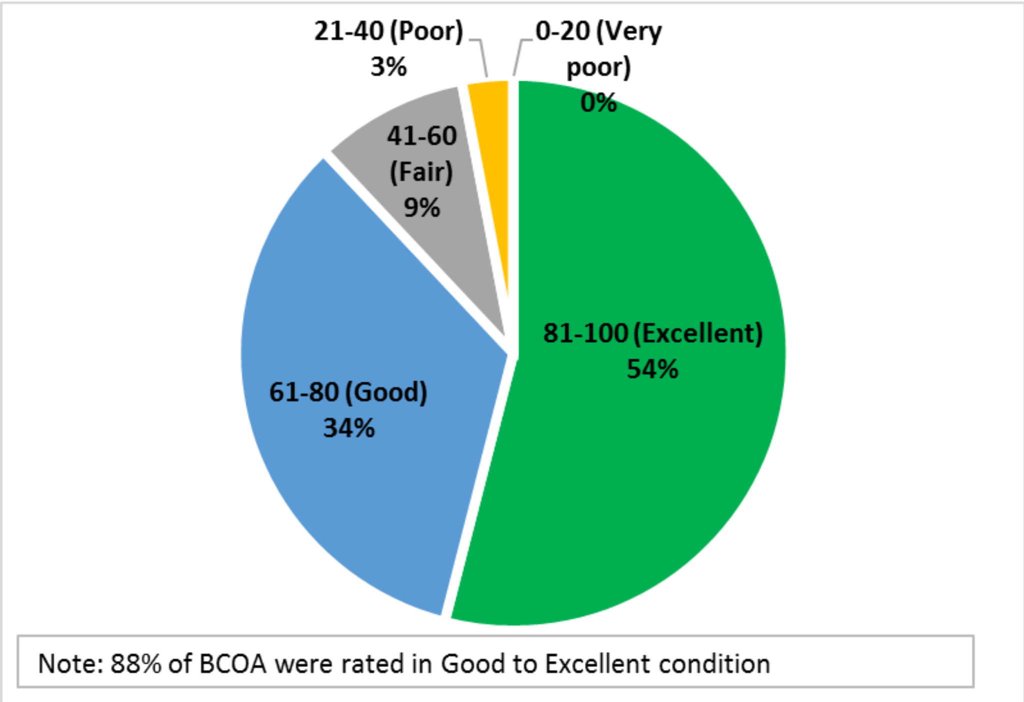


Figure 31. PCI rating of BCOA projects

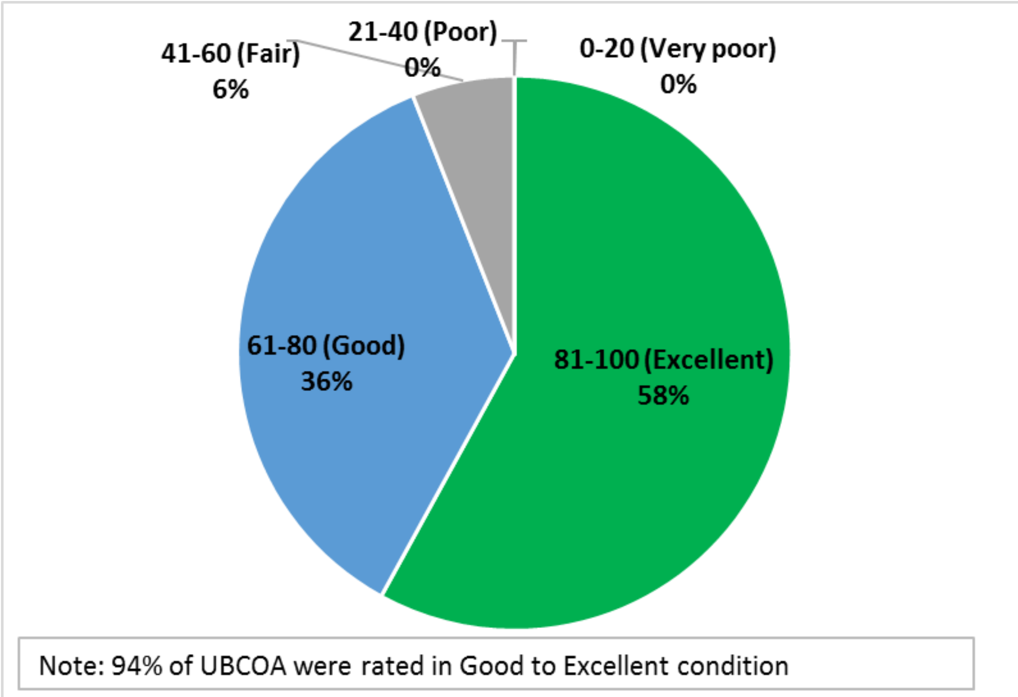


Figure 32. PCI rating of UBCOA projects

From Table 11 and Figure 28, based on PCI ratings it can be seen that 89% of all concrete overlays constructed in Iowa are rated as in good to excellent condition (i.e., in the 100 to 60 PCI range) in accordance with the IPMP. Among the different concrete overlay types, as shown in Figures 28 through 32:

- 72% of BCOCs were rated in good to excellent condition
- 90% of UBCOCs were rated in good to excellent condition
- 88% of BCOAs were rated in good to excellent condition
- 94% of UBCOAs were rated in good to excellent condition

Table 12 and Figure 33 through 37 summarize the IRI values of Iowa concrete overlays.

Table 12. IRI rating for concrete overlay projects

IRI (in/mi)	Concrete Overlay: Percent of Data Based on Number of Projects (%)	BCOC: Percent of Data Based on Number of Projects (%)	UBCOC: Percent of Data Based on Number of Projects (%)	BCOA: Percent of Data Based on Number of Projects (%)	UBCOA: Percent of Data Based on Number of Projects (%)
< 95 (Good)	30	40	28	28	40
96–169 (Acceptable)	63	50	65	66	53
> 170 (Not Acceptable)	7	10	7	6	7
Total	**100**	**100**	**100**	**100**	**100**

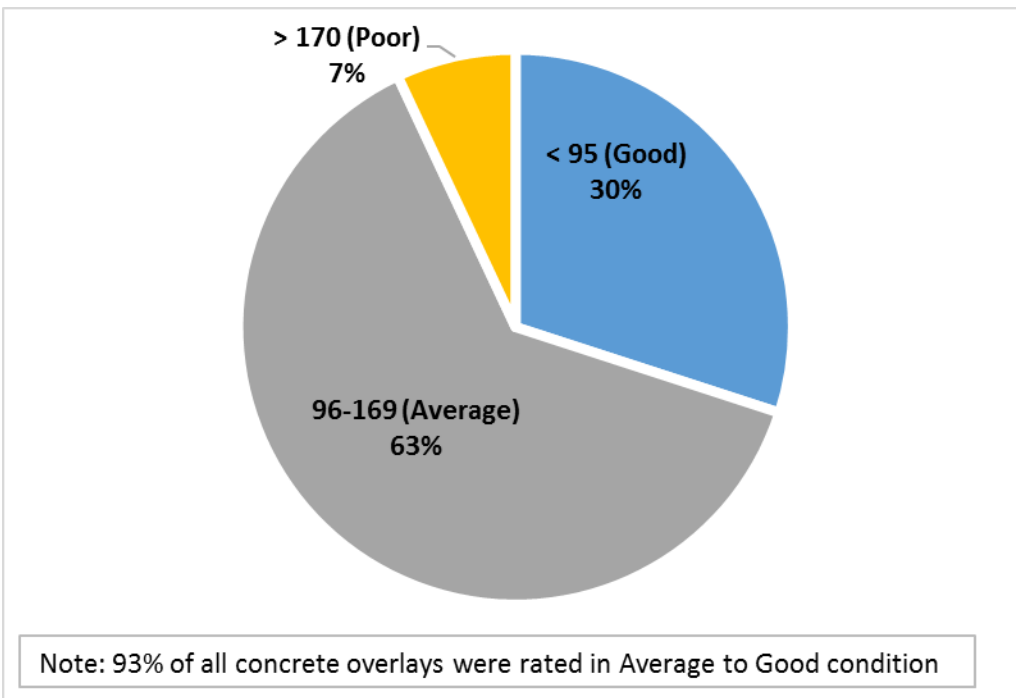


Figure 33. IRI rating of all concrete overlays

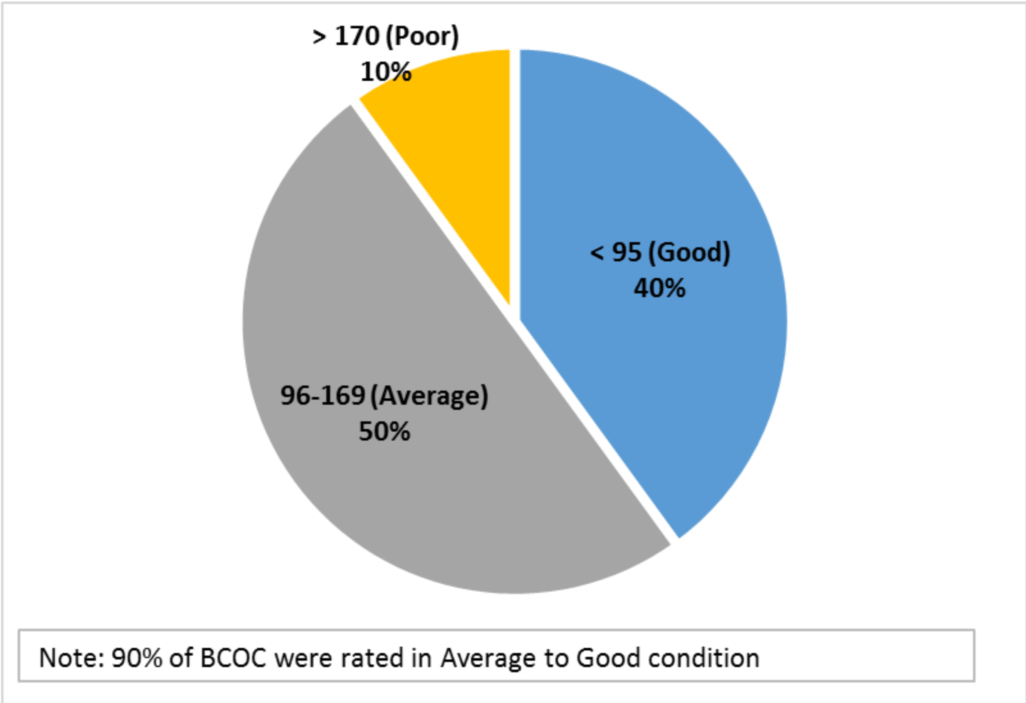


Figure 34. IRI rating of BCOC projects

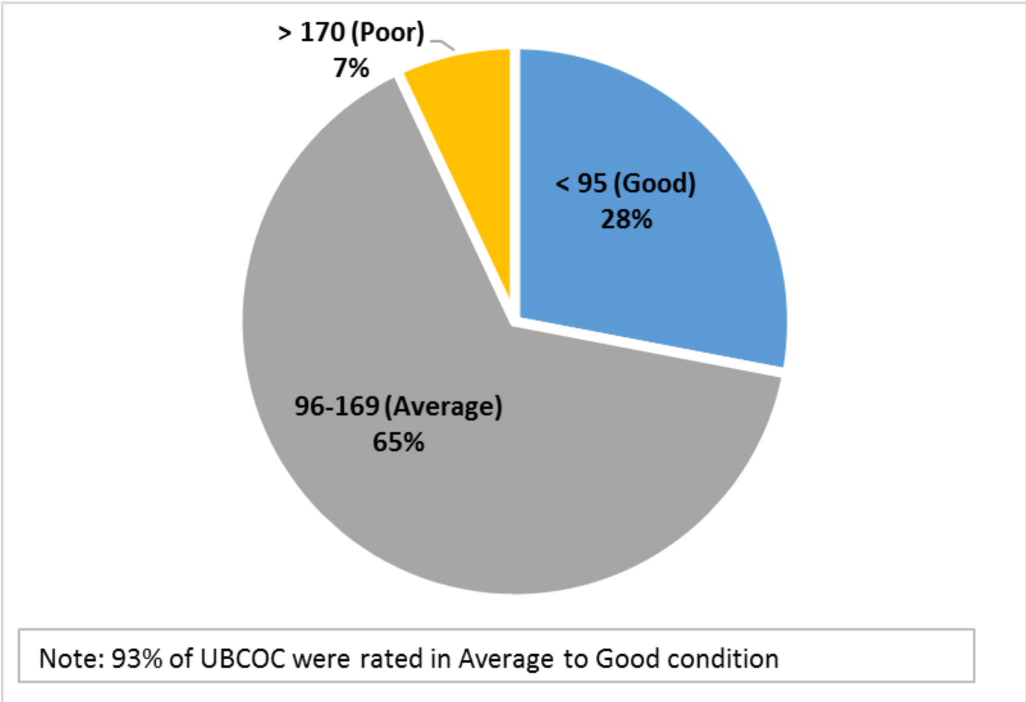


Figure 35. IRI rating of UBCOC projects

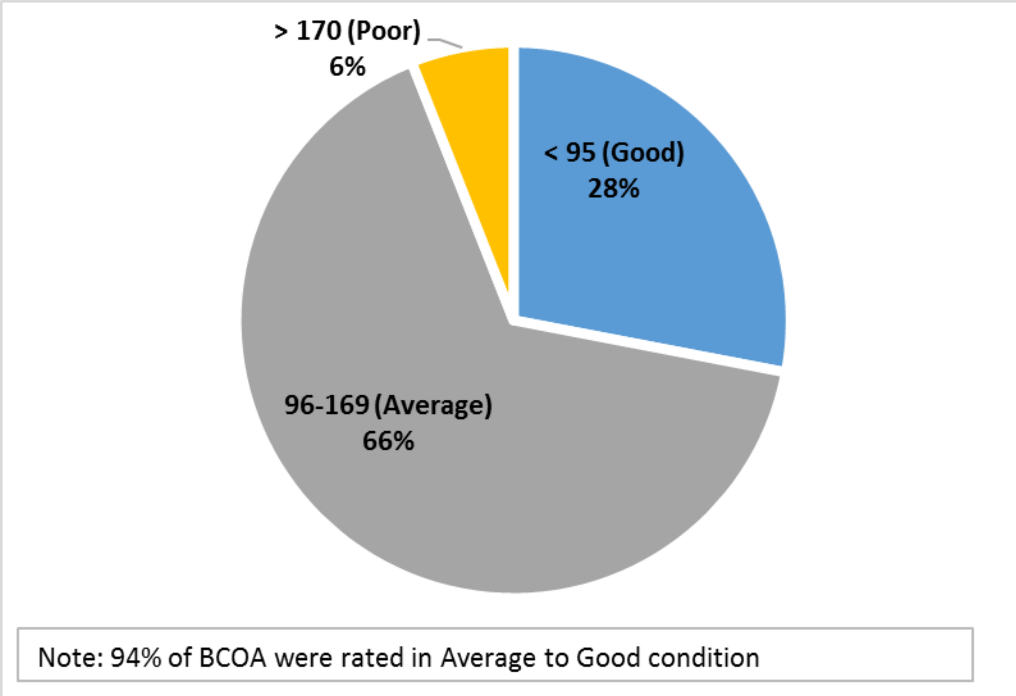


Figure 36. IRI rating of BCOA projects

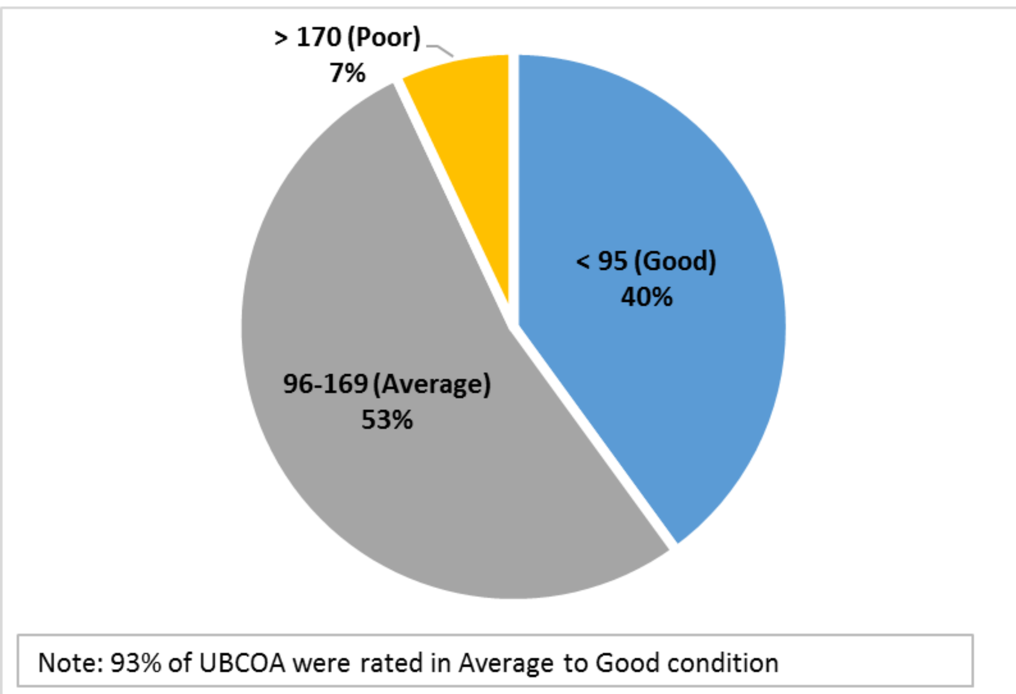


Figure 37. IRI rating of UBCOA projects

Based on IRI ratings, it can be seen that 93% of all concrete overlays constructed in Iowa are rated as being in acceptable to good condition (i.e., less than 170 in/mi of IRI ranges in accordance with the FHWA IRI threshold values). Among the different concrete overlay types, as shown in Figure 33 through 37, results are as follows:

- 90% of BCOCs were rated in acceptable to good condition
- 93% of UBCOCs were rated in acceptable to good condition
- 94% of BCOAs were rated in acceptable to good condition
- 93% of UBCOAs were rated in acceptable to good condition

4.2. Historical Performance Evaluation Results

4.2.1. Performance of Iowa Concrete Overlays Using All Data

Figure 38 and 39 illustrate historical IRI and PCI record distributions of Iowa concrete overlays over a period of 38 years (1977–2015).

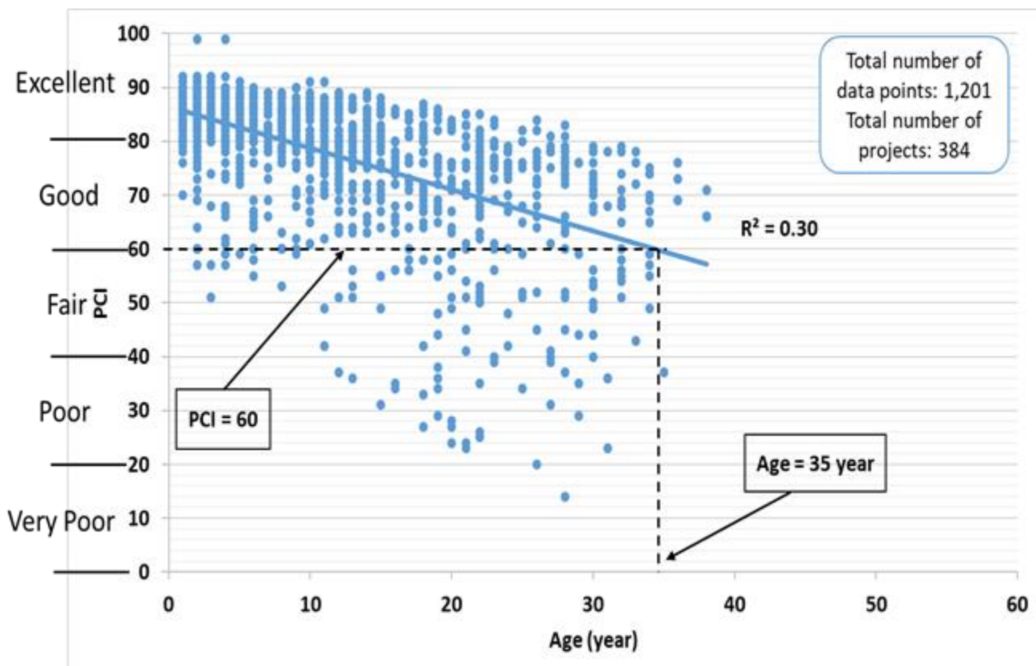


Figure 38. Iowa concrete overlay PCI performance history for all projects

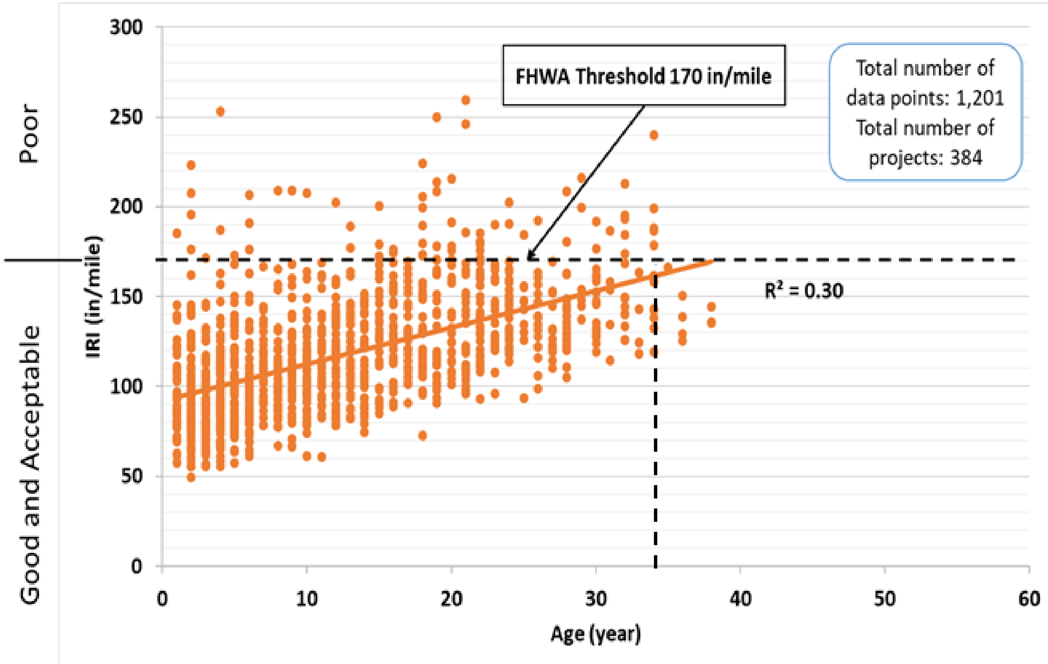


Figure 39. Iowa concrete overlay IRI performance history for all projects

As overlays age, the PCI data follows a downward linear trend, whereas the IRI data follows an upward linear trend. Linear trend lines were plotted in Figures 12 and 13, as well as the data plots in Figures 38 through 63. The trend lines serve as a guide to long-term performance and to relate pavement age to condition, but they may not fully capture long-term behavior. For example, the PCI will often begin to decline more rapidly with age rather than in a linear fashion. Because this data set encompasses comparatively fewer projects that have reached the absolute end of their service life compared to early- or intermediate-life, linear PCI trend lines generally provided the best fit. The key findings for the entire concrete overlay database are as follows:

- With respect to PCI values, a majority of overlays can be rated from excellent to good during the first 35 years of service life before the trend line reaches a PCI of 60.

- With respect to IRI values, a majority of overlays can be rated from good to acceptable during the first 37 years of service life, with the trend line remaining below 170 in/mi.

4.2.2. Performance of Iowa Concrete Overlays Based on Different PCC Slab Thickness

Figure 40 shows the changes in PCI values with age for five different concrete overlay thicknesses.

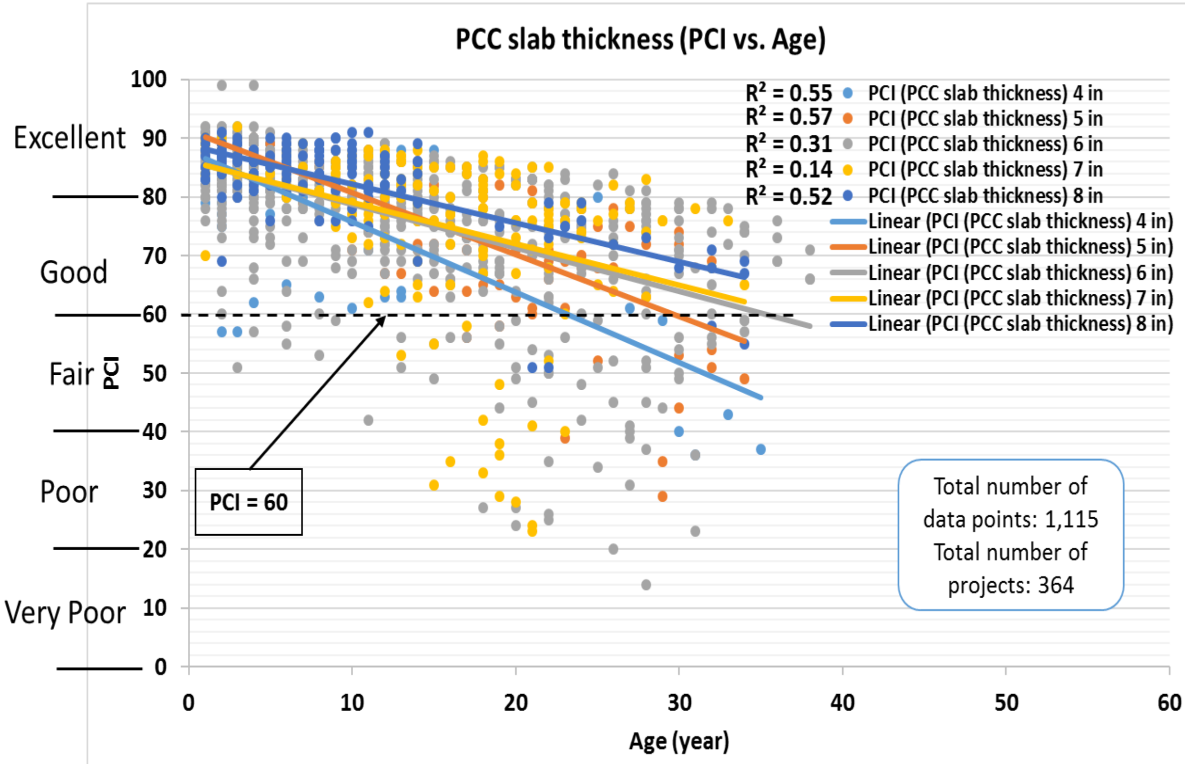


Figure 40. Iowa concrete overlay PCI performance history for five different concrete overlay thickness projects

The key findings for 4- to 8-in. concrete overlays are as follows:

- The PCI trend line for 4-in. thickness decreased gradually during the first 24 years of service life before dropping below 60.
- The PCI trend line for 5-in. thickness decreased gradually during the first 29 years of service life before dropping below 60.
- The PCI trend line for 6-in. thickness decreased gradually during the first 35 years of service life before dropping below 60.
- The PCI trend lines for 7-in. and 8-in. thicknesses decreased gradually but remained above 60 during the first 35 years of service life.
- Higher overlay thickness resulted in increased overlay service life.

Figure 41 shows changes in IRI values with age for five different concrete overlay thicknesses.

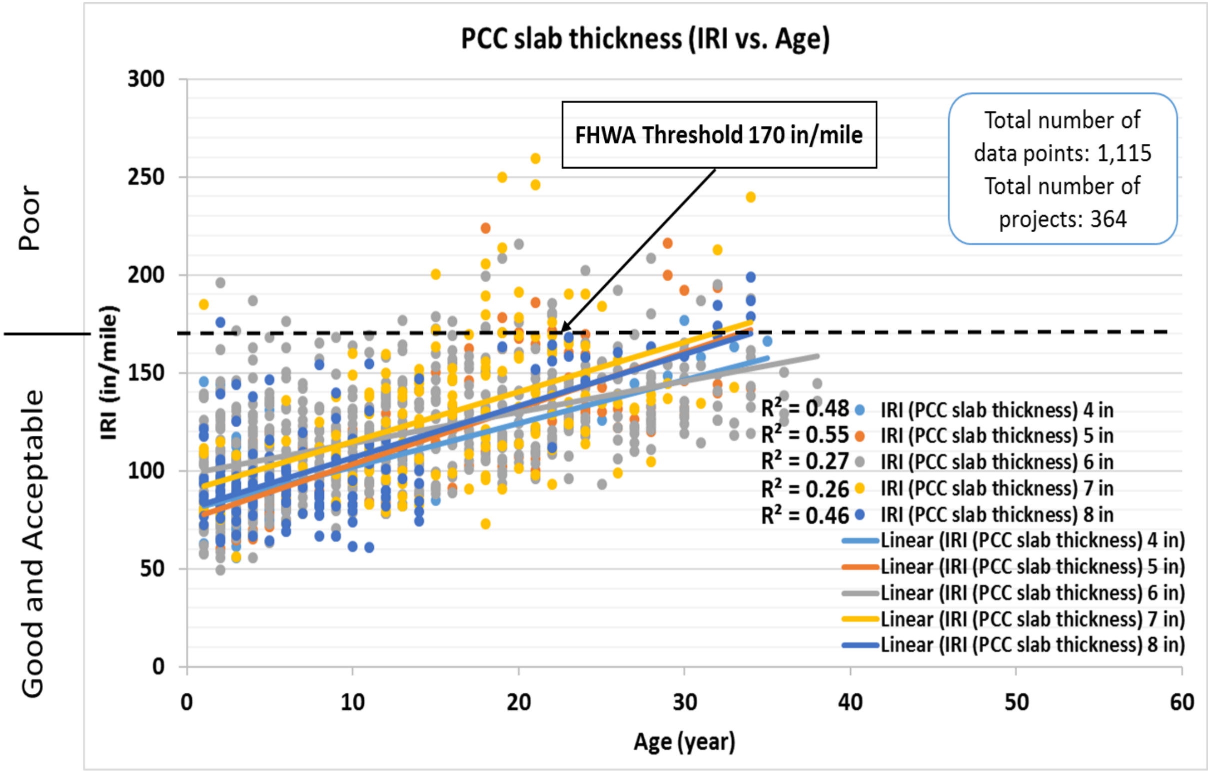


Figure 41. Iowa concrete overlay IRI performance history for five different concrete overlay thickness projects

The key findings for 4- to 8-in. concrete overlay thicknesses can be listed as follows:

- The IRI trend lines for 4-in. and 8-in. thicknesses increased gradually but remained below 170 in/mi over the first 35 years of service life.
- The IRI trend line for 5-in. thickness increased gradually over the first 33 years of service life before exceeding 170 in/mi.
- The IRI trend line for 6-in. thickness increased gradually but remained below 170 in/mi over the first 37 years of service life.
- The IRI trend line for 7-in. thickness increased gradually over the first 32 years of service life before exceeding 170 in/mi.

4.2.3. Performance of Iowa Concrete Overlays Based on Different Joint Spacing

Figure 42 presents changes in PCI values with age for four different concrete overlay joint spacing types.

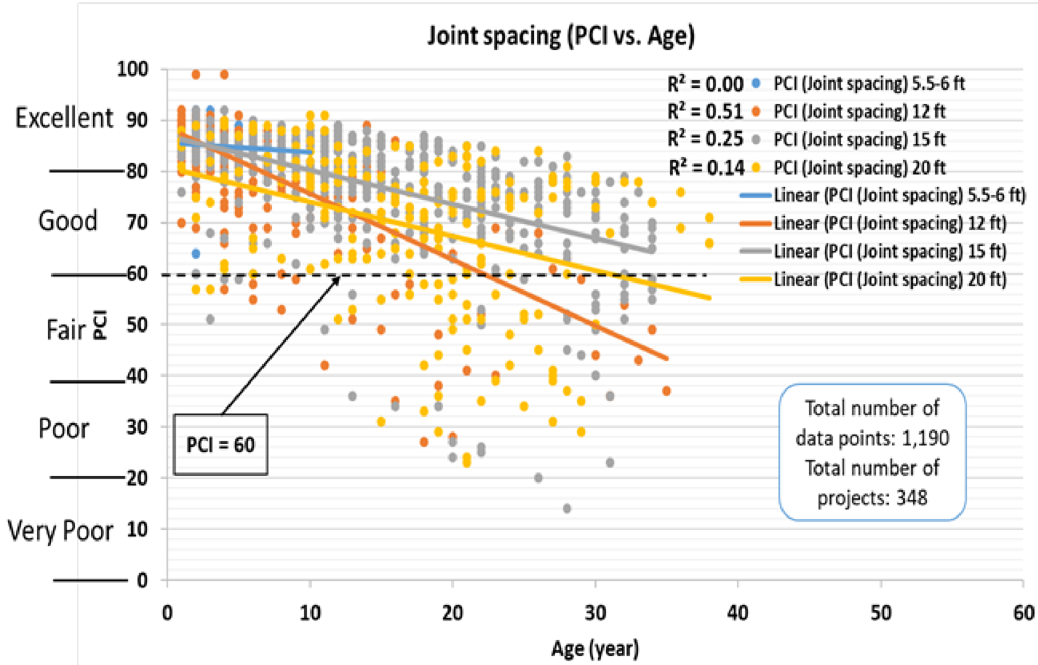


Figure 42. Iowa concrete overlay PCI performance history for four different concrete overlay joint spacing projects

The key findings for the overlay of 5.5- to 6-ft, 12-ft, 15-ft, and 20-ft joint spacing are as follows:

- The PCI trend line for 5.5- to 6-ft transverse joint spacing decreased modestly and remained above 80 during the first 10 years of service life.
- The PCI trend line for 12-ft transverse joint spacing decreased rapidly during the first 22 years of service life before dropping below 60.
- The PCI trend line for 15-ft transverse joint spacing decreased gradually but remained above 60 during the first 33 years of service life.
- The PCI trend line for 20-ft transverse joint spacing decreased gradually during the first 33 years of service life before dropping below 60.
- Shorter slab sizes have only been used since roughly 2004 and have exhibited good performance.
- PCI values for older Iowa concrete overlays (i.e., those after 20 years of life) have shown that larger slab sizes can provide good long-term performance.

Figure 43 presents changes in IRI values with age for four different concrete overlay joint spacing types.

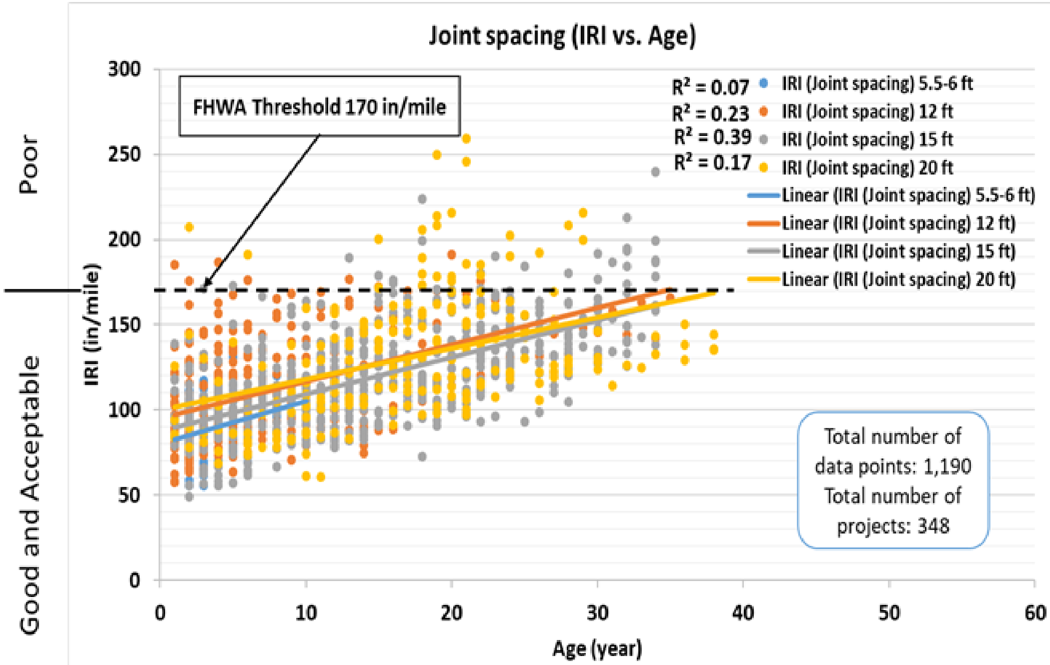


Figure 43. Iowa concrete overlay IRI performance history for four different concrete overlay joint spacing projects

The key findings for concrete overlay 5.5- to 6-ft, 12-ft, 15-ft, and 20-ft joint spacing projects are as follows:

- The IRI trend line for 5.5- to 6-ft transverse joint spacing increased with age but remained below 110 in/mi during the first 10 years of service life.
- The IRI trend line for 12-ft transverse joint spacing increased gradually during the first 35 years of service life before exceeding 170 in/mi.
- The IRI trend line for 15-ft transverse joint spacing increased gradually but remained below 170 in/mi during the first 35 years of service life.
- The IRI trend line for 20-ft transverse joint spacing increased gradually but remained below 170 in/mi during the first 37 years of service life.
- Most concrete overlay projects have maintained IRI values below 170 in/mi throughout their service life, and IRI trend lines were similar for all joint spacings.

- With respect to the IRI, overlays with shorter slab sizes (5.5 to 6 ft) exhibited good performance within the first 10 years of service life.

4.2.4. Performance of Bonded Concrete on Concrete (BCOC)

Table 13 and Table 14 summarize PCC overlay slab thickness and transverse joint spacing data for BCOC projects.

Table 13. Slab thickness summary for BCOCs

PCC Slab Thickness (in.)	Total Number of Projects	Total Number of Data Points
2	3	13
3	4	14
4	***6***	***18***

Values with bold and italic numbers were selected for evaluating historical performance of concrete overlays.

Table 14. Transverse joint spacing summary for BCOCs

Joint Spacing (ft)	Total Number of Projects	Total Number of Data Points
15	3	11
20	***9***	***31***
30	1	3

Values with bold and italic numbers were selected for evaluating historical performance of concrete overlays.

As shown in Table 13 and 14, some of the BCOC overlays lack sufficient points for effective data analysis, so BCOCs with a 4-in. thickness and 20-ft joint spacing were selected for evaluating historical performance.

Figure 44 through Figure 47 show that the PCI data follows a downward linear trend with age, whereas the IRI data changed very little with age.

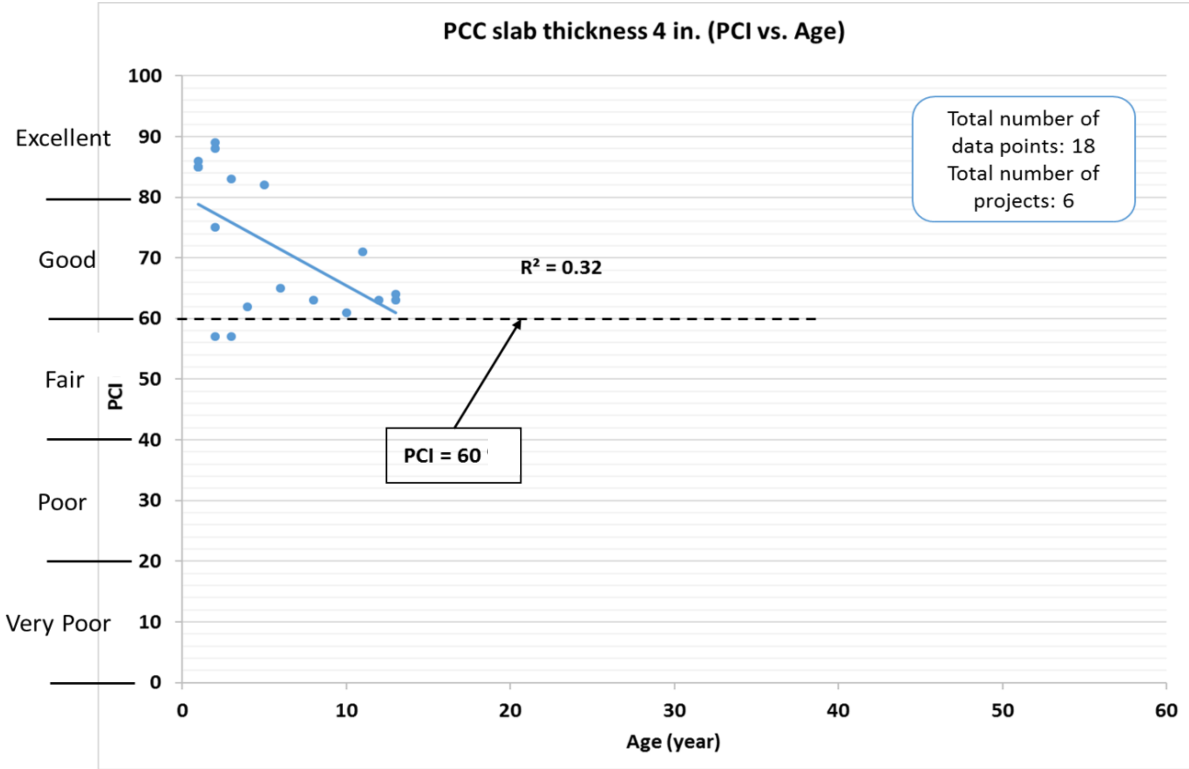


Figure 44. BCOC PCI performance history categorized by concrete overlay thickness

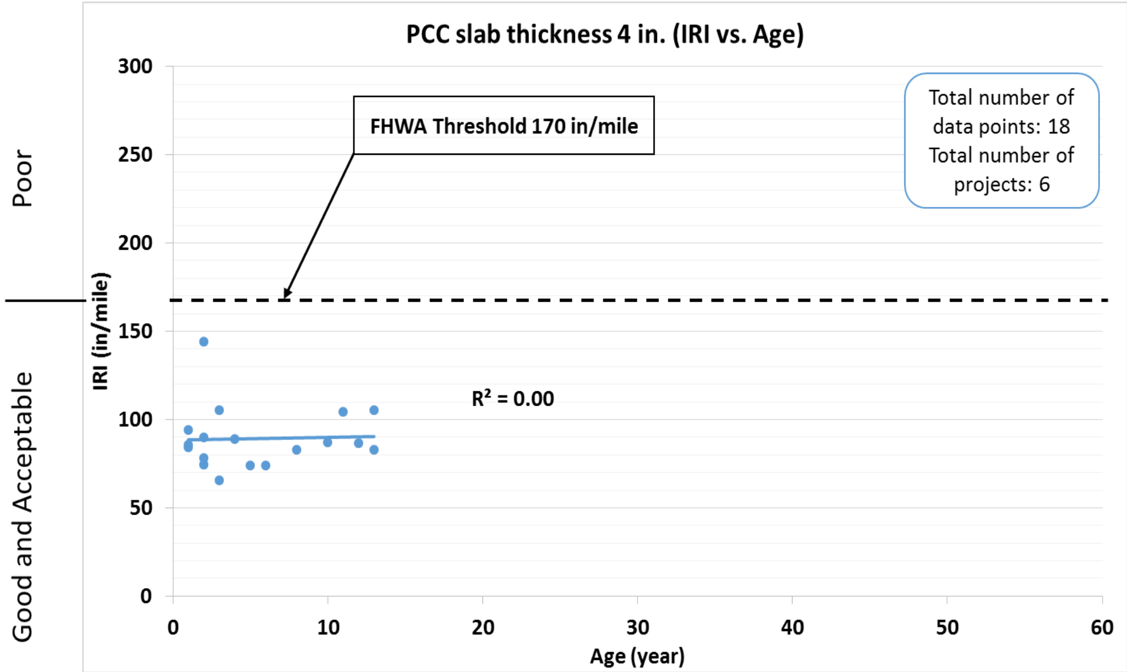


Figure 45. BCOC IRI performance history categorized by concrete overlay thickness

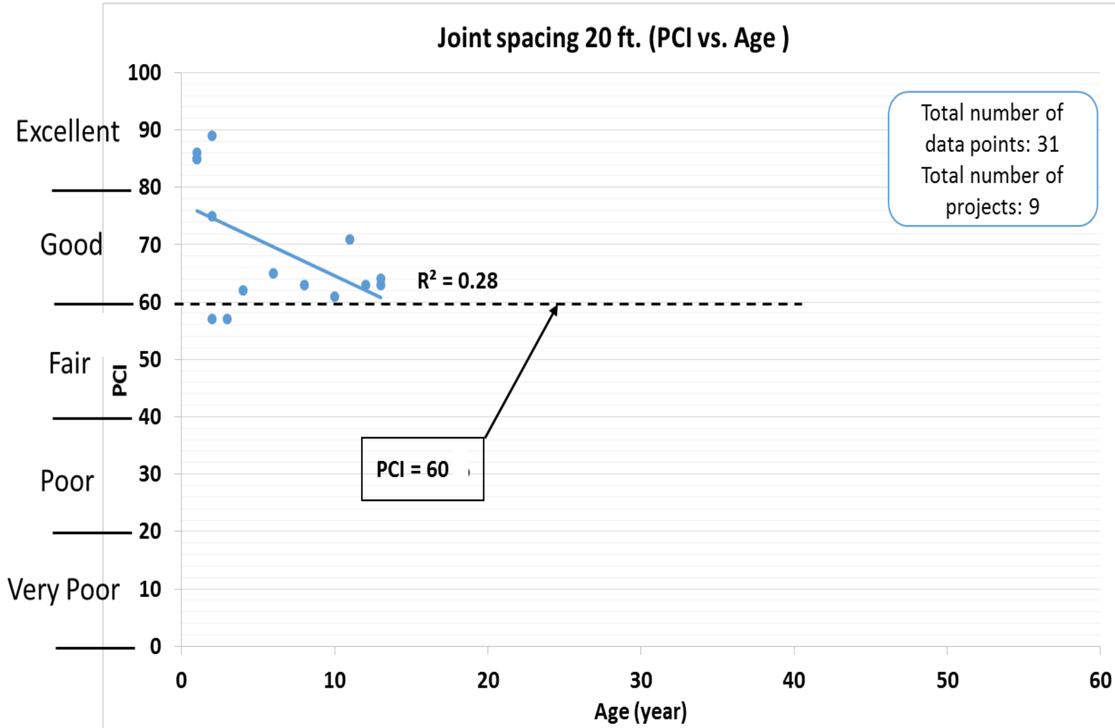


Figure 46. BCOC PCI performance history categorized by concrete overlay joint spacing

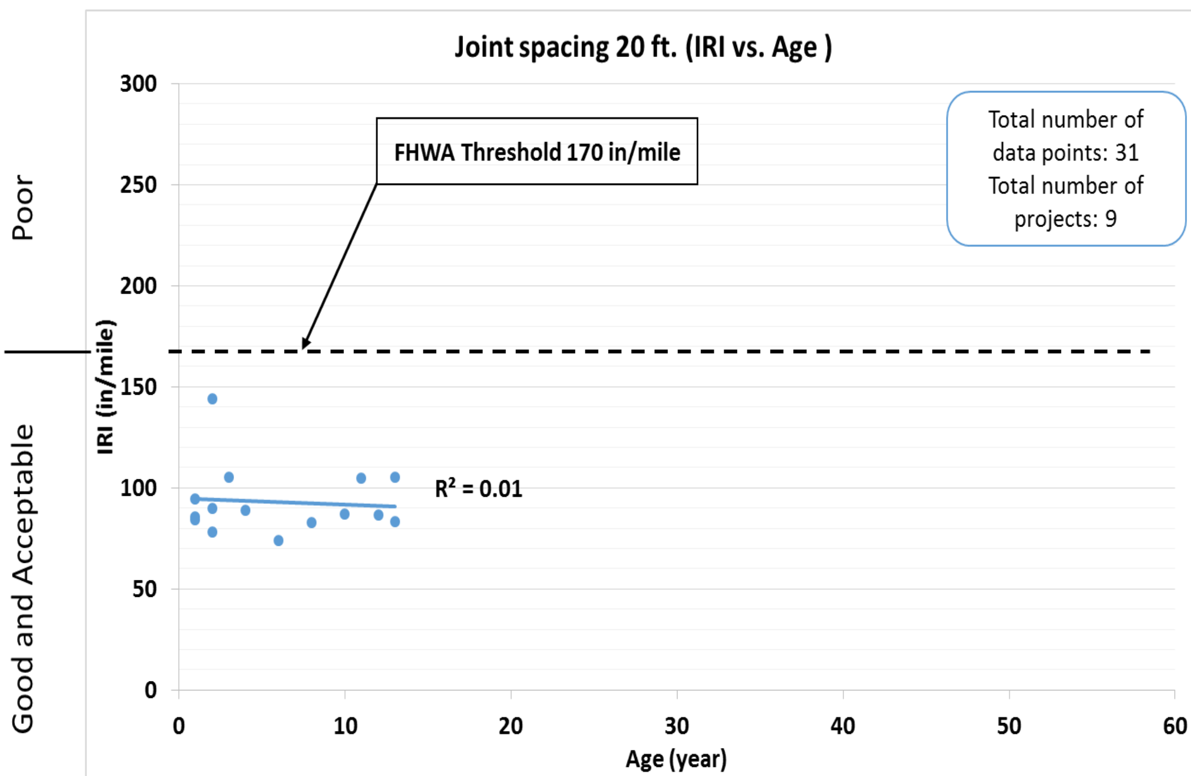


Figure 47. BCOC IRI performance history categorized by concrete overlay joint spacing

The key findings for the 4-in. thickness and 20-ft joint spacing of BCOC projects are summarized as follows:

- For 4-in. thickness of BCOCs:
  - The PCI trend line remained above 60 during the first 15 years of service life
  - The IRI trend line remained below 100 in/mi during the first 15 years of service life

- For 20-ft joint spacing of BCOCs:
  - The PCI trend line remained above 60 during the first 15 years of service life
  - The IRI trend line remained below 100 in/mi during the first 15 years of service life

4.2.5. Performance of Unbonded Concrete on Concrete (UBCOC)

Tables 15 and 16 summarize PCC slab thickness and transverse joint spacing data for UBCOC projects.

Table 15. Slab thickness summary for UBCOCs

PCC Slab Thickness (in.)	Total Number of Projects	Total Number of Data Points
4	3	7
5	***19***	***54***
6	***66***	***263***
7	***20***	***82***
8	***12***	***52***
9	4	23
10	1	2

Values with bold and italic numbers were selected for evaluating historical performance of concrete overlays.

Table 16. Joint spacing summary for UBCOCs

Joint Spacing (ft)	Total Number of Projects	Total Number of Data Points
4.5–5	3	8
5.5	2	3
6	2	12
7	1	4
8	1	1
10	5	9
11	2	14
12	***38***	***112***
12.5	3	33
15	***49***	***204***
20	***19***	***83***

Values with bold and italic numbers were selected for evaluating historical performance of concrete overlays.

As shown in Table 15, UBCOC thickness ranged from 4 to 10 in. There are insufficient data points for 4-in., 9-in., and 10-in. thicknesses, so 5- to 8-in. thick UBCOC overlays were selected for evaluating historical performance. As shown in Table 16, UBCOC overlays had joint spacings from 4.5 to 20 ft. Most UBCOC overlays used 12-ft, 15-ft, and 20-ft transverse joint spacings.

Figure 48 shows changes in PCI values with age for four different concrete overlay thicknesses.

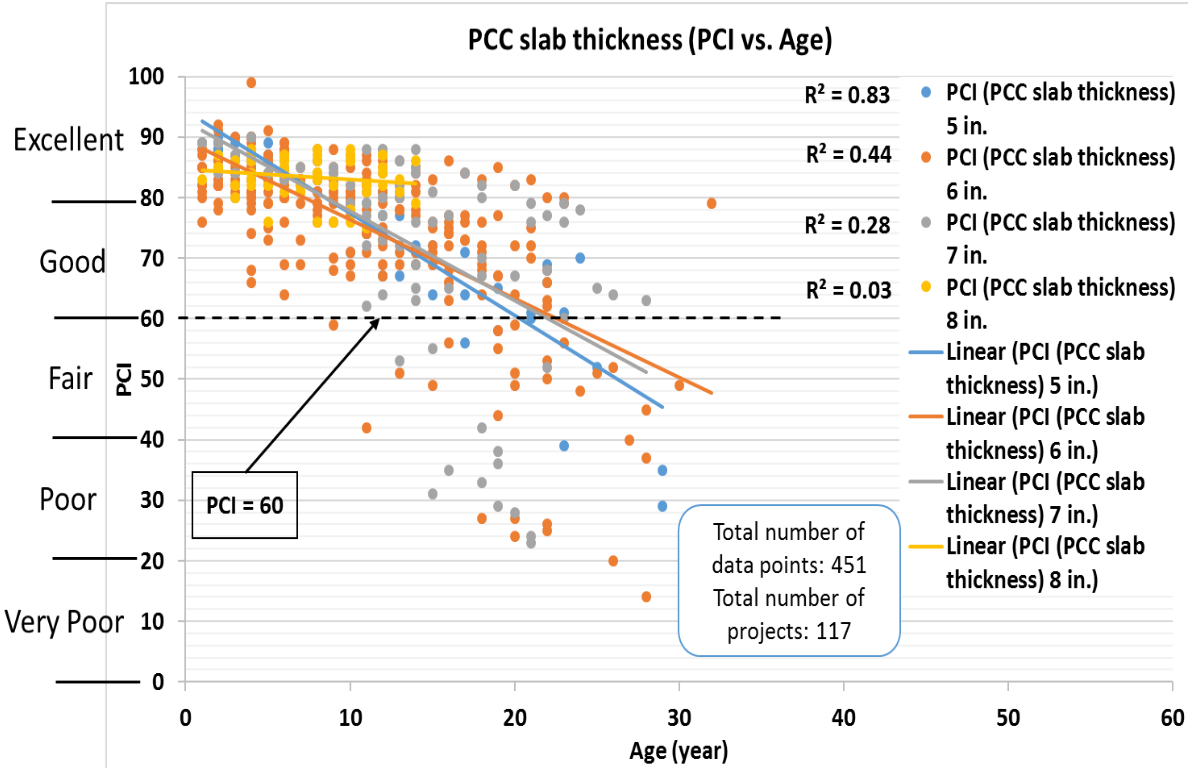


Figure 48. UBCOC PCI performance history categorized by concrete overlay thickness

The key findings for UBCOC projects with 5- to 8-in. thickness can be summarized as follows:

- The PCI trend line for 5-in. thickness decreased gradually during the first 20 years of service life before dropping below 60.
- The PCI trend line for 6-in. thickness decreased gradually during the first 22 years of service life before dropping below 60.
- The PCI values trend line for 7-in. thickness decreased gradually during the first 22 years of service life before dropping below 60.
- The PCI values trend line for 8-in. thickness remained above 80 during the first 15 years of service life.
- Higher overlay thickness led to increased overlay service life.

Figure 49 shows changes in IRI values with age for four different concrete overlay thicknesses.

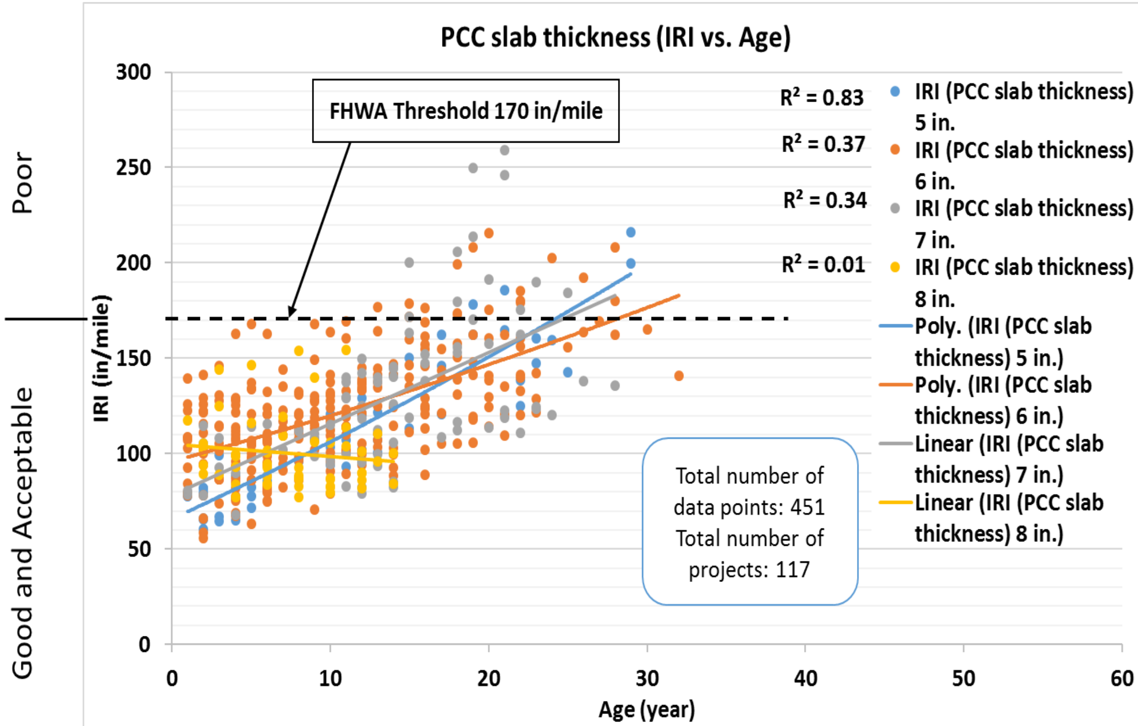


Figure 49. UBCOC IRI performance history categorized by concrete overlay thickness

The key findings for the UBCOC projects with 5- to 8-in. thickness can be summarized as follows:

- The IRI trend line for 5-in. thickness increased gradually during the first 24 years of service life before exceeding 170 in/mi.
- The IRI trend line for 6-in. thickness increased gradually during the first 28 years of service life before exceeding 170 in/mi.
- The IRI trend line for 7-in. thickness increased gradually during the first 25 years of service life before exceeding170 in/mi.
- The IRI values trend line for 8-in. thickness remained below 120 in/mi during the first 15 years of service life.
  - The IRI trend line for this data set appears to be trending in the opposite direction as expected—i.e., smoothness slightly increasing over time. The collection method changed from a point laser to band laser around 2010–2011. This resulted in a minimal decrease (5–10 in/mi) in IRI for many concrete pavements. With a small data set in which values were relatively constant, this change likely caused the data to trend in the opposite direction as expected.

Figure 50 presents changes in PCI values with age for three different concrete overlay joint spacings.

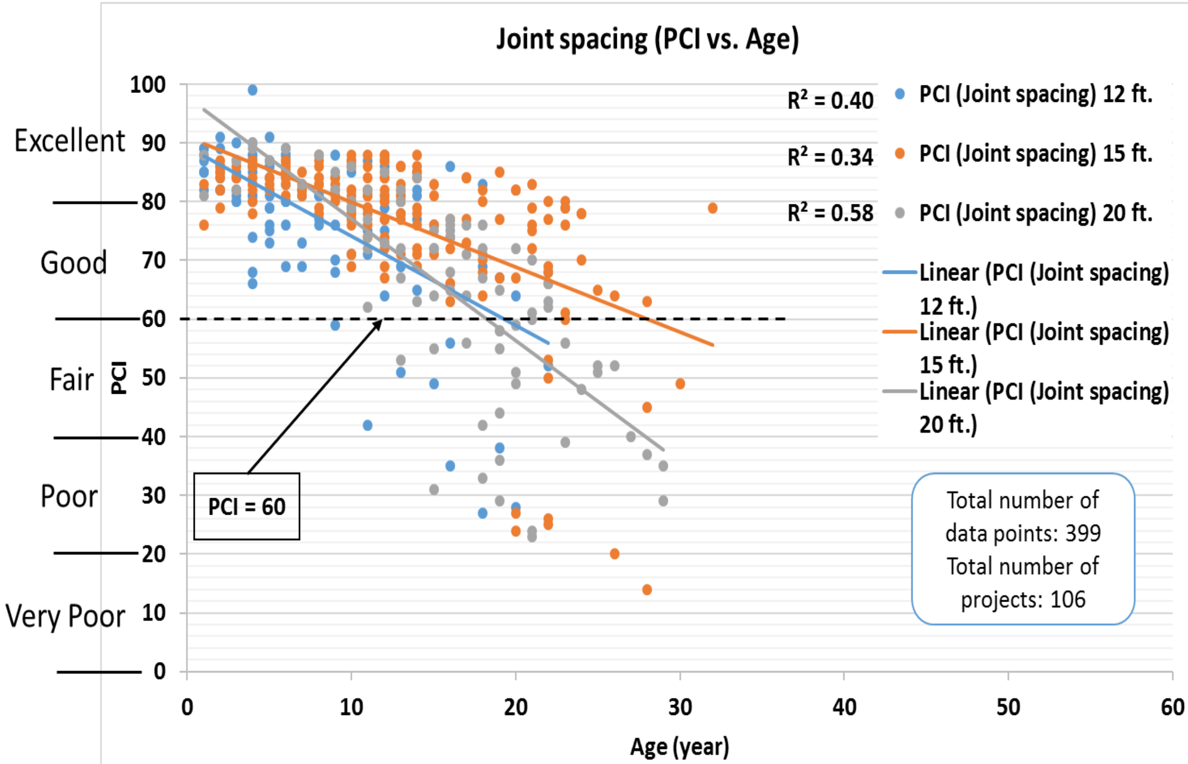


Figure 50. UBCOC PCI performance history categorized by concrete overlay joint spacing

The key findings for UBCOC 12-ft, 15-ft, and 20-ft joint spacing projects can be summarized as follows:

- The PCI trend line for 12-ft transverse joint spacing decreased rapidly during the first 20 years of service life before dropping below 60.
- The PCI trend line for 15-ft transverse joint spacing decreased gradually during the first 28 years of service life before dropping below 60.
- The PCI trend line for 20-ft transverse joint spacing decreased rapidly during the first 19 years of service life before dropping below 60.

Figure 51 presents changes in IRI values with age for three different concrete overlay joint spacings.

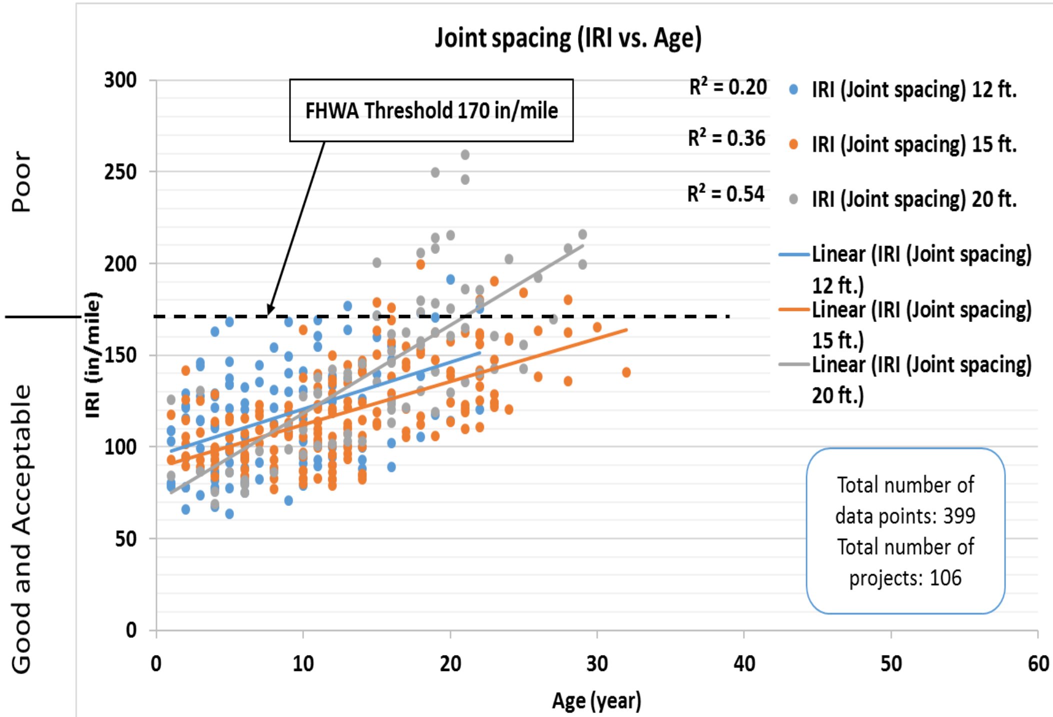


Figure 51. UBCOC IRI performance history categorized by concrete overlay joint spacing

The key findings for UBCOC 12-ft, 15-ft, and 20-ft joint-spacing projects can be summarized as follows:

- The IRI trend line for 12-ft transverse joint spacing increased gradually but remained below 170 in/mi during the first 20 years of service life.
- The IRI values trend line for 15-ft transverse joint spacing increased gradually but remained below 170 in/mi during the first 32 years of service life.
- The IRI values trend line for 20-ft transverse joint spacing increased gradually during the first 20 years of service life before exceeding 170 in/mi.

4.2.6. Performance of Bonded Concrete on Asphalt (BCOA)

Tables 17 and 18 summarize the PCC slab thickness and transverse joint spacing data for BCOA projects.

Table 17. Slab thickness summary for BCOAs

PCC Slab Thickness (in.)	Total Number of Projects	Total Number of Data Points
3	1	7
4	***41***	***49***
5	***17***	***55***
6	***119***	***363***

Values with bold and italic numbers were selected for evaluating historical performance of concrete overlays.

Table 18. Joint spacing summary for BCOAs

Joint Spacing (ft)	Total Number of Projects	Total Number of Data Points
3	1	**7**
5.5	***36***	***35***
6	***7***	***6***
10	7	12
11	4	6
11.5	1	1
12	***53***	***127***
12.5	1	4
13	1	3
15	***53***	***198***
20	***13***	***62***
40	2	11

Values with bold and italic numbers were selected for evaluating historical performance of concrete overlays.

As shown in Table 17, BCOA design thickness ranged from 3 to 6 in., although 3-in. thickness data points are sparse, so BCOA projects with 4- to 6-in. thickness were selected for evaluating historical performance. As shown in Table 18, BCOA designed joint spacings ranged from 3 to 40 ft, and most of the projects and data points used 5.5- to 6-ft, 12-ft, 15-ft, and 20-ft transverse joint spacings.

Figure 52 shows changes in PCI values with age for three different concrete overlay thicknesses.

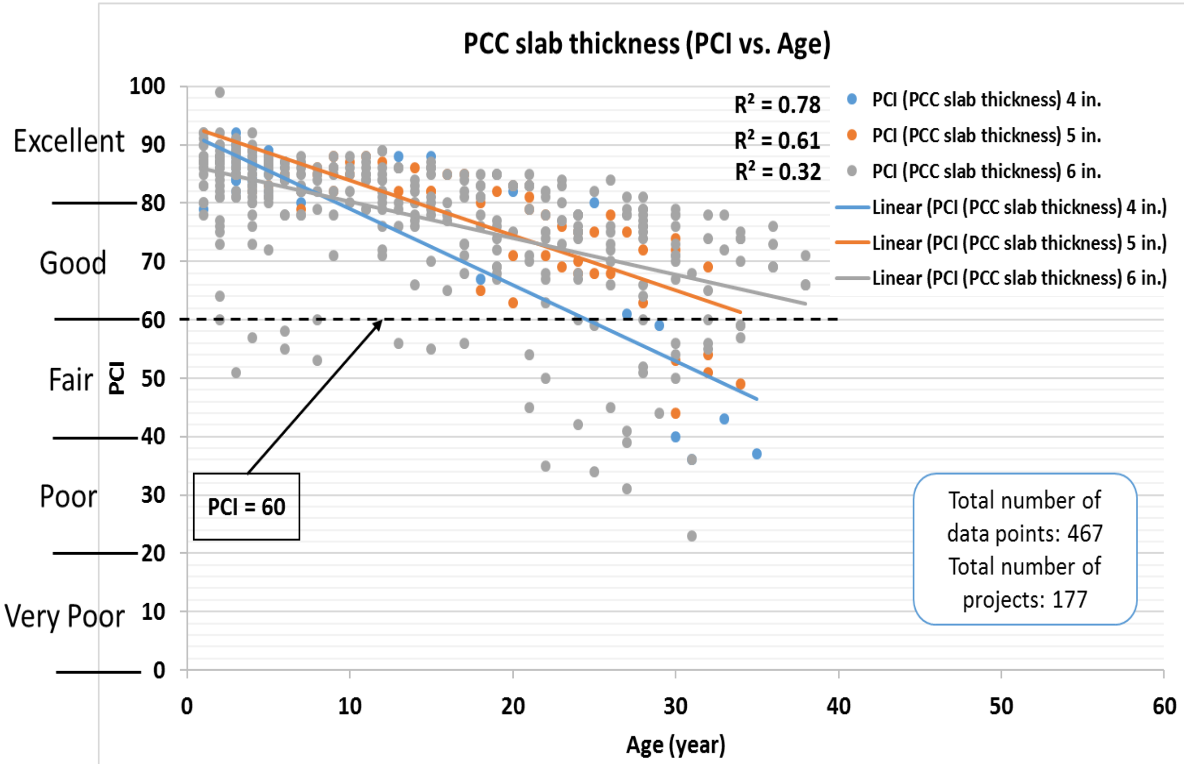


Figure 52. BCOA PCI performance history categorized by concrete overlay thickness

The key findings for BCOA projects with 4- to 6-in. thickness can be summarized as follows:

- The PCI trend line for 4-in. thickness decreased gradually during the first 25 years of service life before dropping below 60.
- The PCI trend line for 5-in. thickness decreased gradually but remained above 60 during the first 35 years of service life.
- The PCI trend line for 6-in. thickness decreased gradually but remained above 60 during the first 37 years of service life.
- Higher overlay thickness led to increased service life.

Figure 53 shows changes in IRI values with age for three different concrete overlay thicknesses.

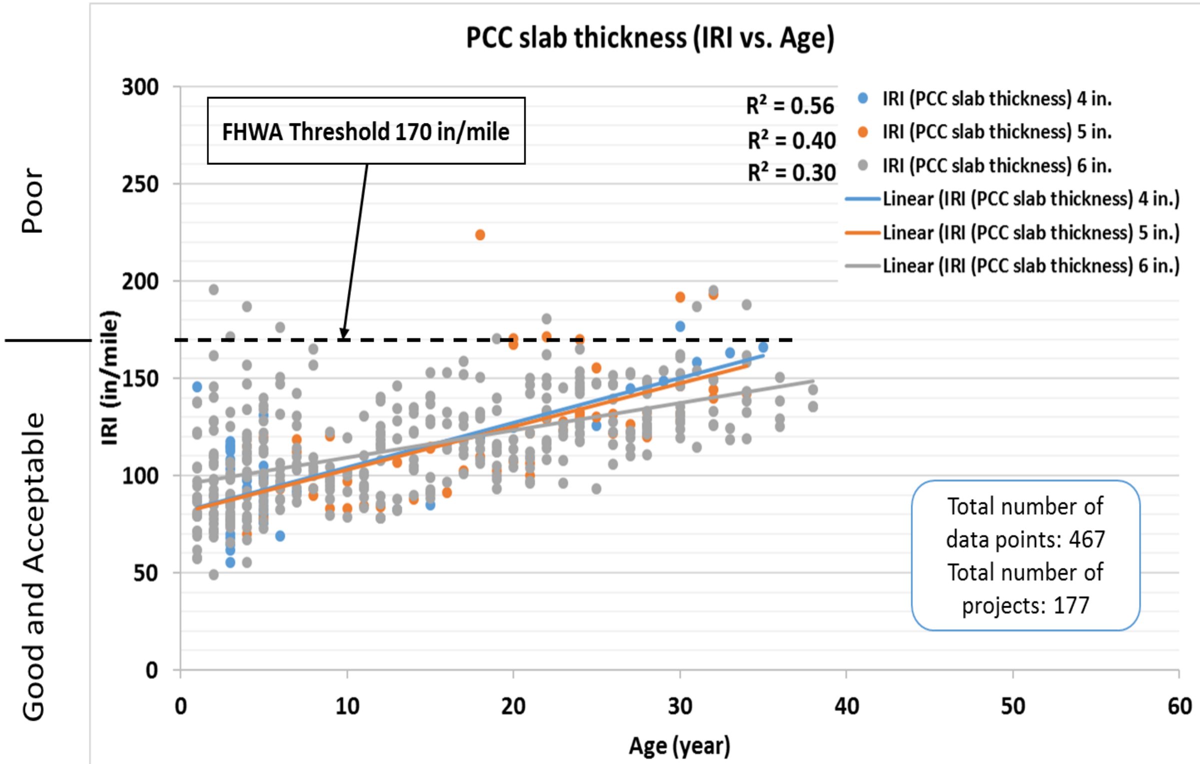


Figure 53. BCOA IRI performance history categorized by concrete overlay thickness

The key findings for the BCOA projects with 4- to 6-in. thickness can be summarized as follows:

- The IRI trend line for 4-in. thickness increased gradually but remained below 170 in/mi during the first 35 years of service life.
- The IRI trend line for 5-in. thickness increased gradually but remained below 170 in/mi during the first 35 years of service life.
- The IRI values trend line for 6-in. thickness increased gradually but remained below 170 in/mi during the first 37 years of service life.

Figure 54 presents changes in PCI values with age for four different concrete overlay joint spacings.

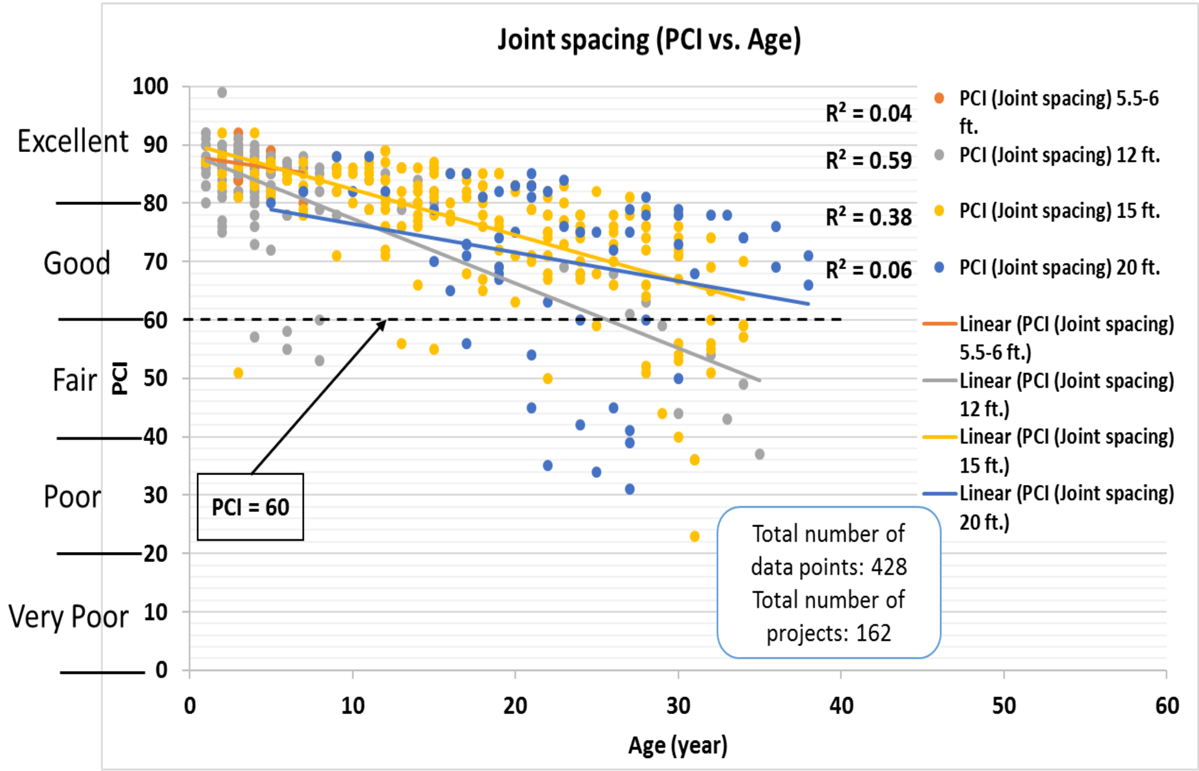


Figure 54. BCOA PCI performance history categorized by concrete overlay joint spacing

The key findings for BCOA 5.5- to 6-ft, 12-ft, 15-ft, and 20-ft joint spacing projects can be summarized as follows:

- The PCI trend line for 5.5- to 6-ft transverse joint spacing decreased modestly and remained above 80 during the first 10 years of service life.
- The PCI trend line for 12-ft transverse joint spacing decreased rapidly during the first 25 years of service life before dropping below 60.
- The PCI trend line for 15-ft transverse joint spacing decreased gradually during the first 35 years of service life before dropping below 60.
- The PCI values trend line for 20-ft transverse joint spacing decreased gradually but remained above 60 during the first 37 years of service life.

Figure 55 presents changes in IRI values with age for four different concrete overlay joint spacings.

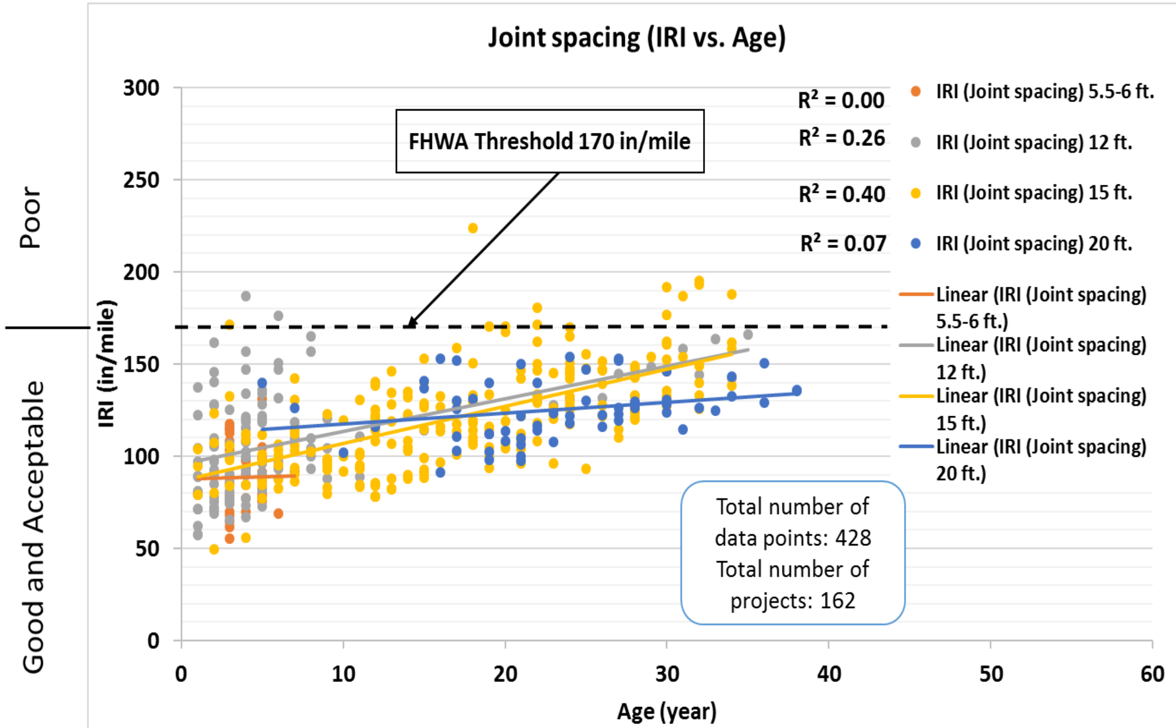


Figure 55. BCOA IRI performance history categorized by concrete overlay joint spacing

The key findings for BCOA 5.5- to 6-ft, 12-ft, 15-ft, and 20-ft joint spacing projects can be summarized as follows:

- The IRI trend line for 5.5- to 6-ft transverse joint spacing increased modestly and remained below 100 in/mi during the first 10 years of service life.
- The IRI trend line for 12-ft transverse joint spacing increased gradually and remained below 170 in/mi during the first 35 years of service life.
- The IRI trend line for 15-ft transverse joint spacing increased gradually and remained below 170 in/mi during the first 35 years of service life.
- The IRI trend line for 20-ft transverse joint spacing increased modestly and remained below 140 in/mi during the first 37 years of service life.

4.2.7. Performance of Unbonded Concrete on Asphalt (UBCOA)

Tables 19 and 20 summarize the PCC slab thicknesses and transverse joint spacings for UBCOA projects.

Table 19. Slab thickness summary for UBCOAs

PCC Slab Thickness (in.)	Total Number of Projects	Total Number of Data Points
7	***22***	***82***
8	***39***	***90***
9	4	17
10	3	26
12	1	3

Values with bold and italic numbers were selected for evaluating historical performance of concrete overlays.

Table 20. Joint spacing summary for UBCOAs

Joint Spacing (ft)	Total Number of Projects	Total Number of Data Points
12	***24***	***43***
12.5	2	2
14	3	17
15	***31***	***112***
20	***8***	***28***

Values with bold and italic numbers were selected for evaluating historical performance of concrete overlays.

As shown in Table 19, UBCOA design thickness ranged from 7 to 12 in. There were insufficient data points for 9-in., 10-in., and 12-in. thicknesses, so the UBCOA types selected for evaluating historical performances were 7-in. and 8-in. thick overlays. As shown in Table 20, UBCOA joint spacing ranged from 12 to 20 ft, and most of the projects and data points were for 12-ft, 15-ft, and 20-ft transverse joint spacing.

Figure 56 shows the changes in PCI values with age for two different concrete overlay thicknesses.

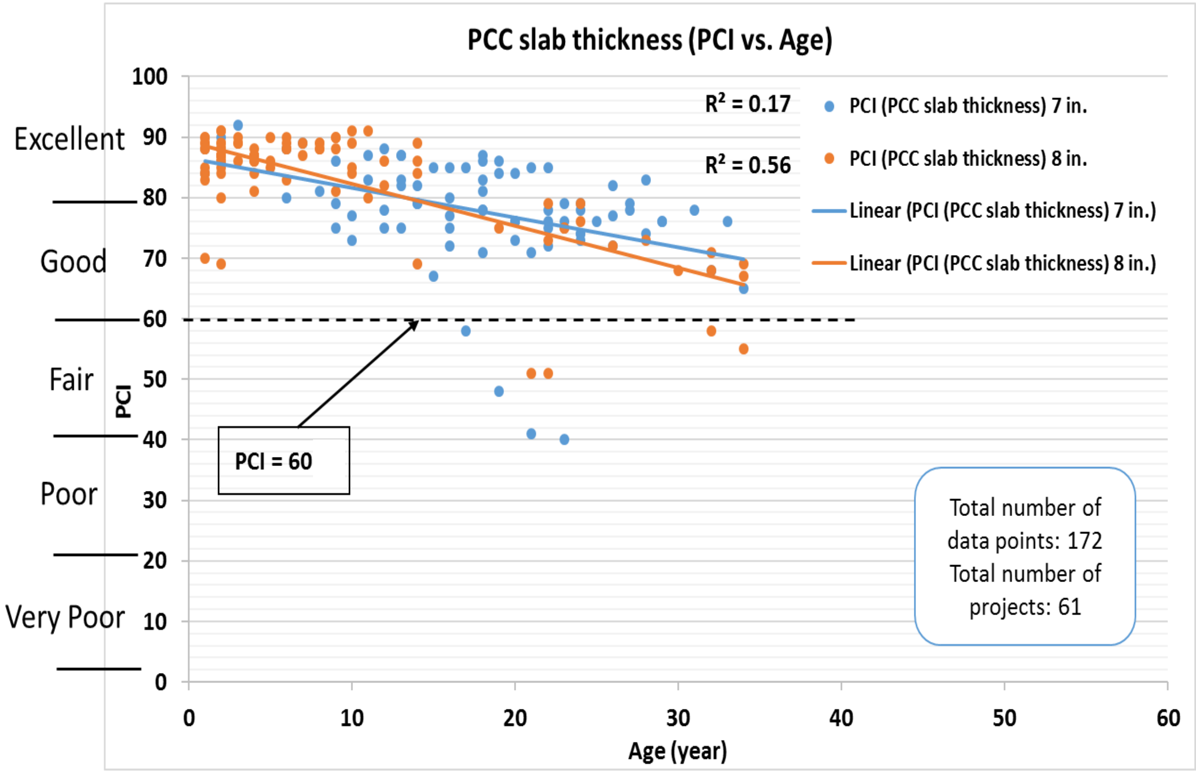


Figure 56. UBCOA PCI performance history categorized by concrete overlay thickness

The key finding for the UBCOA 7-in. and 8-in. thickness projects can be summarized as follows:

- The PCI values trend line for 7-in. and 8-in. thicknesses decreased gradually but remained above 60 during the first 35 years of service life.

Figure 57 shows changes in IRI values with age for two different concrete overlay thicknesses.

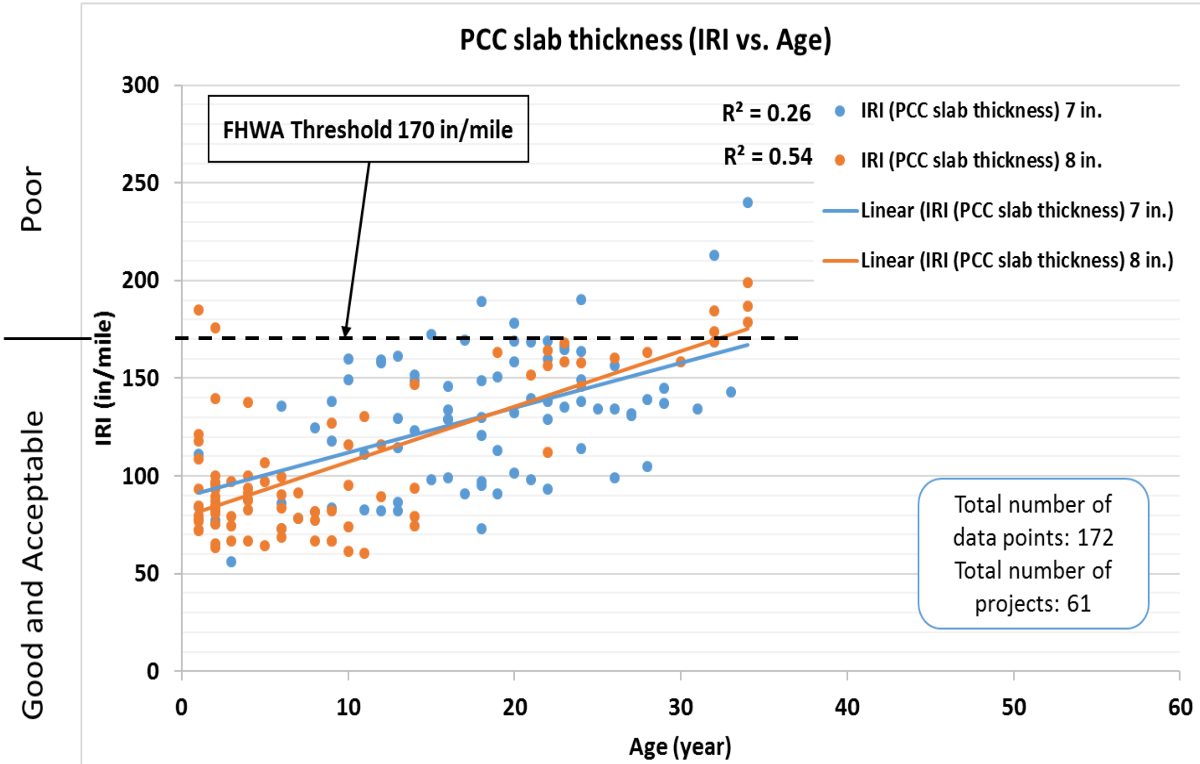


Figure 57. UBCOA IRI performance history categorized by concrete overlay thickness

The key findings for the UBCOA 7-in. and 8-in. thickness projects can be summarized as follows:

- The IRI trend line for 7-in. thickness increased gradually but remained below 170 in/mi during the first 35 years of service life.
- The IRI trend line for 8-in. thickness increased gradually during the first 33 years of service life before exceeding 170 in/mi.

Figure 58 presents changes in PCI values with age for three different concrete overlay joint spacings.

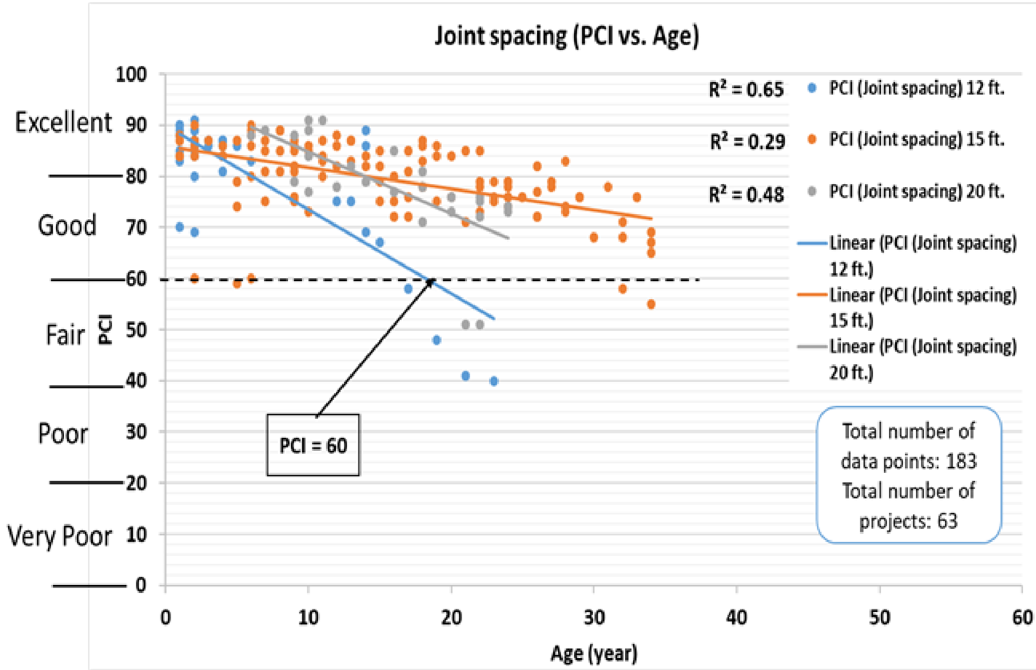


Figure 58. UBCOA PCI performance history categorized by concrete overlay joint spacing

The key findings for UBCOA 12-ft, 15-ft, and 20-ft joint spacing projects can be summarized as follows:

- The PCI trend line for 12-ft transverse joint spacing decreased rapidly during the first 18 years of service life before dropping below 60.
- The PCI trend line for 15-ft transverse joint spacing decreased gradually but remained above 70 during the first 35 years of service life.
- The PCI trend line for 20-ft transverse joint spacing decreased gradually but remained above 70 during the first 22 years of service life.

Figure 59 presents changes in IRI values with age for three different concrete overlay joint spacings.

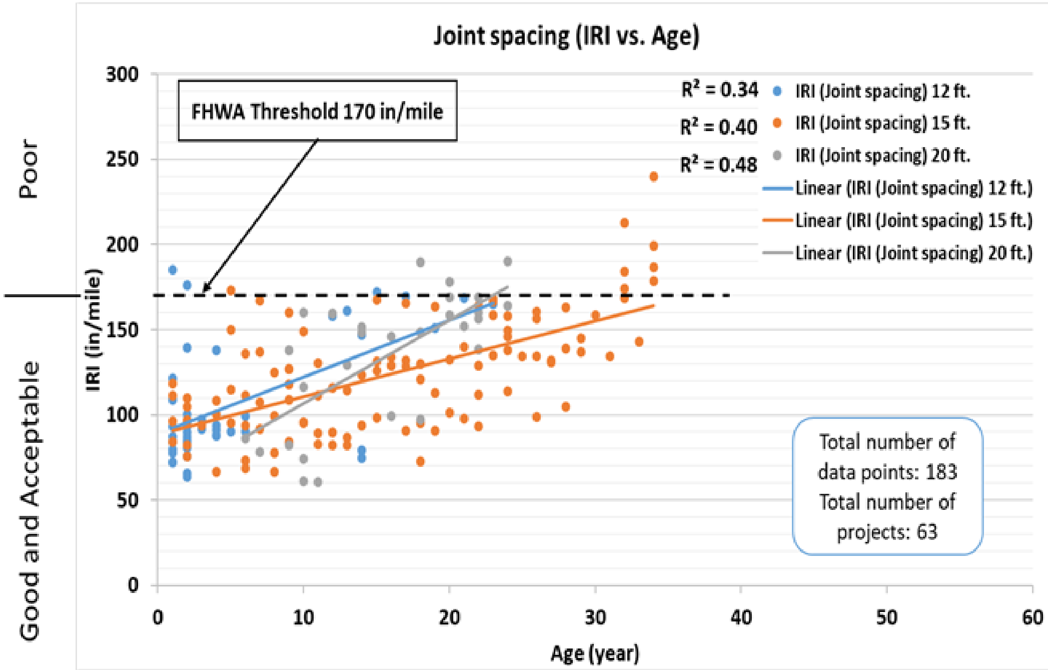


Figure 59. UBCOA IRI performance history categorized by concrete overlay joint spacing

The key findings for UBCOA 12-ft, 15-ft, and 20-ft joint spacing projects can be summarized as follows:

- The IRI values trend line for 12-ft transverse joint spacing increased gradually and remained below 170 in/mi during the first 22 years of service life.
- The IRI values trend line for 15-ft transverse joint spacing increased gradually but remained below 170 in/mi during the first 35 years of service life.
- The IRI values trend line for 20-ft transverse joint spacing increased gradually but remained below 170 in/mi during the first 22 years of service life.

To further evaluate the performance of the individual concrete overlay types, plots of the trend line value at year 20 were developed (see Figures 60 through 63).

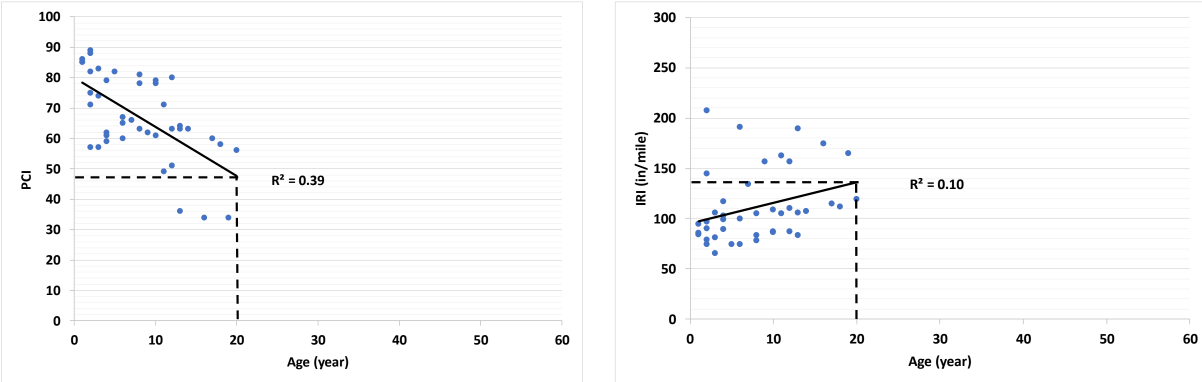


Figure 60. BCOC performance at Year 20

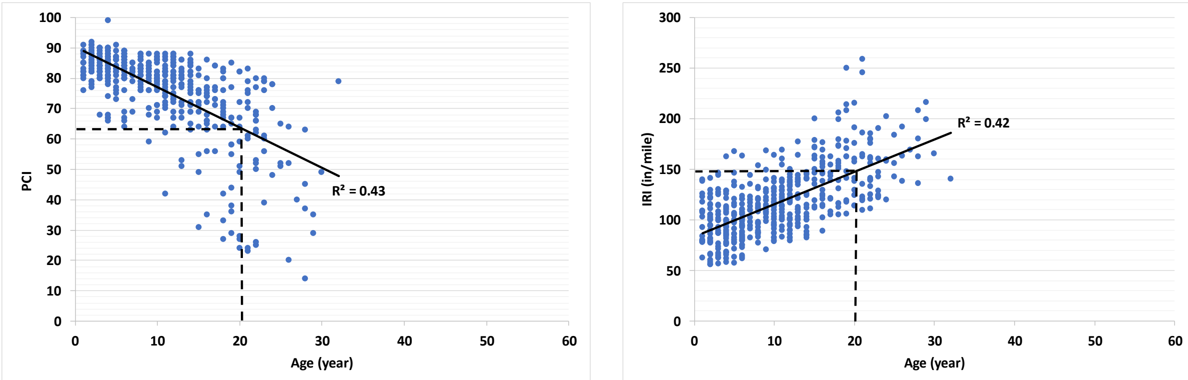


Figure 61. UBCOC performance at Year 20

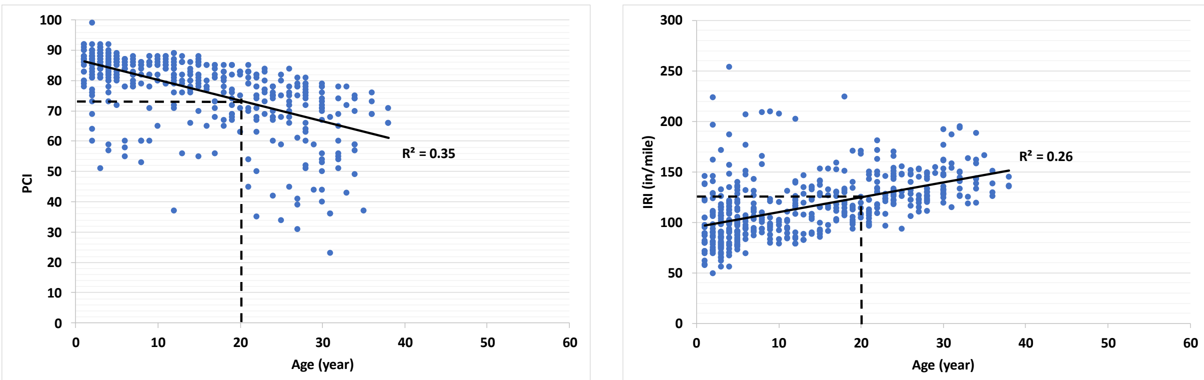


Figure 62. BCOA performance at Year 20

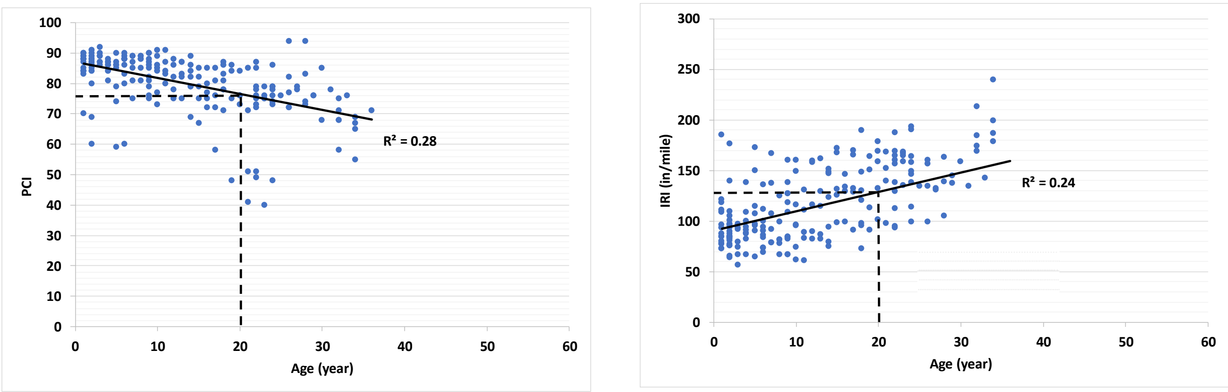


Figure 63. UBCOA performance at Year 20

Table 21 summarizes the PCI and IRI performance values based on the trend line at Year 20.

Table 21. Trend line value of concrete overlay types at Year 20

	BCOC	UBCOC	BCOA	UBCOA
PCI	47	63	74	76
IRI	138	150	125	128

4.3. Summary of Key Findings

Pavement condition data for Iowa's concrete overlays were collected and analyzed. The data were examined to identify the distribution of different overlay characteristics, including overlay type, slab thickness, transverse joint spacing, and performance measures, including the PCI and the IRI. Historical PCI and IRI records of Iowa concrete overlays were also analyzed to identify changes in PCI and IRI during service life and characterize the long-term performance of concrete overlays in Iowa. The key findings from this study are summarized below:

- Based on PCI ratings, 89% of all concrete overlays constructed in Iowa were in good to excellent condition.

- 93% of concrete overlay projects exhibited IRI values lower than 170 in/mi (FHWA upper threshold limit for acceptable ride quality).

- Based on PCI ratings, UBCOCs (90% of UBCOCs were in good to excellent condition) exhibited better performance than BCOCs (72% of BCOCs were in good to excellent condition).

- Among the overlays on asphalt, UBCOAs (94% of UBCOAs were in good to excellent condition) exhibited slightly better performance than BCOAs (88% of BCOAs were in good to excellent condition).

- Higher overlay thickness leads to increased overlay service life in terms of PCI values (see Figure 15).

- UBCOCs with shorter joint spacing (i.e., 12 ft and 15 ft) perform better than those with longer joint spacing (i.e., 20 ft) in terms of IRI values (see Figure 26).

- BCOAs with shorter joint spacing (i.e., 5.5 to 6 ft) perform better than those with longer joint spacing (i.e., longer than 6 ft), with respect to their first 10 years of service life.

- Overlays on asphalt (BCOA and UBCOA) show PCI trend lines for 12-ft joint spacing having lower performance than 15-ft and 20-ft joint spacing (see Figures 29 and 33). This was an unusual finding that was further investigated in the field reviews.

5. BCOA FAULTING

5.1. Background

To further investigate the general performance of BCOAs, analysis was performed on faulting of BCOA pavements. Faulting was defined as the vertical displacement between adjacent slabs. Although faulting was not considered in the calculation of the PCI, the IPMP automated pavement distress surveys have collected faulting-related distress data on all concrete overlays. Faulting was only measured when individual joints were found to have faulted greater than a threshold of 0.12 in. in both the left and right wheel path. From there, the number of faulted joints per roadway segment was counted and classified according to level of severity. The severity levels are defined in Table 22.

Table 22. Faulting severity levels

Type	Description
SEV1	Low severity faulting from 0.12 to 0.24 in. (3 to 6 mm)
SEV2	Medium severity faulting from 0.24 to 0.35 in. (6 to 9 mm)
SEV3	High severity faulting from 0.35 to 0.47 in. (9 to 12 mm)
SEV4	Very high severity faulting more than 0.47 in. (12 mm)
Lt FT	Left wheel path faulted joint
Rt FT	Right wheel path faulted joint

Note that when a joint did not fault beyond the threshold of 0.12 in., no faulting data were recorded for that joint. Thicknesses up to 6.5 in. were included for review to allow for more data in the study of faulting.

The original faulting data provided by the vendor included a total count of faulted joints per severity level per wheel path on each project. For example, one project may have 125 left wheel path severity level 1 faulted joints, 121 right wheel path severity level 1 faulted joints, 15 left wheel path severity level 2 faulted joints, 16 right wheel path severity level 2 faulted joints, etc. See Table 23 for an example of raw faulting data for a project that is 11.96 miles long.

Table 23. Example of raw faulting data

Lt FT SEV1 Count	Rt FT SEV1 Count	Lt FT SEV2 Count	Rt FT SEV2 Count	Lt FT SEV3 Count	Rt FT SEV3 Count	Lt FT SEV4 Count	Rt FT SEV4 Count
125	121	15	16	0	3	4	1

To compare each of the projects in an equivalent manner, the number of faulted joints per severity level was divided by the length of each project in miles, providing a faulting count per mile. In this example, the values in Table 23 were divided by 11.96 (length of project in miles) to determine the faulting count per mile. Table 24 demonstrates an example of faulting count per mile.

Table 24. Example of faulting count per mile

Lt FT SEV1 Count per Mile	Rt FT SEV1 Count per Mile	Lt FT SEV2 Count per Mile	Rt FT SEV2 Count per Mile	Lt FT SEV3 Count per Mile	Rt FT SEV3 Count per Mile	Lt FT SEV4 Count per Mile	Rt FT SEV4 Count per Mile
10.45	10.12	1.25	1.34	0	0.25	0.33	0.08

5.2. Faulting Distress Levels

Table 25 references recommended distress types and severity levels for evaluating concrete overlays.

Table 25. Distress types and severity levels recommended for assessing concrete pavement structural adequacy

Load-Related Distress	Highway Classification	Current Distress Level		
		Adequate	Marginal	Inadequate
Jointed plain concrete medium- and high-severity transverse and longitudinal cracks and corner breaks (% slabs)	Interstate/Freeway	< 5	5 to 10	> 10
	Primary	< 8	8 to 15	> 15
	Secondary	< 10	10 to 20	> 20
Jointed reinforced concrete medium- and high-severity transverse cracks and corner breaks (#/lane-miles)	Interstate/Freeway	< 15	15 to 40	> 40
	Primary	< 20	20 to 50	> 50
	Secondary	< 25	25 to 60	> 60
Jointed plain concrete mean transverse joint/crack faulting (in.)	Interstate/Freeway	< 0.10 (2.5 mm)	0.10–0.15 (2.5–3.8 mm)	> 0.15 (3.8 mm)
	Primary	< 0.125 (3.2 mm)	0.13–0.20 (3.3–5.1 mm)	> 0.20 (5.1 mm)
	Secondary	< 0.15 (3.8 mm)	0.15–0.30 (3.8–7.6 mm)	> 0.30 (7.6 mm)
Jointed reinforced concrete mean transverse joint/crack faulting (in.)	Interstate/Freeway	< 0.15 (3.8 mm)	0.15–0.30 (3.8–7.6 mm)	> 0.30 (7.6 mm)
	Primary	< 0.175 (4.5 mm)	0.18–0.35 (4.6–8.9 mm)	> 0.35 (8.9 mm)
	Secondary	< 0.20 (5.1 mm)	0.20–0.40 (5.1–10.2 mm)	> 0.40 (10.2 mm)
Continuously reinforced concrete medium- and high-severity punchouts (#/lane-miles)	Interstate/Freeway	< 5	5 to 10	> 10
	Primary	< 8	8 to 15	> 15
	Secondary	< 10	10 to 20	> 20
Applicability of Bonded Concrete Overlays				
Applicability of Unbonded Concrete Overlays				

Reprinted from the *Guide to Concrete Overlays*, Third Edition, National CP Tech Center (Harrington and Fick 2014).

As seen in the table, for jointed plain concrete pavements on secondary roadways, mean transverse faulting of 0.15 to 0.30 in. is considered a marginal distress level. Note that the mean value is the average of faulting across all joints, which is different from the faulted joint count data collected by the IPMP for Iowa roadways.

5.3. BCOA Faulting at Various Thicknesses

Figures 64 through 66 show the number of faulted joints per mile based on three different BCOA thickness ranges (3 to 4 in., 4.5 to 5 in., and 5.5 to 6.5 in.).

The x-axis shows faulting at the left and right wheel paths for severity levels 1–3. Faulting in severity level 4 was not displayed because of the low values. In Figures 64 through 66, the data show the majority of faulting per mile is in the severity 1 level, which exhibits faulting between 0.12 and 0.24 in. (3 to 6 mm).

As seen in Figure 64, 8% (9 of 110) of the 5.5- to 6.5-in. BCOA projects have more than 40 faulted joints in the right wheel path in the low-severity category. Assuming an average joint spacing of 15 ft for these projects (352 joints per mile), 40 faulted joints per mile represent 11.3% of the total joints per mile.

As seen in Figure 65, 20% (3 of 15) of the 4.5- to 5-in. BCOA projects have more than 40 faulted joints per mile in the right wheel path in the low-severity category. Assuming an average joint spacing of 15 ft for these projects (352 joints per mile), 40 faulted joints per mile represents 11.3% of the total joints per mile.

As seen in Figure 66, 7.5% (3 of 40) of the 3- to 4-in. BCOA projects had more than 40 faulted joints per mile in the low-severity category. Assuming an average joint spacing of 5.5 ft for these projects (960 joints per mile), 40 faulted joints represents 4.2% of the total joints per mile.

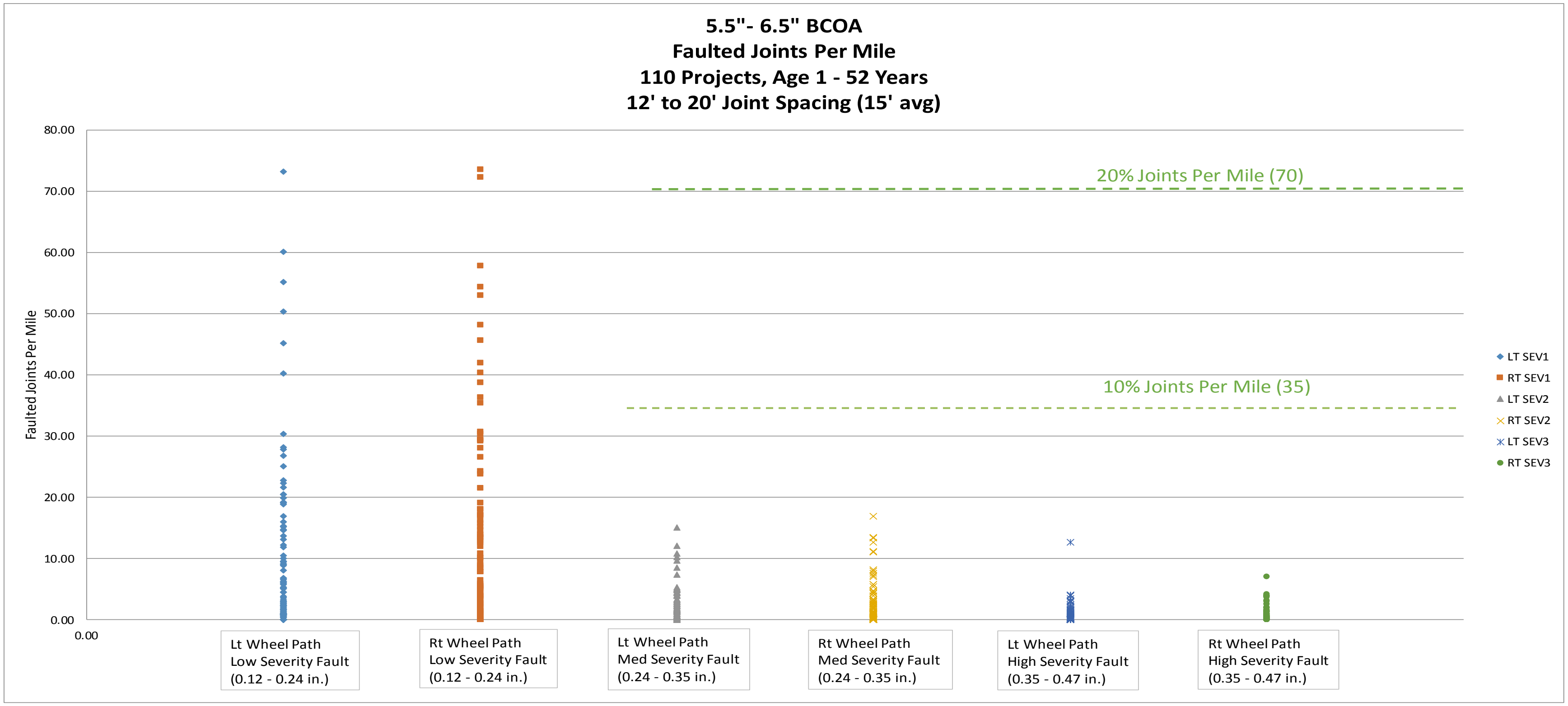


Figure 64. Faulted joints per mile (5.5- to 6.5-in. BCOA) based on severity levels 1–3

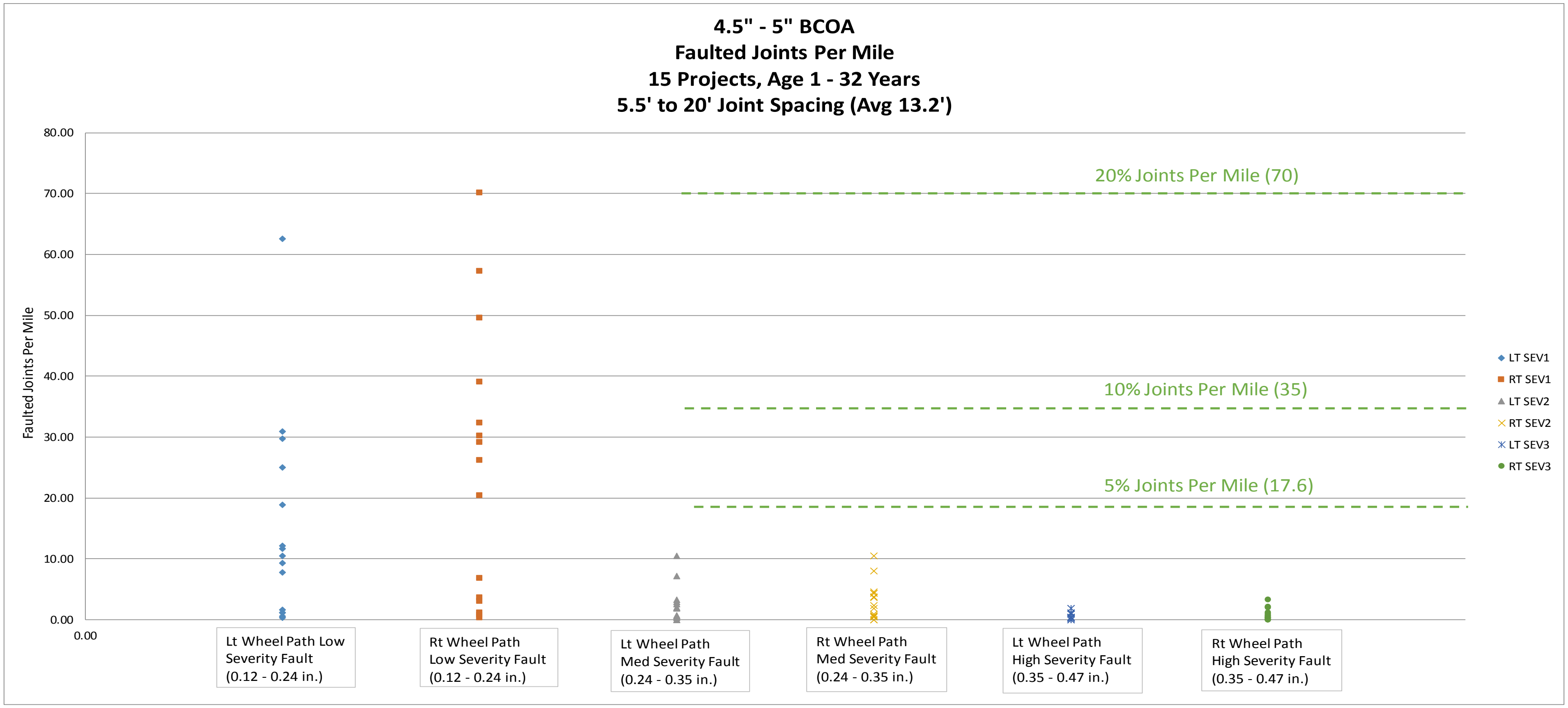


Figure 65. Faulted joints per mile (4.5- to 5-in. BCOA) based on severity levels 1–3

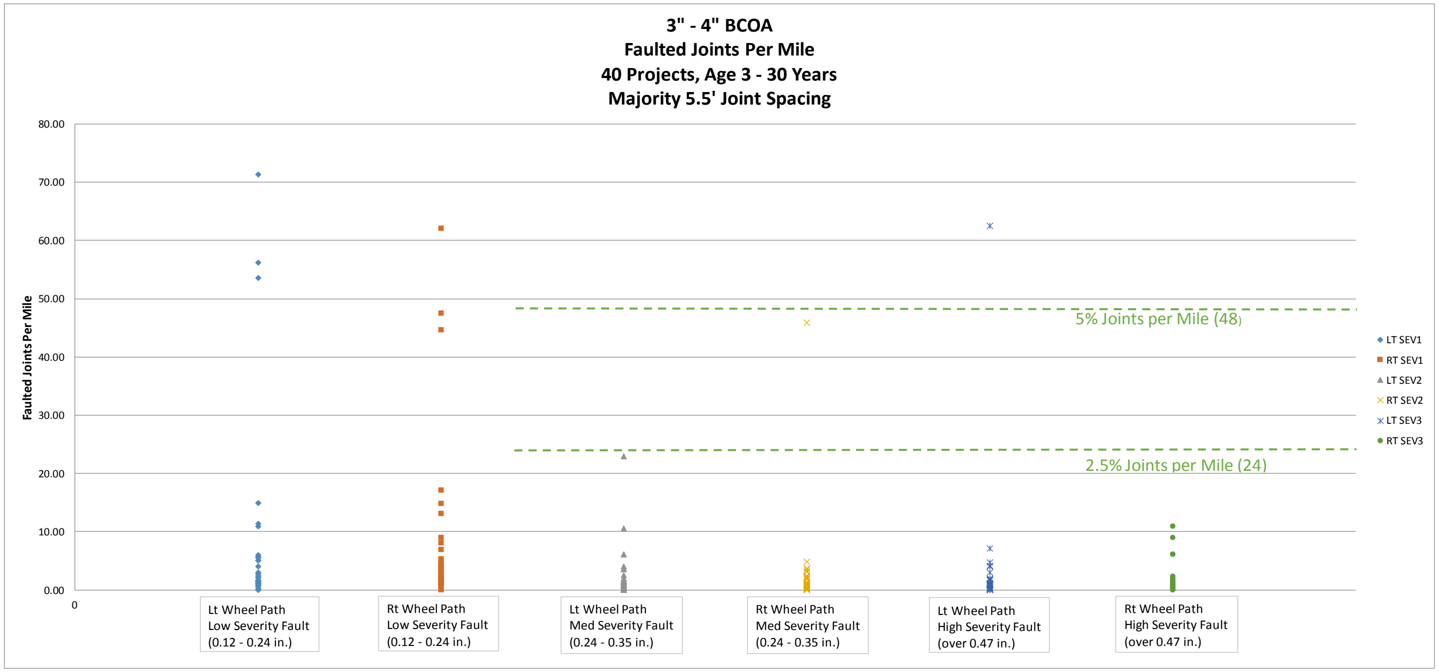


Figure 66. Faulted joints per mile (3- to 4-in. BCOA) based on individual severity levels 1–3

5.4. Wheel Path Faulting Converted to Average Faulting

To simplify the analysis, the remaining figures in this document represent the average number of faults between the left and right wheel path. This was calculated by adding the number of faulted joints in the left and right wheel path and dividing by 2.

5.5. Relationship between Faulting and Existing Asphalt Thickness

Analysis was performed to determine if there was any relationship between BCOA faulting and existing asphalt thickness. While the database contains 165 BCOA projects, only 27 of those projects have known existing asphalt thickness. Figures 67 and 68 show the relationship of total faulting (the sum of all severity levels 1–4) to various existing asphalt thickness for two different overlay thicknesses.

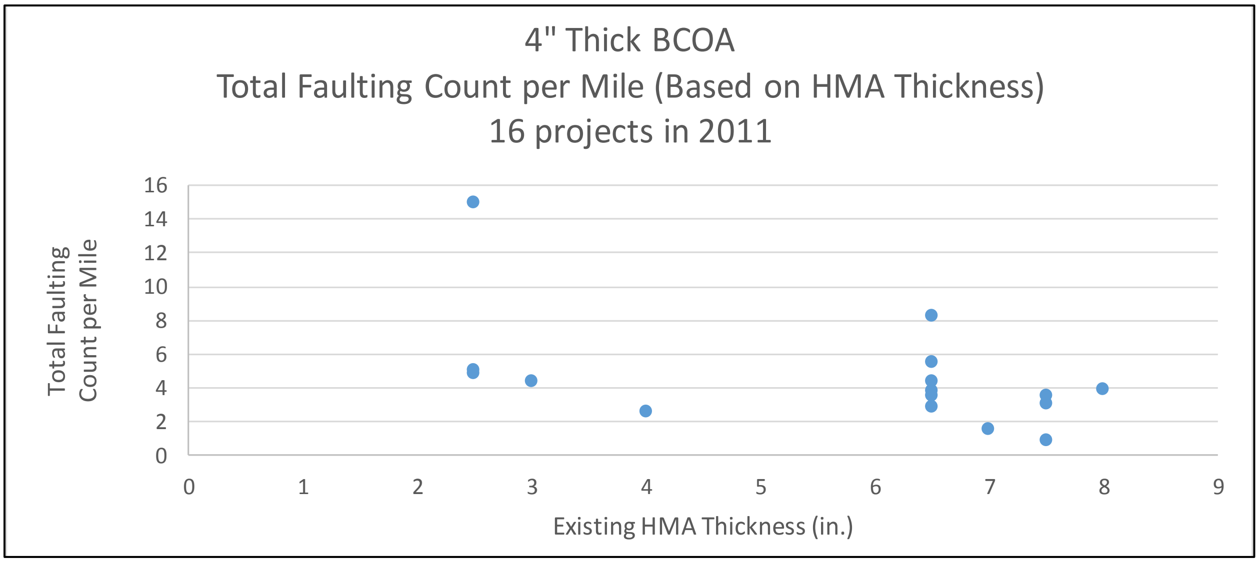


Figure 67. Total faulting count per mile (4-in. BCOA)

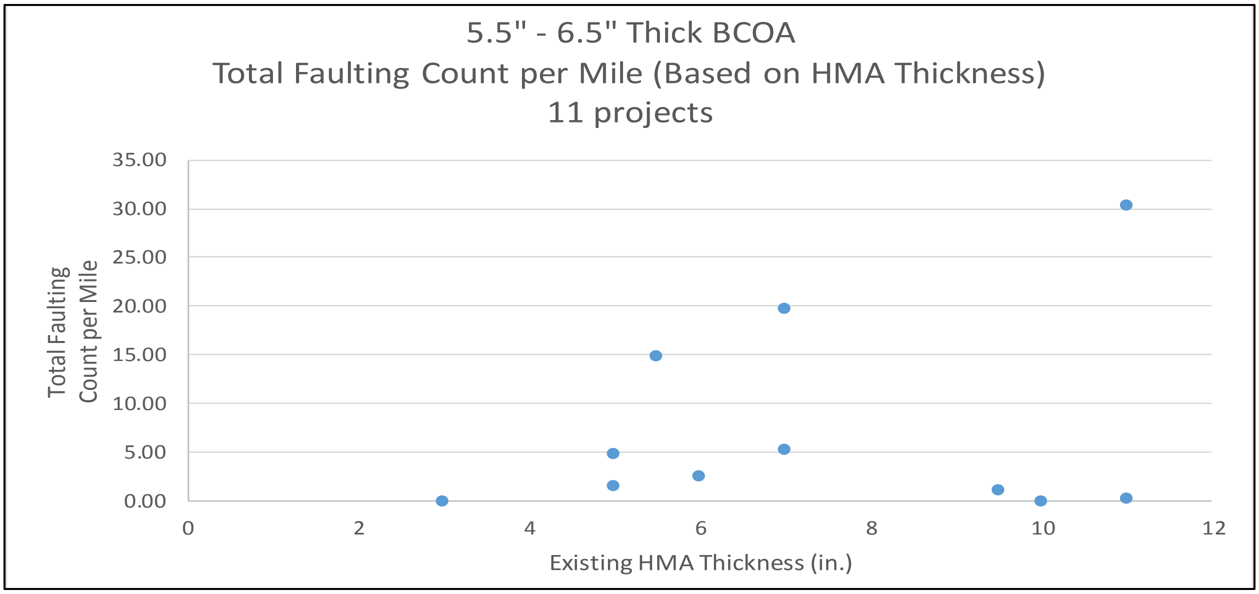


Figure 68. Total faulting count per mile (5.5- to 6.5-in. BCOA)

Both Figure 67 and Figure 68 show little correlation between existing hot-mix asphalt (HMA) thickness and faulting count per mile.

5.6. BCOA Faulting Relationship with Traffic

Figures 69 through 71 compare faulting (severity level 1) with traffic volume measured in vehicles per day for three different overlay thicknesses.

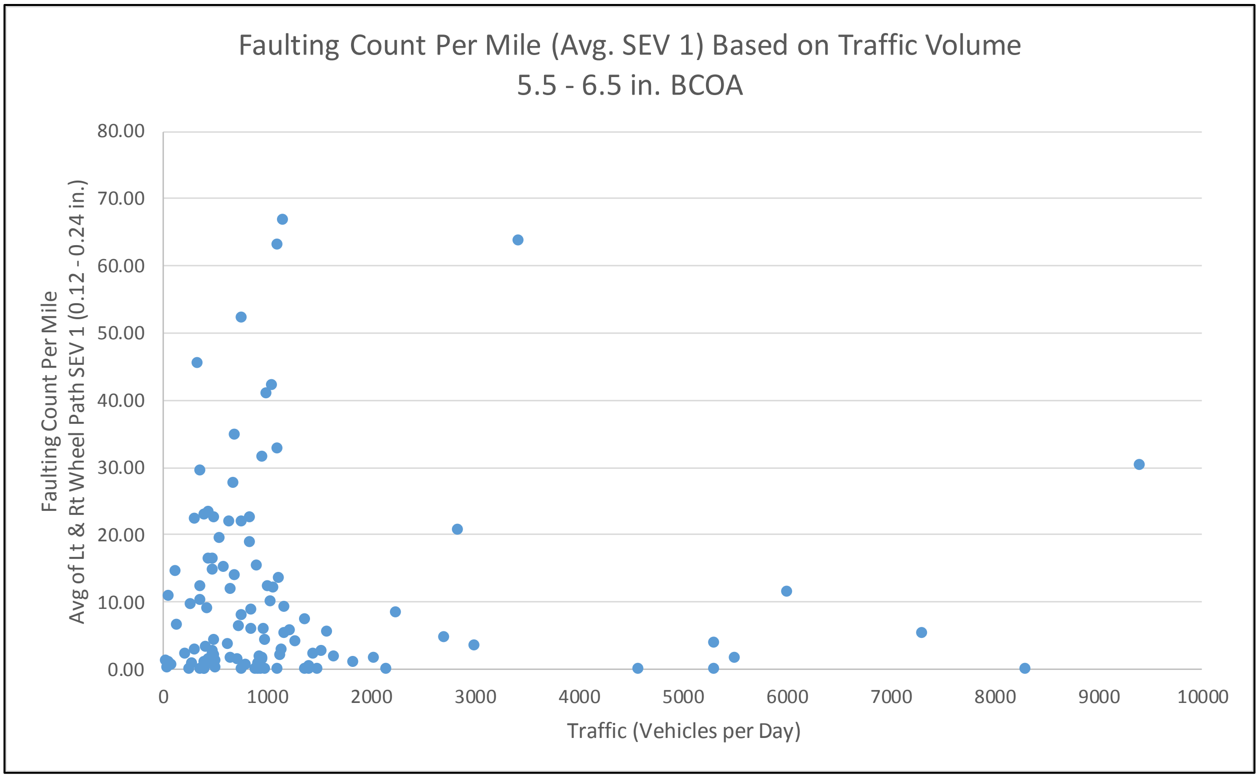


Figure 69. Faulting count per mile (severity level 1) vs. traffic (5.5- to 6.5-in. BCOA)

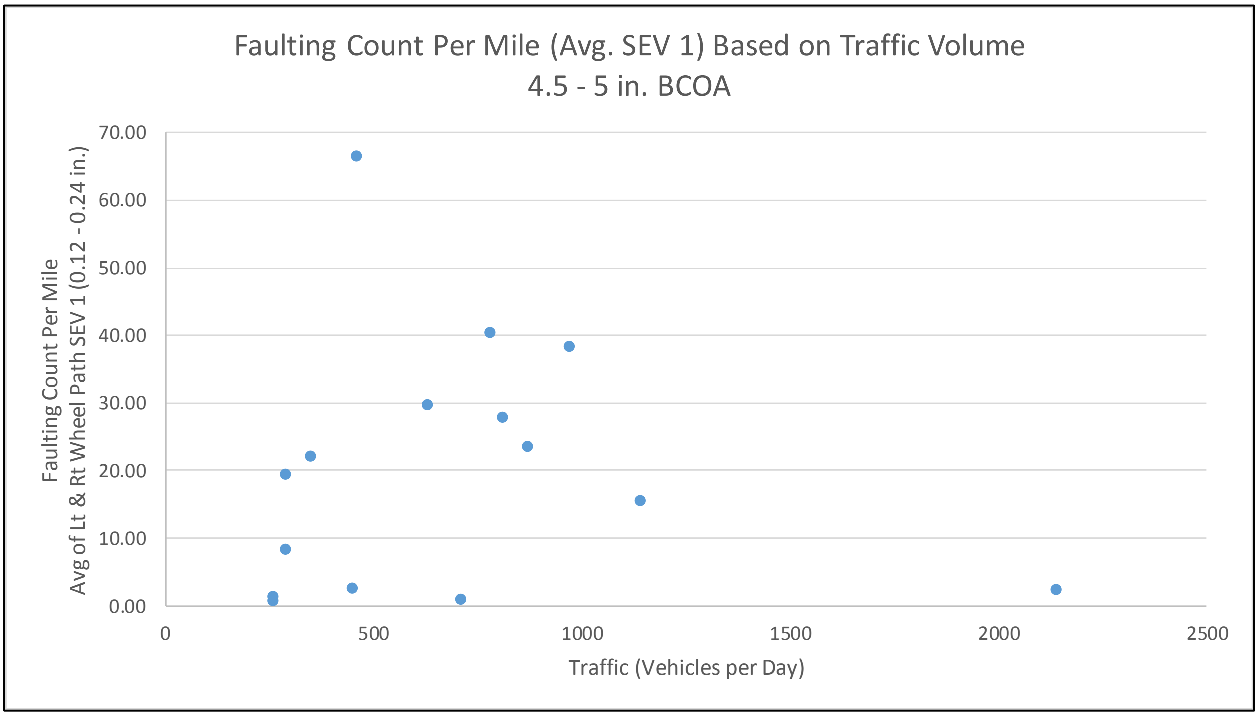


Figure 70. Faulting count per mile (severity level 1) vs. traffic (4.5- to 5-in. BCOA)

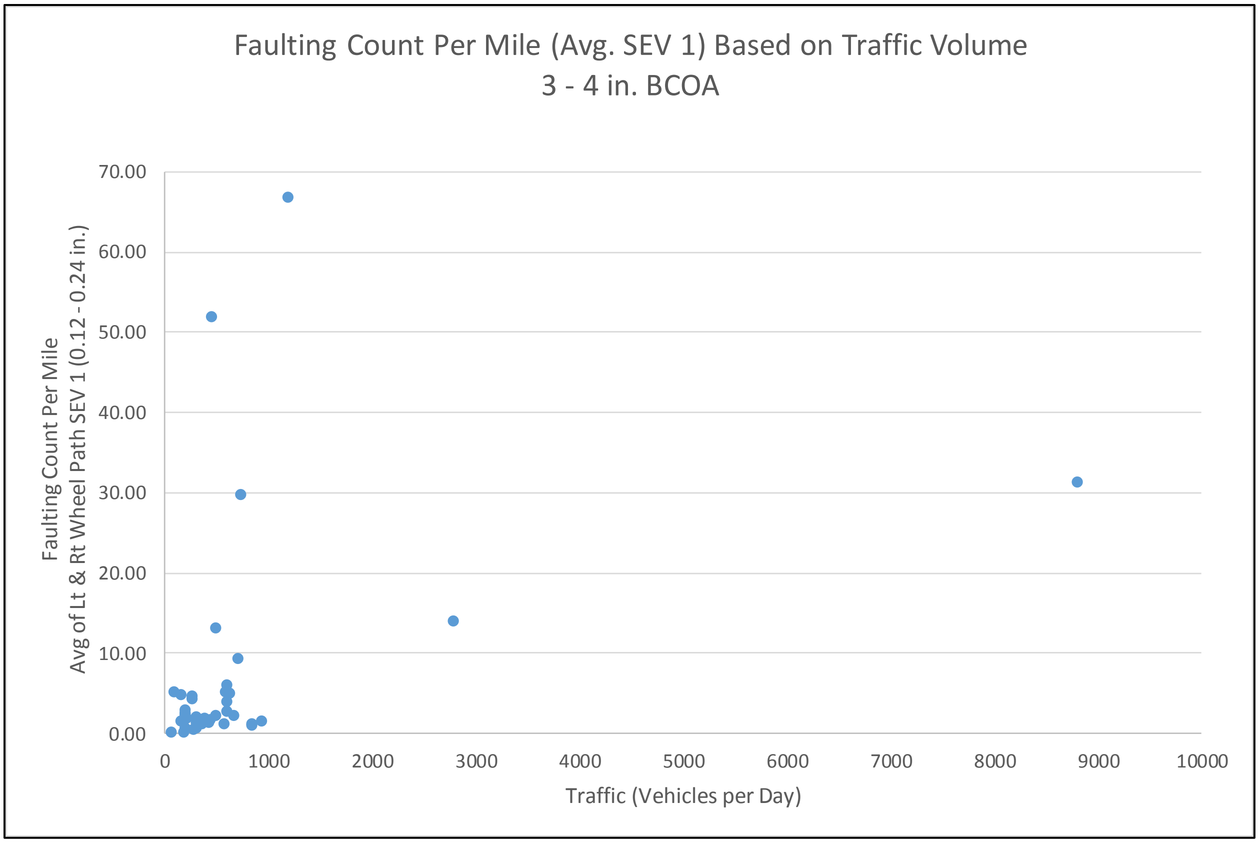


Figure 71. Faulting count per mile (severity level 1) vs. traffic (3- to 4-in. BCOA)

The figures show no correlation between faulting and traffic. It should be noted that most of the BCOA projects have low traffic because they are part of the secondary road system.

5.7. BCOA Faulting Relationship with Age

Figures 72 through 74 compare the average severity level 1 faulting with overlay age for three thickness levels.

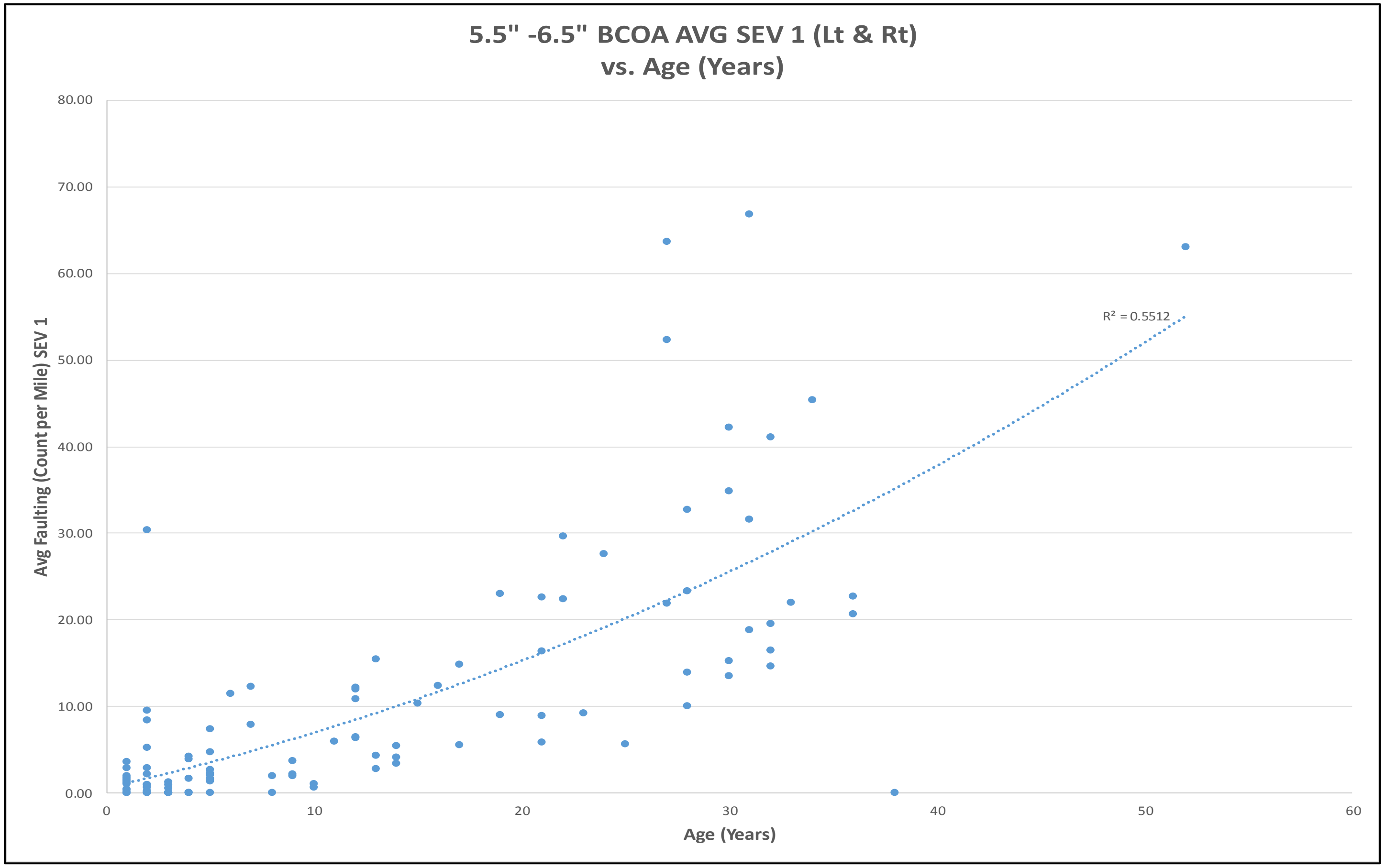


Figure 72. Average faulting (0.12 to 0.24 in.) count per mile vs. age for 5.5 to 6.5 in.

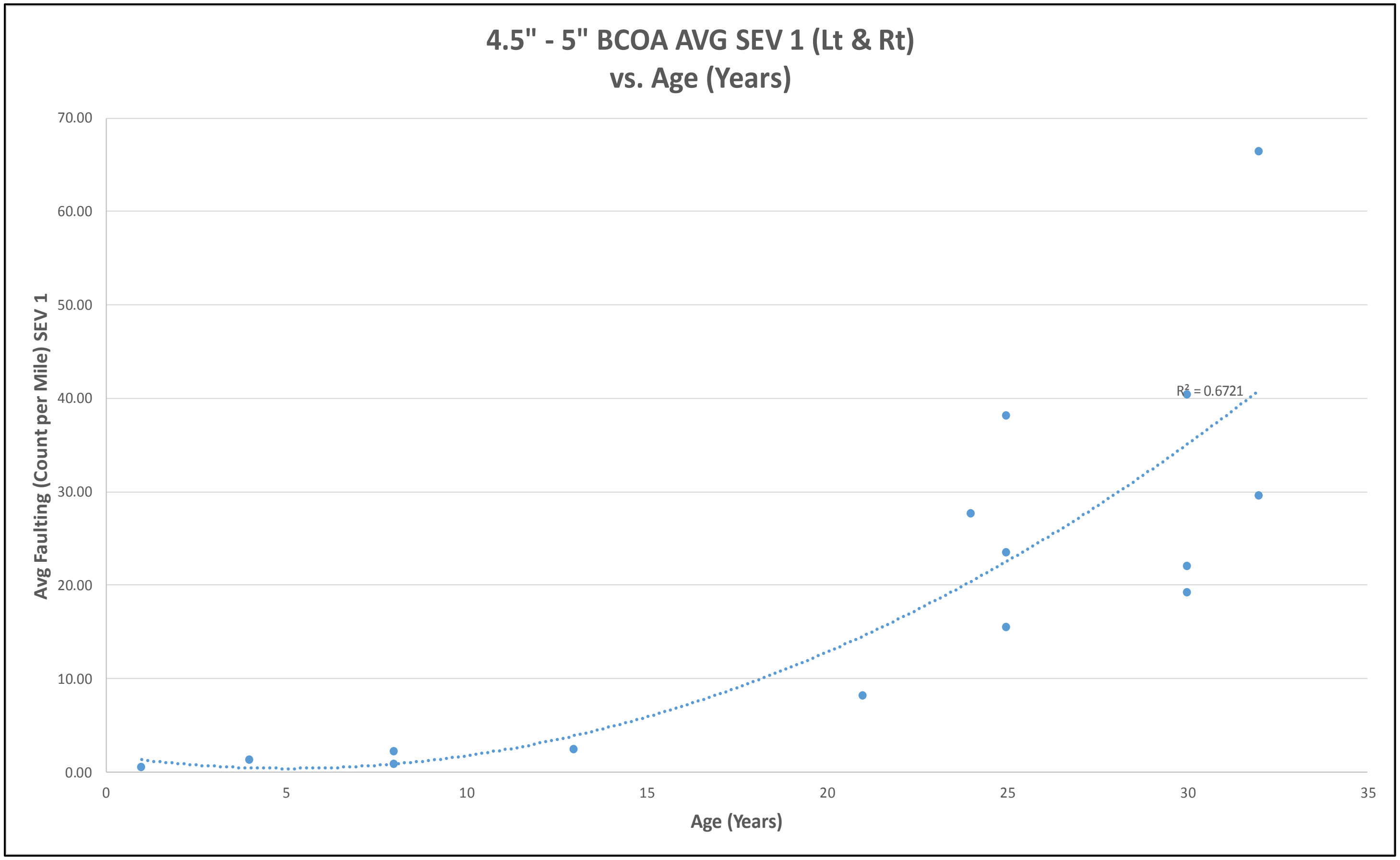


Figure 73. Average faulting (0.12 to 0.24 in.) count per mile vs. age for 4.5 to 5 in.

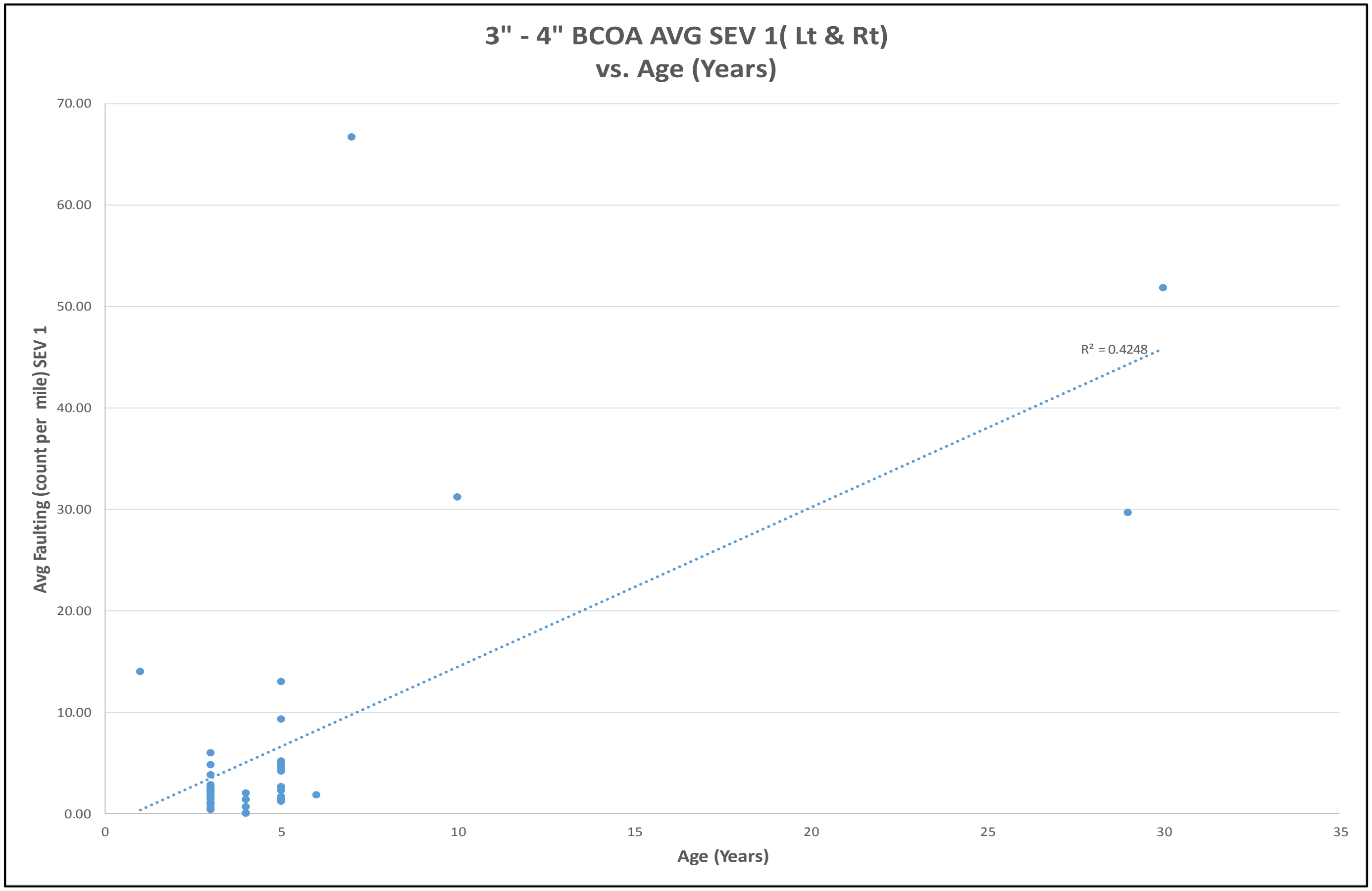


Figure 74. Average faulting (0.12 to 0.24 in.) count per mile vs. age for 3 to 4 in.

Figure 72 includes 110 BCOA projects with thicknesses of 5.5 to 6.5 in. In this example, there is a correlation between average faulting and age. The average transverse spacing of this group was 15 ft. For 15-ft joint spacing, there are 352 transverse joints per mile. At age 25, the faulting trend line is at 20 joints per mile, equivalent to approximately 6% of the total slabs per mile.

Figure 73 includes 15 BCOA projects with thicknesses of 4.5 to 5 in. The average transverse joint spacing of this group of 15 projects was 13.2 ft. Assuming 15-ft joint spacing, there were 352 transverse joints per mile. At age 25, the faulting trend line is at 23 joints per mile, equivalent to approximately 6% of the total number of slabs per mile. Further, the majority of data points in this figure are under 30 faulted joints per mile (equivalent to 8.5% of the total slabs per mile).

Figure 74 includes 40 BCOA projects with thicknesses between 3 and 4 in. The majority of transverse joint spacing in this group is 5.5 ft, which amounts to 960 transverse joints per mile. Most of the data points fall under 14 faulted joints per mile, equivalent to about 1.5% of the total slabs.

As seen in Figures 72 through 74, there was a slight correlation between the number of faulted joints and age, in which older projects exhibited a greater number of faulted joints. That said, for the vast majority of data points, the number of faulted joints was low.

5.8. Conclusions

Based on an analysis of the faulting data on BCOA pavements, it can be concluded that while faulting is present, the vast majority is low severity (0.12 to 0.24 in.). Of the low-severity faulting that was measured, a very small number (9%) of pavements had more than 40 faulted joints per mile. All other BCOA projects had fewer than 40 faulted joints per mile. In conclusion, faulting on BCOA projects is minimal and has not been perceived as a problem in Iowa. Further study will be needed to determine the exact fault dimensions. It is understood that beginning in 2017 the data collection will have the capability for collecting maximum, minimum, and average faulting dimensions for each roadway section.

6. Field Review Sites

6.1. Field Reviews

Field reviews of certain concrete overlays were performed to verify and gain more insight into overlay performance. Fourteen projects were reviewed on site for this study, all on the secondary highway system. Reviews were conducted in September and November of 2016.

Initially, projects were selected for review because of an outlying early-age drop in PCI—i.e., they performed notably worse than the typical trend for overlays with similar design characteristics. From there, additional projects were selected for review based on geographic proximity to the initial selections and notable project characteristics related to age, design features, and distresses. For these reasons, most of the projects reviewed were among the poorer-performing concrete overlays in the data set. Overall, the poorer-performing concrete overlays represented a total of less than 5% of the entire database.

A majority of overlays selected for these field reviews featured a 12-ft transverse joint spacing. As previously noted in the data analysis, some data from projects designed with 12-ft joints showed poorer performance than other overlays across all overlay types. Among other issues, one of the main goals of the field reviews was to better understand the performance of overlays with 12-ft joint spacing.

The condition of each project was documented with notes and photos at the time of the field review. This information was combined with project details and performance data from the database to allow for a full investigation of the performance of each overlay. In some cases, supplementary information was obtained from the county engineer to better understand certain observations and performance trends.

The concrete overlay projects that were reviewed and their most recent condition data (dating to either 2014 or 2015) are listed in Table 26.

Table 26. Summary of project information from field reviews

Overlay Location	Construction Year (Age)	Overlay Type	PCI (2014–15)	IRI (in/mi) (2014–15)
Dallas County R-22	1983 (24)	BCOA	69	140.0
Pottawattamie County L-34	1992 (25)	UBCOC	62	140.0
Dallas County F-31 west of Minburn	1992 (25)	UBCOA	40	164.9
Pottawattamie County G-30	1995 (22)	UBCOC	72	154.9
Buchanan County V-62	1996 (21)	UBCOC	69	172.9
Pottawattamie County L-66	1999 (18)	BCOA	55	153.0
Buchanan County W-35	2000 (17)	BCOA	84	89.6
Dallas County F-31 west of Granger	2000 (17)	UBCOC	49	171.6
Linn County North 10th Street	2002 (15)	UBCOC	69	164.0
Buchanan County W-45	2003 (14)	BCOA	79	110.4
Buchanan County W-40	2006 (11)	BCOA	85	93.2
Dallas County F-90	2006 (11)	UBCOC	68	130.2
Linn County Blairs Ferry Road	2008 (9)	UBCOC	69	120.6
Buchanan County D-22	2013 (4)	BCOA	92	57.4

The overall findings of the field reviews are summarized in Section 6.2, along with descriptions and images of common distresses. Full, complete field review notes, images, project details, and PCI and IRI charts for each individual project are compiled in the appendix.

6.2. Summary of Findings

The field reviews provided good insight into some of the factors that contributed to early-age distress and poor performance in Iowa's concrete overlays. In general, distresses observed during the reviews could be broken down into three categories: material durability issues, rough ride, and cracking issues. More detail is provided in the following sections.

6.2.1. Material Related Distress

Distresses related to material deficiencies were the most common cause of performance drop based on the field reviews. The most extensive material-related distresses were observed on Pottawattamie County Highways L-34 and L-66. Areas of both overlays exhibited map- or web-shaped cracking, suggesting issues with aggregate durability (D-cracking) or reactivity (ASR). These distresses are shown in Figure 75(a). Joint deterioration was also observed on the Pottawattamie County projects, including the example shown in Figure 75(b) at the intersection of a transverse joint and longitudinal crack.

(a) (b)

Figure 75. Material durability-related distresses on (a) Pottawattamie County L-34 and (b) Pottawattamie County L-66 (November 2016)

A pair of overlays in Dallas County on separate sections of County Highway F-31 west of Minburn and west of Granger also exhibited MRD in the form of joint deterioration (see Figure 76).

(a) (b)

Figure 76. Joint deterioration on Dallas County F-31 at sections (a) west of Minburn and (b) west of Granger (November 2016)

The section west of Minburn, shown in Figure 76(a), featured substantial longitudinal joint deterioration. This deterioration appeared to result from poor-durability concrete and poor drainage at the longitudinal joint.

In the section west of Granger, shown in Figure 76(b), transverse joint deterioration was concentrated primarily in areas near a creek crossing. In addition, joints and spalled areas were saturated with water.

These observations suggested that poor local drainage conditions were the primary factor driving the distresses. Some cracking associated with loss of support at the pavement edge was also observed near the creek crossing, which could also have been related to drainage issues causing erosion of the underlying soil.

6.2.2. Rough Ride

Another issue observed during field reviews was rough ride. In one area of study on North 10th Street in Linn County, the rough ride appeared to be the result of faulted dominant joints at an interval of about every three slabs. The faulting at these joints caused significant ride roughness and occasionally appeared to result in joint deterioration, as shown in Figure 77.

Figure 77. Joint deterioration on North 10th Street in Linn County (September 2016)

This pavement is a 6-in. unbonded overlay on concrete using a 1- to 1.5-in. asphalt separation layer with 12-ft skewed joints.

The exact cause of the faulted joints and accompanying distress on North 10th Street was unknown. There was suspicion that cracks may not have developed under every transverse joint on the overlay, perhaps leading to the dominant joint behavior at intervals of every three to four slabs. However, when county crews dug along the shoulder to observe the behavior of the transverse joints at the adjacent slabs, they found that cracks did deploy beneath those joints, as shown in Figure 78.

Figure 78. Crack deployment in joint adjacent to blowup

Another possibility for this behavior could be D-cracking in the original, underlying concrete beneath the overlay.

For other projects where rough ride was found, such as Buchanan County Highway V-62, curling and warping appeared to be the cause. In general, concrete overlays can be more susceptible to curling and warping than full-depth concrete pavements (Harrington and Fick 2014). With a greater ratio of surface area to total slab volume, concrete overlays are more prone to water loss during construction than full-depth concrete slabs. This water loss can lead to the development of higher curling and warping stresses.

Additionally, the rigid base underneath concrete overlays (and unbonded overlays of concrete in particular) can also lead to higher curling and warping stresses. Skewed joints (as constructed in Buchanan County) can also lead to greater curling and warping stresses (Ceylan et al. 2016). Finally, curling and warping tends to increase with slab size, which is one reason why thinner overlays are sometimes constructed with shorter joint spacing (Harrington and Fick 2014). All these factors related to curling and warping may have been contributors to the rough ride on Buchanan County Highway V-62 and elsewhere.

6.2.3. Cracking Issues

Finally, there were some projects that experienced significant amounts of cracking. Cracking issues were most significant on Blairs Ferry Road in Linn County and Dallas County Highway F-90. On Blairs Ferry Road, shown in Figure 79, the transverse and longitudinal cracking patterns appeared to result from loss of support.

(a) (b)

Figure 79. (a) Longitudinal and (b) corner cracking on Blairs Ferry Road (September 2016)

Although loss of support might be unusual for a concrete overlay, it was likely related to a major flood event in 2008 that caused significant erosion underneath the original concrete pavement at that location.

Meanwhile, cracking observed on Dallas County Highway F-90, shown in Figure 80, appeared to be caused by traffic loads.

Figure 80. Cracking on Dallas County F-90 (November 2016)

Faulting was additionally beginning to develop at the transverse joints. Although truck traffic data were not available for this project, discussion with the county engineer indicated that this section served a quarry and carried upward of 30 to 40% truck traffic, so the 6-in. unbonded overlay of concrete was likely beginning to experience load failure.

Two other factors also may have contributed to the cracking on Dallas County F-90. First, since the project featured skewed 12-ft joints and the distresses tended to develop as corner cracks before extending into longitudinal cracks, curling and warping stresses also may have been a contributing factor. Second, county maintenance crews sometimes observed water sitting underneath the underlying concrete slab when performing patching activities, so poor drainage also may have contributed to the distresses.

6.3. Conclusions

Overall, many of the performance issues found during field reviews of concrete overlays in Iowa represented the same types of problems that affect all types of concrete pavements. Most significantly, several overlays were found to be suffering from MRD. These included joint deterioration and aggregate-related distress, including distresses that resembled D-cracking and ASR. As with any concrete pavement, these issues can be mitigated through selection of proper materials, prioritizing durability in mix design, and ensuring proper drainage.

Some projects experienced significant amounts of early-age cracking. In some cases, this cracking appeared to be related to loss of support (e.g., Linn County Blairs Ferry Road). Although this type of failure is not as common in overlays given the presence of the existing pavement as a base layer, this instance showed it can still occur under certain circumstances. In other cases, heavy truck traffic (e.g., Dallas County Highway F-90) appeared to result in early load failure, showing that it is important to account for truck traffic in overlay thickness design.

Curling and warping appeared to result in a rough ride (e.g., Buchanan County Highway V-62) on some projects and potentially even contributed to faulting and cracking (e.g., Dallas County Highway F-90). These findings highlight the importance of the curing process during construction of concrete overlays to mitigate the potential for curling and warping. In some cases, designing overlays with shorter joint spacing could also help reduce curling and warping stresses. There are still, however, unanswered questions with respect to whether all joints deploy in concrete overlays with shorter slabs, as discussed in the appendix.

There is no clear evidence as to why 12-ft transverse joints did not perform as well as other joint spacing designs. Material-related distresses, other than the coincidence of these pavements having MRD, are not design specific. Curling and warping stresses on other projects with skewed 12-ft joints may have contributed to rough ride and some early-age cracking. If curling and warping stresses were a significant problem at this slab size, however, then one would expect the same distresses to occur even more frequently in projects with longer slabs (15 to 20 ft), which was ultimately not the case.

Therefore, it appears most likely that the poor performance observed in some of these projects was primarily a combination of project-specific material- and construction-related issues rather than an inherent design flaw with 12-ft joint spacing. Notably, a number of projects featuring 12-ft joints (Buchanan County Highways W-35, W-40, W-45, and D-22) studied during the field reviews were found to be performing well.

7. LESSONS LEARNED

After reviewing performance trends of the overlay database containing 384 projects and 1,493 miles, Table 27 lists the lessons learned.

Table 27. Lessons learned

Lessons Learned
Concrete overlays are performing very well, with service life trends exceeding the expectations listed in the *NCHRP Synthesis of Highway Practice 204* (McGhee 1994). A majority of projects in the complete overlay data set were on track to achieve a PCI rating of good (PCI = 60) or better and a ride quality rating of adequate (IRI = 170 in/mi) or better during the first 35 years of service life.
UBCOAs performed better than the other three overlay types.
In general, concrete overlays on asphalt performed better than concrete overlays on concrete.
UBCOCs with shorter joint spacings (i.e., 12- and 15-ft) perform better than those with longer joint spacing (i.e., 20 ft) in terms of IRI values.
Although only in existence since about 2004, BCOAs with shorter transverse joint spacing (5.5 and 6 ft) have performed as well or better than 12-, 15-, and 20-ft joint spacings with respect to PCI and IRI.
Traffic count was not a significant parameter in the performance of the overlays because of the overall low volumes. 87% of the data were for traffic counts of fewer than 2,000 vehicles per day.
Higher overlay thickness leads to increased overlay service life in terms of PCI values.

Concrete overlays in Iowa are performing above expectations. In the early years of development and implementation of concrete overlays, the expected service life was approximately 20 years (McGhee 1994). The results of this study showed that concrete overlays in Iowa exceed this service life as indicated by a review of the performance data. There are numerous examples of concrete overlays performing better than expected with respect to design and service life. Figures 81 through 83 show overlays at ages 37 and 38 years (at time of last data collection) with PCI values in the good category and IRI values in the acceptable category (per FHWA and FTA 2006). Figures 84 and 85 are examples of overlays at age 16 (at time of last data collection) that are in the excellent category, with PCI values of 81.

Figure 81. 1978 Grundy County T-55, PCI = 78, IRI = 122 in/mi

Figure 82. 1977 Boone County R-18, PCI = 72, IRI = 115 in/mi

Figure 83. 1977 Washington County W-55, PCI = 78, IRI = 122 in/mi

Figure 84. Louisa County G-62, 6-in. BCOA, PCI = 81, age 18 years

Figure 85. Louisa County X-37, 6-in. BCOA, PCI = 81, age 18 years

Because most of the overlays performed so well, a small selection of the poorer-performing overlays (data outliers) was studied in detail to investigate methods for improvement. The selection set that was investigated accounted for less than 5% of the total database. The investigation showed four different causes for poorer performance. The most common causes of poorer performance were related to structural failure and MRD. Table 28 lists the four conditions as well as recommendations for improvement. Table 29 lists best practices for evaluation and design of concrete overlays (Harrington and Fick 2014).

Table 28. Causes of poorer performance and recommendations for improvement

Cause of Poorer Performance (Data Outlier)	Recommendations for Improvement
Material-related distress	Use high-quality materials Use water/cement ratio 0.40 to 0.43 Use proper air entrainment system
Structural failure	Plan for future truck traffic Use overlay design software: (ACPA StreetPave, BCOA-ME, ACPA BCOA, AASHTO Pavement ME)
Inadequate drainage system	Properly drain existing pavement and new overlays (BCOA, UBCOA, and UBCOC) Consider surface and joints
Excessive joint spacing	Refer to *Guide to Concrete Overlays*, Third Edition (Harrington and Fick 2014)

Table 29. Best practices for evaluation and design of concrete overlays

Project Phase	Recommendations
Project Evaluation and Overlay Selection	• Investigate existing layer conditions by coring, FWD measurements, and as-built drawings. • Core to determine available pavement thickness if milling (3- to 4-in. minimum remaining). • For overlays on asphalt with heavy truck traffic, check existing asphalt layers for evidence of stripping. • Because of freeze-thaw conditions and/or areas with expansive soils, evaluate existing pavement in spring and summer to identify critical pavement distress to be accounted for in design.
Concrete Overlay Design	• For UBCOC, provide positive drainage paths for surface moisture to exit from separation layer to prevent erosion (stripping) under heavy-traffic loadings. Consider a geotextile separation layer for feasibility with respect to construction time and performance. • For BCOA, ensure adequacy of the asphalt layer after milling to avoid structure failure. • Seal pavement joints. • Review construction sequence and traffic control in conjunction with joint layout. Tied longitudinal construction joints can interfere with traffic during construction. • Design transitions and bridge approach pavement sections to minimize hand placement areas. • For BOLs, understand the challenges and pay attention to details. • Improve joint performance by using proper sawing dimensions and depths, adequate air entrainment, and maximization of durability by lowering w/c ratio.
Construction	• Require use of vibrator frequency monitor recorders on the paver to ensure adequate and non-excessive consolidation. • Use standard concrete mixes and maturity measurements to control openings of intersections and access points. Use accelerated concrete mixes only where necessary. • When existing surface milling is required, clearly define vertical and cross-slope limits and required existing surface survey accuracy.

Source: Chapter 1 of the *Guide to Concrete Overlays*, Third Edition, National CP Tech Center (Harrington and Fick [2014])

7.1. Potential for Improved Performance

Even though the concrete overlays are performing very well, the analysis showed that performance can be improved and service life can be extended. This can be accomplished by addressing the conditions listed in Table 28 and following the best practices listed in Table 29. To design a concrete overlay properly, use the *Guide to Concrete Overlays*, Third Edition (Harrington and Fick 2014) and the *Guide Specifications for Concrete Overlays* (Fick and Harrington 2015).

Some of the data sets show clear division of data points. As an example, see Figure 86 showing PCI versus age for the data set of concrete overlays with 12-ft joint spacing less than 20 years old.

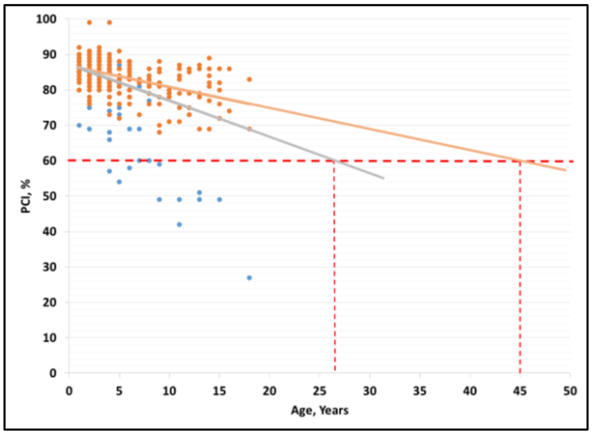


Figure 86. PCI improved performance

The orange points refer to well-performing pavements whereas the blue data points refer to pavements that have deteriorated more quickly than normal. In this study, the reasons for the quicker decrease in performance are related to many factors including joint performance, inadequate drainage, selection of the wrong overlay type, thickness design, and MRD.

In Figure 86, the gray line indicates the linear trend line for the complete data set, showing a pavement age of approximately 27 years at a PCI of 60.

Although this is considered good performance because it exceeds service life based on old guidelines from the NCHRP (McGhee 1994), it can be greatly improved by taking steps to ensure that good quality pavement is placed. This is accomplished by verifying the use of quality materials, providing proper drainage, selecting the correct overlay type, providing adequate air entrainment, and constructing proper joints.

If the pavement quality and construction is improved, service life expectations for concrete overlays may be increased further. Among the well-performing projects, the slope of the linear trend line (in orange) becomes flattened and a PCI of 60 is achieved at Year 45, representing an extension of pavement life of nearly 20 years compared to the subset of projects exhibiting premature deterioration.

7.2. Conclusions

The results of the performance analysis concluded that concrete overlays in Iowa are performing very well with service life trends exceeding expectations listed in the *NCHRP Synthesis of Highway Practice 204* (McGhee 1994). Furthermore, the analysis shows that 89% of the database has a PCI rating of good to excellent, and 93% of the IRI database is below the adequate threshold of 170 in./mile. The poorer-performing pavements chosen for field reviews and additional study were representative of fewer than 5% of the complete project data set. The field reviews showed that poorer-performing pavements were deteriorating based on MRD from substandard materials or material incompatibilities, structural failure, and poor drainage. These reasons are not unique to concrete overlays and are easily correctable.

By properly addressing the limited number of causes of the poorer-performing overlays, the performance of overlays can be improved to a greater extent and provide longer service life.

7.3 BCOA Faulting

A sawed contraction joint where a crack does not deploy may increase the cost of an overlay and subject the pavement to potential distress over the years. For overlays where the joint does not crack, there is potential for dominant joint behavior and additional faulting. In these situations, determination of minimum joint spacing may be advisable, particularly for relatively thin BCOA pavements.

8. FUTURE STUDY OF OPTIMIZED JOINT SPACING

Many concrete overlays in Iowa were originally built with longer panel sizes typically in the 15- to 20-ft range with no mid-panel longitudinal joints and have performed well, particularly on lower traffic volume roadways. For thinner overlays (4 to 6 in.), the current design approach of determining the spacing of longitudinal and transverse joints results in smaller panel sizes normally in the range of 5.5 by 5.5 ft or 6 by 6 ft. Minimizing the number of joints has become a topic of discussion related to the economy of pavement construction and maintenance.

Some field observations have documented that, for pavements with shorter joint spacing, some joints may not be working effectively (lack of crack deployment under the saw cut), particularly on lower volume roadways. Longer joint spacing is more desirable because it reduces the number of joints, in turn reducing the cost of joint installation and maintenance. Longer joint spacing, however, can also result in mid-panel cracking, increased maintenance requirements, or rougher pavements due to curling and warping. A sawed construction joint where a crack does not unnecessarily deploy increases cost of the project and subjects the pavement to potential distress over the years. For overlays where the joint does not crack, there is potential for dominant joint behavior and additional faulting. In such situations, determination of minimum joint spacing is desired, so determination of the optimal joint spacing for concrete overlays is warranted. This is particularly true for relatively thin BCOA pavements.

For the last 10 years, macro-synthetic fibers (shown in Figure 87) have been the predominant type of structural fiber used in concrete pavements rather than steel fibers.

Figure 87. Structural fibers

Structural fiber reinforcement in concrete overlays has been used throughout the US for the last 20 years for the following reasons:

- Increase fatigue capacity and ductility (toughness)
- Reduce overlay thickness
- Help control differential slab movement caused by curling/warping
- Hold cracks tightly together enhancing concrete performance

Recognizing that proper joint spacing and joint construction is essential for long-term performance of concrete overlays, there remain two questions:

- What is the optimum joint spacing for concrete overlays based on thickness, traffic volume, and with or without structural synthetic fibers?

- Is there a lower initial cost with improved performance associated with the optimized joint spacing?

8.1. Objective for Optimized Joint Spacing Study

Additional research is required to answer these questions. Field testing is needed to investigate several constructed concrete overlays with shorter joint spacing to determine whether cracks are deploying under the transverse and longitudinal saw cuts.

The database that includes varying traffic, thickness, and joint spacing from the current study can be utilized to identify project candidates for field testing. The primary objective of this optimized joint spacing study would be a two-phased research project that includes field testing of existing concrete overlays (Phase 2A) and monitoring, analysis, and field testing of newly constructed concrete overlays (Phase 2B).

8.2. Phase 2A

Under Phase 2A, crack deployment at the joints can be determined using field coring on the longitudinal joints and spot shoulder excavation on the transverse joints. An alternative to coring and spot shoulder elevation is to determine crack deployment using nondestructive testing such as MIRA (ultrasonic shear-wave tomography) (see Figure 88).

Figure 88. MIRA ultrasonic shear-wave tomography device

Research is under way at the University of Illinois to determine the validity of using such equipment for lab and field testing. Since Illinois has more concrete overlays with fibers than Iowa, nondestructive testing on fiber-reinforced Illinois overlays will be conducted using one of the two equipment types. Overlays in Iowa may be investigated using the same nondestructive techniques and equipment as the Illinois testing.

In addition, software modeling using PavementME and BCOA-ME will be utilized to evaluate performance of overlays with various joint spacing and use of fibers. The software can also be run using the actual field information and the data output studied to determine the optimized joint spacing ranges both with and without fibers.

Phase 2A Tasks:

1. Develop technical advisory committee.
2. Develop analytical investigation plan and field investigation plans.
3. Execute field and analytical investigations.
4. Analyze collected data and develop Phase 2B research plan.
5. Develop Phase 2A final report and presentation.

8.3. Phase 2B

Phase 2B is a future study that will include the actual construction and performance review of overlays with various test sections. The test sections will include varying joint spacing, varying thickness, and mixes both with and without structural fibers as determined in Phase 2A. This will involve particularly working with counties to identify projects with various traffic volumes (if possible) and overlay thicknesses that will enable definitive results building on the forensic investigation conducted in Phase 2A. The purpose is to verify the results of Phase 2A through field monitoring of test sections within the new projects in Phase 2B. Based on performance data at the end of Phase 2A, the Phase 2A recommendations will be modified if necessary to correspond to actual joint development.

Phase 2A is currently under way and is scheduled to be completed in January 2018. Phase 2B is expected to take two years to provide initial performance data with optional monitoring over a longer time period.

8.4 Benefits

Although Iowa has the highest number of miles of concrete overlays in the US, a study on determination of optimum joint spacing has not taken place. The results from this study will be beneficial to the Iowa DOT and local highway agencies to help in decision-making on the cost-effective selection of the most optimum and efficient joint spacing, for varying thicknesses and traffic counts, both with and without fibers.

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APPENDIX: FIELD REVIEW NOTES

Buchanan County Highway D-22

Buchanan County D-22 from Independence east to Winthrop is a bonded concrete overlay on asphalt constructed in 2013. An overview of the project is shown in Figure A.1.

Figure A.1. Overview of Buchanan County D-22, September 2016

Full project details are provided in Table A.1, along with performance data in Table A.2.

Table A.1. Project details for Buchanan County D-22

Construction Year	2013
Overlay Type	BCOA
PCC Thickness (in.)	6
Joint Spacing (ft)	12
Skewed Joints?	Yes
Interlayer	n/a

Table A.2. Performance data for Buchanan County D-22

Year of Data Collection	2014
PCI	92
IRI (in/mi)	57.4

Buchanan County D-22 was a relatively new pavement at the time of field review. With a PCI of 92 and IRI of 57.4 in/mi, the pavement exhibited typical good performance metrics for its age.

However, even at an age of three years, occasional instances of longitudinal cracking began to develop in this overlay, which can be seen in Figure A.2.

Figure A.2. Longitudinal cracking in Buchanan County D-22, September 2016

Although the county engineer believes these cracks have developed over areas of distress in the underlying asphalt, the pavement will warrant further monitoring in coming years.

Buchanan County Highway V-62

Buchanan County V-62 between Jesup and County Highway D-16 is an unbonded concrete overlay on concrete constructed in 1996. Full project details are provided in Table A.3, along with PCI and IRI performance plots in Figures A.3 and A.4.

Table A.3. Project details for Buchanan County V-62

Construction Year	1996
Overlay Type	UBCOC
PCC Thickness (in.)	6
Joint Spacing (ft)	12
Skewed Joints?	Yes
Interlayer	1 in. HMA

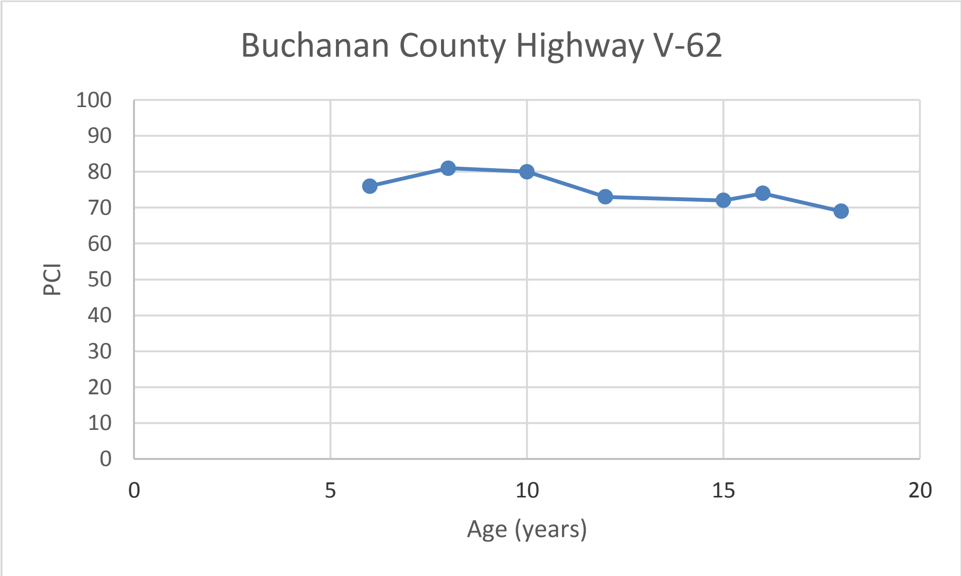

Figure A.3. PCI performance of Buchanan County V-62

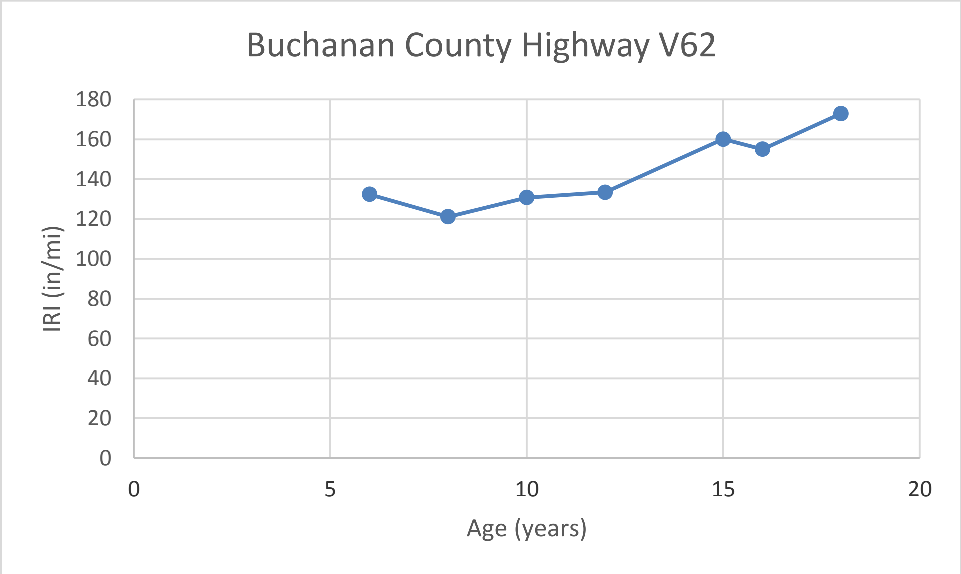

Figure A.4. IRI performance of Buchahan County V-62

This project was selected for review mainly because of its high IRI value, which measured 172 in/mi in 2014 at a pavement age of 18 years. Discussion with the county engineer confirmed that the overlay had a rough ride, which was attributed to roughness upon original construction and curling and warping (as opposed to faulting). As a result, the entirety of the project was rehabilitated with diamond grinding in 2015. A close-up of the ground surface of the overlay taken at the time of the field review in 2016 is shown in Figure A.5.

Figure A.5. Surface post diamond grinding on Buchanan County V-62, September 2016

Although the most recently collected performance data predates the diamond grind, as of 2016, considerable smoothness had been restored to the overlay.

Buchanan County Highway W-35

Buchanan County W-35 from the Linn County Line north to Quasqueton is a bonded concrete overlay on asphalt constructed in 2000. Full project details are provided in Table A.4, along with performance plots in Figures A.6 and A.7.

Table A.4. Project details for Buchanan County W-35

Construction Year	2000
Overlay Type	BCOA
PCC Thickness (in.)	6
Joint Spacing (ft)	12
Skewed Joints?	Yes
Interlayer	n/a

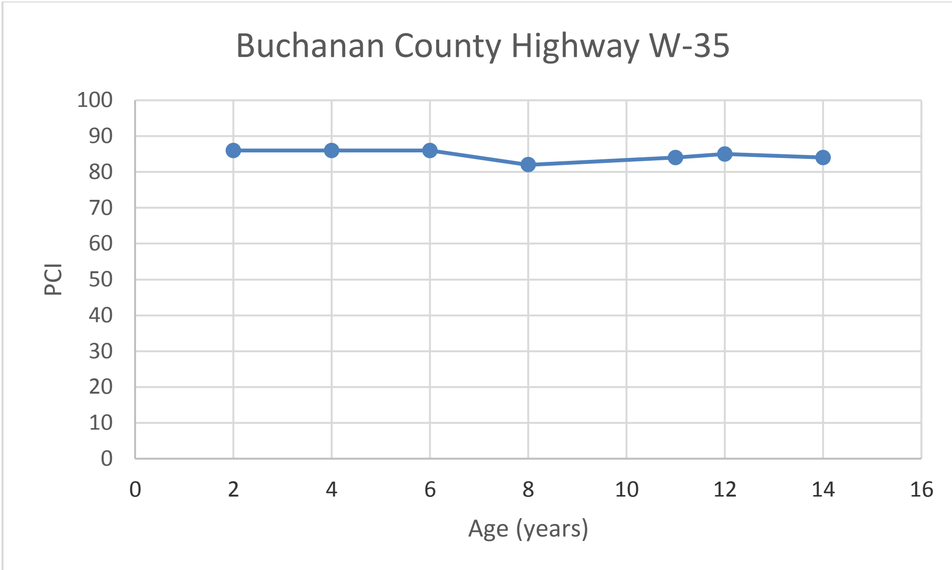

Figure A.6. PCI performance of Buchanan County W-35

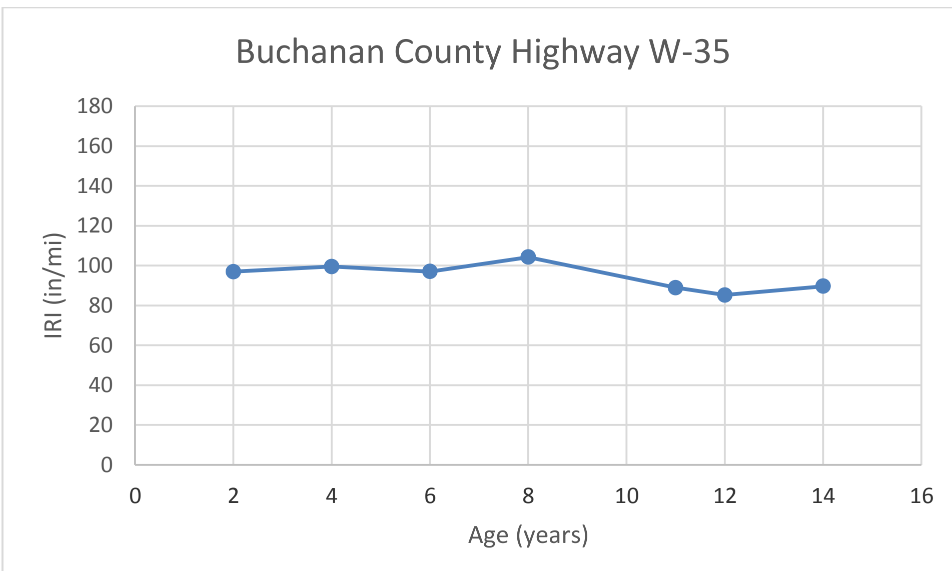

Figure A.7. IRI performance of Buchanan County W-35

No real physical distresses were observed on this project, but a relatively rough ride was noted during the review in September 2016. This roughness appeared to be related to curling and warping, as no significant faulting had developed. Given the most recent IRI reading in 2014 was 89.6 in/mi, this roughness may be a recent development that should be monitored over time. (A drop in IRI from a previous high of 104.2 in/mi recorded in 2008 likely resulted primarily from the change in how IRI was measured, as no rehabilitation activities had occurred on this overlay.)

Buchanan County Highway W-40

Buchanan County W-40, from Quasqueton north 4.2 miles, is a bonded concrete overlay on asphalt constructed in 2006. An overview of this project is shown in Figure A.8.

Figure A.8. Overview of Buchanan County W-40

Full project details are provided in Table A.5, along with performance plots in Figures A.9 and A.10.

Table A.5. Project details for Buchanan County W-40

Construction Year	2006
Overlay Type	BCOA
PCC Thickness (in.)	6
Joint Spacing (ft)	12
Skewed Joints?	Yes
Interlayer	n/a

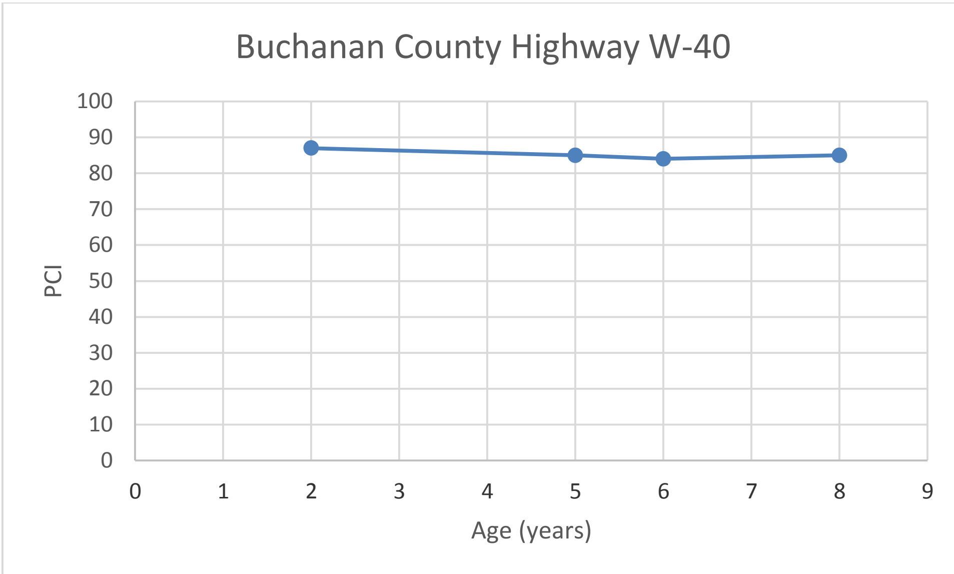

Figure A.9. PCI performance of Buchanan County W-40

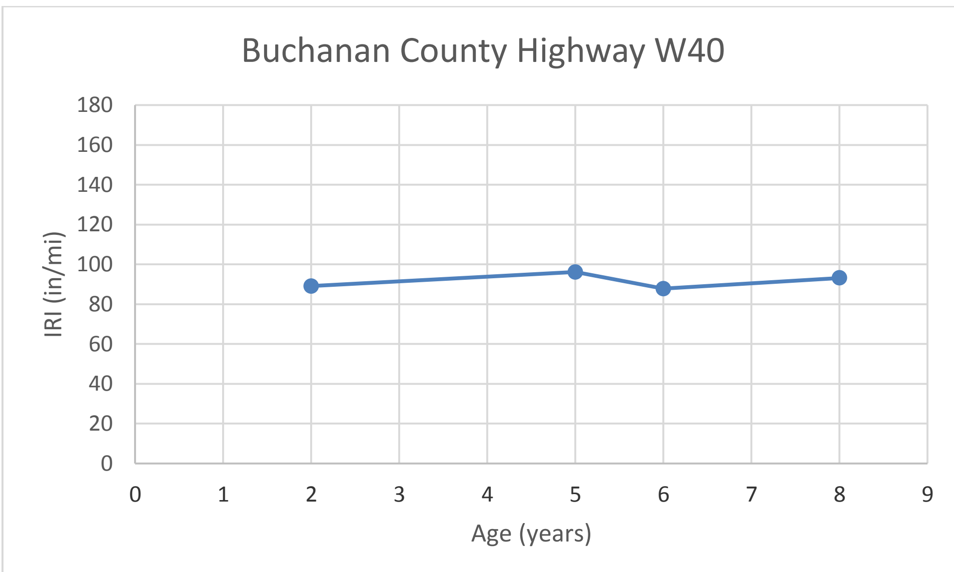

Figure A.10. IRI performance of Buchanan County W-40

Overall, Buchanan County W-40 was found to be in good condition and the performance metrics were in line with the overall trend of similarly designed overlays (PCI of 85 and IRI of 93.2 in/mi at an age of 8 years). However, some distresses had developed in areas along the southbound pavement edge as shown in Figure A.11.

Figure A.11. Longitudinal and corner cracking at slab edge in southbound lane of Buchanan County W-40, September 2016

The county engineer noted that this section was a truck route to Cedar Rapids, and that trucks tended to be loaded traveling southbound versus unloaded traveling northbound. The county engineer also noted that the distresses appeared to occur over areas where there had been distress in the underlying asphalt pavement. Therefore, the distresses were likely a combination of heavy traffic loads occurring over previously distressed areas of the asphalt base. Overall the distresses were not widespread and, where they did occur, did not appear to be contributing significantly to poor ride quality or the overall condition of the pavement.

Buchanan County Highway W-45

Buchanan County W-45, from Winthrop north 2.9 miles, is a bonded concrete overlay on asphalt constructed in 2003. An overview of the project is shown in Figure A.12.

Figure A.12. Overview of Buchanan County W-45, September 2016

Full project details are provided in Table A.6, along with performance plots in Figures A.13 and A.14.

Table A.6. Project details for Buchanan County W-45

Construction Year	2003
Overlay Type	BCOA
PCC Thickness (in.)	6
Joint Spacing (ft)	12
Skewed Joints?	Yes
Interlayer	n/a

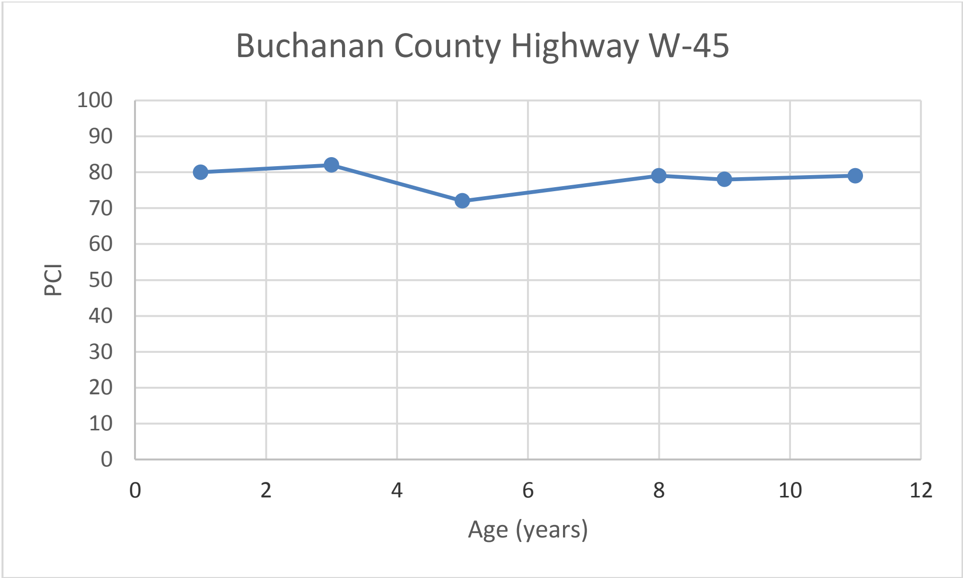

Figure A.13. PCI performance of Buchanan County W-45

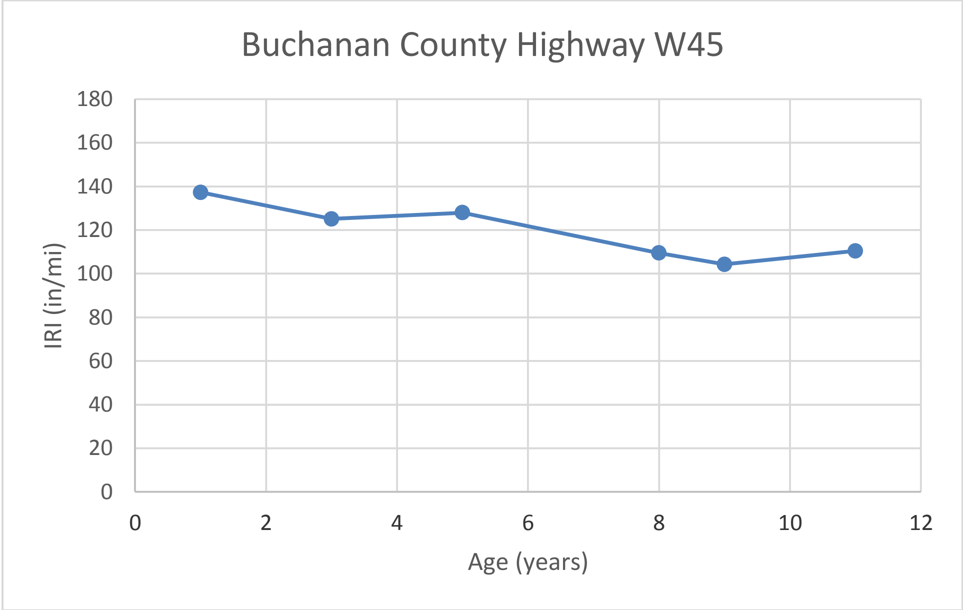

Figure A.14. IRI performance of Buchanan County W-45

County W-45 was found to have performed well at 13 years of service, featuring a PCI of 79 in/mi when last measured in 2014. Some distress was associated with random longitudinal cracking caused by failure to establish the longitudinal joint during construction. This project was initially selected for field review to investigate why PCI and IRI appeared to have rebounded significantly; between 2008 and 2011, PCI increased from 72 to 79 and IRI fell by nearly 20 in/mi.

Discussion with the county engineer revealed that no maintenance or rehabilitation activities had occurred on this pavement during its lifetime. This finding prompted an investigation that led to the discovery that the IRI measurement method changed sometime around the year 2011, leading to a decrease in IRI values.

Dallas County Highway F-31 West of Granger

Dallas County F-31, from Granger west 1 mile, is an unbonded concrete overlay on concrete constructed in 2000. An overview of the project is shown in Figure A.15.

Figure A.15. Overview of Dallas County F-31 west of Granger, November 2016

Full project details are provided in Table A.7, along with performance plots in Figures A.16 and A.17.

Table A.7. Project details for Dallas County F-31 west of Granger

Construction Year	2000
Overlay Type	UBCOC
PCC Thickness (in.)	6
Joint Spacing (ft)	12
Skewed Joints?	Yes
Interlayer	1 in. HMA

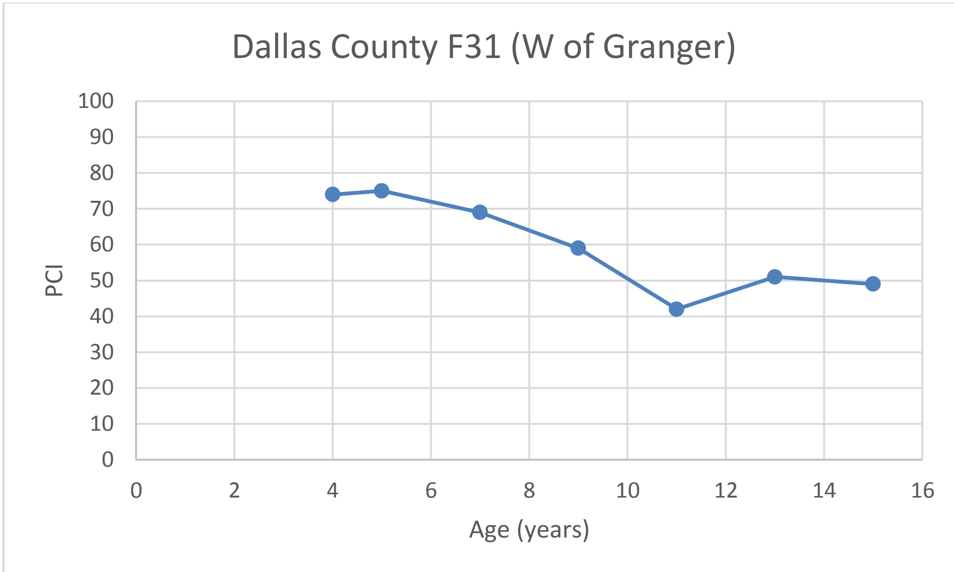

Figure A.16. PCI performance of Dallas County F-31 west of Granger

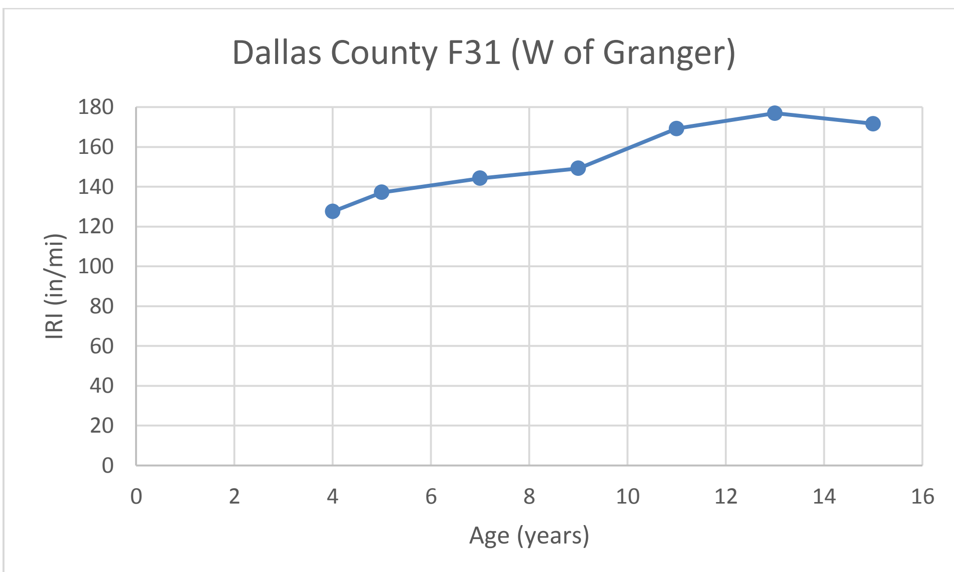

Figure A.17. IRI performance of Dallas County F-31 west of Granger

As is evident in Figure A.15, transverse joint deterioration developed at certain locations along Dallas County F-31, particularly as the overlay approached a creek crossing. Despite sunny conditions on the afternoon of the field review, shadowing from moisture was observed at many of the deteriorated joints and water was found sitting within a spalled joint area, as shown in Figure A.18.

Figure A.18. Water at spalled joint and adjacent joint shadowing on Dallas County F-31 west of Granger, November 2016

In addition, severe cracking along the slab edges was observed in the areas approaching the creek, as seen in Figure A.19.

Figure A.19. Cracking at slab edge approaching creek crossing on Dallas County F-31 west of Granger, November 2016

The presence of moisture and related distresses at this particular location suggested that poor drainage conditions and erosion of the underlying soil could be significant factors in the poor performance of this overlay section.

Dallas County Highway F-31 West of Minburn

Dallas County F-31, from Minburn west 4 miles, is an unbonded concrete overlay on asphalt constructed in 1992. An overview of the project is shown in Figure A.20.

Figure A.20. Overview of Dallas County F-31 west of Minburn, November 2016

Full project details are provided in Table A.8, along with performance plots in Figures A.21 and A.22.

Table A.8. Project details for Dallas County F-31 west of Minburn

Construction Year	1992
Overlay Type	UBCOA
PCC Thickness (in.)	7
Joint Spacing (ft)	12
Skewed Joints?	Yes
Interlayer	n/a

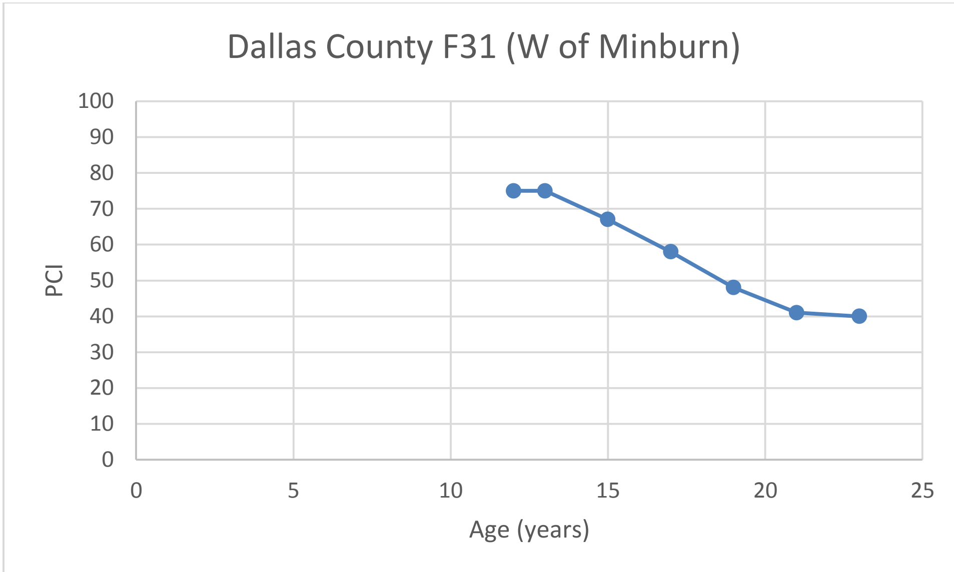

Figure A.21. PCI performance of Dallas County F-31 west of Minburn

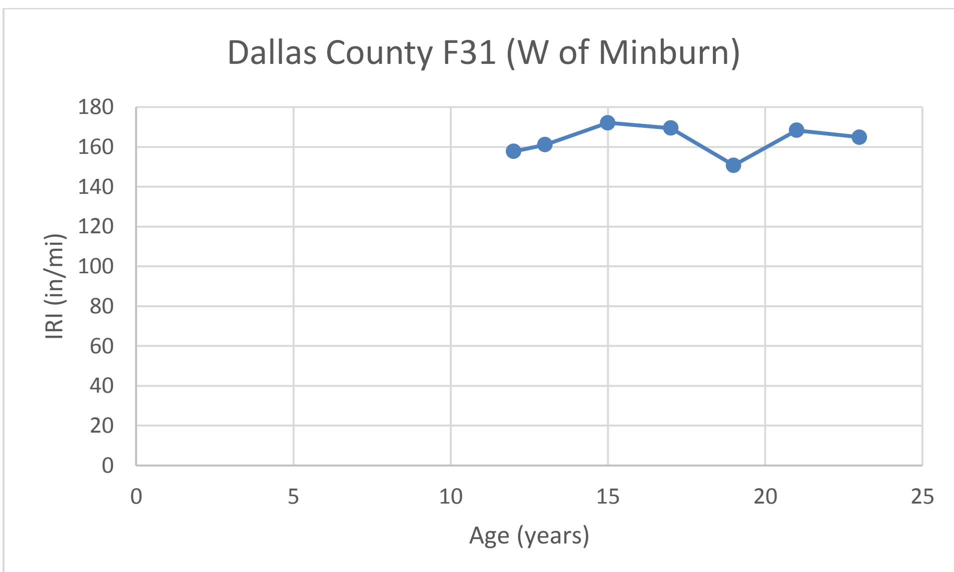

Figure A.22. IRI performance of Dallas County F-31 west of Minburn

By far, the most prevalent distress on this project was deterioration along the longitudinal joint, and sometimes along longitudinal cracks as well, both of which are evident in Figure A.23.

Figure A.23. Deterioration around and underneath the backer rod on Dallas County F-31 west of Minburn, November 2016

These distresses were common throughout the project and appear to be material durability related. Joint deterioration sometimes occurred around and even underneath the backer rod, as shown in Figure A.23, indicating that some of the deterioration may have resulted from poor drainage conditions.

Reaching a PCI of 40 in the year 2015, this project is scheduled to be reconstructed in 2017.

Dallas County Highway F-90

Dallas County F-90, from US 169 east 6 miles, is an unbonded concrete overlay on concrete constructed in 2006. An overview of the project is shown in Figure A.24.

Figure A.24. Overview of Dallas County F-90, November 2016

Full project details are provided in Table A.9, along with performance plots in Figures A.25 and A.26.

Table A.9. Project details for Dallas County F-90

Construction Year	2006
Overlay Type	UBCOC
PCC Thickness (in.)	6
Joint Spacing (ft)	12
Skewed Joints?	Yes
Interlayer	1 in. HMA

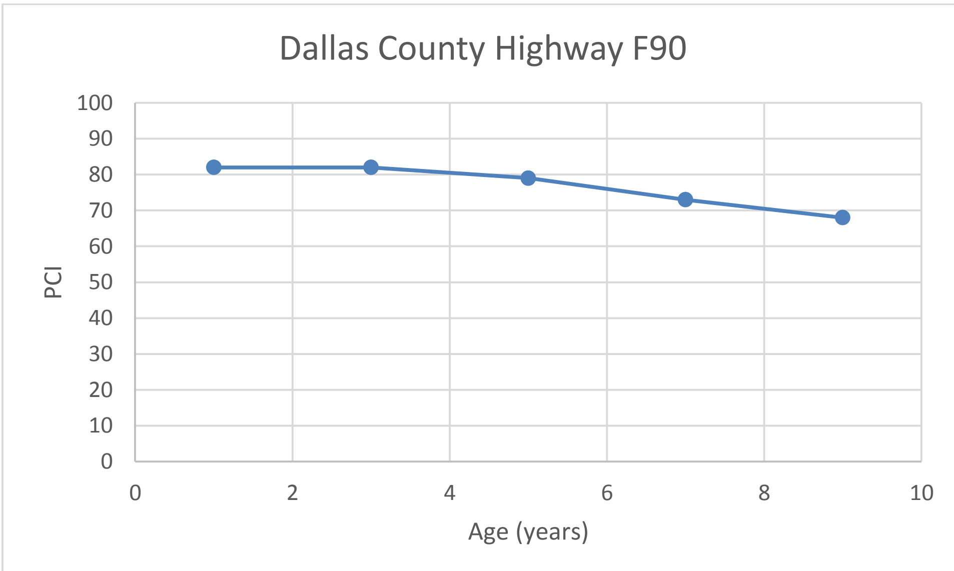

Figure A.25. PCI performance of Dallas County F-90

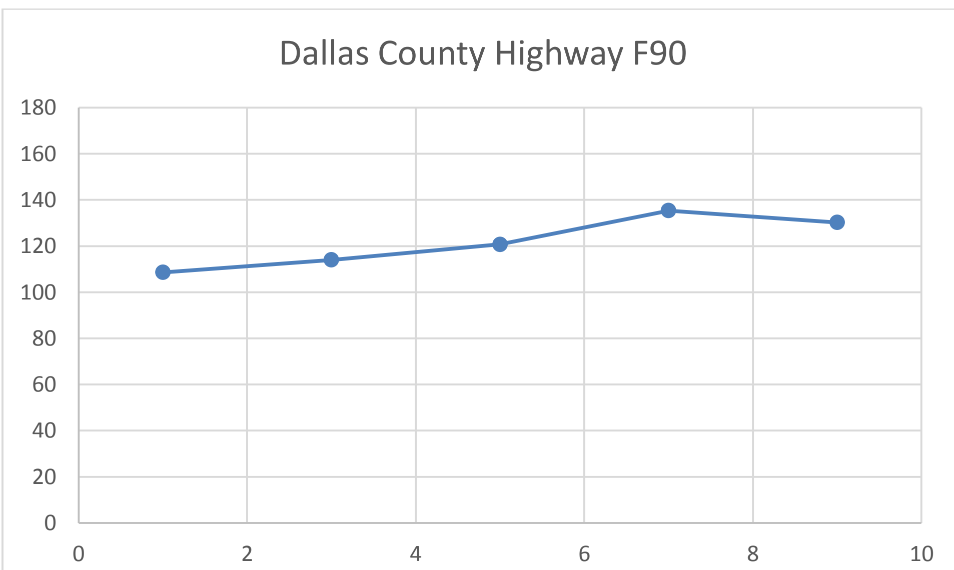

Figure A.26. IRI performance of Dallas County F-90

Dallas County F-90 was observed to have a significant amount of corner and longitudinal cracking, which can be seen in Figure A.24, contributing to a quickly declining PCI of 68 at an age of 9 years. Faulting was also beginning to develop at the joints.

Discussion with county staff indicated that this section served a quarry and featured upwards of 30 to 40% truck traffic. Therefore, the cracking likely resulted from load failure.

The cracks appeared to start at the corners of the slab before developing into further longitudinal and diagonal cracking, which was an observation based on the fact that many more corner cracks had been sealed by maintenance crews compared to longitudinal and diagonal cracks. The engineer also noted that maintenance crews observed water sitting underneath the underlying concrete slab when performing patching activities, indicating a poorly draining subgrade.

Given the heavy truck traffic and poor drainage conditions, this overlay likely would have performed better if it was thicker or had shorter joint spacing. The predominance of corner cracking may suggest, in particular, that curling and warping stresses, caused by the combination of a large slab size (12-ft) and a skewed joint pattern, were significant contributors to the observed distresses. An increase in slab thickness or a reduction in joint spacing to about 6-ft would likely have helped mitigate the stresses from the heavy truck traffic.

Dallas County Highway R-22

Dallas County R-22, from IA 44 to IA 141, is a bonded concrete overlay on asphalt constructed in 1983. An overview of the highway is shown in Figure A.27.

Figure A.27. Overview of Dallas County R-22, November 2016

Full project details are provided in Table A.10, along with performance plots in Figures A.28 and A.29.

Table A.10. Project details for Dallas County R-22

Construction Year	1983
Overlay Type	BCOA
PCC Thickness (in.)	5
Joint Spacing (ft)	15
Skewed Joints?	Yes
Interlayer	n/a

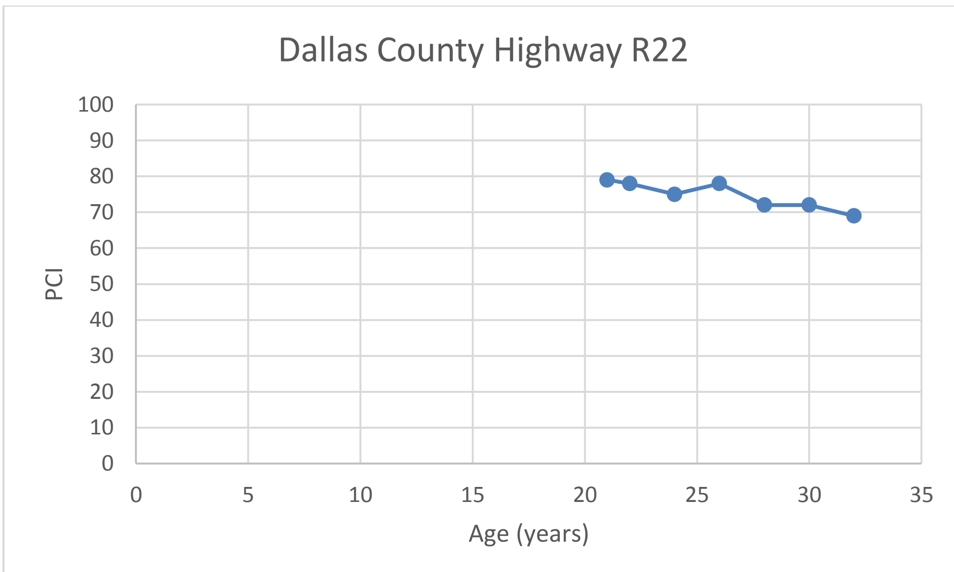

Figure A.28. PCI performance of Dallas County R-22

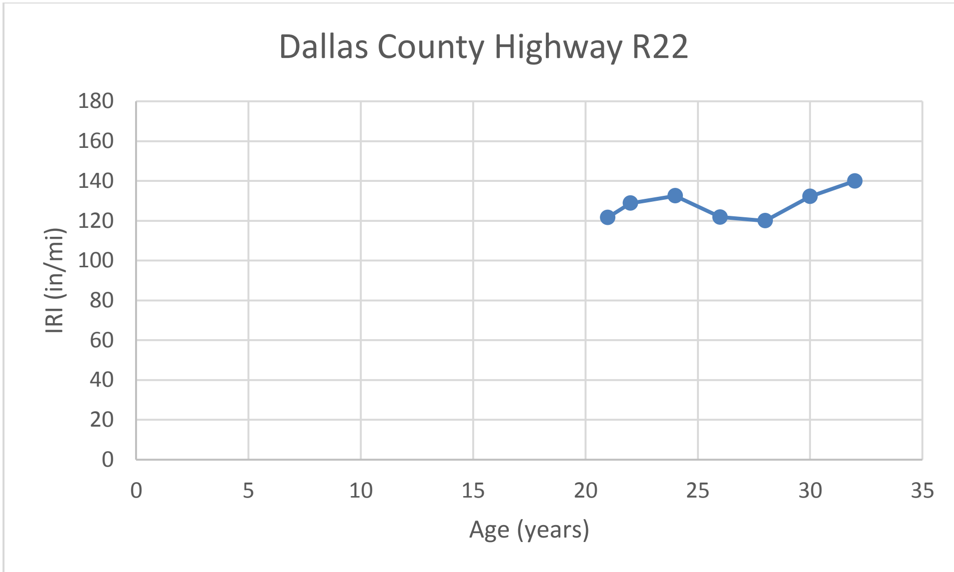

Figure A.29. IRI performance of Dallas County R-22

As seen in the performance plots in Figures A.28 and A.29, Dallas County R-22 has continued to exhibit excellent performance, while in service for more than 30 years, featuring a PCI of 69 at a pavement age of 32 years. The only notable distresses observed on this project were occasional instances of loss of support along the pavement edge, with one example shown in Figure A.30.

Figure A.30. Loss of support along pavement edge on Dallas County R-22, November 2016

Linn County Blairs Ferry Road

Blairs Ferry Road in Linn County, from Palo east to the Mud Lake bridge, is an unbonded concrete overlay on concrete constructed in 2009. An overview of the project is shown in Figure A.31.

Figure A.31. Overview of Linn County Blairs Ferry Road, September 2016

Full project details are provided in Table A.11, along with performance data in Table A.12.

Table A.11. Project details for Linn County Blairs Ferry Road

Construction Year	2009
Overlay Type	UBCOC
PCC Thickness (in.)	6
Joint Spacing (ft)	12
Skewed Joints?	Yes
Interlayer	1 in. HMA

Table A.12. Performance data for Linn County Blairs Ferry Road

Year of Data Collection	2013	2015
PCI	66	69
IRI (in/mi)	121.6	120.6

This overlay on Blairs Ferry Road was constructed after a major flood event in 2008 caused significant erosion under the original concrete pavement. Despite repair of the underlying structure before construction of the overlay, distresses have began to develop in the overlay, resulting in a low PCI value of 69 at an age of 6 years. Typical distresses included both transverse cracking, as shown in Figure A.32 on the left, and longitudinal cracking, as shown in Figure A.32 on the right, and appear to be characteristic of loss of support.

Figure A.32. Longitudinal and corner cracking on Linn County Blairs Ferry Road, September 2016

Linn County North 10th Street

North 10th Street in Linn County, from E-34 south 1.5 miles, is an unbonded concrete overlay on concrete constructed in 2002. An overview of this project is shown in Figure A.33.

Figure A.33. Overview of Linn County North 10th Street, September 2016

Full project details are provided in Table A.13, along with performance plots in Figures A.34 and A.35.

Table A.13. Project details for Linn County North 10th Street

Construction Year	2002
Overlay Type	UBCOC
PCC Thickness (in.)	6
Joint Spacing (ft)	12
Skewed Joints?	Yes
Interlayer	1 in. HMA

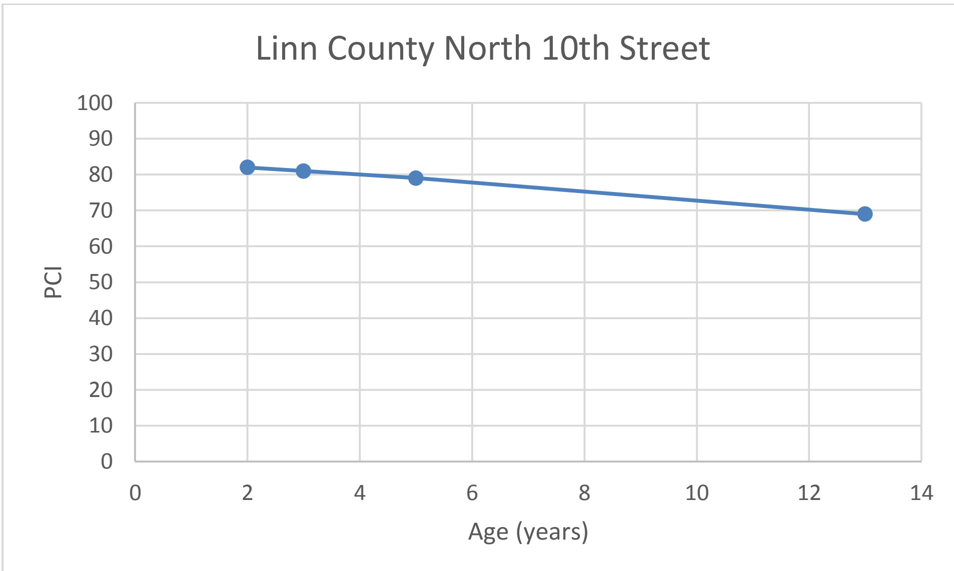

Figure A.34. PCI performance of Linn County North 10th Street

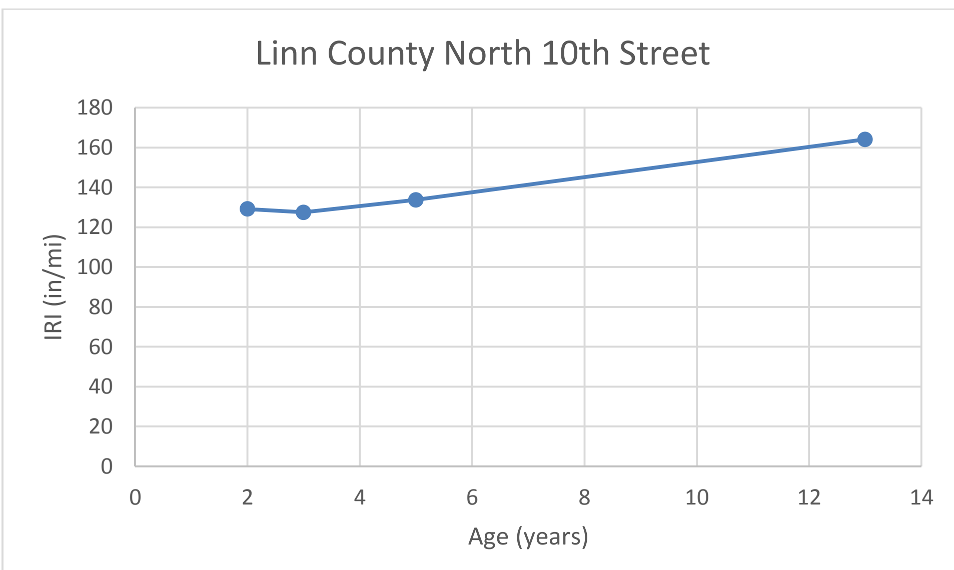

Figure A.35. IRI performance of Linn County North 10th Street

North 10th Street was observed to exhibit a rough ride at a young age (IRI of 164 in/mi at 13 years), and the review found that the roughness was primarily due to significant faults that occurred at a frequency of about every three transverse joints. In one area of study, this faulting resulted in considerable joint deterioration, as shown in Figure A.36.

Figure A.36. Joint deterioration on Linn County North 10th Street, September 2016

One hypothesis for the development of these faults and accompanying distresses was that they may have occurred over areas of D-cracking in the original, underlying concrete pavement. Another hypothesis was that the faults may have developed because some or most transverse joints may never have activated, leading to wide working cracks where the joints did manage to activate. When repairing a joint distress area in late 2016, county crews dug along the shoulder at the transverse joints in the adjacent slabs and confirmed that the transverse joints in the adjacent slabs had indeed activated, as shown in Figure A.37.

Photo courtesy of Linn County

Figure A.37. Activated transverse joint in slab adjacent to blow-up on Linn County North 10th Street

Pottawattamie County Highway G-30

Pottawattamie County G-30, from US 59 east to the Cass County Line, is an unbonded concrete overlay on concrete constructed in 1995. An overview of the project is shown in Figure A.38.

Figure A.38. Overview of Pottawattamie County G-30, November 2016

Full project details are provided in Table A.14, along with performance plots in Figures A.39 and A.40.

Table A.14. Project details for Pottawattamie County G-30

Construction Year	1995
Overlay Type	UBCOC
PCC Thickness (in.)	7
Joint Spacing (ft)	20
Skewed Joints?	Yes
Interlayer	1 in. HMA

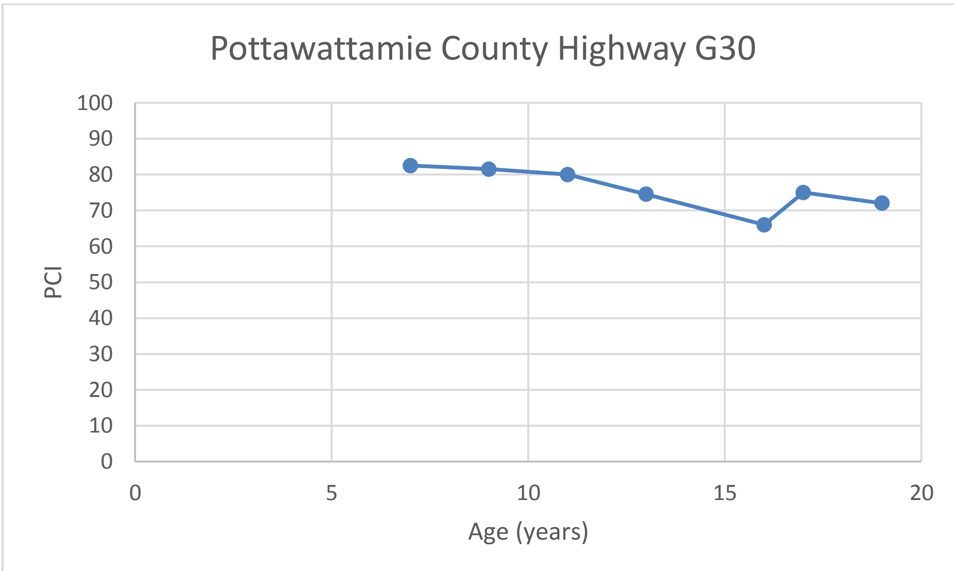

Figure A.39. PCI performance of Pottawattamie County G-30

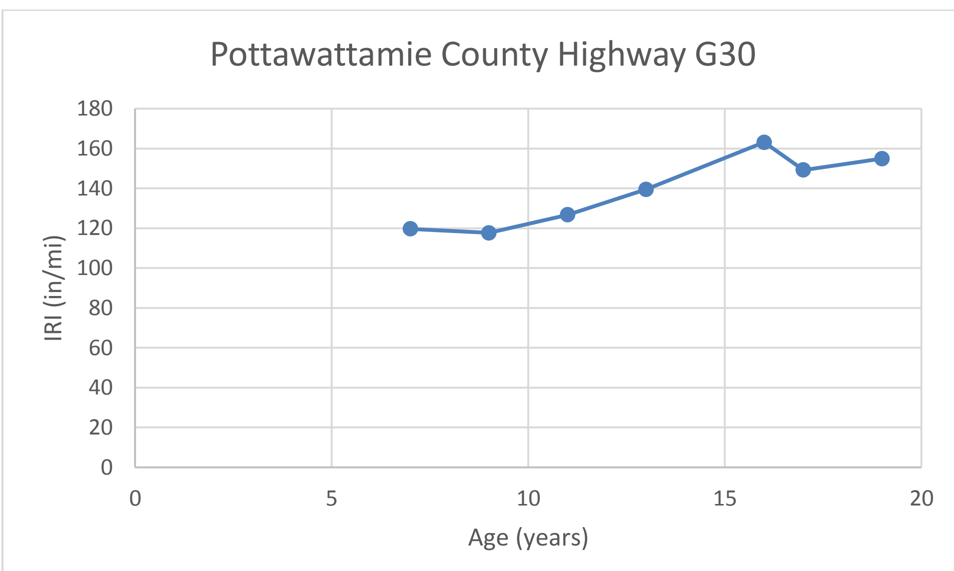

Figure A.40. IRI performance of Pottawattamie County G-30

Pottawattamie County G-30 has performed well for more than 20 years of service. At the time of the most recent measurement in 2014, the project featured a PCI of 72. (The jump from a PCI of 66 in 2011 would appear to be a result of the change in how IRI was measured, accompanying a drop in IRI from 163 in/mi in 2011 to 149 in/mi in 2012.) With the exception of patches in a few areas and rare instances of random cracking along the longitudinal joint, few distresses were observed along the overlay.

Pottawattamie County Highway L-34

Pottawattamie County L-34, from south of I-80 to County Highway G-30, is an unbonded concrete overlay on concrete constructed in 1992. An overview of the project is shown in Figure A.41.

Figure A.41. Overview of Pottawattamie County L-34, November 2016

Full project details are provided in Table A.15, along with performance plots in Figures A.42 and A.43.

Table A.15. Project details for Pottawattamie County L-34

Construction Year	1992
Overlay Type	UBCOC
PCC Thickness (in.)	6.5
Joint Spacing (ft)	12
Skewed Joints?	No
Interlayer	1/4 in. Slurry Seal

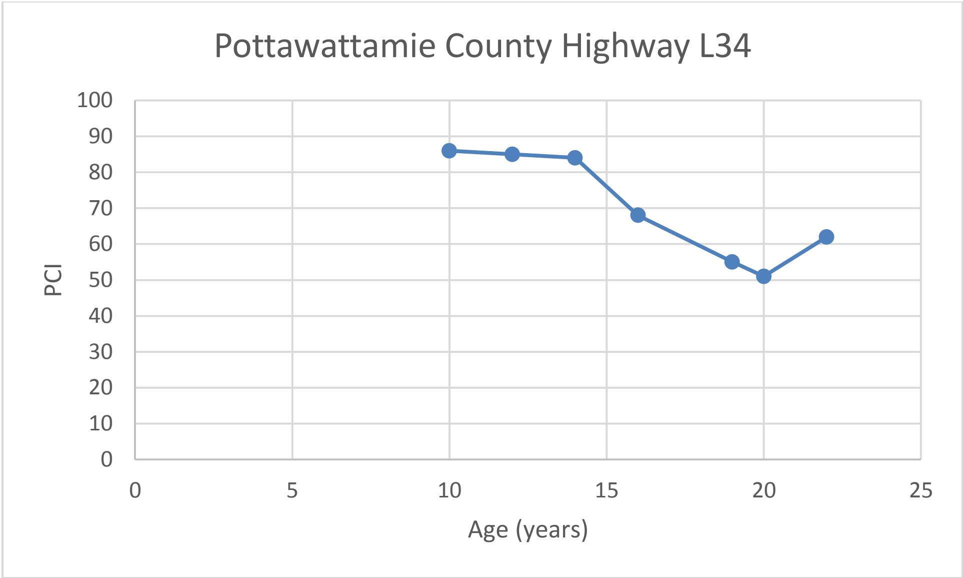

Figure A.42. PCI performance of Pottawattamie County L-34

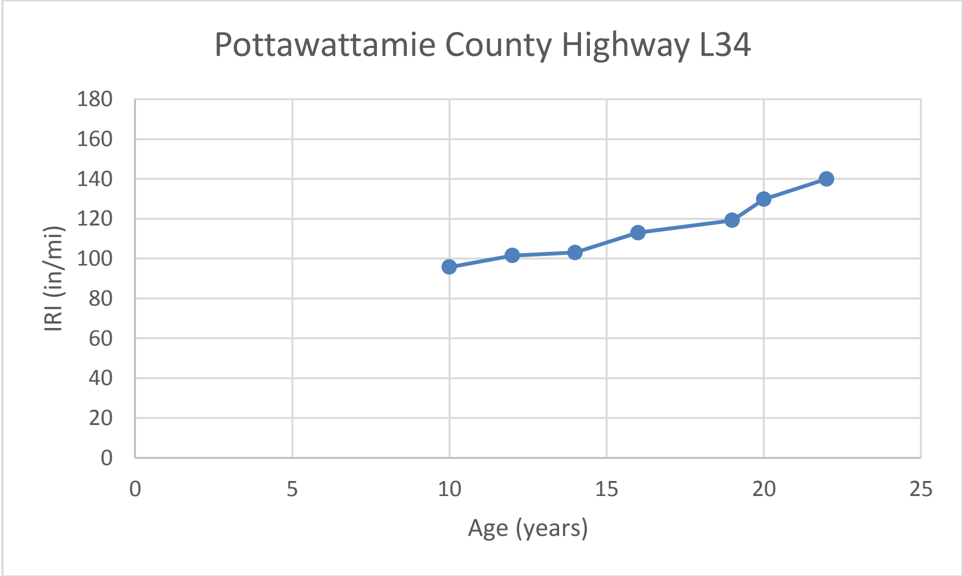

Figure A.43. IRI performance of Pottawattamie County L-34

The predominant issue found with this overlay appeared to be material-related distress. Deterioration along the transverse joints and at transverse-longitudinal joint intersections, as shown on the left in Figure A.44, was most commonly observed throughout the project.

Figure A.44. Apparent material-related distresses at joints on Pottawattamie County L-34, November 2016

Map- or web-shaped cracking, such as the example on the right in Figure A.44, was also observed near the transverse joints in some sections, particularly near the southern end of the project.

Pottawattamie County Highway L-66

Pottawattamie County L-66, from US 6 to IA 83, is a bonded concrete overlay on asphalt constructed in 1999. An overview of the project is shown in Figure A.45.

Figure A.45. Overview of Pottawattamie County L-66, November 2016

Full project details are provided in Table A.16, along with performance plots in Figures A.46 and A.47.

Table A.16. Project details for Pottawattamie County L-66

Construction Year	1999
Overlay Type	BCOA
PCC Thickness (in.)	6
Joint Spacing (ft)	15
Skewed Joints?	No
Interlayer	n/a

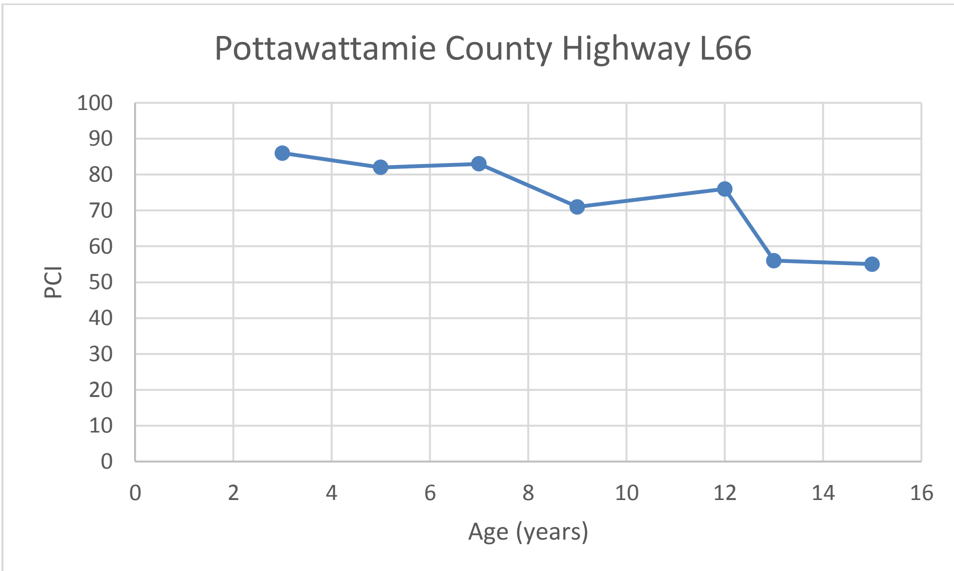

Figure A.46. PCI performance of Pottawattamie County L-66

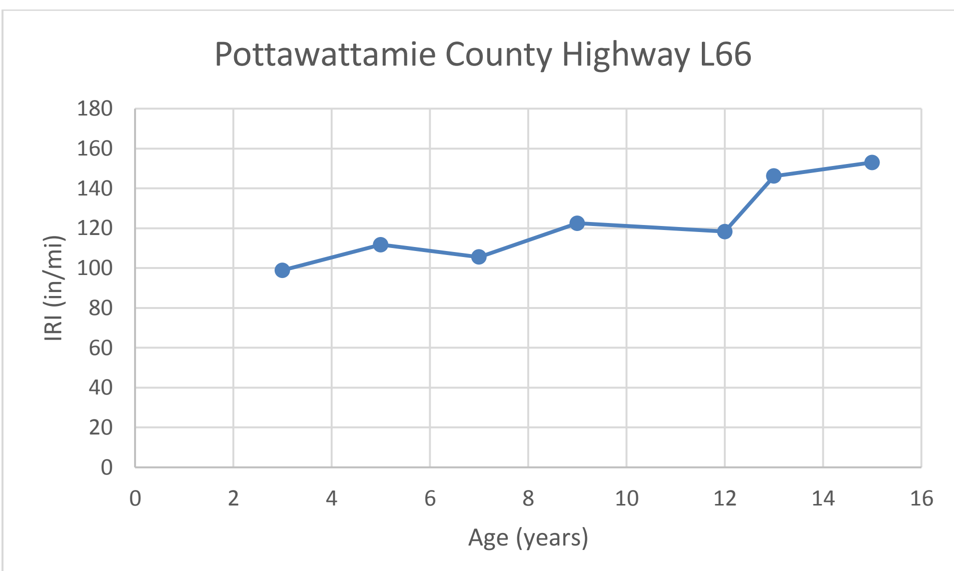

Figure A.47. IRI performance of Pottawattamie County L-66

This project appeared to be suffering from rapidly developing materials related distresses, examples of which are shown in Figure A.48.

Figure A.48. Materials-related distresses on Pottawattamie County L-66, November 2016

Map-shaped cracking was observed both at transverse joints, as shown on the left in Figure A.48, as well as in mid-slab locations along the wheel path, as shown on the right in Figure A.48. Figure A.48 on the right also demonstrates transverse joint deterioration and longitudinal cracking.

Finally, cold patching at what appeared to be a blow-up is shown in Figure A.49.

Figure A.49. Apparent blow-up on Pottawattamie County L-66, November 2016