

Concrete Pavements in the United States and Performance of Concrete Pavements in the  
Washington State Department of Transportation's Network

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Abstract

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This thesis consisted of two major components, a 50-state review of concrete pavement design, construction, and rehabilitation practices, and an evaluation of Washington State Department of Transportation (WSDOT) existing concrete pavement network using detailed Washington State Pavement Management System (WSPMS) data. The last major evaluation of WSDOT concrete pavement design, construction, and rehabilitation practices occurred in 2010. Significant advancements have emerged in pavement materials, design methods, sustainability considerations, and rehabilitation technologies. WSPMS has also been accumulating performance data for over 25 years. Ten states were found to have comprehensive and highly detailed concrete pavement design manuals, with 15 states having less detailed but still robust manuals. These resources served as the basis for identifying national best practices for concrete pavement design, rehabilitation methods, and testing. The WSPMS data consisted of 9055 data points and represented 2090.84 lane-miles and 795.54 center line miles of concrete pavement. Despite the age of WSDOT concrete pavements, indicators such as rutting, faulting, and IRI remain largely within acceptable limits, particularly on segments rehabilitated with dowel bar retrofits (DBR) or diamond grinding. Section specific analysis demonstrates that recent crack, seat, and overlay (CSOL) and grinding projects have greatly improved ride quality and slowed deterioration.

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# 1 Introduction

WSDOT manages 2090.84 lane-miles of concrete pavement. The last comprehensive assessment of WSDOT's concrete pavement policies, design standards, materials, and rehabilitation strategies was completed in 2010 through WA-RD 744 report series. Since then, significant progress has been made in concrete pavement technology and performance data. Advancements in concrete pavement design and fifteen additional years of pavement data collection through Washington State Pavement Management System (WSPMS) highlight the need for a new statewide review of concrete pavement practices.

This thesis is organized into two major components. The first component is a national review of concrete pavement practices across all 50 states. This review documents each state's use of concrete pavements. The analysis includes the associated design details, materials, construction requirements, and rehabilitation strategies. By identifying national trends, common practices, and notable deviations, this first component evaluates where WSDOT aligns with or differs from current industry standards.

The second component analyzes concrete pavement performance within Washington state using data from the WSPMS database. The dataset includes 9055 concrete pavement segments, representing 2091 lane-miles and 795 center line miles. Each datapoint provided location specific condition statistics at approximately 0.1-mile increments. Additionally, WSDOT supplied 30 years of historical section level performance data for the evaluation of long-term trends and the effectiveness of past rehabilitation strategies. Five case studies, four crack seal, and overlay (CSOL) and one unbounded and undoweled concrete overlay examine condition metrics, performance patterns to better understand deterioration mechanisms and rehabilitation outcomes.

Through this combined national benchmarking and state specific performance evaluation, the study provides a foundation for modernizing WSDOT's concrete pavement design and construction guidance to reflect current technologies, and long-term preservation needs.

## 2 Fifty-State Review

The first section reviews the current practices of concrete pavement for all 50 states, including the design details, materials, construction, and rehabilitation. Identify trends, common practices, unique practices, and practices that may be of interest to WSDOT as it reviews its own concrete pavement design and construction practices.

There are two common types of concrete pavements, jointed plain concrete pavements (JPCP) and continuous reinforcement concrete pavements (CRCP). Each state has their own design manual for how these pavements should be constructed, maintained, and rehabilitated. These state design manual requirements are analyzed and compared.

WSDOT manages 2090.84 lane-miles and 795.54 center line miles of concrete pavement. The last comprehensive review of WSDOT concrete pavement policy was completed in 2010 and since that time, notable changes have occurred in concrete material technology, pavement design, and the WSPMS database.

The WSDOT-specific dataset provided a high-resolution basis for analyzing concrete pavement performance across the state. This dataset consisted of 9,055 individual data points representing 2,090.84 lane-miles and 795 centerline miles of concrete pavement, with each data point corresponding to approximately 0.1 miles and including location-specific condition statistics. WSDOT also provided section-level historical performance data spanning 30 years, enabling assessment of rehabilitation outcomes and long-term trends in pavement condition.

### 2.1 Method

A 50-state review was conducted detailing the elements and design factors of concrete pavements throughout the United States of America. The following method describes the basic process for discovering information:

- Determine the inventory of design, construction and rehabilitation processes to be researched. This was collectively determined with the WSDOT project team during the research scoping process and includes: state names and department of transportation abbreviations, pavement type (JPCP/CRCP), design method (AASHTOWare/AASHTO 1993/In-house), design manual (yes/no), design life, JPCP transverse joint spacing, longitudinal joint and tie bars, CRCP rebar (size and grade), tie bar size and spacing, dowel diameter and spacing, shoulders (tied concrete or HMA), dowel bar material and coating, rehab: crack, seat and overlay, rehab: panel replacement, rehab: grinding, and field testing (e.g. MIT scan).
- The design manual for each state for pavement design was used to determine the inventory design, and construction and rehabilitation processes. Each state had a design manual, and the contents of these manuals were categorized as comprehensive, detailed, or basic.
  - There were 10 states (California, Florida, Georgia, Illinois, Minnesota, Montana, Oregon, Texas, Virginia, and Washington) with comprehensive design manuals.

A manual was deemed comprehensive when substantial details were provided for the concrete pavements, the design method and choices, the reinforcement used for the types of concrete pavements, and the rehabilitation methods used based on the types of deterioration.

- Fifteen states (Arizona, Colorado, Connecticut, Delaware, Maryland, Massachusetts, Missouri, Nebraska, New Jersey, New Mexico, New York, Pennsylvania, Tennessee, Vermont, Wyoming) had detailed design manuals but not to the comprehensive level of the first 10 described. These states listed their concrete pavement design preference, their pavement preference, and referenced standard drawings for more information on materials and measurements.
- The remaining 25 states (Alabama, Alaska, Arkansas, Hawaii, Idaho, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maine, Michigan, Mississippi, Nevada, New Hampshire, North Carolina, North Dakota, Ohio, Oklahoma, Rhode Island, South Carolina, South Dakota, Utah, West Virginia, Wisconsin) were classified as basic. Many of the basic states limited guidance on concrete pavements. Standard plans and specifications were used to determine if a mix design or standard plan for concrete pavement was present but did reference concrete designs in their manuals for limited instances, e.g. intersections, or bridges. Based on the design method, e.g. AASHTO 1993, estimates were made according to more detailed design plans as well as the design suggestions from the guideline itself.
- For states in transition for their design methods from AASHTO 1993 to AASHTO Ware Pavement ME (Alabama, Idaho, Texas for JPCP designs), the current design method was used i.e. the AASHTO 1993 design. Washington mentions using a mechanistic empirical method, historical data, and experience was used in the development and validation of design tables.

## 2.2 Results

Table 1 shows results from the 50-state review of concrete pavement state-of-the-practice. Table 2 describes the terms and phrases used in Table 1 and the reasons why they were given the value or a value was omitted.

**Table 1 50-state review of concrete pavement state-of-the-practice**

State	Pavement Type (JPCP/CRPC)	Design Method	Design Life (years)	JPCP Transverse Joint Spacing	Longitudinal Joint (ft)	CRCP Rebar (size & grade)	Tie Bar Size & Spacing	Dowel Diameter & Spacing	Shoulders (Tied Concrete or HMA)	Dowel Bar Material and Coating	MIT	FWD	DCP	CSOL	Overlay	Panel Replacing	Grinding
Alabama	JPCP (CRCP rare)	AASHTOWare Pavement ME	35	~15	12	#5-#6	#5 @ 30"	1.25" @ 12"	Asphalt shoulders	smooth round bars with corrosion resistant coating	No	No	No	No	No	Yes	Yes
Alaska	JPCP	AASHTO 1993	30	~15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt shoulders	smooth round bars with corrosion resistant coating	No	Yes	Yes	No	Yes	Yes	No
Arizona	JPCP	AASHTO 1993	30	~15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt shoulders	smooth round bars with corrosion resistant coating	No	Yes	No	Yes	Yes	Yes	Yes
Arkansas	JPCP	AASHTO 1993	30	~15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt shoulders	stainless steel, zinc clad, epoxy coated	No	No	No	No	Yes	Yes	Yes
California	JPCP (CRCP for select long-life projects)	Caltrans ME	40	14	12	#6 Grade 60 @48"	#6 @ 30"	1.25"-1.5" @ 12"	Tied concrete shoulder on CRCP; HMA shoulder on JPCP	stainless steel, zinc clad, epoxy coated	No	Yes	Yes	Yes	Yes	Yes	Yes
Colorado	JPCP (CRCP rare)	AASHTOWare Pavement ME	30	15	12	-	#6 @ 30"	1.25"-1.5" @ 12"	Asphalt or tied conc. shoulder	stainless steel, zinc clad, epoxy coated	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Connecticut	JPCP	AASHTO 1993	30	~15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt shoulders	smooth round bars with corrosion resistant coating	No	No	No	No	Yes	Yes	No
Delaware	JPCP	AASHTO 1993	30	~15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt shoulders	smooth round bars with corrosion resistant coating	No	No	No	No	Yes	Yes	Yes
Florida	JPCP (CRCP rare)	AASHTOWare Pavement ME	20	15	12	-	#5 @ 30"	1.25"-1.5" @ 12"	Asphalt or tied conc. shoulder	stainless steel, zinc clad, epoxy coated	No	No	No	Yes	Yes	Yes	Yes
Georgia	JPCP (CRCP for high volume projects)	AASHTO 1972	20	15	12	#5-#6	#5 @ 30"	1.25" @ 12"	Asphalt or tied conc. shoulder	-	No	No	No	No	Yes	No	No
Hawaii	JPCP	AASHTO 1993	30	~15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt shoulders	stainless steel, zinc clad, epoxy coated	No	No	No	No	No	Yes	Yes
Idaho	JPCP	AASHTOWare Pavement ME	20	~15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt shoulders	stainless steel, zinc clad, epoxy coated	No	Yes	No	No	Yes	Yes	Yes
Illinois	JPCP (CRCP favored on Interstates)	IDOT Mechanistic	30	15	12	#5-#6	#5 @ 30"	1.25" @ 12"	Asphalt or tied conc. shoulder	-	No	Yes	Yes	No	Yes	No	No
Indiana	JPCP	AASHTOWare Pavement ME	30	15	12	-	#5 @ 30"	1.25"-1.5" @ 12"	Asphalt or tied conc. shoulder	-	No	Yes	No	No	Yes	Yes	Yes
Iowa	JPCP	AASHTO 1993	30	~15	12	-	#5-#6 @ 30"	1.25" @ 12"	Asphalt shoulders	stainless steel, zinc clad, epoxy coated	No	No	No	No	Yes	Yes	Yes
Kansas	JPCP	AASHTO 1993	20	15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt or tied conc. shoulder	stainless steel, zinc clad, epoxy coated	No	Yes	Yes	No	Yes	Yes	Yes
Kentucky	JPCP	AASHTOWare Pavement ME	20	~15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt shoulders	stainless steel, zinc clad, epoxy coated	No	No	No	No	No	Yes	Yes
Louisiana	JPCP (CRCP for high volume projects)	AASHTO 1993	20	~15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt shoulders	-	No	No	No	No	Yes	Yes	Yes
Maine	JPCP	AASHTO 1993	20	~15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt shoulders	-	No	No	No	No	No	Yes	Yes
Maryland	JPCP	AASHTO 1993	25	~15	12	#5 Grade 60 @36"	#5 @ 36"	1.25" @ 12"	Asphalt or tied conc. shoulder	stainless steel, zinc clad, epoxy coated	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Massachusetts	JPCP	AASHTOWare Pavement ME	20	~15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt shoulders	-	No	No	No	No	Yes	Yes	Yes
Michigan	JPCP	AASHTOWare Pavement ME	20	15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt or tied conc. shoulder	stainless steel, zinc clad, epoxy coated	No	Yes	Yes	Yes	Yes	Yes	Yes
Minnesota	JPCP	MnPAVE-Rigid	35	15	12	-	#4-#5 @ 30"	1.25" @ 12"	Tied concrete (widened lane)	-	No	No	No	No	Yes	Yes	Yes
Mississippi	JPCP	AASHTO 1993	35	~15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt or tied conc. shoulder	-	No	No	No	No	Yes	Yes	Yes
Missouri	JPCP	AASHTOWare Pavement ME	25	15	12	-	#5-#6 @ 30"	1.25" @ 12"	Asphalt or tied conc. shoulder	stainless steel, zinc clad, epoxy coated	No	No	Yes	No	Yes	Yes	Yes
Montana	JPCP (CRCP rare)	AASHTO 1993	30	15	12	-	#6 @ 30"	1.5" @ 12"	Tied concrete (widened lane)	stainless steel, zinc clad, epoxy coated	No	Yes	Yes	Yes	Yes	Yes	Yes
Nebraska	JPCP	AASHTO 1993	35	16.5	16	-	#5 @ 30"	1.25" @ 12"	Asphalt or tied conc. shoulder	smooth round bars with corrosion resistant coating	No	Yes	Yes	Yes	Yes	Yes	Yes
Nevada	JPCP (CRCP for high volume projects)	AASHTO 1993	30	~15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt shoulders	stainless steel, zinc clad, epoxy coated	No	Yes	No	Yes	Yes	Yes	Yes
New Hampshire	JPCP	AASHTO 1993	20	~15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt shoulders	smooth round bars with corrosion resistant coating	No	No	No	No	Yes	Yes	Yes
New Jersey	JPCP	AASHTOWare Pavement ME	20	15	14	-	#5 @ 30"	1.25" @ 12"	Asphalt shoulders	-	No	Yes	No	Yes	Yes	Yes	Yes
New Mexico	JPCP	AASHTO 1993	20	15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt or tied conc. shoulder	smooth round bars with corrosion resistant coating	No	Yes	No	Yes	Yes	Yes	Yes
New York	JPCP	AASHTOWare Pavement ME	50	15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt or tied conc. shoulder	-	No	Yes	No	Yes	Yes	Yes	Yes
North Carolina	JPCP	AASHTO 1993	30	15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt or tied conc. shoulder	-	No	Yes	Yes	Yes	Yes	Yes	Yes

North Dakota	JPCP (CRCP for high volume projects)	AASHTO 1993	30	15	12	#5 Grade 60	#5 @ 30"	1.25" @ 12"	Asphalt or tied conc. shoulder	smooth round bars with corrosion resistant coating	No	No	No	No	Yes	Yes	Yes
Ohio	JPCP (CRCP for high volume projects)	AASHTO 1993	30	15	14	#5-#6 (older CRCP)	#5 @ 30"	1.25" @ 12"	Asphalt or tied conc. shoulder	-	No	No	No	No	Yes	Yes	Yes
Oklahoma	JPCP (CRCP for high volume projects)	AASHTO 1993	30	15	12	#5 Grade 60 @36"	#5 @ 30"	1.25" @ 12"	Asphalt or tied conc. shoulder	-	No	No	No	Yes	Yes	Yes	Yes
Oregon	JPCP (CRCP for high volume projects)	AASHTOWare Pavement ME	50	15	12	#5 Grade 60 @36"	#5 @ 36"	1.25"-1.5" @ 12"	Asphalt or tied conc. shoulder	stainless steel, zinc clad, epoxy coated	No	Yes	Yes	No	Yes	Yes	Yes
Pennsylvania	JPCP (CRCP for high volume projects)	AASHTO 1993	50	15	12	#5 Grade 60 @36"	#5 @ 36"	1.25"-1.5" @ 12"	Asphalt or tied conc. shoulder	stainless steel, zinc clad, epoxy coated	No	Yes	Yes	Yes	Yes	Yes	Yes
Rhode Island	JPCP	AASHTO 1993	20	~15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt shoulders	smooth round bars with corrosion resistant coating	No	No	No	No	Yes	Yes	Yes
South Carolina	JPCP	AASHTO 1993	30	15	14	#5-#6 (few CRCP)	#5 @ 30"	1.25" @ 12"	Asphalt or tied conc. shoulder	-	No	No	No	No	Yes	Yes	Yes
South Dakota	JPCP (CRCP for high volume projects)	AASHTO 1993	30	15	12	#5 Grade 60	#5 @ 30"	1.25" @ 12"	Asphalt or tied conc. shoulder	smooth round bars with corrosion resistant coating	No	No	No	No	Yes	Yes	Yes
Tennessee	JPCP	AASHTO 1993	20	15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt or tied conc. shoulder	-	No	Yes	No	No	Yes	Yes	Yes
Texas	CRCP (JPCP (CPCD) on lower volumes)	TxCRCP-ME (CRCP); AASHTO 1993 (CPCD)	30	20ft max	12	#6 Grade 60 (0.6% steel)	#6 @ 24"	1.25"-1.5" @ 12"	Tied concrete shoulder on CRCP; HMA shoulder on CPCD	smooth round bars with corrosion resistant coating	No	Yes	Yes	No	Yes	Yes	Yes
Utah	JPCP	AASHTOWare Pavement ME	40	15	12	-	#5 @ 30"	1.25" @ 12"	Tied concrete shoulder	smooth round bars with corrosion resistant coating	No	Yes	Yes	Yes	Yes	Yes	Yes
Vermont	JPCP	AASHTO 1993	20	15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt shoulders	-	No	Yes	No	No	Yes	No	No
Virginia	JPCP (CRCP for high volume projects)	AASHTO 1993	30	15	12	#5 Grade 60	#5 @ 30"	1.25" @ 12"	Asphalt or tied conc. shoulder	smooth round bars with corrosion resistant coating	No	Yes	No	Yes	Yes	Yes	Yes
Washington	JPCP	AASHTO 1993	50	15	12	#5-#6 (older CRCP)	#5 @ 30"	1.25" @ 12"	Asphalt or tied conc. shoulder	stainless steel, zinc clad, epoxy coated	No	Yes	No	Yes	Yes	Yes	Yes
West Virginia	JPCP	AASHTO 1993	30	~15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt shoulders	-	No	No	No	No	Yes	Yes	Yes
Wisconsin	JPCP	WisPave	20	~15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt shoulders	-	No	No	No	No	Yes	Yes	Yes
Wyoming	JPCP	AASHTOWare Pavement ME	20	15	12	-	#5 @ 30"	1.25" @ 12"	Asphalt shoulders	-	No	No	No	Yes	Yes	No	No

**Table 2 Descriptions to give further explanation to Table 1 column details**

<b>Column Header from Table 1</b>	<b>Description</b>
<b>State</b>	State being addressed
<b>DOT</b>	Department of transportation abbreviation
<b>Pavement Type</b>	"JPCP" - Jointed Plain Concrete Pavement, if concrete pavements are used that this method would be the choice
	"JPCP (CRCP rare)" - Continuous Reinforcement Concrete Pavement. CRCP details are mentioned in manual or standard plans but not common in practice
	"JPCP (CRCP for select long-life projects)", "JPCP (CRCP for high volume projects)", "JPCP (CRCP favored on Interstates)" - CRCP used typically on roads with ADT >10000 vehicles/day
<b>Design Method</b>	"Caltrans ME", "IDOT Mechanistic", "MnPAVE-Rigid", "TxCRCP-ME", "WisPave" - these are all in-house design guides developed by the specific DOTs which were designed with the state's specific conditions in mind
	"AASHTO 1993" - design guide developed by American Association of State Highway and Transportation Officials which uses empirical data obtained from a road test and is the basis of its design
	"AASHTOWare Pavement ME" - like the 1993 counterpart, however each state calibrates local models to field performance
<b>Design Life (years)</b>	The stated design life of the pavement by the DOT. DOTs with design lives under 30 years define this period as initial service prior to rehabilitation
<b>JPCP Transverse Joint Spacing</b>	Explicitly stated spacings. Approximations "~" were made when spacings were not explicit based typical design recommendations from AASHTO 1993, typically between 12-15ft adjusted for local climate and slab thickness
<b>Longitudinal Joint (ft)</b>	Joints that run parallel to the flow of traffic placed between two adjacent lanes
<b>CRCP Rebar (size &amp; grade)</b>	Bars specified #5 or #6 for longitudinal spacing with 6 to 8 inches to maintain crack control. The 36" and 48" spacings are for transverse reinforcement to maintain a 0.6% steel content of the pavement. Some states have "older CRCP" with #6 bars "few CRCP" means select routes used #6 bars instead of the standard #5. States that did not have a value do not use CRCP or defer to the design guide
<b>Tie Bar Size &amp; Spacing</b>	Most states specified #5 bars with 30" spacing. In cases where not explicitly stated, the AASHTO 1993 or similar design guide typically recommended similar bar sizing and spacing. Smaller #4 or larger #6 bars with either 24" or 36" spacings were adjustments made to accommodate traffic loading or slab thickness.
<b>Dowel Diameter &amp; Spacing</b>	Sizing of 1.25" diameter at 12" spacing explicitly stated or recommended through design guides. Larger 1.5" diameter used to accommodate higher loads or thicker slabs.
<b>Shoulders (Tied Concrete or HMA)</b>	Tied concrete shoulders provide structural support and load sharing with the mainline pavement through tie bars which is preferred for high volume or heavily loaded pavements. HMA shoulders are cheaper to construct and maintain.
<b>Dowel Bar Material and Coating</b>	States specifically detail stainless steel, zinc clad, epoxy coated dowel bars and others mention smooth round bars with corrosion resistant coating. States that did not specify a dowel bar material or coating would be expected to use design guide recommendations or do not use concrete pavements.
<b>MIT</b>	Magnetic imaging technology. Scan usually done to verify dowel bar or tie bar placement and alignment.
<b>FWD</b>	Falling weight deflectometer. Device that drops a known weight and measures the deflection to determine the structural capacity and stiffness of materials usually to estimate remaining pavement life.
<b>DCP</b>	Dynamic cone penetrometer. Rapid field test done to determine strength of base materials.
<b>CSOL</b>	Crack, seat, and overlay. Used to rehabilitate old concrete pavements by intentionally cracking to provide stable foundation for a surface topping of usually HMA.
<b>Overlay</b>	Overlay is a generalized rehabilitation of placing a new layer on top of an existing layer to restore ride quality.
<b>Panel Replacement</b>	States that specify panel replacement recommend after 20-30 years of service when corner breaks, spalling, or faulting develops
<b>Grinding</b>	Grinding repairs are typically done around 15-25 years of service or after a dowel bar retrofit

## 2.3 Discussion

This section focuses on key findings on how the different states approach concrete pavements, the use of rehabilitation, and testing of concrete pavements. This section also, where relevant, identifies how WSDOT differs from these states and possible areas for investigation in concrete pavement design.

### 2.3.1 Pavement Type

Forty-two (42) out of the 50 states use JPCP as their main Concrete pavement. California, Georgia, Illinois, Oklahoma, Oregon, South Dakota, Texas, and Virginia prefer CRCP. The Texas Department of Transportation (TxDOT) policy is to use CRCP with JPCP being an acceptable alternative at the discretion of the district engineer. TxDOT has developed a table to determine which method of concrete pavement will be used for various circumstances.

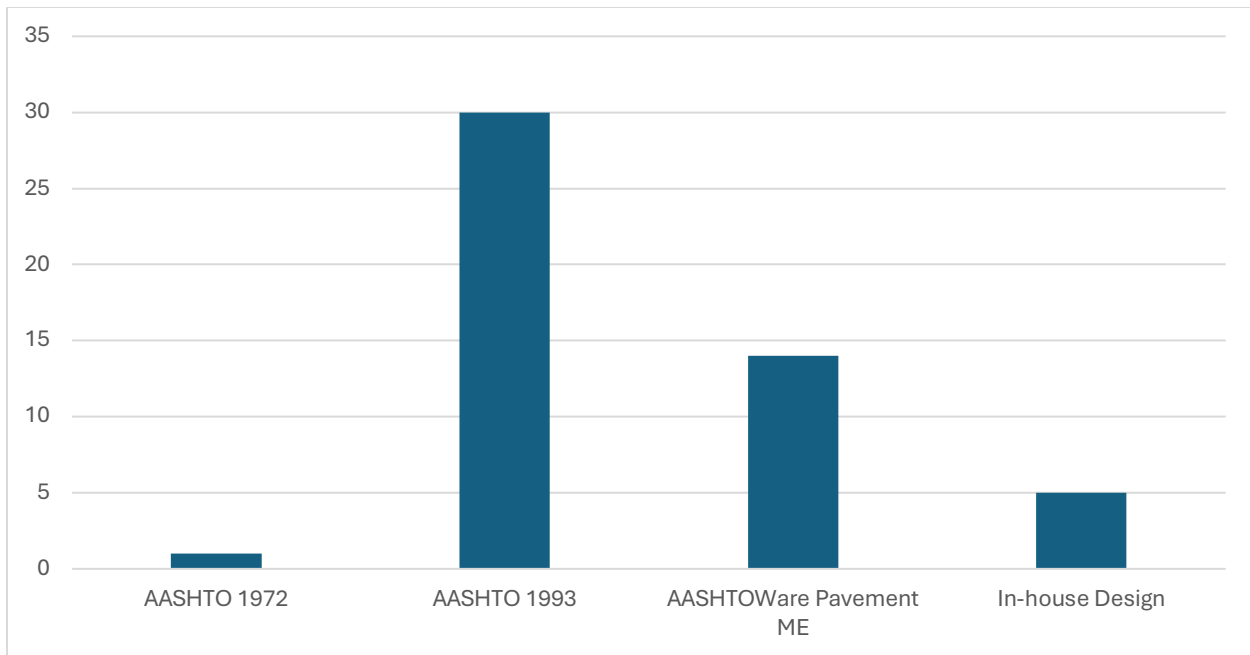
**Table 3 TxDOT Selection of Concrete Pavement Type (Stevenson, 2021)**

<b>Factors</b>	<b>Where/When</b>	<b>JPCP</b>	<b>CRCP</b>
<b>Traffic Level</b>	>40 million ESALS		✓✓✓
	10 – 40 million ESALS	✓✓	✓✓✓
	<10 million ESLAS	✓✓✓	✓
<b>Constructability Under Traffic</b>	Frontage road with numerous leave outs	✓✓✓	
	Intersection/crossings	✓✓✓	
<b>Material Source</b>	Use local coarse aggregate with higher coef. of thermal expansion for traffic levels <40 million ESLAS	✓✓✓	
<b>Support Condition</b>	Natural subgrade with higher risk for heaves		✓✓✓
	On embankment with higher risk for voids under slab		✓✓✓

The states that prefer CRCP for their concrete pavements have extensive design guidelines for CRCP. These extensive design guidelines indicate they have put time and effort into developing them as CRCP is a significant (but not always majority) concrete pavement type that these states use.

### 2.3.2 Design Method

Figure 1 shows the prevalence of concrete pavement design methods amongst the 50 U.S. states.



**Figure 1: Concrete pavement design methods choice distribution.**

There are currently 4 common concrete pavement design methods in use: AASHTO 1972, AASHTO 1993, AASHTOWare Pavement ME, plus a few in-house state design methods. Georgia is the only state still using AASHTO 1972. The majority (30) of states use the AASHTO 1993 design guide which uses empirical data as the basis for this design. The states that use the AASHTO 1993 method include Maine, Vermont, Hawaii, Montana, South and North Dakota. These are states with less Concrete pavements and less heavy road traffic in terms of vehicular weight and traffic volume. AASHTOWare Pavement ME is a mechanistic empirical method currently used by 14 states.

Virginia DOT (VDOT) outlines the criteria for their use of AASHTOWare Pavement ME. VDOT’s Secondary and Subdivision Design Guide will be used for new construction and reconstruction unless the traffic volumes exceed 10,000 AADT. If the traffic volume of the Secondary Roadway exceeds 10,000 AADT, the actual truck count and classification need to be determined and serious consideration shall be given to designing using MEPDG (AASHTOWare Pavement ME) for new construction and reconstruction (Virginia Department of Transportation, 2024).

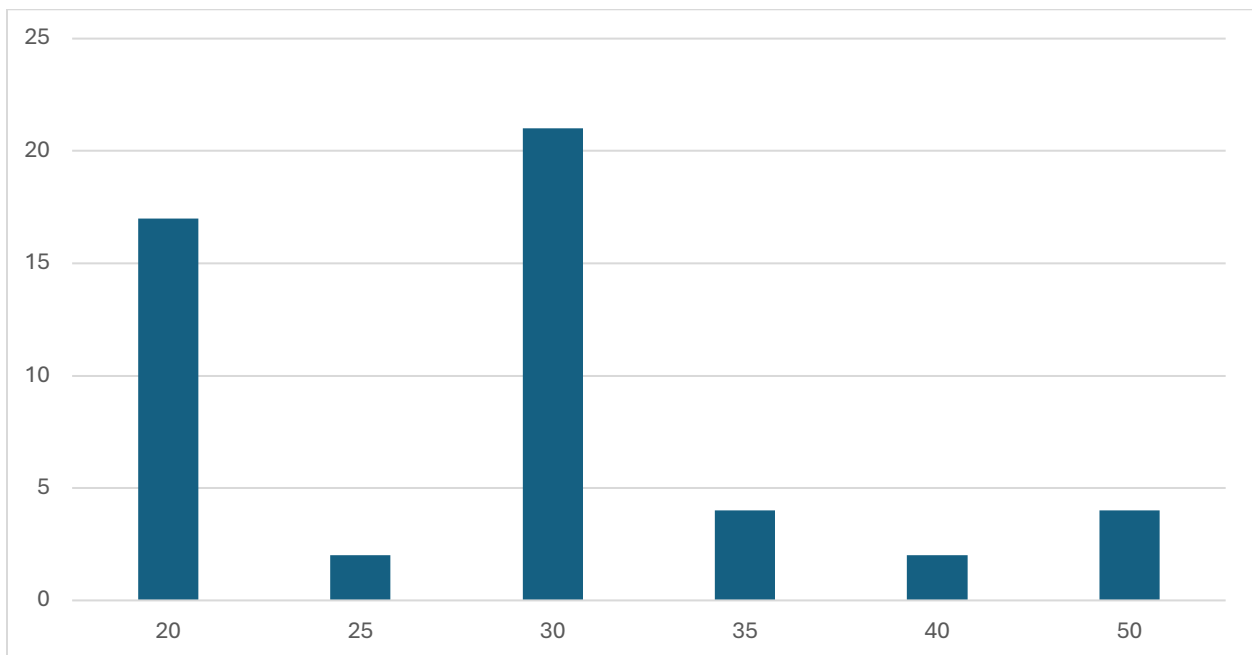
Alabama, Idaho, and Washington have mentioned transitioning to the AASHTOWare Pavement ME design method. This transition is said to be an expensive one and a reason for hesitation for many states as the upfront cost to gather the data necessary is significant. According to Missouri Department of Transportation (MoDOT), Costs for the conversion from the present empirical AASHTO design method to the new AASHTOWare Pavement ME design method are expected to be nearly \$500,000. These costs include the consultant fee to guide MoDOT through the distress-model calibration process, develop materials-testing protocols and data-gathering procedures, and provide a user-design document; and MoDOT labor and material costs to perform the necessary lab tests for distress model calibration (Missouri Department of Transportation, 2004).

There is an opportunity for savings using the ME method as the pavements are refined to the areas they are being used. MoDOT explains that the mechanistic-empirical approach (AASHTOWare Pavement ME) reduces the field data or lab testing data needed. The mechanistic portion of this model is calculating the pavement response, tensile strain, based on the pavement layer thicknesses, material properties, and wheel loads. The empirical portion of this model is inducing tensile strains in an HMA layer to determine the point of fatigue failure. This combined approach will lead to more durable pavements for the designed area (Missouri Department of Transportation, 2004).

California, Illinois, Minnesota, Texas, and Wisconsin have developed their own mechanistic empirical methods specific to their state. Reasons for developing in-house methods vary and are often not readily identifiable. Sometimes these in-house methods are entirely new (e.g., California) and sometimes they represent modifications of more common methods (e.g., Illinois has modified the AASHTOWare Pavement ME to their parameters).

### 2.3.3 Design Life

Figure 2 shows the prevalence of concrete pavement design life amongst the 50 U.S. states



**Figure 2: Design life of concrete pavements as stated in design manuals.**

The design life for Concrete pavements for 17 states is listed at 20 years and two states at 25 years. These 20-year and 25-year lifespan designs are usually JPCP designs with some mentioning that these design lives are just initial life designs, and the life of the pavement can be extended through rehabilitation such as overlays. Twenty-five states have either 30- or 35-year design lives which can also be extended through rehabilitations. Forty- and fifty-year design lives are typically specified for high volume or long-life projects with heavy vehicular traffic that would be severely affected by road deterioration and their subsequent repairs. The design lives selected from the

pavement design manual's concrete road specifications. If there was an option between municipal and highway roads, the highway specifications were used for the design life as the municipal roads were rarely concrete and did not focus on the JPCP or CRCP designs.

#### 2.3.4 Transverse Joint Spacing

The transverse spacing norm is 15ft. Shorter spacings of 12-14ft were seen in cold climates such as Maine, Alaska, and Massachusetts. This can be due to the temperature fluctuations of these places and the risk of panel cracking. Panels that are closer to square will have a smaller likelihood to crack. States may use different spacing depending on the location and use of the pavement, for example, California is open to longer spacing, up to 18ft, in the warmer climate and Texas states a 20ft max spacing in their warmest climates.

#### 2.3.5 Tie Bars

Most states (46) use #5 bars for tie bars for their pavements. The spacing is usually 30 inches for the tie bars (longitudinal joints of the pavement). If tie bars are not mentioned, the state does not use very many Concrete pavements. Michigan and Missouri mention the use of #6 bars for widened lanes or thicker slabs. Texas and Illinois mention shorter tie bar spacings of 24-27 inches for their more trafficked corridors. Iowa and Missouri mention #6 bars for wider and more robust sections of pavement while California, Colorado, Montana, and Texas specify #6 bars exclusively.

#### 2.3.6 Shoulder Types

Asphalt shoulders are the sole choice for 21 states as their concrete pavement use is minimal. It is common to see tied concrete shoulders being used with concrete pavements on high volume pavements of over ten million ESALs according to TxDOT. Concrete shoulders as the only option are only specified in three states, Minnesota, Montana, and Utah, with California and Texas specifying concrete shoulders on their CRCP pavements and HMA on the JPCP equivalents. The prevalent choice of asphalt is likely due to the lower cost of asphalt and the ease of maintenance for a lower use part of a pavement. Tied Concrete pavement shoulders are preferred in states where CRCP is preferred.

#### 2.3.7 Reinforcement

Grade 60, #5 or #6 bars are the main reinforcement used in CRCP. Typical dowel bar specifications are 1.25-inch diameter dowel bars spaced 1 foot on center. California, Texas, and New Jersey sometimes specify up to 1.5-inch diameter bars for their more trafficked or heavier use sections of pavement, but these are not typical.

#### 2.3.8 Field Testing

The state pavement design manuals were analyzed for three field testing metrics, magnetic imaging technology (MIT), falling weight deflectometer (FWD), and dynamic cone penetrometer (DCP). MIT, used for dowel bar and tie bar location verification after installation, was only mentioned by Colorado and Maryland. FWD was much more common with 25 states stating that they use this

testing method for soil to determine the strength of the soil and an estimate of the remaining life of the pavement. DCP was mentioned by 15 states as they use this testing method to determine the strength of the base material.

### 2.3.9 Rehabilitation

Only four (Alabama, Hawaii, Kentucky, Maine) states do not explicitly state overlay as a method of pavement rehabilitation. It should be noted that concrete pavements are not common in these states, and the method of overlay repair is very common for concrete pavements as the pavements deteriorate. This reflects the versatility and cost-effectiveness of overlays, which can be applied to both flexible and rigid pavement structures. Crack, seat, and overlay (CSOL) is listed by 19 states for rehabilitation. CSOL is a more involved overlay process as the name suggests where the cracking and seating of the pavement provides a stabilized base for the overlay which will reduce deformations in the future as the pavement's life is extended.

Grinding, typically performed after 20 to 30 years of service (according to WSDOT and WisDOT design guides), is another widely used rehabilitation measure to restore smoothness and improve ride quality. Panel replacement practices, on the other hand, are more prevalent among states with significant concrete pavement networks where localized distress warrants targeted repairs. In contrast, states with limited use of concrete pavements—often confined to intersections or bridge approaches—are less likely to include panel replacement in their standard rehabilitation practices, reflecting the smaller scale of their rigid pavement applications.

### 2.3.10 Summary

**Concrete pavement type.** JPCP performed in all 50 states and is the design method preferred by 42 states. The remaining eight states are heavily committed to CRCP, but typically only in specific contexts, such as high traffic highways.

**Design.** Most states (30) use AASHTO 1993, Georgia uses AASHTO 1972 and the remaining states use a mechanistic empirical design. Five states use their own in-house design and 14 using AASHTOWare Pavement ME.

**Design life and details.** The most common design life of pavements is 30 years with some states specifying a long-term design life of 30+ years. JPCP longitudinal joint spacing is typically 15ft and tie bars are usually #5 bars and spaced at 30 inches. Dowel bars are typically 1.25 inches in diameter and spaced 1ft on center with a corrosion resistant coating. States that use CRCP usually specify #5 bars.

**Field testing.** MIT for dowel bars and tie bars is not very common as other metrics for design confirmation or performance analysis are preferred especially in states where concrete pavements are preferred. DCP and FWD are more widely utilized for material testing.

**Rehabilitation.** Diamond grinding and panel replacement are common forms of rehabilitation.

## 3 WSPMS Data Analysis

This section uses data from the Washington State Pavement Management System (WSPMS) to analyze concrete pavement performance, condition, and investigate specific case study performance histories.

### 3.1 About the Washington State Pavement Management System (WSPMS)

The Washington State Pavement Management System (WSPMS) is WSDOT's statewide pavement database and analytical performance tracker for pavement conditions (Federal Highway Administration, 1999). WSPMS manages about 18,500 lane miles of state highway pavements with approximately 12% of these lane-miles being surfaced with concrete. WSPMS conducts engineering and economic analyses to improve pavement performance and maximize the benefits of pavement investments. These analyses include pavement smoothness through data such as cracking, international roughness index (IRI), and rutting data. WSPMS uses pavement structural condition (PSC) as a trigger value to identify candidate pavement projects for improvements. This section analyzes 9055 individual data points from the WSPMS.

These data points are from concrete pavements throughout Washington state, and each point represents a highway segment ranging from 0.01 miles to 0.12 miles, with most data points being 0.1-mile segments. Data is collected annually; the data used for this analysis being accurate to 2022.

The adjusted route miles (ARM), state route mile post (SRMP), rutting and faulting are recorded in inches, and IRI in inches/mile. Other information included rehabilitation year of the pavement route, the type of rehabilitation, index rating values for cracking (RCN), dowel bar retrofit (DBR), and grinding (GRND).

### 3.2 Data analysis method

Data analysis is done for all concrete pavement in WSPMS. In all, 9055 lines of data were obtained from WSDOT, representing 2,090.84 lane-miles of concrete pavement. Data includes information up to and including 2022.

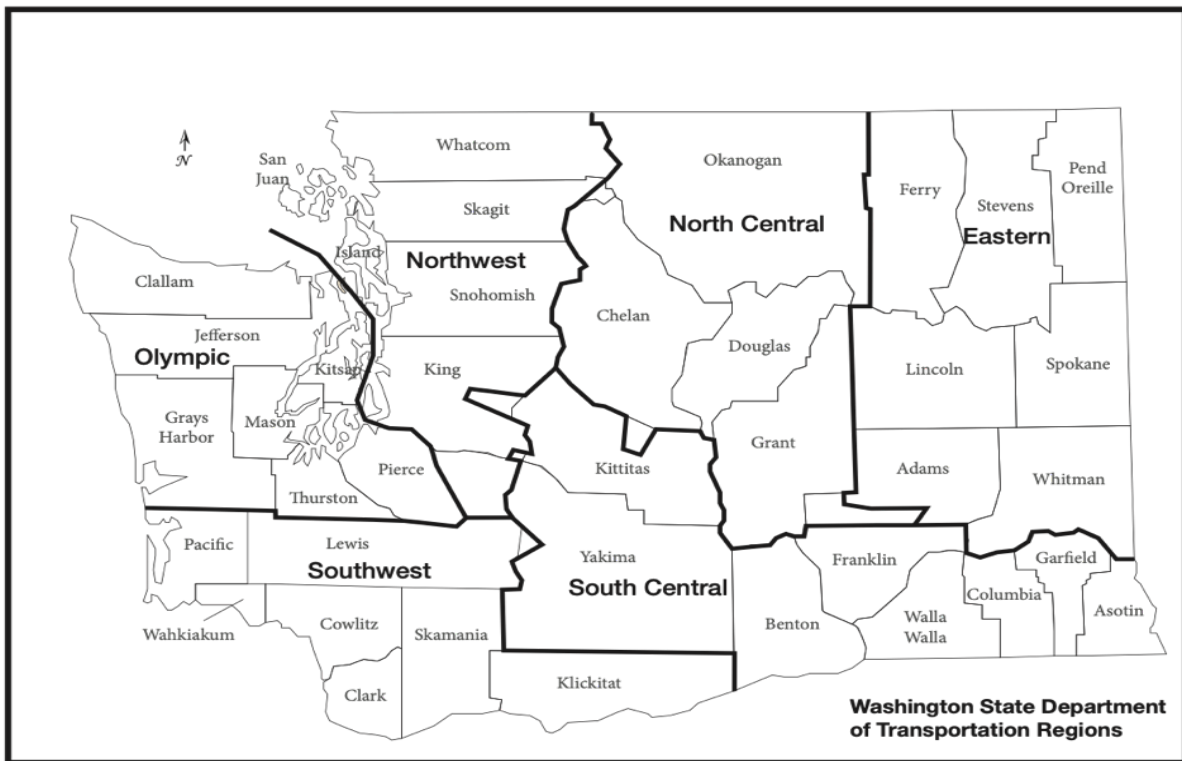
Specific data analyzed are:

- state route (SR)
- recommended rehabilitation type (RRT)
- recommended rehabilitation quantity (RRQ)
- begin and end adjusted route mile (ARM)
- begin and end state route mile post (SRMP)
- direction
- region (see Figure 3: WSDOT regions for concrete pavement analysis.)
- national highway system (NHS)

- federal functional class (rural/urban)
- survey unit identification (ID)
- original alignment date
- due year (rehabilitation)
- due year trigger (rehabilitation index)
- is bridge/near tunnel/near railroad crossing
- surface type
- lane miles
- miles
- rated length
- bridge
- distress survey year
- rutting
- IRI
- faulting
- pave index (RCN, DBR, GRND)
- survey details int ID
- low, medium, and high faulting
- rigid longitudinal/transverse cracking
- sealed rigid longitudinal/transverse
- rigid multi-cracking
- rigid multi-cracking plus
- sealed rigid multi-cracking
- low rigid patching
- medium rigid patching
- high rigid patching
- rigid skin patch
- medium spalling
- high spalling
- PCCP corner crack
- distressed dowels
- survey distress details. Int ID
- original construction date
- average major rehab date
- contract history ID
- contract history state route
- contract history RRT
- contract history RRQ
- contract history begin ARM
- contract history end ARM
- contract history begin SRMP
- contract history end SRMP
- contract history direction to inventory
- contract history ID

- contract history region
- construction date
- major rehab date
- minor rehab date
- minor rehab type
- segment lane miles
- has by lane construction on surface
- ESALs since major rehab
- ESALs since minor rehab
- total thickness
- total surface thickness
- listed surface type
- pavement type
- base type
- construction year
- age
- construction pavement type
- construction contract number
- major rehab year
- major rehab age
- major rehab type
- major rehab
- contract number
- prior major rehab year
- prior major rehab type
- prior major rehab contract number
- contract history due year
- analysis period begin year
- analysis period end year
- analysis period ESALs
- analysis period vehicles

Data for this research was extracted from WSPMS by WSDOT and transmitted to the research team via Microsoft Excel. Data was analyzed using pivot tables and no data were filtered prior to analysis. Each line represented approximately 0.1 miles of concrete pavement. No lines were removed or filtered from the dataset prior to processing. The pivot tables selectively grouped and isolated the necessary fields for each plot. The pivot tables produced figures generated directly from the full dataset while ensuring each chart reflected only the parameter being evaluated.



**Figure 3: WSDOT regions for concrete pavement analysis.**

### 3.3 Results and Discussion

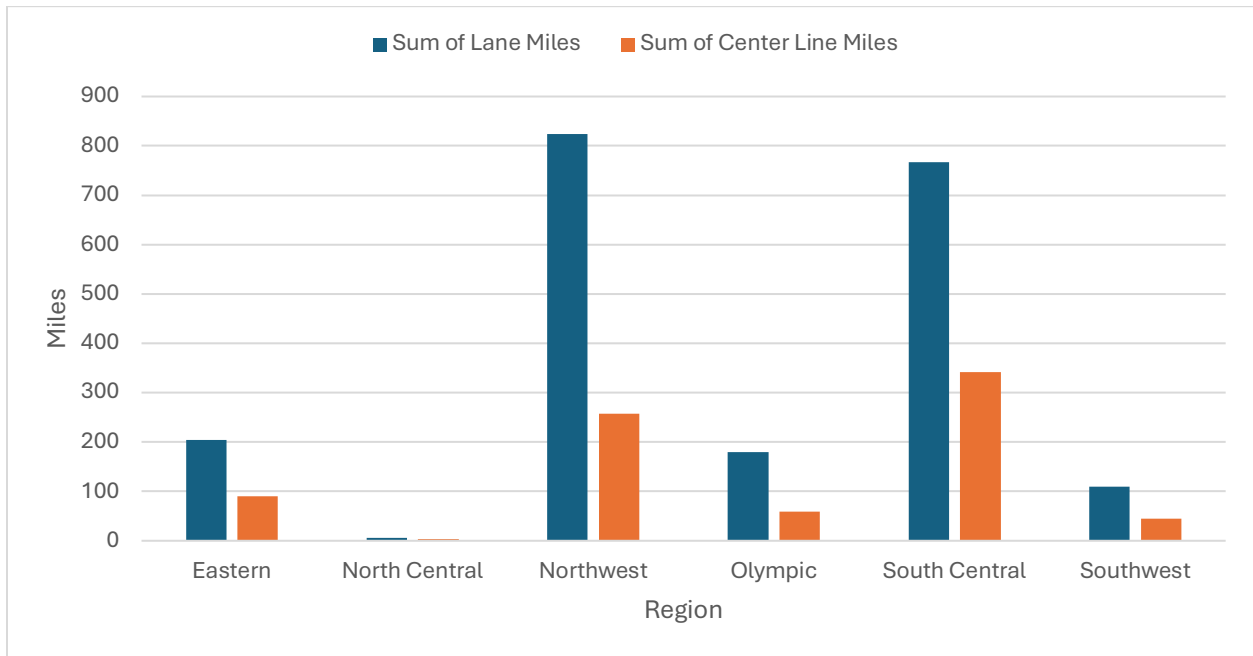
This section is organized into descriptive statistics, condition statistics, and specific section information analysis. Each section has graphs to visualize the data first which is followed by explanatory commentary.

Each graph has accompanying text to provide brief interpretive notes to describe the trends observed, whether the results align with expected performance patterns, and if applicable, whether any outliers exist and if they influence the distribution or the overall shape of the results. When outliers are present, the discussion summarizes whether these are data irregularities, known circumstances, unique project histories, or short test sections.

The datasets used for the graphs can be found in the tables beneath each graph. These tables are made from the pivot tables with the raw data from WSPMS as the reference information

### 3.3.1 Descriptive Statistics

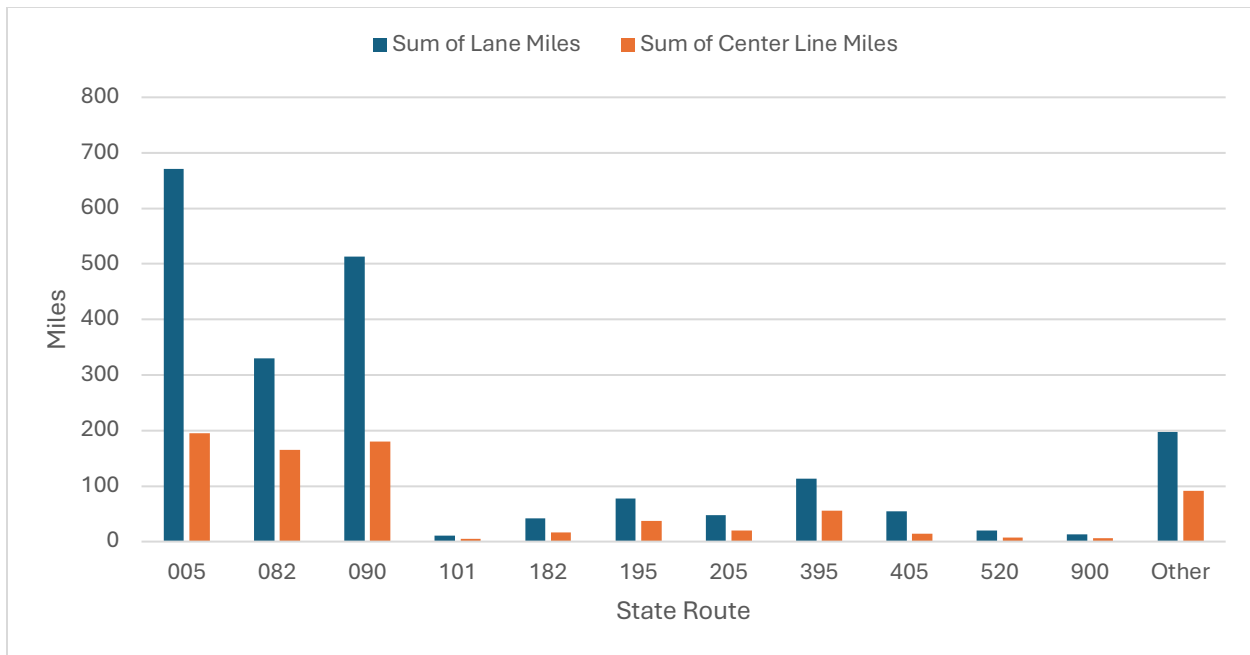
Figure 4 through Figure 8 show the general statistics of Concrete pavements in Washington and their distribution. The regions with the most concrete pavement are the Northwest and South Central. Those regions have the most lane miles and center line miles of concrete pavement. There are a total of 2,090.8 lane miles and 795.5 center line miles of concrete pavement in Washington state.



**Figure 4: Sum of lane miles and center line miles by region.**

**Table 4: Data for Figure 4**

Row Labels	Sum of Lane Miles	Sum of Center Line Miles
<b>Eastern</b>	204.24	90.04
<b>North Central</b>	6.49	3.25
<b>Northwest</b>	824.38	257.23
<b>Olympic</b>	180.01	59.62
<b>South Central</b>	766.71	341.09
<b>Southwest</b>	109.01	44.31
<b>Grand Total</b>	<b>2090.84</b>	<b>795.54</b>



**Figure 5: Sum of lane miles and center line miles by state route.**

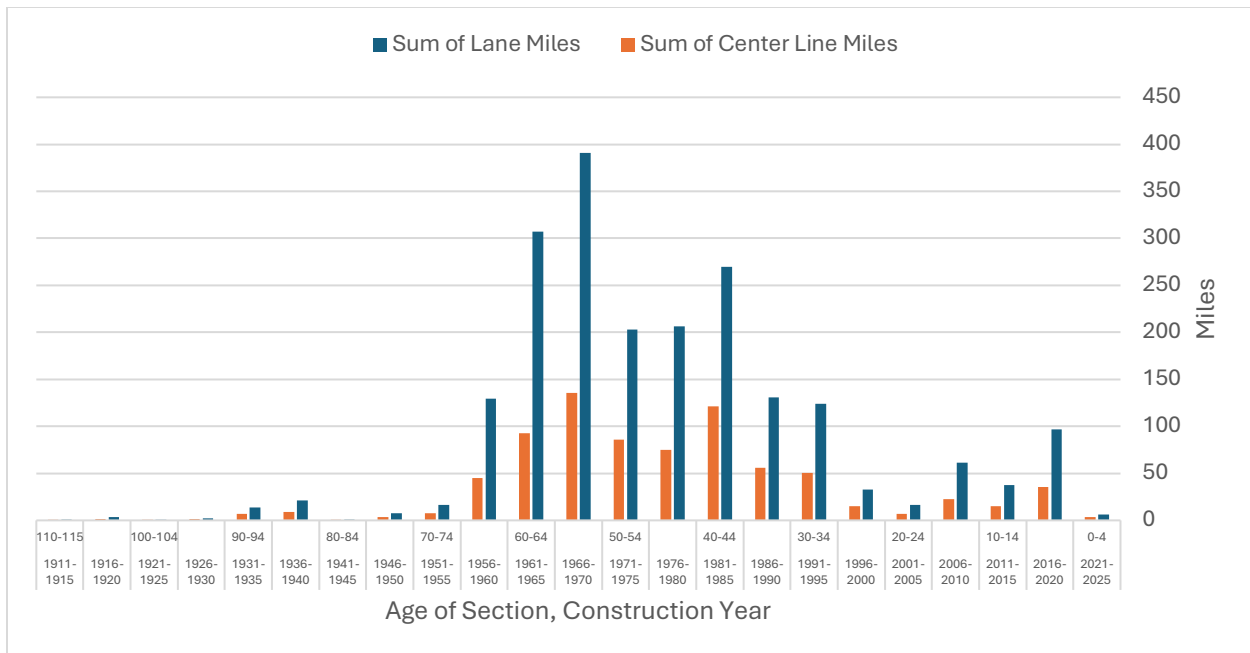
**Table 5: Data for Figure 5**

Row Labels	Sum of Lane Miles	Sum of Center Line Miles
<b>005</b>	670.53	195.33
<b>082</b>	330.14	165.07
<b>090</b>	513.34	180.48
<b>101</b>	10.81	5.40
<b>182</b>	41.57	16.10
<b>195</b>	77.89	37.58
<b>205</b>	48.10	19.71
<b>395</b>	113.77	55.44
<b>405</b>	54.62	14.54
<b>520</b>	20.34	7.84
<b>900</b>	12.84	6.33
<b>Other</b>	196.89	91.72
<b>Grand Total</b>	<b>2090.84</b>	<b>795.54</b>

Comments:

- Most concrete pavements are in the Northwest, South Central and Eastern regions. The Northwest region has the highest lane-miles due to 3+ lanes on I-5 and I-90 throughout the Everett-Seattle-Tacoma urban areas.

- Most concrete pavements are on the following routes: I-5 (24.6% of centerline miles, 32.1% of lane-miles), I-90 (22.7% of centerline miles, 24.6% of lane-miles), and I-82 (20.7% of centerline miles, 15.8% of lane-miles), I-395 (7.0% of centerline miles, 5.4% of lane-miles), I-195 (4.7% of centerline miles, 3.7% of lane-miles), I-205 (2.5% of centerline miles, 2.3% of lane-miles), I-182 (2.0% of centerline miles, 2.0% of lane-miles), I-405 (1.8% of centerline miles, 2.6% of lane-miles), I-520 (1.0% of centerline miles, 1.0% of lane-miles), I-900 (0.8% of centerline miles, 0.6% of lane-miles), I-101 (0.7% of centerline miles, 0.5% of lane-miles), and the remaining concrete pavements are classified in the Other bucket (11.5% of centerline miles, 9.4% of lane-miles).



**Figure 6: Sum of lane miles and center line miles vs age and construction year.**

**Table 6: Data for Figure 6**

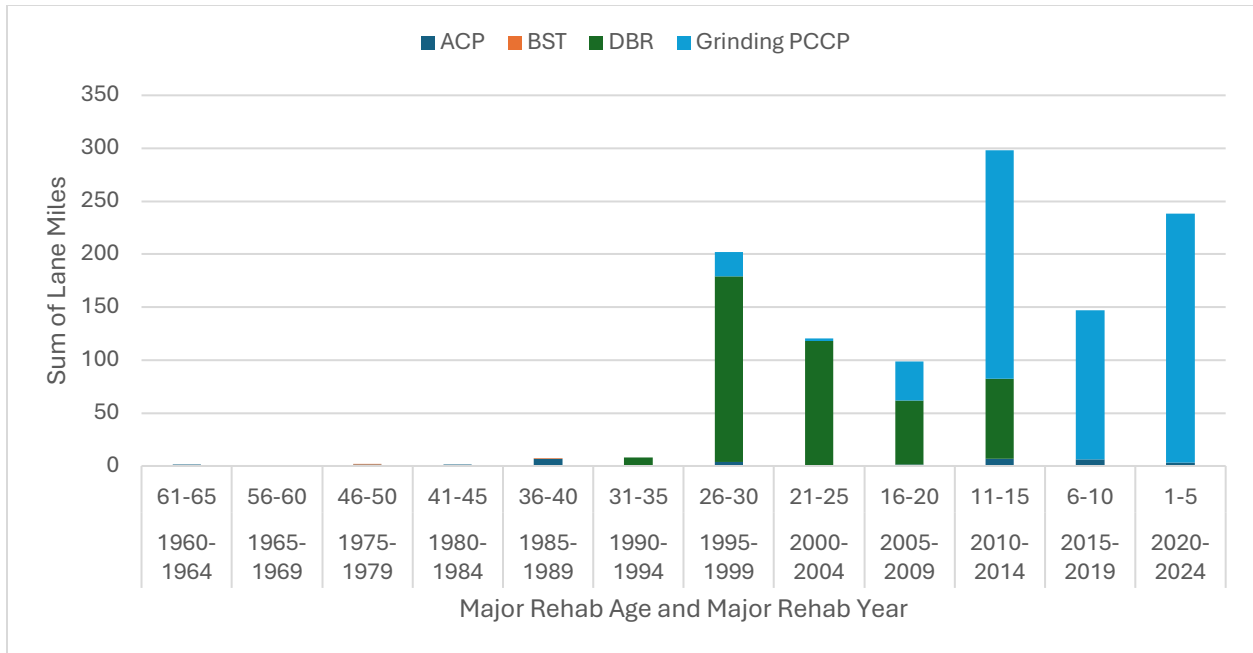
Row Labels	Sum of Lane Miles	Sum of Center Line Miles
2021-2025	<b>6.56</b>	<b>3.28</b>
<b>0-4</b>	6.56	3.28
2016-2020	<b>96.48</b>	<b>35.37</b>
<b>5-9</b>	96.48	35.37
2011-2015	<b>37.37</b>	<b>15.1</b>
<b>10-14</b>	37.37	15.1
2006-2010	<b>61.36</b>	<b>22.29</b>
<b>15-19</b>	61.36	22.29
2001-2005	<b>16.49</b>	<b>7.22</b>
<b>20-24</b>	16.49	7.22
1996-2000	<b>32.48</b>	<b>15.02</b>
<b>25-29</b>	32.48	15.02
1991-1995	<b>123.98</b>	<b>50.35</b>
<b>30-34</b>	123.98	50.35
1986-1990	<b>130.51</b>	<b>55.87</b>
<b>35-39</b>	130.51	55.87
1981-1985	<b>269.52</b>	<b>121.33</b>
<b>40-44</b>	269.52	121.33
1976-1980	<b>206.24</b>	<b>75.16</b>
<b>45-49</b>	206.24	75.16

1971-1975	<b>202.84</b>	<b>85.74</b>
<b>50-54</b>	202.84	85.74
1966-1970	<b>391.12</b>	<b>135.82</b>
<b>55-59</b>	391.12	135.82
1961-1965	<b>307.38</b>	<b>92.82</b>
<b>60-64</b>	307.38	92.82
1956-1960	<b>129.13</b>	<b>45.21</b>
<b>65-69</b>	129.13	45.21
1951-1955	<b>16.75</b>	<b>7.82</b>
<b>70-74</b>	16.75	7.82
1946-1950	<b>7.28</b>	<b>3.64</b>
<b>75-79</b>	7.28	3.64
1941-1945	<b>1.04</b>	<b>0.44</b>
<b>80-84</b>	1.04	0.44
1936-1940	<b>21.03</b>	<b>9.1</b>
<b>85-89</b>	21.03	9.1
1931-1935	<b>13.70</b>	<b>6.68</b>
<b>90-94</b>	13.70	6.68
1926-1930	<b>2.37</b>	<b>1.18</b>
<b>95-99</b>	2.37	1.18
1921-1925	<b>0.24</b>	<b>0.12</b>
<b>100-104</b>	0.24	0.12
1916-1920	<b>3.22</b>	<b>1.61</b>
<b>105-109</b>	3.22	1.61
1911-1915	<b>0.90</b>	<b>0.30</b>
<b>110-115</b>	0.90	0.30
Grand Total	<b>2077.99</b>	<b>791.47</b>

Comments:

- Major rehabilitations are classified as reconstruction and recorded as new pavement. For example, a rural interstate 1.65-mile section of I-90 underwent a major rehabilitation in 2021 in the South-Central region. The previous rehabilitation for this section was a dowel bar retrofit in 1994. The resurfacing of this section of I-90 is now classified as a new construction of pavement and shows in the bucket of 2021-2025 for age of construction.
- Most of the existing concrete pavements centerline miles (83.6%) and lane miles (84.7%) were constructed from 1956-1995. Since the data year for this analysis is 2022, that makes these pavements 27 to 66 years old in 2022.
- Pavements constructed since 2000 are mainly reconstructions. Most of the reconstruction was done on the I-90 (48.5% lane miles of construction since 2000) corridor in the South-

Central region. Prior to these reconstructions, some small sections underwent asphalt concrete treatments in early 2001, dowel bar retrofits in 1994 and 1997, and their PCCP original construction in the 1960-1970 timeframe.

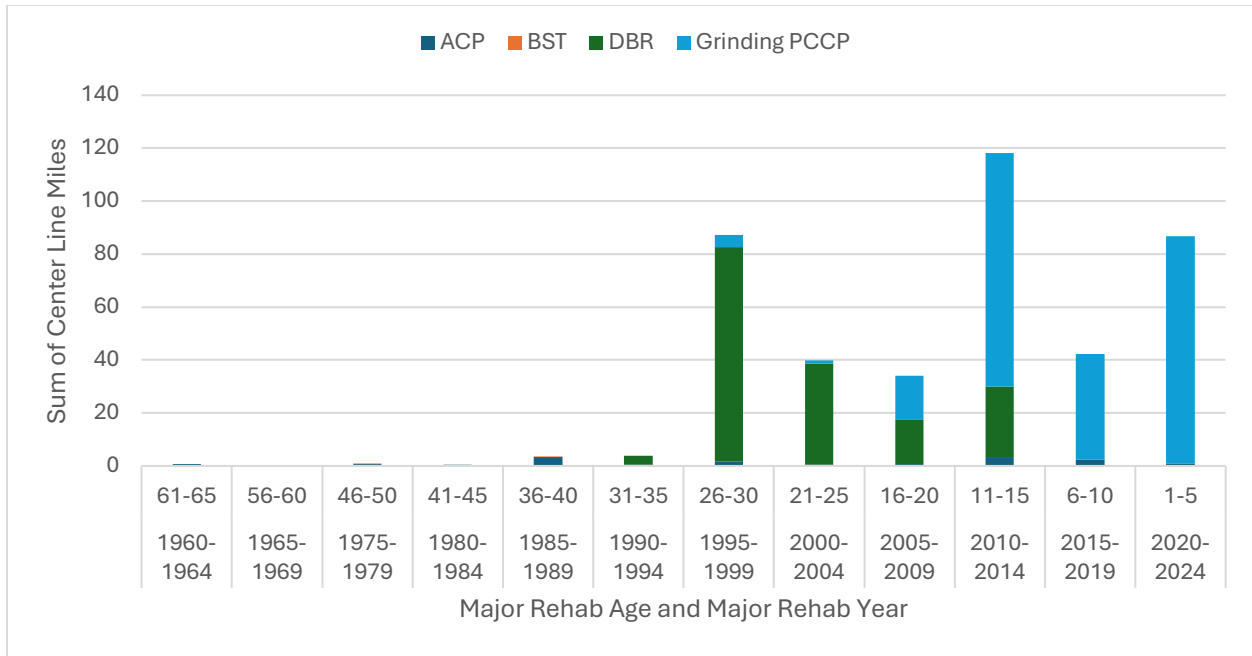


**Figure 7: Sum of lane miles vs major rehab, rehab age, and rehab year.**

**Table 7: Data for Figure 7**

Row Labels	Column Labels	ACP	BST	DBR	Grinding PCCP	Sum of Lane Miles
1960-1964	<b>1.56</b>					<b>1.56</b>
<b>61-65</b>	1.56					1.56
1965-1969	<b>0.16</b>					<b>0.16</b>
<b>56-60</b>	0.16					0.16
1975-1979	<b>1.59</b>		<b>0.20</b>			<b>1.79</b>
<b>46-50</b>	1.59		0.20			1.79
1980-1984	<b>1.18</b>					<b>1.18</b>
<b>41-45</b>	1.18					1.18
1985-1989	<b>6.79</b>		<b>0.12</b>			<b>6.91</b>
<b>36-40</b>	6.79		0.12			6.91
1990-1994	<b>1.02</b>			<b>6.74</b>		<b>7.76</b>
<b>31-35</b>	1.02			6.74		7.76
1995-1999	<b>3.52</b>			<b>175.38</b>	<b>23.17</b>	<b>202.07</b>
<b>26-30</b>	3.52			175.38	23.17	202.07
2000-2004	<b>0.93</b>			<b>117.06</b>	<b>2.54</b>	<b>120.53</b>
<b>21-25</b>	0.93			117.06	2.54	120.53
2005-2009	<b>1.46</b>			<b>60.50</b>	<b>36.63</b>	<b>98.59</b>
<b>16-20</b>	1.46			60.50	36.63	98.59
2010-2014	<b>6.95</b>			<b>75.18</b>	<b>215.80</b>	<b>297.93</b>

<b>11-15</b>	6.95		75.18	215.80	297.93
2015-2019	<b>6.48</b>			<b>140.55</b>	<b>147.03</b>
<b>6-10</b>	6.48			140.55	147.03
2020-2024	<b>3.06</b>			<b>234.95</b>	<b>238.01</b>
<b>1-5</b>	3.06			234.95	238.01
Grand Total	<b>34.7</b>	<b>0.32</b>	<b>434.86</b>	<b>653.64</b>	<b>1123.52</b>



**Figure 8: Sum of center line miles vs major rehab, rehab age, and rehab year.**

**Table 8: Data for Figure 8**

	Column Labels				Sum of Center Line Miles
Row Labels	ACP	BST	DBR	Grinding PCCP	Grand Total
1960-1964	<b>0.61</b>				<b>0.61</b>
<b>61-65</b>	0.61				0.61
1965-1969	<b>0.10</b>				<b>0.10</b>
<b>56-60</b>	0.10				0.10
1975-1979	<b>0.62</b>	<b>0.10</b>			<b>0.72</b>
<b>46-50</b>	0.62	0.10			0.72
1980-1984	<b>0.55</b>				<b>0.55</b>
<b>41-45</b>	0.55				0.55
1985-1989	<b>3.37</b>	<b>0.06</b>			<b>3.43</b>
<b>36-40</b>	3.37	0.06			3.43

1990-1994	<b>0.44</b>		<b>3.37</b>		<b>3.81</b>
<b>31-35</b>	0.44		3.37		3.81
1995-1999	<b>1.58</b>		<b>81.14</b>	<b>4.55</b>	<b>87.27</b>
<b>26-30</b>	1.58		81.14	4.55	87.27
2000-2004	<b>0.56</b>		<b>38.00</b>	<b>1.27</b>	<b>39.83</b>
<b>21-25</b>	0.56		38.00	1.27	39.83
2005-2009	<b>0.72</b>		<b>16.70</b>	<b>16.72</b>	<b>34.14</b>
<b>16-20</b>	0.72		16.70	16.72	34.14
2010-2014	<b>3.29</b>		<b>26.70</b>	<b>88.07</b>	<b>118.06</b>
<b>11-15</b>	3.29		26.70	88.07	118.06
2015-2019	<b>2.38</b>			<b>39.82</b>	<b>42.20</b>
<b>6-10</b>	2.38			39.82	42.20
2020-2024	<b>0.94</b>			<b>85.80</b>	<b>86.74</b>
<b>1-5</b>	0.94			85.80	86.74
Grand Total	<b>15.16</b>	<b>0.16</b>	<b>165.91</b>	<b>236.23</b>	<b>417.46</b>

Comments:

- Terminology
  - Asphalt concrete pavement (ACP) – old concrete pavement is overlaid by new asphalt concrete pavement of varying thicknesses.
  - Bituminous surface treatment (BST) – old concrete pavement is covered with a bituminous surface treatment.
  - Dowel bar retrofit (DBR) – an original jointed plain concrete pavement (JPCP) constructed without dowels is retrofit with steel dowel bars at each transverse joint. DBR was deemed a successful rehabilitation method in 1993 as diamond grinding was determined to be not effective in long-term reduction of faulting and faulting returned after three years for faulting greater than 0.1 inch. DBR is effective in long-term load transfer restoration and minimizing the return of joint faulting. DBR rehabilitation also typically includes a diamond grind of all the lanes (Pierce & Muench, 2009).
  - Grinding PCCP (GRND) – existing concrete pavement is diamond ground to remove roughness from faulting, studded tire wear, and cracking.
- Observations
  - WSDOT concrete pavement rehabilitation started in the mid-1990s and continues through today. Since 1990, DBR appears consistently from 1994 through 2014, while diamond grinding can be seen regularly since 1997 through present day. It may be that those concrete pavements that could benefit from DBR have all or nearly all been retrofit.
  - The following table shows the breakdown of concrete pavement rehabilitation by year and type of rehabilitation. Table shows that 71.6% of center line miles and 72.1% of lane miles have been rehabilitated since 1990.

**Table 9: Concrete pavement rehabilitation types and percentages**

<b>Row Labels</b>	<b>Sum of Miles</b>	<b>Sum of Lane Miles</b>	<b>% Miles</b>	<b>% Lane Miles</b>
<b>2022</b>	37.85	83.32	4.8%	4.0%
ACP	0.63	1.83	0.1%	0.1%
Grinding PCCP	35.62	76.12	4.5%	3.7%
PCCP	1.6	5.37	0.2%	0.3%
<b>2021</b>	23.15	64.81	2.9%	3.1%
Grinding PCCP	19.89	58.29	2.5%	2.8%
PCCP	3.26	6.52	0.4%	0.3%
<b>2020</b>	31.64	104.84	4.0%	5.0%
ACP	0.31	1.23	0.0%	0.1%
Grinding PCCP	30.29	100.54	3.8%	4.8%
PCCP	1.04	3.07	0.1%	0.1%
<b>2019</b>	29.21	105.14	3.7%	5.1%
ACP	0.36	1.15	0.0%	0.1%
Grinding PCCP	16.7	64.25	2.1%	3.1%
PCCP	12.15	39.74	1.5%	1.9%
<b>2018</b>	7.92	21.73	1.0%	1.0%
ACP	0.56	1.19	0.1%	0.1%
Grinding PCCP	0.10	0.30	0.0%	0.0%
PCCP	7.26	20.24	0.9%	1.0%
<b>2017</b>	15.01	44.37	1.9%	2.1%
ACP	1.08	3.21	0.1%	0.2%
Grinding PCCP	5.78	24.97	0.7%	1.2%
PCCP	8.15	16.19	1.0%	0.8%
<b>2016</b>	17.10	37.19	2.2%	1.8%
ACP	0.24	0.51	0.0%	0.0%
Grinding PCCP	10.02	20.04	1.3%	1.0%
PCCP	6.84	16.64	0.9%	0.8%
<b>2015</b>	8.78	34.16	1.1%	1.6%
ACP	0.14	0.42	0.0%	0.0%
Grinding PCCP	7.22	30.99	0.9%	1.5%
PCCP	1.42	2.75	0.2%	0.1%
<b>2014</b>	8.77	24.52	1.1%	1.2%
ACP	0.01	0.03	0.0%	0.0%
DBR	2.98	9.22	0.4%	0.4%
Grinding PCCP	1.11	2.92	0.1%	0.1%
PCCP	4.67	12.35	0.6%	0.6%
<b>2013</b>	27.54	75.1	3.5%	3.6%
ACP	0.03	0.07	0.0%	0.0%
Grinding PCCP	21.4	58.74	2.7%	2.8%

PCCP	6.11	16.29	0.8%	0.8%
<b>2012</b>	4.53	9.07	0.6%	0.4%
ACP	0.03	0.07	0.0%	0.0%
DBR	2.15	4.3	0.3%	0.2%
PCCP	2.35	4.7	0.3%	0.2%
<b>2011</b>	53.22	107.1	6.7%	5.2%
ACP	2.91	5.93	0.4%	0.3%
Grinding PCCP	48.56	97.12	6.1%	4.7%
PCCP	1.75	4.05	0.2%	0.2%
<b>2010</b>	45.24	134.51	5.7%	6.5%
ACP	0.31	0.85	0.0%	0.0%
DBR	21.57	61.66	2.7%	3.0%
Grinding PCCP	17.00	57.02	2.1%	2.7%
PCCP	6.36	14.98	0.8%	0.7%
<b>2009</b>	25.2	53.78	3.2%	2.6%
ACP	0.04	0.10	0.0%	0.0%
DBR	5.53	11.06	0.7%	0.5%
Grinding PCCP	15.4	32.84	1.9%	1.6%
PCCP	4.23	9.78	0.5%	0.5%
<b>2008</b>	13.64	58.31	1.7%	2.8%
DBR	8.12	40.94	1.0%	2.0%
Grinding PCCP	0.23	0.46	0.0%	0.0%
PCCP	5.29	16.91	0.7%	0.8%
<b>2007</b>	7.24	23.71	0.9%	1.1%
DBR	1.44	5.28	0.2%	0.3%
Grinding PCCP	1.07	3.29	0.1%	0.2%
PCCP	4.73	15.14	0.6%	0.7%
<b>2006</b>	7.61	21.39	1.0%	1.0%
ACP	0.02	0.04	0.0%	0.0%
DBR	1.61	3.22	0.2%	0.2%
Grinding PCCP	0.02	0.04	0.0%	0.0%
PCCP	5.96	18.09	0.8%	0.9%
<b>2005</b>	1.35	2.86	0.2%	0.1%
ACP	0.66	1.32	0.1%	0.1%
PCCP	0.69	1.54	0.1%	0.1%
<b>2004</b>	0.46	0.92	0.1%	0.0%
ACP	0.2	0.4	0.0%	0.0%
PCCP	0.26	0.52	0.0%	0.0%
<b>2003</b>	12.01	38.21	1.5%	1.8%
ACP	0.10	0.20	0.0%	0.0%
DBR	9.66	30.81	1.2%	1.5%

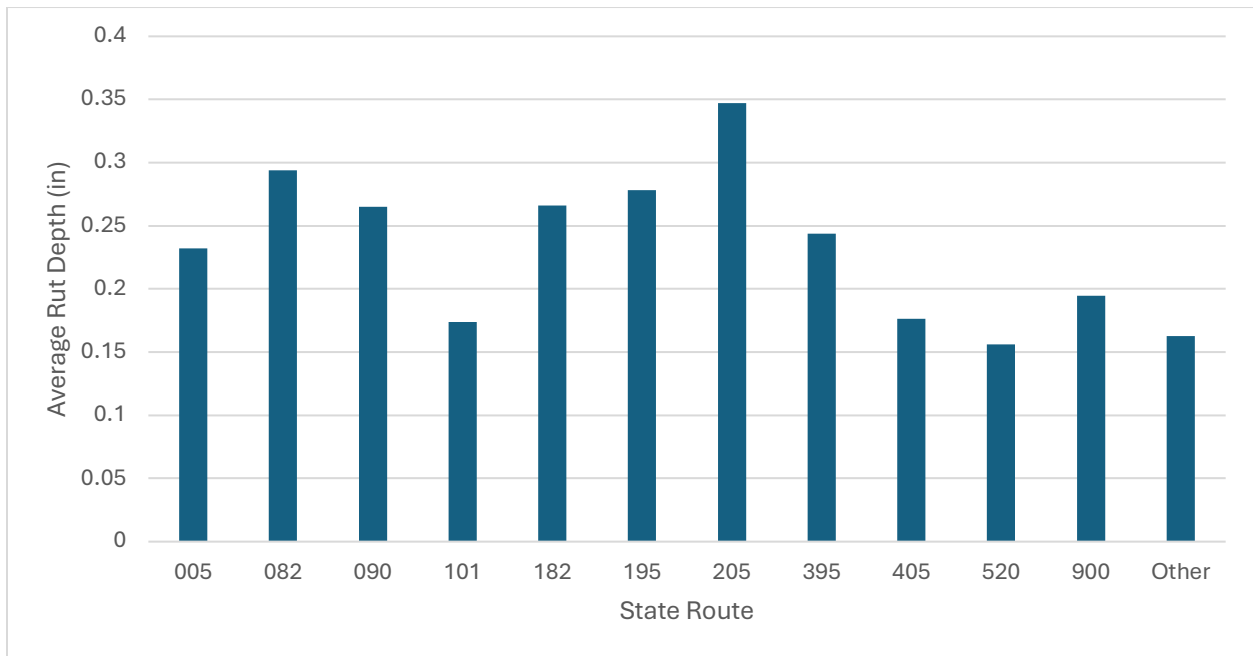
PCCP	2.25	7.20	0.3%	0.3%
<b>2002</b>	5.08	10.17	0.6%	0.5%
ACP	0.06	0.12	0.0%	0.0%
DBR	2.24	4.48	0.3%	0.2%
Grinding PCCP	1.26	2.52	0.2%	0.1%
PCCP	1.52	3.05	0.2%	0.1%
<b>2001</b>	5.03	10.48	0.6%	0.5%
ACP	0.19	0.19	0.0%	0.0%
PCCP	4.84	10.29	0.6%	0.5%
<b>2000</b>	28.28	87.11	3.6%	4.2%
ACP	0.01	0.02	0.0%	0.0%
DBR	26.10	81.77	3.3%	3.9%
Grinding PCCP	0.01	0.02	0.0%	0.0%
PCCP	2.16	5.30	0.3%	0.3%
<b>1999</b>	19.32	54.64	2.4%	2.6%
ACP	0.14	0.32	0.0%	0.0%
DBR	12.43	24.86	1.6%	1.2%
Grinding PCCP	4.46	22.99	0.6%	1.1%
PCCP	2.29	6.47	0.3%	0.3%
<b>1998</b>	10.81	30.42	1.4%	1.5%
ACP	0.87	1.92	0.1%	0.1%
DBR	7.15	21.45	0.9%	1.0%
Grinding PCCP	0.09	0.18	0.0%	0.0%
PCCP	2.70	6.87	0.3%	0.3%
<b>1997</b>	50.48	101.9	6.4%	4.9%
DBR	47.53	95.06	6.0%	4.6%
PCCP	2.95	6.84	0.4%	0.3%
<b>1996</b>	22.32	50.66	2.8%	2.4%
ACP	0.05	0.1	0.0%	0.0%
DBR	14.03	34.01	1.8%	1.6%
PCCP	8.24	16.55	1.0%	0.8%
<b>1995</b>	19.07	41.55	2.4%	2.0%
ACP	0.52	1.18	0.1%	0.1%
PCCP	18.55	40.37	2.3%	1.9%
<b>1994</b>	8.64	17.40	1.1%	0.8%
DBR	3.37	6.74	0.4%	0.3%
PCCP	5.27	10.66	0.7%	0.5%
<b>1993</b>	9.26	24.67	1.2%	1.2%
ACP	0.04	0.08	0.0%	0.0%
PCCP	9.22	24.59	1.2%	1.2%
<b>1992</b>	5.45	12.86	0.7%	0.6%

ACP	0.13	0.26	0.0%	0.0%
PCCP	5.32	12.6	0.7%	0.6%
<b>1991</b>	3.33	6.81	0.4%	0.3%
ACP	0.21	0.50	0.0%	0.0%
PCCP	3.12	6.31	0.4%	0.3%
<b>1990</b>	1.19	2.47	0.2%	0.1%
ACP	0.06	0.18	0.0%	0.0%
PCCP	1.13	2.29	0.1%	0.1%
Totals	566.86	1498.47	71.6%	72.1%

### 3.3.2 Condition statistics

Figure 9 through Figure 13 describe the condition of WSDOT’s concrete pavement network in terms of rutting wear, international roughness index (IRI), and roughness condition number (RCN).

Using data from the WSPMS, concrete pavements were analyzed to describe their functional and structural condition and provide insight into long term performance trends. Comments follow the graphs to discuss factors influencing trends and outliers. Where there are outliers, suggestions are made as to why these are present and offer greater insight for interpretation.

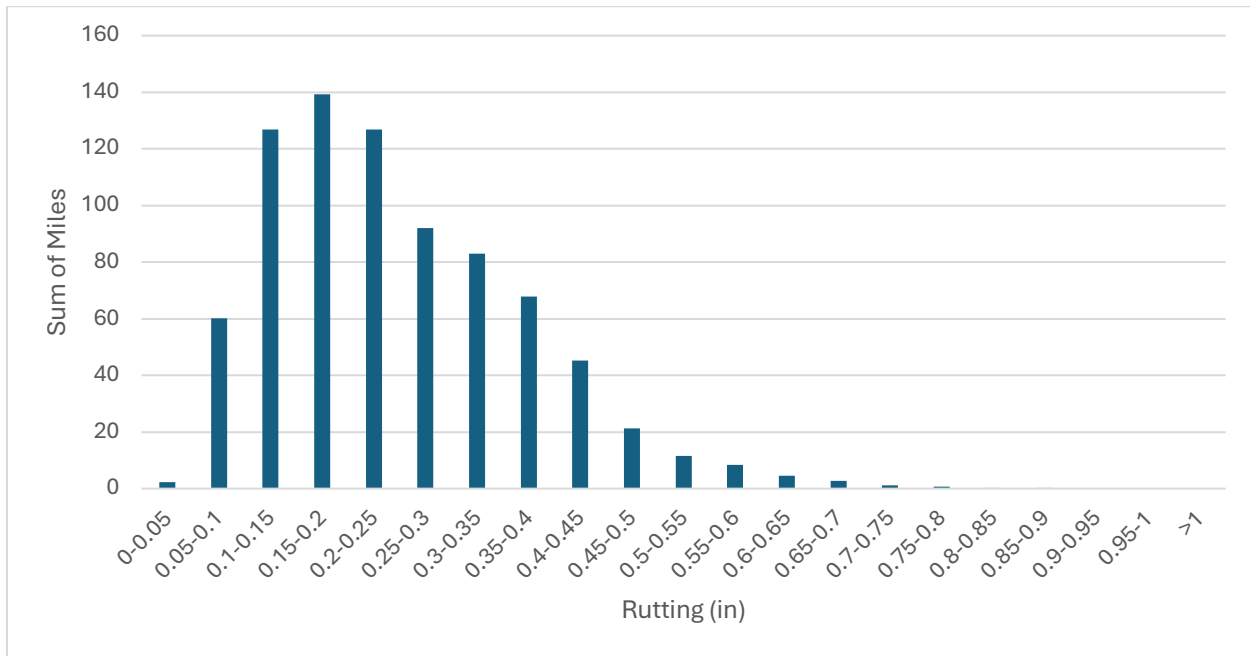


**Figure 9: Average rut wear depth/route vs state route.**

**Table 10: Data for Figure 9**

State Route	Average of Rutting (in)
005	<b>0.23</b>
082	<b>0.29</b>
090	<b>0.27</b>
101	<b>0.17</b>
182	<b>0.27</b>
195	<b>0.28</b>
205	<b>0.35</b>
395	<b>0.24</b>
405	<b>0.18</b>

520	<b>0.16</b>
900	<b>0.19</b>
Other	<b>0.16</b>
Grand Total	<b>0.24</b>



**Figure 10: Sum of center line miles vs rutting wear bins (inches).**

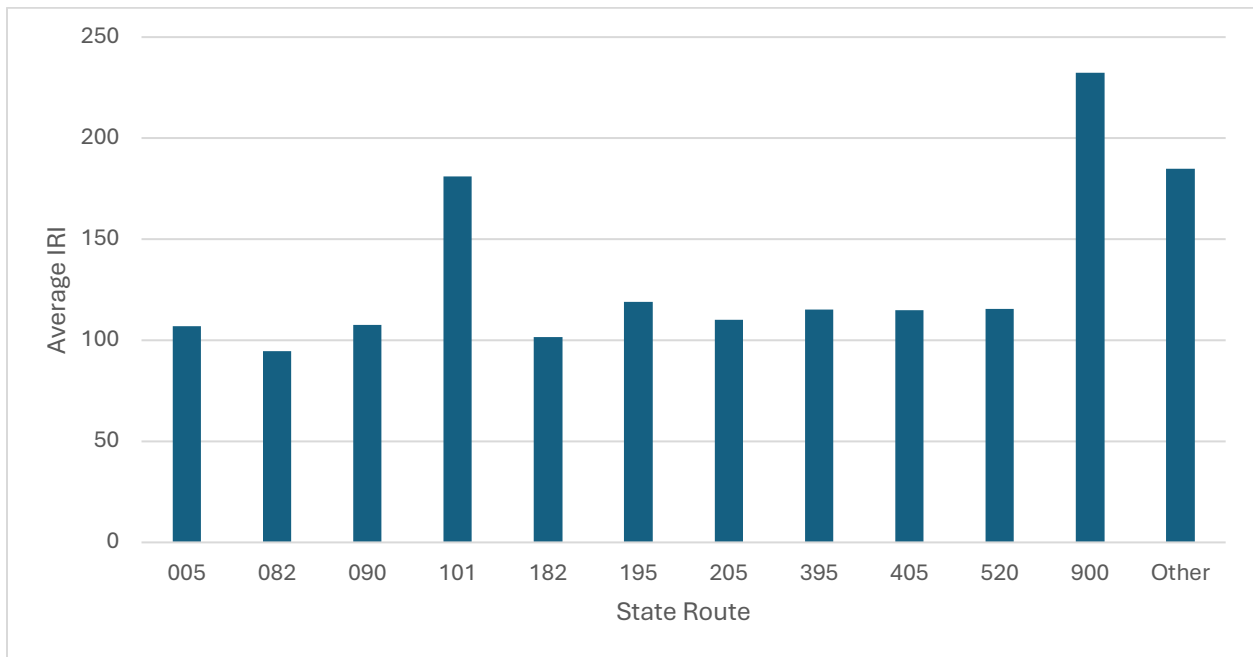
**Table 11: Data for Figure 10**

Rutting (in)	Sum of Miles
<b>0-0.05</b>	2.34
<b>0.05-0.1</b>	60.15
<b>0.1-0.15</b>	126.93
<b>0.15-0.2</b>	139.30
<b>0.2-0.25</b>	126.86
<b>0.25-0.3</b>	92.13
<b>0.3-0.35</b>	83.07
<b>0.35-0.4</b>	67.86
<b>0.4-0.45</b>	45.25
<b>0.45-0.5</b>	21.28
<b>0.5-0.55</b>	11.66
<b>0.55-0.6</b>	8.47
<b>0.6-0.65</b>	4.64
<b>0.65-0.7</b>	2.69
<b>0.7-0.75</b>	1.18

<b>0.75-0.8</b>	0.72
<b>0.8-0.85</b>	0.31
<b>0.85-0.9</b>	0.33
<b>0.9-0.95</b>	0.10
<b>0.95-1</b>	0.10
<b>&gt;1</b>	0.03
<b>Grand Total</b>	<b>795.40</b>

Comments:

- Using the 9055 data points from the WSPMS data, the rutting depth over the concrete pavements is recorded in the fractional mile segments. The average rut for the state route was found and can be seen in Figure 9. State route 205 has the worst average rut wear depth with an average of approximately 0.35 inches. This 0.35-inch average is still below the threshold for triggering a grinding rehabilitation.
- Rutting over 0.4 inches is the trigger for grinding by WSDOT for sections that have been dowel bar retrofitted and for sections that have never been dowel bar retrofitted (Li, 2010). Throughout Washington, only 12.2% of the concrete pavements have rutting above of the trigger value of 0.4 inches or greater. If the 0.4-0.45-inch bin is excluded for being at the cusp of the threshold, the percentage of concrete pavements needing rehabilitation for rutting wear drops to 6.5%.



**Figure 11: Average IRI vs state route.**

**Table 12: Data for Figure 11**

Row Labels	Average of IRI
005	<b>107.12</b>
082	<b>94.78</b>
090	<b>107.49</b>
101	<b>181.15</b>
182	<b>101.45</b>
195	<b>119.11</b>
205	<b>110.13</b>
395	<b>115.08</b>
405	<b>114.89</b>
520	<b>115.63</b>
900	<b>232.39</b>
Other	<b>184.95</b>
Grand Total	<b>120.04</b>

Comments:

- International roughness index (IRI) is used to define the longitudinal profile of a wheel path. The vehicle's suspension motion is measured during a specified distance, and the vertical distance of the vehicle is divided by the specified distance (inches/mile) (Pavement

Interactive, 2025). The greater the vertical distance or the up and down motion of the suspension, the rougher the road and the higher the IRI value.

- According to the Rigid Pavement Index for Reconstruction or Dowel Bar Retrofit (Li, 2010), IRI values greater than 220 inches/mile is the point where rehabilitation would be considered regardless of being dowel bar retrofitted or not.
- The IRI for a state route as seen in Figure 11 is a weighted average of segment roughness over the entire route. The total 9055 data points from the WSPMS data were split by state route and the recorded IRI for the approximately 0.1-mile segments were averaged for the IRI and this gives a general indication of the overall route roughness but does not indicate variation along the length of the route nor identify areas of good or poor performance. The initial findings suggest that the average IRI of SR 900 trigger further investigation for rehabilitation as this average for SR 900 is higher than the 220 inches/mile threshold for rehabilitation from the WSDOT index.

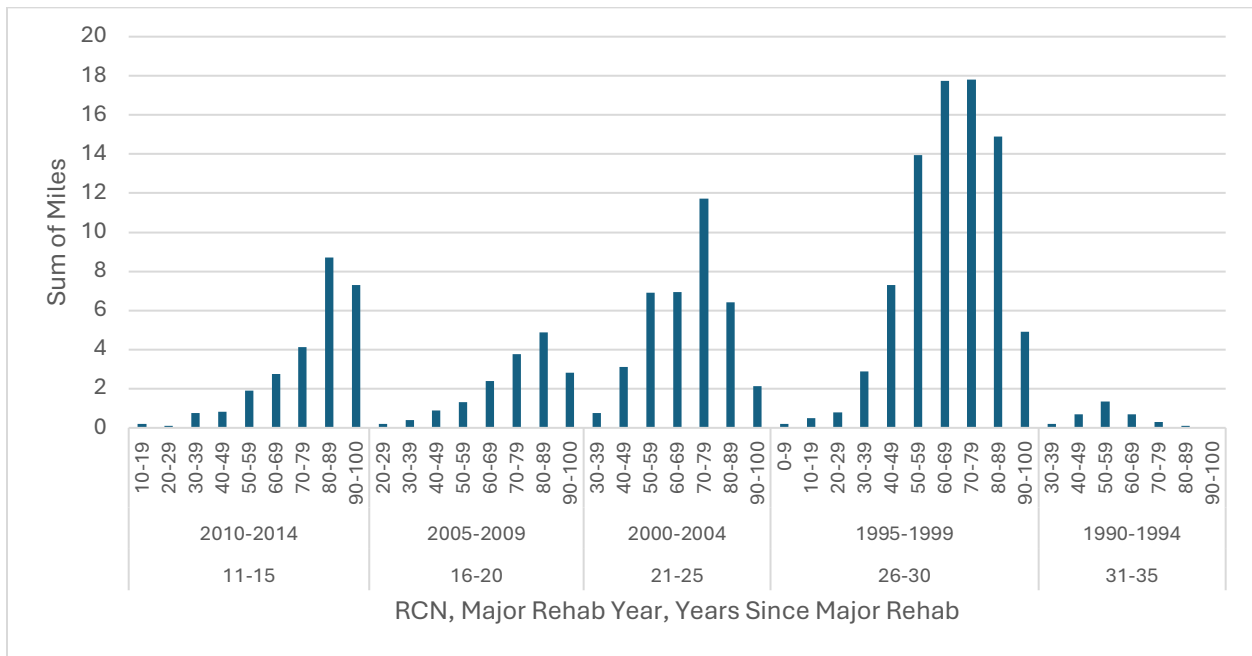


Figure 12: Rehabilitated pavement 2022 composite crack rating (RCN) vs Rehab year.

Table 13: Data for Figure 12

Major Rehab Type	DBR, RCN rating
Row Labels	Sum of Miles
11-15	26.70
2010-2014	26.70
10-19	0.20
20-29	0.10

<b>30-39</b>	0.76
<b>40-49</b>	0.81
<b>50-59</b>	1.91
<b>60-69</b>	2.77
<b>70-79</b>	4.14
<b>80-89</b>	8.71
<b>90-100</b>	7.30
16-20	<b>16.70</b>
2005-2009	<b>16.70</b>
<b>20-29</b>	0.20
<b>30-39</b>	0.40
<b>40-49</b>	0.90
<b>50-59</b>	1.32
<b>60-69</b>	2.39
<b>70-79</b>	3.77
<b>80-89</b>	4.89
<b>90-100</b>	2.83
21-25	<b>38.00</b>
2000-2004	<b>38.00</b>
<b>30-39</b>	0.75
<b>40-49</b>	3.13
<b>50-59</b>	6.91
<b>60-69</b>	6.93
<b>70-79</b>	11.73
<b>80-89</b>	6.42
<b>90-100</b>	2.13
26-30	<b>80.94</b>
1995-1999	<b>80.94</b>
<b>0-9</b>	0.20
<b>10-19</b>	0.50
<b>20-29</b>	0.80
<b>30-39</b>	2.87
<b>40-49</b>	7.29
<b>50-59</b>	13.95
<b>60-69</b>	17.75
<b>70-79</b>	17.80
<b>80-89</b>	14.88
<b>90-100</b>	4.90
31-35	<b>3.37</b>
1990-1994	<b>3.37</b>
<b>30-39</b>	0.20

<b>40-49</b>	0.70
<b>50-59</b>	1.34
<b>60-69</b>	0.70
<b>70-79</b>	0.30
<b>80-89</b>	0.10
<b>90-100</b>	0.03
<b>Grand Total</b>	<b>165.71</b>

Comments:

- RCN as seen in Figure 12 is a composite concrete pavement cracking metric. The higher the rating the better the pavement. There is a 50-point trigger value for rehabilitation to be triggered if the rating falls below this number.
- Figure 12 is arranged with five-year ranges and the age since the writing of this paper in 2025. The year listed is the year of a major rehabilitation. The complete dataset was filtered to dowel bar replacement (DBR) pavement major rehabilitations. The number of miles for a rating group for a particular year would be grouped together. For example, 5 miles of pavement with an RCN rating of 95 in 2022 would be seen in the 90-100 in the 2020-2024 bucket.
- DBR major rehabilitations were seen in the dataset to start in 1994 and appear until 2014, and the RCN ratings are seen to be above the 50-point trigger for another rehabilitation.
- The following table shows the rating system by WSDOT pavement system to describe the ratings from 0-100 and the condition of the pavement (*WSDOT - Pavement Condition - Overview, 2024*).

**Table 14: Rating for concrete pavement**

<b>Category</b>	<b>PSC or RCN</b>
<b>Very Good</b>	80-100
<b>Good</b>	60-79
<b>Fair</b>	40-59
<b>Poor</b>	20-39
<b>Very Poor</b>	0-19

As seen in the table, PSC and RCN show up as composite pavement cracking metrics. PSC includes cracking, faulting, faulting, and patching. The following equations outline how the rating is calculated for a composite pavement cracking metric. The trigger value for rehabilitation is PSC < 50 (Li, 2010).

$$PSC = 100 - 18.6 * EC^{0.43}$$

$$EC = CREC + FLTEC + PTEC + JSEC$$

$$CREC = 0.24 * MC^{1.16} + 0.0054 * LV^{1.84} + 0.0054 * TC^{1.84}$$

$$FLTEC = HFLT + 0.0915 * MedFLT^{1.46} + 0.0015 * LowFLT^{2.32}$$

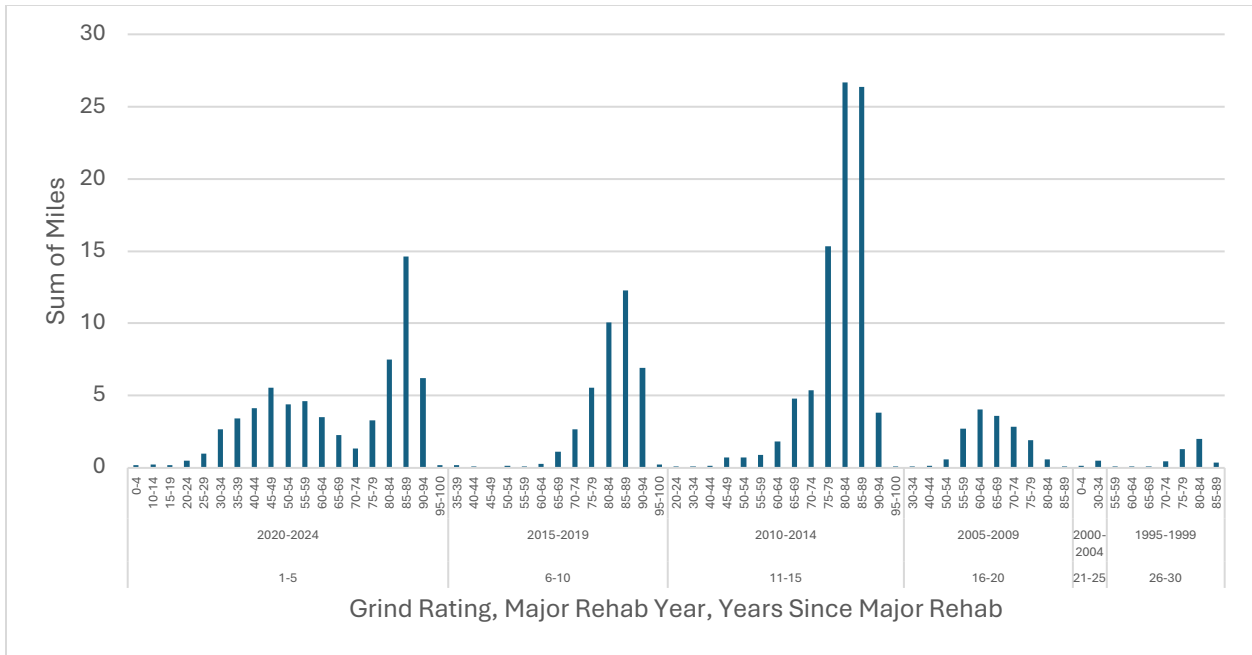
$$PTEC = 0.103 * HPT^{1.19} + 0.0079 * MedPT^{1.55} + 0.00194 * LowPT^{1.57}$$

$$JSEC = 0.075 * HSP^{1.14} + 0.0061 * MedSP^{1.27} + 0.0034 * LowSP^{1.03}$$

The table below explains the meanings of the variables used in the composite pavement cracking metric

**Table 15 Metrics used in equations for composite pavement**

<b>Metric</b>	<b>Meaning</b>
<b>PSC</b>	Pavement structural condition (Rigid)
<b>EC</b>	Total equivalent cracking
<b>CREC</b>	Slab cracking component of equivalent cracking
<b>FLTEC</b>	Faulting component of equivalent cracking
<b>PTEC</b>	Patching component of equivalent cracking
<b>MC</b>	Percent of slabs with multiple cracking
<b>LC</b>	Percent of slabs with 1 longitudinal cracking
<b>TC</b>	Percent of slabs with 1 transverse cracking
<b>HFLT</b>	Percent of panels with greater than ½” faulting at joints or cracks
<b>MedFLT</b>	Percent of panels with ¼” to ½” faulting at joints or cracks
<b>LowFLT</b>	Percent of panels with 1/8” to ¼” faulting at joints or cracks
<b>HPT</b>	Percent of panels patched with 25% or more of panel surfaces covered
<b>MedPT</b>	Percent of panels patched with 10 to 24 percent of panel surfaces covered
<b>LowPT</b>	Percent of panels patched with 1 to 9% of panel surfaces covered
<b>HSP</b>	Percent of joints and cracks with spalls 1/8”- 1” in width
<b>MedSP</b>	Percent of joints and cracks with spalls 1”- 3” in width
<b>LowSP</b>	Percent of joints and cracks with spalls greater than 1” in width



**Figure 13: Rehabilitated pavement 2022 composite grind rating (GRND) vs Rehab year.**

**Table 16: Data for Figure 13**

Major Type	Rehab	Grinding PCCP
Row Labels		Sum of Miles
1-5		<b>65.81</b>
2020-2024		<b>65.81</b>
0-4		0.20
10-14		0.25
15-19		0.20
20-24		0.50
25-29		1.00
30-34		2.66
35-39		3.43
40-44		4.11
45-49		5.53
50-54		4.40
55-59		4.60
60-64		3.50
65-69		2.26
70-74		1.36
75-79		3.29
80-84		7.48

<b>85-89</b>	14.64
<b>90-94</b>	6.20
<b>95-100</b>	0.20
6-10	<b>39.67</b>
2015-2019	<b>39.67</b>
<b>35-39</b>	0.18
<b>40-44</b>	0.10
<b>45-49</b>	0.03
<b>50-54</b>	0.13
<b>55-59</b>	0.10
<b>60-64</b>	0.29
<b>65-69</b>	1.11
<b>70-74</b>	2.69
<b>75-79</b>	5.53
<b>80-84</b>	10.08
<b>85-89</b>	12.27
<b>90-94</b>	6.94
<b>95-100</b>	0.22
11-15	<b>86.87</b>
2010-2014	<b>86.87</b>
<b>20-24</b>	0.10
<b>30-34</b>	0.10
<b>40-44</b>	0.13
<b>45-49</b>	0.70
<b>50-54</b>	0.73
<b>55-59</b>	0.90
<b>60-64</b>	1.81
<b>65-69</b>	4.80
<b>70-74</b>	5.35
<b>75-79</b>	15.33
<b>80-84</b>	26.67
<b>85-89</b>	26.35
<b>90-94</b>	3.80
<b>95-100</b>	0.10
16-20	<b>16.67</b>
2005-2009	<b>16.67</b>
<b>30-34</b>	0.10
<b>40-44</b>	0.13
<b>50-54</b>	0.60
<b>55-59</b>	2.71
<b>60-64</b>	4.04

<b>65-69</b>	3.62
<b>70-74</b>	2.86
<b>75-79</b>	1.90
<b>80-84</b>	0.61
<b>85-89</b>	0.10
21-25	<b>0.63</b>
2000-2004	<b>0.63</b>
<b>0-4</b>	0.13
<b>30-34</b>	0.50
26-30	<b>4.41</b>
1995-1999	<b>4.41</b>
<b>55-59</b>	0.10
<b>60-64</b>	0.10
<b>65-69</b>	0.10
<b>70-74</b>	0.46
<b>75-79</b>	1.31
<b>80-84</b>	1.99
<b>85-89</b>	0.35
Grand Total	<b>214.06</b>

Comments:

- Figure 13, uses the grind rating to describe the performance of grinding rehabilitation. The years are arranged in five-year bins (recall the data is until 2022 but for the ease of representation the data is shown till 2024).
- The better the rating, the better the pavement performance. After the DBR rehabilitation from 1994-2014 the grind ratings show clear improvement as the ratings are above the 50-rating trigger for rehabilitation. The peak rating in the 2005-2009 year is in the 60-70 range. The more recent pavements see higher peaks of 80-90 as these are more recent rehabilitations seen in the 2020-2024 range. It should also be noted that there is a second distribution in the 2020-2024 range with a peak in the 45-49 range as the older rehabilitation efforts in the 1994 years are now 30 years and will likely see decreases in performance.

### 3.3.3 Detailed Analysis of Specific Concrete Pavement Sections

This section analyzes five sections of pavement over time that have undergone rehabilitation to evaluate how the rehabilitation has performed. Four sections have had crack seat overlay (CSOL) and the fifth was an unbonded, undoweled concrete overlay (UUOL).

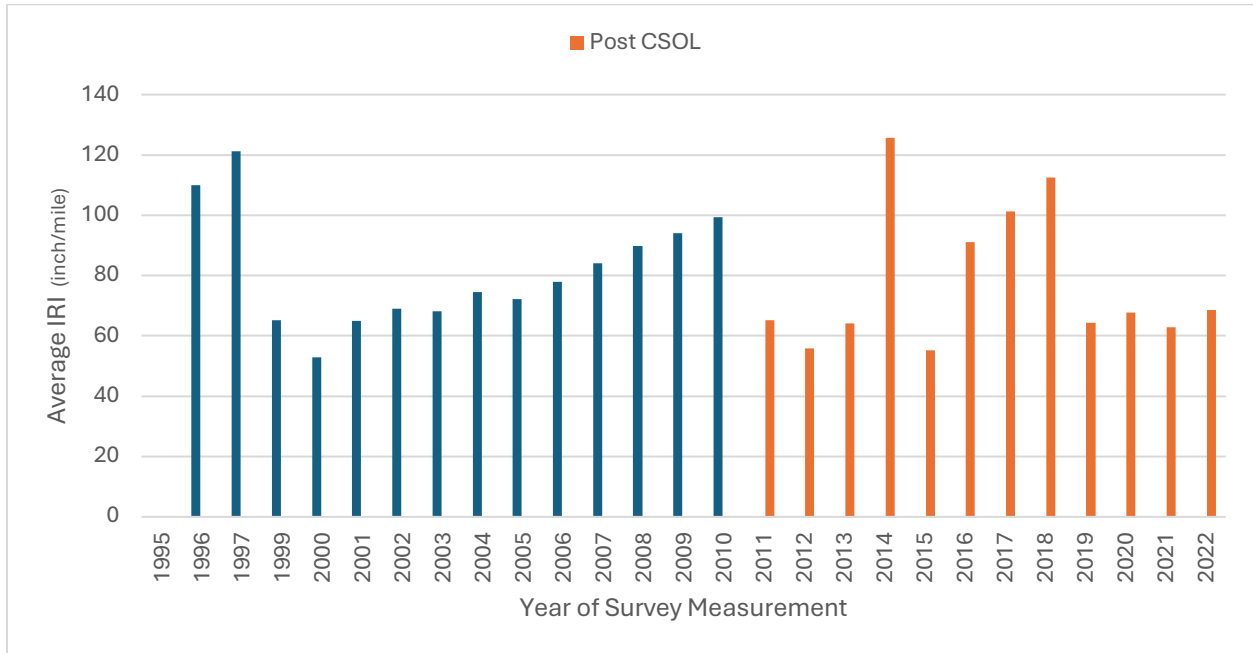
#### Crack Seat Overlay (CSOL)

WSDOT has done four major CSOL rehabilitations from 2011 to 2017 as follows from oldest to newest: I-5 Joe Leary Slough to Mulle Road Vic, I-90 Easton Hill Eastbound and Westbound, I-5 SB South 320<sup>th</sup> Street to Duwamish River Bridge, and I-5 Northbound South 260<sup>th</sup> Street to Duwamish River Bridge

For sections that have had a dowel bar retrofit done to them or contain dowel bars there are different criteria. For reconstruction, more than 15% of the panels need to be cracked and contain multiple cracks. Reconstruction can also be triggered if more than 15% of the slabs have faulting more than 0.5 inches. Similarly, to undoweled sections, grinding is triggered when more than 25% of the slabs have faulting more than 0.125 inches, rutting greater than 0.4 inches, and an IRI greater than 220 inches/mile.

### 3.3.3.1 I-5 Joe Leary Slough to Nulle Road Vic – Paving

- Mile post range – MP 234.08-243.39
- Construction year – 2011
- Existing pavement – concrete pavement overlaid with four-inches of asphalt
- Rehabilitation – this was the first major CSOL for WSDOT in 2011
- Data – after each graph the data is shown in Table 17 through Table 19
- Graphs – see Figure 14 through Figure 16

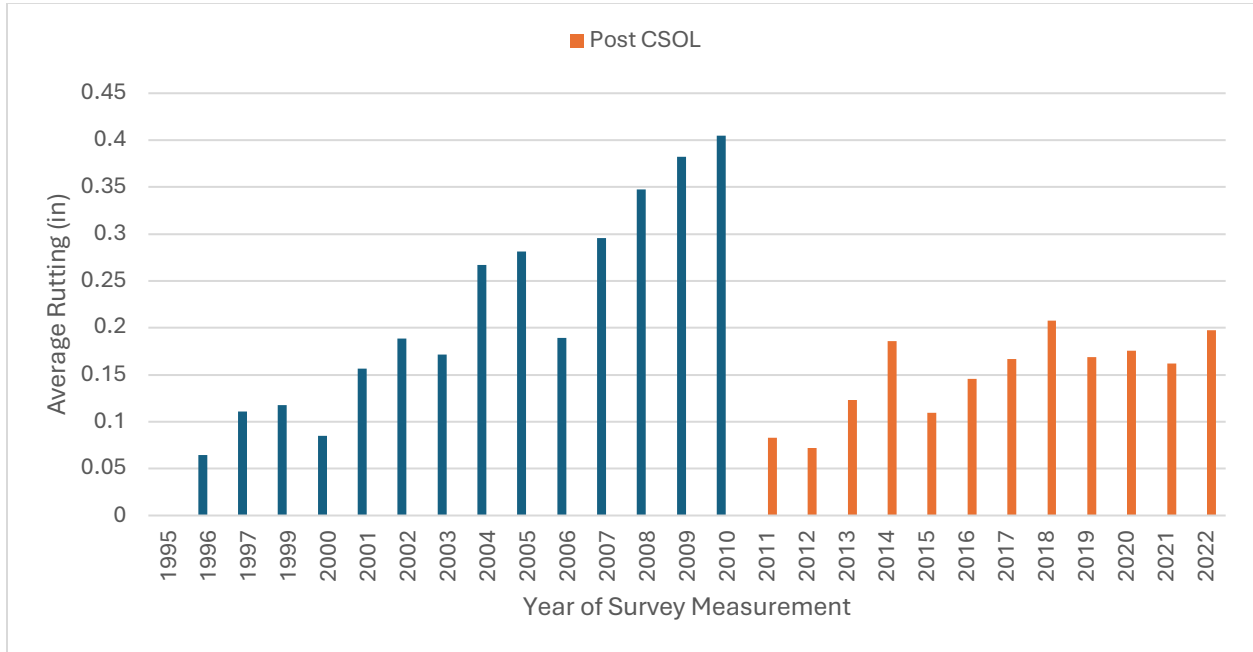


**Figure 14: Average IRI vs year of survey measurement for I-5 MP 234.08-243.39.**

**Table 17: Data for Figure 14**

Survey Year	Average of IRI		
	Pre CSOL	Post CSOL	Grand Total
1995			
1996	<b>110.00</b>		<b>110.00</b>
1997	<b>121.19</b>		<b>121.19</b>
1999	<b>65.21</b>		<b>65.21</b>
2000	<b>52.82</b>		<b>52.82</b>
2001	<b>64.98</b>		<b>64.98</b>
2002	<b>69.10</b>		<b>69.10</b>
2003	<b>68.26</b>		<b>68.26</b>
2004	<b>74.45</b>		<b>74.45</b>
2005	<b>72.25</b>		<b>72.25</b>

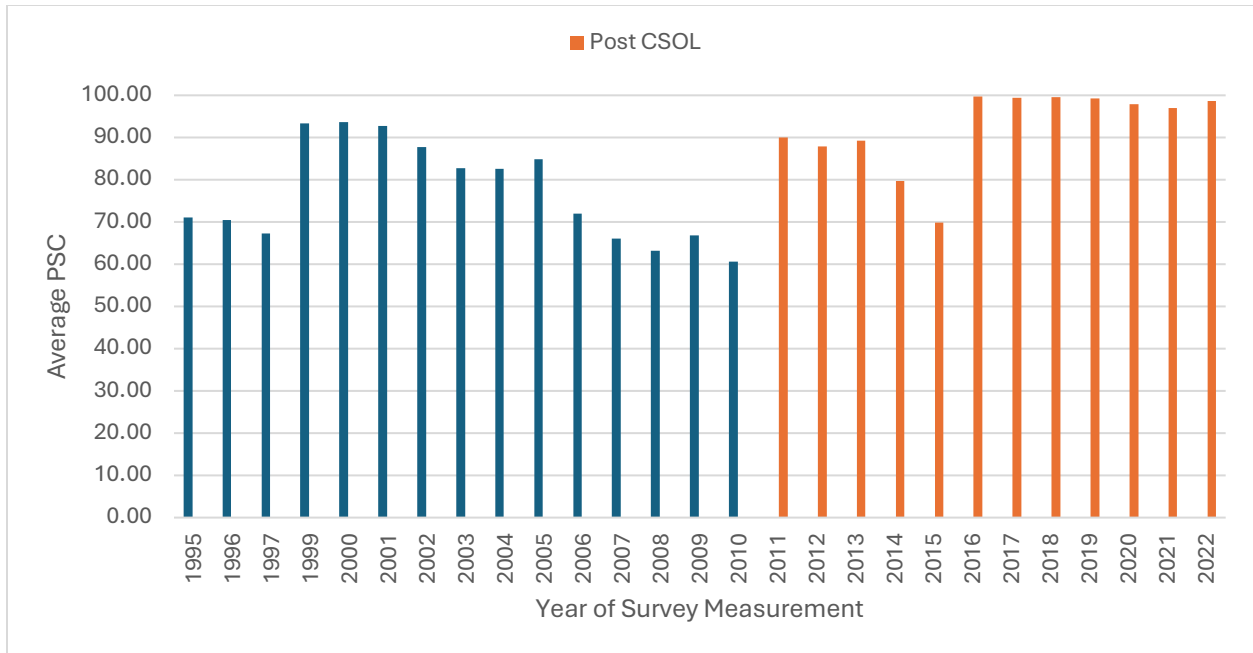
2006	<b>78.00</b>		<b>78.00</b>
2007	<b>84.13</b>		<b>84.13</b>
2008	<b>89.75</b>		<b>89.75</b>
2009	<b>94.10</b>		<b>94.10</b>
2010	<b>99.40</b>		<b>99.40</b>
2011		<b>65.29</b>	<b>65.29</b>
2012		<b>55.96</b>	<b>55.96</b>
2013		<b>64.09</b>	<b>64.09</b>
2014		<b>125.61</b>	<b>125.61</b>
2015		<b>55.19</b>	<b>55.19</b>
2016		<b>91.13</b>	<b>91.13</b>
2017		<b>101.18</b>	<b>101.18</b>
2018		<b>112.52</b>	<b>112.52</b>
2019		<b>64.37</b>	<b>64.37</b>
2020		<b>67.70</b>	<b>67.70</b>
2021		<b>62.82</b>	<b>62.82</b>
2022		<b>68.67</b>	<b>68.67</b>
Grand Total	<b>77.56</b>	<b>65.12</b>	<b>73.66</b>



**Figure 15: Average rutting vs year of survey measurement for I-5 MP 234.08-243.39.**

**Table 18: Data for Figure 15**

Survey Year	Average of Rutting		
	Pre CSOL	Post CSOL	Grand Total
1995			
1996	<b>0.06</b>		<b>0.06</b>
1997	<b>0.11</b>		<b>0.11</b>
1999	<b>0.12</b>		<b>0.12</b>
2000	<b>0.09</b>		<b>0.09</b>
2001	<b>0.16</b>		<b>0.16</b>
2002	<b>0.19</b>		<b>0.19</b>
2003	<b>0.17</b>		<b>0.17</b>
2004	<b>0.27</b>		<b>0.27</b>
2005	<b>0.28</b>		<b>0.28</b>
2006	<b>0.19</b>		<b>0.19</b>
2007	<b>0.30</b>		<b>0.30</b>
2008	<b>0.35</b>		<b>0.35</b>
2009	<b>0.38</b>		<b>0.38</b>
2010	<b>0.41</b>		<b>0.41</b>
2011		<b>0.08</b>	<b>0.08</b>
2012		<b>0.07</b>	<b>0.07</b>
2013		<b>0.12</b>	<b>0.12</b>
2014		<b>0.19</b>	<b>0.19</b>
2015		<b>0.11</b>	<b>0.11</b>
2016		<b>0.15</b>	<b>0.15</b>
2017		<b>0.17</b>	<b>0.17</b>
2018		<b>0.21</b>	<b>0.21</b>
2019		<b>0.17</b>	<b>0.17</b>
2020		<b>0.18</b>	<b>0.18</b>
2021		<b>0.16</b>	<b>0.16</b>
2022		<b>0.20</b>	<b>0.20</b>
Grand Total	<b>0.24</b>	<b>0.12</b>	<b>0.20</b>



**Figure 16: Average PSC vs year of survey measurement for I-5 MP 234.08-243.39.**

**Table 19: Data for Figure 16**

Survey Year	Average of PSC		
	Pre CSOL	Post CSOL	Grand Total
1995	71.03		71.03
1996	70.42		70.42
1997	67.24		67.24
1999	93.39		93.39
2000	93.63		93.63
2001	92.69		92.69
2002	87.76		87.76
2003	82.72		82.72
2004	82.62		82.62
2005	84.85		84.85
2006	71.95		71.95
2007	66.04		66.04
2008	63.26		63.26
2009	66.82		66.82
2010	60.69		60.69
2011		89.95	89.95
2012		87.83	87.83
2013		89.20	89.20

2014		<b>79.69</b>	<b>79.69</b>
2015		<b>69.91</b>	<b>69.91</b>
2016		<b>99.79</b>	<b>99.79</b>
2017		<b>99.43</b>	<b>99.43</b>
2018		<b>99.64</b>	<b>99.64</b>
2019		<b>99.21</b>	<b>99.21</b>
2020		<b>97.97</b>	<b>97.97</b>
2021		<b>96.99</b>	<b>96.99</b>
2022		<b>98.62</b>	<b>98.62</b>
Grand Total	<b>77.27</b>	<b>91.74</b>	<b>80.48</b>

#### Notes

- Figure 14, Figure 15, and Figure 16
  - For the mile post range of I-5 MP 234.08-243.39 there are 1637 data points from the WSPMS dataset.
  - Each mile post segment is 0.1 miles long with two lanes for 0.2 lane miles per segment.
  - Each 0.1-mile segment has 24 years of data from 1999-2022.
  - Blue bars on Figure 14 through Figure 16 indicate distress before the CSOL, orange bars indicate levels of distress after the CSOL.
  - For flexible pavement, the Present Serviceability Condition (PSC) is the index used to measure the quality of the pavement. The index ranges from 0-100, with 100 being the best, and a rating under 50 will trigger a rehabilitation however very few sections are triggered using this index.

#### Data Issues

- Figure 14
  - Data outliers are seen before the CSOL in 1996 and 1997. These bars in the pre CSOL section of the graph are above the apparent trendline. The same thing can be seen post CSOL for the years 2014, 2016, 2017, and 2018. These years of outliers contain less data (8-15 values) compared to the other years containing 47-97 values.
- Figure 16
  - The PSC data is consistent until 2011 when the PSC values are available along the entire section with some gaps. The data for 2012, and 2015-2020 is also patchy and can be partly why there are unexpected rises in the PSC data post CSOL.

#### Trends

- Figure 14
  - The pre CSOL IRI rate for all values was found to be 0.2 inches/mile/year. When the data spikes in the years 1996 and 1997 were eliminated, the IRI rate was found to be 3.6 inches/mile/year. The years 1996 and 1997 were chosen for exclusion as they were well above the trendline of IRI values. These years contained 13 and 14

data points respectively, with the next lowest number of data points being 55 in 1999. This lower number of data points gave an inaccurate representation of the IRI for that year.

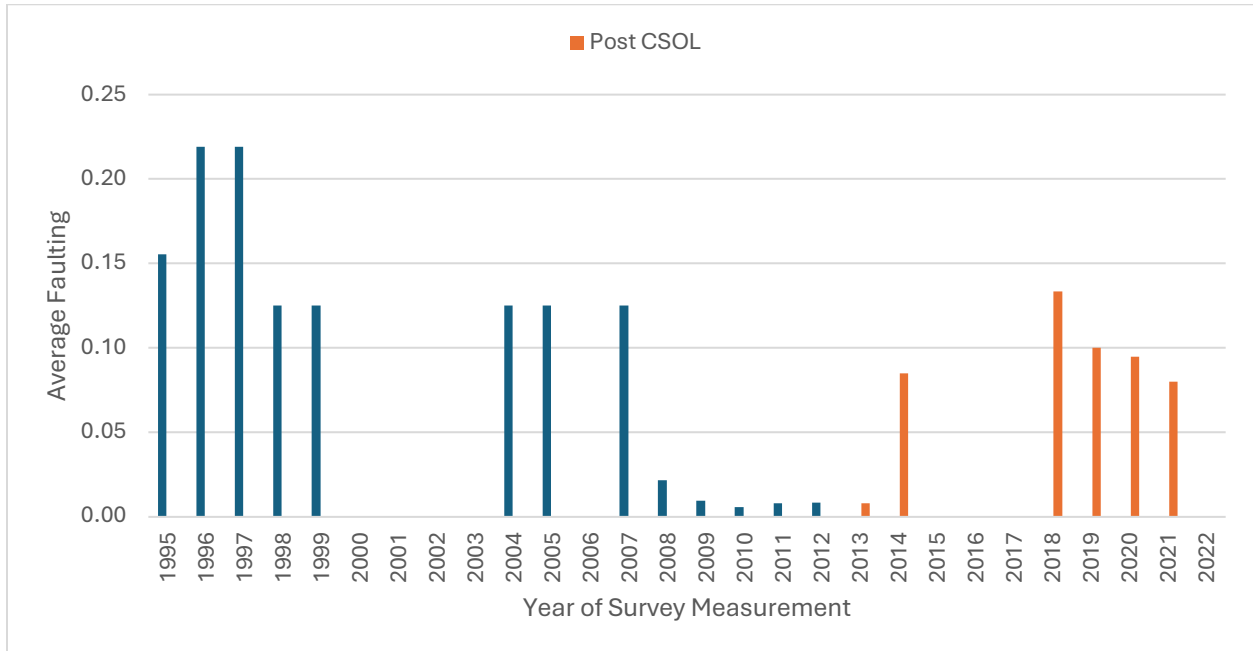
- Post CSOL IRI rate was found to be 0.0002 inches/mile/year which is almost negligible. When the spikes are eliminated from the years 2014, 2016, and 2018 for the post CSOL data, the IRI rate was found to be 0.9 inches/mile/year. Again, these years were selected based on their IRI rate being above the trendline and the number of data points in these years being between 8-15 points with the other years containing at least 47 data points.
- Figure 15
  - The rutting data was consistent for the years measured with each of the years having similar numbers of values for rutting across the mile post area selected. The pre CSOL shows a rutting rate of 0.025 inches/year. The post CSOL shows a rutting rate of 0.01 inches/year which is more than half that of the pre CSOL.
- Figure 16
  - The PSC rate pre CSOL shows negative 1 PSC/year meaning the pavement is losing quality as time progresses. The post CSOL PSC has been relatively consistent at around 80.

#### Observations

- Figure 14
  - These results suggest that the CSOL has had a positive impact on reducing the IRI rate. IRI was reduced from 3.6 inches/mile/year to one quarter that to 0.9 inches/mile/year of before the CSOL (both rates exclude the data spikes). All values, including the years that show spikes due to less data, are well below the WSPMS rehabilitation trigger value of 220 inches/miles.
- Figure 15
  - This decrease in rutting rate suggests that the CSOL has a positive impact on the rutting rate. The rutting values in 2009 and 2010 are approaching the 0.4 inches of rutting that would trigger the rehabilitation according to the WSPMS.
- Figure 16
  - The post CSOL data is hard to properly analyze as the data contains gaps and can incorrectly suggest improvements.
- Summary
  - The 2011 CSOL improved the pavement by all measures. Twelve years after the CSOL the project's asphalt overlay is performing well with an average IRI of 65.12 inches/mile, rut depth of 0.20 inches, and a PSC of 98.62.
  - The IRI rate has reduced from 3.6 to 0.9 inches/mile/year. The rutting rate has decreased from 0.025 to 0.009 inches/year. The PSC score has remained relatively consistent at 80 post CSOL.

### 3.3.3.2 I-90, MP 65.54 to Easton Hill EB and WB – Paving

- Mile post range – MP 65.54-67.43 decreasing only (westbound lanes)
- Construction year – 2013
- Existing pavement – concrete pavement
- Rehabilitation – this was the second major CSOL for WSDOT in 2013
- Data – after each graph the data is shown in Table 20 through Table 22
- Graphs – see Figure 17 through Figure 19

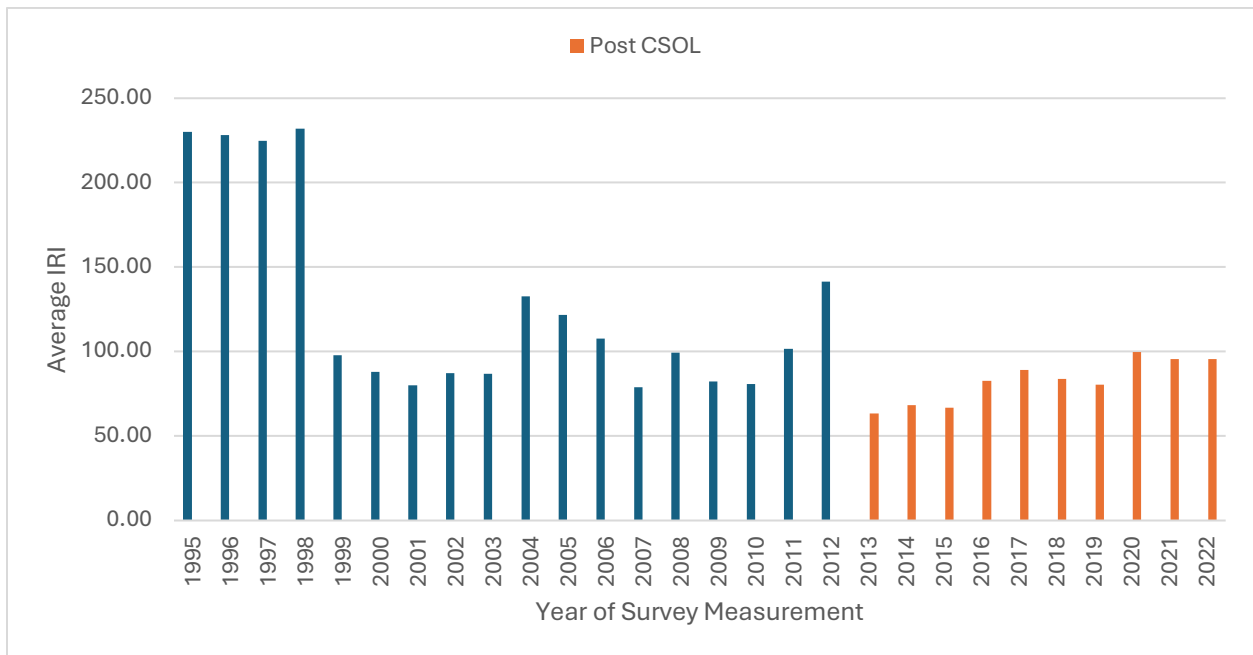


**Figure 17: Average faulting vs year of survey measurement for I-90 MP 65.54-67.43.**

**Table 20: Data for Figure 17**

Survey Year	Average of Faulting		
	Pre CSOL	Post CSOL	Grand Total
1995	0.16		0.16
1996	0.22		0.22
1997	0.22		0.22
1998	0.13		0.13
1999	0.13		0.13
2000			
2001			
2002			
2003			
2004	0.13		0.13

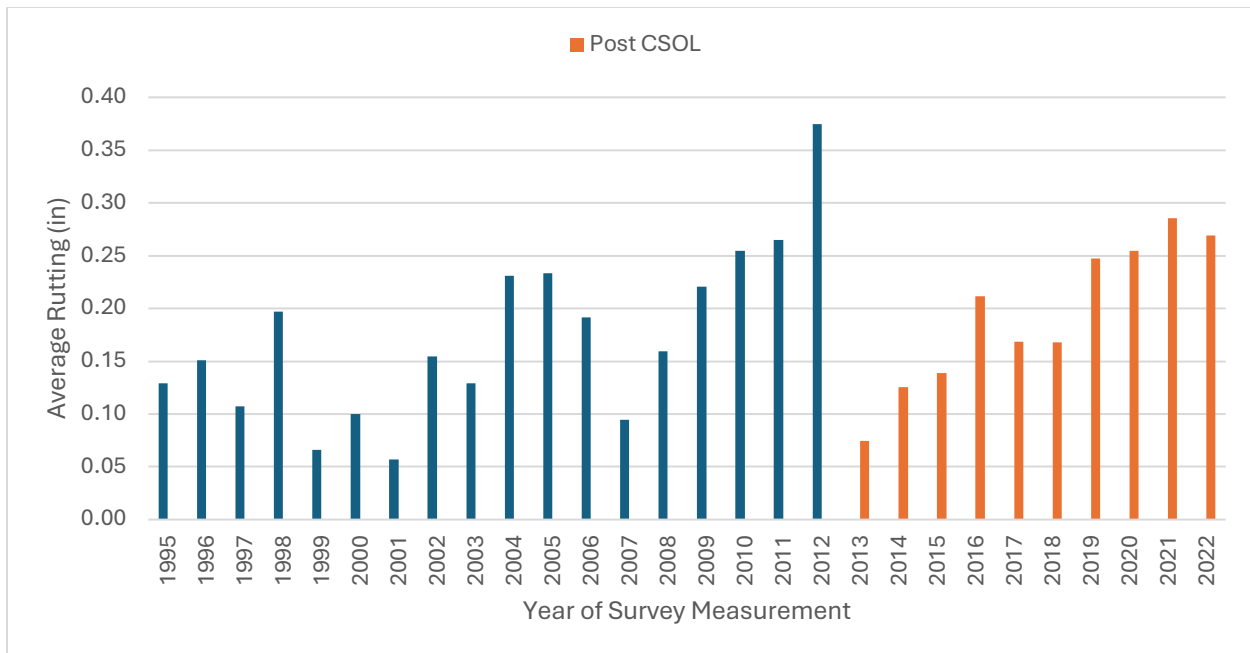
2005	<b>0.13</b>		<b>0.13</b>
2006			
2007	<b>0.13</b>		<b>0.13</b>
2008	<b>0.02</b>		<b>0.02</b>
2009	<b>0.01</b>		<b>0.01</b>
2010	<b>0.01</b>		<b>0.01</b>
2011	<b>0.01</b>		<b>0.01</b>
2012	<b>0.01</b>		<b>0.01</b>
2013		<b>0.01</b>	<b>0.01</b>
2014		<b>0.09</b>	<b>0.09</b>
2015			
2016			
2017			
2018		<b>0.13</b>	<b>0.13</b>
2019		<b>0.10</b>	<b>0.10</b>
2020		<b>0.10</b>	<b>0.10</b>
2021		<b>0.08</b>	<b>0.08</b>
2022			
Grand Total	<b>0.09</b>	<b>0.04</b>	<b>0.09</b>



**Figure 18: Average IRI vs year of survey measurement for I-90 MP 65.54-67.43.**

**Table 21: Data for Figure 16**

Survey Year	Average of IRI		
	Pre CSOL	Post CSOL	Grand Total
1995	230.11		230.11
1996	228.24		228.24
1997	224.65		224.65
1998	232.18		232.18
1999	97.92		97.92
2000	87.92		87.92
2001	80.16		80.16
2002	87.41		87.41
2003	86.79		86.79
2004	132.85		132.85
2005	121.82		121.82
2006	107.59		107.59
2007	78.85		78.85
2008	99.34		99.34
2009	82.13		82.13
2010	80.85		80.85
2011	101.59		101.59
2012	141.50		141.50
2013		63.49	63.49
2014		68.32	68.32
2015		66.75	66.75
2016		82.65	82.65
2017		89.30	89.30
2018		83.65	83.65
2019		80.53	80.53
2020		99.66	99.66
2021		95.43	95.43
2022		95.71	95.71
Grand Total	142.34	82.11	115.41



**Figure 19: Average rutting vs year of survey measurement for I-90 MP 65.54-67.43.**

**Table 22: Data for Figure 19**

Survey Year	Average of Rutting		
	Pre CSOL	Post CSOL	Grand Total
1995	0.13		0.13
1996	0.15		0.15
1997	0.11		0.11
1998	0.20		0.20
1999	0.07		0.07
2000	0.10		0.10
2001	0.06		0.06
2002	0.15		0.15
2003	0.13		0.13
2004	0.23		0.23
2005	0.23		0.23
2006	0.19		0.19
2007	0.09		0.09
2008	0.16		0.16
2009	0.22		0.22
2010	0.25		0.25
2011	0.26		0.26
2012	0.37		0.37

2013		<b>0.07</b>	<b>0.07</b>
2014		<b>0.13</b>	<b>0.13</b>
2015		<b>0.14</b>	<b>0.14</b>
2016		<b>0.21</b>	<b>0.21</b>
2017		<b>0.17</b>	<b>0.17</b>
2018		<b>0.17</b>	<b>0.17</b>
2019		<b>0.25</b>	<b>0.25</b>
2020		<b>0.25</b>	<b>0.25</b>
2021		<b>0.29</b>	<b>0.29</b>
2022		<b>0.27</b>	<b>0.27</b>
Grand Total	<b>0.19</b>	<b>0.19</b>	<b>0.19</b>

#### Notes

- Figure 17, Figure 18, and Figure 19
  - For the mile post range of MP 65.54-67.43 decreasing only (westbound lanes) there are 407 data points from the WSPMS dataset when all the filters are applied for direction and range.
  - Each mile post segment is 0.1 miles long with two lanes for 0.2 lane miles per segment.
  - Each 0.1-mile segment has 28 years of data from 1995-2022.
  - Blue bars on Figure 17 through Figure 19 indicate distress before the CSOL, orange bars indicate levels of distress after the CSOL.

#### Data Issues

- Figure 17
  - Faulting data may not be representative. Values in years 1995-1999 come from averaging 19 recorded data points along the mile post range selected while the following years only come from 2-3 data points per year.

#### Trends

- Figure 18
  - IRI is high from 1995-1998 at around 230 inches/mile. In 1999 it drops to about 98 inches/mile, but no rehabilitation is indicated in WSPMS. From 1999, IRI steadily increase until the 2013 CSOL.
  - The rate of IRI increase post-CSOL in 2013 is approximately 3.8 inches/mile/year. Pre-CSOL from 1995-2012 shows a negative rate due to the high IRI in the early years from 1995-1998. Excluding the high values of 1995-1998, the rate of IRI increase is approximately 1.3 inches/mile/year.
- Figure 19
  - Rutting post-CSOL shows an increasing rate of 0.02 inches/year, while the pre-CSOL shows an increasing rate of 0.01 inches/year, which is quite similar.

#### Observations

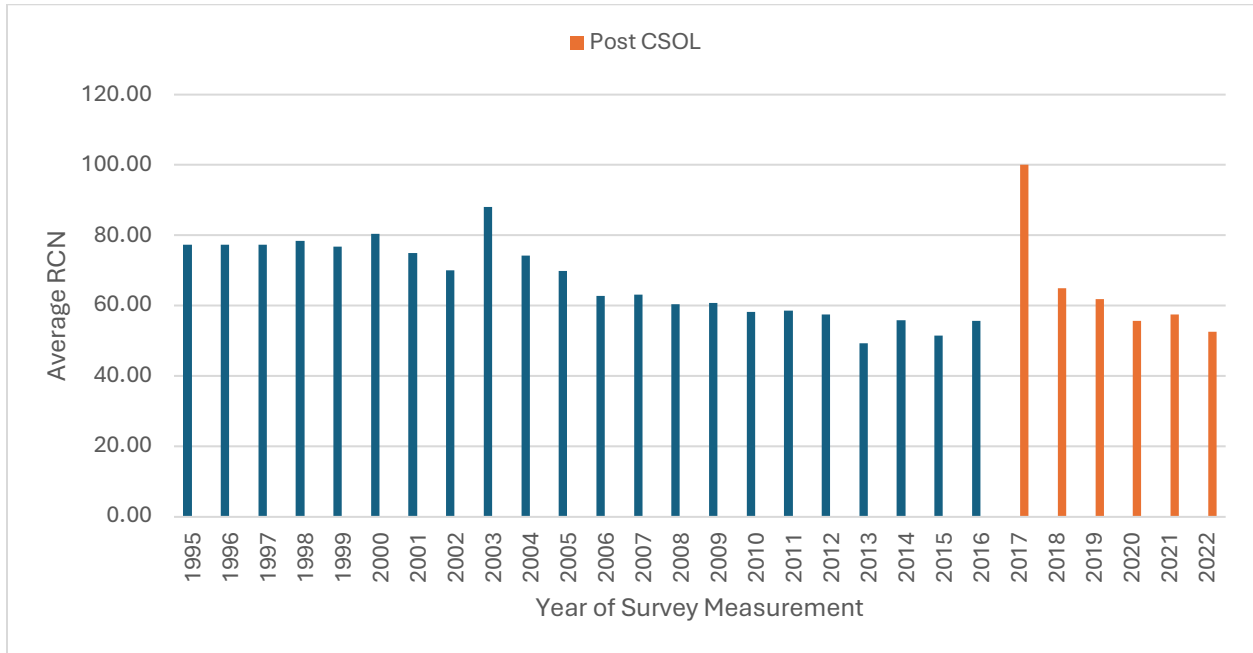
- Figure 17
  - Not enough data to make a comprehensive statement on the change in faulting after the rehabilitation efforts.
- Figure 18
  - The IRI wear rate has seemingly almost tripled post-CSOL. More investigation and consistent data are needed to be sure.
- Figure 19
  - The rutting rate has approximately doubled since CSOL in 2013. From the pre CSOL years 1995-2012 the rutting rate was 0.01 inches/year and the post CSOL years 2013 to 2022 the rutting rate was 0.02 inches/year. The rutting values are all below the WSPMS value of 0.4 inches which would be the trigger for a rehabilitation.

#### Summary

- The CSOL has seemingly had a greatly improved the pavements in the short term, but the long-term effects seem to be negative impact on the IRI and rutting as the rates of deterioration increase. When the spikes in data from 1995-1998 are eliminated, the IRI rate increases from 1.25 inches/year/mile pre CSOL to 3.88 inches/year/mile post CSOL. The rutting rate also appears to increase from 0.01 inches/year from pre CSOL 1995-2012 to 0.02 inches/year post CSOL from 2013-2022.

### 3.3.3.3 I-5 SB S 320<sup>th</sup> St. to Duwamish River Bridge Concrete Pavement Rehab

- Mile post range – MP 149.63-153.29
- Construction year – 2015
- Existing pavement – concrete pavement now surfaced with asphalt
- Rehabilitation – CSOL in 2015
- Data – after each graph the data is shown in Table 23 through Table 26
- Graphs – see Figure 20 through Figure 23

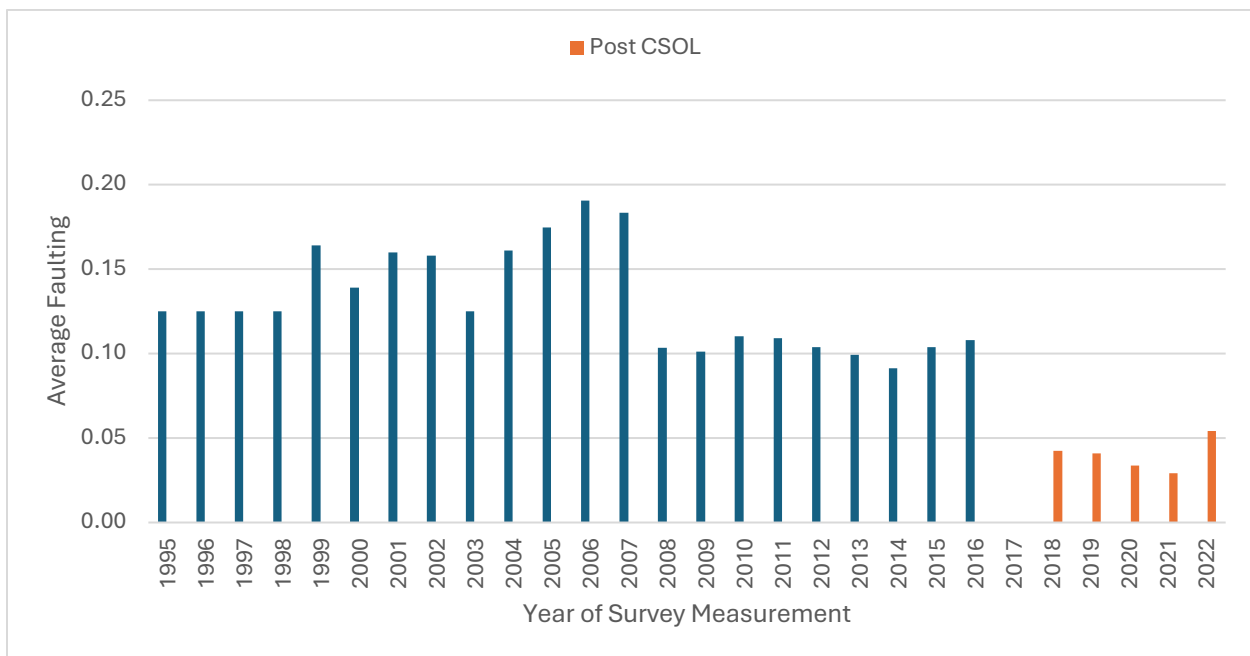


**Figure 20: Average RCN vs year of survey measurement for I-5 MP 149.63-153.29.**

**Table 23: Data for Figure 20**

Survey Year	Average of RCN		
	Pre CSOL	Post CSOL	Grand Total
1995	77.42		77.42
1996	77.42		77.42
1997	77.42		77.42
1998	78.50		78.50
1999	76.75		76.75
2000	80.42		80.42
2001	74.92		74.92
2002	70.00		70.00
2003	88.08		88.08

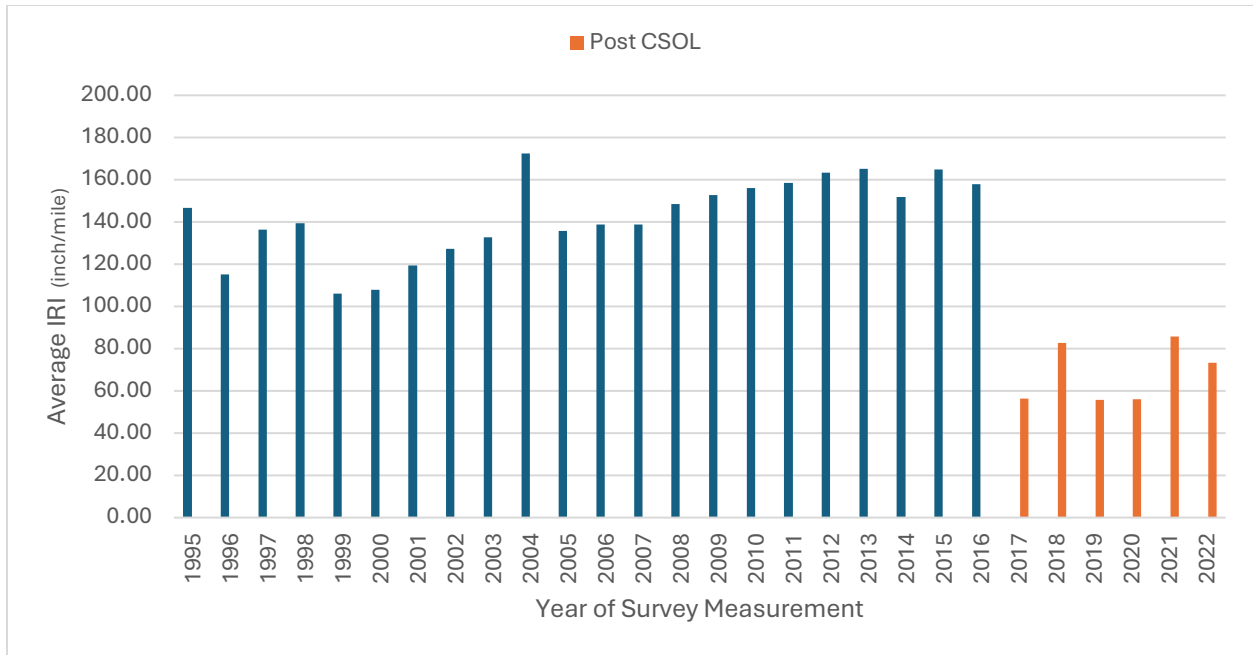
2004	<b>74.33</b>		<b>74.33</b>
2005	<b>69.92</b>		<b>69.92</b>
2006	<b>62.83</b>		<b>62.83</b>
2007	<b>63.17</b>		<b>63.17</b>
2008	<b>60.50</b>		<b>60.50</b>
2009	<b>60.83</b>		<b>60.83</b>
2010	<b>58.25</b>		<b>58.25</b>
2011	<b>58.67</b>		<b>58.67</b>
2012	<b>57.58</b>		<b>57.58</b>
2013	<b>49.33</b>		<b>49.33</b>
2014	<b>55.92</b>		<b>55.92</b>
2015	<b>51.50</b>		<b>51.50</b>
2016	<b>55.75</b>		<b>55.75</b>
2017		<b>100.00</b>	<b>100.00</b>
2018		<b>64.92</b>	<b>64.92</b>
2019		<b>61.92</b>	<b>61.92</b>
2020		<b>55.73</b>	<b>55.73</b>
2021		<b>57.55</b>	<b>57.55</b>
2022		<b>52.67</b>	<b>52.67</b>
Grand Total	<b>67.17</b>	<b>59.32</b>	<b>65.72</b>



**Figure 21: Average faulting vs year of survey measurement for I-5 MP 149.63-153.29.**

**Table 24: Data for Figure 21**

Survey Year	Average of Faulting		
	Pre CSOL	Post CSOL	Grand Total
1995	<b>0.13</b>		<b>0.13</b>
1996	<b>0.13</b>		<b>0.13</b>
1997	<b>0.13</b>		<b>0.13</b>
1998	<b>0.13</b>		<b>0.13</b>
1999	<b>0.16</b>		<b>0.16</b>
2000	<b>0.14</b>		<b>0.14</b>
2001	<b>0.16</b>		<b>0.16</b>
2002	<b>0.16</b>		<b>0.16</b>
2003	<b>0.13</b>		<b>0.13</b>
2004	<b>0.16</b>		<b>0.16</b>
2005	<b>0.17</b>		<b>0.17</b>
2006	<b>0.19</b>		<b>0.19</b>
2007	<b>0.18</b>		<b>0.18</b>
2008	<b>0.10</b>		<b>0.10</b>
2009	<b>0.10</b>		<b>0.10</b>
2010	<b>0.11</b>		<b>0.11</b>
2011	<b>0.11</b>		<b>0.11</b>
2012	<b>0.10</b>		<b>0.10</b>
2013	<b>0.10</b>		<b>0.10</b>
2014	<b>0.09</b>		<b>0.09</b>
2015	<b>0.10</b>		<b>0.10</b>
2016	<b>0.11</b>		<b>0.11</b>
2017			
2018		<b>0.04</b>	<b>0.04</b>
2019		<b>0.04</b>	<b>0.04</b>
2020		<b>0.03</b>	<b>0.03</b>
2021		<b>0.03</b>	<b>0.03</b>
2022		<b>0.05</b>	<b>0.05</b>
Grand Total	<b>0.13</b>	<b>0.04</b>	<b>0.12</b>

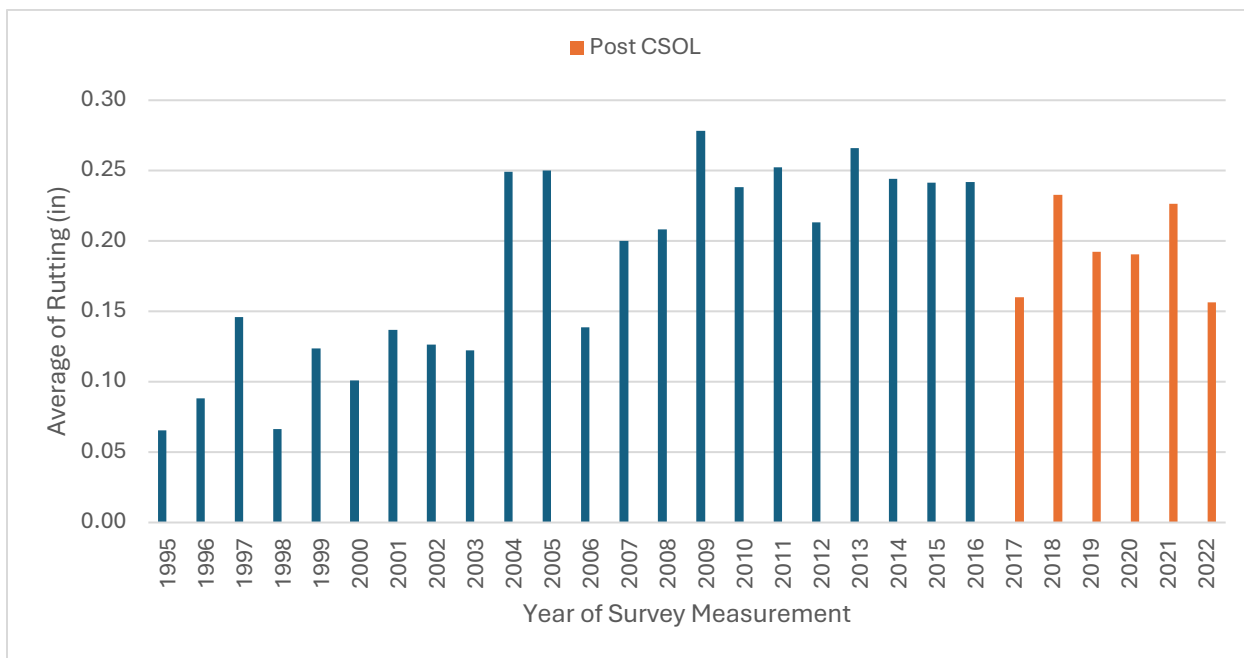


**Figure 22: Average IRI vs year of measurement for I-5 MP 149.63-153.29.**

**Table 25: Data for Figure 22**

Survey Year	Average of IRI		
	Pre CSOL	Post CSOL	Grand Total
1995	146.79		146.79
1996	115.25		115.25
1997	136.33		136.33
1998	139.30		139.30
1999	106.08		106.08
2000	107.90		107.90
2001	119.41		119.41
2002	127.22		127.22
2003	132.89		132.89
2004	172.37		172.37
2005	135.89		135.89
2006	138.92		138.92
2007	138.84		138.84
2008	148.56		148.56
2009	152.81		152.81
2010	156.22		156.22
2011	158.37		158.37

2012	<b>163.46</b>		<b>163.46</b>
2013	<b>165.04</b>		<b>165.04</b>
2014	<b>151.89</b>		<b>151.89</b>
2015	<b>164.77</b>		<b>164.77</b>
2016	<b>158.04</b>		<b>158.04</b>
2017		<b>56.24</b>	<b>56.24</b>
2018		<b>82.64</b>	<b>82.64</b>
2019		<b>55.67</b>	<b>55.67</b>
2020		<b>56.17</b>	<b>56.17</b>
2021		<b>85.73</b>	<b>85.73</b>
2022		<b>73.36</b>	<b>73.36</b>
Grand Total	<b>142.45</b>	<b>62.47</b>	<b>129.90</b>



**Figure 23: Average rutting vs year of measurement for I-5 MP 149.63-153.29.**

**Table 26: Data for Figure 23**

Survey Year	Average of Rutting		
	Pre CSOL	Post CSOL	Grand Total
1995	<b>0.07</b>		<b>0.07</b>
1996	<b>0.09</b>		<b>0.09</b>
1997	<b>0.15</b>		<b>0.15</b>
1998	<b>0.07</b>		<b>0.07</b>

1999	<b>0.12</b>		<b>0.12</b>
2000	<b>0.10</b>		<b>0.10</b>
2001	<b>0.14</b>		<b>0.14</b>
2002	<b>0.13</b>		<b>0.13</b>
2003	<b>0.12</b>		<b>0.12</b>
2004	<b>0.25</b>		<b>0.25</b>
2005	<b>0.25</b>		<b>0.25</b>
2006	<b>0.14</b>		<b>0.14</b>
2007	<b>0.20</b>		<b>0.20</b>
2008	<b>0.21</b>		<b>0.21</b>
2009	<b>0.28</b>		<b>0.28</b>
2010	<b>0.24</b>		<b>0.24</b>
2011	<b>0.25</b>		<b>0.25</b>
2012	<b>0.21</b>		<b>0.21</b>
2013	<b>0.27</b>		<b>0.27</b>
2014	<b>0.24</b>		<b>0.24</b>
2015	<b>0.24</b>		<b>0.24</b>
2016	<b>0.24</b>		<b>0.24</b>
2017		<b>0.16</b>	<b>0.16</b>
2018		<b>0.23</b>	<b>0.23</b>
2019		<b>0.19</b>	<b>0.19</b>
2020		<b>0.19</b>	<b>0.19</b>
2021		<b>0.23</b>	<b>0.23</b>
2022		<b>0.16</b>	<b>0.16</b>
Grand Total	<b>0.19</b>	<b>0.19</b>	<b>0.19</b>

Notes

- Figure 20, Figure 21, Figure 22, and Figure 23
  - For the mile post range MP 149.63-153.29 decreasing, there are 1014 data points from the WSPMS dataset when all the filters are applied for direction and range.
  - Each mile post segment is 0.1 miles long with one lane for 0.1 lane miles per segment.
  - Each 0.1-mile segment has 28 years of data from 1995-2022.
  - Blue bars on Figure 20 through Figure 23 indicate distress before the CSOL, orange bars indicate levels of distress after the CSOL.

Data Issues

- Figure 20
  - Data for RCN is not complete. Across the 1995-2022 timeframe, each year only contains values for 30%-70% of the 0.1-mile segments across the specified mile post range MP 149.63-153.29.

- Figure 21
  - The faulting data is relatively consistent with each year with approximately 80% of the 0.1-mile segments having values across the specified mile post range MP 149.63-153.29.
- Figure 22
  - None.
- Figure 23
  - None.

#### Trends

- Figure 20
  - The post CSOL rate of change for RCN was found to be decreasing at a rate of 7.6 RCN/year. However, this large rate of decline includes a single 100 RCN in 2017 that skews the dataset. After removing this single value from 2017, the rate of decrease of RCN post CSOL can be adjusted to 2.9 RCN/year. This decrease of 2.9 RCN is more accurate and shows that the RCN decline nearly doubles after CSOL.
- Figure 21
  - The pre CSOL faulting did not show much change in values with a near zero rate change. The post CSOL faulting rate was found to be 0.001 inches/year which is also near zero and great in terms of performance of the CSOL. This faulting rate is very minimal, and the pavement would take a significant amount of time to reach the 0.4 inches to trigger a WSPMS rehabilitation.
- Figure 22
  - The pre CSOL rate of increase of the IRI was 2.0 inches/mile/year. The post CSOL rate of increase for the IRI was 2.7 inches/mile/year. All values were significantly under the 220 inches/mile that would trigger the WSPMS rehabilitation.
- Figure 23
  - The rutting rate pre CSOL was near zero (0.009 inches/mile). The post CSOL was also near zero. This rate post CSOL is almost negligible and is based on a small sample size from 2017-2022.

#### Observations

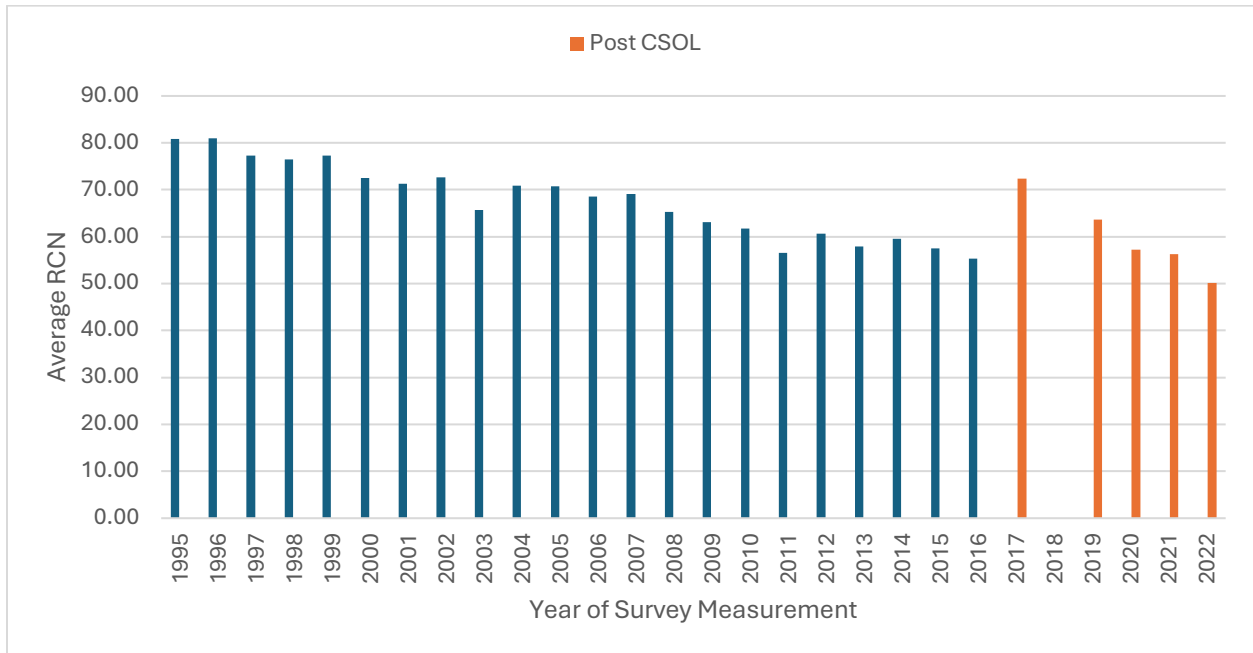
- Figure 21
  - There was a distinctive period in the pre CSOL from 1995-2007 and then from 2008-2016. If these periods are broken up and analyzed separately, the rutting from 1995-2007 was found to be 0.005 inches/year, while the rate from 2008-2016 was almost negligible as it was a negative 0.0004 inches/year. It was hard to determine exactly why the values showed this dramatic drop off, as some of the mile post values stayed consistent throughout the entire pre CSOL period.

## Summary

- The CSOL being so recent has not had the necessary time to show the full effect, but the early indicators show that the rutting and IRI changes are almost negligible. RCN has seen a rate of decline accelerated but this should be further analyzed as more data becomes available.

### 3.3.3.4 I-5 NB S 260<sup>th</sup> St. to Duwamish River Bridge Concrete Pavement Rehab & ADA

- Mile post range – MP 147.64-156.51
- Construction year – 2017
- Existing pavement – concrete pavement
- Rehabilitation – CSOL in 2017
- Data – after each graph the data is shown in Table 27 through Table 30
- Graphs – see Figure 24 through Figure 27

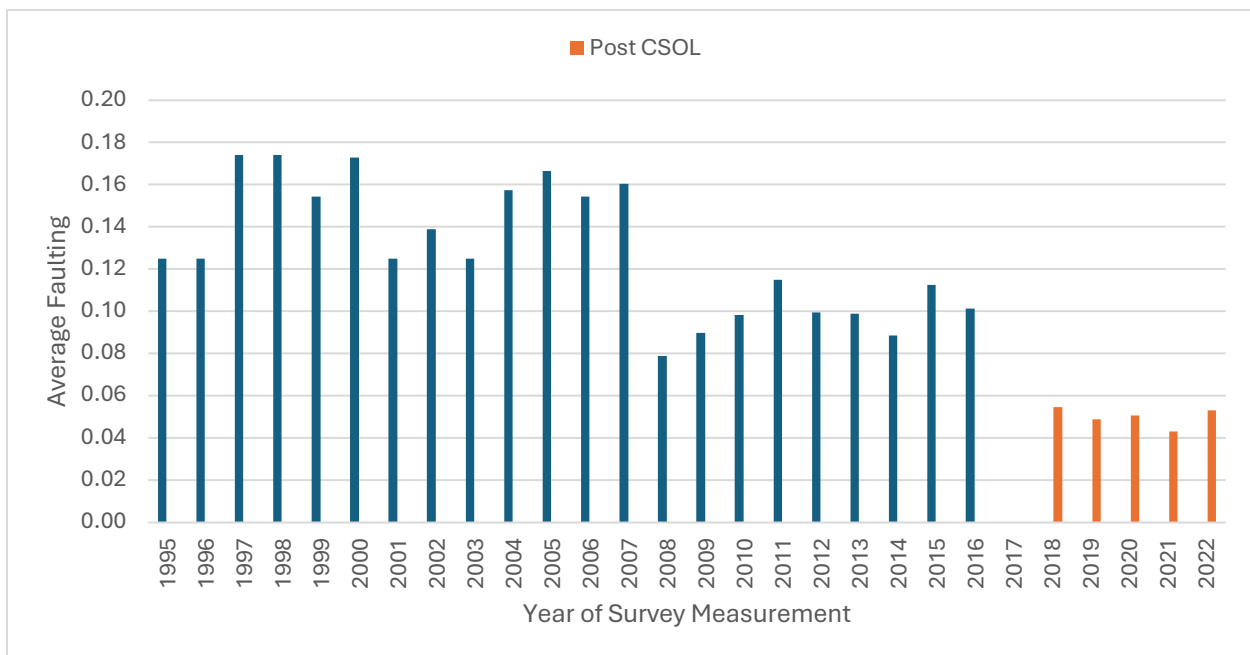


**Figure 24: Average RCN vs year of survey measurement for I-5 MP 147.64-156.51.**

**Table 27: Data for Figure 24**

Survey Year	Average of RCN		
	Pre CSOL	Post CSOL	Grand Total
1995	80.88		80.88
1996	81.02		81.02
1997	77.26		77.26
1998	76.43		76.43
1999	77.29		77.29
2000	72.50		72.50
2001	71.33		71.33
2002	72.71		72.71
2003	65.74		65.74
2004	70.88		70.88

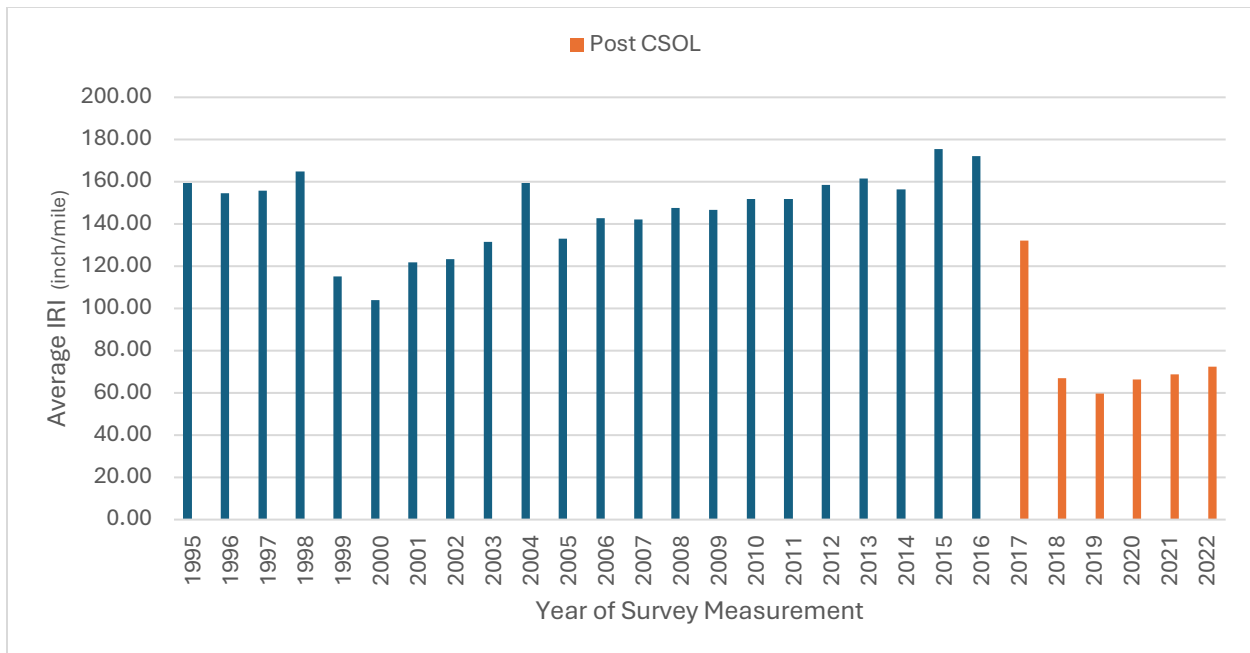
2005	<b>70.71</b>		<b>70.71</b>
2006	<b>68.50</b>		<b>68.50</b>
2007	<b>69.10</b>		<b>69.10</b>
2008	<b>65.33</b>		<b>65.33</b>
2009	<b>63.15</b>		<b>63.15</b>
2010	<b>61.71</b>		<b>61.71</b>
2011	<b>56.52</b>		<b>56.52</b>
2012	<b>60.60</b>		<b>60.60</b>
2013	<b>57.90</b>		<b>57.90</b>
2014	<b>59.62</b>		<b>59.62</b>
2015	<b>57.52</b>		<b>57.52</b>
2016	<b>55.36</b>		<b>55.36</b>
2017		<b>72.40</b>	<b>72.40</b>
2018			
2019		<b>63.69</b>	<b>63.69</b>
2020		<b>57.21</b>	<b>57.21</b>
2021		<b>56.33</b>	<b>56.33</b>
2022		<b>50.17</b>	<b>50.17</b>
Grand Total	<b>67.84</b>	<b>58.13</b>	<b>66.23</b>



**Figure 25: Average faulting vs year of survey measurement for I-5 MP 147.64-156.51.**

**Table 28: Data for Figure 25**

Survey Year	Average of Faulting		
	Pre CSOL	Post CSOL	Grand Total
1995	<b>0.13</b>		<b>0.13</b>
1996	<b>0.13</b>		<b>0.13</b>
1997	<b>0.17</b>		<b>0.17</b>
1998	<b>0.17</b>		<b>0.17</b>
1999	<b>0.15</b>		<b>0.15</b>
2000	<b>0.17</b>		<b>0.17</b>
2001	<b>0.13</b>		<b>0.13</b>
2002	<b>0.14</b>		<b>0.14</b>
2003	<b>0.13</b>		<b>0.13</b>
2004	<b>0.16</b>		<b>0.16</b>
2005	<b>0.17</b>		<b>0.17</b>
2006	<b>0.15</b>		<b>0.15</b>
2007	<b>0.16</b>		<b>0.16</b>
2008	<b>0.08</b>		<b>0.08</b>
2009	<b>0.09</b>		<b>0.09</b>
2010	<b>0.10</b>		<b>0.10</b>
2011	<b>0.12</b>		<b>0.12</b>
2012	<b>0.10</b>		<b>0.10</b>
2013	<b>0.10</b>		<b>0.10</b>
2014	<b>0.09</b>		<b>0.09</b>
2015	<b>0.11</b>		<b>0.11</b>
2016	<b>0.10</b>		<b>0.10</b>
2017			
2018		<b>0.05</b>	<b>0.05</b>
2019		<b>0.05</b>	<b>0.05</b>
2020		<b>0.05</b>	<b>0.05</b>
2021		<b>0.04</b>	<b>0.04</b>
2022		<b>0.05</b>	<b>0.05</b>
Grand Total	<b>0.12</b>	<b>0.05</b>	<b>0.12</b>

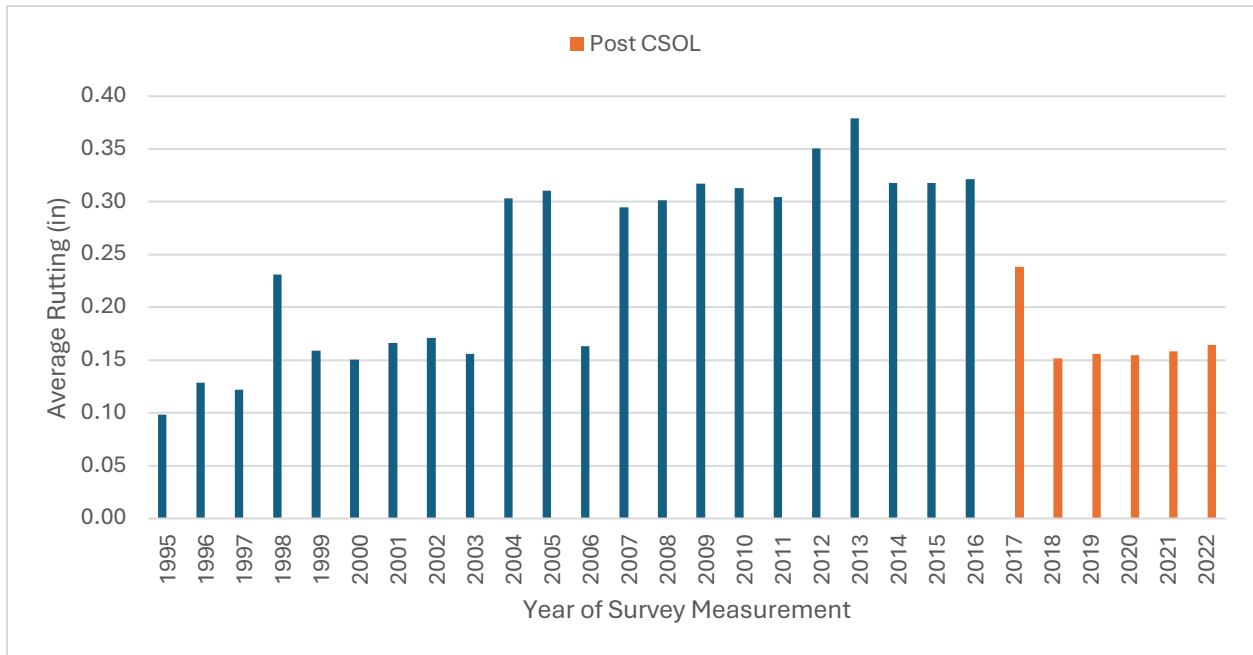


**Figure 26: Average IRI vs year of survey measurement for I-5 MP 147.64-156.61.**

**Table 29: Data for Figure 26**

Survey Year	Average of IRI		
	Pre CSOL	Post CSOL	Grand Total
1995	159.56		159.56
1996	154.64		154.64
1997	155.76		155.76
1998	164.80		164.80
1999	115.16		115.16
2000	103.82		103.82
2001	121.84		121.84
2002	123.41		123.41
2003	131.51		131.51
2004	159.55		159.55
2005	132.94		132.94
2006	142.64		142.64
2007	142.06		142.06
2008	147.67		147.67
2009	146.69		146.69
2010	151.71		151.71
2011	151.87		151.87
2012	158.43		158.43

2013	<b>161.53</b>		<b>161.53</b>
2014	<b>156.37</b>		<b>156.37</b>
2015	<b>175.48</b>		<b>175.48</b>
2016	<b>172.21</b>		<b>172.21</b>
2017		<b>132.25</b>	<b>132.25</b>
2018		<b>66.82</b>	<b>66.82</b>
2019		<b>59.70</b>	<b>59.70</b>
2020		<b>66.39</b>	<b>66.39</b>
2021		<b>68.78</b>	<b>68.78</b>
2022		<b>72.43</b>	<b>72.43</b>
Grand Total	<b>146.77</b>	<b>77.73</b>	<b>131.92</b>



**Figure 27: Average rutting vs year of survey measurement for I-5 MP 147.64-156.51.**

**Table 30: Data for Figure 27**

Survey Year	Average of Rutting		
	Pre CSOL	Post CSOL	Grand Total
1995	<b>0.10</b>		<b>0.10</b>
1996	<b>0.13</b>		<b>0.13</b>
1997	<b>0.12</b>		<b>0.12</b>
1998	<b>0.23</b>		<b>0.23</b>
1999	<b>0.16</b>		<b>0.16</b>

2000	<b>0.15</b>		<b>0.15</b>
2001	<b>0.17</b>		<b>0.17</b>
2002	<b>0.17</b>		<b>0.17</b>
2003	<b>0.16</b>		<b>0.16</b>
2004	<b>0.30</b>		<b>0.30</b>
2005	<b>0.31</b>		<b>0.31</b>
2006	<b>0.16</b>		<b>0.16</b>
2007	<b>0.29</b>		<b>0.29</b>
2008	<b>0.30</b>		<b>0.30</b>
2009	<b>0.32</b>		<b>0.32</b>
2010	<b>0.31</b>		<b>0.31</b>
2011	<b>0.30</b>		<b>0.30</b>
2012	<b>0.35</b>		<b>0.35</b>
2013	<b>0.38</b>		<b>0.38</b>
2014	<b>0.32</b>		<b>0.32</b>
2015	<b>0.32</b>		<b>0.32</b>
2016	<b>0.32</b>		<b>0.32</b>
2017		<b>0.24</b>	<b>0.24</b>
2018		<b>0.15</b>	<b>0.15</b>
2019		<b>0.16</b>	<b>0.16</b>
2020		<b>0.15</b>	<b>0.15</b>
2021		<b>0.16</b>	<b>0.16</b>
2022		<b>0.16</b>	<b>0.16</b>
Grand Total	<b>0.25</b>	<b>0.17</b>	<b>0.23</b>

#### Notes

- Figure 24, Figure 25, Figure 26, and Figure 27
  - For the mile post range MP 147.64-156.51 increasing, there are 2483 data points from the WSPMS dataset when all the filters are applied for direction and range.
  - Each mile post segment is 0.1 miles long with five lanes for 0.5 lane miles per segment.
  - Each 0.1-mile segment has 28 years of data from 1995-2022.
  - Blue bars on Figure 24 through Figure 27 indicate distress before the CSOL, orange bars indicate levels of distress after the CSOL.

#### Data Issues

- Figure 24
  - Despite the inconsistencies in the data for the entire segment, the data for the RCN was missing several data points for mile post markers along the MP 147.64-156.61 segment being analyzed.
- Figure 25

- Post CSOL the asphalt surface means the faulting data is not applicable as faulting is not a factor on asphalt surfaced roads.
- Figure 26
  - The data available for IRI did not miss any mile post segment values across the range selected of MP 147.64-156.51. Pre CSOL the rate of IRI was found to be 1.2 inches/mile/year. If the seemingly abnormal peaks from the 1995-1998 are excluded, the rate from 1999-2013 was a more aggressive 3.3 inches/mile/year.
- Figure 27
  - For post CSOL, if the abnormal data peak in 2017 is removed and the data reassessed, the rate of rutting is now slightly positive but near zero (0.003 inches/year). This shows that the CSOL has significantly reduced the rate of rutting for the years observed from the pre CSOL rutting rate of 0.01 inches/mile/year. The values in 2013 were approaching the 0.4 inches of rutting which would trigger a rehabilitation according to the WSPMS. It should also be stated that this is a short period of analysis.

#### Trends

- Figure 24
  - The RCN rate pre CSOL is 1.2 RCN/year and the rate post CSOL is 4.3 RCN/year. This shows that post CSOL the RCN rate almost triples.
- Figure 25
  - Pre CSOL shows improvement of the pavement over time, with faulting decreasing by 0.0031 inches/year. If the drop off in 2008 is taken into consideration, the faulting increases at a rate of 0.002 inches/year.
- Figure 27
  - The rutting pre CSOL is at a rate of 0.01 inches/year. Post CSOL, the rutting takes on a negative slope of 0.001 inches/year. The data is consistent throughout the data range selected but there is a peak in the numbers post CSOL in 2017. If this spike is removed and the data reassessed, the rate of rutting is now positive and shows an increase in rutting of 0.003 inches/year.

#### Observations

- Figure 24
  - The data for this section was consistent for the beginning and ending of the section with the middle portion being unavailable. There were roughly 89 0.1-mile post segments available but a little less than 50% would have an associated RCN value.
- Figure 25
  - The faulting data was consistent throughout the mile post range with close to 75% of the 0.1-mile segments showing values of faulting for all the mile post points available.

- Post CSOL the faulting rate is almost negligible, showing a decreasing rate of 0.0009 inches/year. This almost negligible rate can be attributed to the limited data range of 2018-2022 as there was no data available for 2017.
- Figure 26
  - There could have been some sort of minor rehabilitation in 1998 to account for this apparent drop off in IRI values in 1999. Post CSOL in 2017, the IRI dropped off in 2017, and then again in 2018 and now shows a negative rate of IRI of 8.2 inches/mile/year. If this peak of 2017 is excluded, rate changes drastically to show an increasing rate in IRI of 2.0 inches/mile/year. All these values are significantly under the 220 inches/mile rehabilitation trigger of the WSPMS.
- Figure 27
  - The rutting data shows that the CSOL has significantly reduced the rate of cracking for the years observed. The values in 2013 were approaching the 0.4 inches of rutting which would trigger a rehabilitation according to the WSPMS. It should also be stated that this is a short period of analysis.

#### Summary

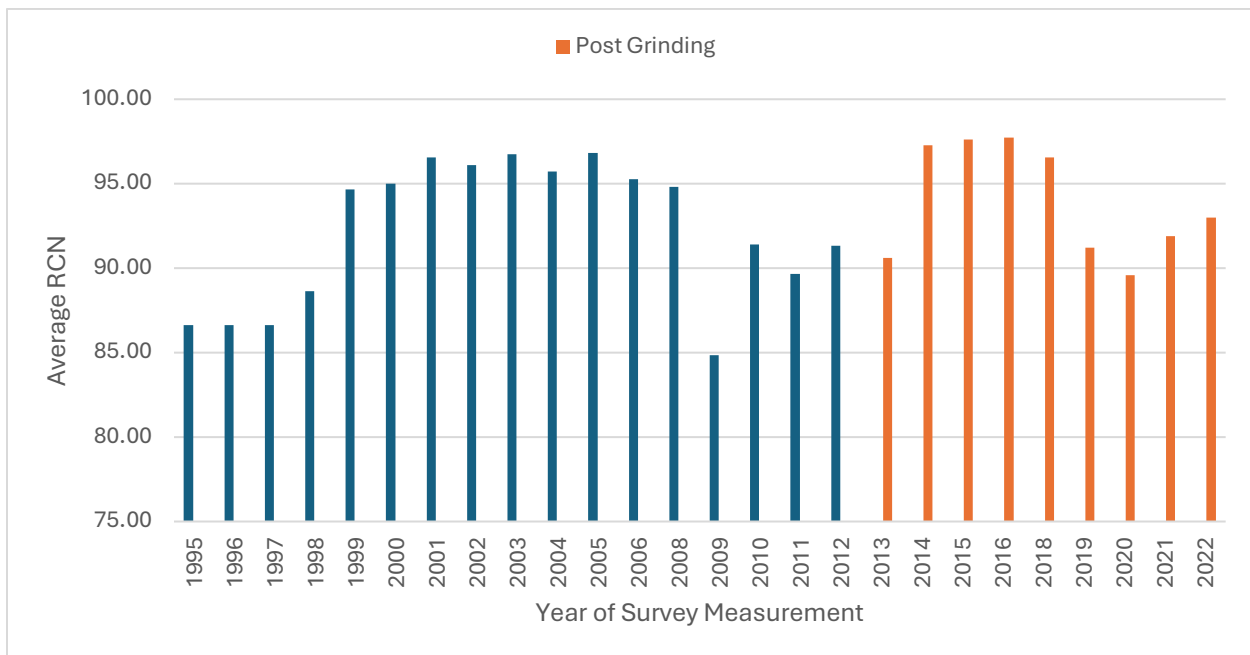
- The CSOL for MP 147.64-151.56 has had a positive impact on the pavement surface. The faulting, IRI, and rutting rates have all significantly decreased. RCN has also shown a steady rate, but this metric contained less data points per year for the analysis period selected.

### 3.3.3.5 I-90 unknown project name from 1973

#### Unbonded, Undoweled Concrete Overlay (UUOL)

In 2013, a short section on I-90 (adjusted route mile 74.89 to 75.96 EB). This section was a project from 1973 and is an undoweled section of PCCP placed on top of an existing three-inch HMA over an older seven-inch concrete section. This section was diamond ground in 2013. This is the only known undoweled PCC section placed on top of an existing asphalt pavement surface. This performance may indicate how a new concrete base would perform without dowel bars, which are currently required by WSDOT (Washington State Department of Transportation, 2018).

- Mile post range – ARM 74.89 to 75.96 increasing (Eastbound)
- Construction year – 2013
- Existing pavement – undoweled section of PCCP placed on top of an existing three-inch HMA and over old seven-inch concrete
- Rehabilitation – grinding in 2013
- Data – after each graph the data is shown in Table 31 through Table 34
- Graphs – see Figure 28 through Figure 31

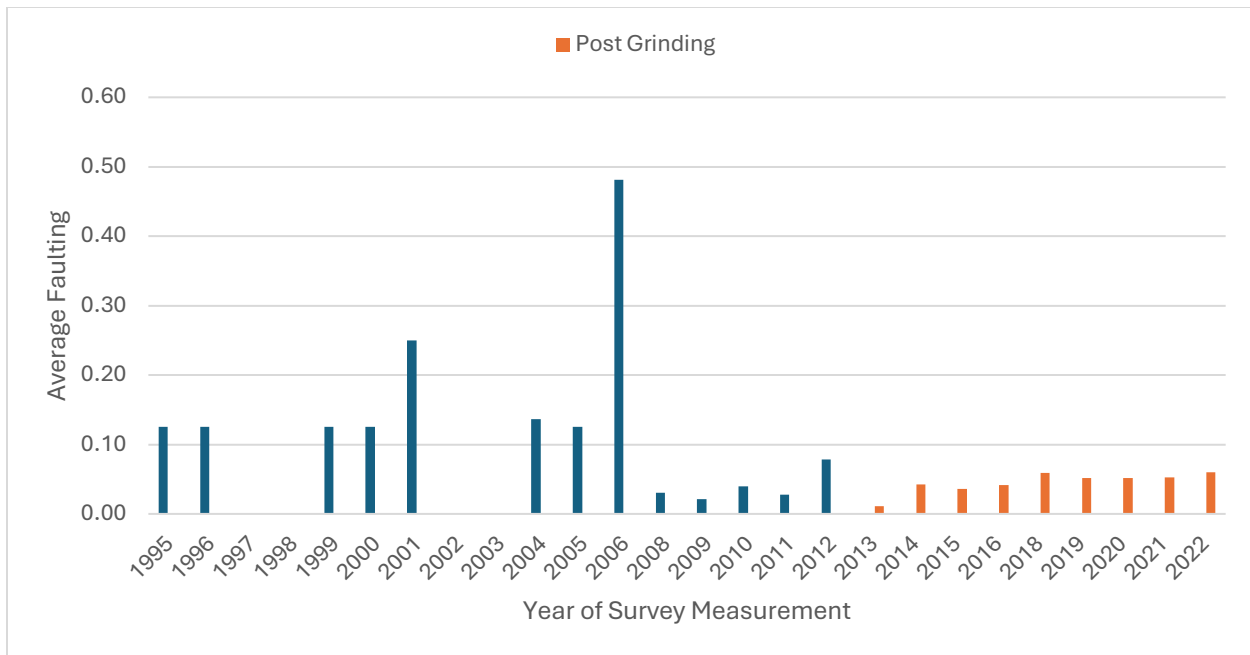


**Figure 28: Average RCN vs year of survey measurement for I-90 MP 74.89-75.96.**

**Table 31: Data for Figure 28**

Survey Year	Average of RCN		Grand Total
	Pre-Grinding	Post Grinding	
1995	86.64		86.64

1996	<b>86.64</b>		<b>86.64</b>
1997	<b>86.64</b>		<b>86.64</b>
1998	<b>88.63</b>		<b>88.63</b>
1999	<b>94.67</b>		<b>94.67</b>
2000	<b>95.00</b>		<b>95.00</b>
2001	<b>96.55</b>		<b>96.55</b>
2002	<b>96.09</b>		<b>96.09</b>
2003	<b>96.73</b>		<b>96.73</b>
2004	<b>95.73</b>		<b>95.73</b>
2005	<b>96.82</b>		<b>96.82</b>
2006	<b>95.27</b>		<b>95.27</b>
2008	<b>94.82</b>		<b>94.82</b>
2009	<b>84.83</b>		<b>84.83</b>
2010	<b>91.40</b>		<b>91.40</b>
2011	<b>89.67</b>		<b>89.67</b>
2012	<b>91.33</b>		<b>91.33</b>
2013		<b>90.60</b>	<b>90.60</b>
2014		<b>97.29</b>	<b>97.29</b>
2015		<b>97.60</b>	<b>97.60</b>
2016		<b>97.71</b>	<b>97.71</b>
2018		<b>96.55</b>	<b>96.55</b>
2019		<b>91.20</b>	<b>91.20</b>
2020		<b>89.60</b>	<b>89.60</b>
2021		<b>91.89</b>	<b>91.89</b>
2022		<b>93.00</b>	<b>93.00</b>
Grand Total	<b>92.57</b>	<b>93.86</b>	<b>92.96</b>

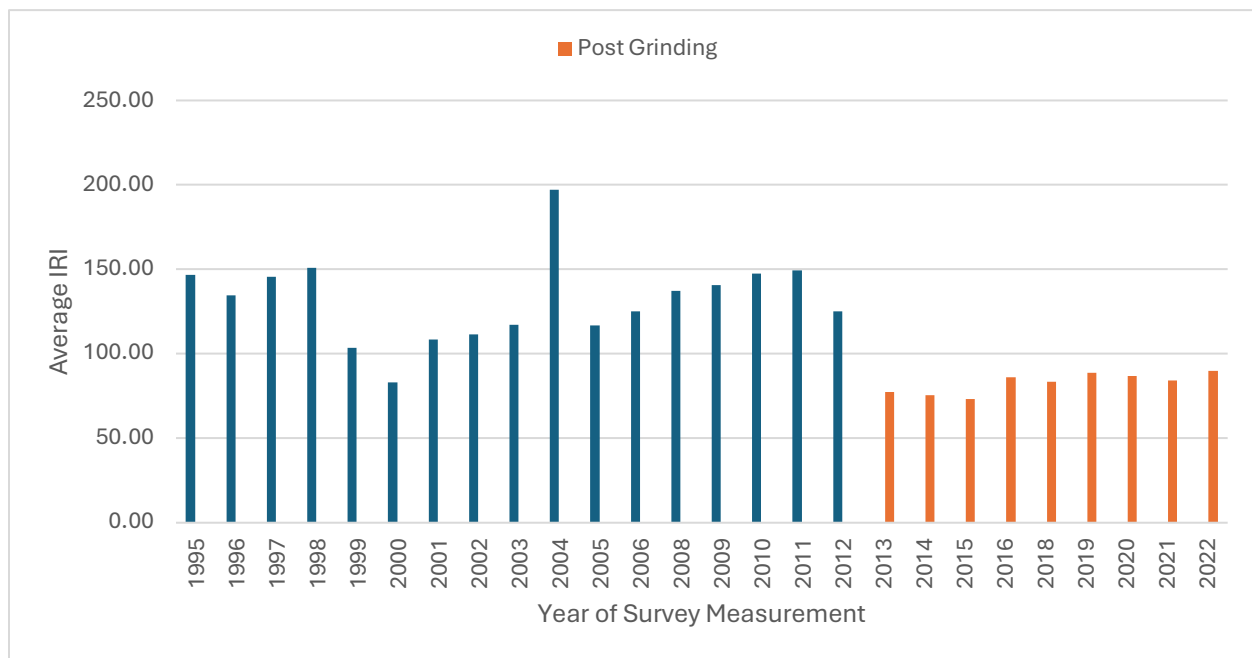


**Figure 29: Average faulting vs year of survey measurement for I-90 MP 74.89-75.96.**

**Table 32: Data for Figure 29**

Survey Year	Average of Faulting		
	Pre-Grinding	Post Grinding	Grand Total
1995	0.13		0.13
1996	0.13		0.13
1997			
1998			
1999	0.13		0.13
2000	0.13		0.13
2001	0.25		0.25
2002			
2003			
2004	0.14		0.14
2005	0.13		0.13
2006	0.48		0.48
2008	0.03		0.03
2009	0.02		0.02
2010	0.04		0.04
2011	0.03		0.03
2012	0.08		0.08
2013		0.01	0.01

2014		<b>0.04</b>	<b>0.04</b>
2015		<b>0.04</b>	<b>0.04</b>
2016		<b>0.04</b>	<b>0.04</b>
2018		<b>0.06</b>	<b>0.06</b>
2019		<b>0.05</b>	<b>0.05</b>
2020		<b>0.05</b>	<b>0.05</b>
2021		<b>0.05</b>	<b>0.05</b>
2022		<b>0.06</b>	<b>0.06</b>
Grand Total	<b>0.10</b>	<b>0.05</b>	<b>0.07</b>

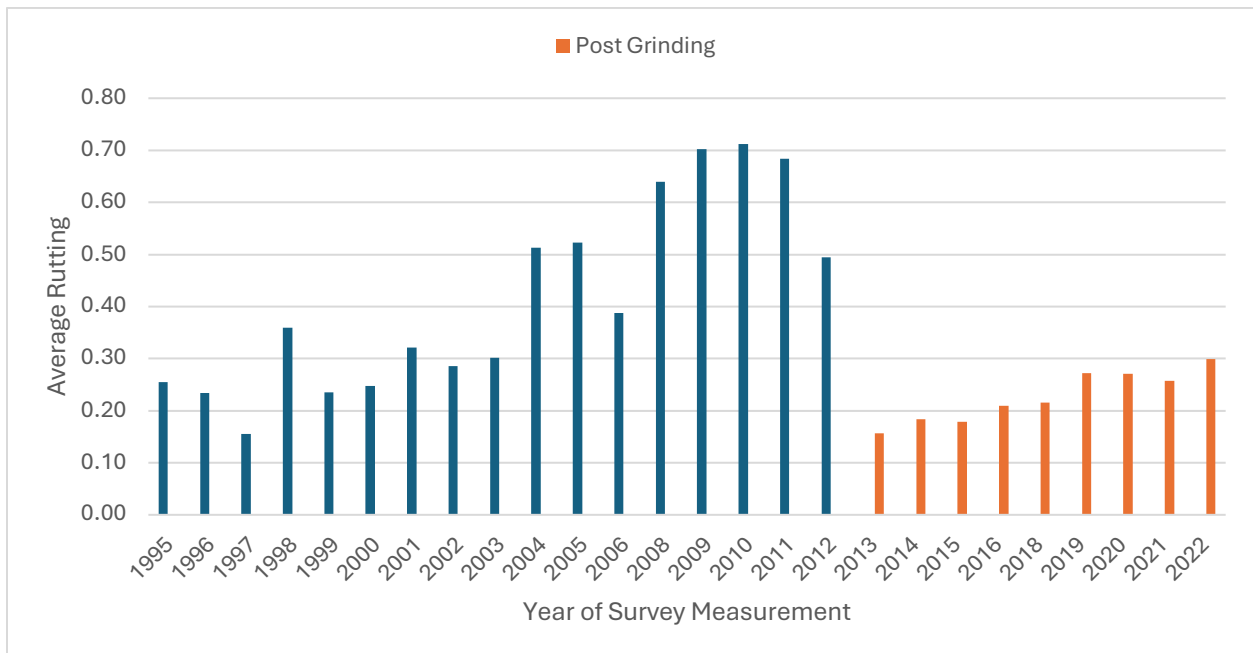


**Figure 30: Average IRI vs year of survey measurement for I-90 MP 74.89-75.96.**

**Table 33: Data for Figure 30**

Survey Year	Average of IRI		
	Pre-Grinding	Post Grinding	Grand Total
1995	<b>146.69</b>		<b>146.69</b>
1996	<b>134.63</b>		<b>134.63</b>
1997	<b>145.48</b>		<b>145.48</b>
1998	<b>151.09</b>		<b>151.09</b>
1999	<b>103.56</b>		<b>103.56</b>
2000	<b>83.21</b>		<b>83.21</b>
2001	<b>108.28</b>		<b>108.28</b>
2002	<b>111.32</b>		<b>111.32</b>

2003	<b>117.20</b>		<b>117.20</b>
2004	<b>197.30</b>		<b>197.30</b>
2005	<b>116.67</b>		<b>116.67</b>
2006	<b>125.20</b>		<b>125.20</b>
2008	<b>137.11</b>		<b>137.11</b>
2009	<b>140.63</b>		<b>140.63</b>
2010	<b>147.61</b>		<b>147.61</b>
2011	<b>149.32</b>		<b>149.32</b>
2012	<b>124.97</b>		<b>124.97</b>
2013		<b>77.29</b>	<b>77.29</b>
2014		<b>75.52</b>	<b>75.52</b>
2015		<b>73.35</b>	<b>73.35</b>
2016		<b>86.07</b>	<b>86.07</b>
2018		<b>83.36</b>	<b>83.36</b>
2019		<b>88.65</b>	<b>88.65</b>
2020		<b>86.93</b>	<b>86.93</b>
2021		<b>84.38</b>	<b>84.38</b>
2022		<b>89.73</b>	<b>89.73</b>
<b>Grand Total</b>	<b>131.03</b>	<b>83.72</b>	<b>116.69</b>



**Figure 31: Average rutting vs year of survey measurement for I-90 74.89-75.96.**

**Table 34: Data for Figure 31**

Survey Year	Average of Rutting		Grand Total
	Pre-Grinding	Post Grinding	
1995	0.25		0.25
1996	0.23		0.23
1997	0.16		0.16
1998	0.36		0.36
1999	0.23		0.23
2000	0.25		0.25
2001	0.32		0.32
2002	0.29		0.29
2003	0.30		0.30
2004	0.51		0.51
2005	0.52		0.52
2006	0.39		0.39
2008	0.64		0.64
2009	0.70		0.70
2010	0.71		0.71
2011	0.68		0.68
2012	0.50		0.50
2013		0.16	0.16
2014		0.18	0.18
2015		0.18	0.18
2016		0.21	0.21
2018		0.22	0.22
2019		0.27	0.27
2020		0.27	0.27
2021		0.26	0.26
2022		0.30	0.30
Grand Total	0.39	0.24	0.34

Notes

- Figure 28, Figure 29, Figure 30, and Figure 31
  - For the adjusted route mile post range 74.89-75.96 increasing only (eastbound only) there are 231 data points from the WSPMS dataset when all the filters are applied for direction and range.
  - Each mile post segment is 0.1 miles long with two lanes for 0.2 lane miles per segment.
  - Each 0.1-mile segment has 24 years of data from 1995-2022.

- Blue bars on Figure 28 through Figure 31 indicate distress before grinding, orange bars indicate levels of distress after grinding.

#### Data Issues

- Figure 28
  - RCN data pre grinding can be further analyzed by removing the years 1995-1998 for a much more realistic picture of the RCN decay.
- Figure 29
  - Faulting data was less conclusive with only 2-3 data points from the 2000s onwards.

#### Trends

- Figure 28
  - Grinding in 2013 shows subtle improvement for the RCN with consistent data for segments. Pre grinding in 2013 the data shows steady improvement in the Concrete pavements with the RCN improving at a rate of 0.2 RCN/year. Post grinding shows the roads losing approximately 0.5 RCN/year.
- Figure 30
  - The data for the IRI and rutting was consistent with 5-point minimums and most years having 10-11 points making it harder to explain any outliers. All data points were significantly under the WSPMS 220 inches/mile IRI trigger point for rehabilitation. There was a noticeable spike in 2004 for no obvious reason. Including this spike in 2004, the rate of increase of IRI pre grinding was approximately 0.6 inches/mile/year.
- Figure 31
  - The data for rutting was also consistent for the years analyzed. The rutting rate pre grinding was approximately 0.03 inches/year while the rutting rate post grinding was approximately 0.02 inches/year.

#### Observations

- Figure 28
  - There was most likely some roadworks in 1998 that improved the RCN so analyzing from 1999-2012 shows a more accurate RCN decay of approximately 0.6 RCN/year. This means that the grinding has so far slowed the rate of decay for RCN.
- Figure 29
  - Faulting data from 2008-2012 was more consistent and the faulting rate from this period was 0.01 inches/year. Post grinding in 2013, the rate decreases to 0.004 inches/year. This means the grinding has approximately halved the rate of faulting although the data is not sufficient to substantiate these rates.
  - Importantly, faulting, which might be expected for a concrete pavement without dowel bars, appears to be low and does not appear to be driving any rehabilitation decisions.

- Figure 30
  - Pre grinding the IRI was steadily increasing. Post grinding, the IRI values have significantly decreased, and the rate is increasing at a slow rate. This may be a significant indicator for grinding improving the values seen for IRI.
  
- Figure 31
  - Rutting data can be used to suggest that the grinding has reduced the rutting rate. The values pre grinding from 2004 show rutting over 0.4 inches which suggests a rehabilitation according to the WSPMS.

#### Summary

- The grinding has significantly reduced the IRI and rutting. The faulting and cracking were not the metrics targeted by this grinding method of rehabilitation.

## 4 Conclusions

This study is a review of current concrete pavement practices nationwide to update the WSDOT pavement policy and specifications. The last major review was done in 2010 with many advancements in material technology, design practices, maintenance, and rehabilitation. This study analyzes the concrete pavement policies of all 50 states to determine the best practices for construction, rehabilitation, and testing. This study also uses site specific concrete data through WSPMS to evaluate how successful pavement rehabilitations have been.

The data collected through the design manuals for the 50-state review was dependent on the state's use of concrete pavements. Ten states have comprehensive design manuals (California, Florida, Georgia, Illinois, Minnesota, Montana, Oregon, Texas, Virginia, and Washington). These comprehensive manuals made it easy to find all the information necessary to determine the quality of concrete pavement being constructed and the reasons behind the selection. Fifteen states had detailed design manuals which were extremely helpful to collect the data for the evaluation criteria, but these manuals were not as detailed as the best ones.

The data for the WSDOT pavement was thorough 9055 data points representing 2090.84 lane-miles and 795 center line miles of concrete pavement. Each data point represented approximately 0.1 miles with location and condition statistics for each data point. This detailed dataset from WSPMS provided the platform for detailed analysis. WSDOT also provided section specific data on concrete pavement performance for 30 years to evaluate the rehabilitation efforts.

Most concrete pavements are in the Northwest and South-Central regions with over 75% of the 2090.84 lane miles (824.38 in the NW, 766.71 in the SC). The lane miles of concrete pavements are concentrated over three major corridors, I-5, I-90, and I-82 (670.53, 513.34, 330.14 lane miles). The concrete pavements in Washington state were mainly constructed between the 1960s-1970s with more than half the lane miles in the state being constructed during this time. Rehabilitations have been conducted since 1990 with DBR being the focus from 1990-2014 with grindings taking over the rehabilitation efforts in 2015.

Taking the rehabilitations into consideration, the condition of the concrete pavements is overall positive. The worst rutting is seen on SR 205 and SR 82 with average ruttings of 0.35 inches and 0.29 inches. However, these values are both below the WSDOT trigger of 0.4 inches. IRI values are also positive with SR 101 and SR 900 being the worst of all the pavements. The average 232.39 inches/mile on SR 900 is above the 220 inches/mile trigger value for WSDOT. The rehabilitation efforts have improved the RCN and GRND ratings with both seeing most of their ratings above the 50-point trigger. It should be noted that ratings are starting to decline as the DBR rehabilitations approach 30 years.

In the specific section analysis, the CSOL in 2011 on I-5 Joe Leary (MP 234.08-243.39) saw IRI and rutting significantly reduced as well as the rates of deterioration also decreased. PSC values were not negatively affected and maintained their levels. CSOL in 2013, I-90 Easton Hill WB (MP 65.54-67.43) immediately improved the IRI and rutting, but the rates of deterioration appear to be negatively affected as they show a steeper increase rate. CSOL in 2015, I-5 S 320<sup>th</sup> (MP 149.63-153.29) does not show any significant change on IRI and rutting but more data is needed to make

any conclusion on the impact. CSOL in 2017, I-5 NB S 260<sup>th</sup> (MP 147.64-153.29) show significant reductions in faulting, rutting, and IRI. The undoweled concrete over the HMA at I-90 (ARM 74.89-75.96) has performed extremely well. The grinding in 2013 significantly reduced the IRI and rutting. This section has demonstrated that further investigation should be done on undoweled concrete over HMA.

## 5 Recommendations

The recommendations are as follows:

1. Continue with current CSOL design practices. This practice is positively impacting the lifespan of the pavements.
2. Continue to monitor DBR sections for performance. WSDOT's oldest DBR jobs in 1994 are now over 30 years old and may warrant a detailed review as a follow up to the DBR study on long term load transfer restoration (Pierce & Muench, 2009).
3. Further investigate the use of undoweled concrete on an asphalt pavement base as a new pavement design. I-90 (adjusted route mile 74.89 to 75.96 EB) section has been performing satisfactorily and has not required further rehabilitation for quite some time.
  - Future project location could be - A dedicated section in the upcoming I-90 Snoqualmie Pass East – Cabin Creek Interchange to West Easton Interchange (Phase 3) project which is undoweled. This undoweled section would be a direct contrast to the traditional JPCP design for Concrete pavements for WSDOT. The undoweled section should be placed over a stiff base like that on the I-90 ARM 74.89 to 75.96. Performance metrics such as IRI, faulting, rutting, and RCN should be monitored regularly through the WSPMS to determine the comparative performance and maintenance needs while seeing this directly compared to the doweled sections in the rest of the project.
  - This would be like The FHWA Specific Pavement Studies (SPS-2) experiment on US-395. This study has provided great opportunities for analysis by varying the concrete conditions and base materials by a series of 500ft sections along a singular corridor. The results would directly inform WSDOT's future pavement design guidance and provide potential opportunities for savings by determining exactly which materials and conditions contribute to long lasting Concrete pavements.

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